Analysis of the Water Distribution Main Replacement Conundrum in Durban

Simon Robert Scruton, Pr. Eng.

851853577

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College of Agriculture, Engineering and Science

University of KwaZulu-Natal

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Supervisor: Professor Derek Stretch

COLLEGE OF AGRICULTURE, ENGINEERING AND SCIENCE

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DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication.)

Scruton, S., 2012. Report for Executive Committee: Report on Non-Revenue Water Reduction Interventions as at 30 June 2012: eThekwini Water and Sanitation, Durban. Q4 2011/12 FY.

Scruton, S., Bosboom, J. & Fijma, A., 2011. The Evaluation of Decision Variables for the Rehabilitation of Water Mains in Durban, South Africa. International No-Dig 2011 29th International Conference and Exhibition. Berlin, Germany, 2011.

Shepherd, M. and Scruton S., 2012. Does Mains Replacement Always Reduce Real Losses? Results and Lessons Learned From a Large-Scale Mains Replacement Program in Durban. Water Institute of South Africa Conference, Cape Town, South Africa, 2012.

Scruton S., 2012. The Evaluation of Decision Variables for the Rehabilitation of Water Mains and the Case Study of Mains Rehabilitation in Durban, South Africa, International Water Association Water Loss 2012 Conference, Manila 2012.

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ABSTRACT

The optimisation of the decision of when to replace water distribution mains is a complex task. There are numerous drivers in the decision making process (informed by financial data, performance data and water quality data) and hundreds of variables and performance indicators that can be considered when trying to reach an optimised decision. Most of the assets under consideration are buried and the internal and external pipe conditions are not easily assessable, forcing the Utility to rely on the available direct and indirect variables from which conclusions on the reliability of the mains are to be inferred. The cost of mains replacement is relatively low but the assessment cost, if carried out can be relatively high. The total value of a metropolitan distribution network typically runs into billions of rands but the impact of an individual pipe failure is generally low. The distribution network is comprised of many different pipe materials and components, of different pressure classes, made by different manufacturers, installed by numerous contractors with different skill levels under differing quality control regimens over many years. To add to this complexity, various parts of the network are operated at different static pressures and varying velocities. Some sections of the network are isolated more often than others and at times there can be large pressure surges that the network is subjected to by either the Utility or Consumer. These pressure surges are known to have a marked detrimental effect on the network.

False markers also exist that can give rise to totally incorrect decisions and therefore performance data cannot be accepted at face value and needs to be scrutinised and cleansed to increase its reliability prior to being utilised in decision making process. This important step has been missed by much of the research carried out to date. In the Durban context, a further complication is caused by consumers tampering with the water mains and also not reporting leaks. This has a negative effect on the performance of the water main that can cause it to be flagged for replacement, but its replacement will not result in an increase in performance if the social issues are not resolved first.

The aim of this research is to make recommendations on the methodology to be employed to improve network performance and thereby delay the point at which the water mains are to be replaced for as long as possible. These recommended activities will be carried out to remove false markers and improve upon the quality and reliability of the data available on the network performance. A further output is to make recommendations regarding the minimum data that can be reasonably collected and analysed in order to determine an optimised result. The recommendation of which mains should be targeted for replacement should result in the highest

benefit for the utility as well as the consumers. By implication, this will result lowest long term capital and operational expenditure and thus the lowest long term tariffs charged to the consumers whilst complying with the water quality criteria and service level targets.

LIST OF ABBREVIATIONS

AC	Asbestos Cement
avg.	Average
AWWA	American Water Works Association
AZNP	Average Zone Night Pressure
BFI	Burst Frequency Index
BMC	Billed Metered Consumption
CBA	Cost / benefit analyses
DMA	District Metered Area
DWA	Department of Water Affairs
EWS	eThekwini Water and Sanitation
GIS	Geographic Information System
HDPE	High Density Polyethylene
ICF	Infrastructure Condition Factor
ILI	Infrastructure Leakage Index
IT	Information Technology
IWA	International Water Association
KPI	Key Performance Indicator
km	Kilometer
l	Liter
m	Meter
m^3	Cubic Meter
MCD	Multi-Criteria Decision
NPV	Net Present Value
NRW	Non-Revenue Water
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride
SABESP	Companhia de Saneamento Básico do Estado de São Paulo

SCADA	Supervisory Control and Data Acquisition
SIV	System Input Volume
TIRL	Technical Indicator of Real Losses
UARL	Unavoidable Average Real Loss
UBL	Unavoidable Background Leakage
UK	United Kingdom
UKWIR	United Kingdom Water Industry Research
WC/WDM	Water Conservation and Water Demand Management
WLTF	Water Loss Task Force (of IWA)
WRC	Water Research Commission
WWTW	Waste Water Treatment Works

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CHAPTER 1 – INTRODUCTION

Definition of "Conundrum"

- A logical postulation that evades resolution, an intricate and difficult problem - http://en.wiktionary.org/wiki/conundrum
- A difficult choice or decision that must be made - http://en.wikipedia.org/wiki/Conundrum
- A puzzling question or problem - http://www.collinsdictionary.com/dictionary/english/conundrum
- A confusing and difficult problem or question - http://oxforddictionaries.com/definition/english/conundrum?view=uk

1.1 BACKGROUND AND IMPORTANCE OF TOPIC

Water distribution networks throughout the world are getting older and deteriorating but their purpose is to deliver high quality potable water to the customers of the utilities (Lambert, 2012). Farley et al. (2002) observe that historically non-revenue reduction strategies have been considered only as an afterthought in water distribution networks. Water loss management has now become of strategic importance for many utilities due to the increasing cost of water losses and the lack of assurance of supply. South Africa is a water scarce country with an average rainfall of just over 400mm per annum. The fresh water sources in this country are finite and therefore in order to serve the needs of a growing population it is important that the existing supplies are utilised as efficiently as possible. One of the primary reasons that potable water is lost is due to leaking and ageing infrastructure that has been poorly maintained. Many different approaches to this conundrum exist: Some say that the aging network requires urgent attention, whilst some say not. Some utilities replace mains based on observed failures rather than try to assess the condition of the pipes. Some use advanced methods of prioritisation and others do nothing and some are starting to consider collecting fault data and implementing methods to analyse the outcomes. As pipes get older in the water distribution network, they are characterized by a decreased hydraulic capacity as well as an increased frequency of breakage (Kleiner et al., 2001).

In terms of the Municipal Management Finance Act (MFMA) and the Local Government Capital Asset Management Guidelines, all Water Service Providers and Water Service Authorities in South Africa have been mandated to efficiently manage their assets. It is therefore a requirement that all assets are quantified and that their condition is also known. Furthermore, the replacement of these assets needs to be predicted and budgets provided for their replacement. Manus et al., (2008) report that the Department of Water Affairs (DWA) has been compiling a national water services infrastructure asset management (IAM) strategy. DWA has identified the elements required for an enabling environment to ensure responsible IAM processes are conducted by the water authorities and then further assisted by identifying the required strategic actions and implementation plans.

Water reticulation mains have a natural rate of attrition and deteriorate over time, but what is unknown is exactly where the problems exist as these assets are buried and largely invisible (Thornton, 2011). The challenge for the water authority is to determine the most cost-effective method to accurately identify which pipes in the network need to be replaced and when they must be replaced, subject to the constraints of service requirements (water pressures, water quality and network reliability etc.) (Kleiner et al, 2001). It is not economically viable to achieve a leak free system and this is never the objective. Some background leakage is always expected even in very efficient networks and it would cost more to eradicate these background leaks than would be gained by eliminating them (Lambert & Hirner, 2000). The service life of a distribution main typically ranges from 30 to 100 years (Trifunovic, 1999) and is influenced by a number of factors, but the performance of the water mains decreases exponentially towards the end of its lifetime. Replacement of these linear assets is extremely expensive (Thornton et al., 2008) and therefore it is of utmost importance that due consideration is taken in each case to ensure that this decision is made at the correct time. Due to the fact that these mains are buried, they cannot be easily examined and if wide scale physical assessments were carried out it would be prohibitively expensive and counterproductive. Reliable methods and indicators need to be determined to analyse the performance of a pipeline and track its deterioration over time. If water mains are prematurely replaced, the asset owner will have to charge a higher water tariff and this will have a negative impact on inflation and the economy.

If water mains are not replaced timeously then water losses will be high, water quality will be compromised, there will be a high burst frequency and the water meters and the income they derive will be negatively affected. This too will result in higher water tariffs, inconvenience to consumers and potentially lead to rotational supply. Commerce and Industry require reliable infrastructure in order to function effectively and a poor level of service could result in a migration of businesses away from areas where there is an unpredictable assurance of water supply.

The non-revenue water volume will be influenced by the pipe material, the number of connections, the quality of installation, the level of asset management and the geology and topography, to mention a few (Lambert & Hirner, 2000). A number of interim measures can be undertaken to reduce losses and extend the service life of the pipeline and these functions are integrally linked with the economic lifetime of the pipeline. These interim actions can delay the replacement and the impact thereof also needs to be assessed when deciding whether to replace a distribution main or not.

Another important dynamic is that the population is increasing and thus more and more people require access to potable water. As people become more affluent, they also tend to increase their water consumption and so the average demand per capita also increases. It is extremely important that water utilities operate as efficiently as possible by running Water Conservation and Water Demand Management (WC/WDM) programmes, carrying out the required maintenance and replacing infrastructure at the correct point time that is required. The engineers and operating crews must work together with the planning and design engineers, Information Technology (IT) staff, and finance staff to collect and interpret conditional data to make effective decisions about maintenance, repairs, rehabilitations and replacements (AwwaRF, 2005). This will thus ensure that the losses are kept to a minimum, the water tariff is optimised, and spare capacity will be available in the system to extend supply to new consumers when required.

Lawless (2007) reports that there is a growing problem caused by the lack of availability of competent engineers and scarce skills and skills gaps are hindering the growth of the engineering sector. This is having a direct impact on the quality of repairs and new installations. The electrical infrastructure is also under strain and this is also having an impact on the functioning and reliability of the water supply. As there are strong linkages and interdependencies between many of the problems the solutions to this complex dynamic actually needs to address many of the aspects across the entire water company.

In South Africa, the challenge of ensuring that there is a reliable water supply is made more complex by an urbanising population that also often do not have a culture of payment. The behaviour of users of the water supply system cannot be forgotten and programmes must address these issues as well in order to reach an efficient equilibrium where the users have a reliable water system with high quality water, the tariffs are affordable and are paid and the costs of running such a system are within acceptable norms.

The designing and construction of a water reticulation system is typically a simple affair. Design standards and hydraulic models are well known and documented. The construction is also not difficult as contractors are held to quality and performance targets through specifications and contractual obligations. It is what happens beyond the end of the one year maintenance period that the issues become less clear. We would like the water mains to satisfy requirements in three main areas. They should deliver high quality water to the consumers and also perform well from both a financial and operational perspective. The information relating to their performance cannot however be easily found in one ring fenced location as the assets are spread over a wide geographic location. eThekwini Water and Sanitation (EWS) provides potable water to some 3.6 million consumers through pipelines of a total length of 11 million metres that have 475 000 service connections, 55000 valves and 33000 fire hydrants. Every connection to a main is a potential leak and the evaluation of the performance of the water mains is a difficult task. Not all the faults are known, but those that are, are recorded in a number of different computer based systems (financial, operational and quality performance) that are not set up to seamlessly exchange information. Pressure and flow data is collected but is not stored in a system where this data is readily accessible. Some data is available from Supervisory Control and Data Acquisition (SCADA) system, but this system is typically used to monitor and control pumps and reservoirs. Where pipe bursts occur, samples are sometimes sent for testing to determine cause of failure but this data is also not recorded in any system for easy analysis or retrieval. These faults occur over a period of time and sometimes are caused by external forces that are not related to the performance or the natural rate of attrition.

In some areas, illegal connections and tampering is rife and this has a marked impact on the performance of the networks. Simply changing these networks without addressing the root causes would not result in sustainable savings in the long term. These pipelines have been installed over many decades by a number of different contractors with varying levels of skill and the materials used also have their own unique characteristics. Lastly, the characteristics of the water produced by the water treatment works and the pressure fluctuations in the distribution network also have an impact over time, which will differ from area to area.

Comprehensively knowing all the above and having access to all the performance data will not necessarily empower a Utility to make optimum decisions. It is certainly possible to collect all this data and analyse it, but a cumbersome system would result. The efficacy of the decisions will not necessarily increase with an increasing amount of data. Risk also needs to be taken into account in terms of likelihood and consequence of failure. The cost of collecting and managing this data would be disproportionate to the benefit and this analysis would not necessarily result in optimised decision making.

EWS need to implement a system whereby a reasonable compromise is reached between what data is collected and analysed versus the benefit that it will produce. In this day and age, it is no longer acceptable for a Utility not to have a reliable method of evaluating the performance of their assets and being able to effectively plan for their maintenance and ultimate replacement. It is also imperative that this data is cleansed before analysed to ensure that the correct decisions are made within the bounds of certainty. Whilst the replacement of pipes will reduce real losses, it is certainly the most expensive alternative. It is therefore of critical importance to ensure that the identification of zones in need of repair, and the replacement of pipes is carried out in an accurate, efficient and effective manner (Scruton et al.,2011).

This thesis will set out the issues at hand, explore the various options and reach realistic practical recommendations with regard to what data should be collected both now and in the future, how this data should be cleansed to ensure its integrity and lastly how it should be analysed. The result of this analysis will thus map out a reasonable progressive way forward that will result in the optimisation of the costs for capital replacement and the operation of the water distribution network.

1.2 SCOPE OF THIS RESEARCH

It has been discovered that the assessment and replacement of water mains is a vast topic and has been researched by many academics and professionals for some decades. In order to focus this study it has been decided to only consider pipe materials that are commonly used in Durban. Lambert et al. (2011) states “the methods, costs, and benefits of addressing transmission (trunk) main leakage are different enough from distribution networks to warrant separate consideration”. Pressures in a reticulation network typically vary from 20m to 90m and pressures trunk mains are known to vary from 2m to 400m. Trunk mains therefore have been excluded from consideration as they also differ from distribution mains from a design, operational and risk perspective. Many Utilities rely on historical burst data in order to track the performance of a distribution main but this approach cannot be tolerated on a trunk main and active condition assessment is practiced in order to gauge the likelihood of failure, so that failures can be proactively prevented altogether. Lastly, as the cost of replacing a trunk main is so high, it is feasible to conduct regular condition assessments and accurately track the deterioration. This is a prohibitively expensive option for distribution mains so the Utility has to adopt a different approach and rely more on indirect data.

The Utility needs to take cognisance of all the issues that raise inefficiencies and increase water losses. The solution to this complex dynamic actually needs to address many aspects across the functioning of the entire water company as well as the behaviour of users of the water supply system. There are strong linkages and interdependencies between many of the problems and solutions. Some of these issues are listed in Table 1.1 for completeness but this dissertation only addresses the reduction of real losses through pressure management, active and reactive leak detection, speed and quality of repairs and predictive pipeline replacement.

Table 1.1: List of Issues Related to Non-Revenue Water

Strategy	Area of Reduction	Benefit
Accuracy of Purchase / Production Meters	Accuracy of Water Balance	Potential decrease in purchase costs; Accurate determination of tariffs to recover costs
Accuracy of System Input Volume (SIV) and District Metered Area (DMA) meters	Accuracy of Water Balance	Accurate quantification of system performance highlighting areas of concern to enable intervention where required
Enforcement of payment / debt collection	Apparent (Commercial) loss reduction	Potential decrease in consumption, increase in payment recovery
Correction selection of water meters, meter installation standards and active replacement of consumer water meters	Apparent loss reduction	Increase in billed revenue
Ensuring all consumers are metered	Apparent loss reduction	Increase in billed revenue
Ensuring all consumers meters are accurately read and bills are received and understood	Apparent loss reduction	Increase in billed revenue
Meter reading data handling and controls to ensure accurate quantification of volume sold	Apparent loss reduction	Increase in billed revenue
Derivation and implementation of policy to address indigents	Real and Apparent loss reduction	Equitable distribution of water services to society
Compilation of water supply bylaws and water policies	Real and Apparent loss reduction	Equitable distribution of water services to society
Enforcement of water policy especially with respect to illegal connections and non-payment	Real and Apparent loss reduction	Equitable distribution of water services to society
Calculation of water tariffs	Management of consumer demand	Equitable distribution of water services to society
Ensuring water quality standards are monitored and achieved	Apparent loss reduction	Maintenance of billed revenue
Material selection of all components	Real and Apparent losses	Assets last longer and perform better
HR policies with respect to recruitment, retention and training	Real and Apparent losses	Staff are trained and motivated to operate the system to the best of their ability

The options considered in this thesis are primarily concerned with the replacement of a water main. The Utility could however decide to rehabilitate a water main at a lower cost and the analysis would have to then be done at this new value, but the lifetime of the rehabilitated asset would be shorter. Similarly, the Utility could opt to replace a main via trenchless technology and this solution will come at different rates with different advantages and disadvantages. These considerations are also beyond the scope of this document.

1.3 CHAPTER 1 - SUMMARY

- Water distribution networks throughout the world are deteriorating.
- Waterloss management is key to addressing the global water shortage and the increasing the costs of supplying potable water.
- A number of interim measures can be undertaken to reduce losses and extend the service life of water mains.
- The Utility is presented with a conundrum as there are many influences on the pipe condition and the pipe condition is not easily and reliably determined.
- The Utility is faced with a variety of projects all competing for funding and therefore needs to prioritise the work according to the objectives of the Utility.
- It is important to ensure that the identification of zones in need of remedial work or pipe replacement is carried out in an efficient and effective manner.
- In order to focus this study it has been decided to only consider pipe materials that are commonly used in Durban and also to only consider distribution mains.
- This thesis only addresses the reduction of real losses through pressure management, active and reactive leak detection, speed and quality of repairs and predictive pipeline replacement. The impact and methods of apparent loss reduction is not discussed.
- This thesis only considers the replacement of a water main, but equally the decisions made could examine various methods of pipe rehabilitation or replacing mains with trenchless technology.
- This thesis aims to present a methodology for EWS to implement to comprehensively embrace their reactive and proactive responsibilities in a cost effective manner.

CHAPTER 2 – LITERATURE REVIEW

2.1 PREAMBLE

In this literature review, considerable reference has been made to information that has been published by non-revenue water reduction specialists because of its relevance to the operational issues at hand. These practioners have decades of first-hand experience as they hold senior positions in their organisations and have been practicing for many years. In many cases however, these reports have not been peer reviewed but as they have been published by world renowned experts in their respective fields, this information is deemed to be both relevant and credible.

2.2 INTRODUCTION

Asset management in the water sector can be described as managing infrastructural capital assets to minimise the total cost of owning and operating them, whilst delivering the service levels that the customers desire (Schulting and Alegre, 2009). IIMM (2011) states that asset management is the combination of engineering, economic and management practices applied to physical assets, with the objective of providing the desired level of service in the most cost effective manner. Brown and Humphrey (2005) have an interesting alternate implying that asset management is more of an art that an exact science. "*Asset management is the art of balancing performance, cost and risk. Achieving this balance requires support from three pillars of competence: management, engineering and information*". IIMM (2011) define advanced asset management (AAM) as "*asset management which employs predictive modelling, risk management and optimised decision making techniques to establish asset management lifecycle treatment options and related long term cash flow predictions*". Shulting and Alegre, (2009) state that AAM is essential for the sustainability of the water supply services. O'Day et al (1986) however states that there is no proven method for classifying mains for replacement and utilities must rely on the information that they collect along with subjective judgement.

The strategy adopted by some water utilities is to replace pipes on an ad hoc basis when it is perceived that the condition warrants replacement. This strategy is not viable economically and the utility must analyse the causes of failure so that the service life of the mains can be extended. This will thus mitigate against the health, environmental, social and economic impacts of burst mains (Hu & Hubble, 2007).

Planning and prioritisation is evolving over time and belongs to the management field. It is impacted by many other spheres of speciality such as labour, human resources, contract law, economics, government involvement, regulations, public involvement, budget, finance, accounting, organisation development and computer hardware and software. In the private sector, capital investment models focus on risk allocation and the return on investments. In the public sector however many utilities include an evaluation of the social costs as well. In terms of prioritisation, pipeline replacement projects often first have to compete with other diverse unrelated public works (comparing apples with oranges). Once funding is allocated then competing projects for renewal need to be compared and priotitised (comparing apples with apples).

The United Kingdom Water Industry Research Institute ((UKWIR) (2011b) states that it is possible to reduce the leakage levels in the United Kingdom (UK) from the 2007/08 levels (of 23% of the system input volume) to roughly 8% by increasing the levels of pipe replacement and active maintenance. Society however, must be willing to pay for the cost of achieving this goal. The document admits that there is inherent uncertainty about what these goals should be in the medium term (5 years) and even more so in the long term (25 years).

2.3 ASSET MANAGEMENT

The technical lifetime of a pipeline is the period that the pipeline can operate satisfactorily from a technical point of view. The economic lifetime of a pipeline is the period of time that the pipeline can operate without it being more costly than its replacement. It stands to reason that the economic lifetime can never be longer than the technical lifetime (Van Der Zwan, 1989).

Mains Replacement

Lumbers et al. (2003) stated that it is generally accepted that inadequate capital maintenance will eventually lead to some form of asset failure. Thornton et al. (2008) stated that pipeline rehabilitation or replacement is the most expensive investment that a utility can make. Conventional wisdom suggests that in average circumstances it is unlikely that mains renewal would be economically justified as a blanket alternative to a “find and fix” (leaks) approach on the basis of leakage savings alone. However, it is a commonly held view that there are hot spots within a network where mains renewal will be an economic alternative (Grimshaw, 2006). Lumbers et al. (2003; 2009) suggests that capital maintenance should be justified on the basis of future impact of failures on the quality of the water service and the cost of the provision of water services.

Thornton et al. (2008) states that the primary decision for mains replacement would be made on the basis of Cost / Benefit but the other factors that could influence the decision are environmental, health, structure, emergency, demand and lack of alternate supplies. The mains that should be target for replacement or rehabilitation are those with:

- High burst rates
- High leakage
- High joint leaks
- Encrustation
- Insufficient hydraulic capacity
- Structurally deficient
- Pose a threat to life or property.

The predominant materials used in Durban are AC and PVC and PE. Encrustation is a phenomenon that occurs in metal pipes. As this study is confined to the Durban area only and there are only 300km (2.7% of distribution system) of cast iron mains in eThekwini, all aspects relating to the degradation and rehabilitation of this pipe will not be dealt with in this document.

The modelling of the condition of a water distribution system requires information regarding the structural condition of the mains. The number of pipe bursts is most commonly used for this purpose (Pelletier et al., 2003). Walski et al. (1982) reports that the basis for deciding whether to replace a water main or not is the present value of costs for replacement and a model to predict water main breaks as a function of pipe age, previous breaks, material type, temperature and diameter. The occurrence of breaks and cost is projected and compared with the main replacement costs and the costs and break prediction model are utilised to calculate the main breaks costs over the next twenty years. Contrary to the report of Walski however, and evidenced by Table 3.5-3.7, the cost of non-revenue water must be considered in this analysis as these costs can be as high as 60% of the operational costs. Thornton et al. (2008) states that the cost of not replacing a main can be evaluated against the following factors:

- Average historic break frequency
- Cost of water lost per incident
- Cost of damage per burst
- Cost of the repair to the main
- Cost of the reinstatement to the surrounding area.

These costs have been determined for a number of zones and this is discussed further in Chapters 3 and 4.

Every Utility has a unique combination of underground assets Thornton (2011), based on its historic development, construction practices, material selection, maintenance history, replacement history and soil conditions. The situation is also dynamic in that it can be constantly changing.

The principal drivers for most mains rehabilitation or renewal programmes will include:

- The need to overcome current and projected future deficiencies in asset performance and service delivered to customers measured against accepted standards
- The need to extend the serviceable life of an existing group of assets (Grimshaw, 2006).

Lambert & Hirner (2000) report that the technical and financial aspects relating to the reduction of non-revenue water is receiving growing global attention with an emphasis on energy reduction, sustainability and the minimising the environmental impact.

Grimshaw (2006) stated that the selection and prioritisation of the mains in the network to be rehabilitated is governed by the current and projected trend of a number of serviceability indicators such as low pressure, water interruptions and water quality issues. He stated however that the challenge is to restore assets to a position where the service to customers is acceptable at a minimum whole life cost.

Grimshaw (2006) however cautioned that there needs to be an awareness of the potential impacts on the areas of the network that have not been selected for replacement. There can be an increase in leakage and burst frequencies in the mains that are not replaced as a result of increased static pressures, an increase in disruptions and transient pressure spikes in the old network during the replacement activities.

Walski et al. (1982) observe that the utilisation of pipe ages as a replacement criterion can be misleading as new pipes may be of superior quality, with better installation or better protection against freezing, corrosion and soil movement. Conversely, it has been seen in Durban and Sao Paulo that water mains laid in the 1950's and 1960's by well-trained artisans are outperforming water mains laid in more recent times.

Grimshaw (2006) estimates that in the UK, with all other aspects remaining the same, a mains replacement rate of 1.1% will be required to combat the Natural Rate of Rise of Leakage (NRR) and to keep leakage at the same levels. Grimshaw (2006) states that it is essential that mains replacement is not considered in isolation but as part of an integrated planning process. Of interest, when calculating the long run marginal costs for mains renewal, the cost water used in the calculation should be that cost derived from the cost of the next constructed water scheme. This cost of water is typically more than double the current cost of water. The cost of renewal should taken as the present value cost of advancement from the year in which the main would have been replaced anyway at the end of its service life. On this basis, it is indicated that mains with a NRR exceeding 60m^3 / kilometres (km) / day (d) could be candidates for replacement.

Choice of Pipe Material

The life span of a new distribution main would be expected to be at least 50 years. UKWIR (2011b) reports that studies that have been conducted on the deterioration of polyethylene (PE) pipe indicate that under normal operating conditions, it should be possible to achieve a 200 year life span. Furthermore, they observe that the implementation of an effective quality control system with the required checks and balances will yield a payback around five years. There is concern around the integrity of the joints in PE pipes and although the failure rate (4 leaks/100km/year) is still the lowest of all pipe materials recommendations have been made to modify construction practices to reduce the failure rate even lower.

Around the world, utilities have moved away from using Asbestos Cement pipes and Cast Iron pipes for distribution mains. Many utilities favour either PE or Polyvinyl Chloride (PVC) pipes. One disadvantage with plastic pipes is that it becomes difficult to detect leaks at low pressures (Thornton et al. 2008).

2.4 FACTORS AFFECTING THE PERFORMACE OF A WATERMAIN

Various components of the water supply and distribution network deteriorate at different rates as can be seen in Table 2.1:

Table 2.1: Average Technical lifetimes of Component (Trifunovic, 1999)

Component	Technical Lifetime
Transmission Mains	30 – 50 years
Reservoirs	20 – 80 years
Pump Stations - Structure	20 – 80 years
Pump Stations – Mechanical and electrical equipment	15 – 30 years
Distribution Mains	30 – 100 years

A survey of worldwide data yielded the following as the main causes of the water leaks (Thornton et al. 2008):

- Soil movement (27%)
- Pipe corrosion (19%)

- Heavy traffic loadings (11%)
- High pressure in the system (8%)
- Damage due to excavations (8%)
- Pipe age (6%)
- Winter temperature (6%)
- Defects in pipes (5%)
- Poor quality of joints (4%)
- Soil conditions (3%)
- Poor quality of workmanship (2%).

Figure 2.1 shows a plot of pipe failures as a function of pipe diameters (Van der Zwan, 1989). It can be seen that the number of pipe failures increases with decreasing diameter.

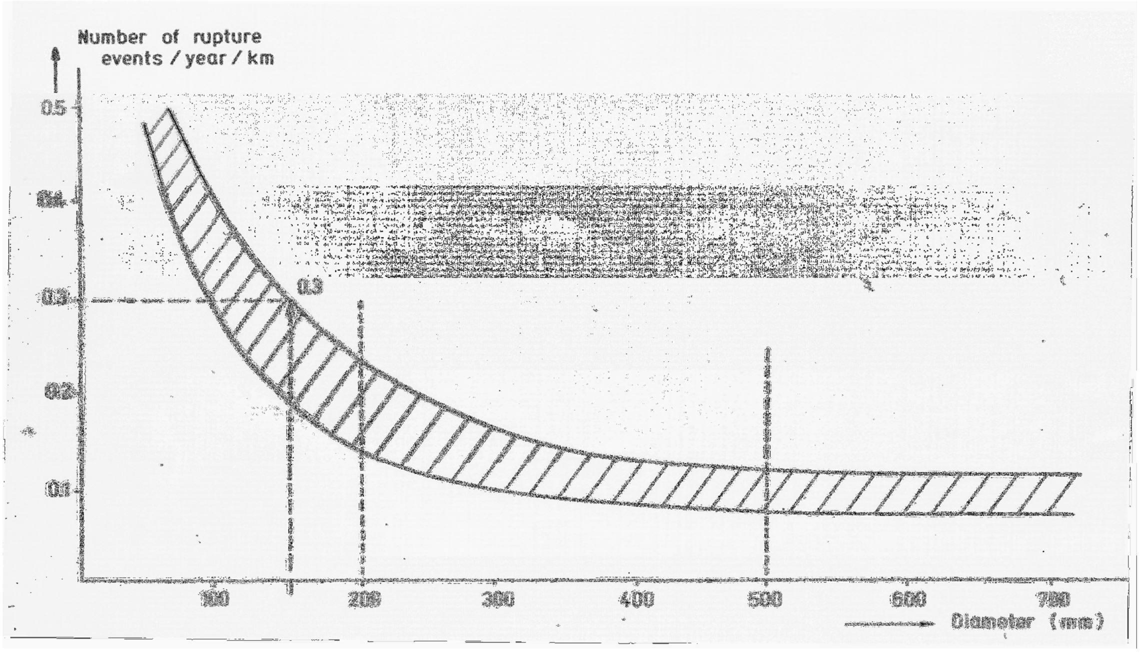

Figure 2.1: Number of failures vs. pipe diameter (Van Der Zwan, 1989)

2.4.1 CONDITION ASSESSMENTS

Condition assessment data is needed for engineering, operations and maintenance, planning and financial decision making (Beuken et al., 2010). The water industry now has a good understanding of how condition assessments are conducted by utilities. Unfortunately, these assessments are not done consistently and the underground condition data is not well known to most utilities. Indicators such as "good" or "poor" are often used, rather than more definitive parametric descriptions such as remaining useful life. These aspects of condition assessments need further improvements in the future in order to be more useful.

Kleiner and Rajani (2002) state, "*The statistical analysis of historical breakage patterns of water mains is a cost effective approach to discern their deterioration, where physical mechanisms that lead to their deterioration are often very complex and not well understood. Furthermore, data required to model these physical mechanisms are rarely available and prohibitively costly to acquire. Several models exist in the literature, which use various statistical methods to analyse patterns of pipe breakage histories. However, predicting a breakage pattern in an individual pipe has proven to be quite a challenge and the validation of these models is generally done on the basis of aggregate breakage rate although the model purports to predict individual pipe behaviour. The structural deterioration of water mains and their subsequent failure are affected by many factors, both static (e.g., pipe material, pipe size, age (vintage), soil type) and dynamic (e.g., climate, cathodic protection, pressure zone changes).*"

Sophisticated computer methods are available for analysis (AwwaRF, 2005), but in order to make effective decisions, more accurate information regarding the actual condition of the pipe at the point in time that the analysis is conducted is required. If unreliable data is used for analysis, the results of this analysis will sub-optimal. Kleiner et al., (2001) makes the point that many of these analyses are also only suitable to small networks due to the complexities and limitations of techniques and equipment.

Beuken et al. (2010) stated, "*Condition assessment technology is used to quantify if actual main characteristics meet their requirements. If better information on the condition of mains is available, adequate decisions can be taken on postponing investments for replacement. Inspection technologies can be used to obtain more knowledge on the condition of mains and could therefore play an important role in improved management of underground assets. Inline inspection technologies are available for metal and cement mains larger than 250 mm. Application of business cases shows that, even if inspection technologies would exist for smaller diameters, the total cost of inspection is higher than the savings due to postponement*".

There are a variety of destructive and non-destructive methods that can be employed to assess the state of readiness of a pipeline and its ability to perform a given function. The component condition of a water main or the system as a whole can be assessed (AwwaRF, 2005). The component assessment can be divided into three distinct groups:

- Location and data logging:
    - Ground penetrating radar
    - Electromagnetic tests
    - Sonic and acoustic tests
- Wall thickness, corrosion and fragility tests:
    - Coupon testing
    - Acoustic emissions
    - Ultrasonic tests
    - Infrared thermography
    - Remote Field Eddy Current tests
    - Magnetic flux leakage
    - Physical inspections
    - Tubercles and deposition:
    - CCTV inspection

System assessments can be performed to evaluate the performance of the network as a whole and are broken up into the following four areas:

- Water loss accounting (Water Audits)
- Hydraulic evaluation (Models, Flow tests, Real time monitoring of key indicators such as minimum night flow, average daily demands, critical point pressures). The critical point in a zone is that point where the dynamic pressure is lowest.
- Water quality evaluations
- Controlled destructive evaluation

Torterotot (2009), observed that the condition of assets changes over time, both continuously and in response to specific events. The technical and economic performance is dependent on the assets themselves and also on how these assets are operated. There is a relationship between condition and time to failure and therefore an understanding of the failure mechanics and advanced data management systems to record and assess this data is required.

Designing and implementing a water main decision planning system is an on-going evolutionary process. It begins with an assessment of the distribution system condition. From this assessment a reactive planning system may be designed and implemented. This, in turn, can lead to the development of a predictive planning system (USEPA, 2007).

Thornton et al. (2008) advises that the Utility consider the benefits of rehabilitation as opposed to replacement. Benefits can be gained by opting for a cheaper rehabilitation solution (often with a lower technical lifetime) as opposed to an outright replacement but this analysis is beyond the scope of this study.

Improved budgetary planning can be a means of justifying additional funding for system improvements (USEPA, 2007). There is convincing evidence supporting the requirement for effective condition assessment but the cautions that there are a number of obstacles to the implementation of this assessment:

- Lack of records
- Inability to inspect pipes in service
- Lack of funding
- Lack of understanding
- Lack of support

To mitigate against this, it is advised to develop better condition assessment tools, provide support and educate key role players regarding its necessity (management, staff and customers) and also to secure adequate resources and staff for its implementation.

AwwaRF (2005) recommend that each Utility compile a faults database and that the following information is included:

- Fault location and other inventory data
- Pipe size and depth
- Corrosion indication
- Type of break / fault
- Repair method utilised
- Pictures

The fault data collected by Dutch water utility Evides BV and the local eThekwini water utility (EWS) have been included in the Appendix.

To facilitate implementation it is advised to create easy templates to follow, incentives for gathering data and accurate and improved tools and materials. UKWIR (2003b) recommend that a mature Utility use electronic methods to capture, store and analyse this fault data. Training and Quality Control are an essential part of this process to ensure that valid representative data is collected.

2.4.2 FAULT ANALYSIS

Elgaard et al., (2009) states that water distribution networks are complicated as they have been laid with different materials of differing quality designed to different standards. There is a mixture of diameters, asset ages, soils, quality of installations, maintenance histories, static and dynamic pressures, water velocities, temperatures and soil moisture contents. The faults that are recorded can be attributed to a variety of reasons including damage by third parties. A five-step process was developed by Kleiner and Rajani (1999) to analyse incomplete burst history data on distribution mains in order to budget for mains replacement. These five steps are to (1) sort the water main break data into homogeneous groups, (2) determine breakage rate patterns for these groups, (3) use these patterns to project future breakage rates, (4) examine probabilistic scenarios for the distribution main life, and lastly (5) determine the future investments that would be required to replace the distribution mains. Whilst this analysis is useful from a financial planning perspective, it does not provide an operational main renewal plan and identify the mains that should be replaced.

For a well maintained distribution system Lambert and Taylor (2010) give the values that would need not to be exceeded in order to achieve the UARL:

- Main Breaks: 13 per 100km per year;
- Service Connection breaks: 3 breaks per 1000 service connections per year.

The Burst Frequency Index (BFI) is calculated by dividing the break frequency of the distribution system by the reference values above. This results in a dimensionless variable that is a good indicator of the condition of the system.

