Guideline for a robust assessment of the potential savings from water conservation and water demand management

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

WA Wegelin

Date:_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

ABSTRACT

Water loss in water distribution systems has been studied for many years in many countries and is continuously leading to the development of new concepts and theories, publications, guidelines and software models. Despite these developments, 45 % of water utilities in South Africa still do not understand the extent of water losses in the distribution systems that they operate (Wegelin *et al.,* 2012:27). It is important, in terms of water services planning, that a realistic estimate of the potential savings from individual water conservation and water demand management (WC/WDM) measures is made as it impacts directly on water security and business matters. If the potential savings were incorrectly or inaccurately calculated, additional resources might have to be developed at short notice to be able to supply in the demand.

Advanced software models, such as BENCHLEAK, PRESMAC, SANFLOW, AQUALITE and ECONOLEAK (McKenzie & Bhagwan, 2000) have been developed to quantify the extent of physical and commercial losses in water supply systems. Similar advanced models are available for estimating water demand. Such advanced models require numerous input parameters, each of which needs to be described accurately. The predicament is that such complex models are often simply not applicable in certain areas with limited resources and limited input data. In contrast, robust guidelines that are relatively insensitive to input parameters are useful in developing countries, where all input values for complex water demand models may be unavailable or inaccurate. No robust method has yet been developed for estimating the potential water savings that would result from WC/WDM interventions. A need thus exists to estimate water savings in a robust way with relatively few inputs.

This guideline promotes the development of a robust WC/WDM strategy, based on a systematic and pragmatic approach, which requires less initial funding and develops with time. The methodologies developed by the Water Loss Task Force (WLTF) of the International Water Association (IWA), were used to develop six basic steps, which need to be followed to develop a WC/WDM strategy. During the six steps, the minimum requirements for implementing WC/WDM will be defined, the current water losses and efficiencies will be determined, and potential targets will be set based on national and international benchmarks. Once targets have been set, 20 key interventions were identified to address water use efficiency, and commercial and physical losses. The motivation behind each intervention is provided based on best practice, case studies and legal requirements. The model ensures that the potential savings from the various interventions are sufficient to ensure that targets are achieved, and if not, that targets must be revised. The potential savings from interventions are based on literature reviews and new formulas developed as part of this guideline. The results from the various interventions would enable the water utility to prioritise interventions. The guideline concludes with a flow diagram describing the methodology.

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ACRONYMS AND ABBREVIATIONS

Abbreviation	Description
ALC	Active leakage control
ADD	Average daily demand
BABE	Burst and background leakage estimate
CARL	Current annual real losses
DMA	District metered area
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation (previously DWAF)
Eq.	Equation
FAVAD	Fix area variable area discharges
HDF	Hour day factor
ILI	Infrastructure leakage index
IWA	International Water Association
KPI	Key performance indicator
ℓ/c/d	litres/capita/day
LHWP	Lesotho Highlands Water Project
m^3	cubic meter
MIIF	Municipal Infrastructure Investment Framework
MNF	Minimum night flow
NRW	Non-revenue water
POSWAR	Personal on-site water resource
PRV	Pressure reducing valve
SIV	System input volume
UARL	Unavoidable annual real loss
UAW or UFW	Unaccounted for water
WC/WDM	Water conservation and water demand management
WLTF	Water Loss Task Force
WRC	Water Research Commission
WTW	Water treatment works

1 INTRODUCTION

1.1 BACKGROUND

Water loss in water distribution systems has been studied for many years in many countries and is continuously leading to the development of new concepts and theories. The Water Loss Task Force (WLTF) of the International Water Association (IWA) was established in 1995 to develop standards and best practice guidelines. The WLTF has subsequently grown to the largest specialist group within the IWA, and their best practice guidelines have been adopted by more than 15 % of water utilities across the world (Waldron, 2010).

Some of the key concepts developed by the WLTF to date include:

- abandoning the ambiguous concept of un-accounted for water (UAW or UFW) and providing improved concepts for defining water loss and non-revenue water (NRW)
- development of the standard IWA water balance which provides a breakdown of authorised consumption, water losses and NRW
- development of the infrastructure leakage index (ILI) as physical water loss indicator
- discouraging the use of % water losses, as the use of percentages can be misleading
- adopting the burst and background leakage estimate (BABE), fixed and variable area discharges (FAVAD) and unavoidable annual real loss (UARL) concepts which were developed by the South African and United Kingdom water industries, providing a systematic and component based technique to assess water loss in a water distribution system
- various guidelines and initiatives on performance benchmarking of water losses, pressure management, leak detection, district metered areas (DMA), physical losses and commercial losses.

Despite these developments, 45 % of water utilities in South Africa still do not understand the extent of water losses in the distribution systems that they operate (Wegelin *et al.,* 2012:27). Gumbo *et al*., (2002) indicted that the implementation of water conservation and water demand management (WC/WDM) in Southern Africa has been dismal, mainly due to lack of management information systems and technology in water utilities. Most of the metros and large municipalities are not reaching their water loss reduction targets and are not realising the consequences and potential benefits of WC/WDM (DWA, 2013a; DWA, 2013b). Although various books, manuals and publications (e.g. Hunt *et al.,* 1998; White, 1998; AWWA, 2006) and software packages (McKenzie & Bhagwan, 2000) have been produced over the years to assist water supply managers with the development of WC/WDM strategies, many water utilities do not have a WC/WDM strategy (DWA, 2011). Mwiinga *et al.* (2008) confirmed that many WC/WDM strategies and guidelines have been written but that the implementation and realisation of the benefits remain a challenge for many water utilities.

It is important, in terms of water services planning, that a realistic estimate of the potential savings from individual WC/WDM measures is made as it impacts directly on water security and business matters. If the potential savings were incorrectly or inaccurately calculated, additional resources might have to be developed at short notice to be able to supply in the demand.

This research project culminates in a robust guideline for the strategic planning of WC/WDM interventions and quantification of the potential savings. This guideline can be used to develop a valid business case to support funding applications and can be used to prioritise different interventions.

1.2 CURRENT CONSTRAINTS

Constraints in terms of WC/WDM application were considered insurmountable by Mwendera *et al.* (2003), who concluded that there was no simple answer for achieving the stated goals. The most notable problems, or perceived problems, with WC/WDM strategies and projects were listed as follows by Wegelin and Jacobs (2013):

(a) Detailed and expensive WC/WDM strategies are often expected to be associated with relatively large budgets, which can often not be funded from internal sources. Very few water utilities are able to obtain external funding, resulting in detailed studies often becoming dormant. WC/WDM strategy budgets should be within the means of the water utility or grant funding, and larger budgets should only be targeted once a proper business plan within the means of the water utility has been developed.

(b) Approximately 45 % of water utilities in South Africa cannot provide a water balance (Wegelin *et al.,* 2012:27), with the result that many WC/WDM projects are identified and implemented based on perceptions without proper water information management, such as a baseline water demand. The results from projects implemented in such an ad hoc manner are often disappointing and do not achieve goals, since the scale of the perceived problem is often much smaller than originally thought, or the wrong intervention was undertaken.

(c) Water utilities tend to suffer from *analysis paralysis* - for example calculating water losses to the third decimal. Buckle and Wegelin (2004) reported that detailed strategies were developed by Rand Water, with relatively large budgets for implementing interventions, while the most basic activities, such as bulk metering, were not even performed properly by the water utility in that case study. The money could have been better used to install bulk meters, for instance, with superior benefits to the water utility.

(d) The Non-Financial Census of Municipalities (SSA, 2010) suggests a staff vacancy rate of 25 % and 14 % in municipal water and finance departments respectively. Vembe District Municipality (SSA, 2010) reported a vacancy rate higher than 60 %, which means that it will be unrealistic to expect the implementation of elaborate WC/WDM plans in situations where human resources are stressed.

(e) Lack of funding (DWA, 2011) to implement WC/WDM projects was often raised during the 2011 WC/WDM Training Workshops, attended by more than 500 water utility officials. The National Treasury Local Government Revenue and Expenditure Report (2013), however, reveals that municipalities had spent only 76.7 % of their aggregate adjusted capital budget by 30 June 2013. The report highlights that municipalities have challenges with the planning and implementation of capital projects and increased revenue in Metros can be attributed to higher rates and tariffs, rather than efficiency improvements in revenue management.

Buckle and Wegelin (2004:3) noted that these constraints listed above are exacerbated by supply-minded thinking, crisis management, lack of water distribution system knowledge, funding, maintenance and the institutional quagmire.

1.3 IMPACT OF WC/WDM

The national and water services sector WC/WDM strategies (DWAF, 2004a; DWAF, 2004b) do not only relate to engineering aspects, but also to financial sustainability, health, service delivery, and the micro and macro environment. Available water resources are under pressure (DWA, 2010) and are highly influenced by the demands of population growth, short and long-term climate change, economic trends, water quality, environmental considerations and the huge cost to develop, operate and maintain new infrastructure. WC/WDM is often viewed as an alternative to water resource development and has been reported to have a direct impact on the following (DWAF, 1999):

- water security, if the water demand exceeds the reliable supply
- financial sustainability of the water utility, particularly in those instances where metering, billing and cost recovery are not properly implemented
- excessive leakage, often resulting in the deterioration of the level of service. The result of such systems is usually intermittent supply and rationing, as the water authority cannot pressurise the bulk supply. Intermittent supply not only damages the water supply infrastructure, but can result in waterborne diseases, due to contaminants which can seep into the pipeline during periods of depressurisation

- water supply infrastructure and assets which are not maintained, resulting in poor service delivery and increased leakage
- micro environment, in cases of high leakage, by creating unnatural wetlands, breeding grounds for mosquitos and other health hazards to the community
- macro environment, by having to construct augmentation schemes such as large dams. WC/WDM can be implemented in a relatively short time span with a limited budget as opposed to large augmentation schemes which usually require major capital investment with considerable implementation times of 10 to 25 years and environmental impacts
- reduced production, through pumping and pipe failure, and chemical costs with subsequent production of greenhouse gases.

Herbertson and Tate (2001) list the following reasons why WC/WDM should be promoted:

- excessive water use requires additional infrastructure, often associated with high debt and high fixed water costs
- WC/WDM intervention measures can be introduced flexibly and incrementally
- the community plays an active role in the success of WC/WDM projects
- WC/WDM requires measurement of all components of the water cycle and good management
- cost reflective water charges support sustainable water services.

1.4 PROBLEM STATEMENT

McKenzie *et al.* (2006) indicate that the BABE, FAVAD and UARL concepts, developed by the South African and United Kingdom water industries, provide a systematic and component based technique to assess water losses in water distribution systems. These concepts have resulted in the standard IWA water balance and advanced software models, such as BENCHLEAK, PRESMAC, SANFLOW, AQUALITE and ECONOLEAK (McKenzie & Bhagwan, 2000) which assists water utilities to quantify the extent of their physical losses and commercial losses.

Similar advanced models are available for estimating water demand. One example is a probability based end-use model for estimating residential water demand (Scheepers & Jacobs, 2014). Such advanced models require numerous input parameters, each of which needs to be described accurately - and in the latter case stochastically. In contrast, robust guidelines that are relatively insensitive to input parameters are useful in developing countries, where all input values for complex water demand models may be unavailable or inaccurate. With this background, two robust models for estimating water use were recently published (Griffioen & Van Zyl, 2014; Jacobs et al., 2013). Both these models used land area as an independent variable, in line with an earlier model used widely in South Africa (CSIR, 2000). The land area is easy to obtain with sufficient accuracy.

Despite these useful models for estimating water demand, no method has yet been developed for estimating the potential water savings that would result from WC/WDM interventions. Jacobs and Haarhoff (2007) noted that effective water demand management policies could only be rationally formulated by means of a comprehensive end-use model, based on micro-components of water use. The predicament is that such complex models are often simply not applicable in certain areas with limited resources and limited input data. A need thus exists to estimate water savings in a robust way with relatively few inputs.

The objectives of this thesis are:

- to provide robust guidelines for the planning of WC/WDM interventions
- to provide a robust quantitative assessment of the potential savings from various WC/WDM interventions
- to provide guidelines for setting realistic targets and related key performance indicators (KPI).

The subsequent guideline presented in this thesis, has through necessity been based on a number of assumptions. The result is based on a combination of available literature, data from case studies and legal requirements.

1.5 DEFINITIONS

1.5.1 Water conservation and water demand management

The Department of Water and Sanitation (DWS) has adopted the collective term of *water conservation and water demand management* (WC/WDM), parts of which have been defined independently in the Water Services Sector Strategy (DWAF, 2004b) as follows:

- WC is the minimisation of loss or waste, the care and protection of water resources and the efficient and effective use of water
- WDM is the adaptation and implementation of a strategy by a water institution or consumer to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability.

From a scientific viewpoint the DWS-definitions may be considered vague. A more detailed description of the terminology was provided by Butler and Memon (2006). The following is a brief review of the notation, promoted by the IWA:

- water conservation means *doing less with less* and is particularly applicable in drought scenarios and water restrictions (example: take shorter showers; do not irrigate the lawn)
- water efficiency means *doing the same (or more) with less* (example: fix leaks; use hydraulically efficient toilet pan and cistern design)
- water sufficiency means *enough is enough* (example: use automatic shut-off of taps; dual flush toilets; careful garden watering)
- water substitution means *replace water with something else, say air* (example: waterless urinals; vacuum drainage; dry cleaning)
- water reuse, (example: grey water reuse on-site; shared bath water; groundwater abstraction on-site).

Some countries (particularly North America) prefer to use the term *demand side management* (DSM) instead of WDM, which complicates matters even further regarding a clear definition. The South African electricity sector uses DSM for *demand management* related issues, while the country's local electricity provider ESKOM prefers *integrated demand management*.

For purposes of this study, the term *water conservation and water demand management* (WC/WDM) as recommended by the DWS has been adopted.

1.5.2 IWA Water Balance

The following definitions are adopted from the *State of Non-revenue Water in South Africa* (Seago & McKenzie 2007):

- *System input volume (SIV)* represents the potable volume input to the water supply system from the water utility's own sources, as measured at the water treatment works (WTW) outlet, allowing for all known errors (i.e. errors on bulk water meters) as well as any water imported from other sources, also corrected for known bulk metering errors
- *authorised consumption* is the volume of metered and / or unmetered water used by registered customers, the water utility and others who are implicitly or explicitly authorised to do so by the water utility, for residential, commercial and industrial purposes
- *water loss(es)* is the sum of the physical and commercial losses and is calculated as the difference between the SIV and the authorised consumption. In most countries, water losses are also considered to be unaccounted for water (UFW) although the exact definition of UFW can vary from country to country

- *billed authorised consumption* is effectively the revenue water, and is the volume of authorised metered and unmetered consumption which is billed by the water utility and paid for by the customer
- *unbilled authorised consumption* is the volume of authorised metered and unmetered consumption that is not billed or paid for
- *commercial losses or apparent losses* are made up from the unauthorised consumption (theft or illegal use), plus all technical and administrative inaccuracies associated with customer metering. If commercial losses are reduced, generally more revenue will be generated by and for the water utility
- *real losses* are the physical water losses from the pressurised system, up to the point of measurement of customer use. In most cases, real losses represent the unknown component in the overall water balance. The purpose of most water balance models is therefore to estimate the magnitude of real losses so that the water utility can gauge whether or not it has a serious leakage problem. Real losses are generally calculated as the difference between total losses and estimated commercial losses
- *NRW* is the volume of water supplied by the water utility but for which it receives no income. NRW incorporates unbilled (metered or unmetered) authorised consumption, apparent / commercial losses and real / physical losses.

2 LITERATURE REVIEW

2.1 INTRODUCTION

A key component of any WC/WDM strategy is the setting of a predetermined target against which potential savings can be measured. A valid target will ensure that the return on investment can be calculated and will provide motivation for future WC/WDM projects or programmes. Targets are often set as a result of a national target, drought situation or deteriorating water services. This chapter reviews some of the national and regional targets set in South Africa.

This chapter summarises the key potential water loss reduction interventions and their benefits, models to calculate the potential savings, KPIs and benchmarks used in South Africa and abroad.

2.2 WC/WDM TARGET SETTING

2.2.1 National WC/WDM target setting

His Excellency JG Zuma, President of the Republic of South Africa, in his 2010 State of the Nation Address stated that "we are not a water rich country. Yet we still lose a lot of water through leaking pipes and inadequate infrastructure. We will be putting in place measures to reduce our water loss by half by 2014". The exact background to this statement is unclear and there is uncertainty regarding the following:

- there was no proper baseline against which water loss performance could be measured as Wegelin *et al.* (2012) indicated in *The State of Non-revenue Water in South Africa*, that 105 of a possible 237 (45 %) water utilities could not provide a water balance and did not know the extent of their water loss
- there is uncertainty whether the proposed savings apply to physical (real) and commercial (apparent) loss or only physical loss - not all physical losses can be avoided and there will always be a component of UARL
- the presidential water loss reduction target makes no mention of reducing the SIV or NRW
- the President made no reference to this statement in his 2014 State of the Nation Address and Wensley (2014), concluded that this target would not be achieved.

Another example of WC/WDM targeting was in North America, when the State of California embarked on the 20X2020 Water Conservation Plan on 28 February 2008. Governor Schwarzenegger called for "a plan to achieve a 20 percent reduction in per capita water use statewide by 2020". The Water Conservation Act of 2009 (Senate Bill X7-7) was subsequently enacted in November 2009, requiring all urban water suppliers to increase water use efficiency. The main requirements of the bills were as follows:

- each urban retail water supplier shall develop water use targets and an interim water use target by 1 July 2011
- the State is required to achieve a 20 % reduction in urban demand per capita consumption by the end of 2020
- at least 10 % of this target must be achieved by the end of 2015 and a baseline must be established by end of 2010
- certain grants and loans would be subject to the implementation of certain water demand management measures.

When comparing the two examples above, a few differences are apparent. The South African target was unclear and not enforced by government, whereas the Californian target was backed by legislation, provided clear guidelines on target requirements and how they should be determined, and is enforced.

2.2.2 Regional WC/WDM target setting

The reconciliation strategies for large systems and metropolitan areas, and the reconciliation strategies for all other towns were developed by the Department of Water and Sanitation (DWS), with the following objectives (DWA, 2010):

- to develop future water requirement scenarios to satisfy human and environmental needs
- to investigate all possible water resources and interventions that could add to water availability, such as surface water, ground water, return flows, reuse, desalination, WC/WDM, rainwater harvesting and catchment rehabilitations
- to investigate all possible methods for reconciling water requirements with available resources
- to provide recommendations for development and implementation of the required interventions and actions
- to offer a system for continuous monitoring and updating of strategies into the future.

The reconciliation strategies are clear, as illustrated by the results from the Vaal River System Reconciliation Strategy. The key strategic outcomes of the study are (DWA, 2014):

- eradicate unlawful irrigation water use by the year 2014
- continue with the implementation of WC/WDM to achieve further targeted savings by 2015
- implement Phase 2 of the Lesotho Highlands Water Project (LHWP) to deliver water to the Vaal river system by the year 2020

- mine water effluent (acid mine drainage) must be treated and ready for use by 2015.

The Vaal river system reconciliation strategy is illustrated in Figure 2.1 and shows the impact on water requirements if the key strategic outcomes are not achieved.

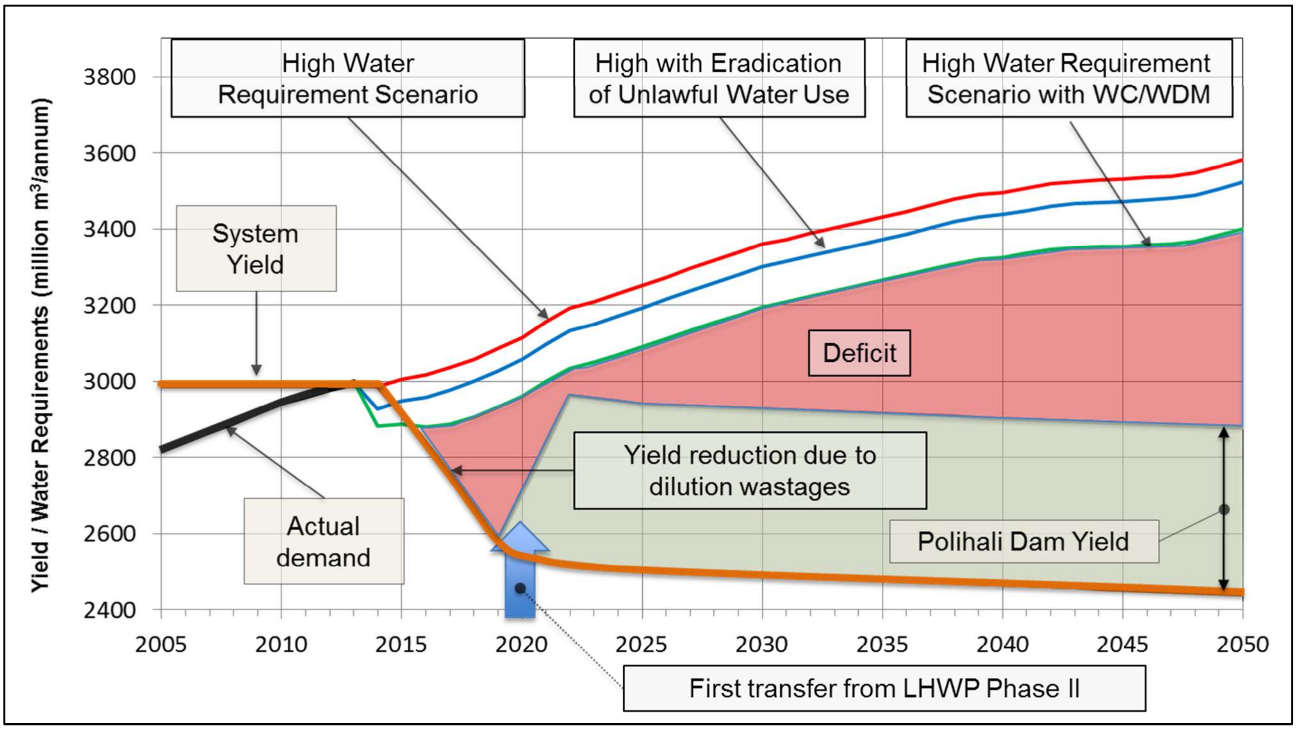

Figure 2.1: Vaal river system reconciliation strategy - scenario 1 (DWA, 2014)

WC/WDM forms an integral part of the Vaal river reconciliation strategy and municipalities were required to reduce their overall consumption by 15 % by 2014. Each municipality was provided with a specific target, based on a scientific analysis of the current demands, water losses and NRW (DWAF, 2007).

The results from the reconciliation strategies for large systems and metropolitan areas, and the reconciliation strategies for all other towns provide clear guidelines on target requirements, based on scientific outcomes, which are continuously monitored and enforced.

2.3 COMMERCIAL WATER LOSS REDUCTION

2.3.1 Consumer metering

Van Zyl (2011:2) indicates that while water metering has many direct and indirect benefits, the primary driving forces are that:

- metering and billing make consumers accountable for the volume of water used

- water efficiency and losses cannot be encouraged, monitored and controlled without proper metering
- economic benefits will accrue to the customer and the water utility as a result of well managed and accurate metering. The water utility benefits from increased sales and income while the consumer only pays for water actually used
- system management information is obtained from proper metering practices, which in turn drive informed decision making.

The metering of consumption is a legal requirement in terms of Clause 13 of the *Regulations Relating to Compulsory National Standards and Measures to Conserve Water* (DWAF, 2001a) which states that a water services institution must fit a suitable water volume measuring device or volume controlling device to all user connections provided with water supply services. It further states that if the water supplied is measured by way of a meter, that meter must comply with the Trade Metrology Act, 1973 (Act No. 77 of 1973).

2.3.1.1 Domestic meter error

Couvelis and van Zyl (2012:100) provide the following guidelines to assess potential apparent water losses related to municipal water metering in South Africa:

(a) Under-registration of volumetric or positive displacement meters due to meter age for domestic use is expressed as:

$$\%\ \text{Meter error}_{\text{Domestic}} = 1 - (0.36 \times \text{average age of consumer meters in years}) \qquad (2.1)$$

New meters (less than 5 years old) tend to under-register at low flow rates, but over-register at high flow rates. A new meter would normally have a negligible under-registration or may even over-register the demand.

(b) The class of meter has a significant impact on the possible under-registration of on-site leakage. A high incidence of on-site leakage can lead to an average meter under-registration rate of 0.9 ℓ/hour/property, or 22 ℓ/day/property. Based on a typical consumption of 1 000 ℓ/day, this results in a typical meter under-registration of 2.2 %.

Arregui *et al.* (2005) indicate that the accuracy of domestic meters is also influenced by installation, fatigue tests, depositions, partial blockage of the inlet or strainer and onsite storage. The accuracy of velocity meters is influenced by water quality and suspended particles that can lead to partial blockages. Volumetric meters or positive displacement meters, however, are less sensitive to flow distortions, dimensional changes and internal friction at low flows than velocity meters.

2.3.1.2 Non-domestic meter errors

Wegelin *et al.* (2009) indicated an 18 % increase in metered consumption following the retrofitting of 176 small to large industrial connections in the Ekurhuleni metropolitan municipality. A total of 207 connections were eventually identified during the technical assessment, many of which were not properly metered. Most meters were located below ground and many were completely buried, making access for meter reading and maintenance difficult. Of the 207 connections, 49 (24 %) meters were illegible or not working, a significant number of meters were more than 15 years old and of questionable accuracy, and a further 25 (12 %) connections had no meters at all.

Astrup *et al.* (2014) documented the results from two non-domestic bulk consumer meter consolidation projects in the Ekurhuleni metropolitan municipality. The Top 500 consolidated project, which targeted specific industries throughout Ekurhuleni, showed an overall increase in billed consumption of 28 % from 182 properties. It was noted that 63 % of the total increase in metered consumption was achieved at 10 of the 182 properties consolidated. The results from the Wadeville consolidation project, which covered a specific area and not just specific large consumers, showed an overall increase in billed consumption of 16 % from 420 properties.

The results indicated that the potential savings from non-domestic audits could conservatively be between 15 and 20 % if a specific area is targeted, and possibly more if specific consumers are targeted.

Arregui *et al.* (2005) indicated that the accuracy of non-domestic meters is mainly influenced by velocity profile distortions and incorrect sizing. Velocity profile distortions are created by valves and bends installed in front of the meter, which distorts the flow entering the meter. These swirls and jets can significantly influence meter accuracy. Astrup *et al.* (2014) confirm this and also mention the type of meter, policy on the metering of fire connections, consolidation of meters to one meter per property, meter sizing and zero pressure test of the property as factors influencing the success of the project. It was also noted that the total monthly consumption of some consumers was reduced, following the installation of the new meters, with subsequent loss of income to the water utility. This was due to consumers becoming aware of leakage on their property, or through implementation of water efficiency programmes.

2.3.2 Commercial loss KPIs

Seago and McKenzie (2007:21) suggested default values for commercial losses in South Africa as summarised in Table 2.1. These defaults values are used to estimate the commercial losses in cases where more accurate and reliable figures are not available.

Table 2.1: Suggested default values for commercial losses in South Africa (Seago & McKenzie, 2007)

Unauthorised connections		Meter accuracy and age			Data transfer	
		Water quality	**Good**	**Poor**		
Very high	10 %	Poor > 10yrs	8 %	10 %	Poor	8 %
High	8 %					
Average	6 %	Average 5-10yrs	4 %	8 %	Average	5 %
Low	4 %					
Very low	2 %	Good < 5yrs	2 %	4 %	Good	2 %

The total commercial losses are calculated with equation 2.2, and expressed as a percentage of the water losses:

$$\text{Total commercial losses} = \sum \left\{ \begin{matrix} \text{\% Unauthorised connections} \\ \text{\% Meter accuracy \& age} \\ \text{\% Data transfer error} \end{matrix} \right\} \times \text{water losses} \qquad (2.2)$$

2.4 PHYSICAL WATER LOSS REDUCTION

2.4.1 Bulk metering and sectorising

SANS 10306 (2010:6) defines a water distribution system as the infrastructure associated with water supply, including the WTW, transmission pipelines, reservoirs, pump stations, distribution pipelines, valves and connections. A water distribution system is divided into smaller systems called districts, sub-districts or zones (SANS 10306:2010), or sectors and DMAs (IWA, 2007) depending on the country, as shown in Figure 2.2.

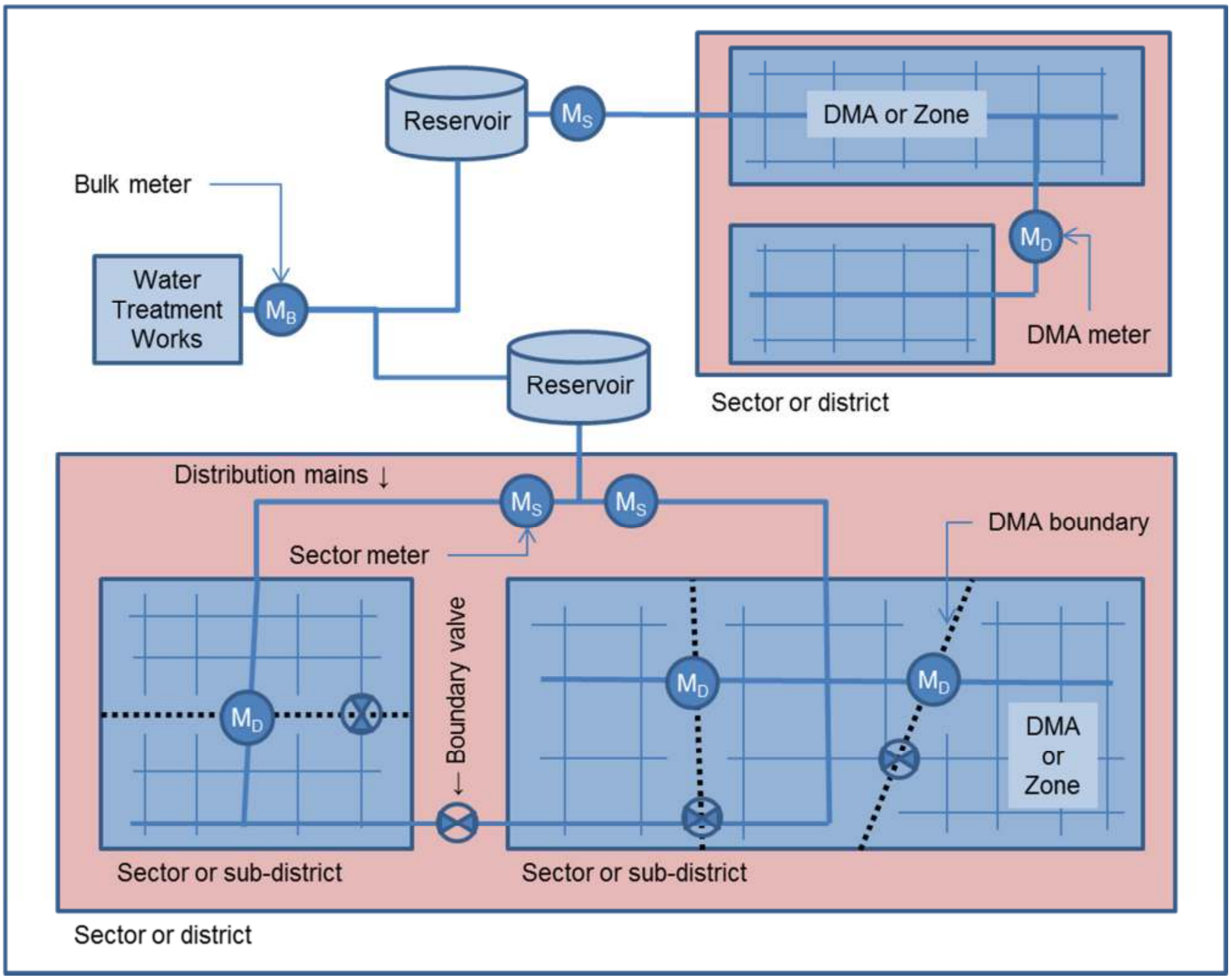

Figure 2.2: Typical water distribution system

The IWA terms *sectors* and *DMAs* were adopted for this study, where a sector is defined as a discrete area in which the water supply can be measured, with no defined size and consisting of a number of DMAs**.** The design of a DMA will depend on the following (IWA 2007:16-17):

- the required economic level of leakage
- size (geographical area and number of customer connections)
- geographical profile
- homogeneity of areas (residential, commercial, industrial areas, or a combination)
- water quality considerations
- pressure requirements
- firefighting requirements
- number of closed valves and bulk meters required and the operation and maintenance thereof
- number of sector or DMA meters required
- infrastructure condition.

The IWA (2007) describes the theory behind DMAs as the prioritisation of leakage repair activities, the determination of levels of leakage and, by monitoring the supply, the identification of new bursts.

Bulk metering and sectorisation are therefore important management tools to leakage control and prioritisation of DMAs. The slogan “to measure is to know” also forms the basis of SANS 10306:2010. Measurement must be accurate and consistent otherwise it will be difficult or even impossible to perform a water audit in order to control water loss.