The Natural Rate of Rise of Leakage is defined as the hypothetical annual increase in leakage that would occur if no leak repairs were carried out. Grimshaw (2006) postulates the following for the total Natural Rate of Rise of Leakage

$$NRR_t = PCF \times [(m \times lfm \times Lm) + (c \times lfc \times Nc)] \times Df$$

Where:

NRR_t	Total NRR (l/hr/year)
l	Liter
hr	Hour
PCF	Pressure Correction Factor
m	The average contribution of mains (and mains fittings) leaks (l/km/hr) to NRR

lfm	Mains Infrastructure Serviceability Factor
Lm	Length of mains (km)
c	The average contribution to leaks from communication pipes and fittings (l/connection/hr) to NRR
Lfc	Communication pipe and supply pipe serviceability factor
Nc	Number of connections
Df	Network disturbance factor

Thornton et al. (2008) recommends that careful analysis is carried out to determine where the problems with the water mains lie and that the Utility should be able to determine if the losses are predominantly on the water mains, the connections, the connection pipes, on the consumer's premises or are in fact associated with meter tampering. This analysis will ensure that the proposed solution will correct the problem and that this solution is implemented at minimum cost.

Deb et al. (2002) has made recommendations for 45 data items to be captured for each main break which illustrates the complexity of the problem.

UKWIR (2002b) lists, after close collaboration with 23 water utilities in the UK (with 362 000km of water mains worth an estimated £30bn) a number of standards that can be used for the recording of faults. The benefits for adopting this robust approach will provide a better understanding of the trends of failures, will inform the need for spending, allows the utilities to compare themselves both internally and externally, enables better customer service and provides feedback to those specifying pipe and related material. To allow utilities to participate at various levels and not be too prescriptive, the data has been broken up into three categories that are deemed Essential, Preferable and Desirable. The standardised list of failures is detailed below:

Failure Types:

- Joint (JO)
- Ferrule (FE)
- Circumferential (CI)
- Longitudinal (LO)
- Pin Hole (PH)
- Gasket/Bolts (GB)
- Electro-fusion (EF)
- No Failure (NF)
- Other (OT)
- Unknown (UN).

UKWIR (2002b) admit that it is a laudable aim to ascribe the cause of failure to each fault but agree that in many cases analysis would be required by an expert in order to be fully confident of being correct. The causes of failure listed are the following: Pressure, corrosion, faulty product, point load, ground movement, 3rd party damage, poor bedding erosion, aging rubber seal, grit in seal, surge event, and poor installation. The user is cautioned when using these causes of failure as there is a need to be cognisant of who has recorded the data, what training they have received and what data validation has taken place.

Surface Classifications:

- Field (FD)
- Footpath (FP)
- Verge (VE)
- Highway – Heavy Traffic (HH)
- Highway – Light Traffic (HL)
- Free Standing Within Duct (DU)
- Unknown (UN).

Soil Types:

- Clay (CL)
- Gravel (GR)
- Peat/Loam (PT)
- Rock (RK)
- Sand (SA)
- Chalk (CH)
- Made Ground (MG)
- Other (OT)
- Unknown (UN).

Detection Methods:

- Reported / Reactive (C)
- Unreported/Proactive Detection (L).

Troterotot (2009) recommends that the storage and management of adequate real time data through the life of the assets regarding the operations, the failures and their impacts will pay back over time for taking operational as well as planning decisions.

Following the work of Ellison (2001) and Deb, Hasit and Grablutz (1998), proposed that the following infrastructure indicators are monitored:

- Physical
- Repair History
- Leaks
- Inoperability
- Unaccounted for Water.

Knowledge of this data will allow the Utility to asses "Infrastructure readiness" and the likelihood that the system will fail and also the rate of degradation. AwwaRF (2005) further recommend that the following Operating indicators are monitored:

- Flow
- Water quality
- Pressure
- Customer data
- Interruptions
- Energy use

Knowledge of this data will allow the Utility to asses "Operational readiness" and whether the system is providing the desired quality and quantity of water. It is difficult to assemble all this data and have confidence in its integrity. Ellison's (2001) report explains how this process can be simplified in the first instance and system capacity and reliability can be evaluated. He admits that no single variable can measure system readiness and suggests that the following be initially measured. He further reports that of all the potentially available data, the burst history report is the most valuable.

Table 2.2: Suggested Initial Variables for System Condition Assessments (Ellison, 2001)

VARIABLE
Break and leak frequency
Non-Revenue Water
Renewal Rates
Renewal Costs

A composite condition index much like a report card could be compiled for each DMA. This simplistic method would not suffice however where multi-attribute measurements are required for system assessments as there is no single best approach to compile such an index. In fact, it is believed that there are similar concerns with seemingly random weightings that some users apply to decide on which mains will be replaced.

AwwaRF (2005) recommend that the indicators of the component and system conditions shown in Table 2.3 are collected to assist with the prediction of failures.

Table 2.3: Variables that predict pipe failure (AwwaRF, 2005)

MATERIAL AND INSTALLATION	ENVIRONMENTAL CONDITIONS	SERVICE CONDITIONS	VULNERABILITY
Poor original materials	Corrosive soils	Corrosive water	Excavations
Defects	Ground movement	Water temperature	Trenchless intrusions
Age	Freezing	Traffic loads	Disasters
Type of material	Stray currents	System pressures	Cross connections
Poor bedding		Water hammer	Nearby loadings
Weak joints		Service history	

Wood and Lence (2009) reported that the amount of water main fault data needed for extensive analysis is generally not available in the majority of water utilities. Most municipalities only have limited fault data and this is often difficult to analyse. (Pelletier et al. 2003) Furthermore, unless rigorous training and quality control has been undertaken, the accuracy of the data is also often questionable. Wood and Lence (2009) report however that often utilities can analyse data from other sources such as archives and models. The typical data that is used by models to predict mains failures and their surrogates are listed in Table 2.4. Wood and Lence state that "*If a utility has sufficient data and the requisite skill and ability, it may be able to apply such knowledge discovery techniques to detect patterns, although for most utilities, rudimentary statistical analyses by technical staff are sufficient for detecting patterns in their data. Additional information may often be obtained efficiently at the time of the break repair by revising forms to collect more information, such as bedding or backfill material"*

Table 2.4. Data Used in Models and Surrogate Factors (Wood et al., 2009)

Surrogate	Factor
Age	Method of pipe manufacture, construction standards, deterioration over time
Pipe material	Construction practices, method of manufacture, failure mechanisms and causes, joint failures
Pipe diameter	Wall thickness and resistance to beam loading, pipe use, method of pipe manufacture, construction standards
Type of pipe lining	Method of pipe manufacture, resistance to corrosion
Bedding and backfill material	Physical stress on pipes caused by construction practices, structural resistance, soil type, fines migration
Pipe protection wrapped/anodes	Structural resistance, life expectancy, construction practices, method of pipe manufacture
Pipe condition	Remaining life
Soil type	Soil corrosivity, physical loading on the pipe such as swelling and frost, level of pipe protection, ground water effects, construction practices, bedding and/or backfill material
Under a roadway	Physical loading from surface loads such as traffic, road salt effects
Depth of cover	Physical loading on the pipe from the weight of soil
Surface material/type	Physical loading from surface use
Normal operating pressure	Internal pressure on pipe structure
Typical flow in area of break	Physical impact from factors such as accelerated internal corrosion from low flow mains, water hammer effects
Traffic classification	Physical loading from surface loads such as traffic volumes and wheel loads

Dandy et al. (2001) state that the water main replacement strategy can be driven either by economic, reliability, or water quality factors. A genetic algorithm can be developed to multiple criteria problems but examining the economic criterion alone ensures that the distribution system is efficiently run, that capital costs are optimised and operational and maintenance costs are minimised. In order for this analysis to be reliably conducted, all costs borne directly by the water authority and as well as those costs borne indirectly by the community need to be accurately known.

2.4.3 FAILURE MECHANICS

O'Day et al. (1986) reports that it is important to understand the causes of failure in a system because all systems are unique and a solution that is applicable in one system will not necessarily transfer to another system. Pipes will fail by different mechanisms, failures can occur singly or in multiples, and failures can be linked to a number of circumstances including human error, construction activities, routine service conditions, installation conditions and manufacturing defects.

Ellison (2001) states that pipes can be divided into critical and non-critical groups by using a weighted score approach. The weak point of this approach is that the underlying data is usually inadequate to yield high confidence in the results. Typical attributes that are tracked are leak history, importance of the pipe in the system, diameter, material type, soil corrosivity, damage potential, and pipe age.

2.5 DECISION SUPPORT SYSTEMS

Torterotot (2009) observed that there are a wide diversity of approaches for considering the various costs and benefits and valuation approaches. The costs and benefits can be considered at three distinct phases:

- Intelligence phase – Possible problems are identified and diagnosed
- Decision phase – Various actions are considered and selected (including the "do nothing" approach)
- Review Phase – Evaluate the results of the decisions made and actions taken.

A key point is that the Utility is free to prioritise the costs and benefits that are consistent with their goals and targets which are logically sound for a given issue. Furthermore, Troterotot (2009) proposes that provided the choices comply with contracts, regulations and standards, the Utility can consider whatever internal and external (social) costs and benefits are justifiable. It is not practical to consider and value all of the many issues simultaneously but the Utility must define their goals and targets and weight the variables accordingly. Some of the many areas to consider are investment costs, social costs, operational costs, asset condition, environmental costs and the cost of failures. The triple bottom line to be considered is a balance between economic, social and environmental targets that therefore produces a trade-off between these three competing areas. Troterotot (2009) states that the choice of costs and benefits is thus a compromise between what matters and what can be reasonably achieved. These costs and benefits occur over the lifetime of the asset and therefore a long term view must be utilised. A multi-criteria approach is thus required using a whole life costing approach in order to properly consider the values and objectives of the decision maker.

Cabrera et al. (1995) recommend that a complete analysis is conducted on a zone by zone basis and that all operational costs are recorded and compared to the cost of replacement. Knowledge is required of leak run times, leakage volumes, and the decrease in leakage event through active leak detection. This enables the utility to establish the relationship between the relevant water main parameters and to quantify the decisions informing the leak detection and repair plan. The connection and burst repair history of the mains will lead to individual analysis and conclusions. Cabrera et al. (1995) further recommend that this analysis is updated every year in order to retain a focused accurate view and to enable the utility to select the preferred option based on the level and quality of service that they wish to supply and the costs that they can afford.

The USEPA (2007) recommends that if a Utility decides that a predictive planning method is required, the first step is the development of a comprehensive water main inventory and maintenance history database, together with the environmental description for each record. The second step is the development of a physical condition assessment model to enable the Utility to approximate the deterioration process and estimate the relative break and leak frequency for the water mains. This will allow the Utility to be more precise with its prioritisation and scheduling capabilities and therefore be cost-effective.

This model can be later augmented with additional information such as hazard assessments, physical condition assessments, and economic evaluation models may also be developed. The USEPA (2007) further recommend that field data is collected and that testing should take place to verify critical model assumptions. This increased planning sophistication will increase the overall capital costs, and these costs must be justified against the benefits of more effective decision-making regarding rehabilitation, replacement and preventive maintenance activities.

Schulting and Alegre (2009) provide an insightful summary: "G*iven the significant investment involved, the decision on how much, where and when and how to maintain and/or rehabilitate networks must be well grounded based on technical, functional and socio-economic criteria. Such decisions are made difficult by the fact that these are buried infrastructures, not easily inspected, and thus implying indirect diagnostic and decision support methods*".

Burns et al. (1999) defines Infrastructure Assets as those assets that have indefinite lives as they are not replaced as a whole but are rather renewed section by section by replacing the individual components whilst maintaining the function of the system as a whole. It is further reported that that economic lives can be assigned to individual components of the distribution system. Troterotot (2009) reports that the pipeline conditions are dynamic and change over time and that the use of historic failure data is unavoidable and very useful, but this information is only partially significant for the future.

Wyatt (2010) observes that the traditional decision support systems used by developed countries consider the direct financial benefits from the replacement of mains (lower real losses and lower burst frequencies) but do not consider the indirect benefits from the reduction of customer minutes lost, the increase in water quality and the improvement in the stability of the billing. These are of significance in developing countries and further reduction to the apparent losses can be achieved by:

- Ensuring that all properties are metered
- Ensuring that all illegal connections are removed
- Ensuring that the meters are accurate
- Improving the read rate of consumer meters.

Troterotot (2009) advises that a sensitivity analysis is also performed with regard to the considered decisions. This is because the uncertainties are numerous and undefined. There are technical complexities, considerations of risk, insufficient knowledge about external costs, data accuracy and completeness issues, estimations of economic data, estimations of future water demands, hidden failures and defects all of which need to be evaluated over a very long term timeframe.

Dandy and Engelhardt (2001) advise that many researches have over the years devised programmes that analyse the replacement conundrum. The challenge faced by these programmes is that they need vast amounts of data and that this data must be accurate. Furthermore, all of these analyses result in identifying certain pipe segments in a network that are inefficient and require replacement. The assumption made here, is that the replacement of an individual pipe will serve to improve the efficiency of the network as a whole. This remains unproven and individual pipe replacement has the potential to do more harm than good.

In order to deal with this complex problem effectively, AwwaRF (2005) concludes, "*Effective planning requires a good water distribution model, a plan, a good decision support model, life-cycle analysis, a Geographic Information System (GIS), system needs prioritisation, critical element identification, coordination with other agencies, feedback from field staff, and a cash flow plan*".

Engelhardt et al. (2000) conducted a review of all the available models and research that has been conducted to date. This review examined some 15 rehabilitation decision approaches that have been proposed to date and whilst they set out to solve some aspects of the problem at hand, they fail to offer a comprehensive, optimised auditable solution. A rehabilitation strategy should satisfy the regulatory requirements of the water authority as well as the business needs and economic, hydraulic, reliability and water quality performance criteria should be simultaneously be optimised. Of interest, two of the researchers who compiled this review were from the University of Sheffield and they have since left the university and formed a company called Seams Ltd. This company supply a product called Wilco that is examined later in this chapter.

2.5.1 CARE-W (Computer Aided REhabilitation of Water Networks)

CARE-W systems (Saegrov, 2005) comprise of an integrated approach that provides five tools to assist in the decision making processes. These are:

- Performance indicators (Identify the performance of the water supply system for monitoring, target setting and benchmarking)
- Failure forecasting (Identify individual pipes and areas with a high failure potential)
- Water supply reliability (Identify the most vulnerable points in a water supply system)
- Long-term rehabilitation planning (Explore the future rehabilitation investment needs and consequences and define the optimal rehabilitation strategy)
- Annual rehabilitation planning (Select the most cost effective rehabilitation projects for an annual rehabilitation programme under consideration of various criteria).

Sixty seven performance indicators are utilised including length, material, installation period, diameter, leak rate, burst rate, repair costs, rehabilitation costs, number of complaints, real loss/connection, energy costs, water quality deficiencies, hydraulic deficiencies, disruptions caused by rehabilitation and impacts of method of repair.

Although this programme has only been tried on small systems in the Czech Republic, France, Germany, Italy, Norway, Portugal and UK, Saegrov (2005) made the following observations:

- 50% of the leaks occur on 10% of the mains
- Two to three years fault data is required in order to give positive results
- Diameter is very important as burst frequency increases as diameter decreases.

Communications with the Norwegian Foundation for Scientific and Industrial Research SINTEF co-ordinator of CARE-W, Ingrid Selseth in July 2012 revealed the following regarding the status of CARE-W.

- CARE-W was completed as a project in 2004. During the last stage of the project, the tools were thoroughly tested by a number of European cities. After the project was completed, single tools were applied in cities in Italy, Portugal, Germany, Scandinavia and the USA.

- However, these tools are not "off the shelf goods" and they are not fully commercial. The single tools were programmed by different scientists of different universities and research institutes. Their use is therefore not straight-forward, and some skills and training are necessary by the engineers wishing to use it. The developers do consider CARE-W fully capable for full-scale use for rehabilitation planning.

Selseth (2012) explained that they believe the strength of Care-W lies in their two fold approach:

- The strategic part includes the determination of service goals and analyses of corresponding service levels by a system of Performance Indicators. The PI system also provides information about condition and resource allocation.
- The tactical planning comprises the analysis of technical condition, hydraulic bottlenecks and consequences due to missing hydraulic capacity. The system includes a coupling of results of the reliability analysis based on hydraulic software in combination with the module to predict future failures.

2.5.2 KANEW

Kanew is a software programme that models the network only and not individual pipes. The input data comprises of pipe age, pipe material, pipe diameter, bedding quality, and the record of past failure rates. Expert opinion is then used to predict the survival rates on the pipes and thus predict life expectancy. The main advantage of this programme is that it assists the Utility to budget correctly over the long term. The limitations are that as a macro model it is not DMA specific and the programme cannot prioritise any areas or identify any mains that require renewal.

2.5.3 WiLCO

SEAMS Ltd who are based in Sheffield in the UK have developed a product called WiLCO that is used by a number of water utilities in the UK (United Utilities, Northumbrian Water, Scottish Water and Severn Trent Water) to optimise their investment decisions using a whole life costing (WLC) approach. Chow (2005) reports that there are a number of benefits of using WiLCO modelling and optimisation:

- Combining data and technology from a variety of sources
- Conducting long term investment planning

- Prioritising the areas of investment
- Meeting supply standards whilst minimising costs.

There are three primary processes in WiLCO and these conduct the modelling and simulations, optimise the level and timing of the investments and then report on the results (numerically and graphically).

Skipworth et al. (2001) advises that a WLC approach to water distribution network management should aspire to achieve the satisfactory network provision at the lowest operating cost. Cognisance should be taken of all relevant costs (indirect, direct, private and societal) in order to sustainably balance the needs of the Water Utility, the customer, society and the environment. If this is achieved a WLC framework should enable least cost decisions to be made that reflect the level of risk that a Water Utility is willing to accept.

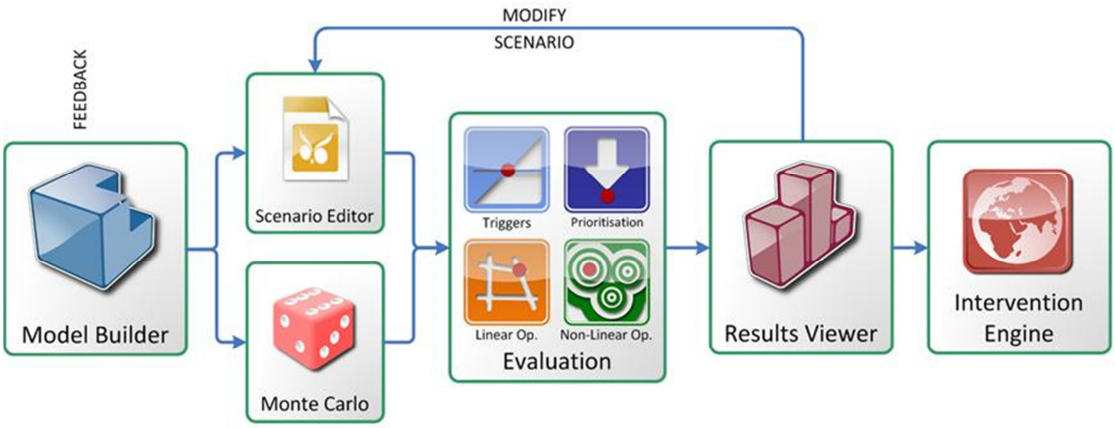

Figure 2.2 The WiLCO Modelling Platform (Seams Ltd, 2012)

WiLCO has been designed to achieve compliance by the UK water utilities to the policies of the regulator Ofwat and to ensure that the private Utilities are investing sufficiently to ensure the long term sustainability of the distribution network. Oakes, (2010) stated during an interview held in his office in Sheffield UK that one of the strengths of WiLCO is that it can compare the predictions made to the actual results achieved once network replacements have taken place. These results are then iteratively used in future calculations to make the prediction increasingly accurate.

2.5.4 WADISO

Dr. Alex Sinske of GLS Software (Pty) Ltd in Stellenbosch developed a genetic multi-variable optimization module to assist with Pipe Replacement Prioritisation (PRP) that is a module with the programme WADISO.

This prioritisation is based on risk which is given as:

PRP = LF x CF, where:

PRP = Pipe Replacement Potential

LF = Likelihood of Failure

CF = Consequence of Failure.

The likelihood of failure of each pipe is based on 12 factors and the weighting below were assigned by City of Tshwane.

Table 2.5 Likelihood of Failure (Sinske, 2012)

Likelihood of Failure Factor	Weighting
Nominal diameter	(0)
Reserve pressure ratio	(10)
Remaining useful life	(20)
Required upgrade foreseen (master plan input)	(10)
Bulk zone leakage volume	(0)
Minimum night flow volume	(5)
Pipe material and geology	(5)
High corrosion potential (steel pipes only)	(2)
Undesired pipe material (e.g. AC)	(10)
High static-dynamic pressure range	(2)
Failure frequency	(0)
Assessed condition (where available)	(0)

Reserve pressure ratio is calculated as (Current pipe static pressure (m) / pipe rating (m)). The remaining useful life is calculated as (Current pipe age / Life expectancy of pipe material). The number shown in brackets after the LF factor is the weighting that was assigned by City of Tshwane.

The consequence of failure of each pipe is based on 8 factors:

Table 2.6 Consequence of Failure (Sinske, 2012)

Consequence of Failure Factor	Weighting
High damage cost to consumer due to pressure	(10)
High damage cost to consumer due to flow	(20)
Extended non-supply over time based on system type	(1)
High repair cost due to location	(5)
Flooding due to steep slopes	(1)
Strategic location (CBD, Hospital, Industry)	(5)
Poor Geology (Clay, dolomite)	(10)
Lack of network redundancy	(10)

The PRP is thus calculated per pipe and this is sorted highest to lowest in order to determine which pipes should be replaced. There is a facility to consolidate these results by political area, by suburb or by street block polygon. Sinske (2012) concludes that upgrades and replacements can now be planned together and executed in a cost efficient manner.

2.5.5 PIONEER

According to Lumbers et al. (2009), the UK water industry has adopted a forward-looking risk-based approach to assessing the requirements for capital maintenance expenditure, known as the Common Framework for Capital Maintenance Planning (CMPCF) or 'Common Framework' (UKWIR, 2002). PIONEER is a system developed by Tynemarch Systems Engineering and meets the requirements of the regulatory bodies and the Common Framework. Lumbers et al. (2009) states that PIONEER is an advanced suite of models that allows the user to forecast customer service measures and costs, as well as producing an optimal set of investments that achieve the specified level of service objectives at the lowest cost.

2.5.6 CRYSTAL BALL

Three Valleys Water (TVW) uses a programme called Crystal Ball to estimate the risk associated with their investment decisions. They analyse three key areas of their business with regard to water main renewals and examine the bursts, the associated risks and develop scenarios to determine the lowest whole life cost. Algaard et al. (2009) observed that increasing the rate of renewal decreases the amount of leakage, reactive maintenance costs and leak detection costs. The call centre costs, the compensation payments, insurance claims and public relations costs are also decreased. A primary output of the model is to determine the mains to be replaced each year in order to keep the number of bursts below a predefined threshold.

2.5.7 UTILITY INFORMATION MANAGEMENT DECISION SUPPORT SYSTEM (UIMDSS)

UIMDSS is used by the Washington Suburban Sanitary Commission (WSSC), USA to identify and prioritise water mains for renewal. It uses a weighted scoring calculated for each pipe on the maintenance activities as follows:

Sum of (maintenance counts x weight factor) / unit pipe length ratio

Table 2.7: Weights Given to Maintenance Activities (AwwaRF, 2005)

MAINTENANCE ACTIVITY	FACTOR
Repair broken main (within the last 5 years)	1.00
Repair broken main (within 2 years of cleaning / lining)	0.85
Repair broken main (not in the last 5 years)	0.80
Repair valve leak	0.75
Routine flushing	0.25
Repair service leak	0.25
Repair fire hydrant leak	0.25
Discoloured water	0.25
Performance	0.25

Candidates for replacement are those that have had four or more breaks in the previous five year period, had six breaks since the pipe was installed, or achieve an overall score of twenty.

2.5.8 APPROACH BY EDMONTON, ALBERTA, CANADA

The engineers at Edmonton adopted a very simplistic reactive approach to mains replacement in 1985. They placed a $4 per month surcharge on the consumers bills and used this funding to replace all mains with a burst frequency greater than 5 breaks / km/ year, based on a five year average. Seargeant (2003) reported that this programme reduced the burst frequency from 1600 main breaks per annum to 468.

2.5.9 APPROACH BY VITENS WATER BV, THE NETHERLANDS

Van Den Brink-Bil, (2012) described the approach by Vitens BV to mains replacement. They have adopted a risk based approach and consider the mains replacement drivers from three different aspects:

- Maximising network performance
- Maximising customer satisfaction
- Maximising financial performance.

The available budget for capital programmes is determined by the tariff and the shareholders. On an annual basis, the budget available for prioritised pipe replacement is determined by subtracting from the total budget amount, the budgets already committed to existing projects and other capital projects. Interactions are held with other service providers (such as Roads, Electricity, Communications, Sanitation) and if the opportunity arises to replace mains whilst other services are being upgraded or replaced, then this work is prioritised over any other. The remaining capital is then allocated to pipe replacements. The merit of this approach is that inconvenience to consumers is minimised in the long term and external damage to services by others is also minimised.

With regard to prioritised mains replacement, Vitens calculate the risk that each water main in the network will fail and identify those mains with the highest risk. Currently, two material types are targeted (Asbestos Cement (AC) and Cast Iron (CI) but this analysis is limited as it is based on age only.

2.6 WATER DEMAND MANAGEMENT AND NETWORK OPTIMISATION

Thornton et al. (2008) reported that proactive maintenance at varying frequencies is required depending on the nature and seriousness of any problem encountered.

UKWIR (2011b) state in their report that in order to reach the long term leakage goals a wide range of strategies will be employed including pressure management, active leakage control and mains renewal. Asset deterioration rates and future operating conditions are of particular interest and concern. It is noted that the current average zone pressure in the UK is currently 42m and in order to reach their long term goals, part of their plan is to reduce the average zone pressure to 25m. By comparison, in the eThekwini area of supply, the current average is 52m and the medium term goal is to lower the average pressure to 42m. The current minimum allowable pressure is 25m in Durban where in the UK it is 10m.

Shepherd et al. (2012) compiled a table to indicate the preferred priority of real loss reduction interventions based on the relative benefit, cost and implementation time.

Table 2.8: Preferred Real Loss Implementation Order

Real Loss Reduction Intervention	Preferred Priority Implementation Order	Relative Benefit Ranking	Relevant Cost Ranking	Relevant Implementation Time Ranking
Pressure Management	1	1	1	1
Active Leak Detection	2	3	2	2
Speed & Quality of Repair	3	4	3	3
Mains rehabilitation/ replacement	4	2	4	4

The recommendation therefore is to explore efficiencies in pressure management, leak detection and speed and quality of repair prior to considering mains replacement.

2.6.1 LEAK DETECTION

Evidence from water undertakings in England and Wales suggests that the marginal costs of active leakage control are increasing to uneconomic levels in some parts of their distribution networks as a result of asset deterioration. This has prompted a move away from purely water quality driven mains rehabilitation towards a greater focus on leakage savings through mains renewal (Grimshaw, 2006)

Wyatt (2010) observes that the values used to calculate the economic level of leakage (ELL) are based on British research on burst flow rates and may or may not be applicable in Africa.

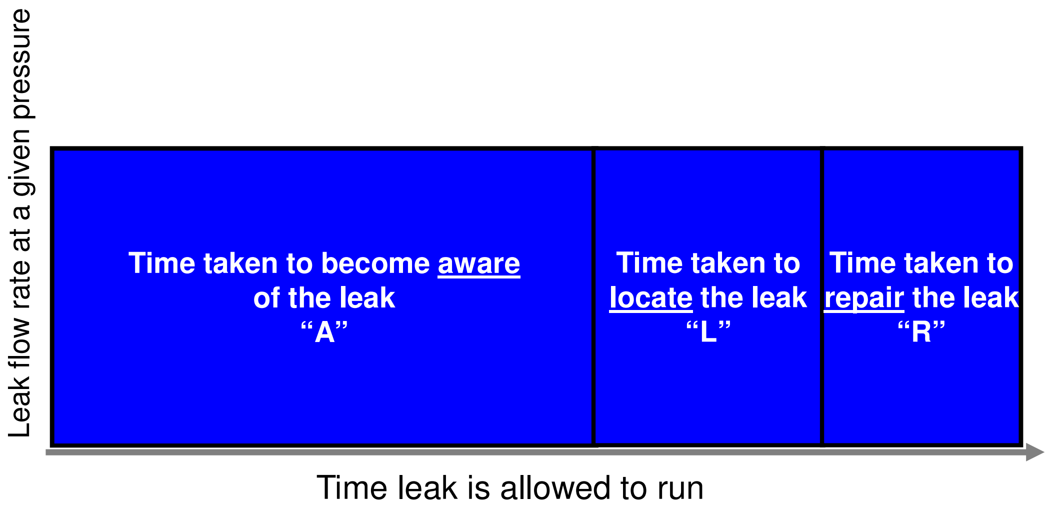

Figure 2.3: Leak Run Time (Lambert et al., 2000)

From Figure 2.3, it is apparent that the reduction of the awareness and location time is key to reducing the volume of real losses.

The indirect benefits of leak detection are that it increases the quality of the customer service, makes the water supply system more stable, reduces the consumer complaints and increases the efficiency of the operations and maintenance activities.

The lower the level of leakage the harder it is to reduce further and the more important forensic analysis is in order to identify new opportunities (Thornton et al., 2008).

2.6.2 PRESSURE MANAGEMENT

The International Water Association (IWA) Water Loss Task Force Definition Pressure Management (Lambert et al., 2010) is "*The practice of managing system pressures to the optimum levels of service ensuring sufficient and efficient supply to legitimate uses and consumers, while:*

- *reducing unnecessary or excess pressures*
- *eliminating transients and faulty level controls.*

all of which cause the distribution system to leak unnecessarily."

The obvious primary benefit of managing pressure is that leakage will be reduced (For every % drop in average zone pressure (AZP), a corresponding % drop in demand is virtually guaranteed), and the many benefits of pressure management are: (Lambert and Thornton, 2011a and 2011b):

- Water resource
  - Reduced volumes of leakage (1:1)
  - Conservation where desired
- Operational
  - Reduced burst frequency (1:1.4)
  - Reduction in impact of transient-induced problems
  - Reduced maintenance costs
  - More efficient use of available operating budget
  - More efficient use of human resource and reduction of repair backlog
  - Change from reactive to proactive management
  - Benefits arising from the transition from an intermittent to a continuous supply
- Asset management
  - Increased asset life of infrastructure components
  - More efficient use of capital budget
- Customers
  - Reduced disruption
  - Improved levels of service
  - Reduced incidence of damages and insurance claims.

As noted by Wyatt (2010), further reductions in apparent losses are also achieved where the distribution network is more stable.

Conventional hydraulic theory states that the discharge through an orifice has a square root relationship to pressure:

$$V = Cd \times \sqrt{2gh}$$

where V is the discharge velocity, Cd is the coefficient of discharge, g is gravity and h is the pipe pressure head.

Contrary to this theory however, it has been found that water leakage follows a different relationship in distribution networks. This is due to the nature and flexibility of the materials in the network and the fact that the leaks are not of a constant diameter and these holes change in size with changes in the pressure (Thornton, 2002). The FAVAD (Fixed and Variable Area Demand) formula is the result and is given by:

$$L_1 = L_0 (P_1/P_0)^{N1}$$

where L_0 is the initial leak flow rate, P_0 is the initial pressure setting, P_1 is the revised pressure setting and L_1 is the new leakage rate. As each network has a unique blend of materials, the value of N_1 in the above formula is determined by experimentation for each section of the network where required. The exponent N_1 will typically vary between 0.5 and 1.5.

According to Thornton et al., (2008),

- For background leakage (undetectable small leaks at joints and fittings), N_1 is close to 1.5
- For bursts on metal mains (ring cracks, corrosion holes), N_1 is close to 0.5
- For bursts on non-metal mains (splits, cracks), N_1 is in range 1.5 – 2.5

The N_1 value in Durban is typically found to be around 1.0 which means that for every percentage drop in pressure, the leakage rate will drop by a corresponding amount. This N_1 value, once determined will accurately predict the savings that are achieved when a Pressure Reducing Valve (PRV) is installed.

Figures 2.4 and 2.5 from the DMA Guidance Notes from the IWA show the typical relationship between flow and pressure in a DMA. As the flow increases in a zone, so the dynamic pressure reduces due to the increase in friction. Conversely, at night, when the demand reduces, then the dynamic pressure increases in a zone. Minimum flows are typically experienced at 2-3am and this is when pressure is the highest and this is often when bursts take place.

Figures 2.4 and 2.5 also show that the flow is broken up into three components and these are legitimate consumption, burst leakage and background leakage. Background leakage can be estimated based on the characteristics of the network and consumers and legitimate consumption can be observed and calculated from the daily flow patterns. Subtracting these values form the total flow gives the burst leakage and this is the volume that is targeted with pressure reduction and leak detection.

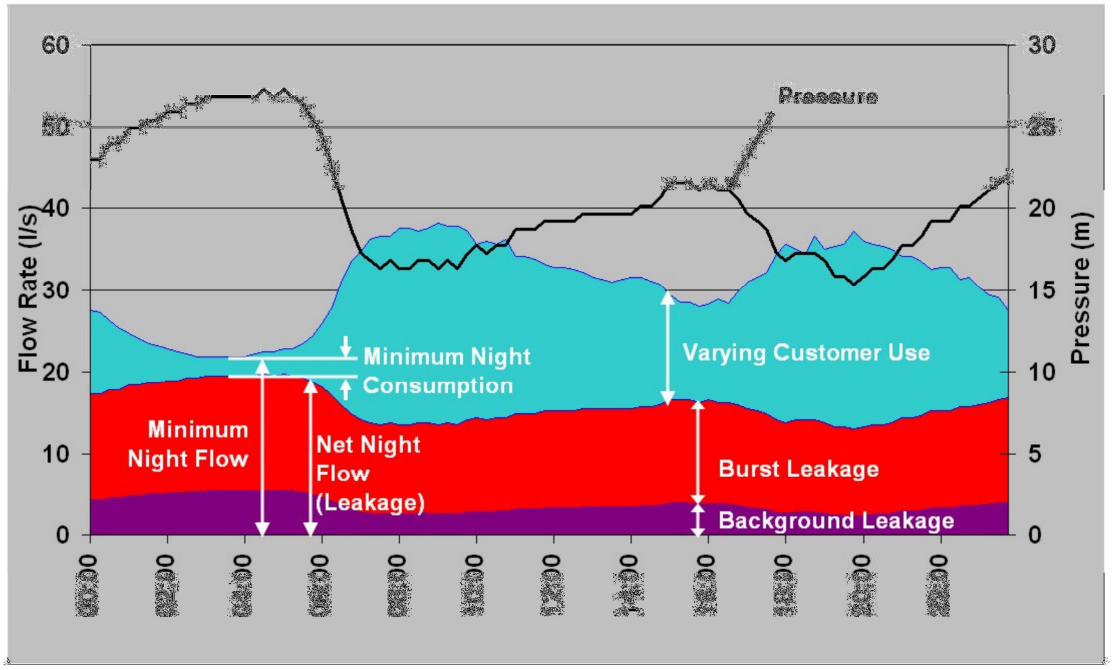

Figure 2.4: Variation of Flow and Pressure in the network (Morrison et al., 2007)

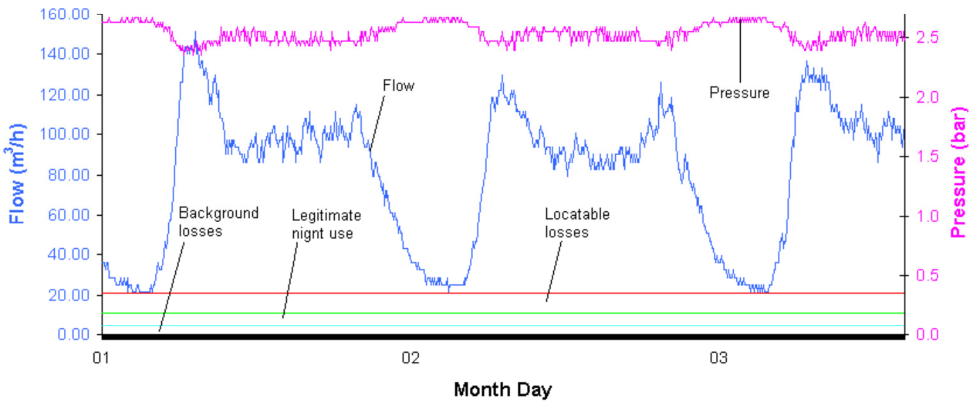

Figure 2.5: A Typical Pressure and Flow Graph from a DMA (Morrison et al., 2007)

Figure 2.6 shows the dramatic reduction in service connection bursts (73%) and mains bursts (56%) when pressure management was implemented in Burleigh, Gold Coast, Australia. In addition, the night flow rates were halved from six to three litres per hour. These results have been sustained for seven years.

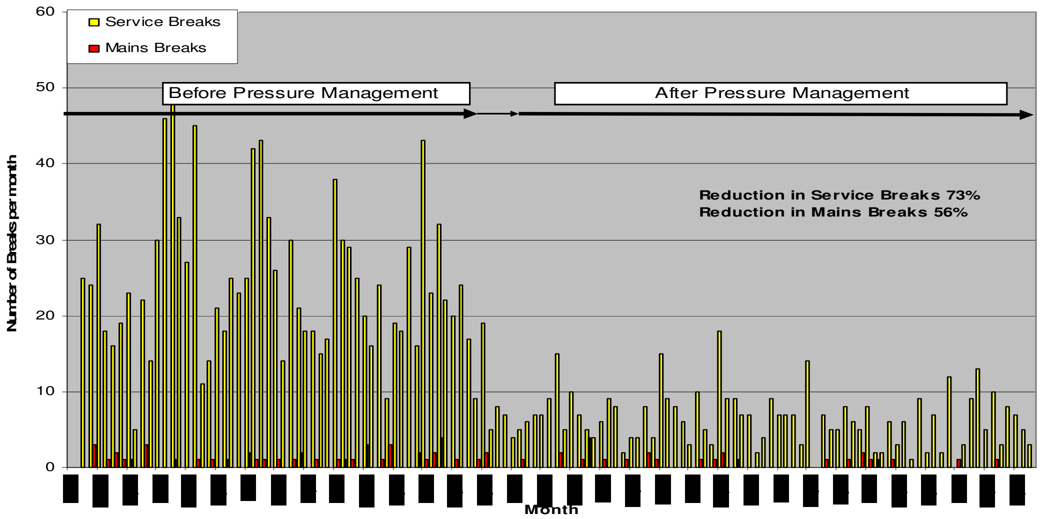

Figure 2.6 Monthly burst reductions on mains and services after pressure management (Lambert, 2010)

2.6.2 APPARENT LOSS REDUCTION

McKenzie et al. (2005) report that apparent losses could be as high as 28% of the total water losses, if there are a large number of illegal connections, the meter condition is poor and the meter reading and data transfer is poor. Where this situation is reversed, the best case scenario is estimated to be 6%. The reduction of these losses therefore must be taken into account so that the overall objective of reducing Non-Revenue Water (NRW) is achieved.

Real losses and apparent losses are not fixed in proportion to each other and initiatives to reduce losses in one area can cause the other attribute to increase. For example, if illegal connections are reduced in a zone, the SIV will decrease, which causes the dynamic pressure to increase. An increase in pressure will cause the real losses to increase. Similarly, if leaks are repaired, the dynamic pressure will increases which can cause apparent losses to increase.

2.7 PERFORMANCE INDICATORS

2.7.1 THE IWA WATER BALANCE

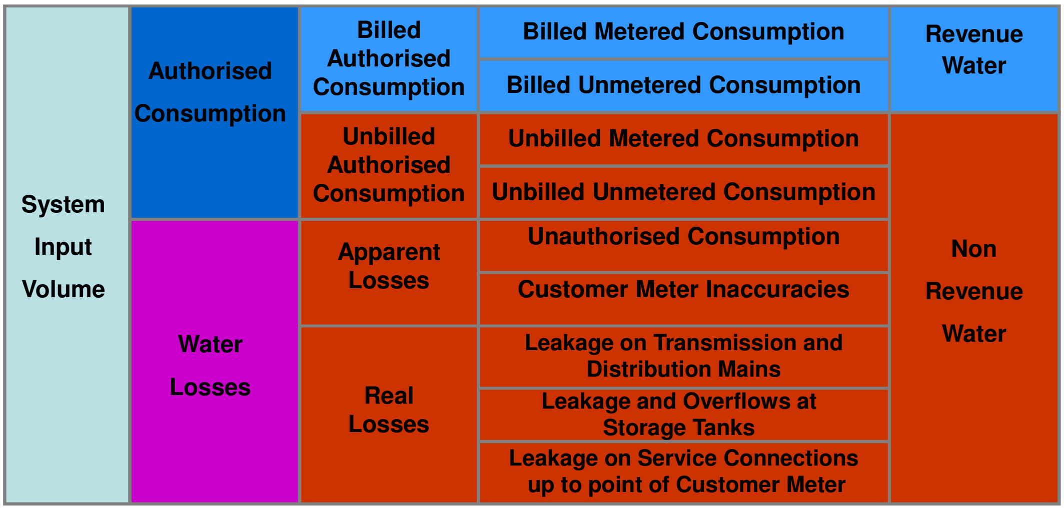

Figure 2.7: The IWA Water Balance (Lambert et al., 2000)

The water balance shown in Figure 2.6 was adopted for use by EWS in 2002 and these figures are calculated monthly and reported on annually. This can be computed using either a top down approach or a bottom up approach depending on the information that is known about the network.

Using the IWA water balance, a Utility can report their status in a competent and standardised manner. Brothers (2003) advises that the term "un-accounted for water" should not be used as standards for its calculation do not exist and no confidence can be given for its accuracy.

2.7.2 INFRASTRUCTURE LEAKAGE INDEX (ILI)

Lambert and Hirner (2000) note that the traditional technical performance indicators for real loss are:

- A percentage of the System Input Volume
- A figure per length of mains per day
- A figure per service connection per day
- A figure per property per day.

Real loss expressed as a percentage of Input Volume (i.e. % NRW) is unsuitable as an indicator because it fails to take the system characteristics into account (i.e. average pressure, number of connections, length of mains, or the time that the system is pressurised). The %NRW is also influenced by changing customer demand which can cause the percentage of losses to change even though the real loss volume doesn't change. To overcome this problem and develop an indicator that takes the above into account Lambert and Hirner (2000) reported that the IWA Water Loss Task Force proposed the following:

ILI = TIRL/UARL, where,

TIRL = Technical Indicator of Real Losses

= Current Annual Volume of Real Losses / Number of Connections, and

UARL = Unavoidable Average Real Loss,

= (A x Lm/Nc + B + C x Lp/Nc) x P (when system pressurised)

where A=18, B=0.8, C=25, Lm=Length of main (km), Nc=Number of connections, P=Pressure in meters and Lp=Length of service connection from the main to customers meter. In South Africa Lp is taken as 0 because the flow meters are located in the road verge.

The formula for UARL was first published by Lambert et al. (1999) and is defined as the lowest technically achievable volume of real loss for each individual system, assuming infrastructure is in good condition and well-maintained. This equation was developed using BABE (Bursts and Background Estimates) and the FAVAD (Fixed and Variable Area Discharges) relationship between pressure and leak discharges (Lambert, 2010).

Lambert (2010), provides more detail on how the values of Unavoidable Background Leakage (UBL) and UARL are calculated in Table 2.9.

Table 2.9: Parameters values used to calculate UBL and UARL at 50m (Lambert, 1999)

Infrastructure Component	Unavoidable Background Leakage (UBL)	Detectable Reported Leaks and Bursts	Detectable Unreported Leaks and Bursts
On Mains	20 litres/km/hr	12.4 bursts/100 km/yr. at 12 m^3/hr for 3 days = 864 m^3/burst	0.6 bursts/100 km/yr. at 6 m3/hr for 50 days = 7200 m^3/burst
On Service Connections, Main to Property Line	1.25 litres/conn/hr	2.25/ 1000 conns/yr. at 1.6 m^3/hr for 8 days = 307 m^3/burst	0.75/1000 conns/yr. at 1.6 m^3/hr for 100 days = 3840 m^3/burst
On Service Conns from Property Line to meter, if customer meter is not located at the property line	0.50 litres/conn/hr*	1.5/ 1000 conns/yr.* at 1.6 m^3/hr for 9 days = 346 m^3/burst * for 15 metres average length	0.50/1000 conns/yr*. at 1.6 m^3/hr for 101 days= 3878 m^3/burst

The units of both TIRL and UARL are litres/connection/day, so the ILI is a non-dimensional index. If a Utility has an ILI=1, it means that the level of real losses is at a minimum and that the system is as close to "perfect" as possible. If a Utility has an ILI=10, this means that their real losses are ten times higher than the minimum value.

Table 2.10: Components of Unavoidable Annual Real Losses (Lambert, 1999)

Components of Unavoidable Annual Real Losses at 50 metres pressure (metric units)					
Infrastructure Component	Unavoidable Background Leakage UBL	Reported Breaks	Unreported Breaks	Unavoidable Annual Real Losses UARL	
Mains	480 litres/km/day	290 litres/km/day	130 litres/km/day	900 litres/km/day	18 litres/km/day/ metre of pressure
Service Connections, main to curb-stop	30 litres/conn/day	2 litres/conn/day	8 litres/conn/day	40 litres/conn/day	0.80 litres/conn/day/ metre of pressure
Service Connections, curb-stop to meter	800 litres/km/day	95 litres/km/day	355 litres/km/day	1250 litres/km/day	25 litres/km/day/ metre of pressure
Typical FAVAD N1	Close to 1.5	0.5 to 2.5, depends on pipe materials and types of leaks		Assumed as average of 1.0 for UARL formula	

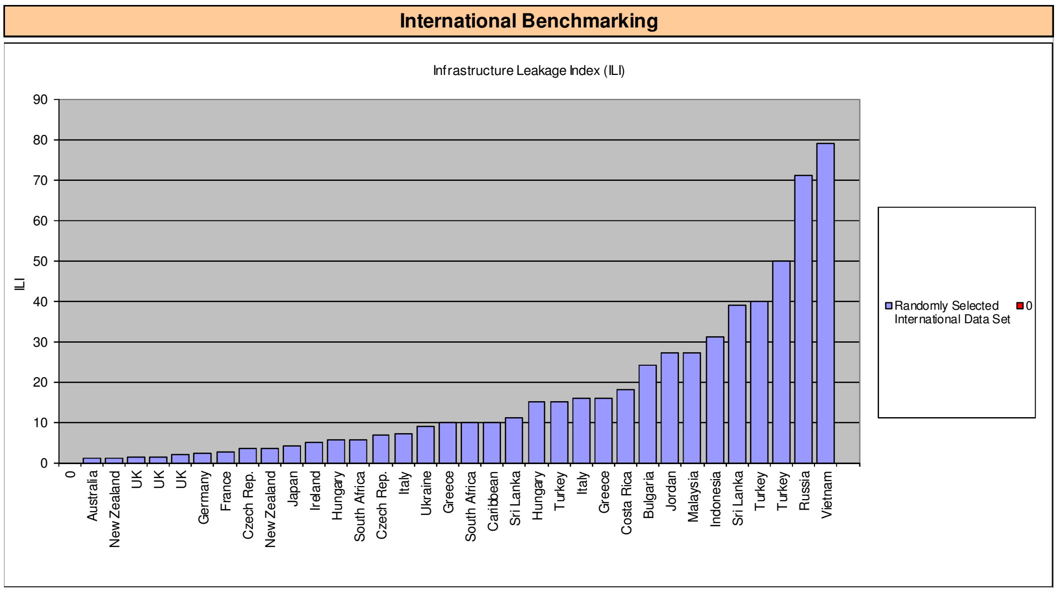

Figure 2.8: ILI dataset from 27 Countries (Liemberger et al., 2005)

Figure 2.8 shows the original dataset of 27 countries where the ILI was calculated when it was developed, showing a spread of values from 1 to 80.

2.7.3 WORLD BANK INSTITUTE PERFORMANCE INDICATORS

Using physical losses/connection/day for various levels of pressure, and the Infrastructure Leakage Index (ILI), Liemberger and McKenzie (2005) have developed targets for both developed and developing countries (Table 2.11). As the levels are banded, this gives a simple and rapid basis for utilities to see where they lie and where they should aspire to be.

Table 2.11: World Bank Physical Loss Assessment Matrix (Liemberger et al., 2005)

Technical Performance Category		ILI	Liters/connection/day (when the system is pressurized) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Country Situation	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 Country Situation	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

A well run Utility in a developed country should achieve real loss rates of 5 litres / connection / day per metre of average pressure. The targets for developing countries are half that of developed countries.

According to Liemberger et al. (2005), the interpretation of the Technical Performance Category is given as follow:

> "A *Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost effective improvement*
>
> B *Potential for marked improvements; consider pressure management; better active leakage control practices, and better network maintenance*
>
> C *Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyse level and nature of leakage and intensify leakage reduction efforts*
>
> D *Horrendously inefficient use of resources; leakage reduction programs imperative and high priority"*

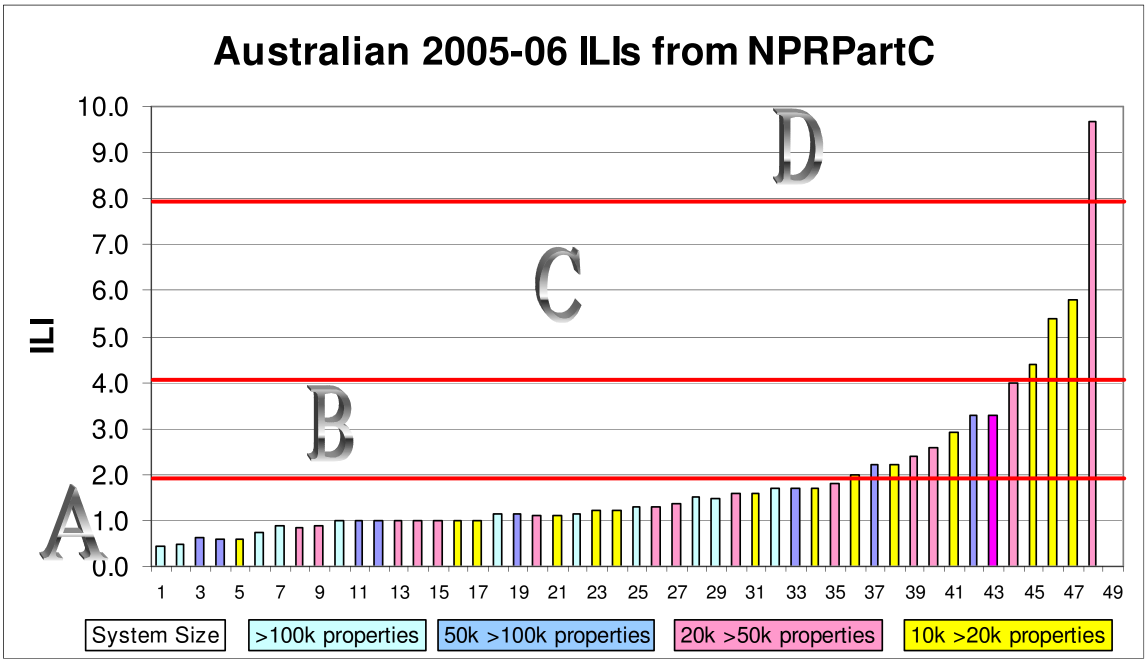

Figure 2.9: Australian ILIs for 2005-06 (McKenzie et al., 2012)

It can be seen from Figure 2.10 that the smaller systems (10 000 to 50 000 properties) tend to perform worse than the bigger systems. This trend is also seen in South Africa, where the rural schemes have much higher loss rates. Two contributing factors to this dynamic are that the connection densities of rural schemes are lower and the staff running these supply schemes are not as skilled or resourced as those operating bigger supply schemes (McKenzie et al., 2012).

2.8 CHAPTER 2 - SUMMARY

- Asset management is the art of balancing performance, cost and risk. A primary objective of asset management is to minimise total cost of ownership whilst delivering the service levels that the customers desire.
- Advanced asset management uses risk management, predictive modelling techniques and optimised decision making techniques to determine long term cash flows and various lifecycle options.
- Pipeline replacement is the most expensive investment that a water services utility can make.
- Predictive modelling should be utilised to best achieve the objectives of the utility.
- Capital maintenance should be justified on the basis of future impact of failures on the quality of the water service and the cost of the provision of water services.

- International data records the top 5 causes of pipe failures, accounting for 73% of pipe breaks, as soil movement (27%), pipe corrosion (19%), heavy traffic loadings (11%), high pressure in the system (8%) and damage due to excavations (8%). The remaining 27 % of failures are attributed to pipe age, winter temperature, pipe defects, poor quality of joints, soil conditions and poor quality of workmanship. Further analysis would have to be done locally to accurately establish causes of failures and their proportional contributions for the local situation.
- The more accurate the information regarding the pipe condition, the more accurate the decisions that can be made regarding their replacement. It is only deemed cost effective to conduct condition assessments on pipes greater than 250mm.
- The literature review revealed that utilities should compile a database of their faults with the following data: the fault location, surface location, soil type, pipe size and material, cause of break, detection method and the repair method utilised. Further, the following should also be available for analysis: non-revenue water, water quality, pressure, energy use . Renewal rates and costs should also be made available.
- Many authors agree that primary mains replacement drivers are average historic break frequency, cost of lost water, hydraulic capacity, cost of damage, cost of the mains repair and the reinstatement cost of the surrounding area. The age of the water main is used by many Utilities to calculate the Remaining Useful Life, but this figure, used in isolation, is an unreliable indicator of the condition of the main.
- Nine different decision support systems were examined (CARE-W, KANEW, WiLCO, WADISO, PIONEER, Crystal Ball and UIMDSS) as well as two approaches used by Edmonton (Canada) and Vitens Water BV (The Netherlands). The majority of these systems are very demanding in terms of the volume of data and the use of the software is specialised and complex. If the input data is not accurate, then the results will not be optimised.
- The Utility must be aware of the impacts on the areas of the network that have not been selected for replacement as it is likely that there will be an increase in leakage and burst frequencies in these mains that are not replaced.
- It is noted that a maturing Utility should aspire to effective planning through the use of a hydraulic model, a decision support model, life-cycle analysis, and a cash flow plan. This would be supported by the GIS, a prioritisation of system needs, the identification of critical elements, coordination with other agencies, feedback from field staff and the use of accurate data from a faults database.
- UK experts predict that with all other aspects remaining the same, a mains replacement rate of 1.1% will be required to combat the NRR and to keep leakage at the same levels.
- Grave concern has been expressed with the seemingly random weightings that some

users apply to decide on which mains will be replaced when using the multi-criterion approach.

- The marginal costs of active leakage control increase to uneconomic levels, as the level of leakage decreases.
- The benefits of pressure management are many and the impact on customers, asset management, operations and water resource are considerable. It is reported to be the cheapest and most effective loss reduction technique.
- Apparent losses can be as high as 28% of the total water losses, if there are a large number of illegal connections, the meter condition is poor and the meter reading and data transfer is poor.
- Further significant savings can be achieved during a pipe replacement programme by ensuring that all properties are metered, ensuring that all illegal connections are removed, ensuring that the consumers' meters are accurate and also by improving the read rate of consumer meters.
- The IWA water balance, together with the indicators ILI, losses per connection and losses per kilometre should be used in preference to quoting percentage water loss values, although it is recognised that the % NRW is quoted most often amongst non-professionals and is readily understood.

CHAPTER 3: REVIEW OF EWS NRW AND OPERATIONAL METHODOLOGIES

3.1 RESEARCH METHODOLOGY

The aim of this research is to analyse the water distribution main replacement conundrum in Durban, South Africa. The water utility has a number of options available to keep the water mains operating efficiently and these involve spending either capital or operating budgets. Data has been procured for the eThekwini system from the following sources:

- The consumer billing database (called COINS)
- The operational faults database (called Faultman)
- Data logging of the flow at various meters (consumer, district, reservoir and custody transfer meters)
- Data logging of the pressure at various points in the reticulation system (upstream of prv's, downstream of prv's, and various and critical points in the network)
- GIS database
- JDE financial database.

This data has been used to analyse the results of a number of actions such as mains replacement, prv installation, prv optimisation and leak detection. The costs of these actions has this been quantified as well as the benefits and this has enabled the plotting of a logical way forward to optimally tackle this conundrum.

3.2 INTRODUCTION

Water distribution mains have a natural rate of attrition and their performance will decrease over time. The real losses will increase, the burst frequency will increase, and the water quality will deteriorate over the life of the water main.

Much of the research conducted to date analyses the variables concerning the performance of the water main. A number of measures can be undertaken during the technical lifetime of the mains to reduce losses and extend the service life and these functions are integrally linked with the economic lifetime of the pipeline. These interim actions can delay the replacement and the impact thereof also needs to be assessed when reaching the decision whether to replace a water main or not.

On average, a Utility will replace somewhere between 0% and 2% of their distribution mains per annum (Table 3.1) and therefore the replacement of mains will not create a significant impact in the overall performance of the system as a whole.

Table 3.1: Mains Replacement Rates of Various Utilities

Name of Water Utility	Length of Distribution Main in System (Km)	Length of Mains Replaced (Km 2007-2011)	Average % Mains Replaced per annum	Presumed Effective Life of Distribution Mains
eThekwini Municipality	11300	1370	2.4%	41 Years
Ekurhuleni Municipality	9750	0	0.0%	Infinite
Tshwane Municipality	9450	169	0.4%	280 Years
Cape Town Municipality	5600	0	0.0%	Infinite
Msunduzi Municipality	1794	18	0.2%	498 Years
Ugu Municipality	3898	12	0.1%	1624 Years
Johannesburg Water	11500	0	0.0%	Infinite
Ilembe Municipality	2362	24	0.2%	492 Years
Drakenstein Municipality	725	44	1.2%	82 years
Stellenbosch Municipality	492	16	0.7%	154 years
Overstrand Municipality	780	55	1.4%	71 years
United Utilities (UK)	40000	3500	1.8%	57 years
Evides Water (Netherlands)	12433	33	0.1%	377 years

It is apparent from Table 3.1 that there is very little consistency amongst the utilities polled in terms of their replacement rates. Trifunovic (1999) gives the average age of distribution mains as 30 to 100 years. As no distribution main is presumed to have a life longer than 100 years the utilities with presumed lives greater than this figure mean that these utilities will have to increase replacement rates at some time in the future. An interesting observation is that pipe age alone is a poor indicator to use for determining when mains should be changed.

The IWA Water Loss Task Force, assembled in 1999, (Lambert et al., 2000) recommend that the following four activities be conducted to reduce the Current Volume of Real Losses to the level of Unavoidable Real Losses (see Figure 3.1):

- Pressure Management
- Speed and Quality of Repairs
- Active Leakage Control
- Pipeline Materials Management.

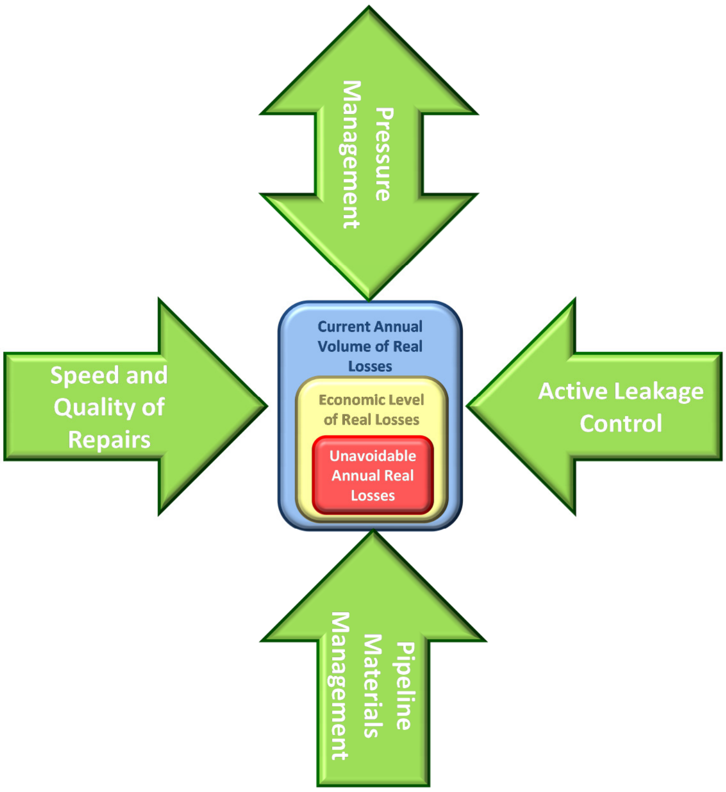

Figure 3.1: The Four Pillars of Real Loss Reduction (Lambert and Hirner, 2000)

Each of these activities will be discussed in detail as they have a significant impact on the operation of the water reticulation system, which of course impacts on the deemed mains replacement rates.

3.2 PRESSURE MANAGEMENT

Table 2.3 shows a comparison of EWS with other northern hemisphere utilities. Average zone pressures range from 25m to 80m and the annual pipe bursts per 100km ranges from 19 to 313. The city of Amsterdam has the lowest AZP (with flat terrain) and also the second lowest pipe burst rate.

Table 3.2 Comparative supply pressures and pipe bursts

(Trifunovic (1999) and Scruton et al. 2011)

Country / City	Average Supply Pressure (m)	Annual Pipe bursts pa/100km
The Netherlands / Amsterdam	25	19
Austria / Wien	80	47
Belguim / Antwerp	50	13
Spain / Barcelona	50	115
Switzerland / Zurich	72	56
South Africa / eThekwini	56	313

Pressure management is dealt with in a number of ways at EWS:

- The existing valves are serviced to ensure that remain at their design settings
- Valves of high importance and high risk have had failure sensing devices fitted
- New DMA's are created and new PRV's are installed
- Existing valves are re-examined (in light of the reduction of the minimum supply pressure from 30 to 25m), to establish if the pressures in these zones can be optimised
- Existing valves are examined to see if they are candidates for some form of advanced control.

Maintenance of the Existing Pressure Reducing Valves (PRV's)

The highest reservoir top water level (TWL) in the EWS distribution system is the Umlaas Road Reservoir with a TWL of 844m above sea level. The lowest elevation supplied is in the Durban central business district and this is 6m below sea level. The topography is undulating and there are 263 separate reservoir zones. There is currently a total of 1752 pressure reducing valves in the network, and there is a mix of direct acting and piloted vales and the sizes vary from 50mm to 400mm as shown in Table 3.3.

Table 3.3: PRV's in the EWS Distribution System

Size of Pressure Reducing Valve	Valve Type	Number in eThekwini Municipality
50mm	Direct	746
80mm	Piloted	403
100mm	Piloted	168
150mm	Piloted	148
200mm	Piloted	271
250mm	Piloted	11
300mm	Piloted	4
400mm	Piloted	1

Prior to 2008, no active maintenance took place and the Utility only attended to reported failures. A three year contract was therefore let in 2008, and based on the size of the valve, an inspection interval was decided upon. Valves greater or equal to 100mm are inspected every three months, valves greater or equal to 80mm are inspected every six months and 50mm valves are inspected every nine months. The scope of the contractors work is:

- Check presence of pilot system isolating valves (bonnet, upstream & downstream)
- Pilot adjustment (confirm valve reacts to change in pilot setting)
- Diaphragm failure check
- PRV blockage check
- Presence of pressure gauge connection points
- Recording of valve(s) in chamber
- Determination of leaking fittings/couplings
- Bypass valve status (if applicable) and setting
- Needle valve obstruction check
- Pilot system tubing flush/bleed
- Pilot system strainer flush.

The contractor is only responsible for carrying out these inspections and informing the Employer of the maintenance requirements at each PRV site. In this manner the risk for the contractor is quantifiable and the valve downtime is considerably reduced.

The results of this work is summarised below but of interest, 10% of the valves were malfunctioning whereby the downstream pressure was not being controlled correctly. A further contract has been advertised in 2012 to continue this important work and it is planned to conduct this work internally from 2015 onwards.

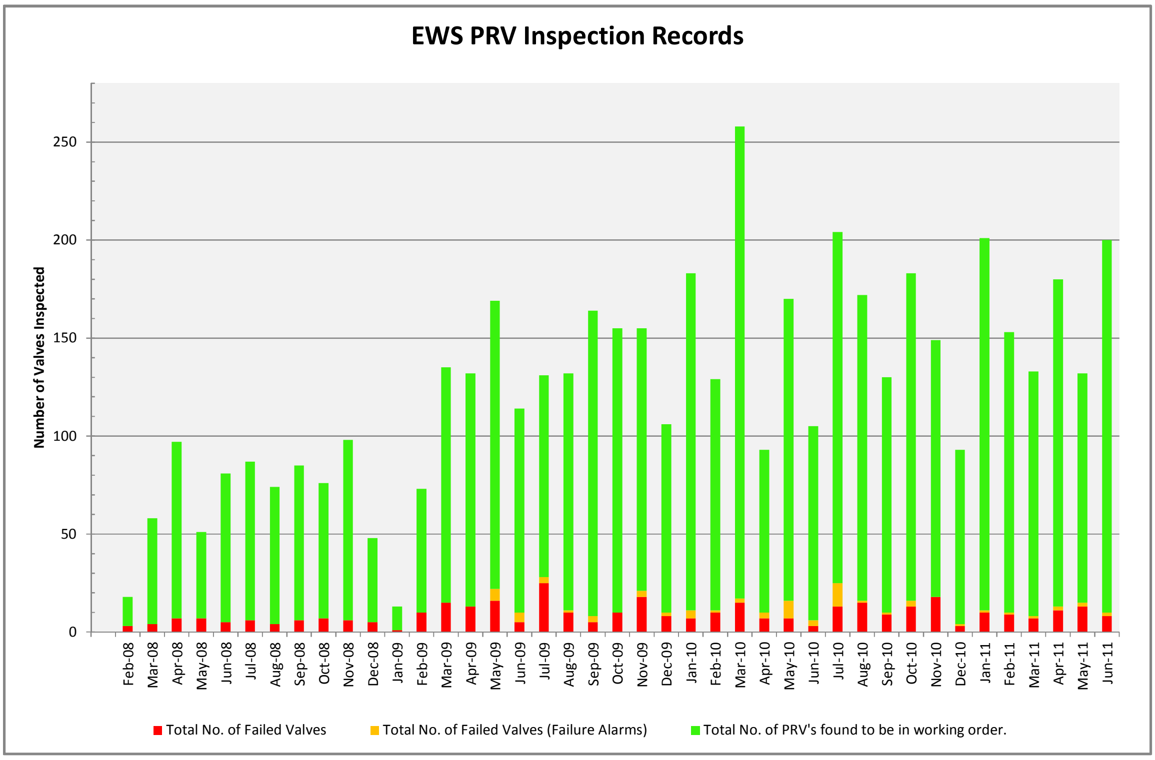

Figure 3.2: Results of PRV Inspections

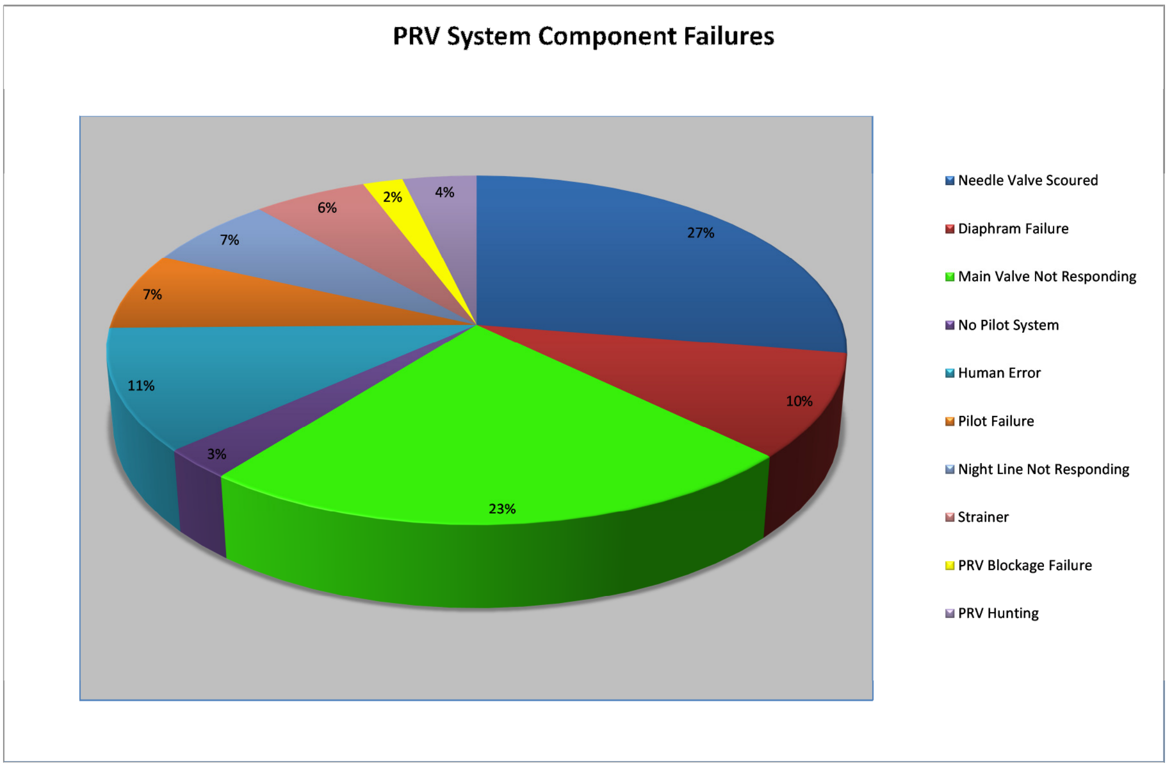

Figure 3.3: PRV Component Failure Data

ETHEKWINI WATER SERVICES

PSC 007 PRESSURE OPTIMISATION SERVICES CONTRACT

PRV INSPECTION FIELD CHECK LIST

Device No:				Date:	yyyy month date	
Address:						
Operations Area	West	North	South			
PRV Chamber GPSed (in GIS)	Yes	No		Actual Position = GIS Position	Yes	No
Meter no. of nearest property						
Digital Photo References						

Main Valve				**By-Pass Valve**		
Status	Open	Closed	By-passed	Status	Open	Closed
	Proposed	Removed		Status	Proposed	Removed
Size (mm)				Size (mm)		
Manufacturer				Manufacturer		
Main Valve Settings	Pilot			By-Pass Valve Settings		
U/S pressure (kpa)				D/S pressure (kpa)		
D/S pressure (kpa) fixed/peak						
D/S pressure (kpa) off-peak						

Pilot System				**Pilot System**		
Pilot present	Yes	No	Removed	Pilot board present	Yes	No
Pilot Control Mechanism	Fixed	Time	Flow	Ball valves present	Yes	No
Pilot make (fixed/peak)				Strainer present	Yes	No
Pilot make (off-peak)				Needle valve present	Yes	No
Advanced Controller Manufacturer				Pressure gauge present	Yes	No
Advanced Controller Serial no.				Quick release couplings present	Yes	No
Solenoid Open	Yes	No				

PRV Failure Device				
Failure mechanism	Transducer	Switch	Device Serial no.	
Manufacturer				

Routine Inspection						
Ball valve on bonnet present	Yes	No	Does main valve respond to its pilot adjustment?	Yes	No	Peak
Needle valve turns from closed				Yes	No	Off-peak
Needle valve scoured?	Yes	No	Does by-pass respond to its pilot adjustment?	Yes	No	
Diaphram failure check	PASS	FAIL				
Pilot system flush/bleed	Yes	No	Any leaking fittings	Yes	No	
Air Valve present	Yes	No	Leaks repaired:			
Strainer cleaned	Yes	No				

Access to chamber - below ground			**Access to chamber - PRV hut**		
Chamber cover present	Yes	No	Door operation	Yes	No
Lock present	Yes	No	Lock present	Yes	No
Lock working	Yes	No	Lock working	Yes	No
Sufficient working room	Yes	No	Chamber/Hut Material		
DV Number Present	Yes	No	DV Stencilled	Yes	No
Valve Marker Posts Present	Yes	No			

Completed by:		Date fault reported	
Note:	[shaded box] = fault report to be forwarded to EWS	Fault no. CV	
Fault description:		Fault no. WC	
		Fault no. M Shop	
		Date Completed	

Figure 3.4: PRV Inspection form

Failure Sensing Devices

To further reduce the downtime of these PRV's, the concept of a "Failure Warning Device" was developed and a Durban based company was commissioned to build these devices. These devices consist of a pressure transducer which is installed to measure the pressure downstream of the PRV and a Programmable Logic Controller (PLC) to monitor the pressure against the set point of the PRV. When an anomaly is detected, a text message (SMS) is sent to the standby technician and an email is also sent to the EWS Contact Centre to register the fault. The proactive inspections detailed in the above section limit the downtime to an average of approximately 4 months but these devices, of which 100 have been installed to date, limit the downtime to less than 24 hours. It is planned to install a further 100 devices in 2013 and eventually roll out to all valves 100mm and above. As budget permits, this device will ultimately be installed on all pilot controlled PRV's.