Waldron (2002a:7) lists the potential benefits of bulk metering and sectorisation as follows:

- continuous monitoring and recording of the total water supply to a DMA
- leak detection teams can prioritise DMAs for leak detection and repair activities and reduce response times if a sudden increase in water demand is noticed through continuous monitoring
- dirty or discoloured water could be contained within one DMA and not spread throughout the network.

2.4.2 Water loss audits

Preparation of a water services audit is compulsory in South Africa under the Water Services Act, 1997 (Act No. 108 of 1997). The BENCHLEAK (McKenzie *et al.,* 2002a) and AQUALITE (McKenzie, 2007) models provide a simple and pragmatic approach to benchmark water losses in water distribution systems. The models provide details of the current water losses, NRW and KPIs, which can then be used to assess and prioritise problem areas and potential savings.

Waldron (2002b:7) recommends that water audits become the starting point of any water loss management programme. Waldron (*ibid.*) assesses the following benefits of water loss audits:

- increased knowledge of equipment and functions
- identification of faults, breakages, and leakage
- accountability for total water consumption and water use subsets
- increased data accuracy
- improved ability to strategically plan and implement water conservation processes.

2.4.3 Leakage control

As discussed in section 2.4.1, one of the main objectives of bulk metering and sectorisation is to prioritise DMAs for leak detection. The prioritisation could be based on the DMA with the highest excess minimum night flow (MNF) where the excess MNF is determined by comparing the actual MNF with the expected MNF as shown in Figure 2.3.

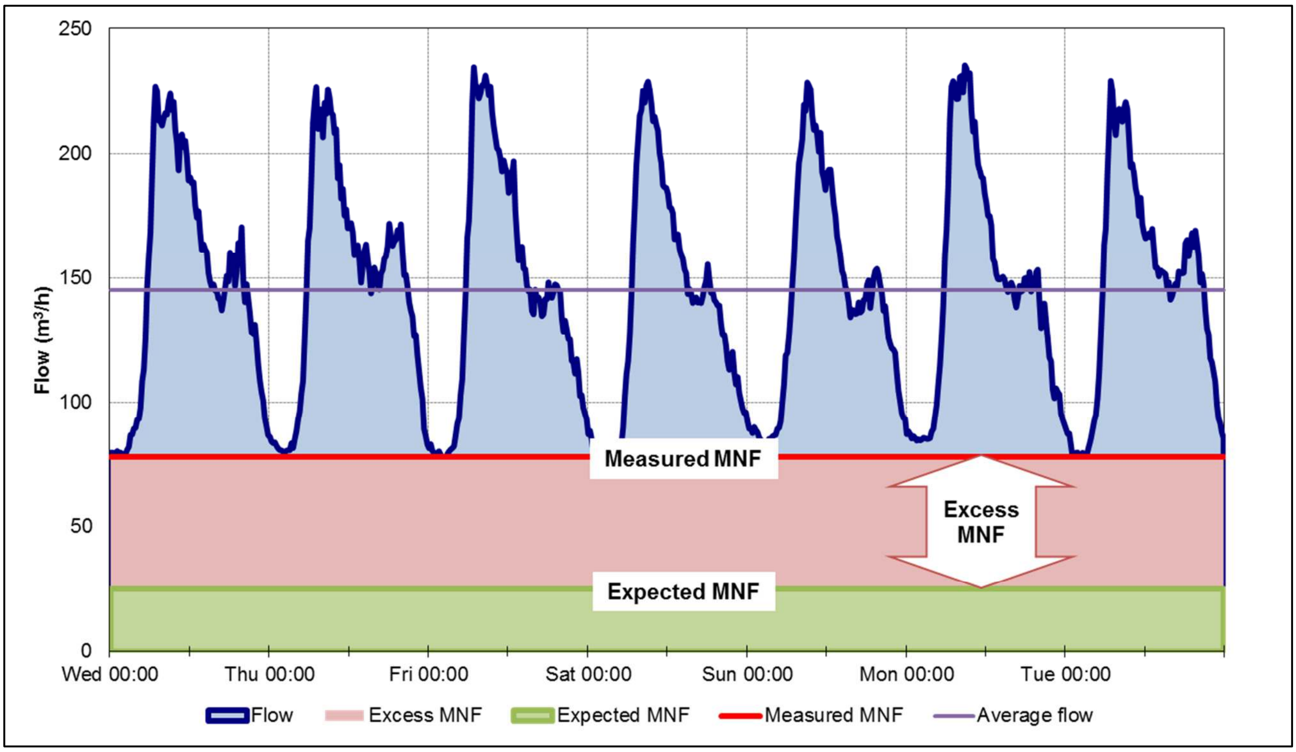

Figure 2.3: Example MNF analysis

The SANFLOW model (McKenzie, 1999) developed to assess MNF provides a standardised approach to evaluating the potential bursts and background losses in water distribution systems. The model analyses the measured MNF which is a function of the burst and background leakage and normal night use. The difference between the measured MNF and the expected MNF provides the excess night flow which provides an indication of the level of leakage in a zone. Although the model is relatively easy to use, it requires complicated inputs, including for example the recorded 24-hour flow patterns to derive the MNF. It is often hard for utilities to provide a 24-hour flow pattern. The SANFLOW model also requires proper bulk metering, sectorisation and a good understanding of the system's operation.

The SANFLOW model incorporates a standard equivalent service pipe burst rate of 1.6 m^3/h at 50m pressure head to express the excess night flow in terms of equivalent service pipe bursts. The equivalent service pipe bursts are equal to the number of bursts the operator is expected to find in the distribution network.

The SANFLOW model provides a pragmatic approach to DMAs if the MNFs are known.

2.4.4 Pressure management

Wegelin and McKenzie (2002:4-1) indicated that pressure management is an effective measure of water demand management, which could result in significant cost effective savings. These savings are both immediate and sustainable if implemented properly and could have the following benefits:

- improved level of service
- reduced level of leakage in the water distribution network
- reduced level of household leakage in areas with poor internal plumbing
- reduced consumption, which is beneficial to the water utility in areas with low cost recovery
- reduced number of bursts and subsequent disruption in supply
- reduced cost to the water utility and customers
- increased design life of the water distribution network
- reduced water and wastewater treatment capacity required.

Waldron (2005:8) supports this view on pressure management and lists the following benefits:

- extended asset life – damage on the bulk supply and distribution system is reduced
- reduced burst pipes – controlling surges and lowering maximum pressures reduce the frequency of new bursts
- improved customer service – fewer bursts result in fewer water services disruptions
- reduced pressure-dependant consumption – pressure management will reduce the background leakage and pressure-dependant consumption like showers, sprinklers and hose pipes
- cost savings – reduced consumption will reduce treatment and pumping costs.

The PRESMAC model (McKenzie, 2001) was subsequently developed to provide a pragmatic approach to evaluate the potential savings from pressure management in potable water distribution systems. Although the model is simple to use once populated, it requires 24-hour flow and pressure loggings of the critical and average zone point of a discrete DMA.

The PRESMAC model is based on the pressure-loss equation of:

$$\frac{L_0}{L_1} = \left(\frac{P_0}{P_1}\right)^{N1} \qquad (2.3)$$

or

$$L_1 = L_0 \times \left(\frac{P_1}{P_0}\right)^{N1} \qquad (2.4)$$

Where

L_0 = initial leakage loss in m^3/h

L_1 = new leakage loss in m^3/h

P_0 = initial pressure in m

P_1 = new pressure in m

N1 = pressure exponent (non-dimensional) which normally varies between 0.5 (default value for burst) and 2.5 (highest value for background leakage) with an average or default value of 1.0.

The pressure-loss equation flow relationship is simple to use, but only applicable to the pressure dependent flows (burst and background losses) and not to the pressure independent flows (general consumption). The pressure-loss equation flow relationship can be used to determine the potential savings from pressure management.

Wegelin and McKenzie (2002) list the following basic considerations which should be taken into account before implementing pressure management:

- the DMA should be sectorised and boundary valves must be regularly checked to ensure they remain closed
- the DMA should have high or fluctuating pressures at the critical point
- the DMA should have a high MNF
- a pressure reducing valve (PRV) should be installed to reduce the pressure to a predetermined fixed outlet pressure
- the installation of an advanced pressure controller can be considered in cases where there is a significant variation in pressure at the critical point between peak and off-peak demands
- a flow meter should be installed to measure the impact of pressure management to ensure that savings are sustained.

2.4.5 Leak detection and repair

Figure 2.4 indicates that quick response times are critical for the awareness, location and repair of water distribution leaks. Large bursts are usually visible and disruptive to network pressures, with the result that they are repaired quickly. Small connection bursts, on the other hand, do not always surface, and are usually not disruptive to network pressures, traffic or pedestrians, with the result that they take longer to repair (McKenzie & Lambert, 2002). The response time to repair leaks is therefore more critical than the actual size of the leak.

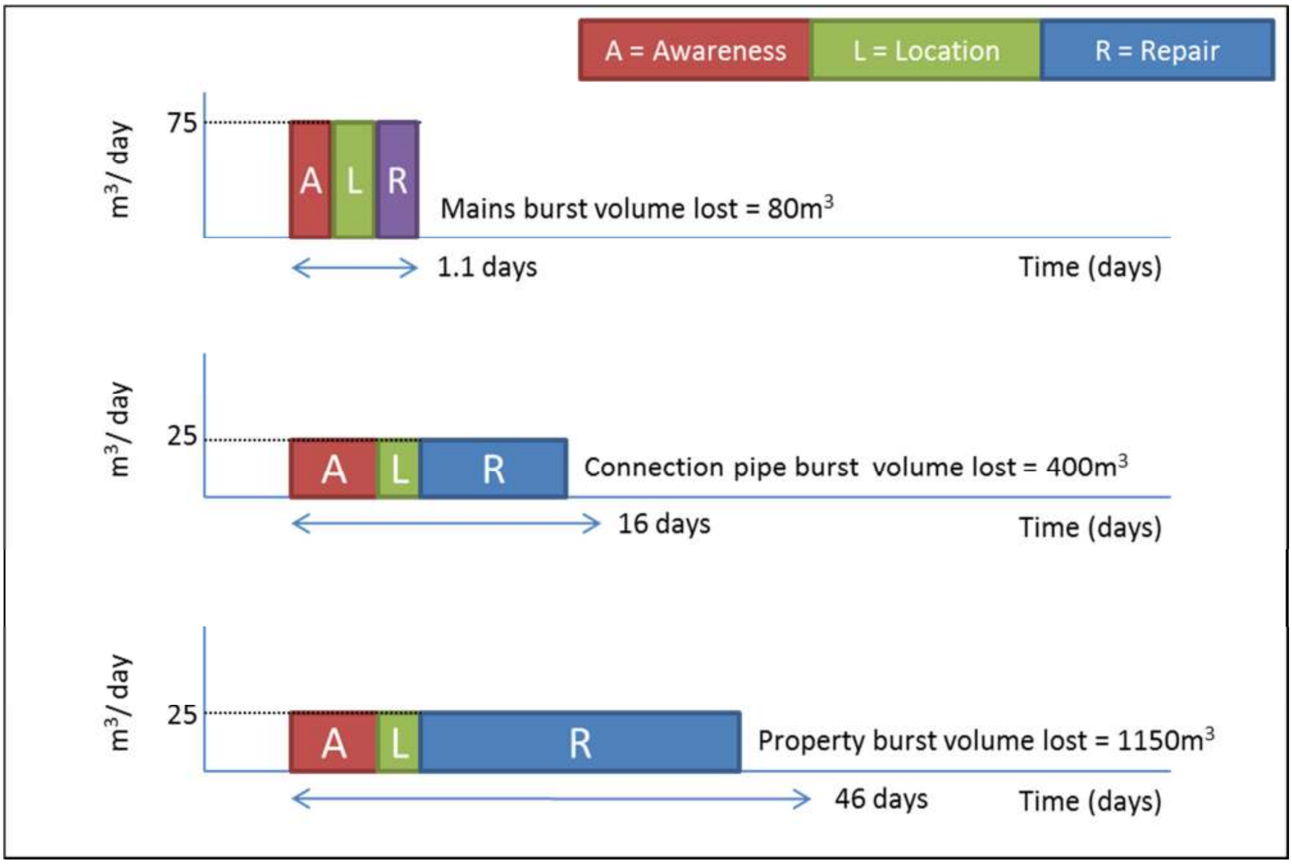

Figure 2.4: Effect of leak repair response times on leak volume (McKenzie & Lambert, 2002)

The quick and proper repair of leaks should therefore form part of any water loss reduction programme and is also a legal requirement in terms of Clause 12 of the *Regulations Relating to Compulsory National Standards and Measures to Conserve Water* (DWAF 2001a) which states that "a water services institution must repair any major, visible or reported leak in its water services system within 48 hours of becoming aware thereof."

The ECONOLEAK model (McKenzie & Lambert, 2002c) is a spreadsheet model for assessing appropriate levels of active leakage control (ALC) in potable water distribution systems. The ECONOLEAK model provides an indication of the frequency at which active leak detection and repair surveys should be undertaken to obtain the optimum economic level of leakage control.

2.4.6 Pipe repair versus replacement

Hamilton and Mckenzie (2014:52) indicate that pipe age, diameter, material, length, historical breakages, pressure, external temperature, surroundings, traffic and construction loads and soil types all contribute to pipe failures. Hamilton and McKenzie (*ibid.*) note that the details of the pipe failure data, operational data, soil characteristics, traffic data and water quality data should be gathered as a minimum to predict failure frequencies and the risk associated with failures. This information is normally only available for water utilities with sufficient capacity and skills.

2.4.7 Physical loss indicators

McKenzie (1999) recommends the following physical water loss indicator where the density of connections is greater than 20 connections per km mains:

$$\text{litres/connection/day} = \frac{\text{Physical losses }(\text{m}^3/\text{day})\times 1000}{\text{Number of connections served}} \tag{2.5}$$

In cases where the density of connections is less than 20 per km of mains, McKenzie (1999) recommends the following physical water loss indicator:

$$\text{m}^3/\text{km mains/day} = \frac{\text{Physical losses }(\text{m}^3/\text{day})}{\text{Length of mains (km)}} \tag{2.6}$$

The ILI is a useful indicator and can often be used to benchmark one system against another. ILI values typically range from 1, implying best practice, to 10, indicating that the physical leakage in a system is 10 times the likely minimum value. In South Africa, the average value for the country is approximately 6.8 (Wegelin *et al.,* 2012) and ranges from approximately 2 to more than 20 in some areas. The ILI is calculated by dividing the current annual real losses (CARL) by the UARL as shown by equation 2.7.

$$\text{ILI} = \frac{\text{CARL}}{\text{UARL}} \tag{2.7}$$

Seago and McKenzie (2007) provide the target ILIs and losses in litres/connection/day for developed and developing countries as summarised in Table 2.2.

Table 2.2: Target ILI and losses for developed and developing countries (Seago & McKenzie, 2007)

Technical performance Category		ILI	Water losses (litres / connection / day) when the system is pressurised at an average pressure of:				
			10m	20 m	30 m	40 m	50 m
Developed countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 – 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	>400	>500
Developing countries	A	1 – 4	<50	< 100	< 150	< 200	< 250
	B	4 – 8	50-100	100-200	150-300	200-400	250-500
	C	8 – 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

2.4.8 Norms and standards

Seago and McKenzie (2007:15) provide the following norms and standards for South African water reticulation systems:

- the density of connections ranges from 18 to 135 connections per km mains with an expected average of 50 connections per km mains
- the average operating pressure ranges from 24 m to 63 m with a maximum of 90 m
- UARL is normally in the order of 50 ℓ/connection/day.

2.5 WATER USE EFFICIENCY

2.5.1 Water wise gardening

Jacobs (2008) indicates that garden water demand is difficult to predict and varies significantly between households, even in the same region, but could be between 0 and 70 % of the total household demand. Siqalaba *et al.* (2009) noticed a 27 % increase in the peak demand and 23 % increase in the average daily demand (ADD) following a consecutive hot and cold day in the Sebokeng / Evaton area as shown in Figure 2.5.

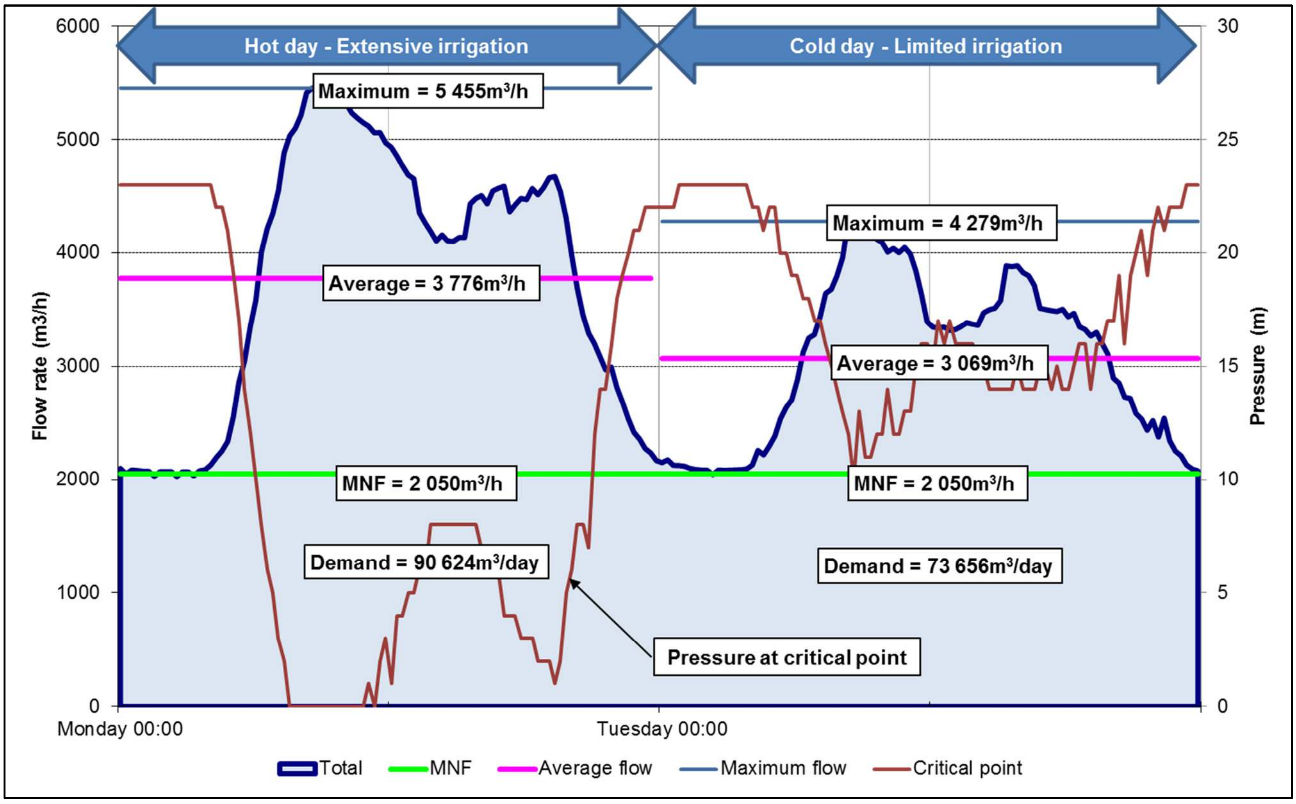

Figure 2.5: Impact of excessive garden irrigation on network pressures (Siqalaba *et al.*,2009)

Most of the increase was due to excessive garden watering in the area. The water distribution system was unable to supply in the peak demand on the hot day, resulting in a pressure drop to zero for almost three hours at the critical point in the network. Promoting water wise gardening therefore not only reduces overall consumption, but may improve service delivery by lowering peak demand.

Jacobs (2010) indicates that the implementation of a personal on-site water resource (POSWAR), as an alternative water source to piped water, could reduce the average annual daily demand by up to 40 % in low density residential areas, with an upper limit of 55 %, if all consumers implement a POSWAR. A POSWAR system may include groundwater abstraction, rainwater harvesting and grey water reuse. Issues to consider before implementing a POSWAR system include the following:

- most POSWAR systems are only found in low density residential areas and are mainly supported by groundwater abstraction
- grey water systems are management intensive, must comply with local bylaws, and the uptake is generally low
- rain water harvesting is unpractical in most parts of South Africa as it is often difficult to obtain a balance between storage required, the summer season and the rainfall season
- water wise gardening has the additional benefit that it reduces peak demand.

2.5.2 Retrofitting and replacement of wasteful devices

Jacobs (2008:3) indicates that the bath, shower, toilet and washing machine contribute up to 80 % of the total indoor water use in a typical suburban home. Still et al. (2008:C-14) indicate that the use of toilets accounts for approximately 30 % of household water consumption, and showers for 25 %. The potential savings from retrofitting and removal of wasteful devices (Texas Water Development Board, 2004) are summarised in Table 2.3.

Table 2.3: Summary of potential savings from household retrofitting programmes (Texas Water Development Board, 2004)

Device	Potential savings
Installation of low flow showerheads and faucet aerators	20 ℓ/device/day
Installation of low volume flush toilets	40 ℓ/capita/day
Installation of low volume with dual flush toilets	50 ℓ/capita/day
Installation of water efficient washing machines	21 ℓ/capita/day

Still *et al.* (2008:202) list the following reasons why people do not install water efficient devices when considering development of a strategy:

- they are not aware of water use efficient devices
- they are not the owner of the property
- they cannot afford to install new devices
- they do not see the need or benefit to make any changes
- they are too old to make changes.

McKenzie *et al.* (2002b) investigated the savings from various household leak repair programmes undertaken by Rand Water. The results are summarised in Table 2.4.

Table 2.4: Summary of savings from retrofitting projects (McKenzie *et al.*, 2002b)

Project name	Intervention	Savings
Schools leak repair programmes		
Boksburg schools	Retrofit of the ablution facilities	Before = 630 kℓ/month/school After = 354 kℓ/month/school Saving = 276 kℓ/month/school 44 % reduction
Kagiso schools	Retrofit of the ablution facilities	Before = 598 kℓ/month/school After = 398 kℓ/month/school Saving = 200 kℓ/month/school 31 % reduction
Household leak repair programmes		
Johannesburg inter city	Retrofit the internal plumbing of 13 buildings or 946 flats	Before = 920 kℓ/month/flat After = 750 kℓ/month/flat Saving = 170 kℓ/month/flat 19 % reduction
Odi retrofit project	Retrofit the internal plumbing of 16 244 households	Before = 22 kℓ/month/house After = 19 kℓ/month/house Saving = 3 kℓ/month/house 13 % reduction
Sebokeng/Emfuleni retrofit project	Retrofit the internal plumbing of 3 500 households	Before = 24 kℓ/month/house After = 15 kℓ/month/house Saving = 9 kℓ/month/house 38 % reduction
Tembisa West Retrofit project	Retrofit the internal plumbing of ±5 000 households	Before = 50 kℓ/month/house After = 31 kℓ/month/house Saving = 19 kℓ/month/house 38 % reduction

From Table 2.4 it is clear that the potential savings from retrofitting projects varies significantly and depends on the initial level of leakage and the success of the execution of the project.

2.5.3 Tariff setting

The *Norms and Standards in Respect of Tariffs for Water* (DWAF, 2001b) states that water tariffs must be cost reflective and must provide for a rising block tariff structure, which will not only support the viability and sustainability of water supply services to the poor but will also discourage wasteful or inefficient water use. It has been shown all over the world that metering and billing creates strong incentives for consumers to use water sparingly (van Zyl, 2011:2).

The Texas Water Development Board (2004) suggests that elasticity studies have shown a 1 to 3 % reduction in demand for every 10 % increase in the average monthly water bill. Hoffman (2011) provides a more conservative result and suggests a 3 % reduction for a 20 % increase in the water tariff.

2.5.4 KPIs

The IWA has developed various water loss KPIs to evaluate and compare different distribution systems. KPIs, while dependant on the availability of information, can form the basis for evaluating the existing system and the setting of realistic targets.

2.5.4.1 % NRW

Although the use of percentages to define water loss is not recommended by the IWA, the term remains widely accepted and used in most parts of the world including the South African water industry. It should be used with caution in the knowledge that it can sometimes be misleading as it is highly influenced by the SIV. The % NRW is calculated as follows:

$$\%\ \mathrm{NRW} = \frac{(\mathrm{SIV} - \mathrm{Billed\ volume})}{\mathrm{SIV}} \times 100 \tag{2.8}$$

2.5.4.2 ℓ/c/d

ℓ/c/d provides an indication of the gross volume of water used per capita per day. Although the calculation is based on the total SIV and not just the domestic component, it does provide a useful indicator. Care should be taken in areas where there is a large non-domestic component of water use. If necessary, the large wet industries should be excluded from the calculation in order to derive a more realistic per capita consumption.

$$\ell/\mathrm{c}/\mathrm{d} = \frac{\mathrm{SIV}}{\mathrm{Population\ served}} \tag{2.9}$$

2.5.5 KPI benchmarks

Unit consumption benchmarks provide a clear indication of the potential savings and achievable targets. The CSIR (2000) provides the following ADDs for different levels of development as shown in Table 2.5.

Table 2.5: Summary of typical domestic and non-domestic water use (CSIR, 2000)

Domestic water use	Typical consumption (ℓ/c/d)	Non-domestic water use	Typical consumption
Standpipes	25	School boarding	90 to 140 ℓ/pupil/day
Yard connections	55	School day	15 to 20 ℓ/pupil/day
Moderate development	80	Hospital	220 to 300 ℓ/bed/day
Moderate to high development	130	Clinics - outpatients - inpatients	5 ℓ/bed/day 40 to 60 ℓ/bed/day
High development	250	Bus stations	15 ℓ/user/day
Very high development	450	Community halls	65 to 90 ℓ/seat/day

Wegelin *et al.* (2012) analysed water balance information for 132 water utilities in South Africa as summarised in Table 2.6, and distribution as summarised in Figure 2.6 to Figure 2.8. The data was categorised according to the Municipal Infrastructure Investment Framework (MIIF) as category A) metros, B1) major cities, B2) minor cities, B3) rural dense and B4) rural scattered municipalities.

Table 2.6: Summary of South African KPI indicators (Wegelin *et al.,* 2012)

Category	A Metros	B1 Major cities	B2 Minor cities	B3 Rural dense	B4 Rural scattered	National average
ℓ/c/d						
Average	285	243	226	176	64	235
Minimum	244	151	73	29	6	6
Maximum	352	404	466	661	237	661
% NRW						
Average	34.3 %	41.3 %	27.0 %	36.6 %	72.5 %	36.4 %
Minimum	25.2 %	4.8 %	3.7 %	4.0 %	1.5 %	1.5 %
Maximum	39.8 %	63.0 %	68.2 %	69.4 %	100.0 %	100.0 %
ILI						
Average	8.2	7.4	5.7	4.7	7.8	6.8

The results for category B1, B2 and B3 compare well with Du Plessis (2007) who benchmarked 56 communities in the Western Cape, which showed an average consumption of 201 ℓ/c/d.

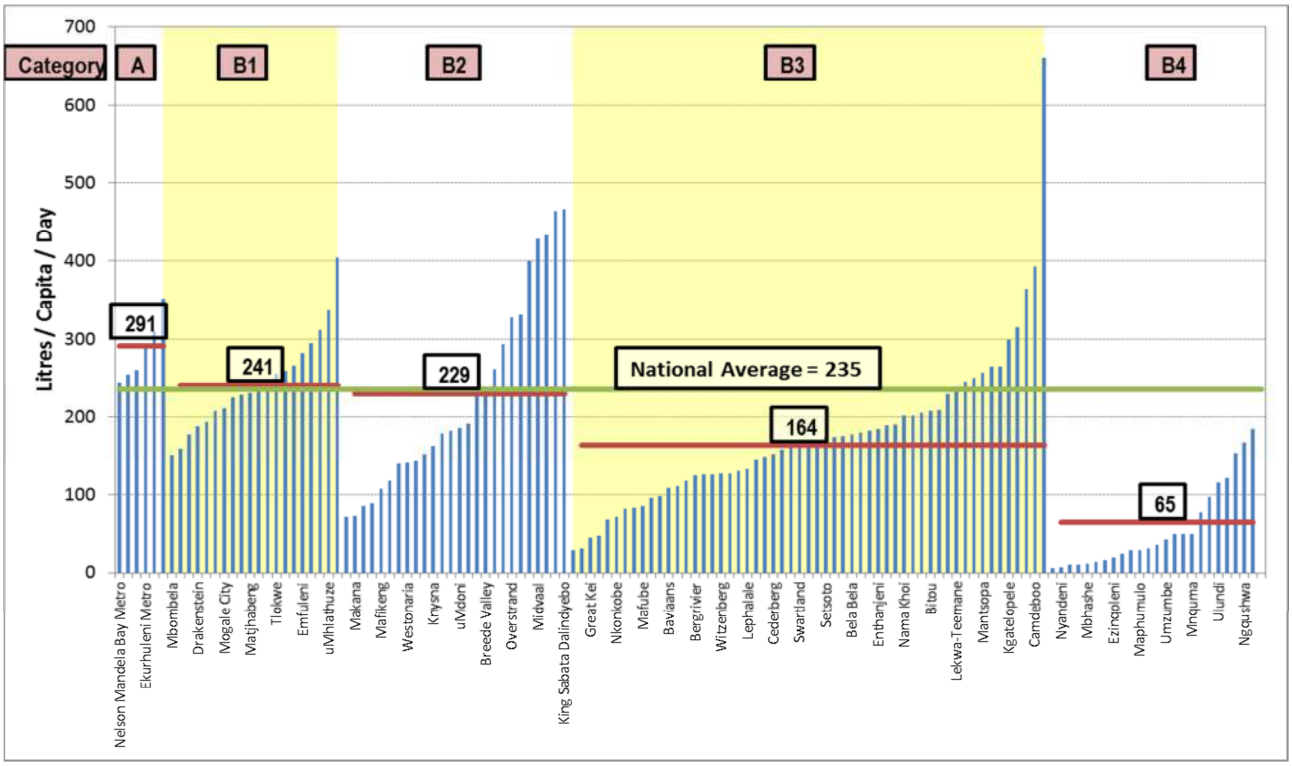

Figure 2.6: ℓ/c/d distribution (Wegelin *et al.,* 2012)

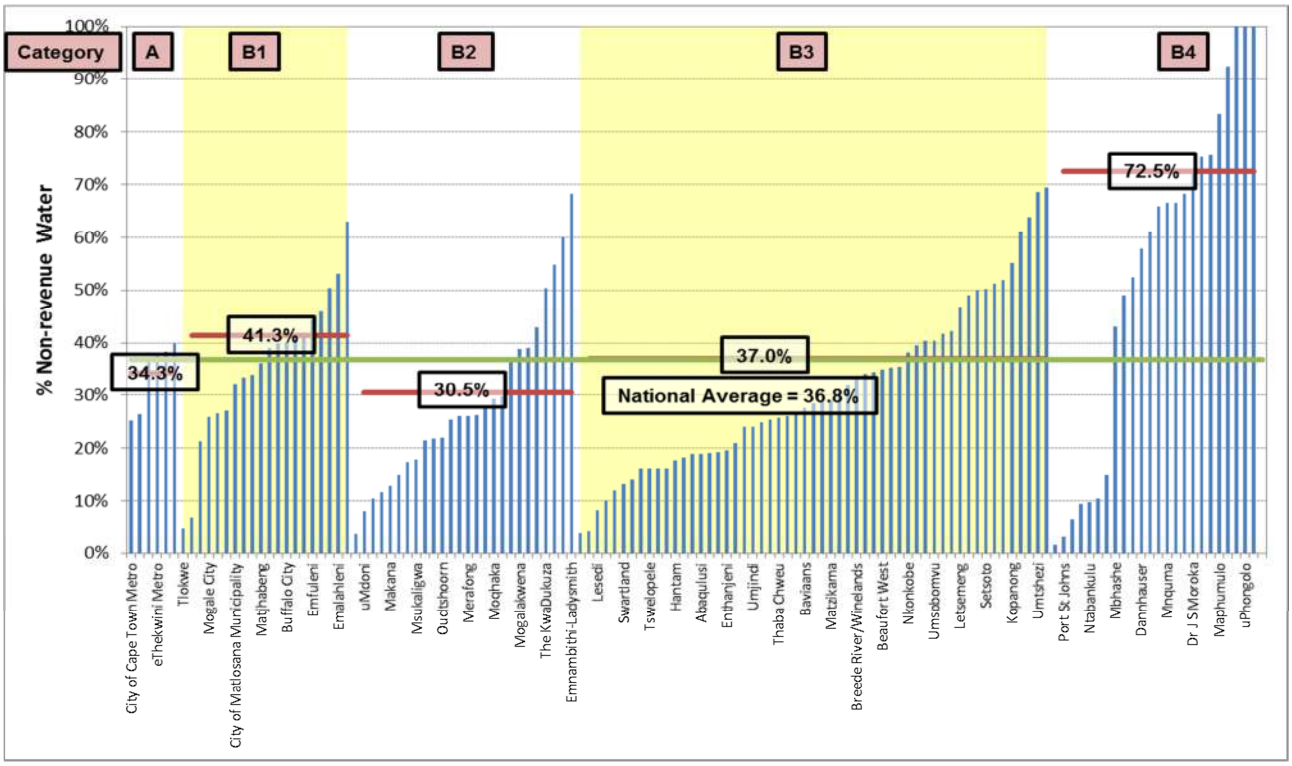

Figure 2.7: % NRW distribution (Wegelin *et al.,* 2012)

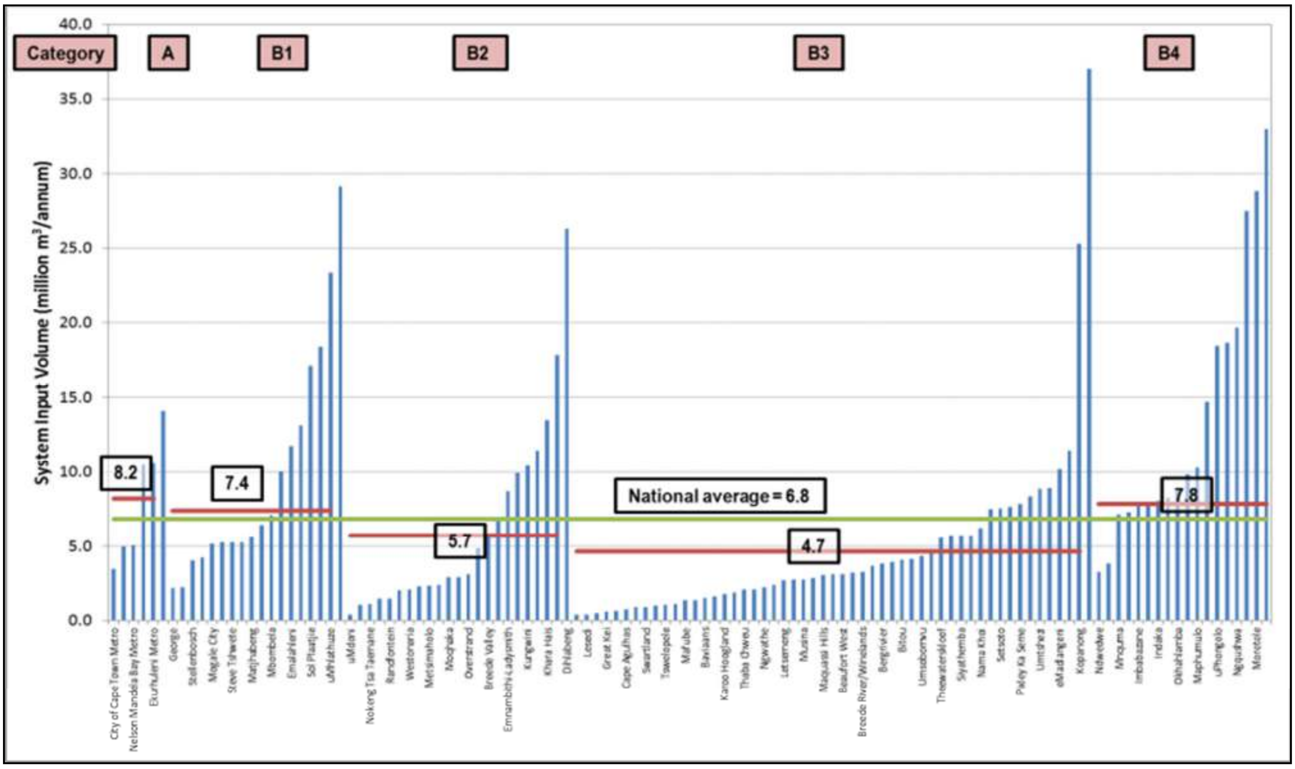

Figure 2.8: ILI distribution (Wegelin *et al.,* 2012)

Wegelin *et al.* (2012) compared the ℓ/c/d for the 132 water utilities in South Africa against water utilities from 67 developed and developing countries as shown in Figure 2.9.