Creation of New DMA's

The Guidelines for Human Settlement Planning and Design (the Red Book) recommends that the static pressure in a distribution system should be between 30m and 90m. This standard was previously adopted by EWS and the upper pressure was lowered to 80m in 2002. In 2008 the pressure range for full pressure connections was further amended to a minimum of 25m to a maximum of 60m. For semi-pressure connections and rural connections, the minimum pressure has been lowered to 15m. In 2008 the average static pressure in the distribution system was 56m and the medium term target is to lower the average pressure to 42m. By comparison, the average pressure in the UK is currently 35m and they plan in the long term to reduce the average pressure to 25m (UKWIR, 2011b). In 2008, 25% of the network in Durban was fed through PRV's and in order to achieve an average system pressure of 42m, approximately 800 valves will need to be installed. It is estimated that 40% of the network will then be controlled by PRV's. To date, 256 valves have been installed and the average zone pressure has been lowered to 52.5m.

Pressure reducing valves 80mm and above are considered strategic and therefore the installations are housed in an easily accessible above ground kiosk and protected by an inline dirt box. A mechanical meter is installed downstream of the PRV and thus the performance of the PRV and the newly formed District Metered Area (DMA) can be monitored. Farley and Trow (2002) state that the network should be broken down into discrete areas ranging from 1000 to 5000 properties. The installation of the PRV thus has an added benefit of creating a new DMA so that it becomes easier to identify areas where problems exist by analysing the characteristics of the flow into the zone.

Figure 3.5. A new PRV Zone in Northdene, Durban

Optimisation of Existing PRV's

This is an opportunistic exercise to check on the settings of existing PRV's in the system and to verify that their downstream settings have been set to give the minimum targeted pressure at the critical point in the zone. It has been found that sometimes either the original design engineer prescribed a higher pressure than needed or the operational staff has raised the pressure for some reason. In order to ensure that this target pressure is achieved at the critical point, the zone pressure and flow is logged at the valve and the pressure is logged at the PRV. Substantial savings can be gained as seen in the example of DV3022 shown in Figure 3.6. The original downstream pressure was 65m and this was lowered to 49m, a difference of 24%. Correspondingly, the average daily demand dropped from 2164 m^3 per day to 1670 m^3 per day, a change of 23%. These gains are an excellent example of the 1:1 ratio that is often used to predict the gains from pressure reduction. The savings generated from this work equate to an annual amount of R660 000 (494 m^3 / day x R3.66/m^3 x 365).

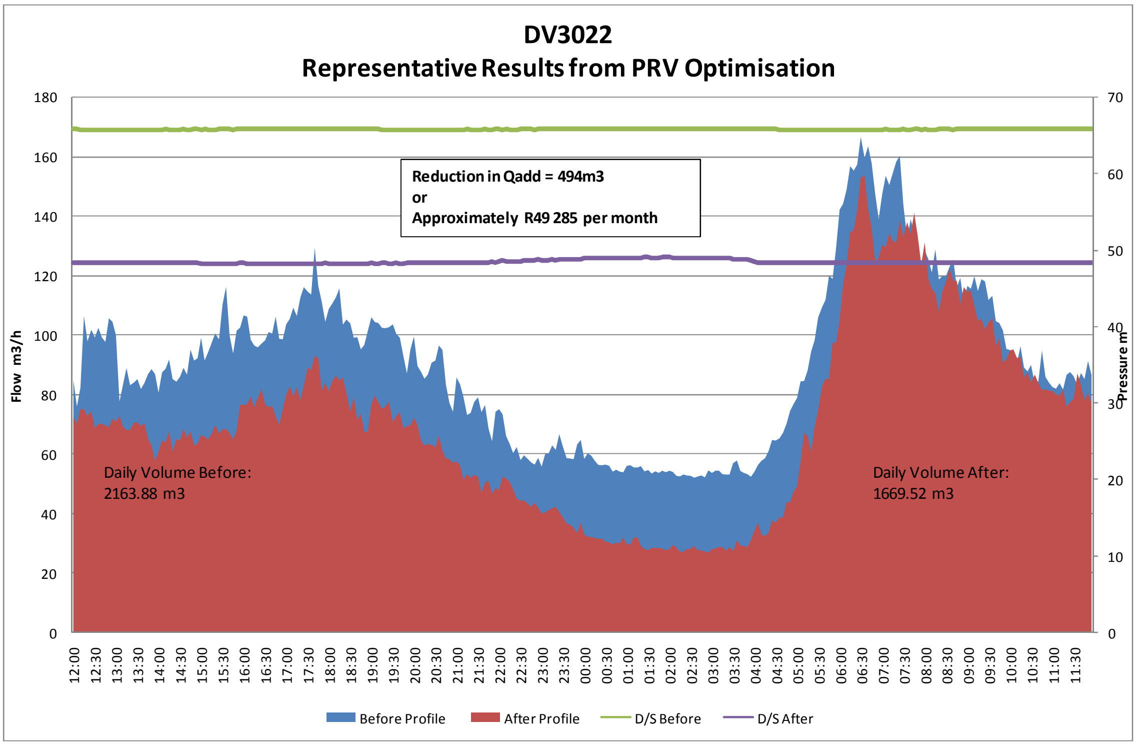

Figure 3.6: Before and After Hydrographs at DV3022

Installation of Advanced Control Devices

Three different options are available to extract further savings from PRV installations, and these options are:

i) Time control devices
ii) Flow control devices, and
iii) Remote node sensing control devices.

i) Time Control Devices

A time control device is the cheapest way to modify the downstream setting of a PRV. Two pilot valves are connected to the PRV and one of the pilots has a solenoid valve connected in series with it. One of the valves is set to the lower downstream setting (say 20m) and the other with the time control device is set to a higher pressure (say 30m). Initially, the times were set to cut in with a lower pressure from 10pm to 4am (6 hours) but later this was changed to only give a high pressure during the morning peak (4 am to 10 am).

These devices are available commercially from a company called Technolog for approximately R10 000 each but EWS elected to have them made locally for R2 500. These have been replaced subsequently with a commercially available sprinkler control device called Rainbird, which retails for R600. These devices typically pay for themselves in less than 3 months.

Figure 3.7: Dual pilot time control system connected to PRV

The pressure profile in Figure 3.8 is from an existing PRV, DV1292 where a time controller device was installed. This graph shows the pressure profile downstream of the valve (in blue) and at the critical point in the zone (in red) and a stepped profile can be seen where the valve is controlled by each of the two pilots.

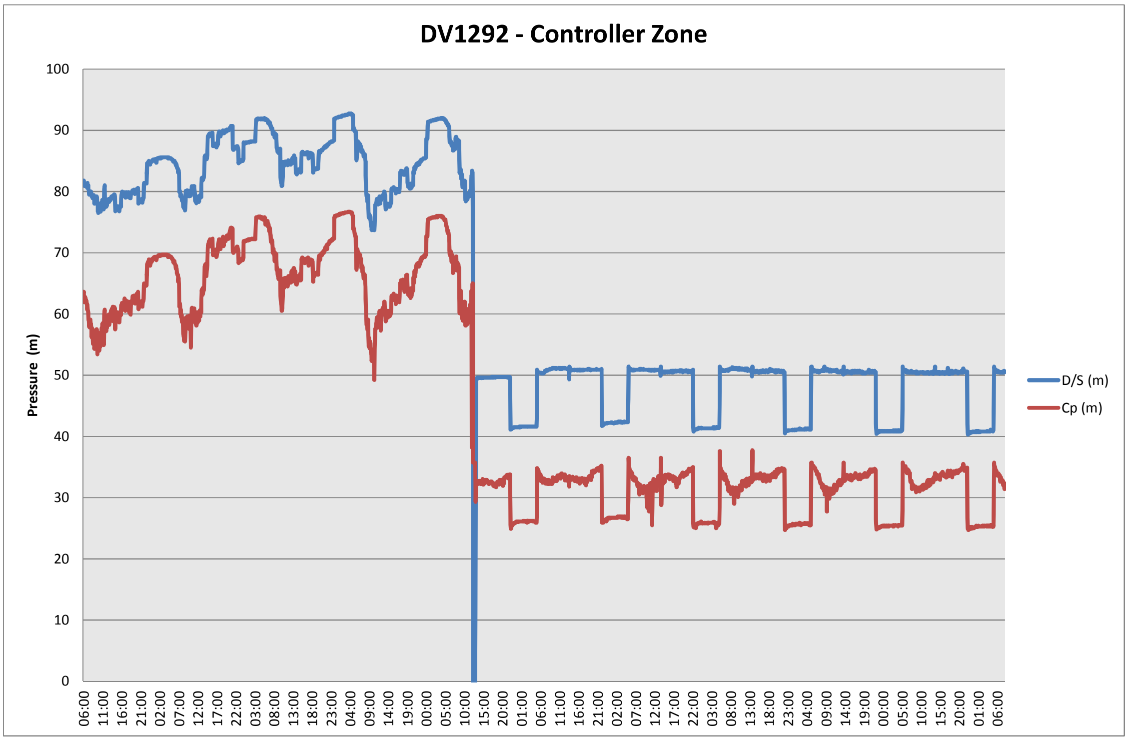

Figure 3.8: Pressure Profile at DV 1292 with time controller fitted

The following table and flow logging have been included to demonstrate the design processes used when trying to establish whether or not a particular pressure reducing valve is suitable for some form of advanced control. As can be seen from the spreadsheet a conservative estimation of 0.3 l/s/km main under control was used and this predicted that R10 793 would be saved per month. From the comparative flow logging shown in Figure 3.9 it can be seen that the difference of the before and after daily flows has yielded a saving of R18 681 per month.

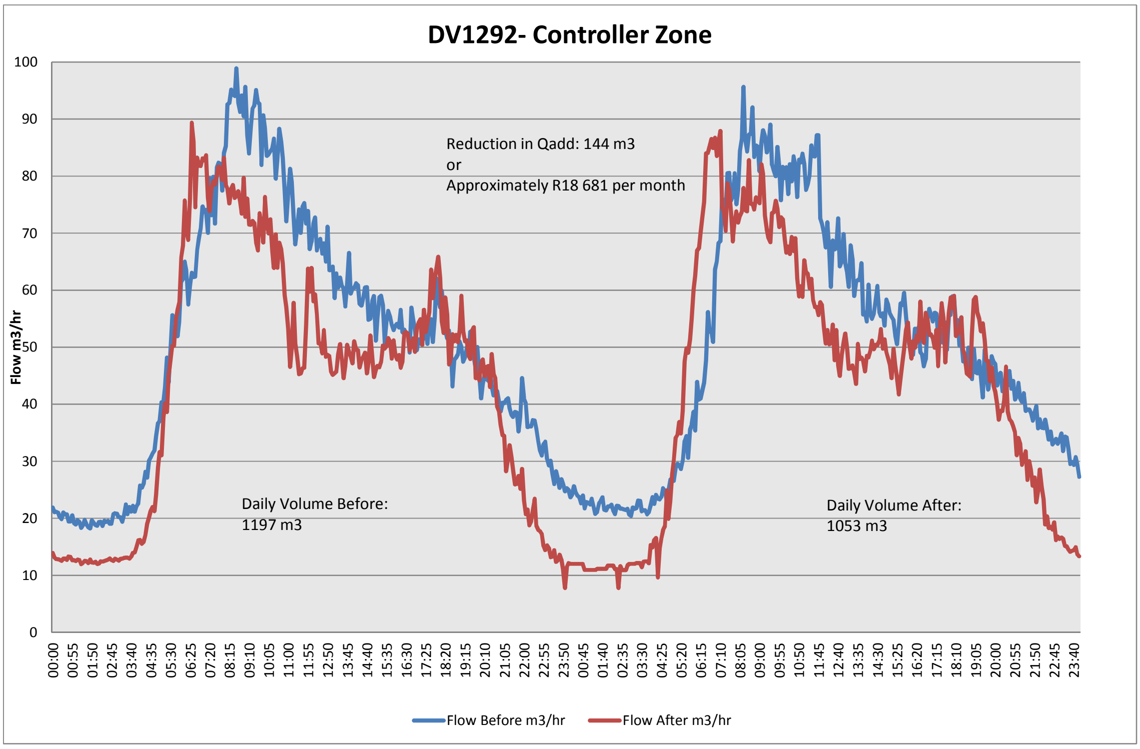

Figure 3.9: Flow Profile at DV 1292 with time controller fitted

CONTROLLER MOTIVATION REPORT

Date: 2010/04/20 (YYYY/MM/DD)

A. Site Details:

Device Number	DV1292	Refence no.	6
Operations Area	SOUTH	Zone Classification	URBAN
Reservoir Supply Zone	WOODLANDS 1&2		
Site Address	BEAUNOIR AVE, MOBENI		
PRV Make and Size	CLAYTON, 150		
Meter Make and Size	SENSUS, WPD 150		
Desktop Meter SIV (kl/day)	1011		
Length of Mains under PRV Control	9.63	km	

B. Desktop Zone System Pressure Characteristics

DV Ground Level	44	m.a.s.l
Highest Supply Zone Contour	60	m.a.s.l
Lowest Supply Zone Contour	30	m.a.s.l
Upstream PRV Pressure	90	m
Downstream PRV Setting	44	m
DV Reduced Level	88	m.a.s.l
Current Max. Zone Pressure	58	m
Current Critical Point Pressure	28	m
Max Allowable Highest Point Hydraulic Head	120	m
Max Allowable Lowest Point Hydraulic Head	90	m
Max Allowable **Design** DV Reduced Level	90	m
Min Allowable **Service** DV Reduced Level	85	m
Controller Maximum DV RL (selected)	90	m

Potential Advanced Controller DV

C. Potential System Pressure Characteristics

	High pressure		Low Pressure	
Proposed Downstream PRV Setting	44	m	41	m
Resultant max pressure in zone	58	m	55	m
Resultant Downstream Pressure Reduction	0	m	3	m
	0	bar	0.3	bar
Expected Reduction in NRW %	0.0%		0.3%	
OR				
Projected Pressure Management Recovery	83.2	kl/day		
0.3 (l/s/km) of mains controlled	R 10 793	/month @ R4.267 /kl		

Note:	Max (m)	Min (m)
1 Rural	60	20
2 Urban	60	25

Figure 3.10: Predicted Savings from DV1292

ii) Flow Modulating Devices

A number of these devices have been installed with great success on the larger PRV's and better control is gained of the critical point. Essentially, the unit is pre-programmed to yield a set downstream pressure based on the flow rate passing through the valve. A maximum of 96 corresponding pressures can be determined by the engineer in advance for a given range of flow rates. What this translates to is that as the flow rate drops in the system, the valve will lower the pressure provided. The cost of these devices are in the order of R60 000 but the savings are significant and the return on investment is typically less than 6 months.

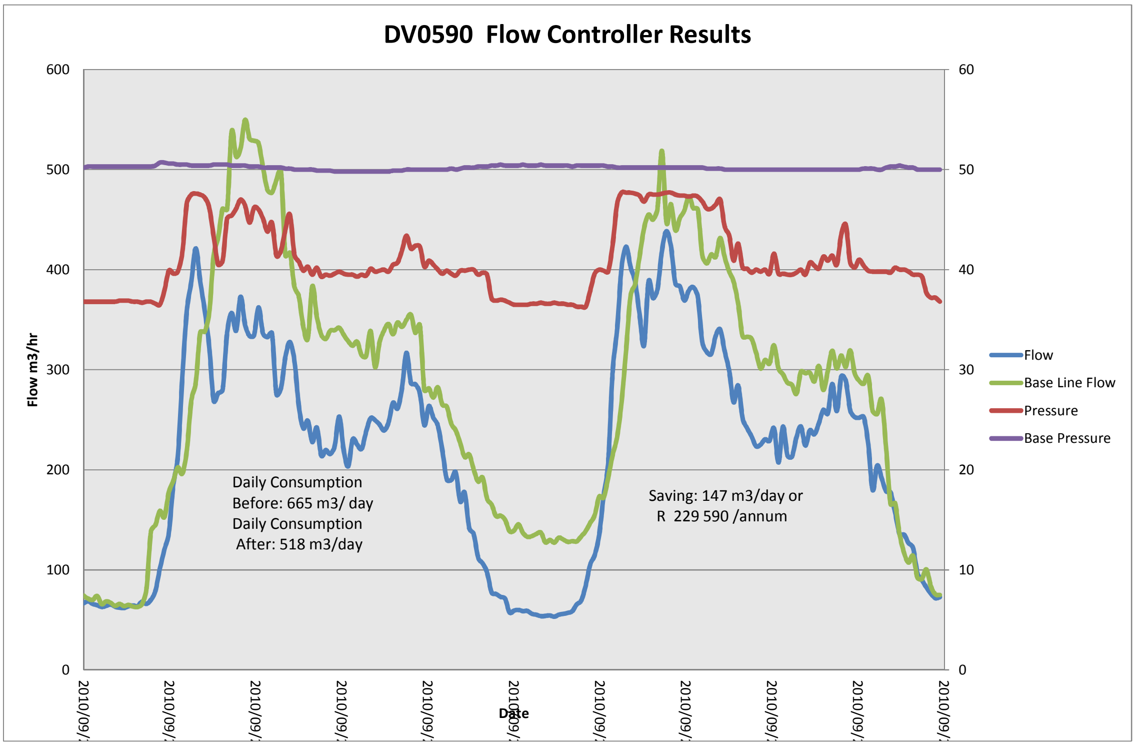

Figure 3.11: Flow and Pressure Graph with Flow Controller Fitted

iii) Remote Node Sensing Control Devices

This type control system is the most advanced of all the control devices currently available and typically costs R120 000 to install. The supplier of these devices at EWS is currently a UK based firm i20 Water Plc. This system is made up of three components – an intelligent logger, a remote controller and optimising software. The intelligent logger is installed at the critical point of the zone and continuously measures the pressure at this point in the zone. The remote controller is installed on the PRV and this allows the system to smoothly adjust the pressure, keeping it just above the level required to meet demand at all times. Remotely and automatically controlling the PRV means pressures are optimised throughout the day, eliminating the any excess pressure in the zone – without affecting service levels. The advanced pressure management system uses the software to learn the pressure demand characteristics of the zone, and gradually adjust the PRV throughout the day to match demand. Maintaining the critical point pressure above the minimum pressure ensures that the pressure levels never fall below the agreed service levels (25m) anywhere in the zone. This device was fitted at DV3022 and annual savings of R275 473 were achieved as shown in the Figure 3.12.

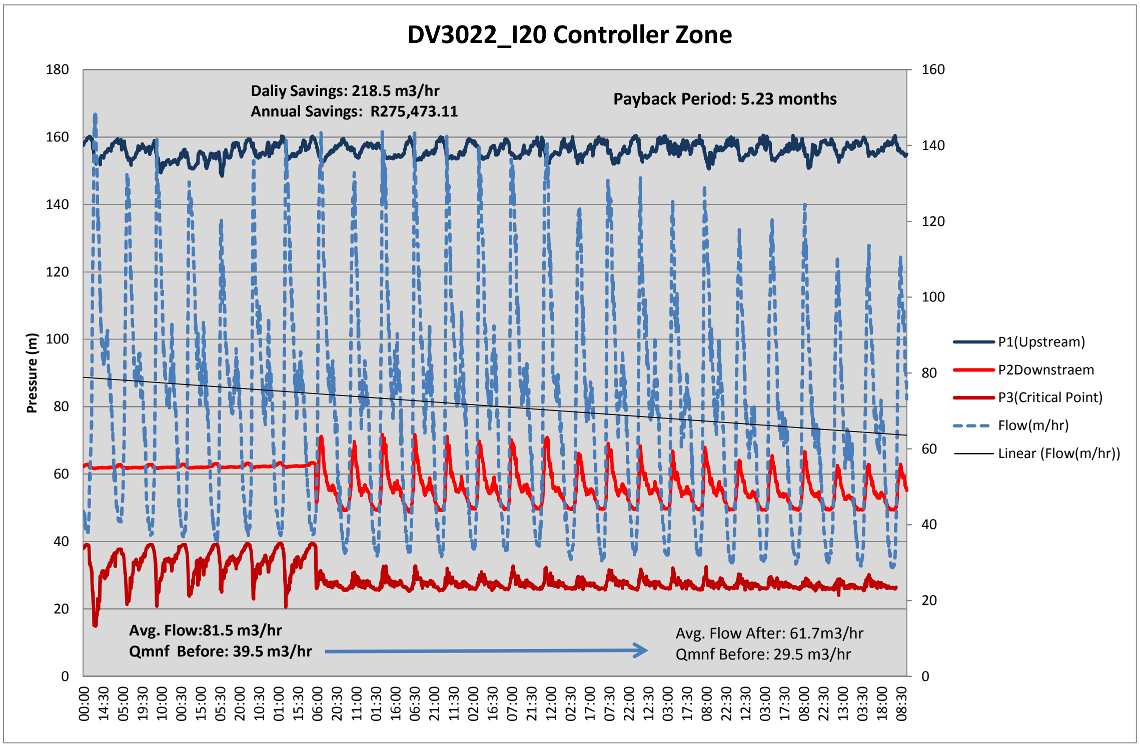

Figure 3.12: Flow and Pressure Graph with i20 Controller Fitted

Areas Under Intermittent Supply

Charalambous (2012) demonstrated that the burst frequency of water mains increases by 200% and the connection bursts increase by 300%, when the network is under intermittent supply. Instead of being more or less constant, the pressures in a network that is regularly filled and emptied can be as much as 400% of the static pressure (Thornton, 2008) and the velocities will exceed the original design guidelines of 3m/s by several orders of magnitude. Further complications develop when these high velocities have a scouring effect in the mains and suspending solids are propelled through the water meters causing damage to these devices. The meters are also damaged by the air in the system and the readings on these meters are known to be inaccurate. As a result, the payment levels in an area on intermittent supply often drops considerably as consumers are unhappy to pay for an unreliable service, but over and above this, the volumes recorded by the water meters are frequently too high or too low. It is also impractical to carry out leak detection when the mains are not pressurised.

Based on the above, areas under intermittent supply should be avoided and immediate corrective action taken when demand and losses outstrip the available supply.

3.3 SPEED AND QUALITY OF REPAIR

Residents of eThekwini are encouraged to actively report visible leaks to the Contact Centre and 5 different platforms are available:

- Toll Free phone call from any land line
- SMS
- MXIT
- Email
- Fax.

Performance targets have been set and every effort is made to isolate leaks as quickly as possible and then repair them. When a leak is reported, a Water Distribution Officer (WDO) will typically isolate the fault within one hour of it being reported. The target is then to repair 92% of all reported leaks in 24 hours and 96% of reported leaks within 48 hours.

With regards to the quality of the repair, high quality material is sourced and issued from the stores to the plumbers. The plumbers employed by EWS are registered according to their capability and authorised to carry out work at a level they are certified to do. This work is supervised and corrective action taken where sub-standard workmanship is detected. The plumbers attend in-house training courses on an ad-hoc basis and training is also given when new and different material is purchased. The contract plumbers are retested on a regular basis and any who do not pass the test are struck off the roster for 6 months and have to be retested before being allowed to conduct plumbing work again.

Francisco Paracampus is the managing director of the Central Area of Companhia de Saneamento Básico do Estado de São Paulo (SABESP) the Brazilian Water Utility in Sao Paulo, South America. SABESP supply water to 21 million people and the Central Area contains 2.5 million connections. Mr Paracampus (SA, 2010) revealed that SABESP holds their plumbers responsible for their work for a period of 12 months from the date of repair. If the plumbers work is discovered to be faulty then the cost of the new repair is docked from their salary. It could be advantageous to introduce this methodology in Durban.

Fijma, (2010), Senior Asset Manager from the Dutch water utility Vitens BV advised that apprentice plumbers are assigned to senior plumbers for a period of three years in order to be comprehensively trained. This system ensures that new staff is exposed to all types of faults, materials and repairs before being permitted to tackle this work on their own. The average NRW percentage loss for Vitens BV where this practice is carried out is 5%, so the benefits of this training and attention to detail are self-evident.

3.4 ACTIVE LEAK DETECTION

In some areas, the residents are not prone to report leaks and therefore the Department has to go out and actively find and repair them. In some cases, the leaks are not visible and sophisticated equipment is used to survey and pinpoint these leaks. This work focuses on the location and repair of visible and non-visible leaks on mains, service connections and fittings, examples of which have been presented in Figure 3.13.

Figure 3.13: Examples of Typical Leaks within eThekwini Municipality

Conventional Leak Detection and Repair

The main factors that influence leakage are the condition of the infrastructure, the static and dynamic pressure, the number of service connections, the length of mains, the annual number of new leaks (reported and unreported) and the average run-time of reported and unreported leaks.

Visible leaks are usually reported by the public and other staff such as maintenance teams and meter readers. Unreported leaks are usually non-visible, ring fractures, splits and corrosion holes on mains, mains fittings, service connections and pipes or on meter installations.

Analysis shows (Brothers, 2003) that in well managed networks, reported bursts account for less than 10% of the annual real losses volume. The largest components of real losses come from long-running unreported leaks and bursts, from background leakage, and from long-running reported leaks which the Water Utility is slow to repair.

Conventional leak detection and repair is carried out by EWS through external contracts procured through a public competitive bidding process. This comprises of leak detection using mechanical or electronic equipment and conducted on 5 different levels:

- Level 1 leak detection comprises of a visual survey (*Figure 3.14*)
- Level 2 leak detection comprises of a mechanical and electronic survey using listening sticks, ground microphones and leak noise correlators (*Figure 3.15-3.17*)
- Level 3 leak detection comprises of leak noise correlators only (*Figure 3.18*)
- Level 4 leak detection comprises the deployment of leak noise loggers (*Figure 3.19-3.20*)
- Level 5 leak detection allows for leak detection surveys to be undertaken on trunk mains using ground microphones (*Figure 3.21*) or intrusive methods such as Sahara (*Figure 3.22*) or Smartball (*Figure 3.23-3.25*).

Figure 3.14: Visual Leak Detection. (Photo courtesy of Mr Chris Otto, 2010)

Figure 3.15: Traditional Mechanical Listening Stick. (Photo courtesy of Mr Julian Thornton, 2010)

Figure 3.16: Mechanical Leak Detection using amplified listening stick. (Photo courtesy of Mr Chris Otto, 2010)

Figure 3.17: Leak detection using a ground microphone. (Photo courtesy of Mr Chris Otto, 2010)

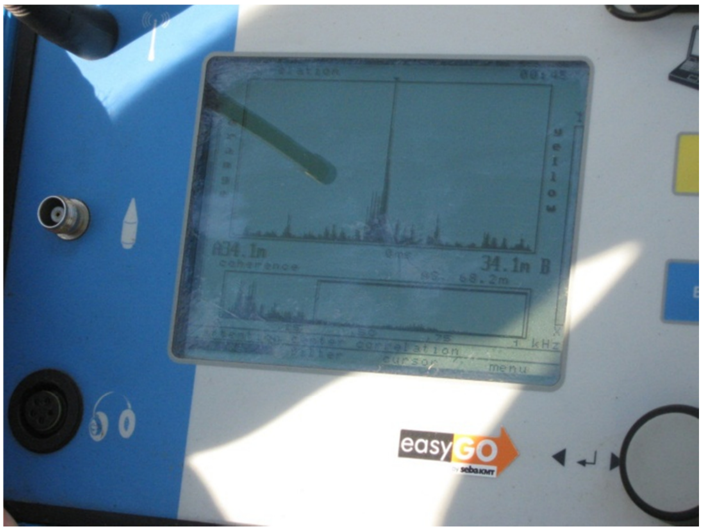

Figure 3.18: Leak Detection Using Leak Noise Correlators Showing an Indication of a Leak. (Photo courtesy of Mr Chris Otto, 2010)

Figure 3.19: Leak Detection Using Leak Noise Loggers. (Photo courtesy of Mr Chris Otto, 2010)

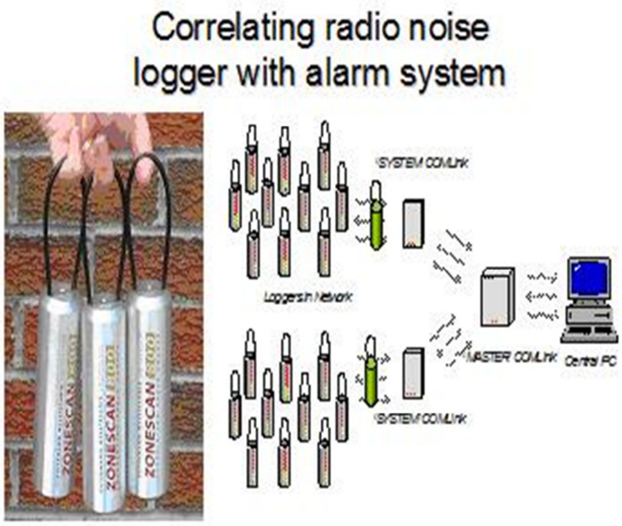

Figure 3.20: Correlating Radio Noise Logger with Alarm System. (Graphic courtesy Guttermann, 2012)

Figure 3.21: Trunk Main Leak Detection with Amplified Listening Stick. (Photo courtesy of Mr Chris Otto, 2010)

The figures 3.22 and 3.23 show an internal tethered pipe technology from SSIS (Pty) Ltd which can survey pipes up to 2000m in length with one deployment. With this system, a head attached to a cable is inserted into a live water main through a fire hydrant or air valve. This head consists of a location sonde, a camera and a hydrophone. The head is thus able to see, hear and pin point the position of a leak. This technology is also useful for showing the internal condition of the pipe and revealing blockages, unknown laterals, tuberculation and many other problems. The downside of this technology is that the preparation and deployment is costly and time consuming. The cable cannot be deployed through too many pipe bends as the accumulated frictional resistance can snap the cable when trying to retrieve the head.

Figure 3.22: Sahara SSIS Leak Detection (Photo courtesy SSIS Consulting Engineers, 2010)

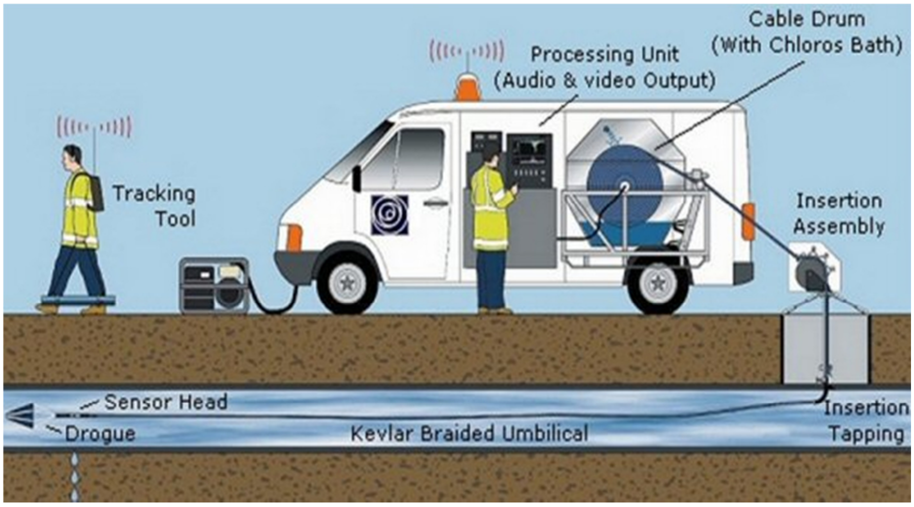

Figure 3.23: An example of In-pipe Acoustic Technology (SSIS Consulting Engineers, 2010)

Non tethered devices consist for example of a ball that rolls down the main which locates leaks as it passes them in the pipe. The ball is captured by a net installed downstream in the pipe and then recovered but this technology is only suitable for pipes 300mm diameter and above. When testing this system in a 450mm steel main in the Durban CBD, the ball failed to arrive in the net.

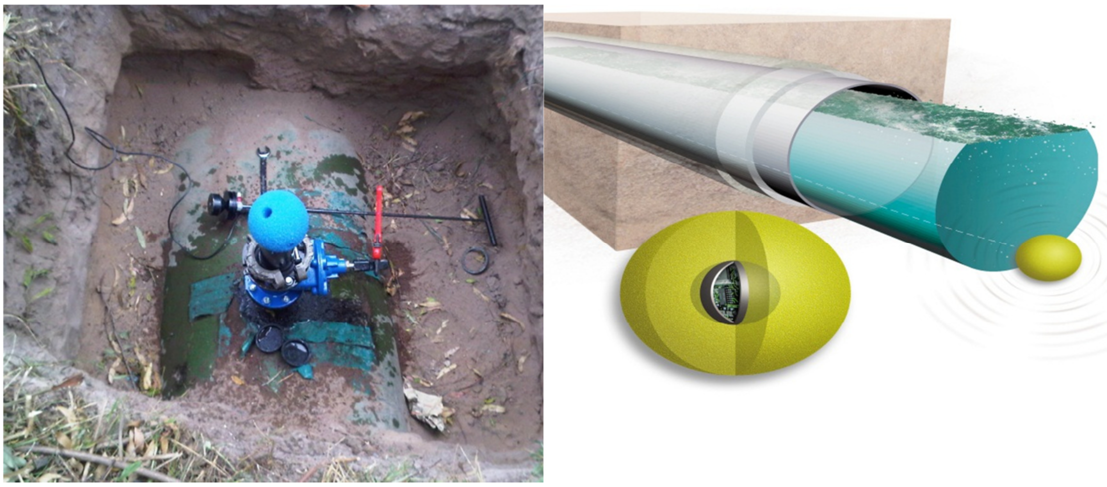

Figure 3.24: Smart Ball Internal Noise/Leak Technology (SSIS Consulting Engineers, 2010)

Figure 3.25: Smartball Leak Detection (SSIS Consulting Engineers, 2010)

There are a few other methods that can be used to help locate leaks in transmission mains:

- Ground penetrating radar
- Step testing
- Pressure testing
- Aerial photography
- Satellite photography
- Thermography
- Using a helicopter to survey trunk main routes from the air in winter and compare flora and ground conditions.

Alternative Leak Detection and Repair

An alternative leak detection and repair strategy was adopted by EWS in January 2011 that allowed quicker leak repair times and surveys to be undertaken in high density low income areas. This involved the use of Category B plumbing teams sourced from the EWS Plumber Roster on a two-week shift basis. These plumbers are allowed to work on live mains up to 54mm diameter.

The plumbers are deployed into areas previously identified and assessed by Non-Revenue Water (NRW) Engineers. The plumbing teams are briefed, provided with repair fittings and then targeted with identifying and repairing all visible leaks (*Figure 3.26*). Quality control is undertaken through GPS coordinates, digital photographs and sample field inspections.

Figure 3.26: Category B Plumbing Leak Detection and Repair. (Photo courtesy of Mr Chris Otto, 2010)

3.5 MONITORING THE SYSTEM

98% Of the reservoir outlets in Durban have been fitted with bulk meters and these are read on a monthly basis by the meter readers. In some areas of concern, data loggers are fitted to the meters and these are regularly downloaded to enable the engineers to analyse the hydrographs. The most advanced method of monitoring is done via the SCADA system and this enables the engineers to observe pressure and flow data on-line and real time. This functionality has also been fitted to the bulk purchase meters where approximately 850Ml of water is purchased from Umgeni Water on a daily basis. The value of this water (at 2011/12 prices) is R3.6m.

In order to improve on the monitoring capabilities, it is planned to roll out the real time monitoring to approximately 1000 sites across the Municipality. It is planned to monitor not only all the reservoirs, but also the district meters and trunk mains as well. In time, alarm functionality with advanced analytics will enhance the capabilities of the monitoring system.

Investigations are currently being conducted with a number of products to enhance the collection and interpretation of data with IBM (Smart Cities), VEC Engineering Consultancy (Integrated Innovative Maintenance Technologies and Solutions - I^2MTS) and Syrinix (Trunk Minder).

3.6 CLEANSING THE DATA – ENSURING ITS CORRECT

Information on the performance of the network originates from a number of sources and in order to be in a position to make informed accurate decisions, it is important to be aware of the accuracy and reliability of this data. The primary sources of data are the GIS, network models, faults data (consumer complaints and repairs), meters (consumer and network), SCADA, laboratory tests, asset management data and the finance data. Sensitivity analyses can be conducted to test the outcome of the proposed decisions and data variances.

It is an on-going exercise to improve the accuracy of the existing information in the GIS as well as to ensure that any changes or additions are accurately captured. It is acknowledged that the faults data is not only incomplete but also difficult to extract and interpret and therefore significant improvements are scheduled in this area. An asset management plan has been drafted to ensure that the meters in the system and particular care is taken when specifying and procuring water meters. As mentioned, the number of real time measurements being recorded in the system is scheduled to be significantly increased. The laboratory already conducts more than double the required number of tests on the potable water in the system and as the laboratory has ISO 90001 accreditation, this data is deemed to have the highest integrity and reliability. Asset management systems still need to be put in place so that the knowledge of the condition of the system components and the scheduled maintenance thereon can be easily determined. The financial data is accurate but some cost centres should be disaggregated so that for example, better data on the cost of repairs can be extracted and used in other calculations.

Regardless of the level of sophistication and computerization involved, each Utility should collect information concerning system conditions, implement preventive maintenance measures, identify chronically failing mains, and prioritize these mains for repair or replacement. The Utility policy and replacement criteria may change from year to year, but the basic process remains the same (USEPA, 2007).

No reference whatsoever could be found in the material that was covered in the research with regard to the accuracy of the performance data and the need to cleanse this data before using it. The literature published by academics demonstrates that they tend to examine problems in sterile laboratory type conditions and these conditions do not resemble the reality of live infrastructure.

It is necessary to undertake a number of steps to ensure that any zone performance data is indicative of the zone that it is supposed to represent. A number of obvious errors can take place, which unless procedures are in place to eliminate the obvious will give rise to totally skewed results leading to premature mains replacement. It is possible that these new mains would continue to perform much the same way that their predecessors did unless these fundamentals have been eliminated first. Some examples of this would be:

- Excessive pressures in a system will result in higher loss rates and burst frequencies. Pressures must therefore be minimised to latest design standards prior to any motivation to replace.

- Pressure reducing valves (PRV's) in a reticulation system that are not working correctly can also lead to a high number of bursts occurring and the solution is to ensure that all PRV's are set correctly and adequately maintained in order to prevent these pressure related bursts from occurring.
- Pressure spikes in a system can also result in high burst frequencies. The cause of these pressure spikes must be determined and eliminated and the system allowed to stabilise before the burst frequency is determined. It is noted that these spikes can emanate from either the municipal infrastructure or the spikes can be caused by equipment being operated incorrectly on the consumers premises.
- A breach in the boundary of a predetermined zone can lead to either water leaving a zone without be quantified or water can enter the zone and seem to improve the performance data. Step testing and proving zone isolation is thus a vital step that must be taken to prove that the water loss figures in the zone are indeed credible.
- The bulk meters in a zone must be verified to ensure that they are accurate as they can either under or over-read. A mechanical meter can be damaged due to debris in the pipeline or may simply slow down over time due to wear and tear. An electronic meter can be damaged by stray currents, lightning, wear and tear, cable damage, coil damage, misalignment, internal pipe restrictions, and air to mention a few causes. The initial installation of any meter could be outside the manufacturers' specification and perform inaccurately from the day it is commissioned. It is therefore a requirement that a continual programme of bulk meter improvement is embarked upon to ensure that these readings are as accurate as possible. A bulk meter at a reservoir can be quickly tested by performing a drop test and the cartridge of a mechanical meter can be changed out at a relatively low cost. Insertion probe magnetic flow meters, insertion turbine meters and strap-on ultrasonic meters can be utilised to check the accuracy of meters in-situ and it would be advisable at the time of installation to plan ahead for these checks to take place.
- One must ensure that active leak detection has been carried out in any zone that has been flagged for replacement. This may have the result that a number of leaks are found and the system performs adequately thereafter and replacement is not required. Alternatively, successive sweeps of leak detection could repeatedly find a high number of leaks resulting in high repair costs and this money could have been used better if channelled towards replacement and not repairs.
- Scour valves could be left open that discharge to either a storm water pipe or a river and this undetected flow could indicate a false level of very high leakage.

- In the South African context, there is a poor culture of payment in certain environments and illegal connections are rife. It is estimate that there are some 40 000 such illegal connections in the eThekwini operational area and these unmetered flows can lead a practitioner to conclude that there are high levels of leakage, when in fact these losses are due to theft. A Waste Water Treatment Works (WWTW) water balance has been conducted and it can be seen in some circumstances the inflow to the works exceeds the water sold in the WWTW zone. These results (not highlighted in pink) are shown in Appendix F. It is therefore a requirement that social campaigns are run either prior to or during a mains replacement programme. A change in consumer behavior could potentially eliminate the need to replace the mains. Another outcome is that after the mains have been replaced, all consumer data is accurate and that all the consumers are paying for the water that they consume.
- It is equally important to determine the modes of failures within a zone and also the causes for these failures. The remedial works can thus be tailored to ensure that these problems do not reoccur. It could be, for example, that a high number of faults occur in a zone triggering potential mains replacement, but upon investigation it could be found that these failures are caused by a poor batch of saddles or by consumer tampering. The performance of the zone could be improved for a fraction of the cost if just the saddles are replaced or consumers are persuaded not to interfere with the municipal infrastructure.
- External damage can occur in an area when another activity takes place alongside an existing water main. For example, another service provider could be installing a fibre optic cable and their activities lead to a high incidence of faults or a roads contractors equipment could be working in close proximity to a water main leading to an unusually high number of faults.
- The workmanship of poorly trained plumbers working to repair existing faults could lead to repeat faults occurring in the system giving the false impression that the main is approaching the end of its service life.
- Similarly, the use of poor quality repair material will also lead to the same fault occurring repeatedly and this could lead the practitioner to falsely conclude that there are a high number of faults occurring in a particular area.

3.7 CUSTOMER SATISFACTION

In the case of EWS, poor water quality reports are seldom received from the laboratory analysis and there is a 99.9% compliance to standards. Of the consumer complaints received, the majority are related to recent bursts and not the pipe material. Red/Brown water complaints are received by utilities with cast iron pipes and ductile iron pipes in the system that has not been lined internally. Only 300km of iron pipes are present (2.7%) in EWS and majority of this pipe has been lined with cement mortar thus eliminating the problem. It is therefore felt that in order to simplify the pipe replacement analysis, these variables should be initially be omitted.

Some complaints are received from consumers with regard to water pressure and or low flow rates and these complaints are due to a number of reasons that must be investigated to find the reason for the change:

- There is a problem with the consumers' internal reticulation. This must be rectified by the consumer.
- There is a problem with the consumers' meter connection. This is rectified by the Customer Services Department.
- The pressure has been lowered intentionally and is still in compliance with water supply standards. In this case, the consumer is further educated on the reasons for the management of the pressure and no further action is taken.
- The pressure is lower due to a legitimate increase in demand. These mains are then modelled hydraulically and flagged for an upsize if required.
- The pressure is lower due to an increase in losses and active leak detection is performed to normalise the situation.
- The zone has been changed from its previous stable situation (intentionally or inadvertently) and is reinstated to its original condition to correct the situation.
- The looped network has been interrupted or there is a blockage or restriction in the pipe due to a partially closed valve.

Water mains are rarely replaced for being undersized as the water mains at EWS are designed with a peak factor of four. When this does occur, there is ample warning of the problem as development takes place slowly over a number of years and the supply problem only takes place initially during the peak demand period.

3.8 ANALYSIS OF REPLACEMENT METHODOLOGIES

Repair only certain problematic mains in a zone

In 2008, when 1370km of water mains were replaced at a cost of R2.1bn EWS chose to only replace the problematic mains in the zones. When the programme started, it was found to be very difficult to decide on which water mains to replace first due to the lack of performance data. One of the challenges of the programme is that the award the consulting contracts were made at the same time as the civil works contracts. As a result, the consultants were on the back foot at the beginning of the programme and had insufficient time to investigate, design and prepare works information. The following methodology was utilised to decide which mains to replace:

- Obtain a list of roads and areas from the Operations Department of where the most problems were occurring. These relays were few in number and were rapidly dealt with.
- Thereafter, a list of reservoir zones was supplied by the NRW Branch listing the key performance indicators in each zone. These indicators were percentage NRW, MNF (Minimum Night Flow), Volume of real losses and R_{am} (Ratio of Average daily flow to Minimum flow)
- These areas were then divided into 3 phases based on the worst performing zones according to the above performance data
- These areas were then grouped together into 5 major areas across the municipality and a contractor was assigned the work in each area, commencing with Phase 1
- The Operations Branch advised that the water main material that was giving the highest number of faults was the AC pipe and within this material type, the AC pipes that had not been dipped in bitumen were subject to "soft water" attack. The water in Durban is known to be "Calcium Hungry" and this water leaches the calcium out of the asbestos cement pipes, rendering the pipes soft and prone to bursting. It was therefore intuitively decided to target only this material sub class, which was also older. Unfortunately, the old as-built records in the GIS did not reflect where this pipe was laid and these pipes had to be located in the field by an extensive proving. The overall mains replacement cost for 100mm and 150mm pipe was approximately R1500/m, and of this cost, proving was approximately 8% (R120/m)
- Additional construction costs were incurred because of the following:
    - Multiple small site establishments and work fronts
    - Extra bends and anchor blocks at every tie in point
    - Additional work to separately replace valves at tie in points

These additional costs have not been specifically quantified but based on information received from Dedekind (2012), these are estimated to total a further 12% of the overall project cost

- It can thus be concluded that a saving of up to 20% can be achieved if a complete DMA is replaced at one time
- Furthermore, older AC mains become less stable over time as they reach the end of their technical lifetime. The rubber used in the joints becomes less flexible and these pipes will retain their integrity if the pressure remains constant. Due to the methodology of how the above work was carried out there was a lot more tie-ins and shut downs conducted in order to commission the small segments of new water mains. This meant that the pipes that were not replaced were subjected to high velocities and pressure fluctuations. The burst frequencies in these zones increased dramatically during mains replacement as can be seen in the figure 3.27. The accumulative cost of this additional repair work of the 4 year programme was a total of R315m.

Averaging these costs out over all the mains replaced, this additional repair work added another 10% to the cost of the project.

- Over and above these costs, the water mains that were not replaced were previously under an average pressure of 56m. In zones where the non-bitumen dipped mains were selectively replaced, the benefit was that these new mains leaked less. The negative however was that the dynamic pressure of the entire zone was raised by a few meters and this higher pressure increased the losses in the older un-replaced pipes. This higher pressure was enough to increase the overall burst frequency in these zones. As a result, many of these areas performed worse after mains were replaced than before. This event is specifically covered by Morrison et al. (2007) in the IWA DMA Guidance Notes which state "*Care should be taken however when a partial substitution of the worst mains is undertaken, that the leakage in the original network does not increase.*"
- For optimised replacement of pipes to take place within a reservoir zone, comprehensive data will be required on the performance of all the mains in order to prioritise their replacement. This additional information, as well as the different analysis will also come at an additional cost.

The positive side of this approach however was that it allowed the Utility to directly and quickly target the mains that overall had the highest incidence of faults.

Mains Replacement With and Without Pressure Management

In order to analyse the impact of mains replacement with or without pressure management, detailed flow and pressure measurements were recorded in 90 DMA's in the eThekwini area during the AC Mains replacement programme over a 17-month period. Baseline conditions were established and the reaction of the zone hydraulics during mains replacement programme were monitored to observe and quantify the results. Of the 90 DMA's that were observed, 44 DMA's had mains replacement without pressure management and in the remaining 46 DMA's the pressure was optimised during and after mains replacement. The results of this comparison are shown in Chapter 5.

Impact of Mains Replacement on Burst Frequency

Closely linked to the impact of increased operating pressures in DMA's where mains replacement was implemented, it became evident over time that the frequency of bursts on both mains and service connections changed during and after mains replacement. A five-year history of faults was analysed to determine the impact of the mains replacement programme on burst frequency.

Once the seasonal variation in bursts on both mains and service connections had been established and a decent baseline determined, the impact of disruption during the mains replacement programme became clearly evident. Figure 3.27 presents the burst frequency trends for both mains and service connections for the entire EWS area of supply. Considering that only 12% of the reticulation network was replaced, the increase in burst frequency was disproportionate (approximately 9% on mains and 90% on service connections). Once the mains replacement programme was completed, the burst frequencies returned to pre-mains replacement values.

It was realised that pressure management was key to controlling not only unreported leakage and reducing overall leakage in partial mains replacement areas, but also to minimizing the burst frequency on mains and service connections during mains replacement contracts. Failure to manage the pressures (along with quality control on the actual replacements themselves) during construction will result in an unnecessarily high increase in leakage volumes.

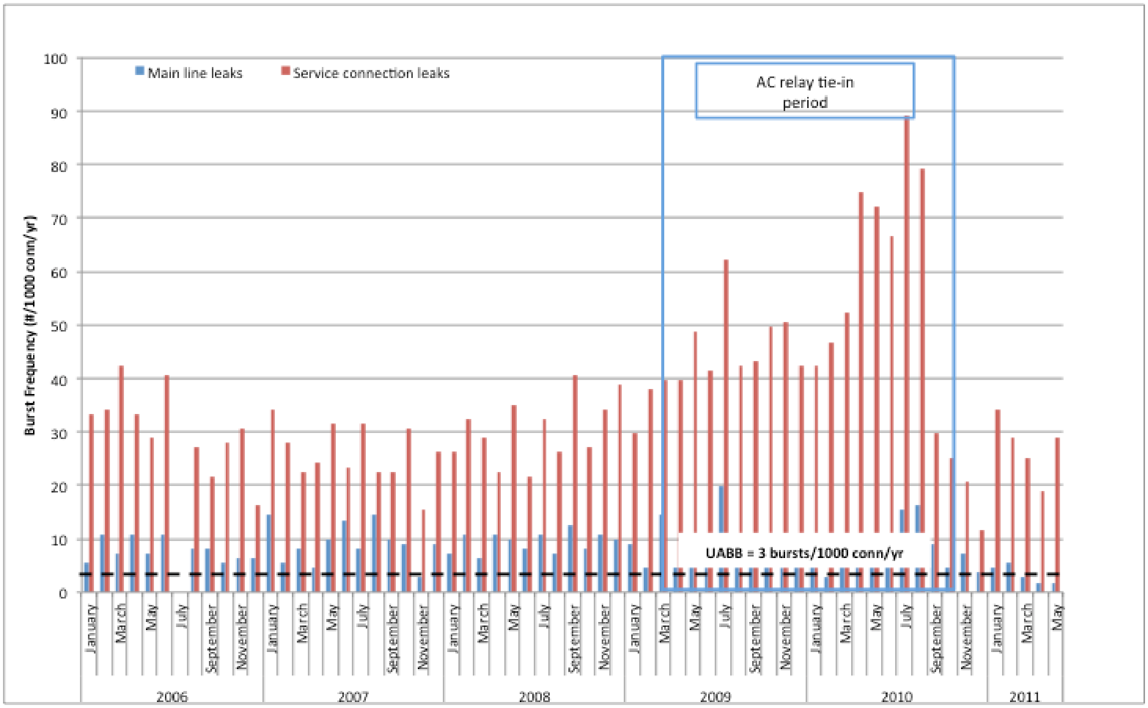

Figure 3.27: Burst Frequency Trends in the eThekwini Municipality

Impact of Intermittent Supply on Burst Frequency and Billed Volumes

Empirical evidence at EWS suggests that the burst frequency increases dramatically in areas where the mains are not pressurised on a continuous basis. The impact on consumer billing has also been observed but not quantified. It is known however that the debris suspended in the water damages the meter and the air that travels through the meter causes to rotate at very high speeds that it was not designed for and this causes damage. Furthermore, in high lying areas large volumes of air are sucked into the system from open taps in the consumers' plumbing and this can cause negative readings to occur on the consumers' bill.

In a case study conducted in Cyprus, Charalambous (2012) recorded an increase of 12.8% in the System Input Volume after intermittent supply had occurred in a supply system without a corresponding increase in billed volumes. As reflected in Table 3.4, there was also a 300% increase in mains burst frequency and a 200% increase in connection burst frequency.

Table 3.4: Effect of intermittent supply on reported pipe bursts (Charalambous, 2012)

DESCRIPTION	NUMBER OF REPORTED BREAKS		
	BEFORE	AFTER	% INCREASE
Mains	1 in 7.14 km	1 in 2.38 km	300
Service Connection	15,5 in 1000	29.7 in 1000	200

Where distribution systems have been designed for continuous supply, intermittent supply should be avoided.

Impact of Mains Replacement on Consumer Billing

One of the unintended negative consequences of the mains replacement programme was the impact on consumer billing. This was linked to the increase in burst frequency that was evident during the construction phase. The increased burst frequency led to an increase in interruptions to water supply, as well as isolation, scouring and refilling of pipelines. In spite of operational procedures to bleed and flush the affected reticulation after re-commissioning the pipelines, a temporary decrease in water quality was experienced. This increased the levels of suspended solids and air in the water which ultimately found their way to the consumer meter. Accelerated wear on the meters then occurred leading to a decrease in consumer meter accuracy.

A total of eight DMA's comprising of 18 500 consumer connections was analysed to determine the impact of the mains replacement programme on consumer sales. The results of this analysis have been included in Chapter 5.

Replace all mains in a DMA

The benefits of replacing all the mains simultaneously in one DMA (subject to limitations discussed below) are:

- There are economies of scale to be realised (estimated at 20% of the project cost)
- The contractor can be made contractually accountable for achieving certain predetermined performances on the workmanship
- The social disruptions will be minimised in the long term
- It is easier to coordinate with other service providers
- There are smaller work fronts to control
- The impact on water meters can be managed and minimised
- The savings at zone level will be tangible which will give the programme accountability and engender support from all concerned.

As per the Victoria Mains Replacement (VMR) programme in London, it is recommended that pipes less than 10 years old are not replaced and are tested and made leak free in-situ. This reduces costs and fruitless expenditure and ensures that a good performance of the entire zone will be achieved. Separate procedures should be developed for water mains of diameter 300mm and above to determine their condition and residual life so that they can be dealt with appropriately.

A prerequisite to this operation is that the reticulation system is first broken down into reasonable sized DMA's. The recommended size of a DMA is somewhere between 500 and 3000 connections (Farley and Trow, 2002) with a reasonable size being 1500. In EWS, there are currently 475000 connections and 263 reservoir zones (as at June 2012) yielding an average number of connections per reservoir zone of 1806. Whilst this sounds ideal, in practice there are some very small reservoir zones and some very large zones and it is these large areas that need to be divided up into manageable sizes.

Currently, 25% of the water mains in the network are controlled by PRV's and many of these points have meters installed. A motivation has been submitted to increase the area controlled by PRV's to 40% over a 4 year period and then ultimately to 50%. This will greatly assist with creating more DMA's that will be smaller and easier to manage.

Where the network does not lend itself to being broken up into smaller pockets supplied through individual meters, it is possible to install multiple meters that are used to calculate the consumption of a "virtual" zone.

The VMR programme is replacing approximately 500km per annum in the city of London. Catherine Moore (2010), Project manager of the VMR Programme for Thames Water stated that they have adopted the approach of replacing an entire DMA at the same time. The entire network has already been broken up into discrete areas of approximately 1000 connections each and these areas are monitored on-line, real time with the use of Magnetic Flow meters and GSM communications. The real loss volume is the key performance indicator for the Utility and this is calculated for all DMAs. This volume is aggregated for the entire network and is tracked and reported to the regulator OFWAT. Thames Water is letting works contracts on a frequent basis and therefore the cost of replacement of mains is competitive and well quantified. As each of the zones is monitored, it is a fairly simple exercise to calculate the cost of the real loss as well as the cost of replacement. All mains within the zone are replaced, except the mains that are less than 10 years old and greater than 250mm. The payback period is calculated based on the predicted real loss volume after replacement and this calculation is continually refined as more and more DMA's are replaced. The cost of the water is taken not as the current cost of water production, but at the cost of water if a new production facility had to be built. An additional requirement of the contract is that the contractor is held responsible for achieving the predicted real loss volume. The responsibility for the operation of the new mains is not returned to the Utility until the agreed level of real loss volume has been achieved. There is thus a major incentive for the contractor to install the mains with the utmost care and diligence, all to the benefit of the Utility. This approach by Thames Water is delivering excellent results as the minimum level of background losses is achieved with each new zone completed. These results are also sustainable as they are continually monitored and active intervention occurs whenever the losses are seen to increase.

3.9 PIPE REPLACEMENT FINANCIAL MODELS

Cost / benefit analyses (CBA) and Net Present Value (NPV) analyses can be utilised where the calculations and considerations can be reduced to financial terms. Where other non-financial factors need to be considered, then a multi-criteria decision (MCD) methodology must be employed. With MCD, each factor is given a weighting and then differing options can be ranked say on a scale of one to 5. The product of these values is totalled and then this calculation is done for each competing option. The option with the highest score is then typically the option that is chosen.

The following benefits will be realised by the Utility and society but have not been incorporated in these simple models:

- Reduction in administration costs from handling burst reports
- Reduction in costs to commerce and industry due to interruption to supply
- Reduction in costs to road users due to traffic delays during repairs
- Increase in business confidence resulting in an increase in investment
- Reduction in damage to water meters (causing sales volumes to drop) and decrease in maintenance costs to unblock meters
- Reduction in inflows to waste water treatment works (where illegal connections are reduced)
- Improvement in the scores of the DWA Blue Drop assessments
- Improvement in the consumers' perception of the Utility.

The following costs currently incurred have been used in the models and the following assumptions have been made:

- The costs of main bursts are presumed to reduce to the Unavoidable Annual rate of 13 bursts/100km/year
- The costs of connection bursts are presumed to reduce to the Unavoidable Annual rate of 3 failures/1000 connections/year
- The cost of water lost due to background leakage (taken at short run cost price of water of R4.279 (2012/13 prices)). This has been conservatively estimated to drop to twice the Unavoidable Annual Real Loss rate
- The cost of water lost during bursts and flushing of mains after burst repair (taken at short run cost price of water of R4.279 (2012/13 prices))

- The reduction in apparent losses (at average selling price of R12.97/m^3) has been conservatively been estimated to be reduced by 25%.
- The reduction in leak detection and repair activities has also assumed to be halved.

As the municipality is zero rated by the South African Revenue Service, all costs and benefits are excluding VAT.

The Cost / benefit Analysis

Savings from a mains replacement programme come from three major sources which are reduction in the cost of burst repairs, reduction in cost of connection burst repairs and the reduction in the real loss volume. The cost for the repair of a 100mm and 150mm pipe burst is shown in Table 3.5.

Table 3.5: Calculating the Average cost of a 100mm and 150mm burst repair

	ETHEKWINI WATER AND SANITATION			
	COST OF PIPE BURSTS			
Description	**Units/ No. of Items**	**Rate (Unit) 2012/13**	**100mm Pipe Failure**	**150mm Pipe Failure**
Staff				
Artisan / Supervisor (TK9) x 1	8 Hours	168.31	R 1 346.48	R 1 346.48
General Workers (TK3) x 3	24 Hours	65.01	R 1 560.24	R 1 560.24
Shift Controller (TK11)	2 Hours	223.72	R 447.44	R 447.44
General Workers (TK3) x 1	2 Hours	65.01	R 130.02	R 130.02
Material				
Pipe - Mpvc - 6m 100mm	1 x 6m length	211.04	R 211.04	
Pipe - Mpvc - 6m 150mm	1 x 6m length	512.04		R 512.04
Long Collar 100mm	2	172.32	R 344.64	
Long Collar 150mm	2	281.84		R 281.84
Backfill (Crusher run)	8 m3	241.58	R 1 932.64	R 1 932.64
Tar Patching	6 m2	512.14	R 3 072.84	R 3 072.84
Plant				
Pick Up - lt LDV - Supervisor	2 Hours	47.08	R 94.16	R 94.16
Truck 4 Ton - Artisan / Supervisor	8 Hours	113.56	R 908.48	R 908.48
Truck 7 Ton Transport of Backfill	2 Hours	209.11	R 418.22	R 418.22
Truck 7 Ton Spoil Removal	4 hours	419.61	R 1 678.44	R 1 678.44
TLB	4 Hours	265.89	R 1 063.56	R 1 063.56
Low Bed Truck (To transport TLB)	2 Hours	1 006.78	R 2 013.56	R 2 013.56
Water Pump (50mm)	8 Hours	20.77	R 166.16	R 166.16
Water				
Water lost during leak (m3)	113.04	4.28	R 241.85	R 483.70
Water used to flush (m3)	56.52	4.28	R 120.92	R 241.85
TOTAL COST OF PIPE BURSTS (2012 / 13)			**R 15 750.69**	**R 16 351.67**
AVERAGE COST OF PIPE BURSTS (2012 /13)				**R 16 051.18**

With reference to Morrison (2007) in the IWA DMA Guidance notes, Background Leakage is calculated in the following manner:

(Infrastructure Condition Factor (ICF) x (0.02 x metres of main + 1.25 x no of connections) + (ICF x 0.033 l/metre of private pipe)) x (Average Zone Night Pressure (AZNP)/50) $^{1.5}$ + (0.25 litres per household or non-household x (AZNP/50) $^{1.5}$

An example, where ICF = 1, length of Mains in the DMA is 23km, Number of connections =1000, Supply connection pipe = 5m, AZNP=54m

Background leakage = {1.0 x [(23000 x 0.02) + (1000 x 1.25) + (1000 x 5 x 0.033)] x $(54/50)^{1.5}$ }+{(1000 x .25) x $(54/50)^{1.5}$ }

= 2175 litres / hour

= 52m^3 / day

Lambert and Hirner (2000) give the UARL formula (which is part of the ILI formula) as:

UARL (litres/day) = (18 x Lm + 0.8 x Ns + 25 x Lp) x P

Substituting values in the above formula yields,

UARL = ((18 x 23 + 0.8 x 1000 + 0) x 54

= 65 556 l/day

= 65 m^3/day

The achievable background losses in a zone 23km long with 1000 connections at a pressure of 54m will thus range somewhere between 52 and 65m^3/day with the average value being 58m^3/day. It is thus possible to estimate a payback period in the following manner: (where Lm = 23000m, Replacement cost = R1040/m and the cost of water = R4,279 / m^3):

Table 3.6: Calculating the payback period for replacement using the short run cost of water

DESCRIPTION	VALUE
Length of mains in zone (m)	23000
Average replacement mains cost	R 1 040
Cost to replace zone	R 23 920 000
Cost of water (m^3)	R 4,279
Cost per burst repair	R 16 051
Number of bursts per 100 km per year	313
Cost of Bursts per zone pa	R 1 155 524
Cost per service connection failure	R 1 000
Number of bursts per km per year	10
Cost of Bursts per zone pa	R 230 000
ILI of zone	12
Average UARL (m^3 / day)	58,5
Leakage in Zone (m^3 per day)	644
Cost of excess leakage pa	R 1 005 041
Cost of leakage, bursts and connection failure	R 2 390 565
Payback period (years)	**10,0**

For illustrative purposes, if the cost of water is taken at the long run cost of providing water from a new source (approximately R10 / m^3), the payback period drops to 6.4 years as shown in Table 3.7. Both of these periods are still deemed advantageous and the programme would be given the go-ahead on this basis. When consulted, the manager of the EWS finance department, (Rosh Maharaj, 2012) stated that as loans are often repaid over a 15 or 20 year period, a return from a relay project of less than ten years would be ideal.

Table 3.7: Calculating payback period for mains replacement using the long run cost of water

DESCRIPTION	VALUE
Length of mains in zone (m)	23000
Average replacement mains cost	R 1 040
Cost to replace zone	R 23 920 000
Cost of water (m^3)	R 10,000
Cost per burst repair	R 16 051
Number of bursts per 100 km per year	313
Cost of Bursts per zone pa	R 1 155 524
Cost per service connection failure	R 1 000
Number of bursts per km per year	10
Cost of Bursts per zone pa	R 230 000
ILI of zone	12
Average UARL (m^3 / day)	58,5
Leakage in Zone (m^3 per day)	644
Cost of excess leakage pa	R 2 348 775
Cost of leakage, bursts and connection failure	R 3 734 299
Payback period (years)	**6,4**

Cost Benefit Analysis

A more in depth analysis was conducted using refined data for the entire operational area and also a number of reservoir zones to determine the cost / benefit. The breakdown of the size of the mains in each area was determined and the actual replacement cost per diameter was used. The payback period is a variable in the spreadsheet and can be used to determine the sensitivity of the calculations by varying this period from 10 to 20 years. As per the VMR programme, it was assumed that mains less than 10 years old and mains greater than 300mm would not be replaced. For these mains, a sum was allowed to test these mains as well as locate and repair all leaks. The cost for the replacement or testing of mains worked out to an average of R935 / m. In all cases, the short run price of water was used, but the long run price could be used for comparative purposes.

Table 3.8: Base data for calculating the cost / benefit analysis

DECISION TOOL TO CHECK VIABILITY OF MAINS REPLACEMENT

Name of Zone	Entire eThekwini System	Umlazi 1&7 Reservoir Zone	Ensimbini Reservoir
Performance Data			
System Input Volume (kl/day)	870003	16081	6928
Billed Metered Consumption (kl/day)	561881	7979	2442
Unbilled Metered Consumption (kl/day)	20818	238	118
Billed Unmetered Consumption (kl/day)	24576	1	0
Unbilled Unmetered Consumption (kl/day)	43477	568	356
Apparent Losses (kl/day)	73510	2271	802
Illegal Consumption (kl/day)	53844	2111	717
Metering Inaccuracies (kl/day)	19666	160	85
Real Losses (kl/day)	234412	5024	3209
Total Water Losses (kl/day)	304805	7295	4011
NRW by Volume (%)	35,0%	45,4%	57,9%
Real Losses (litres/conn/day) - TIRL	494	672	2847
Real Losses (m3/km/day)	21	40	144
Apparent Losses (litres/conn/day)	155	304	712
Total Water Losses (litres/conn/day)	643	976	3559
UARL	65	60	82
ILI	7,7	11,3	34,7
Minimum Night Flow (m3/hr)	9767	441	133,7
Main Bursts pa	11207	126	62
Connection Bursts pa	27577	433	111
Main Burst Frequency (#/100km/year)	99,1	99,0	277,8
Connection Burst Frequency (#/1000/year)	58,2	58,0	98,5
Frequency of leak detection and repair surveys pa	1,1	3	1,1
Zone Attribute Data			
Total Length of Mains (m)	11313000	126860	22320
Length of Mains <10 years old (33%)	3746518	41864	7366
Length of 50mm and smaller (21%)	2365554	26641	4687
Length of 80mm (12%)	1238138	15223	2678
Length of 100mm (18%)	2007116	22835	4018
Length of 150mm (7%)	825903	8880	1562
Length of 200mm (4%)	481469	5074	893
Length of 250mm (1%)	108724	1269	223
Length of 300mm (2%)	269207	2537	446
Remaining length of mains > 300mm (2%)	270371	2537	446
Total Number of Registered Connections	474193	7472	1127
Average Zone Pressure (m)	52,5	54	71

Table 3.9: Decision Tool for calculating the cost / benefit analysis for individual reservoir zones

DECISION TOOL TO CHECK VIABILITY OF MAINS REPLACEMENT

Name of Zone		**Entire eThekwini System**		**Umlazi 1&7 Reservoir Zone**		**Ensimbini Reservoir**
Performance Data						
Cost Estimate Data						
Short Run Cost Price of Water	R	4,28	R	4,28	R	4,28
Long Run Cost Price of Water	R	10,00	R	10,00	R	10,00
Average selling price of water	R	12,97	R	12,97	R	12,97
Testing and Repair of Mains <=300mm and <10 years old	R	1 498 607 200	R	16 745 520	R	2 946 240
Replace 50mm and smaller	R	1 419 332 460	R	15 984 360	R	2 812 320
Replace 80mm	R	1 188 612 297	R	14 614 272	R	2 571 264
Replace 100mm	R	2 408 539 641	R	27 401 760	R	4 821 120
Replace 150mm	R	1 486 624 572	R	15 984 360	R	2 812 320
Replace 200mm	R	1 155 525 820	R	12 178 560	R	2 142 720
Replace 250mm	R	326 171 723	R	3 805 800	R	669 600
Replace 300mm	R	969 146 699	R	9 133 920	R	1 607 040
Testing and Repair of mains > 300mm	R	135 185 309	R	1 268 600	R	223 200
Upgrade of consumer connections	R	684 260 499	R	10 782 096	R	1 626 261
Total Repair and replacement costs	**R**	**11 272 006 221**	**R**	**127 899 248**	**R**	**22 232 085**
Loan Repayment Costs						
Annual Interest Rate		10%		10%		10%
Years of Loan		20		20		20
Present Value of Loan	R	-11 272 006 221	R	-127 899 248	R	-22 232 085
Annual Loan Payment	R	1 305 327 598	R	14 811 065	R	2 574 533
Savings to be Gained From Replacement						
Reduction in main line bursts	R	156 279 269	R	1 751 177	R	948 599
Reduction in service connection bursts	R	9 154 047	R	143 836	R	37 667
Reduction in leak detection and repair	R	18 837 480	R	4 224 737	R	37 165
Reduction in NRW	R	270 507 039	R	6 453 195	R	4 722 869
Increase in Billed Authorised Consump	R	87 000 004	R	2 687 757	R	949 177
Total Savings from Pipe Replacemen	**R**	**541 777 839**	**R**	**15 260 703**	**R**	**6 695 477**
Benefit:Cost Ratio		**0,4**		**1,0**		**2,6**

This tool may be used to prioritise the replacement of one zone over another. It can be seen in the above example that Ensimbini reservoir zone has a Benefit/Cost Ratio of 2.6 compared to Umlazi 1&7 Reservoir zone with a ratio of 1.0. The entire eThekwini system has a ratio of 0.4, highlighting the need to search for the zones where the highest benefit will occur.

Net Present Value Analysis

The formula to calculate Net Present Value (NPV) is:

$$\text{NPV} = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where, i is the interest rate, N is the number of periods, and R_t is the net cash flow at time 't" (i.e. the cash inflow minus the cash outflow at time "t").

With reference to Thornton et al. (2008) and Snell (2011),

- NPV is used to calculate the present value of multiple future cash flows.
- NPV analysis takes all of the future cash flows and discounts them back to time 0 then compares them against the initial cost.
- NPV analysis can be used to analyse various business decisions.
- The higher the NPV the more beneficial the decision.
- NPV analysis can be used to evaluate a single decision or compare several choices.

Wyatt (2010) makes two interesting observations:

1. As the replacement of mains should be a permanent activity, it is better if the Utility sources the funding not from loans but directly from the tariff.
2. The tariff model of the Utility should provide to replace mains at the end of their predicted life (say 50 years for AC pipes). When deciding whether or not to replace these mains at say 40 years of age, the capital cost to be considered is not the full cost of replacement, but the cost of bringing the replacement forward in time by ten years.

The subjective variables in all of these analyses are the time over which the project is considered, the interest rate and the discount rate and these must be determined with care. As stated, in the case of EWS, loans are typically sourced over 15 or 20 years period. According to the Global Credit Rating Company (2012), the municipality has an AA^- credit rating and loans are sourced at an average fixed interest rate of 9.5%. The remaining uncertainty in these calculations is thus only inflation.

These new assets however will continue to bring benefit to the Utility for 50 to 100 years. Currently, the interest rate on loans is very similar to the inflation rate. It is therefore more appropriate to use a simpler Cost / Benefit analysis or to calculate the payback period.

3.10 STUDY OF DIFFERENT PIPE MATERIALS

Several pipe materials are available for use in distribution systems and both the short term and long term implications of these decisions were examined. In a municipal environment, the Finance and Procurement Departments frequently influence the choice of material and supplier, and the outcome is sometimes detrimental to the optimum whole life cost of the distribution mains. It is important to be cognisant of the implications of the material options and how these materials will perform throughout their economic lifetime. The current material of choice at EWS is modified Polyvinyl Chloride (mPVC) and this was compared to High Density Polyethylene (HDPE), although the principles would remain the same to compare any materials. Van der Zwan (1989) quotes pipe ages being anywhere from 30 to 100 years and it was also part of the evaluation to identify what could be done to increase the performance of the distribution main over the long term.

The similarities between the materials are that they are both elastic, malleable, mouldable, recyclable, corrosion resistant and lightweight. The benefits of these properties are that the pipes will absorb surges, will not shatter on impact, they are easy to shape, environmentally friendly, do not require cathodic protection and they are easy to handle. The major differences in the performances are that for PVC, the joints are spigot and socket type and therefore the pipes are discontinuous and cannot resist longitudinal tension. These pipes also cannot resist internal vacuum conditions. On the other hand, HDPE joints are welded and therefore restrained and the pipe is continuous. This pipe can withstand tension as well as internal vacuum. HDPE pipes have a much thicker pipe wall compared to PVC so lower quality bedding can be used, but the detracting factor is that more material is used.