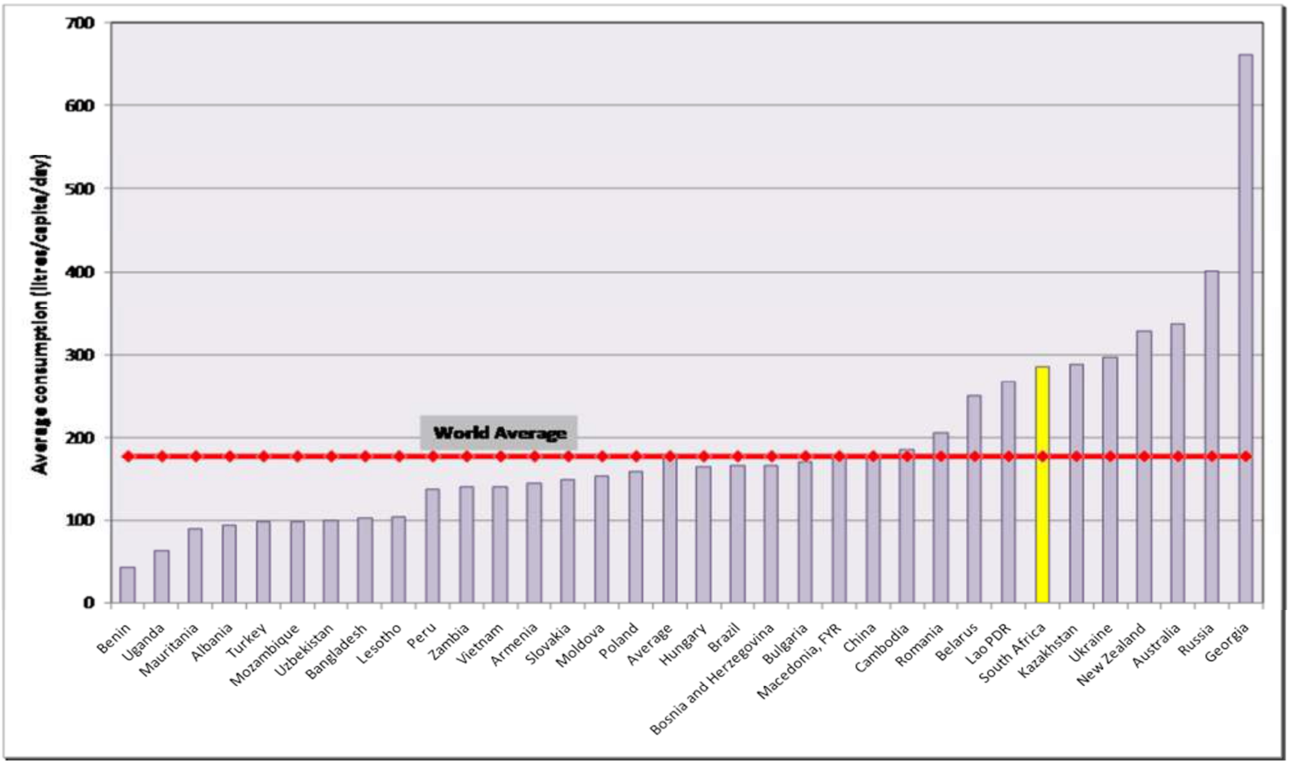

Figure 2.9: International comparison of average ℓ/c/d (Wegelin *et al.,* 2012)

The results indicate that South Africa's average water consumption is higher than the international average. South Africa's consumption is influenced by some metropolitan municipalities having a disproportionally large concentration of wet industries, but may also be a reflection of poor water use practices often observed throughout many parts of the country.

Wegelin *et al.* (2012) compared the % NRW for the 132 water utilities in South Africa against water utilities from 67 developed and developing countries as shown in Figure 2.10. The results indicate that South Africa's average % NRW compares well with international trends.

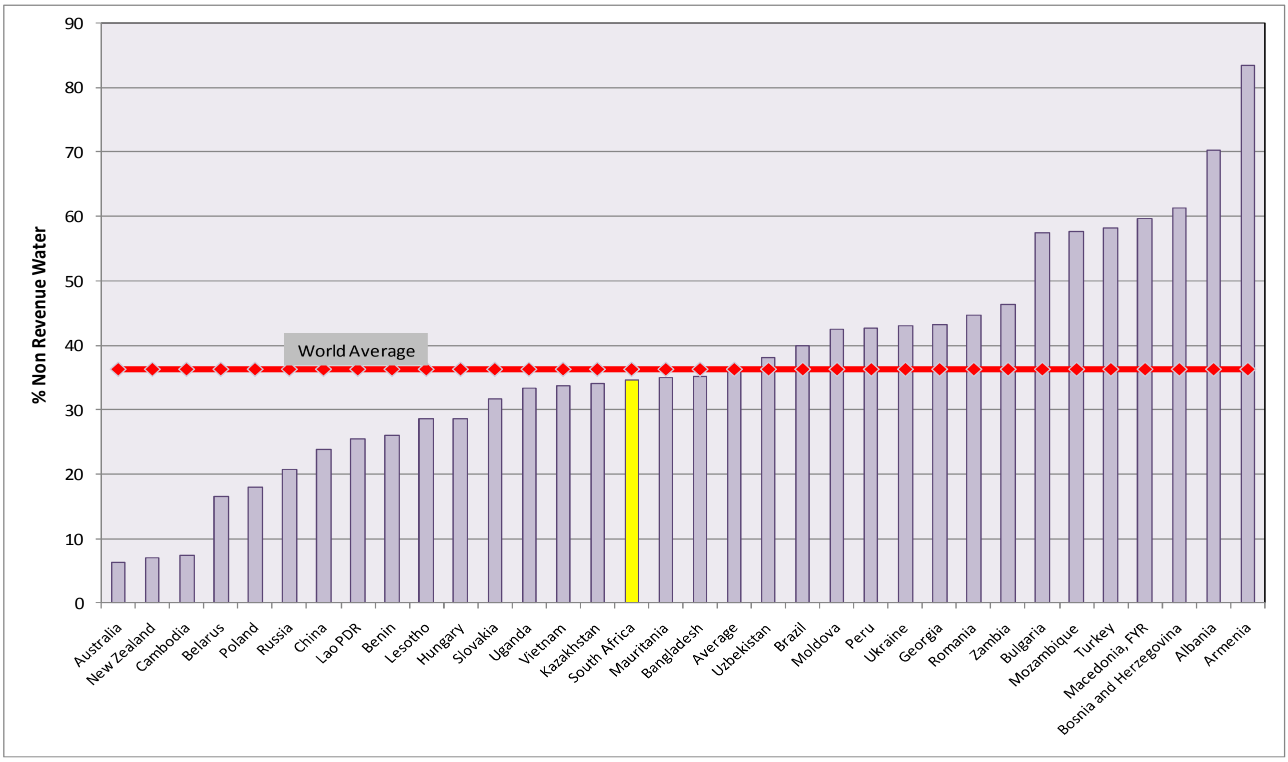

Figure 2.10: International comparison of average % NRW (Wegelin *et al.,* 2012)

2.6 DISCUSSION

A key component of any WC/WDM strategy is the setting of a predetermined target against which the potential savings envisaged can be measured. Targets should preferably be region or project specific, clearly defined and based on scientific analysis to meet local conditions, as opposed to national targets, which are often difficult to implement as each water utility has different levels of leakages, efficiencies and challenges.

Various comprehensive and rule of thumb models are available to determine the potential impact of WC/WDM interventions. Comprehensive models require a considerable amount of logging data which is often not available, too expensive to obtain, or insufficiently budgeted for to perform a detailed analysis of each potential intervention. Rule of thumb estimates can provide a very useful first order estimate of the potential savings.

3 THE IWA WATER BALANCE AND INTERVENTIONS

3.1 APPROACH

The principles developed by the IWA for reducing water loss are adopted in this thesis, of which the main components include:

- the IWA standard water balance, modified for South African conditions to allow for free basic water
- key measures for reducing commercial losses
- key measures for reducing physical water losses.

The following additional components have been developed as part of this study:

- minimum requirements for implementing WC/WDM
- key measures to improve water use efficiency
- alignment of the IWA water balance and interventions.

The components are discussed in the following sections.

3.2 MODIFIED IWA WATER BALANCE

The water balance, as shown in Figure 3.1, provides a breakdown of the SIV, authorised consumption, NRW, and apparent and physical losses. Once the water balance has been calculated, various KPIs can be calculated to measure the performance of the water supply system. With the water balance and KPIs available, the water utility can determine which components must be targeted first to improve efficiency, reduce commercial losses, physical losses or NRW. Once the main water loss contributing components have been identified and quantified, it is important to identify the most effective WC/WDM intervention to address these losses. It is therefore important to obtain a clear understanding of what impact various WC/WDM interventions would have to ensure that targets are achieved.

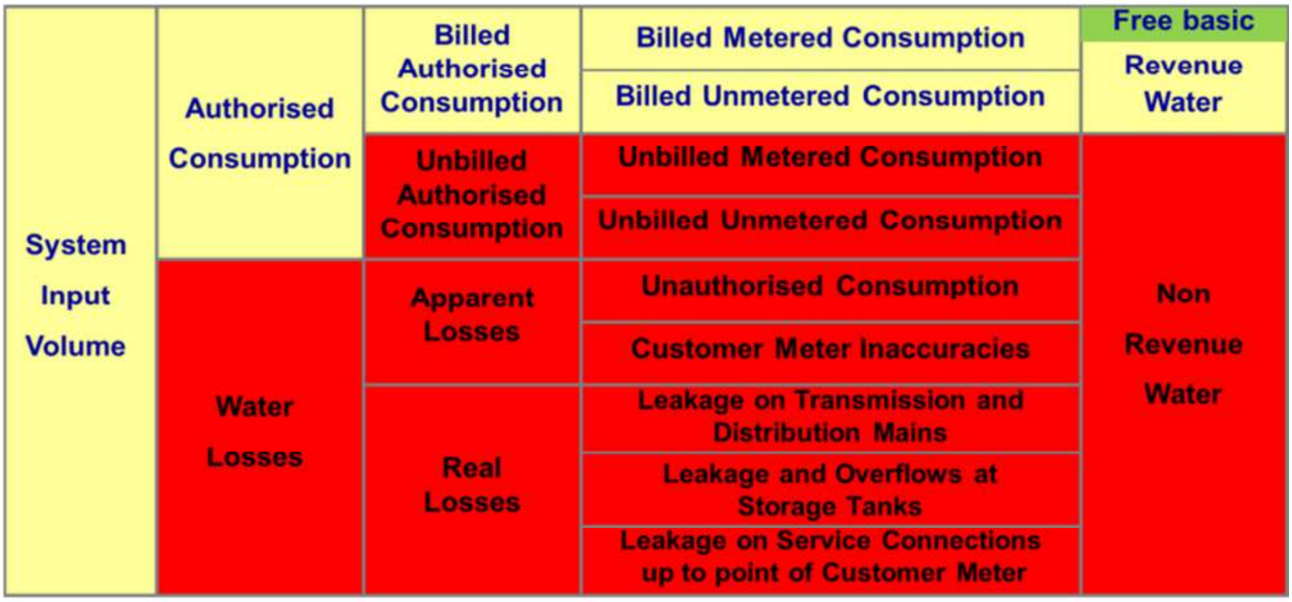

Figure 3.1: Modified IWA water balance (Seago & McKenzie, 2007)

3.3 COMMERCIAL WATER LOSS REDUCTION

The IWA WLTF (Rizzo *et al.,* 2004) has adopted four key commercial water loss interventions as shown in Figure 3.2. The four key commercial water loss reduction measures include theft and unauthorised use, meter accuracy and measurement, data transfer errors, and data analysis and assumption errors. For all these interventions to reduce commercial losses there is a current level of commercial losses and an unavoidable level of annual commercial losses. The objective for the water utility would be to identify suitable interventions that address the potentially recoverable commercial water losses within budget constraints, information systems and staff capacity of the organisation. The difference between the target and the unavoidable level of commercial loss is considered the economic level of commercial water loss reduction. Currently no clear guidelines are available to indicate what is considered an acceptable level of unavoidable annual commercial loss.

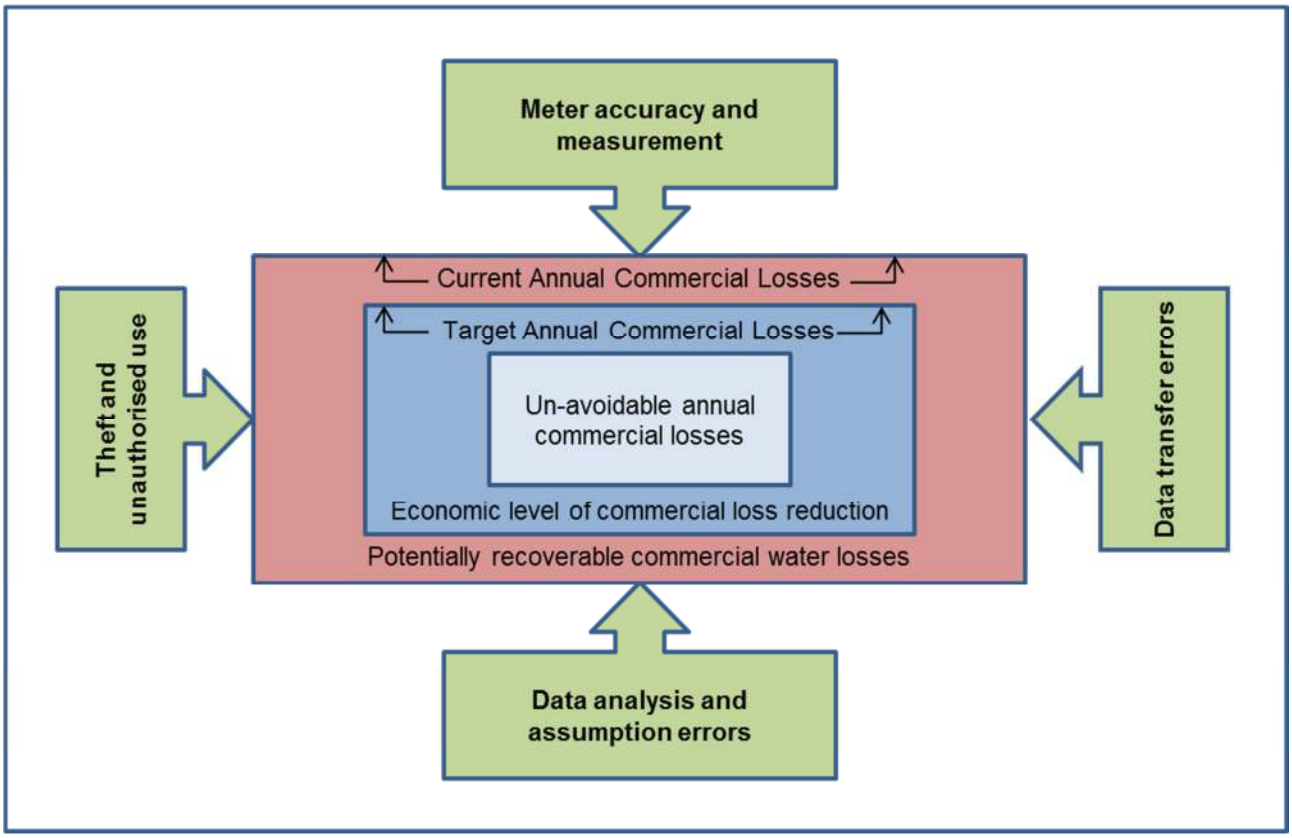

Figure 3.2: Components of commercial water loss reduction (Rizzo *et al.,* 2004)

3.4 PHYSICAL WATER LOSS REDUCTION

The IWA WLTF (Brothers, 2003) has adopted four key physical water loss interventions to reduce physical water losses as shown in Figure 3.3. The four key interventions consist of pressure management, active leak control, speed and quality of repairs, and mains replacement (pipeline asset management, maintenance and renewal). For all these interventions, a current level of annual physical loss and an unavoidable level of annual physical loss is available. The objective for the water utility would be to identify suitable interventions that will address the potentially recoverable physical water losses within the budget constraints, information systems and staff capacity of the organisation. The difference between the target and the unavoidable level of physical loss is considered the economic level of physical water loss reduction. The UARL is pressure dependant and subsequently, pressure management would be the only intervention to influence the UARL. The CARL divided by the UARL provides the ILI as discussed earlier and provides an indication of the physical water losses in a distribution system.

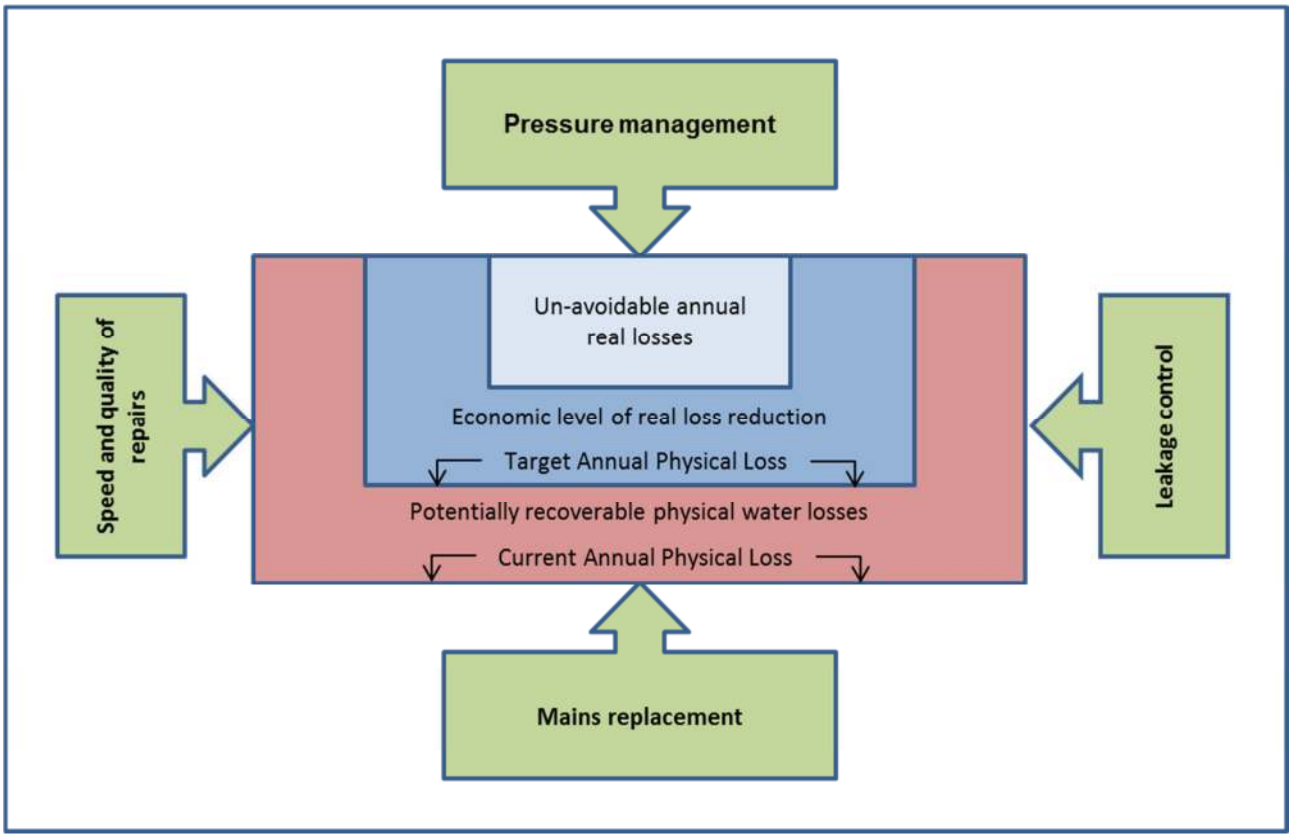

Figure 3.3: Components of physical loss reduction (Brothers, 2003)

3.5 MINIMUM REQUIREMENTS FOR IMPLEMENTING WC/WDM

Each water supply system needs to comply with certain minimum requirements before WC/WDM can be implemented, as shown in Figure 3.4.

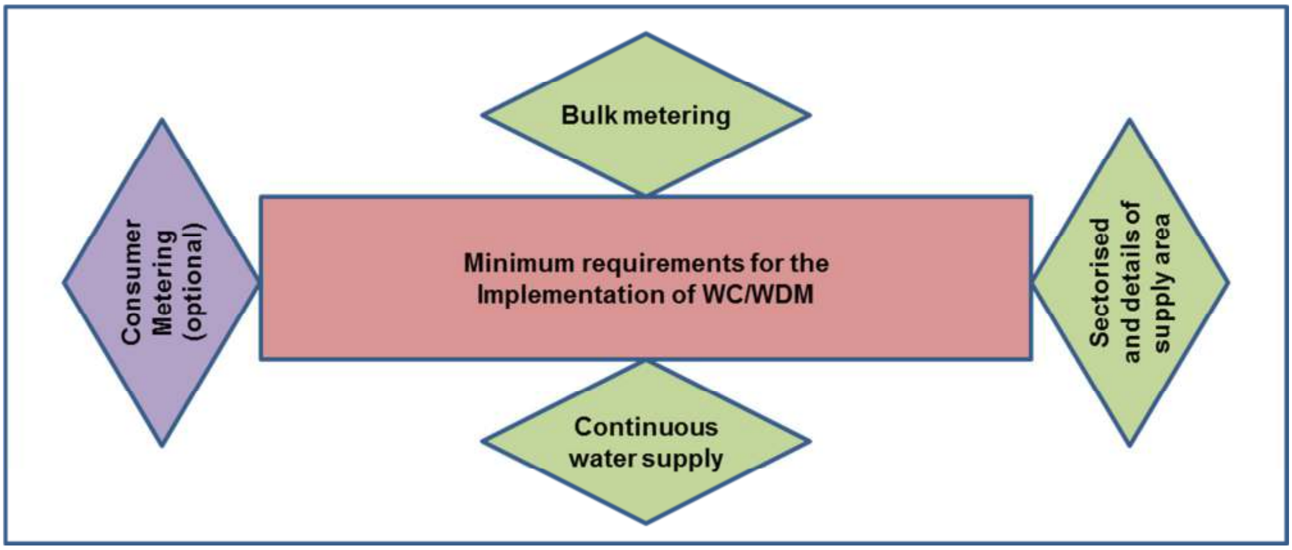

Figure 3.4: Minimum requirements for WC/WDM implementation

The minimum requirements for WC/WDM are based on the following:

(a) Bulk metering: without bulk metering, the SIV will not be known and efficiency and losses in the system cannot be determined.
(b) Sectorisation and area details: the area of supply must be known, otherwise it will not be possible to analyse bulk supply to the system. If a larger area than anticipated is supplied, then water loss and efficiency will be underestimated and conversely, if the area is smaller than anticipated, loss and efficiency will be overestimated. Details of the area, including information on the population and households served, length of mains, average system pressure and number of connections are required to calculate KPIs.
(c) Continuous water supply: the water supply infrastructure must be operational and able to supply water continuously. WC/WDM cannot be implemented, or is difficult to implement, if there is no water in the bulk or distribution network. Charalambous (2011) indicates that intermittent supply in a water supply system is usually because of hydraulic incapacity or severe deterioration in the network, but intermittent supply could also be a result of rationing imposed as a last resort during water shortages.
(d) Consumer meters: are required to determine the authorised metered consumption in the water balance. In the absence of consumer meters, authorised consumption must be estimated.

3.6 IMPROVEMENT OF WATER USE EFFICIENCY

Education and awareness, water wise gardening, retrofitting and removal of wasteful devices and tariff setting are some of the key interventions to promote water use efficiency among consumers as shown in Figure 3.5. The water utility would implement these interventions to achieve a benchmark authorised consumption. Due to consumer habits, budget constraints, the environment and other non-technical factors, it might only be possible to achieve the target water demand. The difference between the current authorised water demand and the target water demand provides the potential water demand reduction.

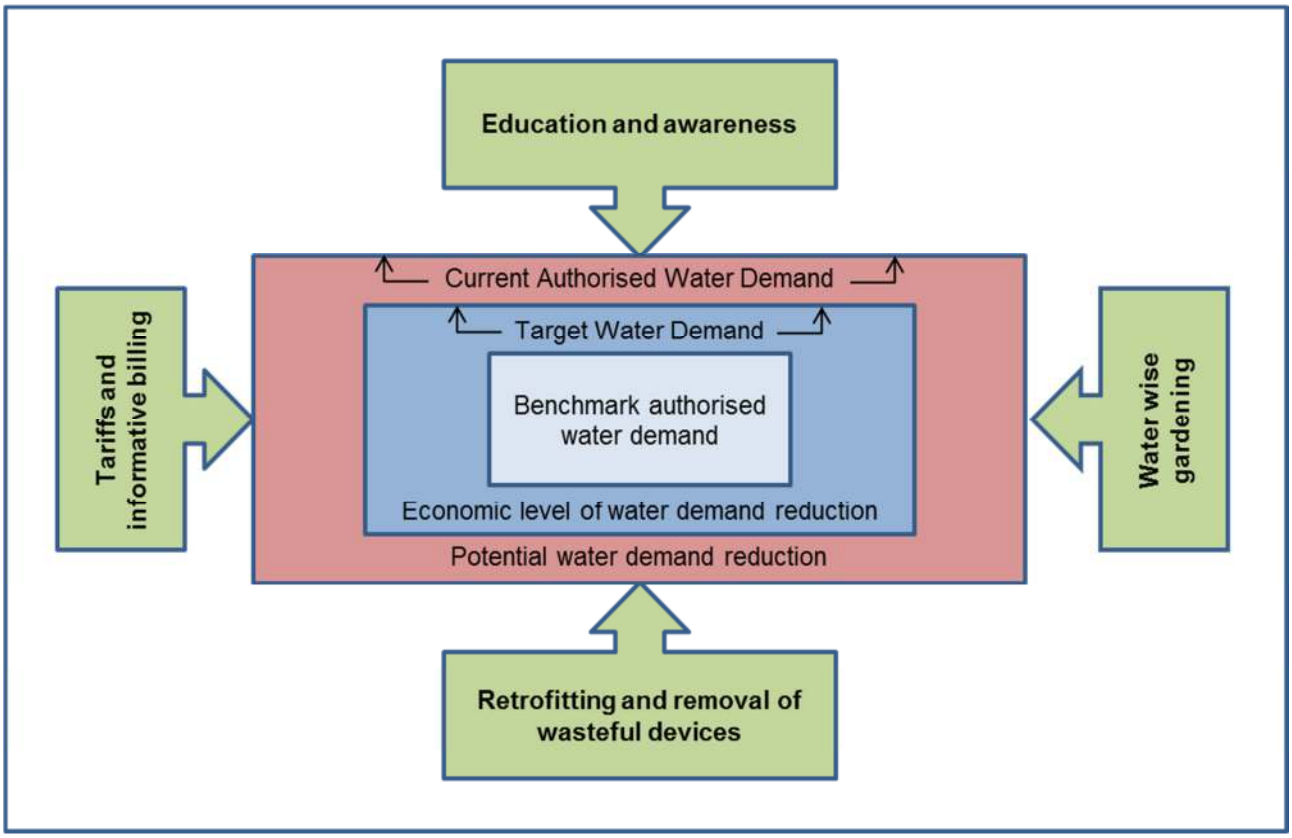

Figure 3.5: Components to improve water use efficiency

3.7 ALIGNMENT OF THE IWA WATER BALANCE AND INTERVENTIONS

The IWA water balance provides an indication of the efficiency, the commercial and physical water loss in a water distribution system, and is the basis for any WC/WDM strategy. With knowledge of the existing water balance and KPIs, it is possible to develop a target water balance based on national and international KPIs. The difference between the current and target water balance provides an indication of the potential savings which could be achieved through improved efficiency and reduced water loss.

The target water balance provides a baseline against which the success of WC/WDM interventions can be quantified. The most effective interventions should be implemented first to ensure the greatest savings and return on investment. The potential savings from the various interventions should always be more than the potential savings from the target water balance, or else the target needs to be reduced. If the potential savings from the interventions are more than the potential savings from the target water balance, then the target should be achievable. The alignment of the IWA target water balance and possible interventions are shown in Figure 3.6.