Table 3.10: Comparative Cost Calculator (Fischer and Scruton, 2012)

CONTRACT WQ 64/7430
COMPARATIVE STUDY FOR THE USE OF PVC
AND HDPE WATER MAINS

Pipe Diameter (mm)	DN75		DN110		DN160		DN200	
Ratio of Insitu material	50%	60%	50%	60%	50%	60%	50%	60%
to Imported bedding material:	50%	40%	50%	40%	50%	40%	50%	40%
Costs (R/m)	mPVC PN12	HDPE-100 PN12.5	mPVC PN12	HDPE-100 PN12.5	mPVC PN12	HDPE-100 PN12.5	mPVC PN12	HDPE-100 PN12.5
Site Clearance (R/m)	6.75	6.75	7.10	7.10	7.60	7.60	8.00	8.00
Trench Excavation, backfill and compact, including for disposal of surplus/unsuitable material (1) (R/m)	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Bedding (2)								
From Excavations (Screened)	20.38	24.45	44.48	26.69	50.56	30.33	55.50	33.30
From Commercial Sources	43.66	34.93	47.65	38.12	54.17	43.33	59.47	47.57
Reinstatement of Road Excavation	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78
Handle, lay, joint/weld, disinfect and test pipe	5.26	114.79	10.30	168.36	21.74	244.89	33.94	306.11
Thrust Blocks/m (3)	0.91		0.91		0.91		0.91	
Add: Preliminary and General (20%)	39.15	59.94	45.85	71.81	50.75	88.99	55.32	102.75
Supply pipe (4)	26.29	44.50	51.50	96.32	108.68	200.83	169.71	313.50
Total (R/m) (5)	261.19	404.15	326.58	527.18	413.20	734.76	501.63	930.02
Quality Control (R/m)	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
NPV Repair & Leakage Cost (R/m)	833.04	1122.43	1059.16	1465.51	1393.52	2060.35	1732.51	2623.81
Total Cost (R/m)	R 1 094.23	R 1 526.58	R 1 385.73	R 1 992.69	R 1 806.72	R 2 795.12	R 2 234.14	R 3 553.83

Table 3.11: Decision Making Spreadsheet (Fischer and Scruton, 2012)

DECISION MAKING WORKSHEET
I Must Choose : A PIPE MATERIAL FOR WATER RETICULATION PIPES

OBJECTIVES & CRITERIA				OPTION				COMMENTS
PARAMETERS	PRIORITIES		CRITERIA	(A)		(B)		
	MUST HAVE ?	WEIGHT	Make measurable	mPVC		HDPE-100		
Construction Cost		10	% of lowest	10	100	6.1	61	Refer to Life Cycle Costing Spreadsheet
Life Cycle Cost (NPV)		10	% of lowest	10	100	8.8	88	Refer to Life Cycle Costing Spreadsheet
Ease of Repair		10	Equipment, training, stores	10	100	8	80	Relative ease of repairing a burst
Pressure Class		10	% of highest	9.6	96	10	100	mPVC (PN12), PE-100 (PN12.5)
Hydraulic Efficiency		10	ID & Headloss/m	10	100	7	70	Headloss calculated using Colebrook-White; Ks=0.06
Integrity of Joints		8	Jointing method & requirements	6	48	7	56	Strength of joints (assuming proper assembly and installation)
Low Tech Installation		6	Equipment, training, stores	8	48	7	42	HDPE requires welding machinery, certified welders
Anticipated Service Life		4	Not ≤ 100 years	10	40	10	40	Includes 'residual life' - pipes don't operate at rated pressures
Energy Efficiency		4	MJ of energy required per meter	10	40	8	32	Based on manufacturing process only
Vacuum Condition	Y	10	Y/N	0	0	10	100	Vacuum in pipe must not cause failure
			SCORE	672		669		

The comparative cost calculator spreadsheet has been formulated (by Fischer and Scruton) in such a manner that the engineer can evaluate the costs on a project by project basis. The decision making spreadsheet enables the engineer to assess multiple criteria and reduce these criteria to a numeric form so that these parameters can be scored accordingly. The spreadsheets shown in Table 3.10 and Table 3.11 have been compiled to calculate the installation costs and the operational costs using the NPV method over a period of 100 years. This allows the engineer to rank and score diverse aspects of each material over time and reach an objective total. It is recommended that the pipe with the highest total is then not simply accepted as being the material of choice but that further judgement is used to ultimately decide on the material to be used. This analysis revealed that EWS should continue to use the mPVC pipe.

For any pipe to last 100 years it is essential to have adequate expenditure on QA during pipe manufacture and installation. Furthermore, it is essential that the contractors' staff is properly trained and that there is rigorous inspection of the work in progress. It is believed that greater attention should be placed on this aspect of mains installation as the cost / benefit ratio is favourable.

3.11 OPERATIONS AND MAINTENANCE CONSIDERATIONS

There are three types of maintenance that take place on the reticulation network (Van Der Zwan, 1989)

- Reactionary maintenance takes place under emergency conditions and is not scheduled.
- Planned preventative maintenance is carried out on a scheduled basis. This can be carried out on a regular time based schedule or based on the results of inspection data.
- Planned corrective maintenance is triggered after an expected and accepted number of failures have occurred.

It is important that planned preventative maintenance is carried out by the Utility in order to keep the assets in good condition. This planned work increases the knowledge of the infrastructure and also assists in making the results of other NRW reduction activities sustainable.

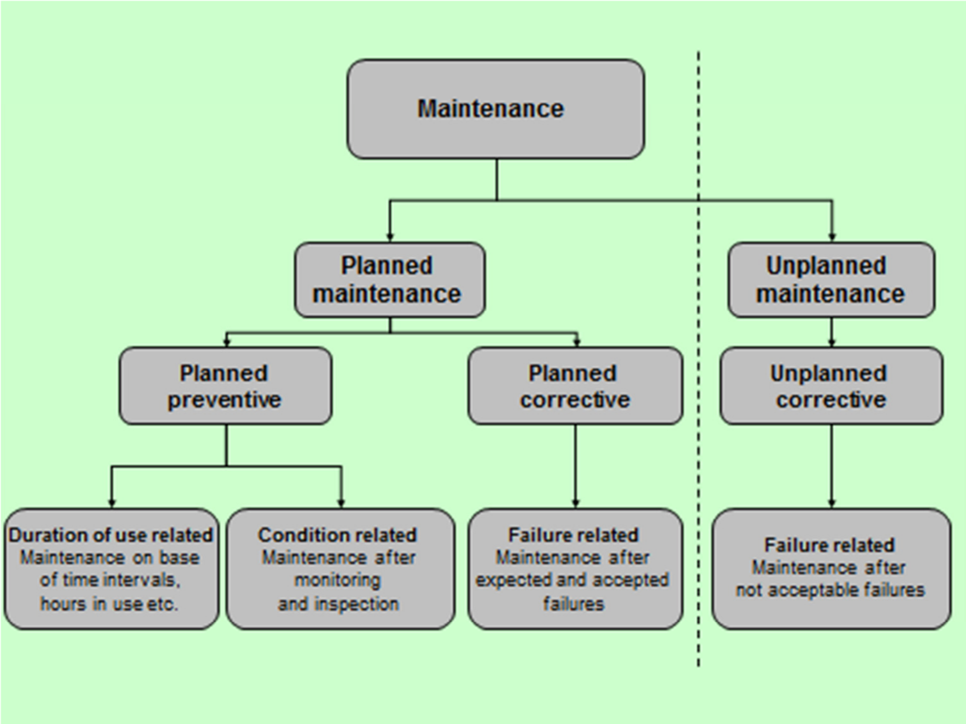

Figure 3.28: Schematic of Planned and Unplanned Maintenance (Van Der Zwan, 1989)

Examples of O&M techniques

Temporary remedial techniques include mains flushing, ball scouring, high pressure jet cleaning, air scouring and swabbing. Valve exercising is a very important activity that should be conducted every 12 to 24 months. Knowing where line valves are located, what their condition is and status is, is vital to the network operator being able to operate the network effectively. Exercising these valves on a regular basis ensures that these valves will be able to function effectively when required. This ensures that the valves have not been “lost” due to the valve cover being covered by earth in the sidewalk or the cover being tarred over when the road was resurfaced. It is important to also locate, reinstate and paint the concrete valve markers and also the painted indicators on the road that point to the position of the valves. Typically, different paint colours are used to indicate the different function of the valves and it is important that these colours are preserved and maintained as well. Boundary valves, linking one zone to another are the most important valves to preserve and know the status of. Sometimes, these boundary valves are used to purposefully supply one zone from another on a temporary basis if there is a problem in one of the zones. It is important that a system is in place to document these zone status changes so that when a zone is temporarily breached, this change is not forgotten due to human error. If one of these valves is accidently opened, higher pressures typically will result in one of the zones and the respective water balance calculations for the zones will be incorrect. This flexibility in the network allows the Utility to keep as much of the network pressurised as possible (and thereby minimise the inconvenience to consumers) in the event of planned maintenance or an emergency. It therefore stands to reason that if these valves cannot be located quickly then they will not be able to be used when the situation arises.

3.12 EWS PERFORMANCE INDICATORS

The performance indicators measured for eThekwini Water and Sanitation for the financial year end 2011/12 are summarized in Table 3.12, Figure 3.29 and Table 3.13 (Scruton, 2012). These figures are calculated monthly and reported on quarterly. The system input volume (SIV) is taken from the purchase and production meters, the average water sales is taken from the data reported by Treasury, the number of connections is taken from the billing database, and metering inaccuracies is estimated to be 3.5% of the sales volume. Knowing the average zone pressure and the length of mains in the system allows the Infrastructure Leakage Index (ILI) to be calculated. The balance of the fields below are computed from a "top down" water balance calculation in accordance with the recommendation of the IWA (Lambert et al., 2002).

Table 3.12: Comparison of Water Balance Components for the eThekwini Supply System: 2007/08 to 2011/12 Financial Years (Scruton, 2012)

Indicator	Financial Year					Change
	2007/08	2008/09	2009/10	2010/11	2011/12	
Total Number of Connections in Municipality	420044	431856	442721	460723	474193	13470
Fi46 NRW by Volume (%)	36.4%	38.9%	37.5%	33.2%	35.4%	2.2%
WR1 Inefficiency of Use (%)	22.1%	24.9%	25.8%	23.9%	26.9%	3.0%
Op29 Infrastructure Leakage Index	9.3	8.8	8.4	6.8	7.2	0.4
Op23 Total Water Losses per Connection (l/conn/day)	734	794	753	631	631	0
Average SIV (kl/day)	876970	908665	912554	861642	870003	8361
Average Water Sales (kl/day)	558178	554930	570609	575829	561881	-13948
Real Loss Volume (kl/day)	193696	226257	235302	206571	234412	27841
Unbilled Authorised and Illegal Volume (kl/day)	105560	108055	86672	59088	51991	-7097
Total Water Losses (kl/day)	308236	342929	333278	279758	304805	25047
Non-Revenue Water Volume (kl/day)	318792	353735	341945	285813	308122	22309
Metering Inaccuracies (kl/day)	19536	19423	19971	20154	21719	1565
Illegal Consumption (kl/day)	95004	97250	78005	53033	48674	-4359

Note: Fi46, WR1, Op29 and Op23 refer to the financial, water resource and operational key performance indicators compiled by Alegre et al., (2006) and adopted by EWS.

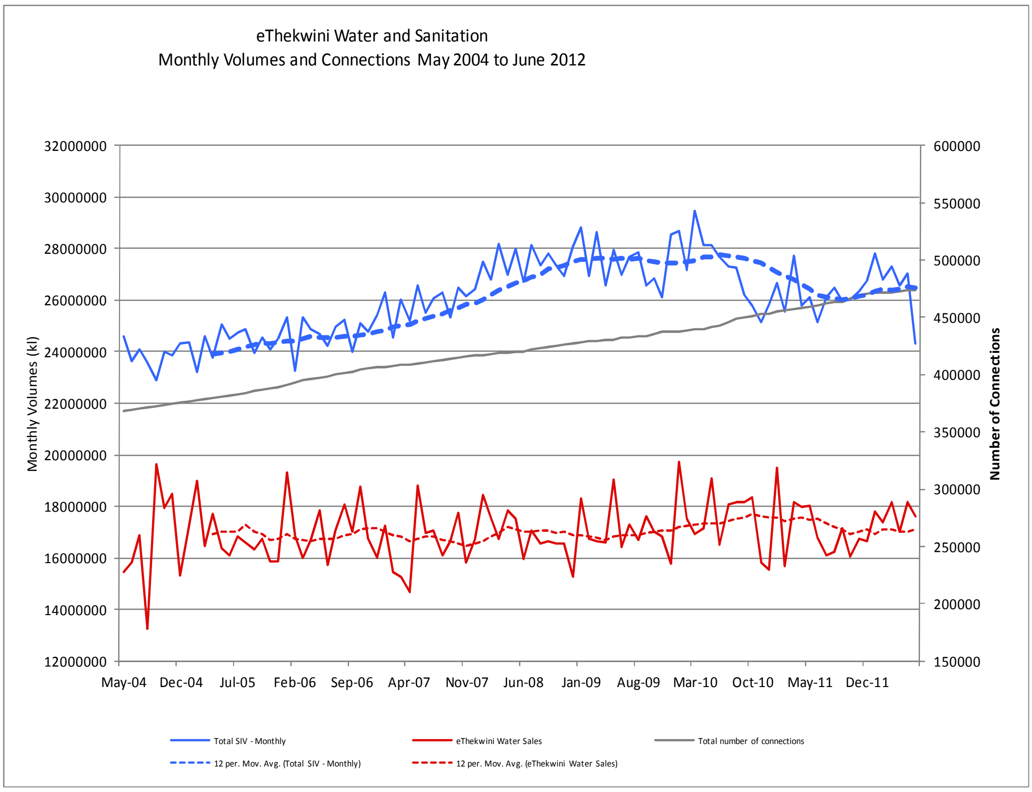

Figure 3.29: Average Monthly Trends of Bulk Water Purchases, Total Water Sales and Number of Connections

Table 3.13: eThekwini Municipality Water Balance for 2011/12 Financial Year with 95% Confidence Limits

ETHEKWINI MUNICIPALITY

2011/12 FINANCIAL YEAR WATER BALANCE

System Input Volume (kl/year) 317 551 273 ± 3.7%	Authorized Consumption (kl/year) 206 297 341 ±6.7%	Billed Authorised Consumption (kl/year) 205 086 705 ±6.9%	Billed Metered Consumption (kl/year) 205 086 705 ±6.9%	Potential Revenue Water (kl/year) 205 086 705 ±6.9%
			Billed Unmetered Consumption (kl/year) 0 ±0.0%	
		Unbilled Authorised Consumption (kl/year) 1 210 705 ±25.0%	Unbilled Metered Consumption (kl/year) 328 500 ±25.0%	Non –Revenue Water (kl/year) 112 464 568 ±16.4%
			Unbilled Unmetered Consumption (kl/year) 882 205 ±25.0%	
	Water Losses (kl/year) 111 253 932 ±6.9%	Apparent Losses (kl/year) 25 693 552 ±12.1%	Illegal consumption (kl/year) 17 766 149 ±15.0%	
			Metering inaccuracies (kl/year) 7 927 403 ±20.0%	
		Real Losses (kl/year) 85 560 380 ±8.2%	Leakage on mains	
			Leakage and overflows at storages	
			Leakages on service connections up to point of customer metering	

A comparison with the some of the other utilities in the Kwa-Zulu Natal province is shown in Table 3.14 and Figure 3.30.

Table 3.14: Regional Comparison of ILI and Real Losses per Connection (Shepherd et al., 2012)

System/Town	Number of Registered Connections	ILI	Real Losses per Connection (l/conn/day)
eThekwini	474 193	7,2	482
Msunduzi	76 473	8,0	718
Ugu	46 466	3,7	425
iLembe	31 410	5,6	688
City of uMhlathuze	35 021	10,3	1 072

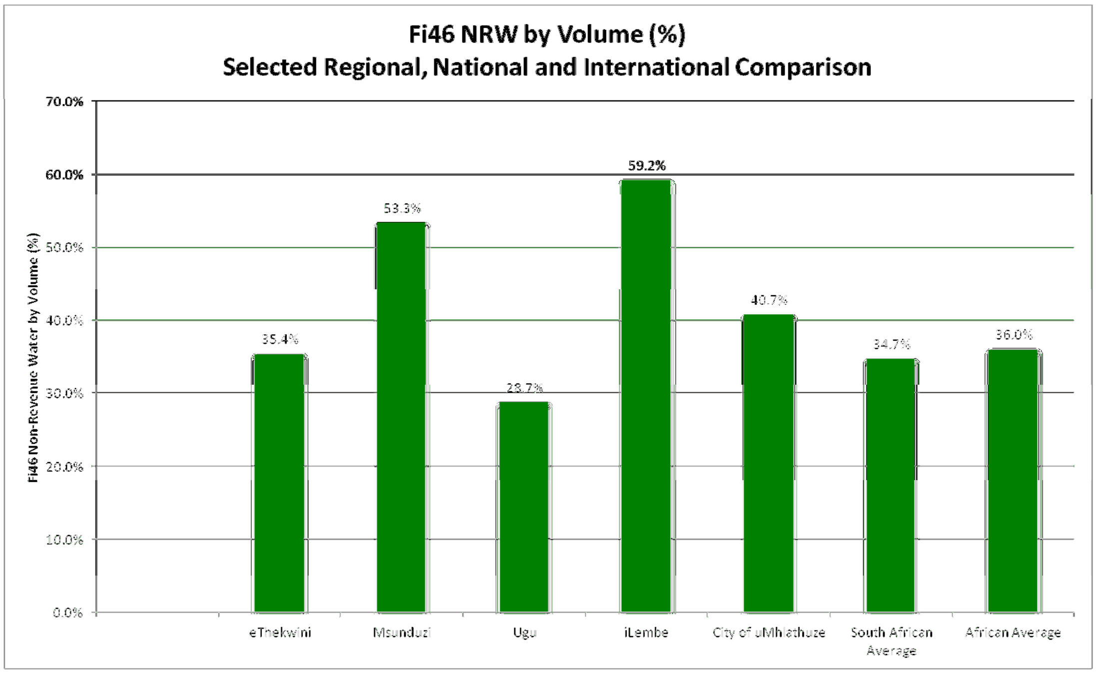

Figure 3.30: Selected Regional Comparison of Non-Revenue Water by Volume (%) (Shepherd et al., 2012, Water Research Commission, 2012)

Only 132 out of 237 (56%) of the utilities in South Africa participated in a survey conducted by McKenzie et al., (2012) to determine the state of Non-Revenue Water in South Africa. It is assumed that the systems of those utilities who have not reported data are in fact worse than the average, so this figure should be viewed as an optimistic one. The average ILI for the South African utilities has been calculated to be 6.8 and the NRW is 34.7%.

Table 3.15 lists the targets in terms of Fi46 (NRW by volume) and Op29 (Infrastructure Leakage Index) that have been set for EWS for the next seven years.

Table 3.15: Targets for NRW Reduction Programme (Scruton, 2012)

Financial Year	NRW by Volume	ILI
2012/13	33,0%	6.8
2013/14	31,0%	6.2
2014/15	29,0%	5.4
2018/19	25,0%	4.8

In EWS for the financial year 2010/11 the Natural Rate of Rise of Leakage (NRR) was measured at 72 litres / connection / day. In 2011/12, this figure had deteriorated to 83 litres / connection per day. Multiplying this number by the number of connections (474193), yields a result of 39.36 Ml/day. This means that real losses will increase by this value on an annual basis if no corrective action is taken. Of concern, is also that the trend in this value is increasing.

In order to achieve the improvements in Table 3.13 it will thus be necessary to regain the losses from the NRR before any improvements will be noticed.

3.13 MITIGATION AGAINST THE CAUSE OF FAILURES

Some selected photos of failed pipes and fittings are shown in Appendix D that were taken at the EWS Mobeni Depot. The following preventative actions can be taken against the ten main causes of mains failures in order to extend the technical lifetime of the mains. The percentage contribution to the overall pipe failures is given by Thornton (2008). To a large extent, it is a case of "prevention is better than cure", so many of the actions below need to be adhered to at the time new pipes are laid.

1. Soil Movement (27%)
    a. Select and install pipeline materials that are not rigid such as mPVC and HDPE.
    b. Select and install pipe with flexible jointing systems.
    c. Select and install flexible connections than will not rupture in the event of small soil movements.
2. Soil Conditions (3%)
    a. Ensure that the bedding, bedding cradle and backfill is provided and installed in accordance with the relevant specifications. (SANS 1200 L)
3. Pipe corrosion (19%)

   Corrosion in pipes causes leaks to occur as opposed to fractures which typically cause visible bursts.

a. Select and install pipes that are not susceptible to corrosion such as mPVC and HDPE as opposed to metallic pipes such as steel, GI, DI and CI.
b. Where metallic pipes are installed utilise preventative measures against corrosion such as internal lining, external coating, tape wrapping, cathodic protection, pipeline monitoring and cross bonding.
c. Condition and monitor the water to ensure that the pH does not promote corrosion.
d. Test the metallic pipes regularly to ensure the effectiveness of the above actions.

4. Heavy traffic loads (11%)

   Traffic loads typically cause visible bursts to occur as opposed to small leaks.

   a. Where possible, avoid laying pipelines under roads.
   b. Where pipes are laid under roads they should be laid with sufficient cover (minimum 1.0 meter and ideally greater than 1.2 meters).
   c. Where pipes are laid under roads ensure that the trenches are backfilled with 100% Mod AASHTO compaction.
   d. Ideally, under Class A and B roads, and pipelines say greater than 200mm diameter, install pipelines inside Class 100D concrete sleeves and have isolation valves at either end of this sleeve.
   e. Where small roads have been laid in wide road reserves, lay the main close to the property boundary so that future road widening will not cover the main.

5. Damage due to excavations (8%)

   Damage by third parties typically causes visible bursts as opposed to leaks.

   a. Ideally record X, Y and Z coordinates of all pipelines in the as-built data.
   b. Ensure that GIS records are up to date and available.
   c. Coordinate with all services providers (for example during a road rehabilitation programme) and get all service providers to replace their services at the same time to limit future disturbances. If this cannot be done, the owners of services should warrant that they will not excavate of a period of say 5 years following a road rehabilitation programme or face severe penalties.
   d. Contractors working in the presence of other services should be closely supervised to limit damage by third parties. In all cases, known services should be shown on the construction drawings.
   e. Contractors must be made to prove and protect these existing services.

6. High pressure and pressure transients (8%)

a. The pressure of the water in the mains should be reduced by using break pressure tanks or pressure reducing valves. Currently, the average pressure in eThekwini area of supply is 52.5 metres.
b. Pump stations should be fitted with soft starting mechanisms and steps should be taken to minimise the potential for pump trips.
c. Pipelines should be installed with a sufficiently high enough pipe class above the maximum predicted static pressure.
d. Pipeline and PRV design should be conducted to build in sufficient factors of safety to allow for the failure of one PRV without the static pressure exceeding the rated pressure of the pipe.
e. PRV's should be maintained on a regular basis to ensure that they are functioning correctly and not introducing higher pressures into the water mains.
f. Strategic PRV's can be fitted with "failure warning devices" to alert the Utility that a failure has occurred.
    i. A pressure relief valve that vents into a visible area will alert the general public that a failure has occurred and they can report this to the contact centre. Whilst this system discharges a considerable amount of water that is wasted, it has the added benefit of preventing higher pressure from entering the downstream network;
    ii. A pressure transducer can be fitted to the downstream pipework on the PRV and when linked to GSM, it can report on the pressures and alert the Utility when the valve is not controlling to specification.
g. Analyse and prevent pressure surges from occurring in pumped systems by incorporating sound principles of design such as surge anticipating valves, variable speed drives, double acting air vales, dump valves and surge chambers.
h. Ensure that consumers connected to the reticulation system do not cause pressure surges in the reticulation system from:
    i. Opening and closing valves rapidly.
    ii. Pumping directly from the distribution main.
i. In some networks that are stressed, there can be considerable differences between the day time and night time pressures. The distribution network performs better when the pressure is constant as pressure volatility places an added strain on the network.

7. Pipe Age (6%)

    a. Renew water mains before they fail at the end of their economic lifetime.

8. Temperature changes (6%)
    a. The temperature changes in Durban are not as extreme as other climates such as Russia and Canada where the temperature can go as low as -40 degrees centigrade. Temperatures in the Durban area have however gone into the low negatives and frost has occasionally occurred in places. To minimise the impact of temperature changes, the water main should be buried at a sufficient depth and the standard one metre cover is deemed sufficient.
9. Pipe Defects (5%)
    a. It is important to have rigorous tender specifications to ensure that the pipe material and fittings are purchased from reputable suppliers and the following criteria should be insisted upon:
        i. The manufacturer should hold ISO9001 accreditation;
        ii. The manufacturer should produce the pipes in accordance with all the relevant SANS specifications;
        iii. The manufacturer should be a member of SAPPMA.
    b. All material should be inspected upon delivery to ensure compliance.
    c. Proportionally representative pipe samples should be selected for testing to ensure compliance with the specifications and the following tests are suggested:
        i. Melt flow index test on the pipe material;
        ii. Elasticity tests on the rubber utilised in the joints (where applicable);
        iii. Pressure test;
        iv. Impact test;
    d. Ensure traceability on the material used during the pipe manufacture to ensure that only virgin material is used in the process and that no reground material is used to manufacture new pipes.
    e. Ensure that pipes are handled properly during transportation and offloading;
    f. Ensure that the manufacturers are adhering to their own QA/QC procedures.
10. Quality of workmanship (2%)
    a. Ensure that contractors are adequately trained and certified.
    b. Test and retest the staff to ensure that all procedures are understood and complied with.

c. Educate staff to ensure that they are fully aware and understand the importance of their tasks and the implications of faulty workmanship.

d. Incorporate rigorous quality control procedures to ensure that:

    i. Pipes are transported, stored and handled in compliance with the specifications;
    ii. Trenches are at the consistently correct depth and are straight where required;
    iii. Pipes are not bent beyond their specified tolerances and that bends are used where required;
    iv. Anchor blocks are used and correctly installed where required;
    v. Bedding and backfill is installed to specification;
    vi. Joints are left visible during the pressure test to check for visible leakage;
    vii. All saddles and connection pipes are installed prior to the pressure test so that these connections are also tested during the test of the pipeline;
    viii. Pipelines must be flushed and sterilised prior to being put into service;

e. Reward staff for achieving and exceeding the quality specifications.

f. Entire sections of a looped network should be installed at one time and ideally this new section should be monitored with its own zone meter. This will enable the client to set performance and acceptance specifications with regards to the acceptable level of real losses that will be tolerated in a newly installed portion of the network.

g. Supervise the installation of all new mains with suitably qualified and experienced staff. The amount of time spent on site by the supervisory staff must be sufficient to ensure that all aspects of the job are inspected and that no below standard work is accepted.

3.14 THE RISK BASED APPROACH

Many advanced utilities advocate that the triple bottom line (social, financial and operational) be considered when deciding which distribution mains should be replaced. In order to conduct detailed studies and take all aspects into account a greater level of detail is required. There are advantages and disadvantages to this approach as detailed in Table 3.16.

Table 3.16: Comparison of approach with differing levels of detailed data (IIAM, 2011)

Level of Detail	Advantages	Disadvantages
Macro approach	Quick results	Lower confidence in data accuracy
	80:20 Pareto principle	Solutions may not be optimised
	Does not require many resources	Cannot do advanced analysis
	Does not require exhaustive data collection	
Micro approach	Higher confidence in accuracy of recommendations	Resource intensive and time consuming
	Can do advanced modelling and economic analysis	Huge amount of data required that is not currently available
		Obvious solutions can get lost in the depth of the data
		Accuracy of the data collected from field questionable; Training and quality assurance mandatory

It is advocated that a top down approach is adopted with an initial plan. As more and reliable data is available through advanced collection methodologies, an interim plan can be utilised which will later mature into an advanced plan using detailed information. This minimum data will be sufficient to make strategic decisions and comply with the Generally Recognised Accounting Practice (GRAP) requirements.

The majority of complaints from consumers are due to interruptions to supply. This variable can therefore be initially omitted as the burst frequency on the distribution mains will be tracked.

3.15 CREATION AND MONITORING OF DISTRICT METERED AREAS (DMA'S)

Farley and Trow (2002) recommend that in order to effectively manage the system, it must be broken up into smaller reservoir areas that can be monitored. If an average zone size of 2000 connections is assumed, this will yield a total of 250 discrete areas in the EWS distribution system that be managed. This practice will be complimented by the installation of PRV's as each new PRV zone is metered so that it becomes a DMA as well.

At present, the reservoir and district meters are read on a monthly basis. Areas of interest are monitored further with the use of flow and pressure loggers and a few areas are monitored on line with the use of radio and GSM. A recommendation and been made to senior management to rather monitor all of these areas real time and this has been accepted. It is envisaged that this system will be put in place over the next three years and it will enable a better system of control on each of the DMA's. The Utility will thus be able to know at any point in time exactly what the flows and losses are in any one area, and this information will be aggregated up to the reservoir area, each of the six operational areas and to the entire system as a whole. The Utility will be able to set parameters for alarm functionality and also be able to track trends over time and plan their interventions accordingly.

According to Farley (2012), there is an alternate to traditional discrete DMA design. Where the discretisation of a network leads to problems of low pressures and poor water quality particularly in dead ends, virtual zones can be created by installing meters at the position where the zone would normally be isolated. Water is then free to mix from one zone to another through multiple feeds, and the SIV can be determined for each area by using the totalised flow from the meters.

CHAPTER 3 - SUMMARY

- A number of interim measures can be undertaken to reduce losses and extend the service life of the pipeline .
- Of the four real loss initiatives examined, pressure reduction has the highest return, followed by active leakage control, speed and quality of repairs and lastly, pipeline materials management.
- Five activities are conducted to explore and maximise the potential savings from pressure management:
  - The existing valves are serviced to ensure that remain at their design settings
  - Valves of high importance and high risk have had failure sensing devices fitted
  - New DMA's are created and new PRV's are installed
  - Existing valves are re-examined to lower older settings
  - Existing valves are examined to see if they are candidates for some form of advanced control.
- Of all the advanced control techniques, the remote node sensing and control produces the highest returns.
- Areas under intermittent supply should be avoided and immediate corrective action taken when demand and losses outstrip the available supply.
- Five different levels of leak detection are used at EWS. The best return comes from the "find and fix" approach using Category B plumbers.

- Information on the performance of the network originates from a number of sources and in order to make informed accurate decisions, it is important to be aware of the accuracy and reliability of this data. The accuracy of this data needs to be improved over time.
- Morrison et al., (2007) warned that "*Care should be taken however when a partial substitution of the worst mains is undertaken, that the leakage in the original network does not increase.*"
- Various approaches to mains replacement were examined and the benefits and drawbacks of each were examined. Partial mains replacement without pressure management will invariably increase the losses and burst frequency.
- Where distribution systems have been designed for continuous supply, intermittent supply should be avoided. The frequency of connection and mains bursts can increase in the order of 300%.
- The Cost / Benefit, Payback Period and Net Present Value analyses were all examined and calculations made for various zones to check potential project viability. The simpler CBA is sufficient for most public sector utilities.
- The comparative cost analyses conducted using both the NPV and MCD analyses revealed that EWS should continue to use the mPVC pipe.
- Regular planned maintenance is important to keep the infrastructure in good condition and NRW reduction results sustainable.
- Ten of the main causes of pipe failures were identified and mitigating actions compiled to reduce the causes of these failures.
- A macro approach to handing the data collection and analysis is considered appropriate in the initial stages of the programme as it will yield quick results, it will not require many resources and it will not require exhaustive data collection.
- In order to effectively manage the distribution system, it must be broken up into smaller reservoir areas that can be managed. An alternate to this is to create dynamically metered zones.

CHAPTER 4 – ANALYSIS OF DECISION VARIABLES

4.1 THE IWA PERFORMANCE INDICATORS

There are 170 performance indicators in the book "Performance Indicators for Water Supply Services" by Helena Alegre et al., and this text covers many of the indicators that are required to monitor the performance of a Utility and a water distribution network. These indicators are spread across six key areas of the business as shown in Table 4.1.

Table 4.1: The IWA Performance Indicators (Alegre, 2006)

IWA Performance Indicator	Abreviated Name	Total Number of Indicators
Water Resource	WR	4
Personnel	PE	26
Physical	Ph	15
Operational	Op	44
Quality of Service	QS	34
Economic and Financial	Fi	47
Totals		**170**

Many of these indicators relate to the Utility as a whole and some of these relate to the performance of the water mains. In addition to this, there are a number of further indicators that can be tracked to provide further information on the distribution system.

Many of these identified indicators are used in the analysis programmes that were discussed in Chapter 2. The complete set of indicators is shown in Appendix B. 22 Indicators have been chosen that are considered to be primary indicators used to inform a mains replacement programme. These are listed in Table 4.2:

Table 4.2: The Primary Performance Indicators for Mains Replacement (Alegre, 2006)

ABBREVIATED NAME	PERFORMANCE INDICATOR	DESCRIPTION OF PERFORMANCE INDICATOR
Wr1	Inefficiency of use of Water Resources (%)	Percentage of water that enters the system and is lost by leakage and overflows up to the point of customer metering.
Ph3	Treated Water Storage Capacity (days)	Capacity of transmission and distribution service reservoir per unit volume of system water input.
Op5	Active Leakage Control Repairs (No./100km/year)	Number of leaks detected and repaired due to active leakage control per unit of main length.
Op23	Water Loss per Connection (m³/connection/year)	Total (apparent and real) losses, expressed in terms of annual volume lost per service connection. This indicator is adequate for urban distribution systems.
Op24	Water Losses per Mains Length (m³/connection/year)	Total (apparent and real) losses, expressed in terms of annual volume lost per mains length. This indicator is adequate for bulk supply and low service connection density distibution systems.
Op25	Apparent Losses (%)	Percentage of the water provided to the system (system input volume minus exported water) that corresponds to apparent losses. This indicator is adequate for urban distribution systems.
Op27	Real Losses per Connection (l/connection/day) when system is pressurised)	Real losses, expressed in terms of the average daily volume lost per connection. This indicator is adequate for urban distribution systems.
Op28	Real Losses per Mains Length (l/km/day) when system is pressurised	Real losses, expressed in terms of the average daily volume lost per mains length. This indicator is adequate for bulk supply and low service connection density distribution systems.
Op29	Infrastructure Leakage Index (-)	Ratio between the actual real losses and an estimate of the minimum real losses that could be technically achieved for the system operating pressure, average service connection length and service connection density.
Op31	Mains Failure (No./100km/year)	Average number if mains failures per 100km of mains and per year.
Op32	Service Connection Failures (No./1000 connections/year)	Average number of service connections failures, expressed per 1000 connections and per year.
Qs10	Pressure of the Supply Adequacy (%)	Percentage of the delivery points (one per service connection) that receive and are likely to receive adequate pressure.
Qs11	Continuity of Supply (%)	Percentage of hours when the (intermittent supply) supply system is pressurised.
Qs14	Interruptions per Connections (No./1000 connections/year)	Average number of interruptions per service connection per year.
Qs18	Quality of Supplied Water (%)	Percentage of the total number of treated water tests performed that comply with the applicable standards or legislation.
Qs21	Physical -Chemical Tests Compliance (%)	Percentage of the total number of physical-chemical tests of treated water performed that comply with the applicable standards or legislation.
Qs28	Pressure Complaints (%)	Percentage of service complaints regarding pressure problems.
Qs30	Water Quality Complaints (%)	Percentage of service complaints regarding water quality problems.
Qs31	Interruption Complaints (%)	Percentage of service complaints regarding interruption problems.
Fi1	Unit Revenue (R/m³)	Revenue per cubic meter of authorised consumption.
Fi35	Average Age of Tangible Assets (%)	Percentage of the historical value of tangible assets that corresponds to depreciated historical value of tangible assets.
Fi46	Non-Revenue Water by Volume (%)	Percentage of the system input volume that corresponds to non-revenue water.

Table 4.3 details another 22 indicators that have not been included in the work of Alegre (2006). These indicators have been developed by the author and will provide further insight into the performance of the water mains over and above the pipe information that will be stored in the GIS. The indicators highlighted in bold are those deemed to provide direct and useful insight when trying to prioritise mains for investigation / replacement.

Table 4.3: Additional Performance Indicators

ABBREVIATED NAME	PERFORMANCE INDICATOR	DESCRIPTION OF PERFORMANACE INDICATOR
AI 1	**Reactive Leakage Control Repairs (No./100km/year)**	**Number of leaks detected and repaired due to reactive leakage control per unit of main length.**
AI 2	Geotechnical Environment	Geotechnical Environment / Instability
AI 3	Soil type	Soil type
AI 4	Saturated soils	Saturated soils
AI 5	Fault lines	Fault lines
AI 6	Soil temperature	Soil temperature
AI 7	Predominant Failure Mechanism	Predominant Pipe Failure Mechanism
AI 8	Quality of Installation	Quality of Installation by Contractor
AI 9	**Pressure Fluctuations**	**Dynamic Pressure Fluctuations**
AI 10	Residual pipe pressure reserve	Difference between pipe class and static pressure
AI 11	Traffic Loading	Traffic Loading present over pipe
AI 12	**Illegal Connections**	**Density of Illegal Connections present in area**
AI 13	Aggressive Water	Aggressive Water Chemical Composition
AI 14	Energy usage	Energy usage in pumped system (kw/h)
AI 15	**Failure growth rate**	**Failure growth rate pa**
AI 16	Pipe Roughness	Pipe Roughness coefficient
AI 17	**Pipe Criticality**	**Pipe Criticality in network status**
AI 18	Flow Delivered	Flow Delivered (m3/hr)
AI 19	Critical facilities - Hospitals / industry / commerce / Schools	Critical facilities - Hospitals / industry / commerce / Schools
AI 20	**Street Paving**	**Street Paving present over pipe**
AI 21	**Traffic analysis**	**Impact on traffic if main replaced by open cut**
AI 22	**Area to be expanded**	**Area to be expanded and new demand for new connections**

In Table 4.4, the 192 indicators have been distilled down into the most useful system indicators, useful DMA indicators and recommended and mandatory indicators for mains replacement.

Table 4.4: Summary of Performance Indicators

PERFORMANCE INDICATOR	ABBREVIATED NAME	TOTAL NUMBER OF INDICATORS	NUMBER OF USEFUL SYSTEM INDICATORS	NUMBER OF USEFUL DMA INDICATORS	RECOMMENDED INDICATOR INDICATOR FOR MAINS REPLACEMENT	MANDATORY INDICATOR FOR MAINS REPLACEMENT
Water Resource	WR	4	2	1	1	0
Personnel	PE	26	20	0	0	0
Physical	Ph	15	7	3	1	0
Operational	Op	44	32	21	9	3
Quality of Service	QS	34	25	23	8	3
Economic and Financial	Fi	47	26	3	3	0
Additional Indicators	Ai	22	1	22	8	0
Totals		**192**	**113**	**73**	**30**	**6**

4.2 FAULT DATA ANALYSIS

Table 4.5 shows the data that is collected in the UK National Faults Database. These codes and fields were determined after consultation with 21 UK water utilities and is the most comprehensive dataset available. The balance of the database structure is shown in the Appendix. This enables detailed information regarding the faults that occur in the field to be collected. All these utilities now collect the data in this format and this enables comparison and trending to be conducted on a national scale. This analysis is both useful and important in terms of being able to determine the main causes of failures and the materials on which they are occurring. The engineers are then enabled to make informed decisions regarding the spending of Operational and Capital budgets.

Table 4.5: Fault Data Collected in the UK National Faults Database (UKWIR, 2003b)

Failure Location	Failure Mode	Cause
Pipe	Longitudinal Split	Pressure
		Corrosion (Iron)
		Faulty Product
		Point Load (generally only PVC)
		Ground movement
		3rd party damage
	Circumferential crack	Corrosion (Iron)
		Poor bedding
		Ground movement
		3rd party damage
	Hole	Corrosion
		Erosion
		3rd party damage
Joint (socket & spigot)	Seal	Rubber ageing
		Grit in Seal
		Ground movement
		3rd party damage
	Pull Out	Ground movement
		Surge event
		Poor installation
		3rd party damage
Threaded ferrule	Pulled out of main(Iron)	Corrosion
		Poor workmanship
		Faulty product
		3rd party damage
	Hole in Ferrule body	Corrosion
		Faulty Product
		3rd party damage
	Seal to service pipe failed	Corrosion
		Poor workmanship
		Faulty Product

		3rd party damage
Mechanical ferrule	Pulled off main/seal	Corrosion
		Poor workmanship
		Faulty Product
		3rd party damage
	Hole (in ferrule body)	Corrosion
		Faulty Product
		3rd party damage
	Bolt Failure	Corrosion
		Poor workmanship
		Faulty Product
		3rd party damage
Electro-fusion fittings (incl. top-tees/saddles)	Leak/ blown off /pull out	Faulty Product
		Poor workmanship
		Overpressure
		3rd party damage
Mechanical Fitting	Seals	Ground movement
		Loose/too few bolts
		Corrosion
		Faulty Product
		Poor workmanship
		Overpressure/ surge
		3rd party damage
	Hole (in fitting body)	Corrosion
		Faulty Product
		Overpressure/surge
		3rd party damage
Service pipes	As for pipe	
Valve/meter	As for mechanical fittings	

EVIDES BV Faults Database

Meijer, (2012) reported that the fault data detailed in Table 4.6 is that collected by the Dutch Water Utility Evides BV. The management of assets at this Utility is fairly advanced and analysis of this fault data enables Evides to expand the traditional reporting framework and consider the triple bottom line of social, environmental and financial performance (people, planet and profit). Their capital expenditure programmes are designed to minimise risk and achieve optimal management of their physical assets. The likelihood and consequence of failure of all system components is examined thus embracing the concepts of the Publicly Available Specification (PAS55) published by the British Standards Institution. The balance of the database structure is shown in the Appendix.

Of interest, the NRW in The Netherlands is the lowest in Europe and is approximately five percent.

Table 4.6 Fault Data used by Evides BV

FAULT DESCRIPTOR
Awareness time
Location time
Repair time
Duration to repair the fault
Plumber assigned
Fittings used for fixing the fault
Cost of repair
Estimated rate of leakage
Last fixer of the fault on the section
Date of last fault for the section of the pipeline
Frequency of bursting
Nature of fault
Mode of failure
Size of the fault
Possible cause of the fault
Point of fault
Function of the pipeline
Depth of pipeline
Material
Diameter
Construction year of the pipeline
Construction date of the pipeline
General condition of the pipe
Average zone night pressure
Average pressure
Recommendation
General Remark

Table 4.7 Fault Codes used by Evides BV

POINT OF FAULT	TYPE OF BREAK	MODE OF FAILURE
On the joint	Burst pipe	Longitudinal
Along the pipeline	Broken pipe	Circular (Circumferencial)
Valve point	Leaking Valve	Hole/ Pit
	Underground leak	Joint
	Leaking Meter	Broken pipe
	Multi broken pipe	Unclassified
	No water	
	Leaking pipe	
	Low pressure	
	Heavily leaking pipe	

One cannot fault the exceptionally low levels of losses achieved by Evides BV. Comparing the data in Table 4.6 and Table 4.7 with that collected in the UK national faults database, there is some duplication and more importantly, a number of important options have been omitted. As the pipes age and the levels of failure rise in the Dutch system, it will be more difficult to analyse the meagre data collected to pin point causes of failures. This omission will cause their replacement programmes to be sub-optimal.

EWS Fault Database

A fault recording and job scheduling system called "Faultman" is used at EWS. It was written in-house in the early 1990's and was designed to record and track the progress of reported faults. Faultman fulfils this primary task adequately, but the fault data in this system is extremely difficult to interrogate as much of the data is recorded in simple text fields with no control or consistency applied to the input.

Apart from the material and pipe diameter, the following data is currently recorded for all faults that are repaired by EWS.

Table 4.8 EWS Faultman Codes

ITEM TYPE	TYPE OF BREAK	CAUSE OF BREAK
None	None	None
Pipe	Broken Back	Soft AC
Coupling / Collar	Split	Damaged
Valve	Hole	Roots
Ferrule	Leak	Pressure
Meter	Other	Corrosion
Gasket		Earth Movement
Tee		Shallow
Bend		Bedding
Meter Assembly		Workmanship
Saddle		Packing
Hydrant		Unknown
Air Valve		
PRV		
Other		

The data collected by EWS is more comprehensive than the data collected by Evides BV but not as comprehensive as the in UK National Faults Database. It was found in this investigation that the database in which this data is stored is extremely difficult to access as several fields of free flowing text exist that contain critical data. This data is also not currently spatially linked so the engineer is unable to graphically visualise where the faults are taking place. This would be an invaluable enhancement. It is also imperative that standard drop down lists with programmatic logic checks on the input. Ideally, this information will be captured electronically by the artisans on site with a low cost ruggedized device such as the "Juno" manufactured by Trimble (Pty) Ltd, which has the added advantage of being able to capture photos and the coordinate of the repair. As this device is fitted with GSM this data can be transmitted back instantaneously to the server at head office.

It would be of further advantage to collect and analyse samples from the field to conclusively determine the cause of failure. These tests can also for instance predict the remaining useful life in the case of asbestos cement pipes.

Of greater concern however, is that no training or quality control is currently taking place to ensure that this data is reliably and accurately captured. As a consequence, the data recorded in this system is not only extremely difficult to interrogate but the credibility of much of the data is also questionable. This data is the most important data that is required in the mains replacement decision making process. It is essential that attention is given to these aspects so that in the future, optimised decisions can be made with confidence.

4.3 DISCUSSION ON PERFORMANCE INDICATORS

Macleod (2012) reported that the primary reasons for mains replacements are to reap the financial and operational benefits. Environmental and social aspects could be taken into account under exceptional circumstances should these issues become critical but are not used on a day to day basis.

Improving the primary operational drivers of burst frequency and NRW will result in the following 21 primary indicators previously identified also improving as they are closely linked:

• Water Resource Indicator	Wr1	Inefficiency of use of Water Resources
• Physical Indicator	Ph3	Treated Water Storage Capacity
• Operational Indicators	Op5	Active Leakage Control Repairs
	Op23	Water Loss per Connection
	Op24	Water Losses per Mains Length
	Op27	Real Losses per Connection
	Op28	Real Losses per Mains Length
	Op29	Infrastructure Leakage Index
	Op31	Mains Failures

		Op32	Service Connection Failures
•	Quality of Service Indicators	Qs10	Pressure of the Supply Adequacy
		Qs12	Continuity of Supply
		Qs14	Interruptions per Connections
		Qs18	Quality of Supplied Water
		Qs21	Physical -Chemical Tests Compliance
		Qs28	Pressure complaints
		Qs30	Water quality complaints
		Qs31	Interruption complaints
•	Financial Indicators	Fi35	Average Age of Tangible Assets
		Fi46	Non-Revenue Water by Volume

The South African environment is very different to that of the developed countries where the losses are lower, consumer bodies are more vocal, advanced reliable data collection is taking place and the ratio of engineers to person served is considerably higher. The utilities in these countries are in a position to utilise sophisticated software programmes to analyse their networks to determine the most beneficial areas where mains replacement should take place. These decisions are often influenced by public pressure and environmental considerations. According to Van Den Brink-Bil (2012) in some European cities, especially those with historical significance, all service providers coordinate their efforts so that all services are replaced at one time so that the inconvenience to the public is minimised in the long term.

In SA the networks in many areas have deteriorated to such an extent that the losses are over 50% and the mains are well overdue for replacement (McKenzie, 2012). Providing that the obvious reporting errors have been eliminated, replacing the networks is likely to bring about an improvement in these areas. It is therefore just a matter of deciding which area to replace first to maximise the returns.

Table 4.9: Minimum Six Performance Indicators for Mains Replacement

Abbreviated Name	Performance Indicator	Description of Performance Indicator
Op27	Real Losses per Connection (l/connection/day when system is pressurised)	Real losses, expressed in terms of the average daily volume lost per connection. This indicator is adequate for urban distribution systems.
Op31	Mains Failure (No./100km/year)	Average number if mains failures per 100km of mains and per year.
Op32	Service Connection Failures (No./1000 connections/year)	Average number of service connections failures, expressed per 1000 connections and per year.
QS12	Continuity of Supply (%)	Percentage of hours when the (intermittent supply) supply system is pressurised.
QS14	Interruptions per Connections (No./1000 connections/year)	Average number of interruptions per service connection per year.
QS18	Quality of Supplied Water (%)	Percentage of the total number of treated water tests performed that comply with the applicable standards or legislation.

Of the 21 primary IWA indicators, the above six indicators have been identified as the most pivotal in monitoring the performance of a DMA. Kleiner & Rajani (2002) report that an efficient method of assessing the water main condition is to analyse pipe break frequencies over time. Of the six indicators, the real losses and failures are the most important. Threshold levels such as three breaks / km / year in one section or real loss rates exceeding say 0.06Ml/km/day can be used to trigger an investigation leading to pipe replacement.

It is suggested that the primary drivers in the initial phases of the mains replacement programme should financial only. Many of the other social and environmental criteria will be met as the financial situation is improved. Provision should be made however, for a local investigation to be triggered in the event of the burst frequency exceeding a given level of say three times higher than the average or on request of senior management.

CHAPTER 4 - SUMMARY

- It is essential that a Utility measure and monitor its performance and the IWA performance indicators are an excellent basis on which to do this.
- It is also essential that a pipe replacement programme is guided by the faults that are occurring in the field.

- The UK national faults database has been researched by many professionals and practitioners and is an excellent comprehensive methodology to subscribe to.
- The fault data that is collected must be checked for accuracy and consistency in order that the decisions that result can be relied upon. Training of staff will be an essential component to be used to achieve this.
- The 170 IWA indicators can be distilled to 21 primary indicators, which can be further reduced to just 6 indicators to be used to guide replacements. Of the six indicators, the real losses and failures are the most important.
- Initial mains replacement decisions are to be made based on financial grounds only. An exception to this would be where a localised main exceeds a given threshold for number of bursts/km/year.
- Over time, all of the 170 performance indicator data should be recorded or calculated as applicable.

CHAPTER 5 – RESULTS OF ANALYSES AND INVESTIGATION

5.1 IMPACT OF THE WATER MAIN REPLACEMENT METHODOLOGIES

Records from reservoir zones totalling 2438km were analysed where a total of 506km (21%) of the distribution mains were replaced. As revealed in the literature review, Grimshaw (2006) and Morrison et al. (2007) both cautioned about the negative impacts of partial mains replacement in a zone. The comparison of the average daily demand, real losses and average operating pressures has been detailed in Table 5.1 and this highlights the benefits of pressure management and an integrated approach.

Table 5.1: Before and After Performances with and Without Pressure Management

	DMA's Without Pressure Control	DMA's With Pressure Control	Combined DMA's
Total zone reticulation length (km)	1 611	827	2 438
Total reticulation length rehabilitated / analysed (km)	289	217	506
% of reticulation replaced	18%	26%	21%
Average Daily Demand before mains rehabilitated (kl/day)	6 097	4 022	10 119
Real losses before mains replacement (kl/hr)	2 489	2 715	5 203
Average Operating Pressure before mains replacement (m)	57	59	57
Average Daily Demand after mains replacement (kl/day)	7 180	3 074	10 254
Real losses after mains replacement (kl/hr)	2 325	1 695	4 019
Average Operating Pressure after mains replacement (m)	57	52	56
% reduction in AZP	0%	-11,5%	-3,1%
% reduction in average daily demand	+17,8%	-23,6%	+1,3%
% reduction in real losses	-6,6%	-37,6%	-22,8%

The primary objectives of replacing water mains are to lower the losses, lower the burst frequency and improve the quality of service. Table 5.1 shows that where mains were replaced without pressure management, the daily demand increased by 17.8% and the real losses reduced by only 6.6%. In contrast, where pressure management was carried out with mains replacement the daily demand decreased by 23.6% and the real losses reduced by a 37.6%. It is acknowledged that these results could be influenced by other outside factors such as the season or economics. As the analysis has been conducted over a period of approximately 18 months, small seasonal variations will cancel each other out and the results overwhelmingly point to the advantage of pressure reduction.

In Figure 3.27, prior to the replacement of mains, the burst frequency index (BFI) for mains was 5.6 and the BFI for services was 17.3. After the construction activities were completed the BFI for mains was 6.5 and the BFI for services was 19.2. From a macro perspective, this shows the burst frequency before and after mains replacement has remained virtually unchanged after 1370km of mains were replaced. This replaced length represents 12% of the total system and intuitively, one would expect to realise some tangible benefit in this regard. At a reservoir zone level, the post mains replacement burst frequency often increased due to a number of reasons:

- The existing mains do not react well to the large pressure variations when contractors are replacing mains.
- The new mains have lower real loss rates which results in the dynamic head being raised in the system. This subtle change in pressure results in an increase in losses in the unchanged pipes and an increase in burst frequency.

Another important observation in the areas where partial mains replacement took place was that many of the water meters were damaged due to air and debris during the course of the works.

Table 5.2: Impact of Mains Replacement on Consumer Meter Sales Volumes

DMA/Zone	Number of Connections Analysed	Difference in Average Daily Consumption (kl/day) Before anf After Mains Replacement
Alverstone Nek	813	-28
Bluff South	644	22
Chatsworth 4	2 827	3
Emoyeni Knelsby	1 214	-155
Montille	146	-467
Phoenix	3 892	-204
Tongaat South	2 254	43
Umlazi 1	6 760	-542
Totals	**18 500**	**-1 330**

Table 5.2 shows that in summary, the overall average daily billed metered volume decreased by 1 330 kl/day, or approximately 4,7% from the baseline billed volumes. Arising from this discovery, a meter maintenance programme was initiated that followed the areas in which mains

replacement occurred in order to ensure that optimal billing was maintained.

5.3 RESULTS OF LEAK DETECTION

Leak Detection and Repair Statistics – eThekwini Municipality

The summary of key statistics and results achieved through the leak detection and repair program for the period April 2009 to December 2010 have been presented in Figures 5.1 and 5.2 as well as Tables 1 to 5. Figures 5.1 and 5.2 present the overall number of leaks repaired per month, both overall and specifically for the Category B plumbers.

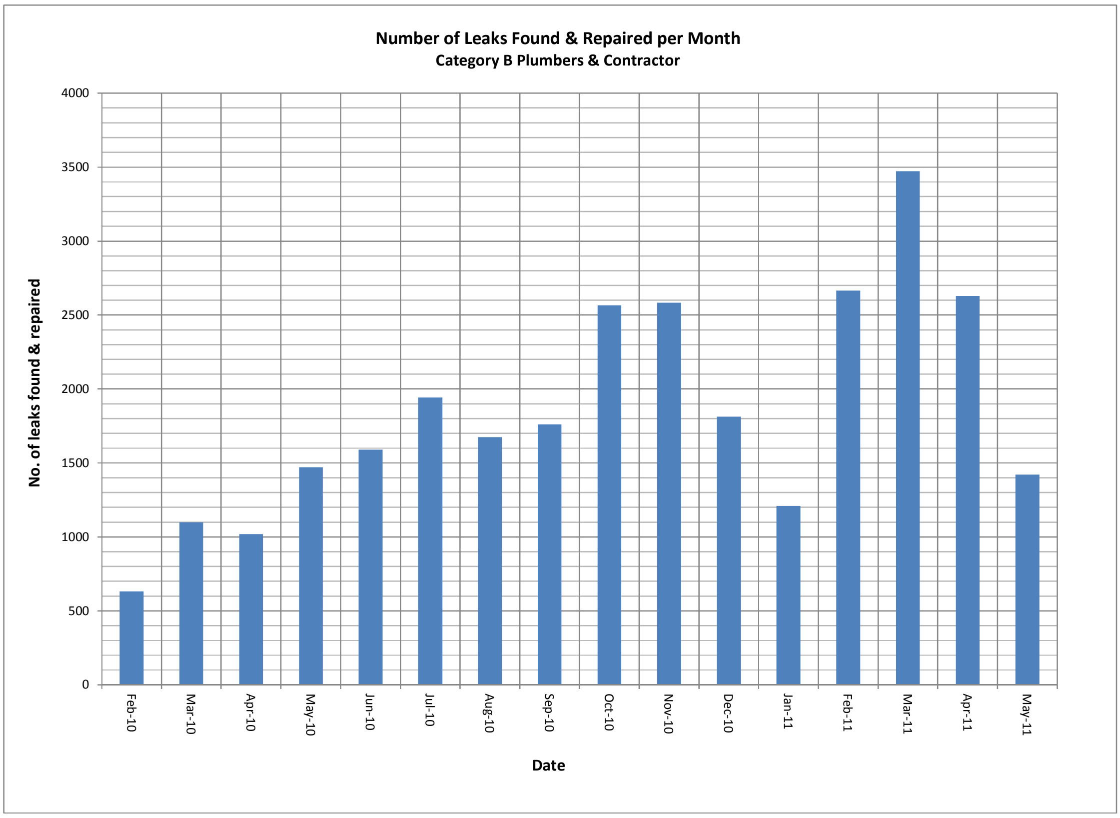

Figure 5.1: All Leak Detection and Repair Results per Month

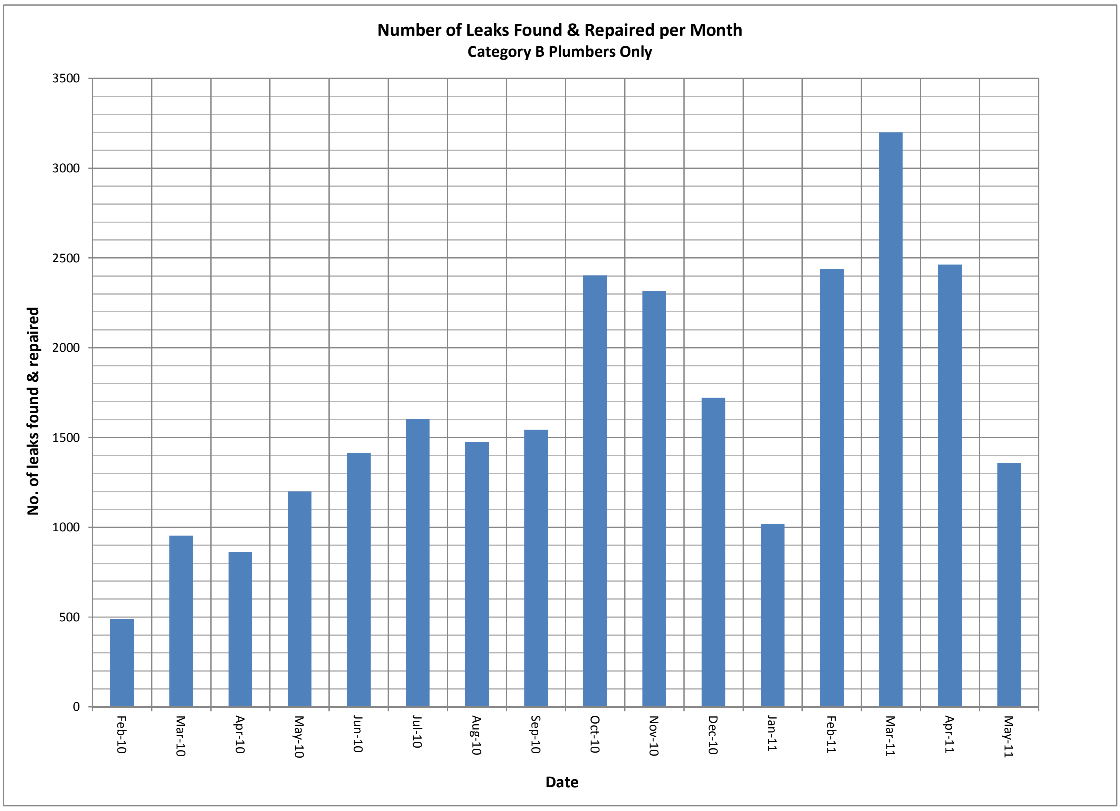

Figure 5.2: Leak Detection and Repair Results per Month – Category B Plumbers

Tables 5.3 to 5.7 present, respectively, total length of mains surveyed, total number of leaks located and repaired, breakdown of the type of leaks, location of leak and leak repair time analysis.

Table 5.3: Total Length of Reticulation Mains Surveyed

Length Of Main Surveyed (Km)	*North (Km)*	*South (Km)*	*West (Km)*	*Totals (Km)*
Level 1	*121*	*8 455*	*9 379*	*17 955*
Level 2	*2 425*	*3 445*	*4 434*	*10 304*
Level 3	*658*	*1 978*	*531*	*3 167*
Level 4	*-*	*23*	*8*	*31*
Level 5	*-*	*44*	*46*	*90*
Total	*3 204*	*13 945*	*14 398*	*31 547*

Table 5.4: Total Number of Leaks Located and Repaired

	North	*South*	*West*	*Total*
Total Leaks Located	*10 768*	*15 589*	*11 591*	*37 948*
Total Leaks Repaired	*10 471*	*13 302*	*10 262*	*34 035*

Table 5.5: Breakdown of Type of Leaks Found and Repaired

Type Of Leaks	North	South	West	Total
Total Visible Leaks	10 764	15 099	11 558	37 421
Total Visible Repaired	9 925	12 866	10 229	33 020
Total Non-Visible Leaks	4	490	32	526
Total Non-Visible Leaks Repaired	4	432	32	468

Table 5.6: Breakdown of Leak Location

Leak Location	North	South	West	Total
Mainline Leaks	1 828	4 521	2 558	8 907
Service Connection Leaks	8 100	8 912	5 868	22 880
Meter Leaks	843	2 156	3 165	6 164

Table 5.7: Breakdown of Leak Repair Time and Quality Control

Leak Repair Time/Quality	North	South	West	Total
Average Repair Time (Days)	46	21	15	82
Total No. Of Quality Checks	349	1 926	943	3 218
% Quality Control	8%	19%	13%	40%
% Still Leaking	16%	15%	9%	13%

Impact of Leak Detection and Repair on Overall eThekwini Municipality Bulk Water Purchases

Individual Reservoir Supply Zones

In terms of determining the impact of leak detection and repair activities on the levels of water loss, it was decided to focus attention on certain reservoir supply zones that either had high minimum night flows or had known problems with water leaks and bursts. For the purposes of this report therefore, the results and analysis of six reservoir supply zones shall be presented.

Table 5.8 presents the numbers of leaks found in the Chatsworth 4, Umlazi 1, Umlazi 2, Mpumalanga 6, Wyebank and Hammarsdale High Level Reservoir zones as well as the estimated and confirmed volume of water recovered (in kl/hr). Estimated volume figures are derived from approximate volume lost per leak, while the confirmed volume of water recovered is obtained by subtracting the Minimum Night Flow (Q_{mnf}) achieved at the end date of the reservoir outlet flow profile from the start date of the profile.

Table 5.8: Estimated & Confirmed Volume of Water Recovered per Reservoir Zone

Reservoir Zone	*No. of Leaks Found*	*Estimated Volume Recovered (kl/hr)*	*Confirmed Volume of Water Recovered (kl/hr)*
Chatsworth 4	1 329	99	128
Umlazi 1	3 152	366	190
Umlazi 2	3 162	354	121
Mpumalanga 6	560	32	30
Wyebank	796	48	68
Hammarsdale HL	349	28	5
Totals	**9 348**	**927**	**542**

Figures 5.3 to 5.8 present the flow profiles and number of leaks found per month for the Chatsworth 4, Umlazi 1, Umlazi 2, Mpumalanga 6, Wyebank and Hammarsdale High Level Reservoir supply zones respectively. The Minimum Night Flow (Q_{mnf}) dropped from 502 kl/hr to 374 kl/hr in Chatsworth 4, from 631 kl/hr to 441 kl/hr in Umlazi 1, from 1093 kl/hr to 972 kl/hr in Umlazi 2, from 48 kl/hr to 18 kl/hr in Mpumalanga 6 and from 128 kl/hr to 60 kl/hr in Wyebank and from 19 kl/hr to 14 kl/hr in Hammarsdale HL zone.