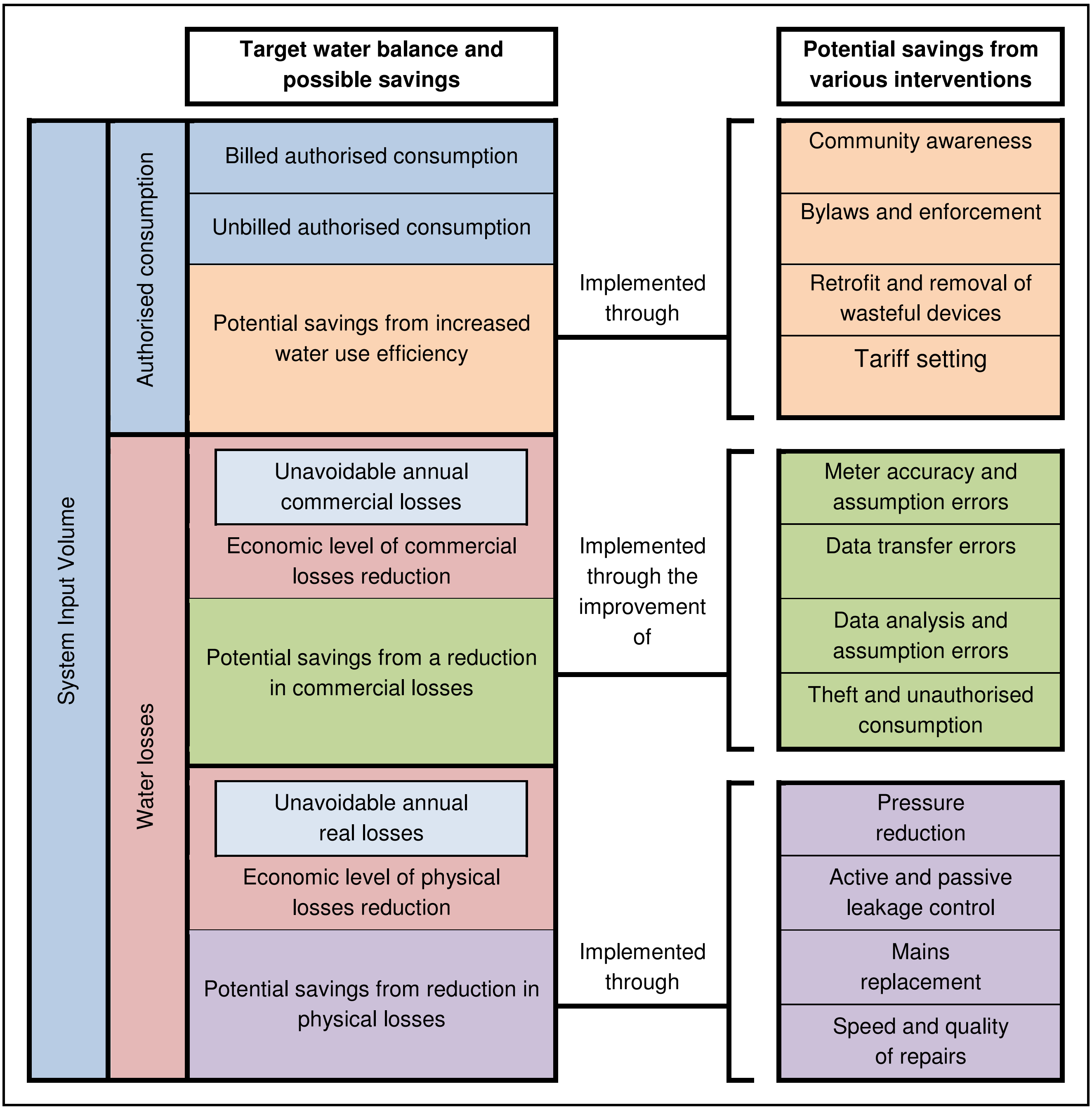

Figure 3.6: Alignment of the IWA water balance and interventions

3.8 DISCUSSION

Alignment of the IWA water balance with commercial and physical water loss interventions and improved water use efficiency interventions forms the basis of a systematic and pragmatic approach to the development of a WC/WDM strategy and quantification of potential savings.

4 TARGET SETTING AND ANALYSIS OF INTERVENTIONS

4.1 INTRODUCTION

This section addresses target setting, the development of a WC/WDM strategy, and the quantification of possible savings on commercial and physical losses, and the improvement of efficiencies. The development of the WC/WDM strategy follows a pragmatic and systematic approach, and is based on the methodology presented in section 3.

The strategy and target for each intervention was based on legislation, the literature review and good practice observed during the implementation of WC/WDM projects across South Africa.

4.2 TARGET SETTING

Based on the literature review, it was apparent that South Africa had set an unrealistic national water loss reduction target. The reconciliation and all town strategies (DWA, 2010) provide a more realistic target, based on scientific analysis. Clear and realistically achievable targets must address the following:

- the base demand and year must be defined
- the projected demand without WC/WDM must be defined
- the projected demand with WC/WDM must be defined and by which year it should be achieved
- the available yield must be indicated to ensure that water resources and demand are in balance
- if the target or saving is defined as a percentage, the numerator and denominator in the percentage calculation must be clearly defined
- distinction must be made between water loss, NRW and SIV targets. Reducing water loss and NRW will not necessarily reduce the SIV and, conversely, a reduction in SIV will not necessarily reduce water loss and NRW.

Figure 4.1 shows a typical demand projection over time, incorporating a WC/WDM target based on a 5-year implementation programme. The water demand projection without WC/WDM is the projected demand if no WC/WDM measures were implemented, suggesting that the demand will exceed the available yield by 2017 in this case. The projected water demand without WC/WDM is usually based on extrapolating the historical demand with due consideration of future population growth, economic growth, climate change, and environmental and societal factors (DWA, 2010). The water demand projection with WC/WDM is the expected demand if WC/WDM is implemented successfully over 5 years, with sustained savings afterwards. In the example, the demand is predicted to exceed the yield in 2024 if WC/WDM could be successfully implemented and sustained. This method of presenting the data highlights that the water utility will gain nine years before new resources have to be developed.

The projected demand with WC/WDM is determined by subtracting the current potential saving from the future demand or by determining a reduction in the future demand as a percentage of the current or future demand.

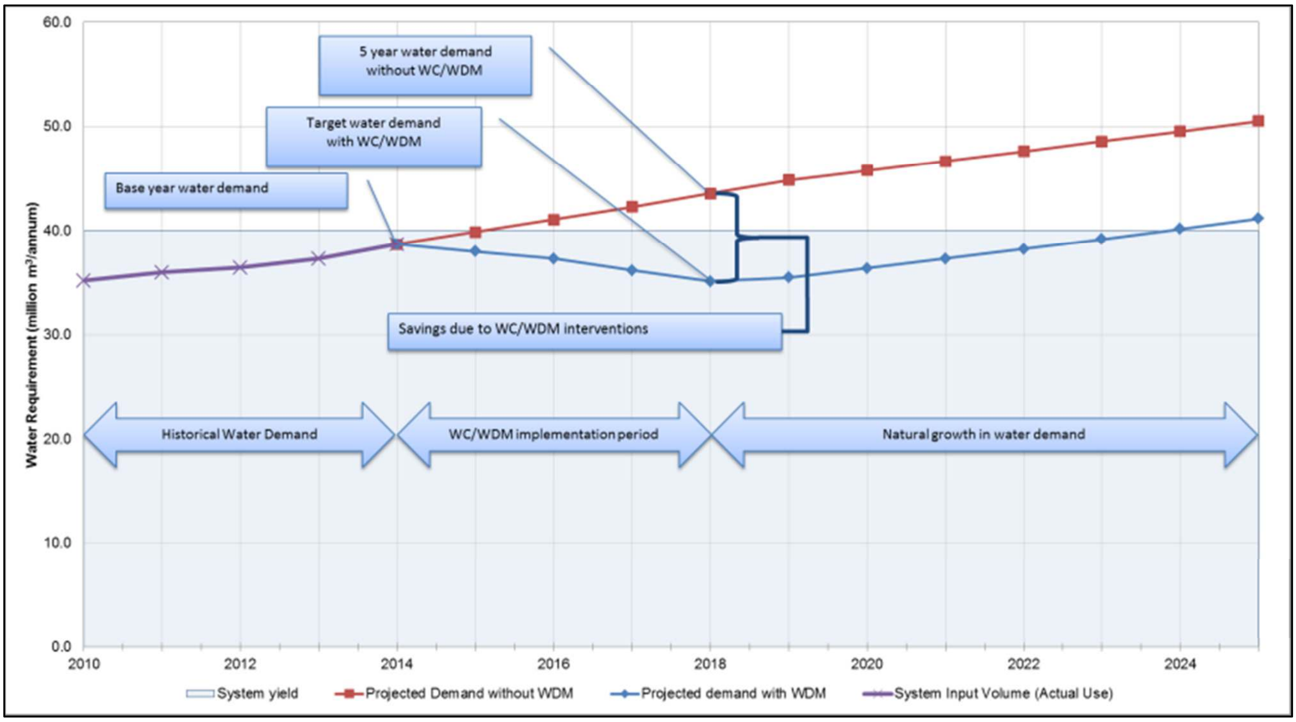

Figure 4.1: Projected water demand with and without WC/WDM

Two notable examples of clearly defined target setting in the Gauteng province of South Africa include the Sebokeng Evaton Advanced Pressure Management project (WRP, 2010) and the Emfuleni Water Loss Reduction Project - Project Boloka Metsi (Management Consultant, 2014).

Figure 4.2 shows the projected water demand with and without WC/WDM for the Sebokeng Evaton Advanced Pressure Management Project. The water demand projection without WC/WDM was based on statistical analysis of the historical consumption from July 1995 to June 2005. The potential savings were estimated at 7 million m^3/annum or 583 333 m^3/month using PRESMAC. The impact of this pressure management project was immediately apparent as the demand dropped by approximately 700 000 m^3/month in the first month and was sustained for the full 5 year contract period. The audited savings amounted to 8 271 673 m^3/annum or 689 306 m^3/month, indicating that the estimated savings were conservative but within 20 % of the target (WRP, 2010).

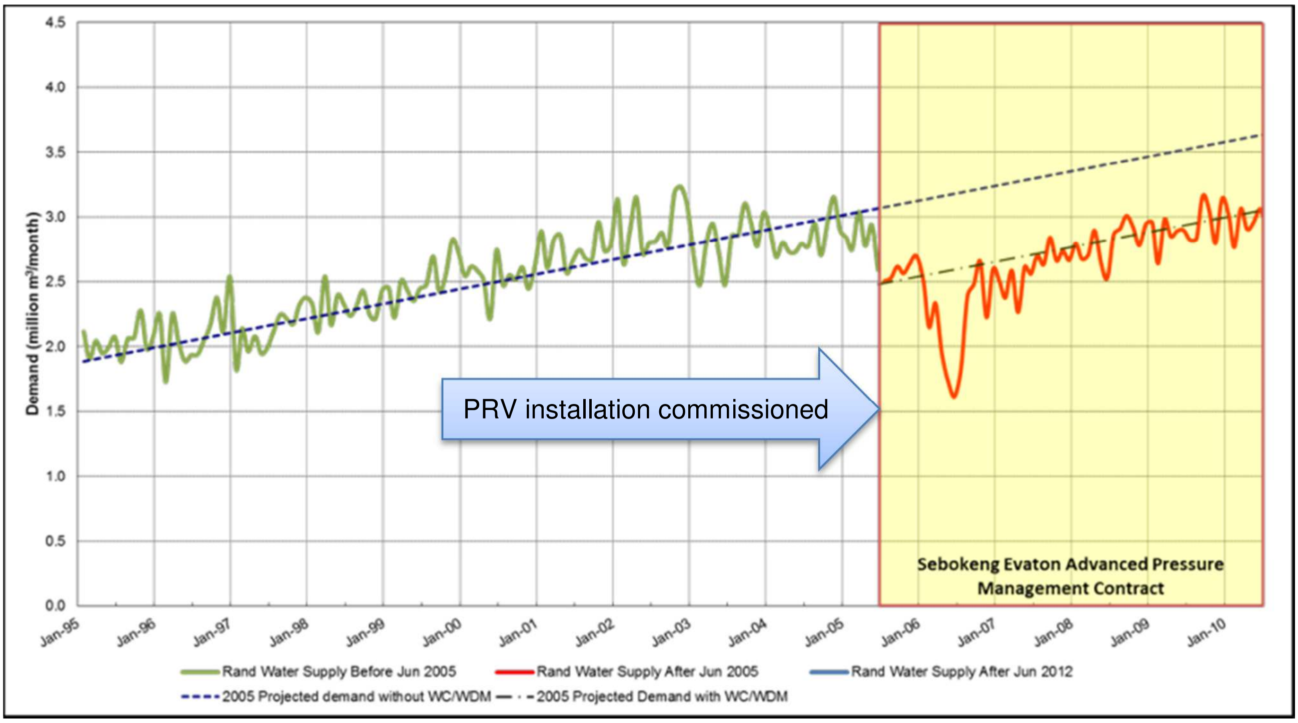

Figure 4.2: Water savings from the Sebokeng Evaton Pressure Management Project (WRP, 2010)

Figure 4.3 shows the results from the Emfuleni Water Loss Reduction Project - Project Boloka Metsi, also in the Sebokeng Evaton area, which involved retrofitting the internal plumbing of 106 000 households. The water demand projection without WC/WDM was based on statistical analysis of the historical consumption from Jul 2005 (after the advanced pressure management installation was commissioned) to June 2012. The target was to reduce the June 2014 consumption by 15 % or 7 082 393 m^3 over the project period to comply with the requirements of the Integrated Vaal River System Reconciliation Strategy (DWAF, 2007). In this case, the project was implemented over two and a half years and its impact was not immediately apparent. The audited savings amounted to 6 840 373 m^3/annum, which was within 3 % of the target (Management Consultant, 2014).

Figure 4.4 shows the water demand profile for the Sebokeng Evaton area over the past 20 years and clearly indicates the impact of both projects (Management Consultant, 2014).

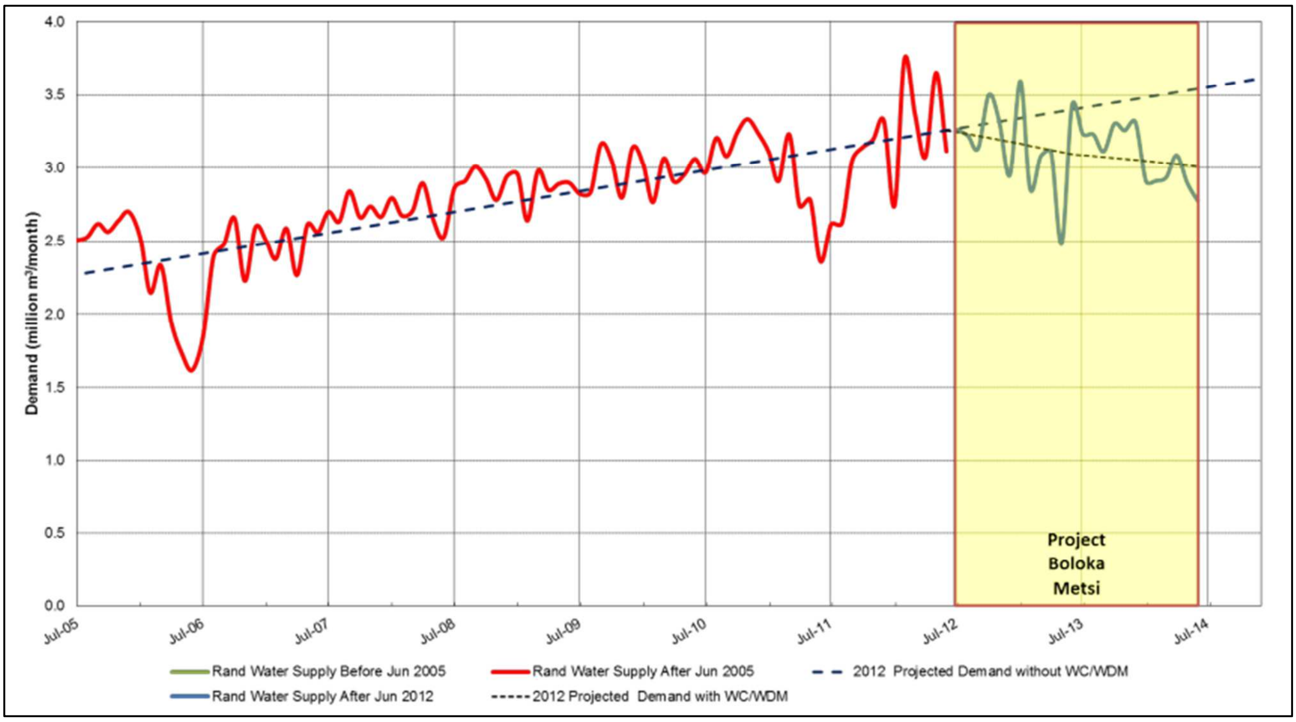

Figure 4.3: Water savings from Project Boloka Metsi (Management Consultant, 2014)

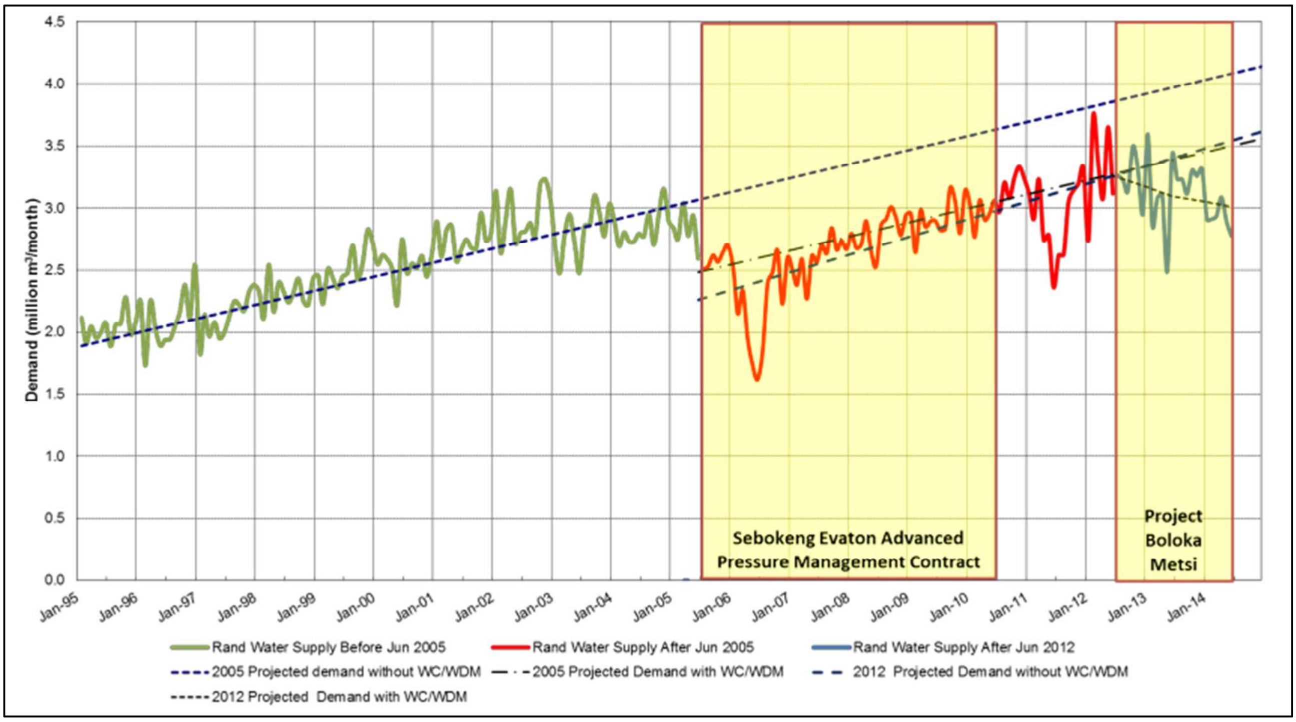

Figure 4.4: Sebokeng Evaton 20 year water demand profile (Management Consultant, 2014)

4.3 WC/WDM MINIMUM REQUIREMENTS

As was discussed in section 3.5, bulk metering, sectorisation and continuous supply are prerequisites for implementing WC/WDM. Consumer metering is considered important and should be implemented as a priority, otherwise authorised consumption has to be estimated.

4.3.1 Bulk metering strategy

The main objectives of bulk metering are to determine the total supply and the MNF into an area. The priority metering points are shown in Figure 4.5.

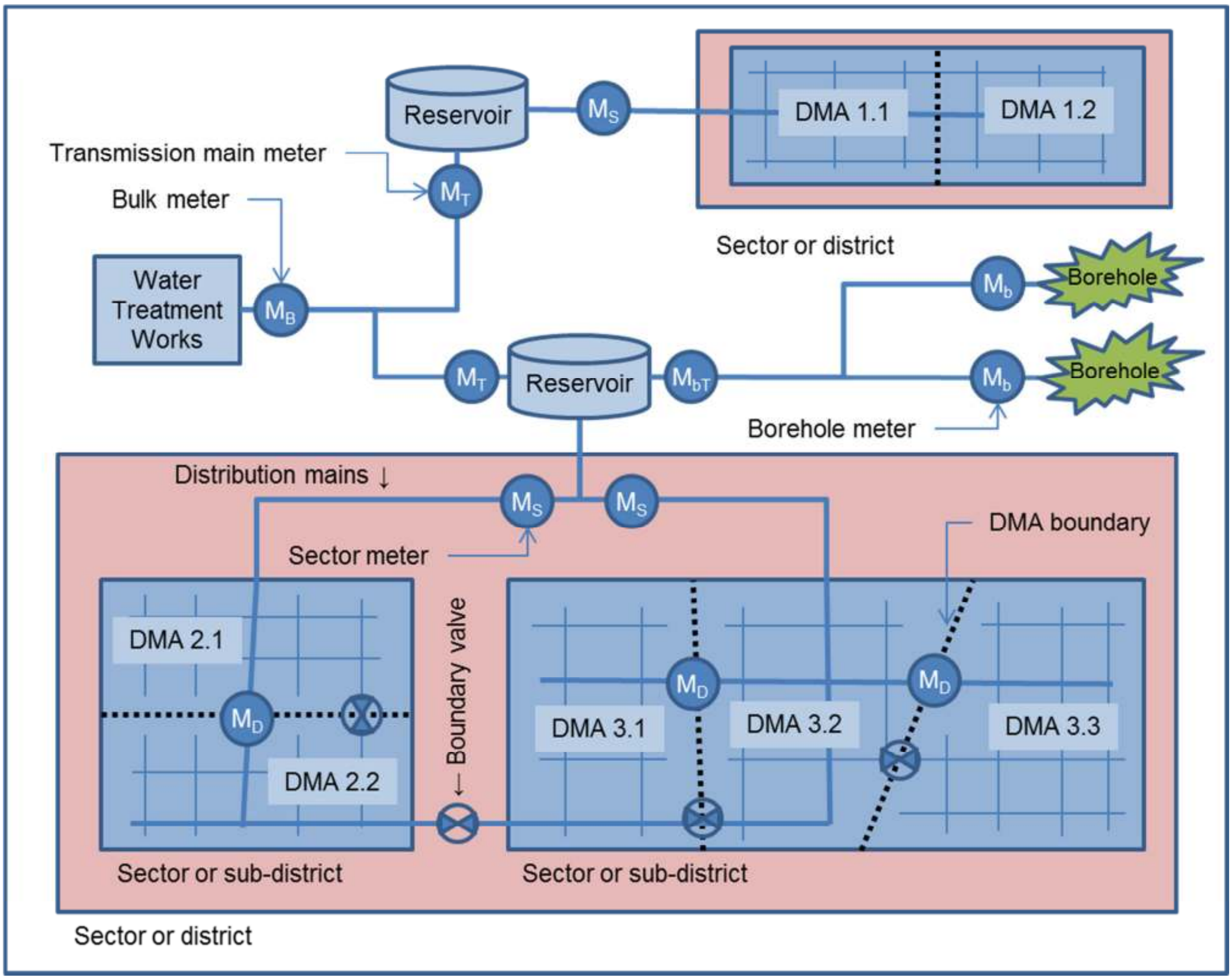

Figure 4.5: Priority bulk metering points

Based on Figure 4.5, bulk meters should be installed in the following order of priority:

- SIV: the first priority is determining the SIV. In this case, it will be the WTW outlet (meter M_B) and the total supply from boreholes (meter M_{bT}) followed by individual borehole meters (M_b). If budget is a limitation and all supply points cannot be metered immediately, the Pareto principle

(80-20 rule) should apply whereby the main sources should be metered first followed by the secondary sources

- sector meters: the second priority is measuring the supply to the various sectors. Installing meters on the reservoir outlets (meters M_S) will enable the water utility to measure MNF and prioritise sectors
- transmission mains: the third priority is to measure water losses on the transmission mains (meters $M_{B,}$ $M_{T,}$ M_b and M_{bT}), especially in areas where the transmission mains are long and run through open fields where leaks cannot be easily detected
- DMA meters: the fourth priority is to install meters (M_D) on each of the DMA's inlets and outlets.

Bulk meters installations must be maintained and read on a regular basis. The meter readings should be analysed and monitored to determine an accurate SIV.

4.3.2 Sectorisation strategy

Clause 11 of the *Regulations Relating to Compulsory National Standards and Measures to Conserve Water* (DWAF, 2001a), states that a water services institution must measure the quantity of water provided to each supply sector or DMA within its supply area, and determine the quantity of water lost on a monthly basis. Bulk metering and sectorisation are therefore not only a prerequisite for implementing WC/WDM but are also a legal requirement.

The size of sectors and DMAs has been the point of debate at several IWA Water Loss conferences. McKenzie (Mckenzie *et al.*, 2010) argued that larger zones are generally easier to manage and require less maintenance while Trow (Mckenzie *et al.*, 2010) argued that with smaller DMAs, targeting 2 000 properties, it is easier to identify an increase in MNF, something which would be difficult to pick up on larger DMAs. Kanellopoulou (Mckenzie *et al.*, 2010) confirms McKenzie's view and indicates that Athens Water is finding it increasingly difficult to maintain the large number of small DMAs and is reverting to larger zones with fewer bulk meters and boundary valves.

Step testing is an alternative to small DMAs and can be used to locate leaks and prioritise DMAs. Step testing is the process of isolating parts of the distribution network towards the sector, or DMA inlet, while monitoring the MNF water loss (IWA, 2007). For example, if DMA 1.2 in Figure 4.5 was isolated from DMA 1.1, the leakage in DMA 1.2 can be determined by calculating the difference in demand. Figure 4.6 shows the step testing logging results (WRP, 2011) for a DMA in Betty's Bay in the Western Cape. By isolating sections of the distribution network, it was possible to localise and identify a major leak in the DMA, based on the sectorisation strategy.

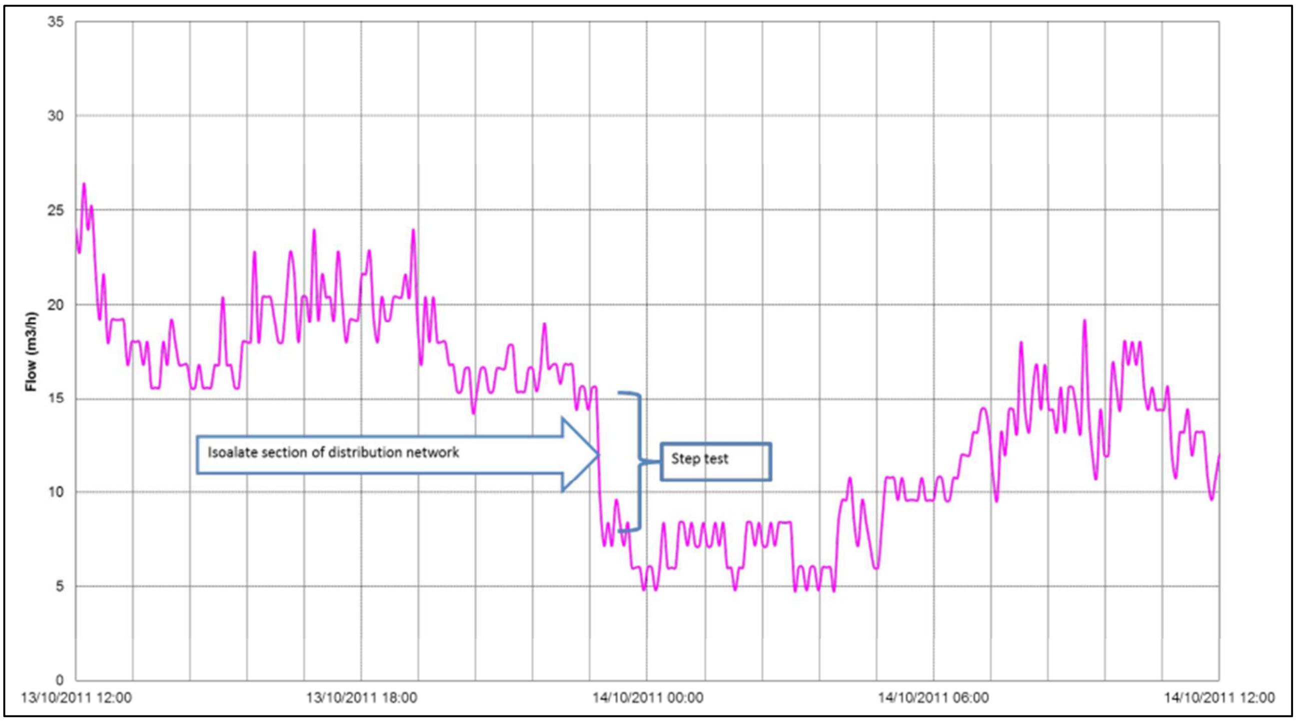

Figure 4.6: Logging result from step testing on actual reservoir (WRP, 2011)

Basic information on the population and households served, number of connections, length of mains and average system pressures are required for each water supply system, sector or DMA.

4.3.3 Intermittent supply

Intermittent water supply problems have been observed in the western highveld region (WRP, 2005) due to severe water wastage and leakages; in the Sebokeng / Evaton region (WRP, 2009) due to closed network valves and decommissioned infrastructure; and in Gaborone (WRP, 2014) due to the drought situation and imposed water restrictions. Problems associated with intermittent or rationed water supply include:

- positive and negative (vacuum) pressures damage pipe seals and shorten the design life of the pipelines. These pipe seals can only be repaired through total pipe replacement
- air drawn into the distribution network during depressurisation is released mainly through consumer meters. Air passing through a consumer meter does not only damage the meter but also corrupts the meter reading. Corrupted meter readings will impair the metering and billing system and upset consumers
- dirt, sewage and other contaminants can enter the water distribution network when depressurised with a subsequent high risk of causing water borne diseases
- increased burst frequency and discomfort to consumers. Charalambous (2011) observed an increase of 300 % in mains and 200 % in connection bursts following the severe drought and

resultant intermittent operation of the water supply system during 2008 to 2009 in Lemesos in Cyprus

- intermittent supply is expensive to operate and maintain through increased overtime and number of bursts,
- infrastructure, such as isolating valves, is damaged when operated outside their intended use
- over time it becomes increasingly difficult for the water utility to pressurise the distribution system. It is almost impossible to fill pipes, reservoirs and towers when customers leave taps open in anticipation of filling buckets, bathtubs and tanks
- intermittent supply affects the local economy as businesses cannot plan and operate as intended.

Figure 4.7 shows the logging results (WRP 2005) for Kameelrivier B in the western highveld region.

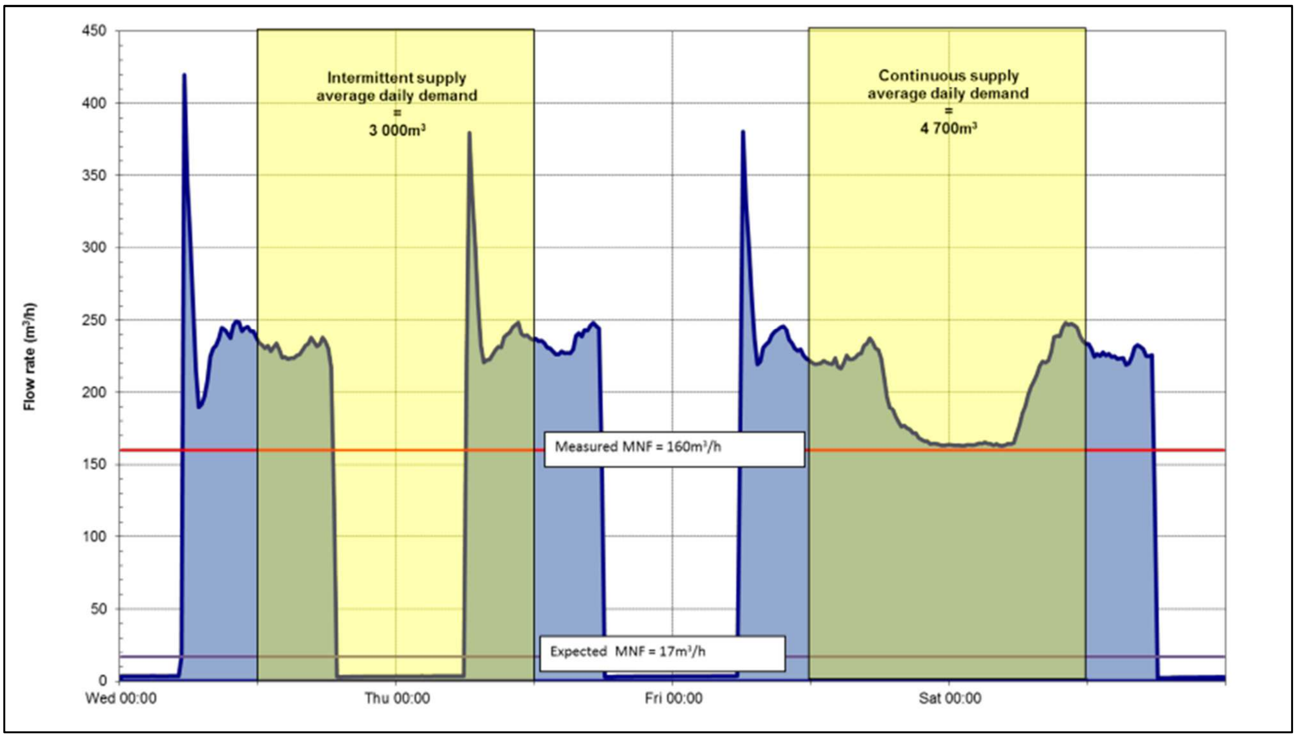

Figure 4.7: Kameelfontein intermittent water supply (WRP, 2005)

Rationing was implemented in this area to curb excessive leakages and enable the water utility to pressurise the bulk distribution system. Although rationing of the water supply reduced the ADD by 1 700 m^3 or 36 %, the measured MNF (160 m^3/h) was almost 10 times higher than the expected MNF (17 m^3/h). The excessive MNF is an indication of damage done to the distribution network and people leaving taps open in anticipation of water supply being restored.

Unwanted closed valves in the pipe network occur when repair and maintenance teams do not re-open all the isolating valves after repairs. Over time, an excessive number of closed valves can cause bottlenecks in the distribution system and resultant network failure during peak demand. Figure 4.8 shows the logging results for Beverley Hills in Evaton and the effect of closed valves in the distribution network (WRP, 2004d). Although static pressure at this point is 80 m (it is one of the lowest points in the distribution network), the water utility was receiving complaints of low pressure during peak demand. Further investigation revealed that on some days the head loss during peak demand exceeded 60m and that there were several closed valves in the distribution network. Once these network valves were located and opened, the network operated as expected.

Problems associated with intermittent supply are considerable and should be eliminated as a key strategic priority before embarking on any WC/WDM programme.

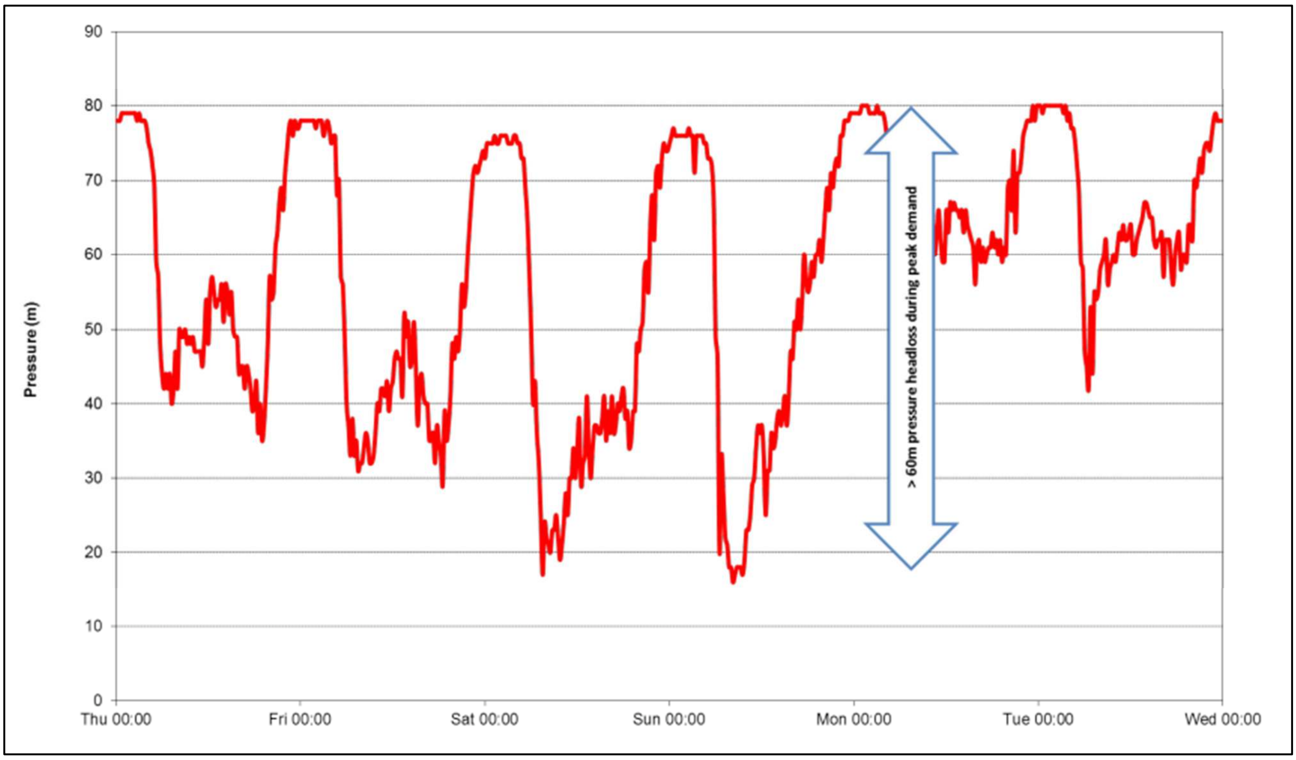

Figure 4.8: Impact of closed valves in the distribution network – Evaton (WRP, 2004d)

No savings are expected from bulk metering, sectorisation and the resolution of intermittent water supply. Sectorisation might reduce network pressures and subsequent burst pipes but its potential savings are considered negligible and are excluded from calculations.

4.4 WATER BALANCE CALCULATION

The IWA water balance was discussed in section 3 and provides an indication of the potential reduction in SIV, authorised consumption, water loss and NRW. All these parameters must be taken into consideration when developing a strategy, determining targets and deciding on appropriate interventions. These indicators are important from the following perspective:

- the SIV provides an indication of the water security and efficiency of the water distribution system – the SIV cannot exceed the available yield
- the average consumption per capita per day provides an indication of the efficiency of the system
- water loss is unattractive from a financial and environmental perspective and should be reduced to acceptable levels. The percentage commercial losses, ILI and losses per connection per day provide an indication of water loss in the system
- NRW impacts on financial sustainability of the water utility
- water use efficiency is improved by metering as has been shown all over the world. Consumers tend to conserve water and fix leaks on their property if water is paid for.

NRW and water loss impact directly on possible augmentation of available water resources. NRW, for example, might be high for a specific system but water is used efficiently and water loss is under control, which is sometimes the case with rural water supply schemes where the per capita consumption is very low but metering and billing systems are ineffective. If demand were to exceed available yield, augmentation should be considered as water is used efficiently and losses are low.

Alternatively, water loss and NRW might be low but water is used inefficiently, which is sometimes the case with water utilities with sufficient resources. If demand should exceed available yield, augmentation cannot be considered as water is used inefficiently which should be addressed through tariff setting and community awareness.

4.5 WATER USE EFFICIENCY

Education and awareness, water wise gardening, retrofitting and removal of wasteful devices, and tariffs and informative billing have been identified as measures to improve water use efficiency. KPIs such as litres/capita/day, m^3/connection/month and m^3/household/month provide indications of water use efficiency. Improved water use efficiency would result in reduced billed consumption and SIV.

4.5.1 Education and awareness

4.5.1.1 Strategy

The purpose of education and awareness programmes is to inform the community of the value of water, that it must be paid for, and that it must be conserved for generations to come. Community education and awareness campaigns can adopt many formats but should have a clear message. Awareness campaign message content can include payment for services, water wise gardening, water wise practices at home, reporting visible leaks and fixing of own leaks. Community awareness programs are not considered an event and should be ongoing to ensure water conservation becomes a lifestyle.

Education and awareness programmes can be enhanced by involving the community in the execution of WC/WDM programme as was demonstrated in Emfuleni (WRP, 2005; WRP, 2009; Management Consultant, 2014). Community members, for example, were involved with:

- education and awareness programmes in the community, at schools, clinics and public spaces like shopping centres
- retrofitting of households by local plumbers
- fixing of visible leaks and performance of network maintenance by local contractors

4.5.1.2 Potential savings

Measuring results from education and awareness programmes is relatively difficult since education and awareness programmes are usually undertaken in conjunction with other interventions. Two awareness projects undertaken in isolation in Johandeo (WRP, 2009) and Boitumelo (Siqalaba *et al.,* 2009) were researched to determine the savings. The projects resulted in a reduction of 8 % and 10 % of the ADD respectively. These projects were undertaken in areas with excessive leakage and the savings might be optimistic. A 5 to 10 % target might be more realistic. The potential savings from education and awareness could be expressed by equation 4.1:

$$\text{Savings}_{\text{Education \& awarenss}} = 5 \text{ to } 10\ \% \text{ of the authorised consumption} \tag{4.1}$$

A knowledge, attitude and perception (KAP) survey completed for 776 households before and after interventions in Sebokeng and Evaton revealed the following (Management Consultant, 2014):

- 93 % of respondents indicated that education and awareness programmes are necessary
- 94 % of respondents found the presence of a conservation warrior and literature as helpful
- 84 % indicated that the project has altered the way they think and behave
- 68 % had never received any information on WC/WDM

- some of the most noticeable behavioural changes observed include irrigation early or late in the day, repairing of leaks, reducing the amount of water used when washing clothes, washing clothes only when there is a full load, and teaching children about WC/WDM.

Education, awareness and community involvement have many indirect benefits, which are difficult to quantify, but are often critical to the overall success of a project.

4.5.2 Water wise gardening

4.5.2.1 Strategy

The purpose of a water wise gardening programme is to permanently reduce garden watering consumption through alternative water resources such as grey water or borehole water, xeriscape gardening and mulching.

4.5.2.2 Potential savings

Jacobs (2008) estimated the potential savings from xeriscaping could be as high as 40 % of the ADD in medium to high-income areas, but the expected savings are a function of the initial state of a property. The potential savings from water wise gardening could be expressed by equation 4.2:

$$\text{Savings}_{\text{Water wise gardening}} = \leq 40\ \%\ \text{of the authorised consumption} \qquad (4.2)$$

4.5.3 Retrofitting and removal of wasteful devices

4.5.3.1 Strategy

The objective of retrofitting and removal of wasteful devices is to reduce leakage and wastage on private properties. In developed countries, most water conservation projects are geared towards the installation of water efficient devices, such as low flow showerheads, dual flush toilets, and water efficient dishwashers and washing machines. The average South African household income prevents the installation of these relatively expensive devices, if funded by consumers, for the reasons listed in section 2.5.2.

4.5.3.2 Potential savings

Potential savings vary significantly from one water distribution system to the next. The expected savings are dependent on the level of internal plumbing leakage or existing inefficiencies. The potential savings from retrofitting and removal of wasteful devices in low-income areas could be expressed by equation 4.3:

$$\text{Savings}_{\text{Retrofit low income}} = \text{Current water demand} - \text{target water demand} \qquad (4.3)$$

In equation 4.3, the current water demand is the actual household water use and the target water demand is the expected water use based on the level of service provided. The potential savings for medium to high-income areas are based on the installation of low flow showerheads, dual flush and low volume toilets and washing machines as discussed in the literature review. The potential savings could be expressed by equation 4.4:

$$\text{Savings}_{\text{Retrofit med to high income}} = \sum \left\{ \begin{array}{c} \text{Showerheads} = 20\ \ell/\text{device/day} \\ \text{Low volume flush toilets} = 40\ \ell/\text{capita/day} \\ \text{Low volume and dual flush toilets} = 50\ \ell/\text{capita/day} \\ \text{Washing machine} = 21\ \ell/\text{capita/day} \end{array} \right\} \quad (4.4)$$

4.5.4 Tariffs and informative billing

4.5.4.1 Target

The purpose of cost reflective water tariffs is to ensure the financial viability of the water utility and ensuring that the consumer appreciates the value of water by using it efficiently. Informative billing promotes awareness among consumers by providing historical consumption figures, water saving tips and general information about water services in the area. Water tariffs should be cost reflective, suggesting the revenue generated from selling water should be sufficient to cover all operational, maintenance, asset renewal and administration costs.

4.5.4.2 Potential savings

The potential saving from increased water tariffs have already been determined in the literature review and is calculated using equation 4.5:

$$\text{Savings}_{\text{Tariffs}} = 3\ \%\ \text{reduction in billed authorised consumption for every}\ 20\ \%\ \text{increase} \quad (4.5)$$

4.6 COMMERCIAL WATER LOSS REDUCTION

Commercial water loss reduction refers to reducing water loss from unauthorised connections (unlawful use), meter errors, data transfer errors and meter reading errors. Reducing commercial losses usually results in increased revenue for the water utility.

4.6.1 Meter accuracy and measurement

4.6.1.1 Strategy

A proper metering strategy is usually based on the assumption that connections are metered, that all meters are properly installed and in working condition, and that the average meter error is within economic limits and in line with the latest legislation. Van Zyl (2011:83) recommended that domestic meters should be considered for replacement before the age of 10 years, and bulk meters before 5 years. Water utilities should therefore endeavour to replace 8 % to 12 % (8 to 12 years design life) of consumer meters per annum to avoid possible meter replacement backlogs, resulting in having to replace all meters at once. Consumer meters should be repaired, replaced and maintained on a continuous basis. Regular meter testing should be undertaken to assess meter accuracy.

4.6.1.2 Domestic meter potential savings

The potential savings from improved domestic meter accuracy and measurement have already been determined in the literature review and are calculated using equations 4.6 and 4.7:

$$\%\ \text{Meter error}_{\text{Domestic}} = 1 - (0.36 \times \text{average age of consumer meters in years}) \tag{4.6}$$

for positive displacement meters.

$$\text{Savings}_{\text{Domestic meter error}} = \%\ \text{Meter error}_{\text{Domestic}} \times \text{domestic metered consumption} \tag{4.7}$$

4.6.1.3 Non-domestic meter potential savings

The potential savings from improved non-domestic meter accuracy and measurement have already been determined in the literature review and are calculated using equation 4.8:

$$\text{Savings}_{\text{Non-domestic meter error}} = 10 \text{ to } 20\ \% \times \text{non} - \text{domestic metered consumption} \tag{4.8}$$

The potential savings from improved meter accuracy and measurement can be verified by using the suggested default values for apparent losses as shown in Table 2.1 and equation 4.9:

$$\text{Savings}_{\text{Meter error}} = (\text{Current error } (\%) - \text{Target error } (\%)) \times \text{water loss} \tag{4.9}$$

where a 10 % meter error is considered high and 2 % is considered low. Equations 4.7 and 4.8 are based on the metered consumption whereas Equation 4.9 is based on water loss, which could be significantly less than the metered consumption in well-managed systems. The sensitivity of using metered consumption or water loss is discussed in more detail in section 5.

4.6.2 Data transfer errors

4.6.2.1 Strategy

Data transfer errors represent the differences between the actual meter readings on site and the meter readings on the billing system. Meter manufacturers have made tremendous strides with new technologies to address this problem through automatic meter reading, pre-paid metering, smart metering and electronic data collection systems. Each new technology has its own challenges and water utilities should strive towards achieving a balance between staff competence and the latest technologies. Data transfer errors could be reduced and maintained through monthly meter reading audits and training of meter readers.

4.6.2.2 Potential savings

The potential savings from reduced transfer errors can be determined by using the suggested default values for apparent losses as shown in Table 2.1, or through sample testing. The potential saving through improved data transfer can be calculated using equation 4.10:

$$\text{Savings}_{\text{Data transfer}} = (\text{Current error } (\%) - \text{Target error } (\%)) \times \text{water loss} \qquad (4.10)$$

where 8 % data transfer errors is considered high and 2 % is considered low. The same sensitivity test as for equation 4.9 is performed in section 5.

4.6.3 Data analysis and assumption errors

4.6.3.1 Strategy

A water utility should have clear guidelines on the processing of meter reading exception codes. Exception code investigation should take preference to averages and assumptions. Meter readings may be correct but much higher than recordings in the billing system because readings have been averaged for a long time. The billing system operator then questions the high consumption and because it is not further investigated, reverts back to an estimated reading.

Meter reading exception codes should be clearly understood by the meter readers, billing system operators and technical staff. Any meter reading with an exception code should be referred to the technical department for meter repairs or replacement. If no problems are found, the meter reader confirms the meter reading.

4.6.3.2 Potential savings

No specific formula was available to address the potential savings that would result from meter reading errors. For purposes of this research, savings of this nature were assumed to be included in the potential savings from data transfer errors.

4.6.4 Unauthorised connections and theft

4.6.4.1 Strategy

Unauthorised connections and theft related instances occur where consumers deliberately tampered with their metered connection to reduce or eliminate flow. Unauthorised connections and theft can be determined by analysing the billing database for a sudden drop in consumption, connections with zero consumption, recording of any suspicious activity at the meter, by the meter reader, such as fresh scratch marks on the meter connection points, or signs of excavations around the meter. An advanced programme can include a zero pressure test on the property by closing all the known connections and then checking each water point on the property to ensure it is dry.

It should be noted that not all unauthorised connections are fraudulent. Consider for example, the western highveld region (WRP, 2005) where it was found that most households made their own household connection from communal standpipes, due to accessibility or security reasons. Several communities in the western highveld region without a formal water supply infrastructure made ad hoc connections on the nearest bulk supply pipeline (WRP, 2005). In Mbombela, the formal water distribution system deteriorated to such an extent that people subsequently connected to the main bulk supply line, which supplies the reservoir. Disconnecting these households would have to be integral to an alternative water supply, or else it would agitate the community (WRP, 2013). Examples of unauthorised connections are shown in Figure 4.9.

Figure 4.9: Examples of unauthorised connections on bulk water supply mains

4.6.4.2 Potential savings

The percentage of illegal connections should be determined by field investigations and equation 4.11:

$$\% \text{ Unauthorised connections} = \frac{\text{Number of unauthorised connections}}{\text{Total number of connections}} \tag{4.11}$$

Ten percent illegal connections represents 10 unauthorised connections per 100 connections. The volume lost due to illegal connections is calculated by using equation 4.12:

$$\text{Savings}_{\text{Theft}} = \text{number of unauthorised connections} \times \text{average consumption} \tag{4.12}$$

where the average consumption is equal to the average consumption per connection in the area.

The potential savings from unauthorised connections and theft can be verified by using the suggested default values for apparent losses as shown in Table 2.1. The potential savings through improved unauthorised connections and theft can be calculated using equation 4.13:

$$\text{Savings}_{\text{Theft}} = (\text{Current }(\%) - \text{Target }(\%)) \times \text{water loss} \tag{4.13}$$

where 10 % unauthorised connections is considered high and 2 % is considered low. The same sensitivity test as for equations 4.9 and 4.10 will be performed in section 5.

4.7 PHYSICAL WATER LOSS REDUCTION

The IWA physical water loss reduction measures include active and passive leakage control, pressure management, mains replacement and speed and quality of repairs. Other measures, which were investigated as part of this study, included water loss from leaking and overflowing reservoirs. Reducing physical water loss will usually reduce the SIV for the utility.

4.7.1 Active and Passive Leakage Control

4.7.1.1 Purpose

Active leakage control (ALC) and passive leakage control ensure that all leaks and bursts are located, reported and repaired as soon as possible. ALC involves sending out maintenance teams to actively identify leaks, while passive leakage control relies on the public to report leaks through customer call centres. Benefits of continuous MNF monitoring were observed in Johannesburg (WRP, 2001) and Emfuleni (Management Consultant, 2014) as demonstrated in Figure 4.10 to Figure 4.12. Continuous monitoring enables the water utility to timeously identify and repair leaks.

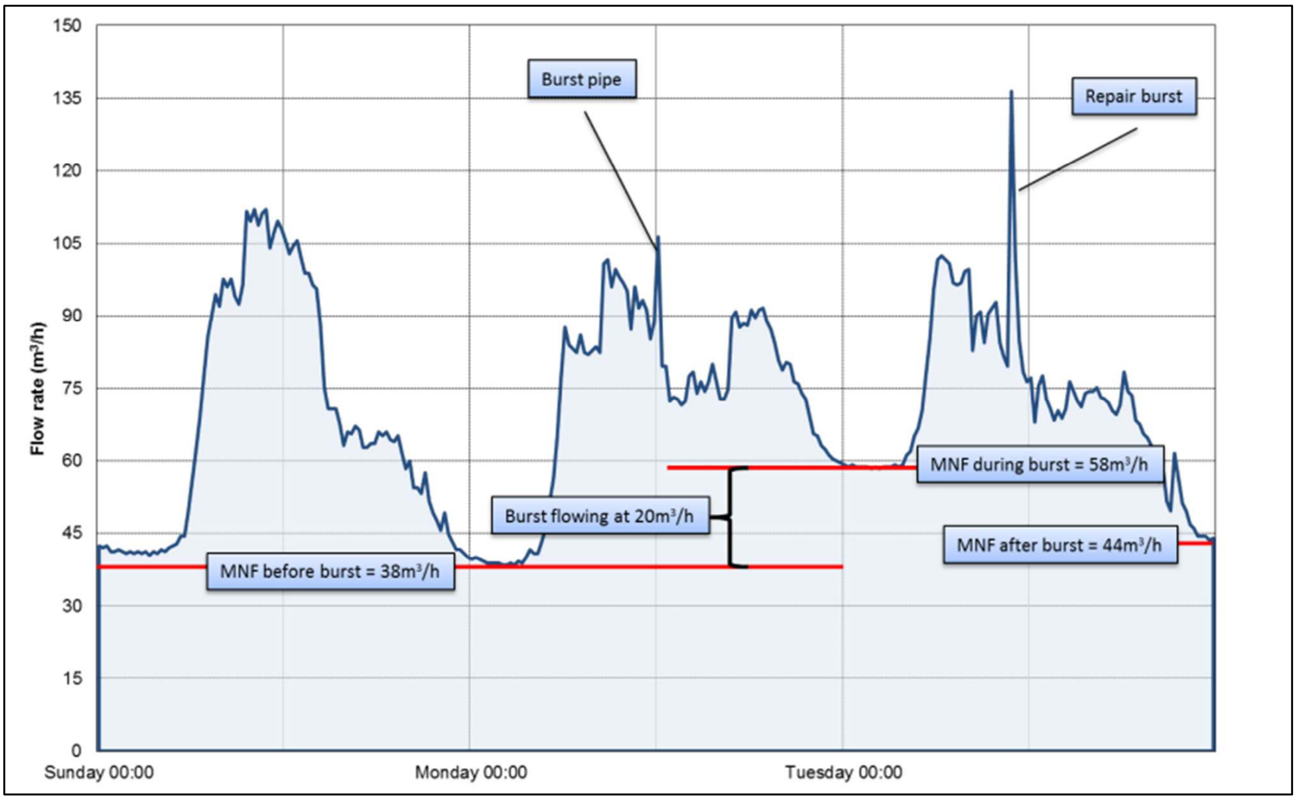

Figure 4.10: Increased MNF due to burst pipe (WRP, 2001)

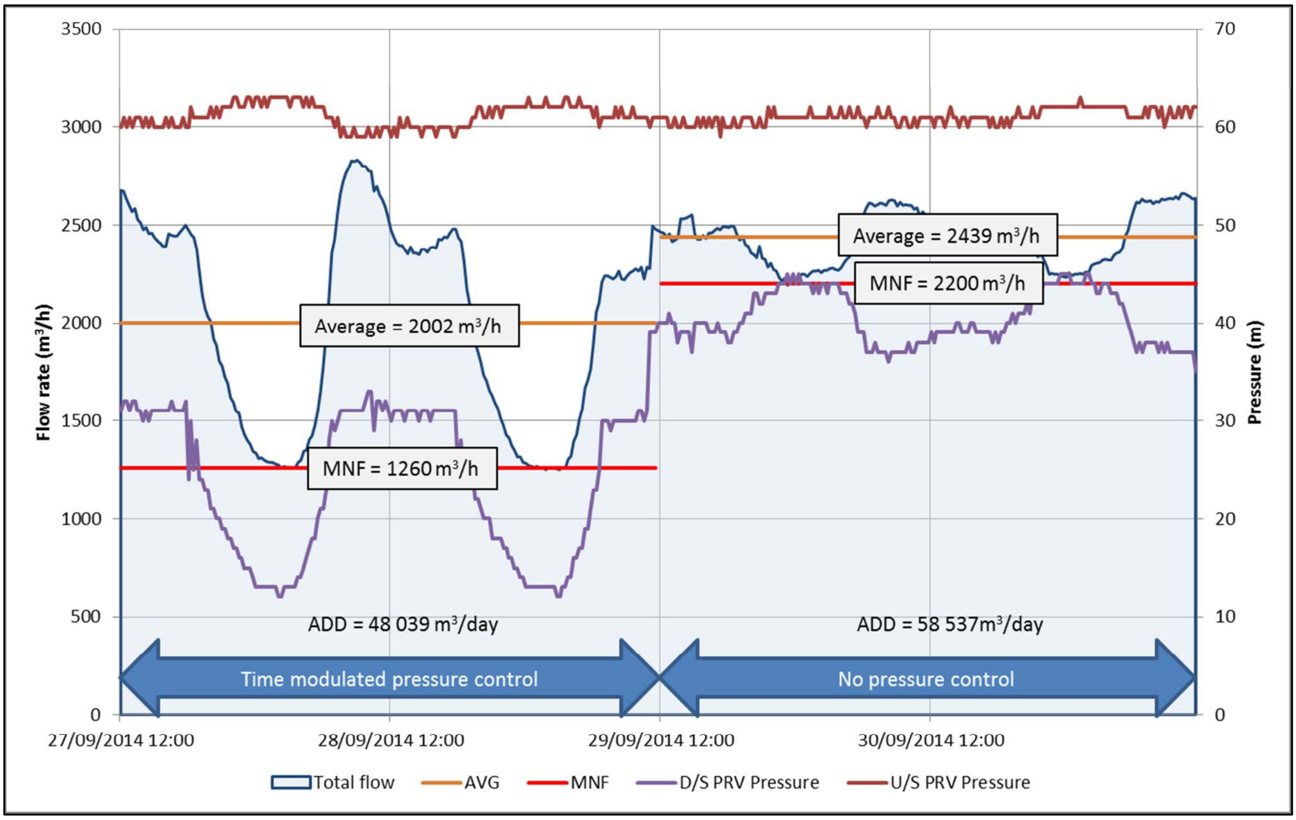

Figure 4.11: Increased MNF due to PRV failure (Management Consultant, 2014)

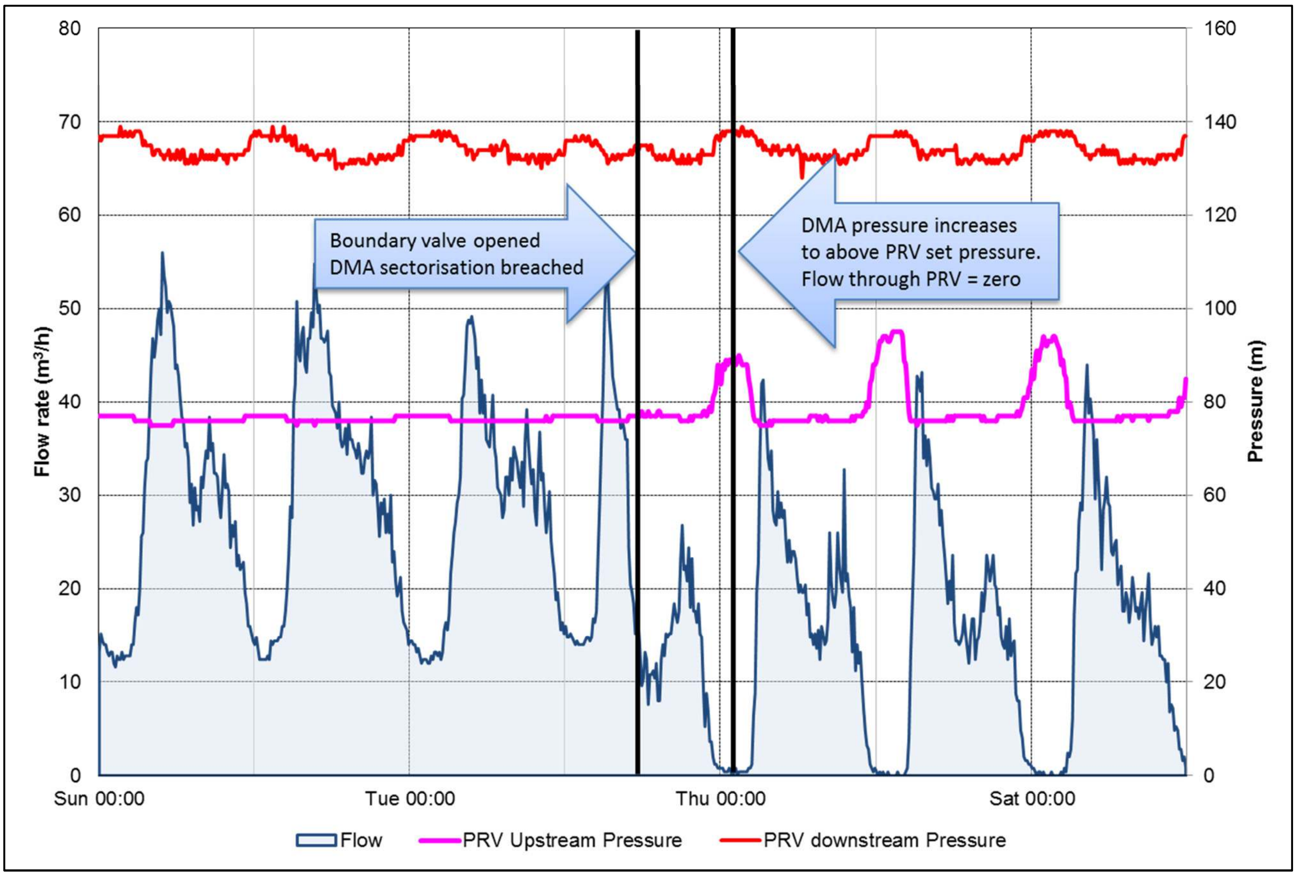

Figure 4.12: Change in flow profile due to open boundary valves (WRP, 2001)

4.7.1.2 Potential savings

Potential savings can be determined using SANFLOW analysis, based on the principle of subtracting the expected MNF from the measured MNF to determine the excess MNF. Logging results are usually not readily available since it requires a discreet DMA with a bulk meter and data logger.

MNF expressed as a percentage of ADD, can be used as a rough guide to assess the level of leakage in an area, where a rigorous MNF analysis is not possible. To determine the relationship between the MNF and ADD, the logging results for 30 mixed residential, commercial, industrial areas were analysed as shown in Figure 4.13. The results were obtained from Johannesburg (WRP, 2001; Wegelin & McKenzie, 2002), Ekurhuleni (WRP, 2004a; WRP, 2004b; WRP, 2004c), Emfuleni (WRP, 2003), City of Tshwane and City of Cape Town (Wegelin & McKenzie, 2002).

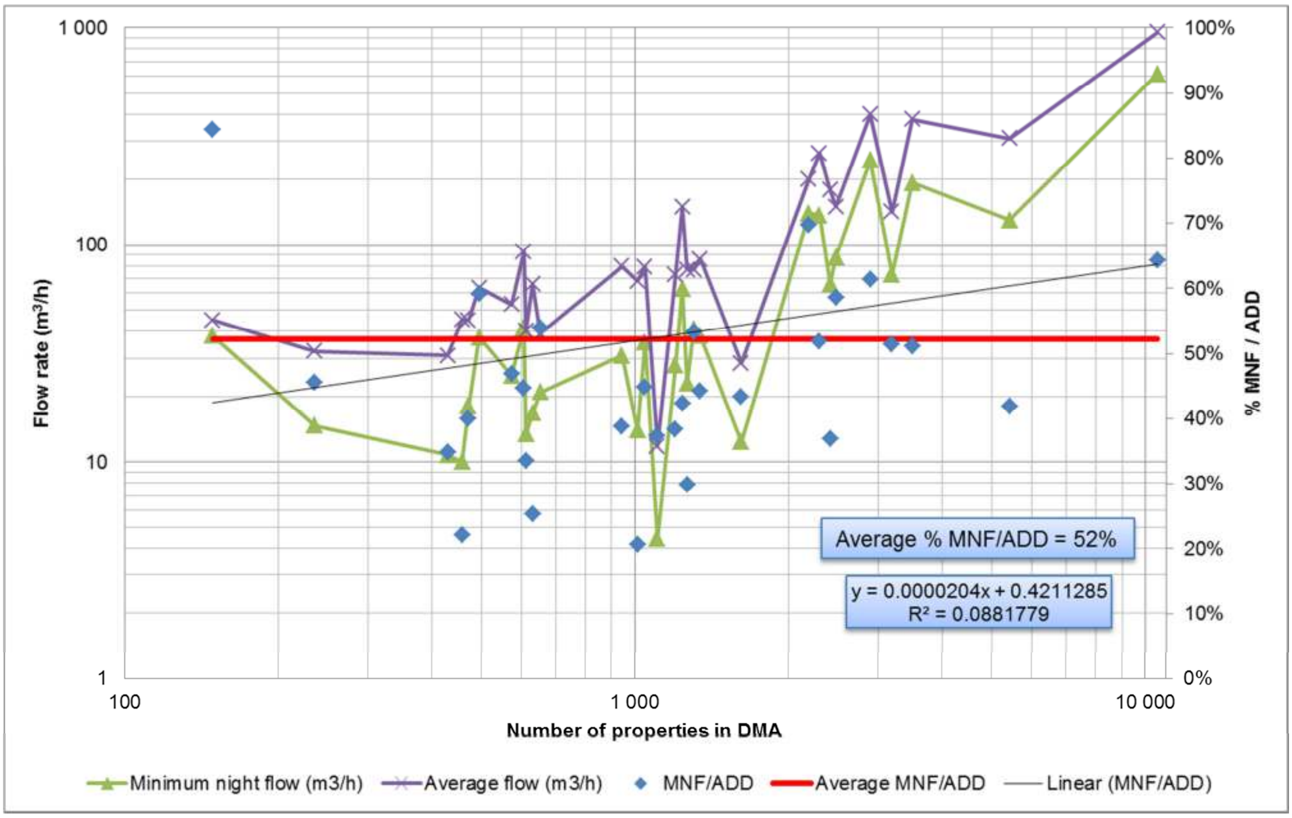

Figure 4.13: Expected MNF for mixed residential, commercial and industrial areas

Figure 4.13 expresses MNF as percentage of ADD in terms of the number of properties in the DMA. MNF is on average 52 % of ADD. A linear regression analysis of MNF as percentage of ADD is shown by equation 4.14 and gives an R^2 value of 0.0881779:

$$\%\,\mathrm{MNF} = 0.0000204 \times \text{number of properties in DMA} + 0.4211285 \qquad (4.14)$$

The average DMA in the sample was 1 744 properties. Using equation 4.14, the percentage MNF of ADD varies from 44 % for a 1 000 properties, 52 % for 5 000 properties and 63 % for 10 000 properties. Equation 4.14 should not be used for supply areas larger than 12 000 properties as the percentage MNF becomes unrealistically high. The low R^2 value suggests that it is difficult to predict the MNF based on the number of properties in the DMA, and result from equation 4.14 is close to the average of 52 %.

The same analysis was performed for 27 low cost housing and yard connection areas, as shown in Figure 4.14. The results were obtained from Johannesburg (WRP, 2001; Wegelin & McKenzie, 2002), Ekurhuleni (WRP, 2004a; WRP, 2004b; WRP, 2004c), Emfuleni (WRP, 2003), City of Tshwane, City of Cape Town and Buffalo City (Wegelin & McKenzie, 2002) and western highveld (WRP, 2005).

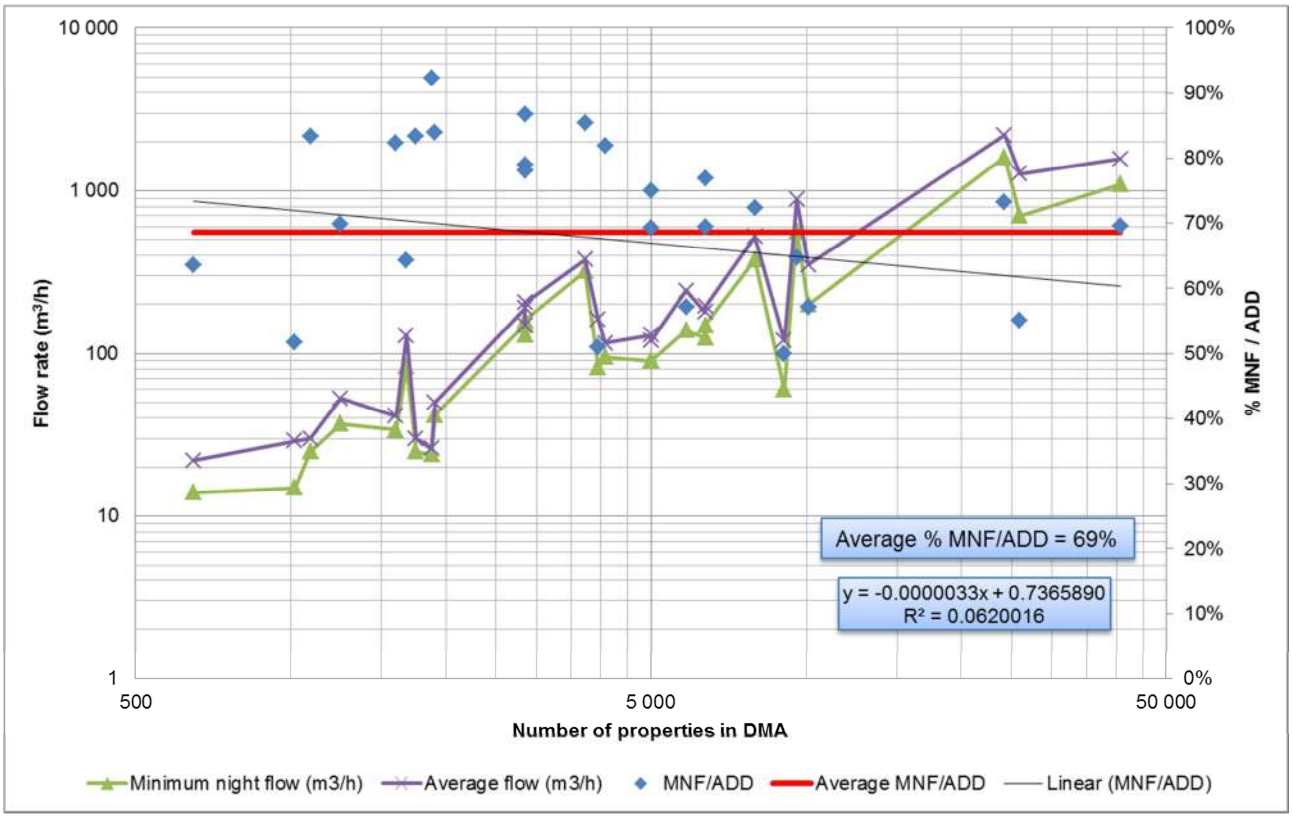

Figure 4.14: Expected MNF for low income / yard tap areas

Figure 4.14 expresses the MNF as percentage of ADD in terms of the number of properties in the DMA. The MNF is on average 69 % of ADD. A linear regression analysis of MNF as percentage of ADD is shown by equation 4.15 and gives an R^2 value of 0.0620016:

$$\% \, MNF = -0.0000033 \times number\ of\ properties\ in\ DMA + 0.7365890 \qquad (4.15)$$

The average DMA size in the sample was 7 010 properties which is significantly larger than for the mixed residential, commercial and industrial areas. Using equation 4.15, the percentage MNF of ADD varies from 73 % for a 1 000 properties, 67 % for 20 000 properties and 60 % for 40 000 properties. Equation 4.15 should not be used for supply areas larger than 45 000 properties. The low R^2 value suggests that it is difficult to predict the MNF based on the number of properties in the DMA, and result from equation 4.15 is close to the average of 69 %.

Equations 4.14 and 4.15 provide an indication of the expected MNF which can be used to estimate loss in a water distribution system and the potential savings from pressure management.

The ILI can also be used to calculate the potential real loss saving and the results checked against the excess MNF. The potential real loss is calculated using equation 4.16:

$$\text{Savings}_{\text{Real loss}} = \text{Physical loss} - (\text{UARL} \times \text{target ILI}) \qquad (4.16)$$

4.7.2 Pressure management

4.7.2.1 Strategy

Pressure management aims to reduce pressure in the water distribution network to minimum acceptable levels, in line with the water utility's pressure policy. Clause 15 of the *Regulations Relating to Compulsory National Standards and Measures to Conserve Water* (DWAF, 2001a), states that a water services institution must design and maintain every water reticulation system to operate below a maximum pressure of 900 kPa. The CSIR (2000:29) recommends a minimum residual pressure at the critical point, under instantaneous peak demand, of not less than 240 kPa for residential areas, or 100 kPa for yard taps and tanks. Pressure in the distribution network should therefore be between 240 kPa and 900 kPa according to South African guidelines.

Once implemented, pressure management should be maintained through continuous monitoring and control of PRVs. Time modulated, flow modulated and closed loop pressure control can be considered in addition to fixed outlet pressure control by installing an electronic or hydraulic controller on the PRV to introduce further pressure reduction during off-peak demand.

4.7.2.2 Potential savings

The PRESMAC model can be used to determine the savings from implementing pressure management, but requires logging results and a basic knowledge of the distribution system. Such information is often not available or too costly to obtain.

In section 2.4.4 it was shown that the pressure-loss equation can be used to calculate potential savings. If the existing pressure, MNF, N1-value and target pressure are known, potential saving from pressure management can be calculated. Existing pressures can be determined from topographical maps or field measurements, and MNF can be determined using equations 4.14 and 4.15. McKenzie (2001) recommends a default N1-value of 1.0 if no better estimate is available. To test this calculation, the actual savings from 23 new pressure management installations were compared with the calculated savings, using the pressure-loss equation and N1-values of 0.5, 1.0 and 1.5. The results were obtained from Johannesburg (WRP, 2001; Wegelin & McKenzie, 2002), Ekurhuleni (WRP, 2004a; WRP, 2004b), Emfuleni (WRP, 2003), City of Tshwane, City of Cape Town and Buffalo City (Wegelin & McKenzie, 2002), and western highveld (WRP, 2005) with the results shown in Figure 4.15.

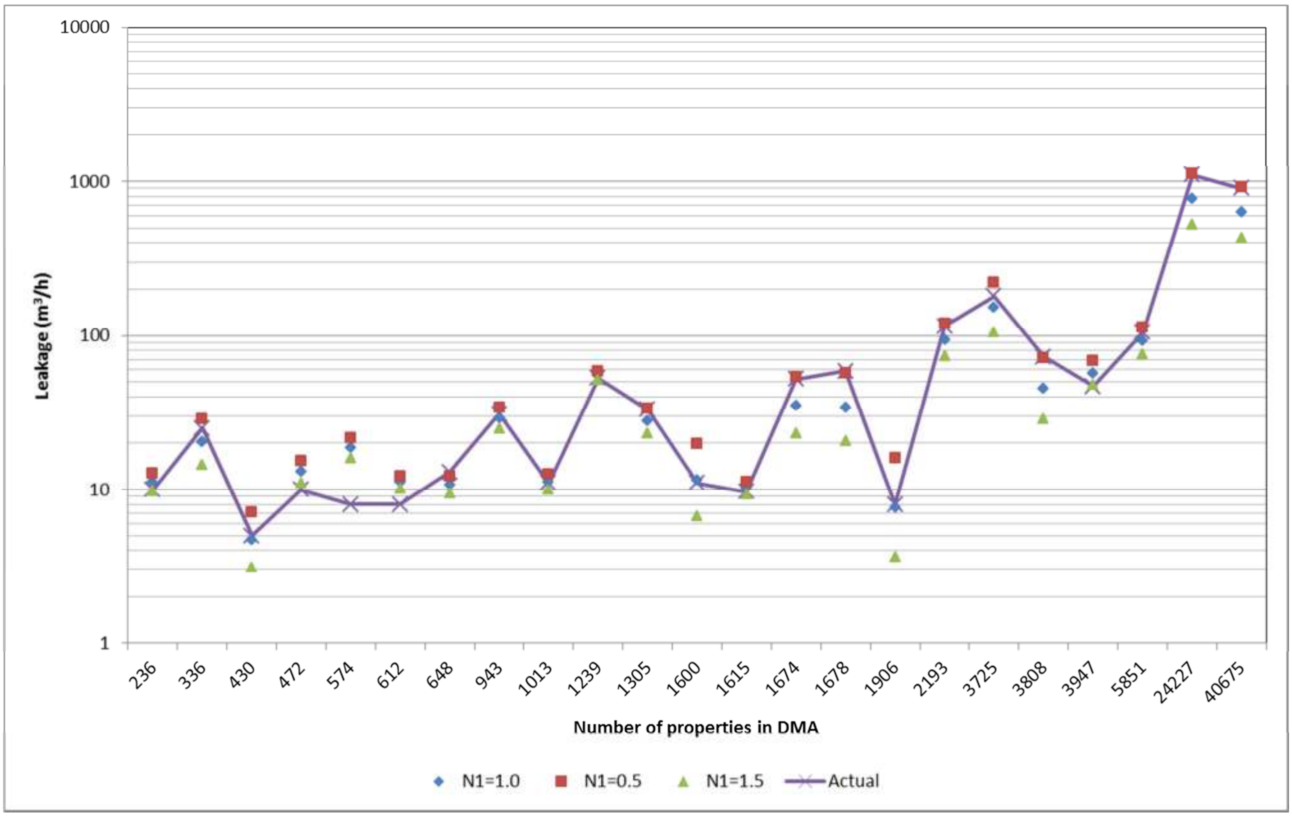

Figure 4.15: Comparison of actual versus calculated reduction in MNF

For each DMA, relatively close correlation was obtained between the actual and calculated reduction in MNF. The N1-values for small (<1 000 properties) DMAs tend to be closer to 1.0 or more, while the larger (>1 000 properties) DMAs tend to be closer to 0.5. An average N1 = 0.8 value was obtained for the 23 systems, confirming McKenzie's (2001) recommendation of using N1 = 1.0. On the relatively large DMAs (>2 000 properties) it could have a significant impact and an accurate N1-value must be determined for each specific DMA. Calculating an accurate N1-value requires extensive data logging which might be difficult or costly to undertake. The pressure-loss equation is shown in equation 4.17:

$$L_1 = L_0 \times \left(\frac{P_1}{P_0}\right)^{N1} \quad (4.17)$$

Where

L_0 = initial leakage loss in m^3/h

L_1 = new leakage loss in m^3/h

P_0 = initial pressure in m

P_1 = new pressure in m

N1 = pressure exponent (non-dimensional) which normally varies between 0.5 (default value for burst) and 2.5 (highest value for background leakage) with an average or default value of 1.0.

Alternatively, results from the 23 new pressure management installations were analysed to determine the average reduction in MNF. The results were used to determine potential savings. Figure 4.16 expresses the reduction in MNF in terms of pressure reduction in meters. The results clearly indicate that higher pressure differential induced by pressure reduction, corresponds to higher reduction in MNF.

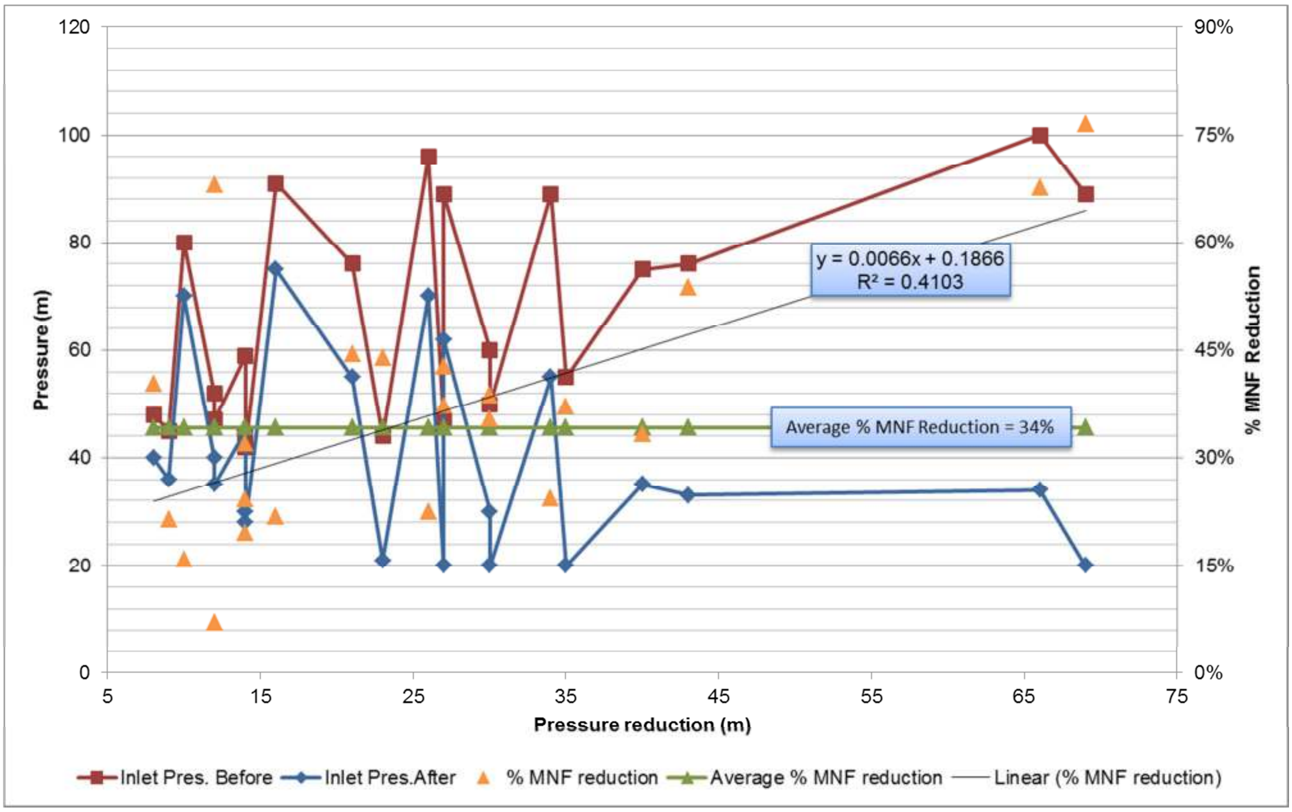

Figure 4.16: % MNF reduction by pressure management

An average reduction of 34 % in MNF was obtained and the pressure-loss relationship is clear. A linear regression analysis of the percentage MNF reduction is provided in equation 4.18 and gives an R^2 value of 0.4103:

$$\text{\% Reduction in MNF} = 0.0066 \times \text{Pressure reduction (m)} + 0.1866 \quad (4.18)$$

The potential savings through pressure management is calculated using equation 4.19:

$$\text{Savings}_{\text{Pressure management}} = \text{MNF} \times \text{\% MNF reduction} \times \text{HDF} \quad (4.19)$$

where hour day factor (HDF) is a factor that can be applied to indicate total daily saving (or increase) in pressure dependent flow that can be expected over a 24-hour period. A value of between 18 and 22 was considered to be typical, based on various case studies and the literature review. In areas which are already operating under some form of advanced pressure control, values in excess of 24 can be expected (McKenzie et al. 2002d).

4.7.3 Mains replacement or repair

4.7.3.1 Strategy

All pipelines have a limited design life and should be replaced on a continuous basis to prevent backlogs. The water utility would be expected to implement a water mains replacement or repair programme as part of their asset renewal and replacement programme. The replacement priority should be based on sound engineering principles and case specific historical data.

4.7.3.2 Estimated savings

Potential savings from mains replacement programmes are hard to predict without proper water information management. The SANFLOW model (McKenzie, 1999) provides suggested default values for background leakage from mains, connections and installations as summarised in Table 4.1.

Table 4.1: Suggested background leakage values (McKenzie, 1999)

Background leakage	Units	SANFLOW Range	SANFLOW Default Value
Mains	ℓ/km/h	20 to 100	40.0
Connections	ℓ/connection/h	1.0 to 5.0	3.0
Installations	ℓ/installation/h	0.5 to 1.5	1.0

Table 4.1 suggests that if a distribution network is new or in good condition, mains and connection leakage could be as low as 20 ℓ/km/h and 1.0 ℓ/connection/h respectively. If the distribution network is in a poor condition and reaching the end of its design life, leakage could increase to more than 100 ℓ/km/h and 5.0 ℓ/connection/h respectively.

Based on leakage rates presented in Table 4.1, the potential savings from mains and corresponding connections is summarised in Table 4.2.

Table 4.2: Estimated savings from mains and connection replacement

Background leakage	Units	Good	Average	Poor	Potential saving
Mains	ℓ/km/h	20.0	40.0	100.0	80.0
Connections	ℓ/connection/h	1.0	3.0	5.0	4.0

Using the results from Table 4.2 and assuming 50 connections/km main, the potential water savings per annum from replacing mains and connections are calculated as shown in Figure 4.17.

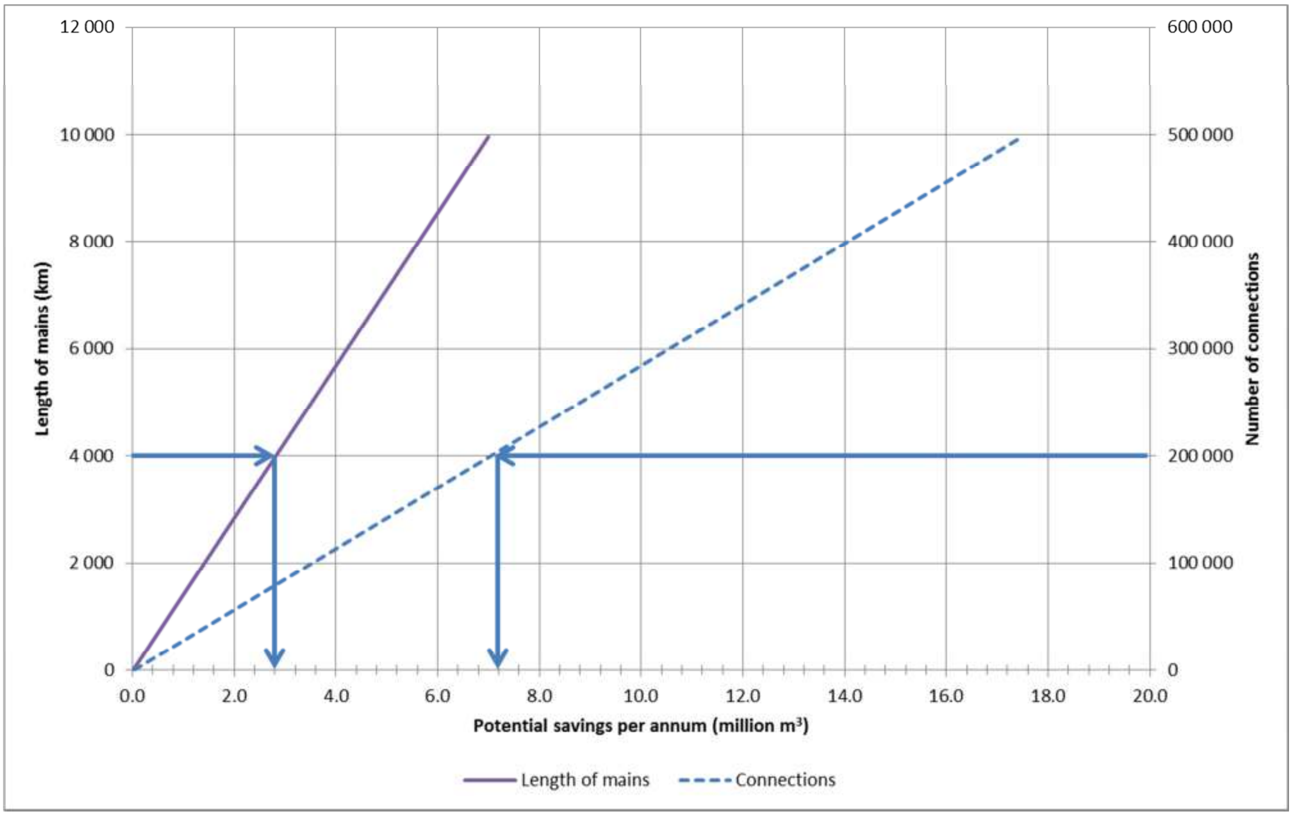

Figure 4.17: Potential savings per annum from connection and mains replacement

The results from Figure 4.17 indicate that the potential savings from replacing connection pipes could be 2.5 times more than the potential savings from replacing the reticulation mains. In addition, the design life of connection pipes is often shorter than that of the reticulation mains, suggesting that it may be more economical to only replace the connection pipes and not both.

4.7.4 Speed and quality of repairs

4.7.4.1 Strategy

Clause 12 of the *Regulations Relating to Compulsory National Standards and Measures to Conserve Water* (DWAF, 2001a), states that a water services institution must repair any major, visible or reported leak in its water services system within 48 hours of becoming aware thereof. This target can be reduced at the discretion of the utility.

4.7.4.2 Estimated savings

Potential savings from improved speed and quality of repairs is difficult to predict without a detailed analysis. The water utility should assess whether speed and quality of repairs can be improved, which in turn will impact on potential savings from active and passive leakage control.

The potential savings that can be linked to the speed and quality of repairs have been included in the leakage control analysis.

4.7.5 Reservoir Water Loss

4.7.5.1 Strategy

Water loss from overflowing and leaking reservoirs can be significant, as overflows usually last for several hours. Leaks in reservoirs should be fixed, even if they are difficult to repair. Reservoir control valves should be maintained on a continuous basis to prevent malfunctioning.

4.7.5.2 Estimated savings

The CSIR (2000:28) recommends that the capacity of the supply main to the reservoir should be designed to provide an inflow rate of not less than 1,5 x annual ADD for the area served by the reservoir. Under normal circumstances, the reservoir would be supplied the ADD in approximately 16 hours (24 hours ÷ 1.5) but if the inlet control valve mechanism were to fail or the pumps were not switched off, the reservoir would overflow at 1.5 x annual ADD when full. The estimated volume lost per day would then be 1.5 x annual ADD (supplied) less 1.0 x annual ADD (demand) equals 0.5 x annual ADD. The expected saving from overflowing reservoirs can be calculated using equation 4.20:

$$\text{Savings}_{\text{Overflows}} = \left(\frac{0.5 \times \text{ADD}}{24}\right) \times \text{average overflowing time} \times \text{number of times a year} \quad (4.20)$$

Figure 4.18 shows the expected water loss per m^3 supplied per annum to a reservoir, as a function of various durations and frequencies. Using this chart, water loss from a reservoir with an ADD of 1 000 kℓ/day, which overflows once every two weeks for 12 hours per day, would be in the order of 6 500 kℓ/annum or 1.8 % of the annual ADD. This is equivalent to 10 service pipe bursts flowing at 1.6 m^3/h for 17 days.

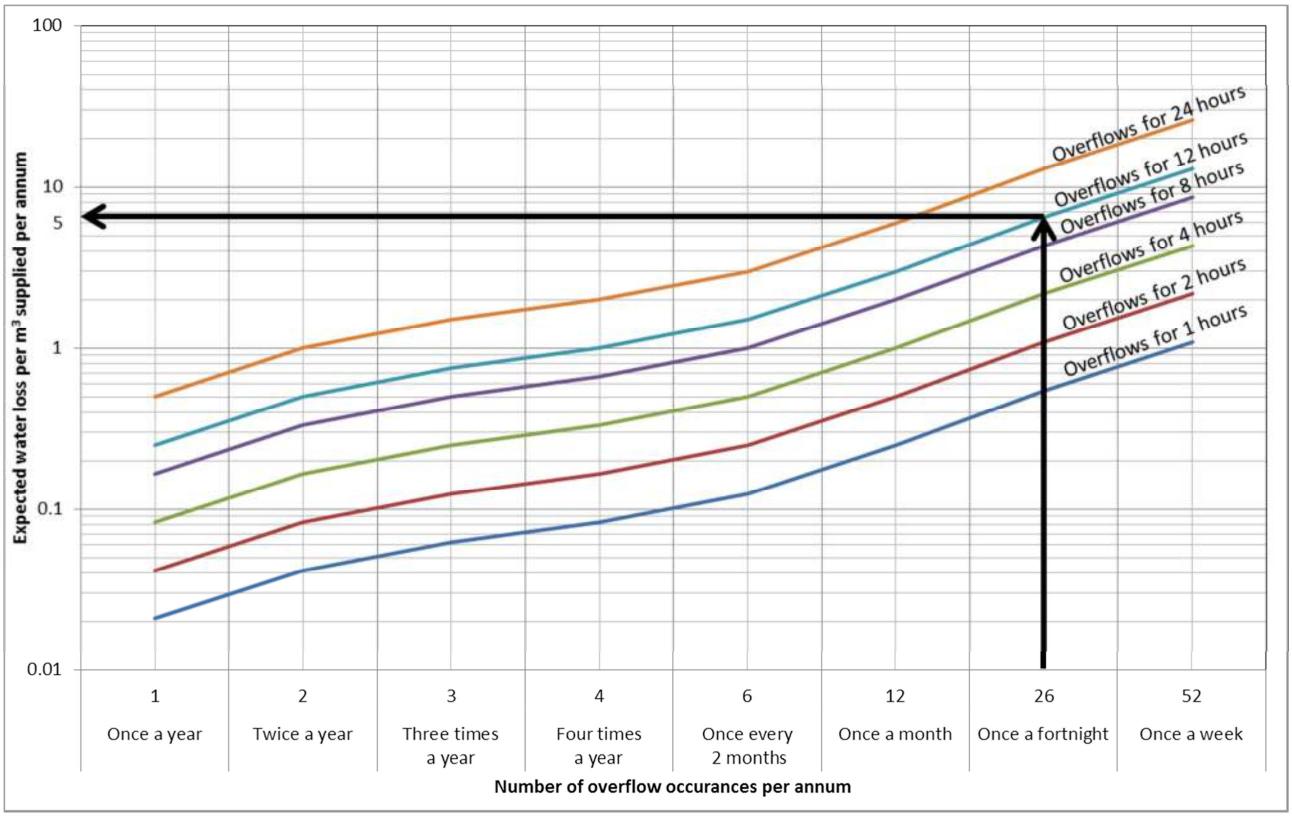

Figure 4.18: Estimation chart for reservoir overflow water loss

5 WORKED EXAMPLE

5.1 BACKGROUND INFORMATION

Developing a WC/WDM strategy and quantifying the potential savings is best demonstrated through a theoretical example. The hypothetical example describes a water utility with one WTW and two boreholes, which supply two reservoirs and three sectors. The water utility has basic information for each sector and five years of historical consumption data. The water utility is a category B2 municipality in terms of the MIIF. The system layout is shown in Figure 5.1.

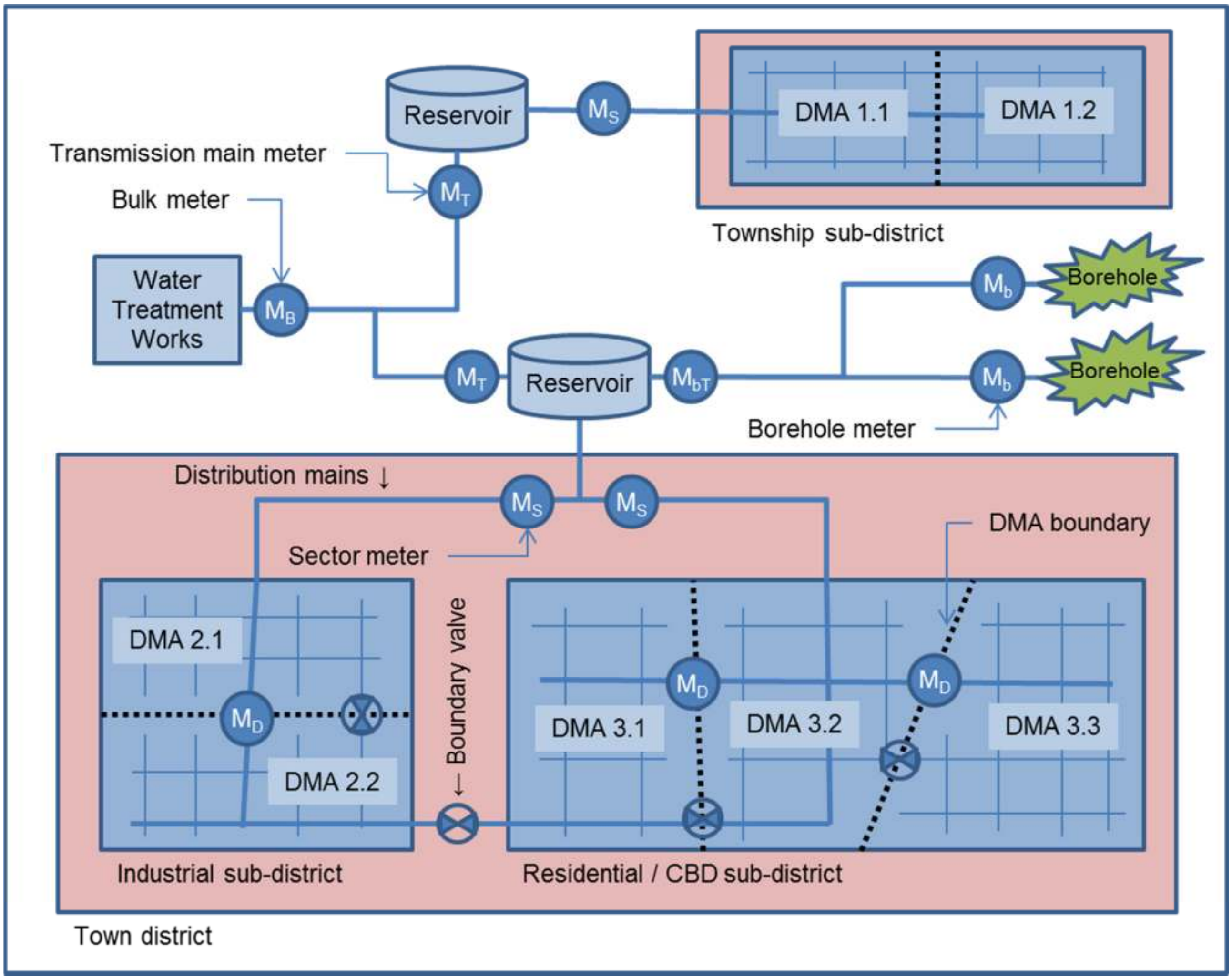

Figure 5.1: Hypothetical water supply system layout

The three sectors are named Township, Industrial and Town. Background information on each of the sectors is as follows:

(a) *Township* sector (DMA 1) has no domestic meters and customers are billed on a flat rate of 12 kℓ/connection/month. Internal plumbing leakage is known to be high and independent investigations have shown that the actual use is on average 20 kℓ/connection/month. The average system pressures are 52 m, increasing to 74 m in the low-lying areas of DMA 1.2. There are many visible leaks in the distribution system, which usually take up to 2 weeks to repair. The reservoir overflows biweekly for a minimum of 12 hours. There are pockets of low pressures in some of the areas.

(b) *Industrial* sector (DMA 2) has average system pressures of 45 m, increasing to 60 m in the low-lying areas. Consumer meters are 8 to 10 years old. The network is approximately 20 years old and very few mains and connection bursts occur per month.

(c) *Town* sector (DMA 3) has average system pressures of 38 m, increasing to 54 m in the low-lying areas. The pipe network is in excess of 50 years old with many mains and connection bursts per month. The majority of bursts are fixed within 48 hours and the balance within a week. Consumer meters are between 15 and 20 years old and maintained reactively. Meter readings are performed manually with limited quality control and audits.

5.2 STEP 1: IMPLEMENT MINIMUM REQUIREMENTS

The status quo and strategy to comply with the minimum requirements to implement WC/WDM is summarised in Table 5.1.

Table 5.1: Minimum requirements strategy

Intervention	Status quo	Strategy
Bulk metering	The water supply system is metered at the WTW. All sectors have a bulk meter installed. DMA meters are not operational.	The SIV for the system and sectors can be determined. DMA meters must be repaired.
Sectorisation	The water supply system is discrete. The sectors are sectorised and boundary valves confirmed closed. The DMAs are not sectorised.	The supply area of the bulk meters is known and an accurate analysis can be performed. The DMAs must be sectorised.
Intermittent supply	All infrastructure is operational and there is continuous supply in areas except pockets of low pressures in Township sector.	Perform a network valve audit in Township sector to resolve pockets of low pressure.
Consumer metering (optional)	The consumer meters in Town and Industrial sectors are operational and reactively maintained. Only the non-domestic consumers in Township are metered.	The metered consumption to all consumers could be determined in Town and Industrial areas. The metered consumption to non-domestic consumers can be determined in the Township area.

Basic information for the water supply system is summarised in Table 5.2.

Table 5.2: Summary of basic information

Basic information	Unit	Township	Town	Industrial	Total
Population served	**No**	**118 600**	**244 937**	**4 838**	**368 375**
Households served	**No**	**32 054**	**74 456**	**1 308**	**107 818**
Connections – total	**No**	**19 419**	**58 530**	**1 245**	**79 194**
Connections – metered	No	800	58 530	1 245	60 575
Domestic	No	0	52 948	0	52 948
Non-domestic	No	800	5 582	1 245	7 627
Connections - unmetered	No	18 619	0	0	18 619
Households / connection	**No**	**1.7**	**1.3**	**1.1**	**1.4**
Length of mains	**km**	**236**	**1 388**	**27**	**1 651**
Connections / km	**No / km**	**82**	**51**	**46**	**56**
Average system pressure	**m**	**52**	**38**	**45**	**45**
Time system pressurised	**%**	**100 %**	**100 %**	**100 %**	**100 %**
Apparent losses	**%**	**12 %**	**26 %**	**20 %**	**19 %**
Consumer meter age	%	6 %	8 %	6 %	7 %
Illegal connections	%	2 %	10 %	6 %	6 %
Data transfer	%	4 %	8 %	8 %	7 %

The average density is 1.4 households per connection, which increases to 1.7 households per connection in Township due to the high number of backyard shacks and 1.3 households per connections in Town due to a high number of townhouse developments. All the areas are metered except for Township where only the non-domestic consumers are metered. The number of connections per km and the average system pressures are within the expected range (refer to section 2.4.8). Apparent losses were estimated using Table 2.1.

5.3 STEP 2: WATER BALANCE AND KPI CALCULATION

5.3.1 Current water balance

The current water balance results are summarised in Table 5.3 and the total water balance is shown in Figure 5.2. Data obtained from the bulk supply and consumer meters are used to calculate the SIV and billed metered consumption. The billed unmetered consumption is based on the number of unmetered connections in Township which are billed on a deemed consumption rate of 12 kℓ/connection/month. The water utility has no unbilled metered consumption. Non-domestic use includes all commercial and industrial consumption.

Table 5.3: Current water balance information

Indicator	Unit	Township	Town	Industrial	Total
SIV	**kℓ/annum**	**8 373 555**	**29 575 627**	**757 058**	**38 706 240**
Authorised Consumption	**kℓ/annum**	**5 252 894**	**21 548 581**	**606 437**	**27 407 912**
Billed authorised	**kℓ/annum**	**3 018 614**	**21 548 581**	**606 437**	**25 173 632**
Billed metered	kℓ/annum	337 478	21 548 581	606 437	22 492 496
Domestic	kℓ/annum	0	20 175 036	0	20 175 036
Non-domestic	kℓ/annum	337 478	1 373 545	606 437	2 317 460
Billed unmetered	kℓ/annum	2 681 136	0	0	2 681 136
Unbilled authorised	**kℓ/annum**	**2 234 280**	**0**	**0**	**2 234 280**
Unbilled metered	kℓ/annum	0	0	0	0
Unbilled unmetered	kℓ/annum	2 234 280	0	0	2 234 280
Water Losses	**kℓ/annum**	**3 120 661**	**8 027 046**	**150 621**	**11 298 328**
Commercial / Apparent losses	kℓ/annum	374 479	1 926 491	30 124	2 109 021
Physical / Real losses	kℓ/annum	2 746 182	6 100 555	120 497	9 189 307
UARL	kℓ/annum	375 485	995 977	24 342	1 528 727
Potential real loss saving	kℓ/annum	2 370 697	5 104 578	96 155	7 660 579
Revenue water	**kℓ/annum**	**3 018 614**	**21 548 581**	**606 437**	**25 173 632**
NRW	**kℓ/annum**	**5 354 941**	**8 027 046**	**150 621**	**13 532 608**

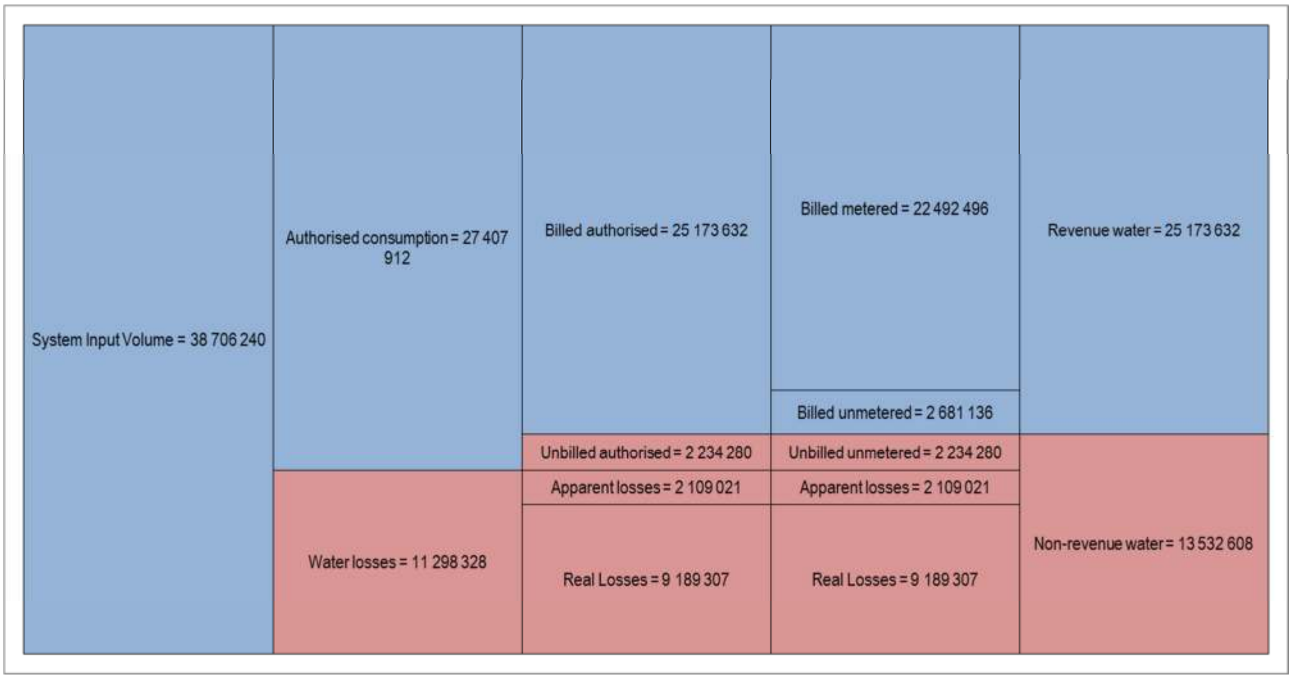

Figure 5.2: Current IWA water balance

The KPIs for the sectors and water supply system are summarised in Table 5.4. The results indicate high NRW and water losses in Town and Township sectors but the system average compares well with the South African average of 36.6 % NRW. The total average ℓ/c/d is above the South African national average (238 ℓ/c/d) and category B2 municipalities (243 ℓ/c/d) but is influenced by the Industrial sector (refer Table 2.6). The ILI is relatively high in all areas (refer Table 2.2).

Table 5.4: Current efficiency and water loss KPIs

KPI	Township	Town	Industrial	Total
Indicator as % of SIV				
% NRW	64.0 %	27.1 %	19.9 %	35.0 %
% Water Losses	37.3 %	27.1 %	19.9 %	29.2 %
SIV unit consumption				
litres/capita/day	193	331	429	288
m^3/household/month	22	33	48	30
m^3/connection/month	36	42	51	41
Authorised unit consumption				
litres/capita/day	121	241	343	204
m^3/household/month	14	24	39	21
m^3/connection/month	23	31	41	29
Domestic m^3/connection/month	22	32	0	29
Non-domestic m^3/connection/month	35	21	41	25
Water loss indicators				
UARL (litres/connection/day)	53	47	54	53
CARL (litres/connection/day)	387	286	265	318
ILI	7.3	6.1	5.0	6.0

5.3.2 Target water balance

Based on the results from section 5.3.1, it is clear that there is scope to improve efficiency and commercial and physical losses. Utilising international best practice guidelines, a target water balance was developed with the results shown in Table 5.5. The main objectives of the target water balance are to:

- install consumer meters and eliminate all unmetered consumption, thereby reducing NRW
- reduce commercial water loss from the current 19 to 14 %
- reduce physical water loss and target an ILI of 2.8 from 6.0
- SIV targets were achieved by reducing Township demand by 50 %, Town by 25 % and Industrial by 19 %
- improve efficiency by reducing current billed metered consumption in all sectors by 5 %.

Table 5.5: Target water balance information

Indicator	Unit	Township	Town	Industrial	Total
SIV	**kℓ/annum**	**5 024 133**	**23 660 502**	**643 499**	**29 328 134**
Authorised Consumption	**kℓ/annum**	**3 672 024**	**20 471 152**	**576 115**	**24 719 291**
Billed authorised	**kℓ/annum**	**3 672 024**	**20 471 152**	**576 115**	**24 719 291**
Billed metered	kℓ/annum	3 672 024	20 471 152	576 115	24 719 291
Domestic	kℓ/annum	3 351 420	19 166 284		22 517 704
Non-domestic	kℓ/annum	320 604	1 304 868	576 115	2 201 587
Billed unmetered	kℓ/annum	0	0	0	0
Unbilled authorised	**kℓ/annum**	**0**	**0**	**0**	**0**
Unbilled metered	kℓ/annum	0	0	0	0
Unbilled unmetered	kℓ/annum	0	0	0	0
Water Losses	**kℓ/annum**	**1 352 109**	**3 189 350**	**67 384**	**4 608 843**
Commercial / Apparent losses	kℓ/annum	189 295	446 509	9 434	645 238
Physical / Real losses	kℓ/annum	1 162 814	2 742 841	57 950	3 963 605
UARL	kℓ/annum	303 276	995 977	24 342	1 415 488
Potential real loss saving	kℓ/annum	859 537	1 746 864	33 609	2 548 116
Revenue water	**kℓ/annum**	**3 672 024**	**20 471 152**	**576 115**	**24 719 291**
NRW	**kℓ/annum**	**1 352 109**	**3 189 350**	**67 384**	**4 608 843**

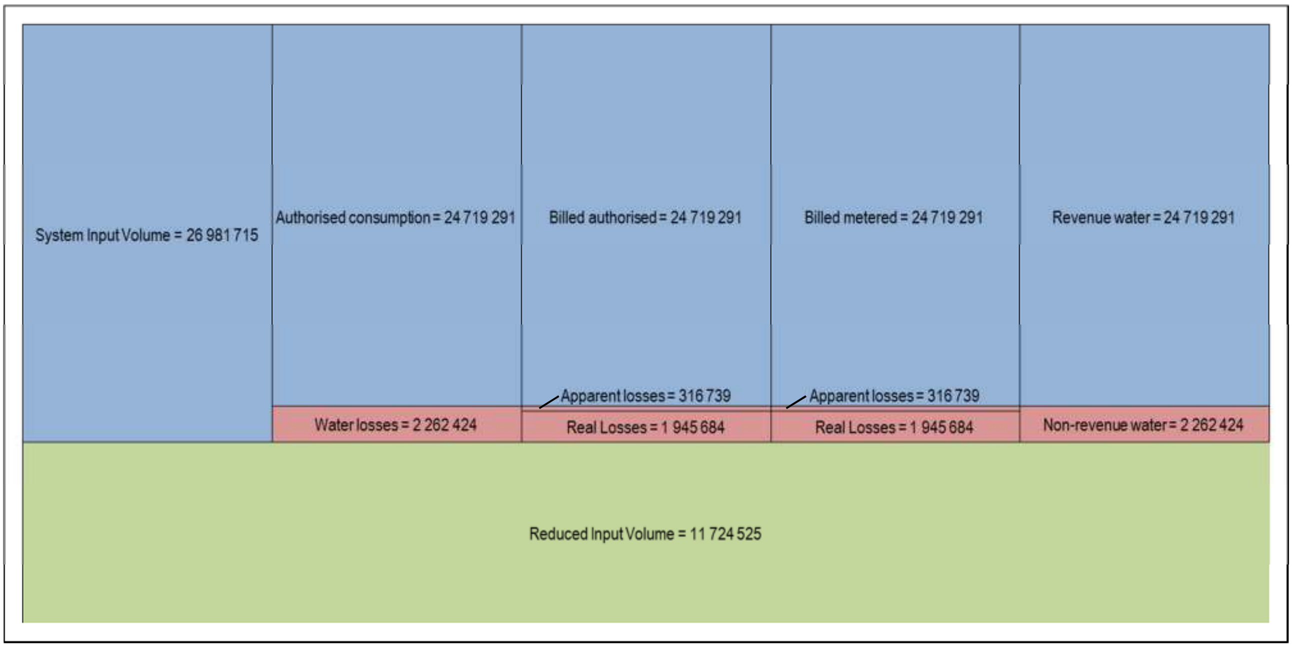

Figure 5.3: Target IWA water balance

The target KPIs for the water supply system and sectors are summarised in Table 5.6. The results indicate a significant improvement in efficiency, commercial and physical water losses.

Table 5.6: Target efficiency and water loss KPIs

KPI	Township	Town	Industrial	Total
Indicator as % of SIV				
% NRW	26.9 %	13.5 %	10.5 %	15.7 %
% Water losses	26.9 %	13.5 %	10.5 %	15.7 %
SIV unit consumption				
litres/capita/day	116	265	364	218
m³/household/month	13	26	41	23
m³/connection/month	22	34	43	31
Authorised Unit Consumption				
litres/capita/day	85	229	326	184
m³/household/month	10	23	37	19
m³/connection/month	16	29	39	26
Domestic m³/connection/month	15	30	0	26
Non-domestic m³/connection/month	33	19	39	24
Water loss indicators				
UARL (litres/connection/day)	43	47	54	49
CARL (litres/connection/day)	164	128	128	137
ILI	3.8	2.8	2.4	2.8

The improved commercial loss estimates are summarised in Table 5.7.

Table 5.7: Commercial loss improvement summary

% Commercial losses	Unit	Township	Town	Industrial	Total
Current	**%**	**12 %**	**24 %**	**20 %**	**19 %**
Consumer meter age	%	6 %	8 %	6 %	7 %
Illegal connections	%	2 %	8 %	6 %	5 %
Data transfer	%	4 %	8 %	8 %	7 %
Target	**%**	**14 %**	**14 %**	**14 %**	**14 %**
Consumer meter age	%	5 %	5 %	5 %	5 %
Illegal connections	%	4 %	4 %	4 %	4 %
Data transfer	%	5 %	5 %	5 %	5 %
Improvement	**%**	**-2 %**	**10 %**	**6 %**	**3 %**
Consumer meter age	%	1 %	3 %	1 %	1 %
Illegal connections	%	-2 %	4 %	2 %	1 %
Data transfer	%	-1 %	3 %	3 %	1 %

Commercial losses are expected to increase in Township once domestic meters have been installed.

The improved KPIs are summarised in Table 5.8.

Table 5.8: Summary of current and target KPIs

KPI	Current	Target	Improvement
Indicator as % of SIV			
% NRW	35.0 %	15.7 %	19.2 %
% Water losses	29.2 %	15.7 %	13.5 %
SIV unit consumption			
litres/capita/day	288	218	70
m³/household/month	30	23	7
m³/connection/month	41	31	10
Authorised Unit Consumption			
litres/capita/day	204	184	20
m³/household/month	21	19	2
m³/connection/month	29	26	3
Domestic m³/connection/month	29	26	3
Non-domestic m³/connection/month	25	24	1
Water loss indicators			
UARL (litres/connection/day)	53	49	4
CARL (litres/connection/day)	318	137	181
ILI	6.0	2.8	3.2

Achieving the target KPIs as summarised in Table 5.8, would result in the potential savings as summarised in Table 5.9.

Table 5.9: Summary of potential water savings

Indicator	Unit	Current	Target	Potential saving
SIV	kℓ/annum	38 706 240	29 328 134	9 378 106
Authorised Consumption	kℓ/annum	27 407 912	24 719 291	2 688 621
Billed authorised	kℓ/annum	25 173 632	24 719 291	454 341
Billed metered	kℓ/annum	22 492 496	24 719 291	-2 226 795
Domestic	kℓ/annum	20 175 036	22 517 704	-2 342 668
Non-domestic	kℓ/annum	2 317 460	2 201 587	115 873
Billed unmetered	kℓ/annum	2 681 136	0	2 681 136
Unbilled authorised	kℓ/annum	2 234 280	0	2 234 280
Unbilled unmetered	kℓ/annum	2 234 280	0	2 234 280
Water Losses	kℓ/annum	11 298 328	4 608 843	6 689 485
Commercial losses	kℓ/annum	2 109 021	645 238	1 463 783
Physical losses	kℓ/annum	9 189 307	3 963 605	5 225 702
UARL	kℓ/annum	1 528 727	1 415 488	113 239
Potential real loss saving	kℓ/annum	7 660 579	2 548 116	5 112 463
Revenue water	kℓ/annum	25 173 632	24 719 291	454 341
Non-Revenue water	kℓ/annum	13 532 608	4 608 843	8 923 765

5.4 STEP 3: WATER USE EFFICIENCY INTERVENTION STRATEGY AND SAVINGS

The water use efficiency intervention strategy and potential savings are summarised in Table 5.10.

Table 5.10: Water use efficiency intervention strategy and potential savings

Intervention	Strategy	Estimated savings (kℓ/annum)
Education and awareness	Promote water use efficiency through informative billing, community water awareness campaigns, internal awareness campaigns, schools awareness campaigns and community outreach activities in all areas. Involve the community in the project through the appointment of plumbers, water warriors and contractors. **Estimated savings (Eq. 4.1)** = 5 % reduction in authorised consumption = 5 % × 27 407 912 kℓ/annum	1 370 396
Water wise gardening	Excessive garden watering is not a significant problem and will be promoted as part of the awareness campaign.	0
Retrofitting and removal of wasteful devices	Retrofit households in Township area. **Estimated savings low income areas (Eq. 4.3)** = 20 kℓ (current) – 15 kℓ (target) = 5 kℓ saving/household/month = 18 619 × 5 kℓ x 12	1 117 140
	Promote installation of low flow showerheads and low volume toilets in Town and Industrial area. Assume to reach 10 % of consumers **Estimated savings high income areas (Eq. 4.4)** Toilet = 249 775 × 10 % x 40 ℓ/c/d Showers = 75 764 × 10 % x 20 ℓ/device/day	412 915
Tariff setting	Review the existing rising block water tariff to promote water use efficiency. **Estimated savings (Eq. 4.5)** Allow for a 20 % increase in water tariffs = 3 % × current billed metered consumption = 22 492 496 × 3 %	674 775
Total potential saving from improved efficiency		**3 575 226**
Success rate required to achieve target = 75 % × 3 575 226		**2 681 420**
Target potential saving from water balance		**2 688 621**

The results indicate that the largest benefit will be from retrofitting and removal of wasteful devices followed by community awareness. A 75 % implementation success rate is required to achieve the water balance target.

5.5 STEP 4: COMMERCIAL WATER LOSS INTERVENTION STRATEGY AND SAVINGS

The commercial water loss intervention strategy and potential savings are summarised in Table 5.11.

Table 5.11: Commercial water loss intervention strategy and potential savings

Intervention	Strategy	Estimated savings (m^3/annum)
Meter accuracy and measurement	Install water meters in Township area Test water meters continuously to determine accuracy Develop and implement a meter replacement programme Develop and implement a meter maintenance programme **Domestic estimated savings (Eq. 4.6 & 4.7)** Estimated meter error in Town = 1 - 0.36 × 17 years = - 4.4 % = 4.4 % × billed domestic metered consumption = 4.4 % × 20 175 036	887 702
	Non-domestic estimated savings (Eq. 4.8) Sum of non-domestic meter error = 20 % (Township) + 20 % (Town) + 10 % Industrial = 20 % × 337 478 + 20 % × 1 373 545 + 10 % × 606 437	402 848
	Meter accuracy and measurement test using Table 2.1 **Estimated savings (Eq. 4.9)** Current average estimated meter error loss = 7 % (Table 2.1) Target average estimated meter error loss = 5 % (Table 2.1) Meter error as percentage of commercial loss = (Current 7 % - Target 5 %) × 11 298 328 = 225 967 m^3/annum Meter error as percentage of billed metered consumption = (Current 7 % - Target 5 %) × 22 492 496 = 449 850 m^3/annum The saving based on commercial loss seems unrealistically low as it represents only 1.0 % of the metered consumption and contradicts equations 4.7 and 4.8	0
Data transfer errors	Implement electronic meter reading systems and perform monthly audits **Estimated savings (Eq. 4.10)** = Current average estimated data transfer loss = 7 % (Table 2.1) = Target average estimated data transfer loss = 5 % (Table 2.1) Meter error as percentage of commercial loss = (Current 7 % - Target 5 %) ×11 298 328 = 225 967 m^3/annum Meter error as percentage of billed metered consumption = (Current 7 % - Target 5 %) × 22 492 496 = 449 850 m^3/annum The saving based on commercial loss seems unrealistically low as it represents only 1.0 % of the metered consumption	449 850

Intervention	Strategy	Estimated savings (m^3/annum)
Data analysis and assumption errors	Review meter reading exception codes and ensure all anomalies are investigated and resolved Estimated savings included in data transfer errors	0
Theft and unauthorised use	Audit all existing water connections in Township, Town and Industrial sectors to ensure all supply points are metered Perform monthly audits of properties with zero consumption **Estimated savings (Eq. 4.12)** Township = 2 % × 800 connections × 23 kℓ/connection/month Town = 4 % × 58 530 connections × 31 kℓ/connection/month Industrial = 2 % × 1245 connections × 41 kℓ/connection/month	892 788
Total potential saving from commercial loss interventions		**2 633 188**
Success rate required to achieve target = 56 % × 2 633 188		**1 474 585**
Target potential saving from water balance		**1 463 783**

The results from the commercial water loss intervention strategy indicate that the largest benefit will be from meter replacement followed by removal of unauthorised use. A 56 % implementation success rate is required to achieve the water balance target.

Equations 4.9, 4.10 and 4.13 should be used with caution, as the results seem unrealistically low. It is recommended that the percentage improvement should rather be expressed as a percentage of the metered consumption and not the water loss.

5.6 STEP 5: PHYSICAL WATER LOSS INTERVENTION STRATEGY AND SAVINGS

The physical water loss intervention strategy and potential savings are summarised in Table 5.12.

Table 5.12: Physical water loss intervention strategy and potential savings

<table>
<tr><th>Intervention</th><th>Strategy</th><th>Estimated savings (m^3/annum)</th></tr>
<tr><td>Leakage control</td><td>Implement active and passive leakage control in all sectors.
Expected MNF (Eq. 4.13)
<table>
<tr><th>Area</th><th>ADD (m^3/h)</th><th>% MNF</th><th>Estimated MNF (m^3/h)</th></tr>
<tr><td>Township</td><td>956</td><td>67 % (Eq. 4.12)</td><td>643</td></tr>
<tr><td>Town</td><td>3376</td><td>52 %</td><td>1756</td></tr>
<tr><td>Industrial</td><td>86</td><td>45 % (Eq. 4.11)</td><td>39</td></tr>
</table>
The percentage MNF for Town is based on the average MNF for mixed residential, commercial and industrial areas as Town has 58 530 connections and cannot be used with Eq. 4.11.</td><td>4 908 871</td></tr>
<tr><td></td><td>Estimated savings (SANFLOW)
<table>
<tr><th>Area</th><th>Expected MNF (m^3/h)</th><th>Estimated MNF (m^3/h)</th><th>Excess MNF (m^3/h)</th></tr>
<tr><td>Township</td><td>164</td><td>643</td><td>479</td></tr>
<tr><td>Town</td><td>339</td><td>1756</td><td>1417</td></tr>
<tr><td>Industrial</td><td>20</td><td>39</td><td>19</td></tr>
<tr><td>Total</td><td>523</td><td>2438</td><td>1915</td></tr>
</table>
A total reduction in MNF will result in a saving of 16 775 400 m^3/annum which is more than the current water loss
Utilising equation 4.16 and Table 5.3 the potential savings can also be calculated as:
= 9 189 307 (water loss) – (1 528 727 (UARL) × 2.8 (target ILI))
= 4 908 871 m^3/annum
4 908 871 m^3/annum represents only 29 % of the excess night flow which is a conservative but achievable target</td><td></td></tr>
<tr><td>Pressure management</td><td>Implement pressure management in Township
Monitor and control sector and DMA pressures
Monitor burst frequencies and identify problem areas and pipelines
Estimated savings (Eq. 4.18 and 4.19)
% MNF reduction = 0.0066 × 15 m + 0.1866 = 28.6 %
Savings = 28.6 % × 50 % of area x 643 m^3/h × 20 HDI = 1 865 m^3/day</td><td>680 616</td></tr>
<tr><td></td><td>Estimated savings (Eq. 4.17)
$L_1 = L_0 \times (P_1 / P_0)^{N1}$ = 643 m^3/h × 50 % × $(37 / 52)^{1.0}$ = 229 m^3/h
Reduction in MNF= (643 m^3/h × 50 % - 229 m^3/h) × 20 HDI = 1 850 m^3/h
There is close correlation between the two results</td><td>0</td></tr>
</table>

Intervention	Strategy	Estimated savings (m^3/annum)
Mains replacement	Develop a management information system to inform mains replacement programme Implement a mains replacement programme **Estimated saving in Town (Table 4.2)** = 60 ℓ/h × 1388 km + 2 ℓ/h × 58 530 connections	1 754 978
Speed & quality of repairs	Improve repair speed and quality of repairs to ensure all known leaks are fixed within 24 hours	0
Reservoir overflows	Service and repair all reservoir control valves **Estimated saving in Township (Eq. 4.20)** = (0.5 × ADD / 24) × duration of overflow x frequency of overflow = 0.5 × 22 941 / 24 × 12 × 26	149 117
Total potential saving from physical loss interventions		**2 584 711**
Success rate required to achieve target = 70 % × 7 493 582		**5 245 507**
Target potential saving from water balance		**5 225 702**

Based on the analyses of the various physical water loss interventions, most benefits will be achieved from leak detection and repair followed by mains replacement. A 70 % implementation success rate is required to achieve the water balance target.

5.7 STEP 6: CORRELATE POTENTIAL SAVINGS AND WATER BALANCE DIAGRAM

The final step in the prioritisation and quantification of the potential savings is to compare the targeted savings from the water balance calculation with the potential savings of the various interventions. The results are summarised in Table 5.13.

Table 5.13: Comparison of the targeted versus potential savings

Indicator	Unit	Targeted saving from water balance	Potential savings from interventions	Savings as % of interventions
SIV	kℓ/annum	9 378 106	11 697 305	
Authorised consumption	kℓ/annum	2 688 621	3 575 226	26 %
Water losses	kℓ/annum	6 689 485	8 115 015	74 %
Commercial losses	kℓ/annum	1 463 783	2 633 188	19 %
Physical losses	kℓ/annum	5 225 702	7 493 582	55 %

The results from Table 5.13 indicate that the target water balance is achievable and all potential savings from the various intervention categories exceed the targeted savings. The largest potential savings should be through physical loss reduction, followed by efficiency improvement and commercial loss reduction. A 68 % implementation success rate is required to achieve the targets.

Once the potential savings have been confirmed, the water resource balance diagram can be prepared. The impact of the potential savings, implemented over a period of 5 years, is shown in Figure 5.4.

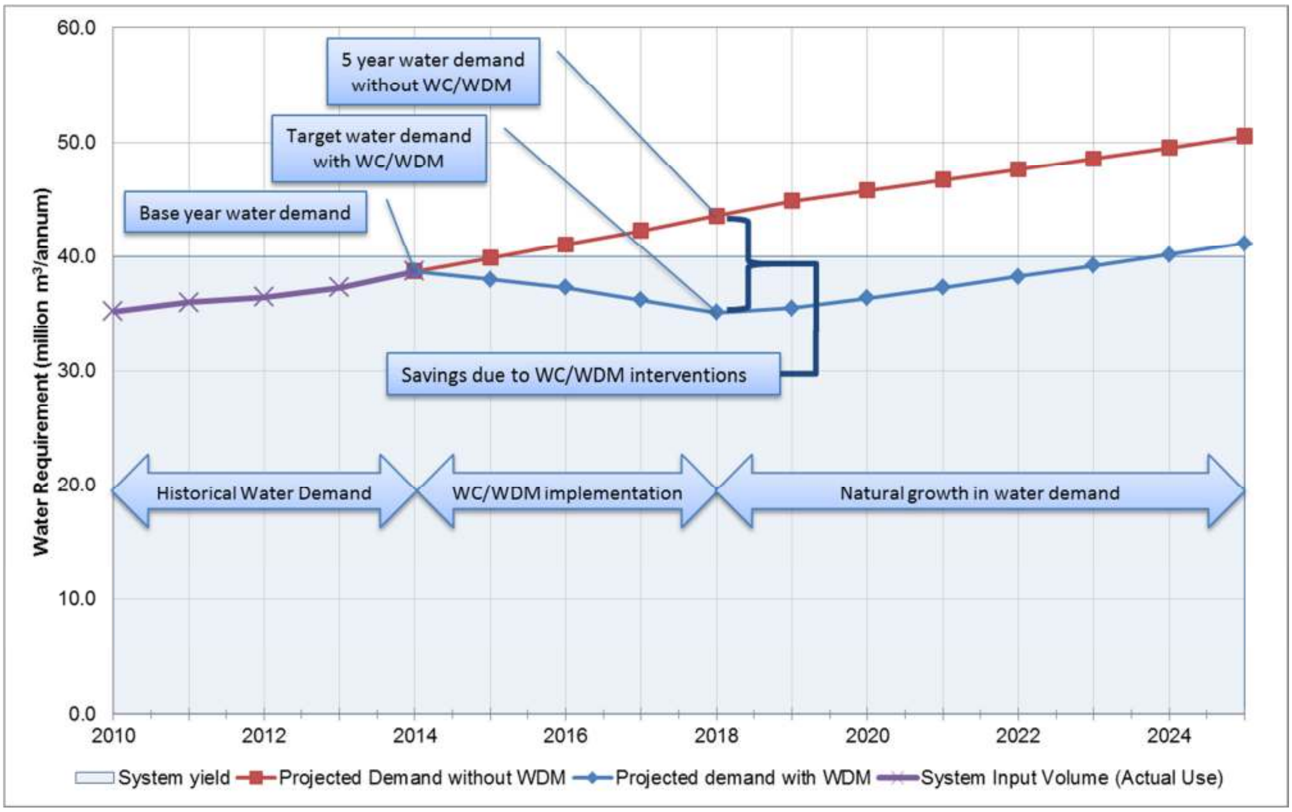

Figure 5.4: Water resource balance diagram

6 WC/WDM IMPLEMENTATION GUIDELINE

The guideline that was derived in this study follows a systematic and pragmatic six step approach, as shown in Figure 6.1. The detailed explanation of the six steps is summarised in Figure 6.2 to Figure 6.7.

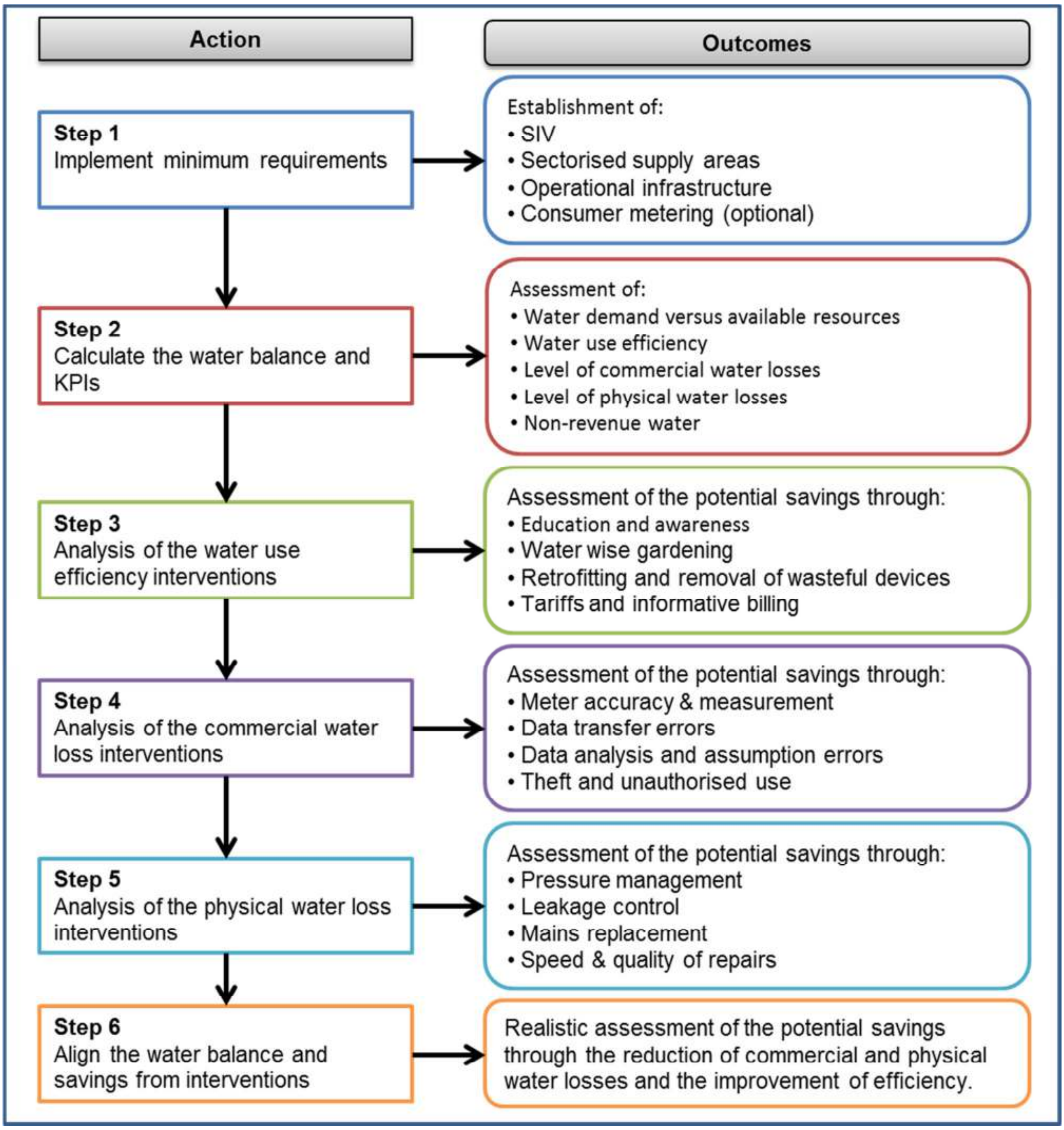

Figure 6.1: WC/WDM strategy and potential saving assessment flow diagram

Step 1: Implement minimum requirements

- **Water Supply System 1**
  - ? Intermittent water supply
    - ✓ Infrastructure operational
      - ✓ Proceed to *continuous water supply*
      - ✗ Resolve pockets of low pressures through network valve audits
    - ✗ Infrastructure not operational
      - ✓ Fix or upgrade infrastructure and achieve continuous supply
  - ? Continuous water supply
    - ? Bulk metering
      - ✓ Bulk meters are operational and maintained
        Bulk meter readings are monitored and controlled
        SIV is available
      - ✗ Identify all system supply and exit points
        Install or repair bulk water meters
        Monitor and control bulk meters and readings
        Determine SIV
    - ? System sectorised
      - ✓ All boundary valves identified and closed
        Boundary valves monitored and checked
        System basic information available
        - Population and households served
        - Number of connections
        - Average system pressure
        - Length of mains
      - ✗ Identify all cross boundary connections
        Install boundary valves or cut and cap pipes
        Close boundary valves and mark as normally closed valves
        Obtain basic information to calculate and assess KPIs
    - ? Consumer metering
      - ✓ Age and condition of consumer meters known
      - ✗ Consumers not metered, limited or no information
- **Water Supply System 2**
- **Water Supply System 3**
- **Water Supply System ...**

Legend: ? Question ✓ Yes ✗ No

Figure 6.2: Step 1 – WC/WDM minimum requirements flow diagram

Step 2: Water balance and KPI calculation

- **SIV**
  - ? Demand is higher than available yield
    - ? Water is used efficiently and water losses are low?
      - ✓ Sustain water use efficiency and low water losses and augment supply
    - ? Water is used inefficiently or water losses are high?
      - ? Inefficient water use?
        - ✗ Proceed with Step 3: Water use efficiency interventions
      - ? High water losses?
        - ✗ Proceed with Steps 4: Commercial loss interventions
        - ✗ Proceed with Steps 5: Physical water loss interventions
  - ? Demand is lower than available yield
    - ? Water is used efficiently and water losses are low?
      - ✓ Sustain water use efficiency and low water losses
    - ? Water is used inefficiently or water losses are high?
      - ? Inefficient water use?
        - ✗ Proceed with Step 3: Water use efficiency interventions
      - ? High water losses?
        - ✗ Proceed with Steps 4: Commercial loss interventions
        - ✗ Proceed with Steps 5: Physical water loss interventions
- **Water losses**
  - ? High water losses
    - ? High commercial losses
      - ✗ Proceed with Steps 4: Commercial loss interventions
    - ? High physical losses
      - ✗ Proceed with Steps 5: Physical water loss interventions
  - ? Low water losses
    - ✓ Sustain low water losses
- **NRW**
  - ? High NRW
    - ✗ Reduce water losses
      - ✗ Proceed with Steps 4: Commercial loss interventions
      - ✗ Proceed with Steps 5: Physical water loss interventions
    - ✗ Reduce unbilled authorised consumption
  - ? Low NRW
    - ✓ Sustain low NRW
- **Calculate current KPIs**
- **Calculate target Water Balance and KPIs**

Legend: ? Question ✓ Yes ✗ No

Figure 6.3: Step 2 – Water balance and KPI calculation flow diagram

Step 3: Water use efficiency intervention strategy and savings

- ? **Education and awareness**
  - ✓ Consumers value water
    - Maintain interventions listed below
  - ✗ Consumers do not value water
    - Implement informative billing
    - Promote efficiency through community water awareness campaigns
    - Promote efficiency through internal awareness campaigns
    - Promote efficiency through schools awareness campaigns
    - Promote efficiency through community outreach activities
- ? **Water wise gardening**
  - ✓ Consumers practice water wise gardening
    - Maintain interventions listed below
  - ✗ Consumers do not practice water wise gardening
    - Promote xeriscape gardening
    - Promote rain water harvesting
    - Promote grey water use
    - Promote ground water use
- ? **Retrofitting and removal of wasteful devices**
  - ✓ Consumers use and install water efficient devices
    - Maintain interventions listed below
  - ✗ Internal plumbing leakage a major contributor to water losses
    - Undertake household leak repair programmes
    - Promote installation and use of water efficient devices
- ? **Tariff setting**
  - ✓ Water tariffs are cost reflective and promote water use efficiency
    - Review water tariffs annually
  - ✗ Water tariffs are not cost reflective and do not promote water use efficiency
    - Review water tariffs to ensure it is cost reflective
    - Implement a rising block water tariff to promote water use efficiency
- **Calculate the potential savings from water use efficiency interventions**

  Education and awareness
  - $\text{Savings}_{\text{Education \& awareness}}$ = 5 to 10 % of the authorised consumption

  Water wise gardening
  - $\text{Savings}_{\text{Water wise gardening}}$ = ≤ 40 % of the of the authorised consumption for medium to high income areas

  Retrofitting and removal of wasteful devices
  - $\text{Savings}_{\text{Retrofit low income}}$ = Current water demand – target water demand
  - $\text{Savings}_{\text{Retrofit med to high income}}$ = ∑ {Showerheads = 20 ℓ/device/day, Low volume flush toilets = 40 ℓ/capita/day, Low volume and dual flush toilets = 50 ℓ/capita/day, Washing machine = 21 ℓ/capita/day}

  Tariff setting
  - $\text{Savings}_{\text{Tariffs}}$ = 3 % reduction in demand for a 20 % increase in the water tariff

Legend: ? Question ✓ Yes ✗ No

Figure 6.4: Step 3 – Water use efficiency improvement flow diagram

Step 4: Commercial water loss intervention strategy and savings

Meter accuracy and measurement (Question)

- Yes: Consumer meters generally in good condition
  - Test water meters continuously to determine accuracy
  - Develop and implement a meter replacement and maintenance programme
- No: No consumer meters or generally in poor condition
  - Install or replace non-domestic consumer meters
  - Install or replace domestic consumer meters

Data transfer errors (Question)

- Yes: Small error between actual meter readings and billing system
  - Sample and audit a % of monthly meter readings
  - Train water meter readers
- No: Large error between actual meter readings and billing system
  - Sample and audit a % of monthly meter readings
  - Implement electronic or automatic meter reading
  - Train water meter readers

Data analysis and assumption errors (Question)

- Yes: Small number of billing assumptions and queries
  - Maintain integrity of billing system
- No: Large number of billing assumptions and queries
  - Review meter reading exception codes
  - Review assumptions

Theft and unauthorised use (Question)

- Yes: Limited or no unauthorised consumption
  - Analyse monthly consumption patterns and trends
  - Sample and audit water meters to ensure all supply points are metered
- No: Extensive unauthorised consumption
  - Perform meter audits to ensure all supply points are metered
  - Community awareness and education

Calculate the potential savings from commercial water loss interventions

Meter accuracy and measurement

- % Meter error $_{\text{Domestic}}$ = 1 – (0.36 × average age of meters in years)
- Savings $_{\text{Domestic meter error}}$ = % meter error $_{\text{Domestic}}$ × domestic metered consumption
  Savings $_{\text{Non-domestic meter error}}$ = 10 to 20 % × non-domestic metered consumption
  or Savings $_{\text{Meter error}}$ = (Current error (%) – Target error %)) × water loss*

Data transfer errors

- Savings $_{\text{Data transfer}}$ = (Current error (%) – Target error (%)) × water loss*

Data analysis and assumption errors

- Included in data transfer errors

Theft and unauthorised consumption

- Savings $_{\text{Theft}}$ = number of unauthorised connections × average consumption for area
- Savings $_{\text{Theft}}$ = (Current (%) – Target (%) unauthorised consumption) × water loss*

* where *current %* and *target %* are obtained from Table 2.1 but the results should be treated with caution and compared against using metered consumption and field investigations.

Legend: ? Question ✓ Yes ✗ No

Figure 6.5: Step 4 - Commercial water loss reduction flow diagram

Step 5: Analysis of physical water loss interventions

- **Pressure management**
  - System pressure below allowable maximum
    - Monitor and control sector and DMA pressures
    - Monitor burst frequencies and identify problem areas and pipelines
    - Review maximum pressure policy and reduce if possible
  - System pressure above allowable maximum
    - Perform pressure analysis using PRESMAC
    - Reduce pressures through sectorisation or PRVs
    - Implement advanced pressure management control

- **Leakage control**
  - ALC programme
    - Night flow analysis
      Perform regular or continuous flow logging sectors and DMAs
      Monitor and control night flows and analyse using SANFLOW
    - ALC programme
      Develop an ALC programme
    - Passive leakage control programme
      Continuously promote reporting of leaks through customer care centre
      Monitor and assess number of calls per month.
      Ensure all reported leaks are fixed within 48 hours.
  - No leakage control programme
    - Analyse MNF, burst frequencies and pressures to prioritise sectors and DMAs
    - Setup and train an active leak detection team
    - Promote reporting of visible leaks by the community

- **Mains replacement**
  - Low burst frequency
    - Implement main replacement programme
  - High burst frequency
    - Gather mains replacement management information
    - Analyse management information and determine priority areas and pipelines

- **Speed and quality of repairs**
  - All leaks are repaired in less than 48 hours
    - Sustain speed and quality of repairs to remain below 48 hours
  - Leak are repaired in excess of 48 hours
    - Identify factors that influence the speed and quality of repairs
    - Implement corrective measures
    - Monitor and control speed and quality of repairs

- **Reservoir and tower overflow**
  - Reservoirs and towers overflow infrequently
    - Maintain and control inlet control valves
    - Monitor and control inlet control valves
  - Reservoirs and towers overflow frequently
    - Replace, repair or service inlet control valves
    - Monitor and control inlet control valves

Calculate the potential savings from physical water loss interventions

Leakage control

- Expected MNF $_{\text{Mixed residential / industrial / commercial areas}}$ = % MNF × ADD
  where % MNF = 0.0000204 × number of properties in DMA + 0.4211285
  with an average of 52 % and a maximum of 12 000 properties
- Expected MNF $_{\text{Low cost housing and yard tap areas}}$ = % MNF × ADD
  where % MNF = -0.0000033 × number of properties in DMA + 0.7365890
  with an average of 69 % and a maximum of 45 000 properties
- Savings $_{\text{Excess MNF}}$ = Current MNF – expected MNF
- Savings $_{\text{Real loss}}$ = Physical loss – (UARL x achievable ILI)

Pressure management

- % Reduction in MNF = 0.0066 × Pressure reduction (m) + 0.1866
- Savings $_{\text{Pressure management}}$ = MNF × % MNF reduction × HDF

Mains replacement

- Savings $_{\text{Mains replacement}}$ = 80 ℓ/km/h
- Savings $_{\text{Connection replacement}}$ = 4 ℓ/connection/h

Speed and quality of repairs

- Potential saving included as part of leakage control assessment

Reservoir overflow

- Savings $_{\text{Overflows}}$ = (0.5 × ADD / 24) × average overflowing time × number of times a year

Legend: ? Question ✓ Yes ✗ No

Figure 6.6: Step 5 - Physical water loss reduction flow diagram

Step 6: Correlate potential savings and prepare water resource balance diagram

? Total estimated savings from water balance calculation - Step 2

Estimated potential savings from improved water use efficiency
Estimated potential savings commercial losses
Estimated potential savings physical losses

? Total estimated savings from various intervention

Estimated potential savings from Step 3 - Improved water use efficiency
Estimated potential savings from Step 4 - Commercial losses
Estimated potential savings from Step 5 - Physical losses

? Potential savings correlation

✓ Savings from interventions exceed water balance targets
- Accept estimated savings and prepare water resource balance diagram

✗ Savings from interventions do not exceed water balance targets
- Revert back to Step 2, 3, 4 or 5 and review targets

? Prepare water resource balance diagram

Legend: ? Question ✓ Yes ✗ No

Figure 6.7: Step 6 – Correlate potential water savings

7 CONCLUSION AND RECOMMENDATIONS

The objectives of this study were to develop a guideline for the strategic planning of WC/WDM interventions, based on a sound approach that involved a quantitative assessment of the potential savings from various WC/WDM interventions, and to provide guidelines for setting realistic targets and related KPIs. The results from this study provide a high-level systematic and pragmatic approach towards the development of a WC/WDM strategy. A process flow diagram was compiled which can be used to guide the development of a WC/WDM strategy and assess potential savings. Adherence to the guideline will ensure that predetermined targets can be achieved through specific interventions.

Based on the results, the following conclusions and recommendations are made:

(a) The alignment of the IWA water balance with the interventions from improved commercial loss, physical loss and efficiencies, forms the basis for a systematic and pragmatic approach towards the development of a WC/WDM strategy and quantification of potential savings.

(b) The water utility must ensure compliance with the minimum requirements for implementing WC/WDM before embarking on large-scale WC/WDM programmes. Without these minimum requirements, which include bulk metering, sectorisation, basic information and continuous supply, the assessment of the potential savings through WC/WDM cannot be quantified and will probably be unrealistic.

(c) The IWA water balance formed the basis of current and target water balances. The water utility should ensure that the current balance is based on accurate data and the target balance is based on realistic targets and benchmarks.

(d) The interventions for improved water use efficiency include education and awareness, water wise gardening, retrofitting and removal of wasteful devices, and tariffs and informative billing. Improving water use efficiency will reduce billed consumption and SIV. Potential savings from improved water use efficiency through retrofitting and removal of wasteful devices, water wise gardening and tariffs have been well documented. The potential savings from these interventions are clear although a subjective view is required on target water use benchmarks. Two education and awareness case studies in low-income areas were presented to assess potential savings. Further research is required to assess the potential savings from education and awareness programmes in medium to high-income areas. Community and awareness programmes should include involvement of the community in the execution of the projects through the appointment of water conservation warriors, plumbers and contractors.

(e) The interventions from improved commercial losses include reducing water losses from unauthorised connections (unlawful use), meter errors, data transfer errors and meter reading errors. Reducing commercial losses usually results in increased revenue for the water utility.

The potential saving from meter errors has been well documented and there are numerous case studies and formulas to support the estimated savings. Further research is required to improve the quantification of data transfer and meter-reading errors – the potential savings seem lower than expected. The potential savings from unauthorised use may be accurate if the water utility has a clear understanding of the number of unauthorised connections and estimated water use.

(f) The IWA interventions from improved physical losses include active and passive leakage control, pressure management, mains replacement and speed and quality of repairs. Other measures which were investigated as part of this study include losses from leaking and overflowing reservoirs. Reducing physical losses will usually reduce the SIV for the utility. The SANFLOW analysis forms the basis for leakage control and can only be performed if the MNF is available, which is often not available or difficult to obtain. The results from this study can be used to estimate the MNF based on the ADD and included in the SANFLOW model. PRESMAC can be used to determine the potential savings from pressure management but the model requires a detailed analysis of the potential pressure DMA. The results from this study provide a high level assessment of the potential savings through pressure management utilising the reduction in MNF. Further research is required to assess the potential savings from mains replacement programmes and overflowing reservoirs, although this varies for every system. This should be verified during field investigations and audits.

(g) An accurate assessment of potential savings will enable the water utility to prepare a realistic water resource balance diagram, which will provide an indication of water security and interventions required to ensure a sustainable water supply.

(h) The 20 interventions proposed in this study should form the basis of any WC/WDM intervention plan. These interventions are based in international and national best practice. Each intervention has its own merit and it is up to the utility to determine which intervention provides the best return on investment based on potential savings, available budgets, and prioritisation.

(i) The equations presented in this study provide a sound base for determining potential water savings through WC/WDM. Success will however only be achieved if water utilities continue to perform proper field investigations and audits to verify assumption and potential savings.

8 REFERENCES

American Water Works Association (AWWA). 2006. Manual of Water Supply Practices – M52, First Edition. Water Conservation Programs: A Planning Manual.

Astrup, B, Vorster, J & McKenzie, RS. Large Consumer Meter Consolidation and Improvements: Planning, Implementation and Benefits. Proceedings of the WISA 2014 Biennial Conference. Nelspruit, Mpumalanga, South Africa, 26-28 May 2014.

Arregui, F, Cabrera Jr., E, Cobacho, R & Garcia-Serra, J. 2005. Key factors affecting water meter accuracy. Proceedings of the Leakage 2005 leakage management conference. Halifax, Canada. 12 to 14 September 2005.

Butler, D. & Memon, FA. 2006. Water Demand Management. IWA Publishing, London.

Buckle, JS & Wegelin, WA. 2004. Rand Water's Water Loss Project – The Emfuleni Case Study on Pressure Management. Proceedings of the 4th IWA World Water Congress and Exhibition Programme. Marrakech, Morocco. 19 to 24 September 2004.

Brothers, K. 2003. Practical Approach Initiatives to Water Loss Reduction. Water21. IWA publishing. Issue 5.3. June 2003.

Charalambous 2011. Distribution Networks. Proceedings of the 6th IWA Specialised Conference on Efficient Use and Management of Water, 29 March – 2 April 2011, Dead Sea Jordan.

CSIR Building and Construction Technology. 2000. Guidelines for Human Settlement Planning and Design – Chapter 9 Water Supply. Boutek Report No. BOU/E2001. ISBN 0-7988-5498-7. Reprint 2005, Capture Press, Pretoria.

Couvelis, FA & van Zyl, JE. 2012. Apparent Water Losses Related to Municipal Metering in South Africa. WRC Report No. 1998/1/12. ISBN 978-1-4312-0313-0. South Africa, August 2012.

du Plessis, JA. 2007. Benchmarking water use and infrastructure based on water services development plans for nine municipalities in the Western Cape. Journal of the South African Institution of Civil Engineering. Vol 49 No 4, 2007, Pages 19–27, Paper 641.

DWA. 2010. Integrated Water resource Planning for South Africa. Department of Water Affairs, South Africa, October 2010.

DWA. 2011. Report on WC/WDM Training Workshops under the Masibambane III. Department of Water Affairs, South Africa, February 2011.

DWA. 2014. Vaal River System Reconciliation Strategy: Strategy Steering Committee. Status report of 9th Strategy Steering Committee of the Vaal River System. Department of Water Affairs, South Africa, January 2014.

DWA. 2013a. Metropolitan Municipality Non-revenue / Water Loss Assessment. Report prepared by the Business Intelligence Team: Water Services Planning and Information. Pretoria. July 2013.

DWA. 2013b. Secondary City Non-revenue / Water Loss Assessment. Report prepared by the Business Intelligence Team: Water Services Planning and Information. Pretoria. July 2013.

DWAF. 1999. Draft Water Conservation and Demand management National Strategy Framework. South Africa. May 1999.

DWAF. 2001a. Regulations Relating to Compulsory National Standards and Measures to Conserve Water under the Water Services Act, Act No. 108 of 1997. Vol. 432, Pretoria 8 June 2001.

DWAF. 2001b. Norms and Standards in Respect of Tariffs for Water Services in Terms of Section 10 (1) under the Water Services Act, Act No. 108 of 1997. June 2001.

DWAF. 2004a. National Water Conservation and Water Demand Management Strategy. South Africa, August 2004.

DWAF. 2004b. Water Conservation and Water Demand Management Strategy for the Water Services Sector. South Africa, August 2004.

DWAF. 2007. Potential savings through WC/WDM in the Upper and Middle Vaal water management areas. Department of Water Affairs, South Africa, May 2007.

Effective Utility Management Collaborating Organizations. 2007. Findings and Recommendations for a Water Utility Sector Management Strategy. 30 March 2007.

Griffioen, ML and van Zyl, JE. 2014. Proposed guideline for modelling water demand by suburb. Technical Paper in the Journal of the South African Institution of Civil Engineering Vol 56 No 1, April 2014, Pages 63–68, Paper 947.

Gumbo, B., Juizo, D. & van der Zaag, P. 2003. Information is a prerequisite for water demand management: experiences from four cities in Southern Africa, Physics and Chemistry of the Earth, 28 (2003):827–837, Elsevier Ltd.

Henderson, PW & Tate, EL. 2001. Tools for water use and demand management in South Africa - Technical Reports in Hydrology and Water Resources no. 73. Report WMO/TD – No. 1095. Published by the Secretariat of the World Meteorological Organization. Geneva, Switzerland. 2001

Hoffman, JJ. 2011. Ekonomiese besluitnemingskriteria vir Wateraanvraagbestuur & waterbesparing. Unpublished Masters in Civil Engineering, Unversity of Stellenbosch, Stellenbosch.

Hunt, JB, McDevitt, W, & Hunt, G. 1998. Water Efficiency Manual for Commercial, Industrial and Institutional Facilities. A joint publication of the Division of Pollution Prevention and Environmental Assistance and Division of Water Resources of the North Carolina Department of Environment and Natural Resources, and the Land-of-Sky Regional Council - WRATT Program, August 1998.

IWA Water Loss Task Force - DMA Team. 2007. District Metered Areas – Guidance Notes. Publication by the IWA Specialist Group: Efficient Operation and Management – Water Loss Task Force.

Jacobs, HE. 2008. Residential water information management. South African Journal of Information Management, 10(3), September 2008. Available online: www.sajim.co.za/default.asp?to=peer3vol10nr3.

Jacobs, HE. 2010. Assessing the impact of personal on-site water resources in serviced residential areas on water demand and wastewater flow. Proceedings of the WISA 2010 conference. Durban, South Africa, 18 to 22 April 2010.

Jacobs, HE & and Haarhoff (2007). End-use modelling as a means to predict the effects of water demand management. Paper presented at the Biennial Conference of the Water Institute of Southern Africa (WISA). ISBN Number: 1-86845-844-X. , Durban, South Africa. 19 to 23 May 2002.

Jacobs, HE, Scheepers HM & Sinske, SA. 2013. Effect of land area on average annual suburban water demand. ISSN 0378-4738 (Print). Water SA Vol. 39 No. 5 October 2013.

Management Consultant. 2014. Project Boloka Metsi – Close out report: Phase 1 and 2 – Final. WRP Consulting Engineers. 29 August 2014.

McKenzie, RS & Bhagwan, JN. 2000. Managing unaccounted for water in potable water distribution systems: recent software developments through the WRC. The Official Journal of the Institution of Municipal Engineers, January 2000, pp. 53-58.

McKenzie, RS. 1999. Development of a standardised approach to evaluate burst and background losses in water distribution systems in South Africa. WRC Report Report: TT 109/99. ISBN 186845 490 8. Republic of South Africa. July 1999.

McKenzie, RS. 2001. PRESMAC Pressure Management Program. Report TT 152/01. ISBN No. 1 86845 722 2. Republic of South Africa. April 2001.

McKenzie, RS, Lambert, AO, Kock, JE & Mtshweni, W. 2002a. Benchmarking of Leakage for Water Suppliers in South Africa - User Guide for the Benchleak Model. WRC Report No. TT 159/01. ISBN 1 86845 773 7. Republic of South Africa. January 2002.

McKenzie, RS, Wegelin, WA & Meyer N. 2002b. Leakage Reduction Projects undertaken by Rand Water. UN-Habitat, ISBN 0 620 29503 1. August 2002.

McKenzie, RS & Lambert, AO. 2002c. Economic Model for Leakage Management for Water Supplies in South Africa. WRC Report No. TT 169/02. ISBN 1 86845 832 6. Republic of South Africa. January 2002.

Mckenzie, RS, Meyer, N & Lambert, AO. 2002d. Calculating Hour-Day Factors for Potable Water Distribution Systems in South Africa - User Guide for the HDF Model. WRC report TT Republic of South Africa. January 2002.

McKenzie, RS. 2007. Aqualite water balance software – Version 2.0.2 User Guide. WRC Report Number TT 315/07. Pretoria. September 2007

McKenzie, RS, Kanellopoulou, S, Trow, S. 2010. The great debate – choosing the optimal DMA size. Proceedings of the IWA Water Loss 2010 conference. Sao Paulo, Brazil. 6 to 9 June 2010.

Mwendera, EJ, Hazelton, D, Nkhuwa, D, Robinson, P, Tjijenda, K, & Chavula, G. 2003. Overcoming constraints to the implementation of water demand management in southern Africa, Physics and Chemistry of the Earth 28 (2003):761-778, Elsevier Ltd.

Mwiinga, G, Gumbo, T, & Mkoka, I. 2008. Water Conservation and water demand management in practice – South Africa Case studies. Proceedings of the WISA 2010 conference. Durban, South Africa, 18 to 22 April 2010.

National Treasury. 2013. Local Government Revenue and Expenditure: Fourth Quarter Local Government Section 71 Report (Preliminary Results) for the period: 1 July 2012 – 30 June 2013. Press release. 30 August 2013.

Rizzo, A, Pearson, D, Stephenson, M & Harper, N. 2004. Apparent water loss control: a practical approach. Water21. IWA Publishing. Issue 6.3. June 2004.

South Africa. 1997. Water Act, Act 36 of 1997. Vol. 390, Cape Town, 19 December 1997.

South Africa. 1973. Trade Metrology Act, Act No. 77 of 1973.

SABS. 2010. SANS 10306:2010 - The management of potable water in distribution systems. Edition 1.1. Pretoria: 2010.

Scheepers, HM & Jacobs, HE. 2014. Simulating residential indoor water demand by means of a probability based end-use model. IWA Publishing 2014 Journal of Water Supply: Research and Technology. 2014. AQUA Vol 63.6 p476.

Seago, CJ & McKenzie, RS. 2007. *Non-Revenue Water in South Africa.* WRC Report No. TT300/07. ISBN 978-1-77005-529-2, Republic of South Africa. January 2007.

SSA. 2010. P9115 - Non-Financial Census of Municipalities. Statistics South Africa, South Africa, June 2010.

Siqalaba, Z, Wegelin, WA & Willoughby, C. 2009. Public Participation and Education in Water Demand Management. Proceedings of the IWA Water Loss 2009 Conference. Cape Town. 26 – 29 April 2009.

Van Zyl, JE. 2011. Introduction to integrated water meter management - Edition 1. WRC Report No. TT 490/11. ISBN 978-1-4312-0117-4, Republic of South Africa. October 2011.

Texas Water Development Board. 2004. Report 362 - Water Conservation Best Management Practices Guide. Texas Water Development Board, Austin, Texas.

White, S. 1998. Wise water management - a demand management manual for water utilities. Water Services Association of Australia, Edited by S. White, Institute for Sustainable Futures, University of Technology, Sydney, Research Report No.86, November 1998.

Waldron, T. 2002a. Managing and reducing Losses from Water Distribution Systems – Manual 4 Establishing Pressure Management Zones and District Metered Areas: The toolkit. State of Queensland, Environmental Protection Agency and Wide Bay Water. ISBN 0 7242 9493 7. 2002.

Waldron, T. 2002b. Managing and reducing Losses from Water Distribution Systems – Manual 2 Water Audits. State of Queensland, Environmental Protection Agency and Wide Bay Water. ISBN 0 7242 9492 9. 2002.

Waldron, T. 2005. Managing and reducing Losses from Water Distribution Systems – Manual 5 Advanced Pressure Management and PRV Selection. State of Queensland, Environmental Protection Agency and Wide Bay Water. ISBN 0 7242 9496 1. 2005.

Waldron, T. 2010. *The Path Forward.* Proceedings of the IWA Waterloss 2010 Conference. São Paulo City, Brazil, 6 to 9 June 2010.

Wensley A. 2014. Benchmarking of water losses and NRW in South African municipalities until 2011/12. Proceeding of the 4th Regional African Water Leakage Summit 2014. DBSA, Midrand, South Africa. 19 to 20 Augustus 2014.

Wegelin, WA, & McKenzie RS. 2002. Leakage reduction through Pressure Management in South Africa – Concepts and Case Studies. WRC Report TT 186/02. ISBN 1 86845 878 4, Republic of South Africa. August 2002.

Wegelin, WA, McKenzie, RS, & Davidson D. 2009. The benefits of non-domestic consumer meter audits and retrofitting – the Ekurhuleni Case Study. Proceedings of the IWA Water Loss 2009 Conference. Cape Town. 26 – 29 April 2009.

Wegelin, WA, Mckenzie, RS, & Siqalaba, ZN. 2012. The state of non-revenue water in South Africa. WRC Report TT 522/12. ISBN 978-1-4312-0263-8, Republic of South Africa. August 2012.

Wegelin, WA & Jacobs, HE. 2013. The development of a municipal water conservation and demand management strategy and business plan as required by the Water Services Act, South Africa. ISSN 0378-4738 (Print), Water SA Vol. 39 No 3 WISA 2012 Special Edition 2013 p415-422.

WRP. 2001. Completion report for the Implementation Phase of the Pressure Management Project in the Northern and Western Administration Units. August 2001.

WRP. 2003. Water loss project in the Rand Water / Gauteng area – Emfuleni Local Municipality. September 2003.

WRP. 2004a. Ekurhuleni Pressure Management Study – Brakpan. February 2004.

WRP. 2004b. Ekurhuleni Pressure Management Study – Kempton Park / Tembisa. September 2004.

WRP. 2004c. Ekurhuleni Pressure Management Study – Nigel. September 2004.

WRP. 2004d. Beverley Hills logging results.

WRP. 2005. Western Highveld Sibambisene Phase 2: Water Conservation and Water Demand Management Project: Technical Implementation Completion Report.

WRP. 2009. Final Close Out Report for the Implementation of WC/WDM in Emfuleni Local Municipality. Pretoria. December 2009

WRP. 2010. Sebokeng Evaton Advanced Pressure Management Project - Monthly efficiency gain report. 28 Jun 2010.

WRP. 2011. Pressure Management Investigation for Betty's Bay. Pretoria. November 2011.

WRP. 2013. Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area - Mbombela Local Municipality Water Conservation and Water Demand Management Potential Assessment, Strategy and Business Plan.

WRP. 2014. Water loss reduction project with Water Utilities Corporation Botswana - Evaluation report. Pretoria. October 2014