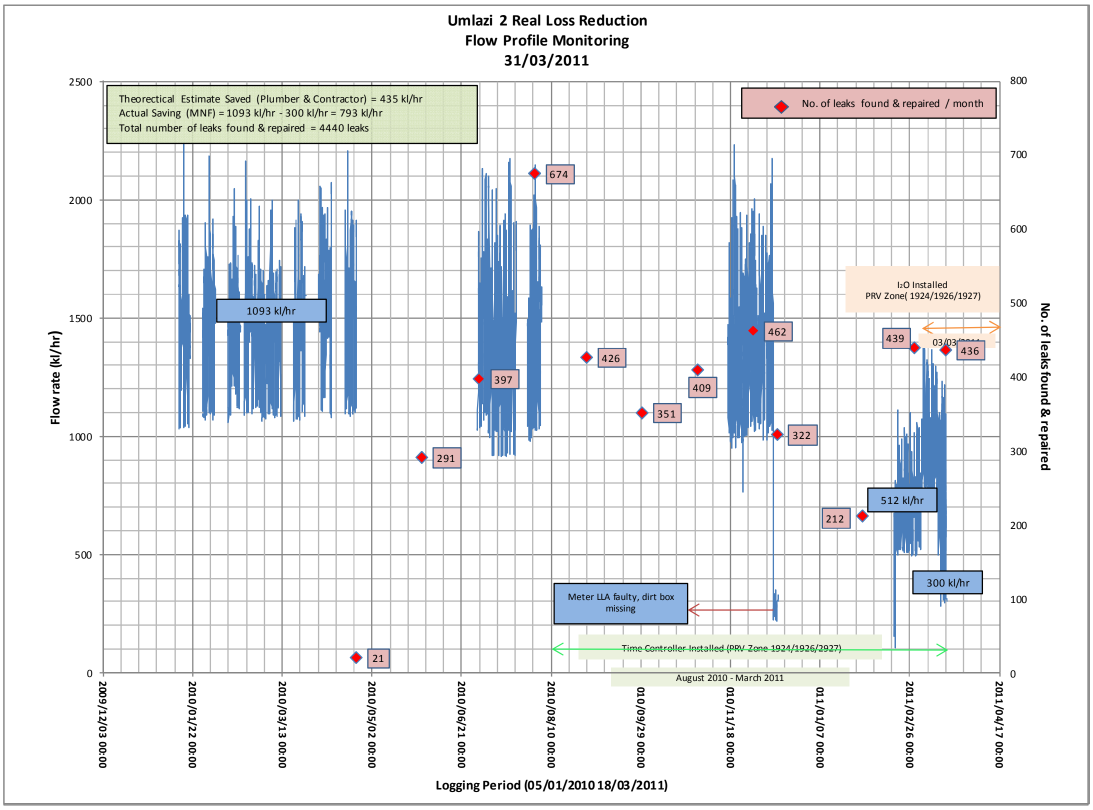

Figure 5.3: Umlazi 2 Reservoir Outlet Flow Profile and Results

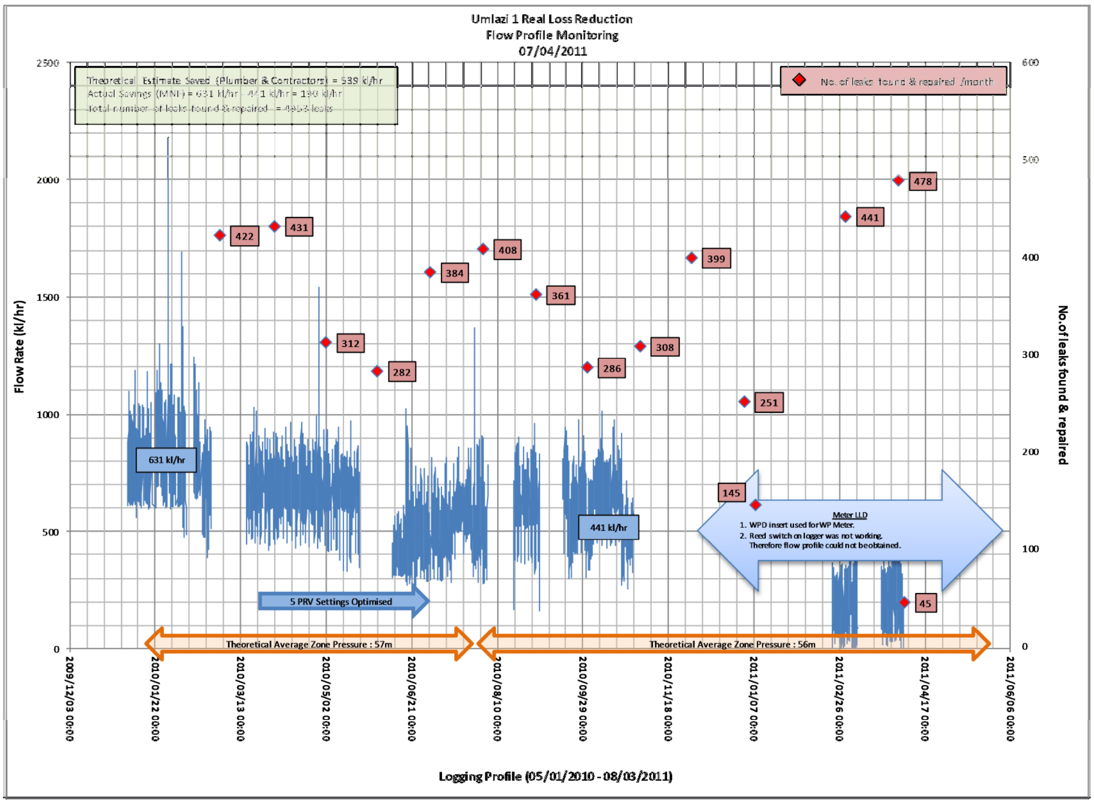

Figure 5.4: Umlazi 1 Reservoir Outlet Flow Profile and Results

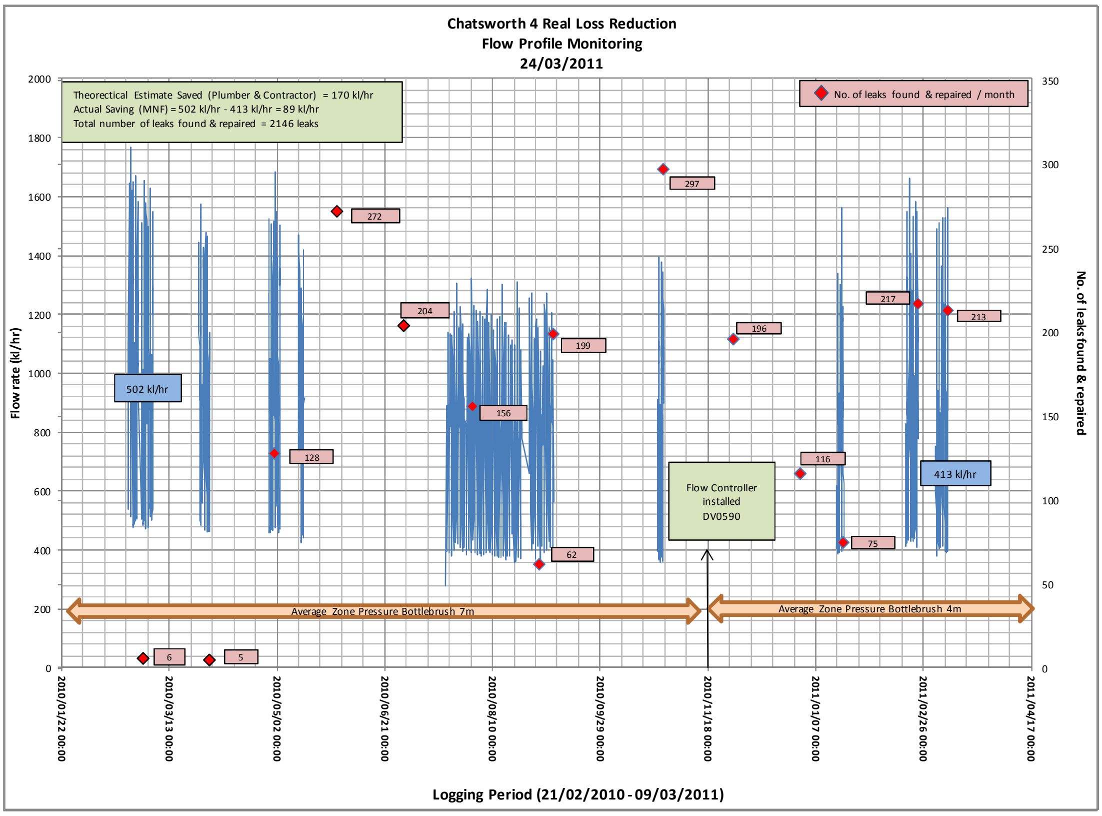

Figure 5.5: Chatsworth 4 Reservoir Outlet Flow Profile and Results

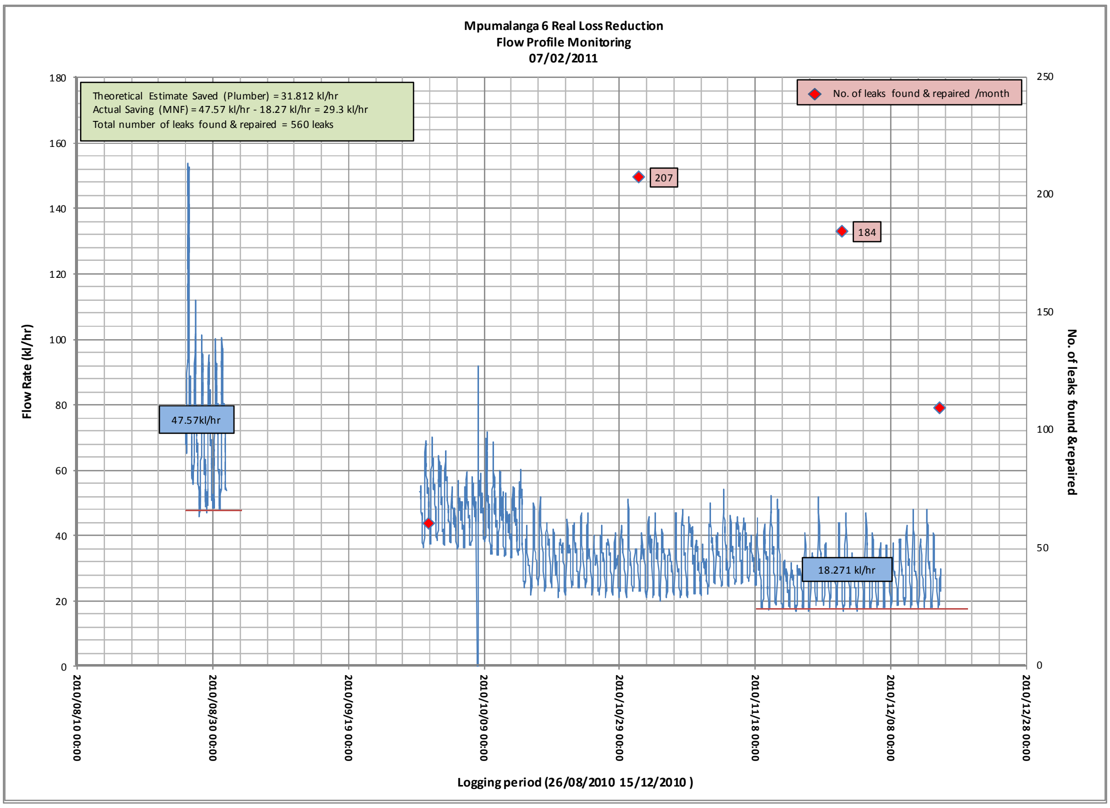

Figure 5.6: Mpumalanga 6 Res Outflow Flow Profile and Results

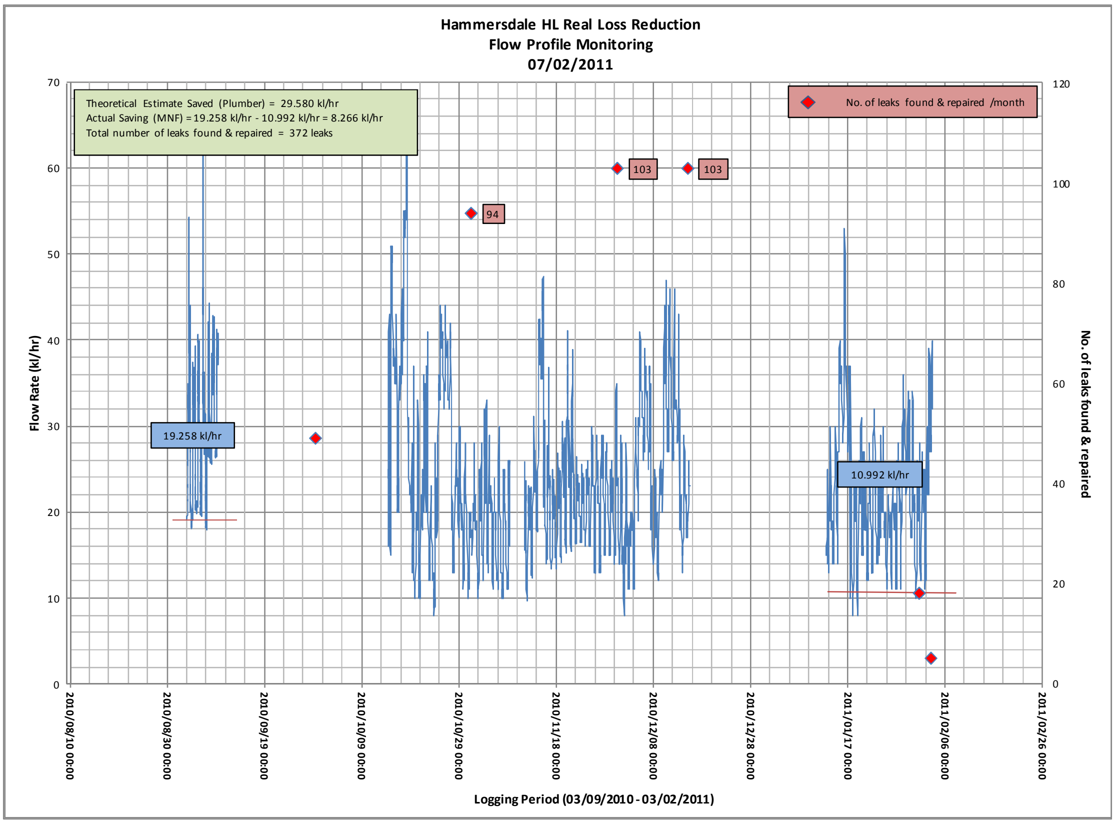

Figure 5.7: Hammarsdale HL Res Outlet Flow Profile and Results

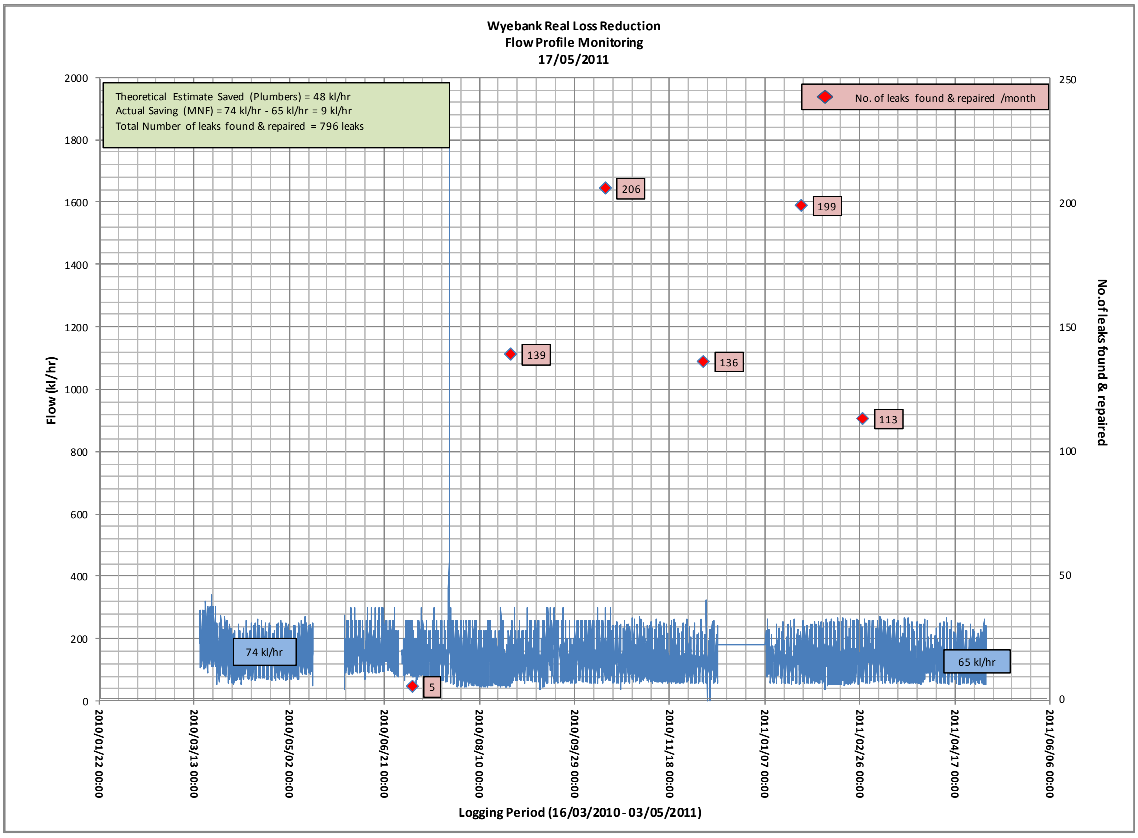

Figure 5.8: Wyebank Reservoir Outlet Flow Profile and Leak Detection Results

Impact of Pressure Management on Main Burst Frequency and Service Connection Leak Frequency

Example 1 – The Durban CBD

The water pressure in the Durban CBD has been lowered from an average of 61m to 37m, a decrease of 39%. The zone has 130.4km of mains and 4790 consumer connections. As shown in the Figures 5.9 and 5.10, the mains bursts dropped from an average of 34.5/100km/year to 9.6/100km/year (72%). The service connections leaks dropped from an average of 29.3/1000 connections/year to 16.7/1000 connections per year (43%). To put these numbers in perspective, Lambert and Thornton (2011a), report that an ideal system would have no more than 13 mains bursts/100km/year and 3 service connection leaks /1000 connections/year.

The SIV has dropped by 24.8Ml / day representing a saving of R38 733 508 per annum. The cost of this installation was R2.1m representing an excellent return on investment. By comprision, if R2m had been spent on mains replacement, only 2km out of the 130km in the zone would have been replaced.

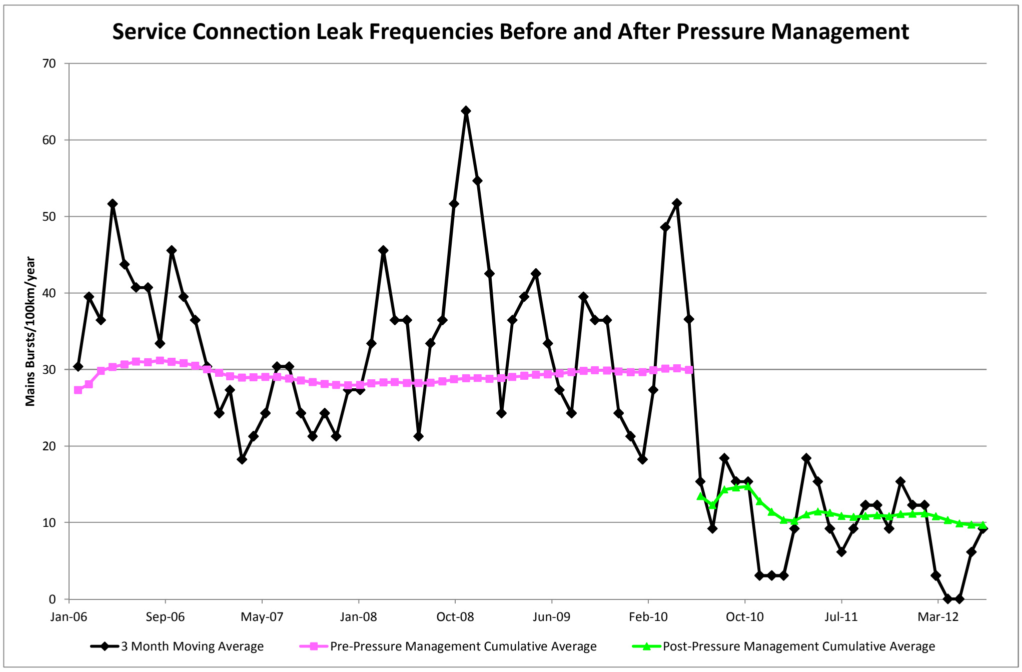

Figure 5.9: Service Connection Leak Frequency Before and After Pressure Management in the Durban CBD

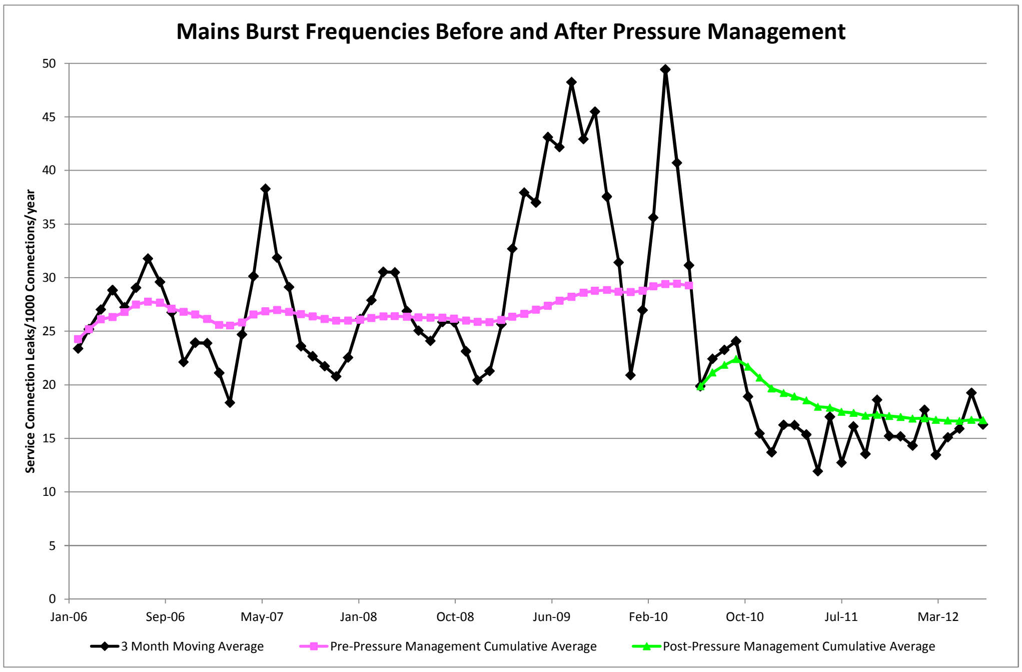

Figure 5.10: Mains Burst Frequency Before and After Pressure Management in the Durban CBD

Example 2 – Ten small reservoir zones

In this example, ten small reservoir zones had PRVs installed and the results have been aggregated and shown as a total. The water pressure on average has been lowered from 87m to

57m, a decrease of 35%. The zone has an accumulative mains length of 76.9km and 3679 consumer connections. As shown in the Figures 5.11 and 5.12, the mains bursts dropped from an average of 72.0/100km/year to 14.7/100km/year (80%). The service connections leaks dropped from an average of 42.8/1000 connections/year to 10.1/1000 connections per year (76%). The SIV dropped by 28.1kl/hour which equated to R1 011 466 / year saved.

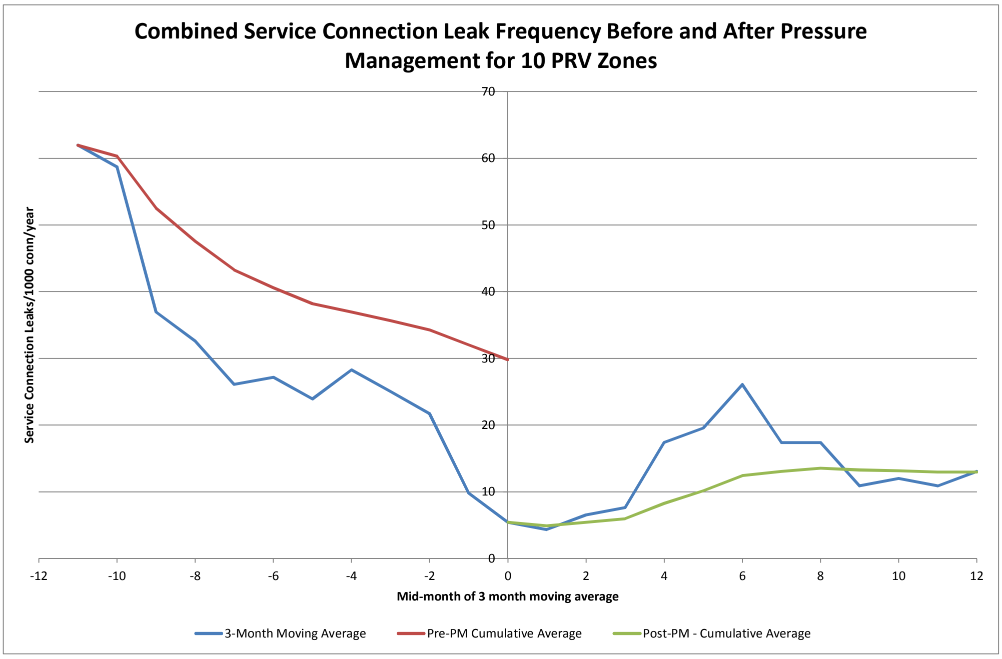

Figure 5.11: Connection Leak Frequency Before and After Pressure Management in 10 Small Zones

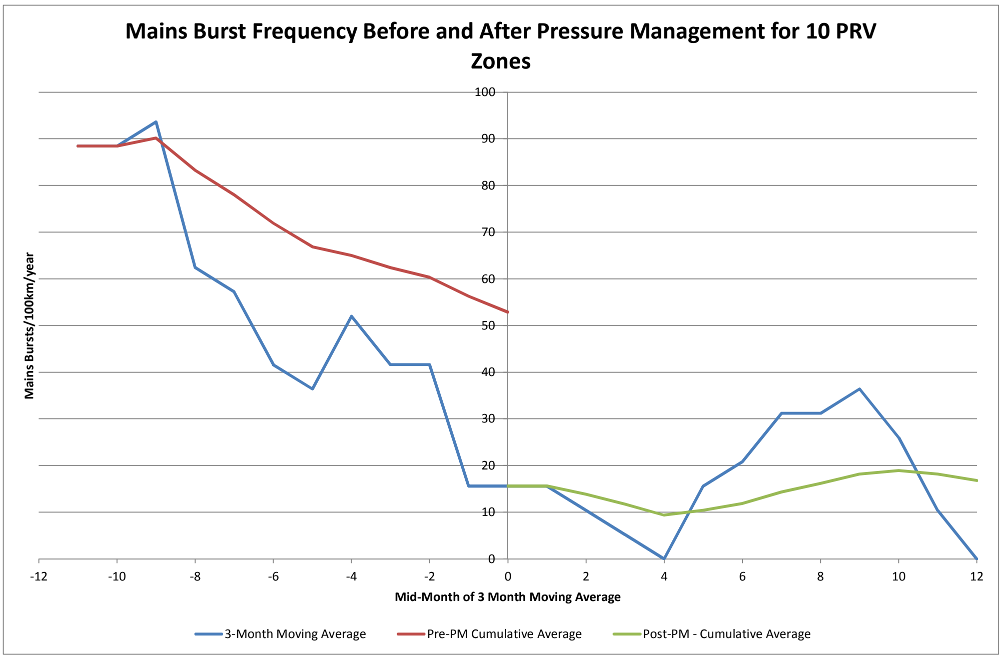

Figure 5.12: Mains Burst Frequency Before and After Pressure Management in 10 Small Zones

The implementation cost per zone is in the order of R100 000 per zone and the total cost for ten zones was approximately R1m. Annual savings of R1m equate to a payback period of 12 months representing an excellent return on investment. By comparison, if R1m had been spent on mains replacement, only 1km out of the 76.9km in the zone would have been replaced.

5.4 ANALYSIS OF THE EWS FAULTS DATABASE

The design Faults Database at EWS does not lend itself towards easy manipulation and interrogation. At present the Operational staff use the programme to track and schedule the work and also report on the total number of outstanding jobs. There is no direct spatial link with this data and therefore the fault data cannot be seen spatially in the GIS. The quality control on the data entry is poor and a number of fields allow for the entry of free flowing text which is counterproductive to those wishing to analyse and product statistical reports. That being said, aspects of the data are credible (date, pipe diameter, material) and certain trends and inferences can be understood from this analysis. The following four tables have been produced from the manipulation of a 108MB data extract from the five year period from 2006 to 2010.

Table 5.9a: EWS Mains and Service Break Statistics

Statistics 2006 to 2010	Breaks on	Breaks on	EWS	EWS
Year	**Mains =32mm>**	**Services <32mm**	**Mains length Km**	**No. Connections**
2006	8 451	22 387	10 572	398 331
2007	9 510	21 386	10 713	410 455
2008	10 246	22 676	10 915	420 044
2009	10 805	26 374	11 206	431 856
2010	11 271	25 880	11 348	442 721
Total	50 283	118 703		
Distribution	30%	70%		
Average	10057	23741		

Table 5.9b: EWS Mains and Service Break Statistics

Statistics 2006 to 2010	Main leaks	Service Leaks	UARL	UARL	BFI	BFI
Year	100Km	Per 1000	Mains/100	Services /1000	Mains	Services
2006	80	56	13	3	6.1	18.7
2007	89	52	13	3	6.8	17.4
2008	94	54	13	3	7.2	18.0
2009	96	61	13	3	7.4	20.4
2010	99	58	13	3	7.6	19.5
Average	91.7	56.4	13.0	3.0	7.1	18.8

A number of trends can be gleaned from Tables 5.9a and 5.9b. There is a 70/30 ratio of connection leaks to mains breaks. This is in line with international trends. The number of main leaks has increased from 80/100km in 2006 to 99/100km in 2010. The number of service connection leaks increased from 56/1000 in 2006 to 61/1000 in 2009 and then dropped to 58/1000 in 2010. From the UARL, a well maintained system would have 13 main leaks/100km per year and 3 service connection leaks /1000 connections per year. A ratio of the leaks occurring to this ideal value gives the Burst Frequency Index (BFI). The BFI for the EWS mains is an average of 7.1 and the BFI for service connections is 18.8. This means that the mains leaks are 7 times higher than the ideal and the service connection leaks are nearly 19 times higher than the ideal.

Table 5.10: EWS Mains per Pipe Diameter

EWS System Distribution Main Burst Frequency		
Pipe Diameter	**Number of Breaks**	
50mm	117	breaks/100 km
75mm	72	breaks/100 km
100mm	58	breaks/100 km
150mm	34	breaks/100 km
200mm	17	breaks/100 km
250mm	16	breaks/100 km
300mm	19	breaks/100KM

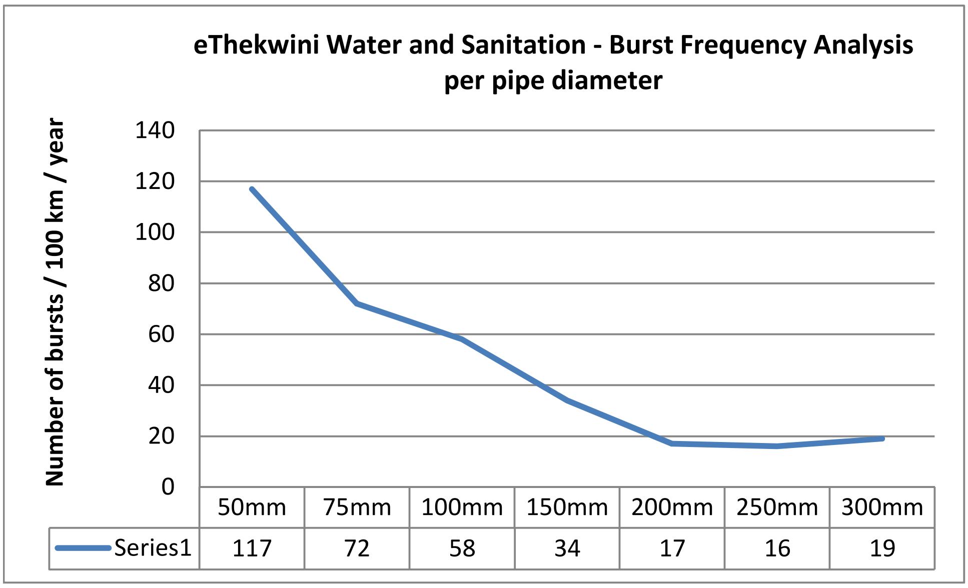

Figure 5.13: EWS Average Pipe Burst Frequency per Pipe Diameter

Table 5.10 and Figure 5.13 show that the numbers of failures follow a decreasing trend as the main size increases. To a large extent, this is due to the greater structural rigidity and higher hoop stress value of the larger pipes due to a thicker pipe wall.

CHAPTER 5 – SUMMARY

- Where mains were replaced without pressure management, the daily demand increased by 17.8% and the real losses reduced by only 6.6%. In contrast, where pressure management was carried out with mains replacement the daily demand decreased by 23.6% and the real losses reduced by a 37.6%.
- The burst frequency before and after mains replacement has remained unchanged after changing 1370km of mains (12% of the total system).
- The average daily billed metered volume decreased by 1 330 kl/day, or approximately 4,7% from the baseline billed volumes in a study area.
- In six zones, leak detection was conducted and 9358 leaks were located and a saving of 542m^3/hour was achieved.
- In the Durban CBD, lowering the pressure from 61 metres to 37 meters achieved a reduction in mains burst frequency of 72% and a reduction of service connection leaks of 43%. The SIV has dropped by 24.8Ml / day representing a saving of R38 733 508 per annum.
- In ten small reservoir zones, lowering the pressure on average from 87 metres to 57 meters achieved a reduction in mains burst frequency of 80% and a reduction of service

connection leaks of 76%. The SIV dropped by 28.1m^3/hour and this volume equates to - R1 011 466 saved per annum

- The mains leaks are 7 times higher than the ideal and the service connection leaks are nearly 19 times higher than the ideal in the EWS system. The overall trend is that these leaks are also increasing.

CHAPTER 6 – DISCUSSION

6.1 MAINS REPLACED WITH AND WITHOUT PRESSURE MANAGEMENT

From Table 5.1 it can be seen that there was a 6.6% reduction in real losses where mains were replaced without pressure management and a 37.6% reduction in real losses where mains were replaced with pressure management. It is thus clearly evident that the leakage was substantially reduced when pressure management was implemented and this reduction can be attributed to the impact of the lowering of the average zone pressure. Where some distribution mains in a zone were replaced without pressure management, the leakage on the replaced mains decreased and therefore the average zone pressure increased. The impact of this was that the overall leakage for the zone increased. This increase in leakage followed the N_1 relationship for the zone.

6.2 MAIN REPLACEMENT WITHOUT METER REPLACEMENT

From the analysis conducted in eight reservoir zones and 18500 metered connections it can be seen that the average daily billed metered consumption reduced by 1 330 kl/day which represents a 4,7% drop from the baseline billed volumes.

The damage to the water meters is caused by a number of factors (Van Zyl, 2011):

- Many of the meters present in the system are not protected by strainers and susceptible to damage by suspended particles;
- When water mains are drained prior to a tie in, some air is sucked in through consumer connections and this causes the meters to spin backwards at very high speeds which damages the meters. Typically, meters are designed for water to pass through at velocities of 1 to 3m/s and can handle a brief peak of up to 5m/s. Air in the system can cause velocities much higher than this which damages the bearings and gears in the water meters;
- When the mains are charged after a tie in has taken place, the operational staff will scour the mains through available fire hydrants but even this practice will be unable to prevent some dirt finding its way into a water meter and damaging it;
- When the mains are charged after a tie in has taken place, high velocities have a scouring effect and sand and debris that was present in the existing un-replaced mains, is put into suspension and then this debris goes through the water meters causing damage;

- When the mains are charged after a tie in has taken place, it is unavoidable that some air is present in the system and then causes the meters to spin at speeds that they are not designed to handle causing damage to the meters as discussed above;
- As discussed above, it is a common occurrence that some mains suffer a higher burst frequency when some of the mains are replaced and some sand and debris will find its way into the meters during these events. In some cases, the amount of dirt is so severe that it completely blocks the meters and then they have to be flushed out.

6.3 THE EFFECT OF LEAK DETECTION AND PRESSURE MANAGEMENT ON MAINS REPLACEMENT

Figure 6.1 generically indicates how pressure management and leak detection and repair increase the economic lifetime of the distribution mains.

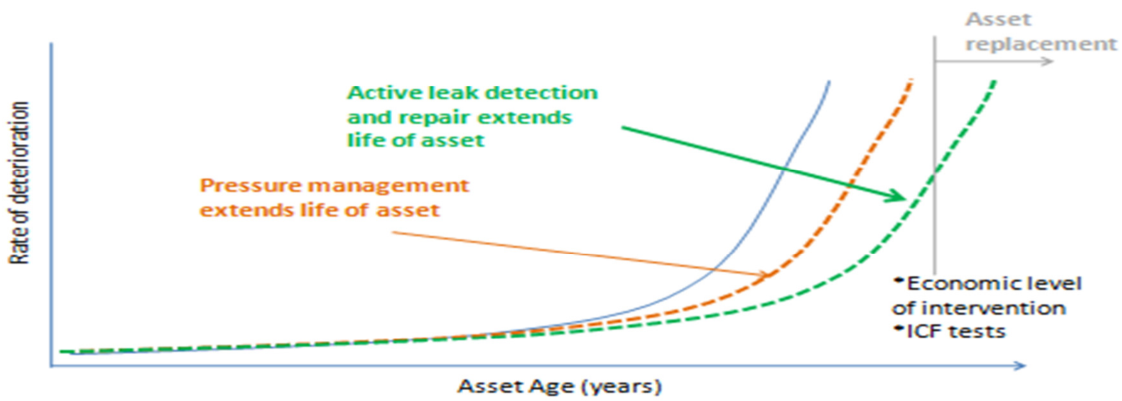

Figure 6.1 - The effect of pressure management and LD&R (Shepherd et al., 2012)

Conversely, Figure 6.2 demonstrates the impact of a loss of institutional knowledge, operational mismanagement and neglect, poor quality of materials and installation and incorrect expenditure. It is therefore equally important that these issues are also recognized and addressed in order to maximize the economic lifetime and delay the date at which a main must be rehabilitated / replaced.

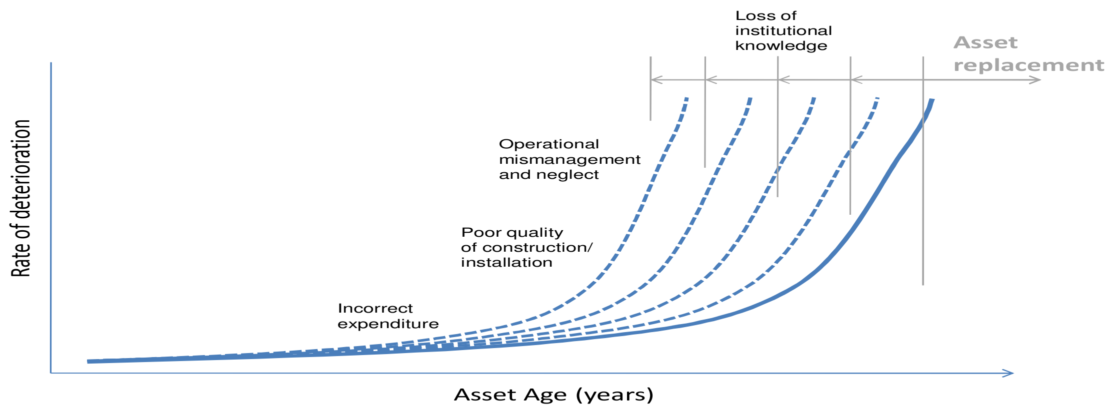

Figure 6.2 – The negative effect on asset life (Shepherd et al., 2012)

A number of lessons were learned throughout the analysis of the on-going EWS leak detection interventions which enabled a refinement of approach and methodology to be undertaken. Some of these lessons were:

i) Sweeping areas for leaks ahead of the EWS Amnesty Program (rectification of illegal connections) raised the profile of EWS and promoted a positive message in support of service delivery and payment for services

ii) Use of plastic rather than brass fittings minimised theft and vandalism, allowing for better results and greater savings, both from a lost water perspective and cost of repair

iii) Use of Category B plumbers in high density informal areas to maximise coverage and minimise leak repair times yielded better results. This selection of appropriate technology has dramatically improved the impact of this intervention – the leak frequency increased from 0,9 leaks/km to 2,1 leaks/km using this approach

iv) Keeping a permanent presence in problematic areas to sustain results achieved. Due to the nature of some of the supply areas, it was deemed cost-effective to retain a permanent presence of Category B plumbers in certain areas and have them constantly sweep areas for leaks

v) Keeping consumers informed of activities improves results – once consumers see a high-profile presence and the use of different types of media (such as street pole signage and Mxit) promoting their involvement, they do tend to become more responsible

vi) The need for adequate and reliable metering for monitoring and evaluation purposes. In order to undertake constant monitoring and evaluation and to determine the extent of demand reduction, meters must be installed and maintained so that flow information can be analysed and optimum intervention decisions made

vii) Sometimes areas needed multiple surveys before the actual results were realised. A flexible approach to respond to challenges and adjust the approach and methodology is needed to maximise results

viii) The best results are achieved when all real loss reduction interventions are implemented either simultaneously or successively. For example, the results of leak detection and repair were maximised when used together with pressure management.

6.4 PIPE REPLACEMENT MODEL

The following methodology has been developed to create a standardised procedure for the replacement of distribution mains. Five distinct phases have been identified that need to be conducted to ensure that a satisfactory return on investment is obtained.

1. Preliminary Investigation Month 1 to 6
2. Zone Rectification and Pressure Reduction Month 7 to 12
3. Monitoring and Clean Data Collection Month 13 to 24
4. Mains Replacement Month 25 to 36
5. Twelve Month Maintenance Period Month 37 to 48

Table 6.1: Phase 1 – Month 1 to 6 - Preliminary Investigation

Select zones of interest based on water balance, high real loss value and high main burst frequency	Confirm zone discreteness, reservoir and district meter meter accuracy. Log all flow meters	Locate all line and scour valves and confirm status and operation; Update GIS with valve data	Perform step testing and active leak detection sweeps	Log minimum and maximum pressures, optimise prv settings and check all prvs working correctly	**Decision**: If real loss rates and burst frequency are still above threshold levels, proceed to Phase 2

10% Of the distribution mains are selected for analysis in Phase 1 based on the areas that have the highest real losses and highest burst frequencies. The replacement programme will at this point be in its infancy and will need reliable data on which to make decisions to establish a proven track record. A replacement rate of 2%, which assumes a pipe life of 50 years, should be initially targeted. As the pipe replacement programme gains momentum and the input data improves, the replacement rates should be based on least cost optimisation. This calculation will be performed to compare the cost of replacement (or the cost of bringing the replacement forward in time), versus the cost of maintenance. The replacement rate thereafter will then be based on that replacement rate that returns the best value for the Utility in the long term and not the based short term view of what replacement rates the tariff can support.

Table 6.2: Phase 2 – Month 6 to 12 - Zone Rectification and Pressure Reduction

Design and install additional prv's to minimise AZP. Commission advanced control and failure warning devices where appropriate	Create additional DMA's to maximum recommended size of 2000 properties / 10km and install meters	Analyse burst information and investigate causes of bursts and reduce where possible	Perform step testing and active leak detection and calculate the Net Rate in Rise in leakage for the zone	Log minimum and maximum pressures, optimise prv settings and check all prvs working correctly	**Decision**: Conduct Cost / Benefit and NPV analysis and if favourable, proceed to Phase 3

It is currently planned to roll out pressure reduction throughout the municipal area to lower the AZP to 46m over a four year period. Once this programme has been completed, the AZP will be lowered to 42m over a further five years. Where the minimum AZP has not yet been achieved in each zone where mains replacement is contemplated, then this work will be conducted during the relay investigation. This pressure reduction step can therefore be omitted from the year 2022 onwards.

Table 6.3: Phase 3 – Month 13 to 24 - Monitoring and Clean Data Collection

Install electronic equipment to monitor pressure and flow data on line and real time. Log minimum and maximum pressures, optimise prv settings and check all prvs working correctly	Continue to monitor performance data to determine if it will be beneficial to replace mains. Conduct Infrastructure Condition (ICF) Tests and analyse field samples where appropriate	Ensure that all properties are metered. Verify accuracy of ICI customer meters. Remove all illegal connections	Perform step tests on all mains above 300mm to check on real loss rates and if replacement is warranted. Replace connections on these mains as part of investigation if deemed beneficial	Perform step testing and active leak detection Calculate the Net Rate in Rise in leakage	**Decision**: If real loss rates and burst frequency are still above threshold levels, proceed to Phase 4. Prioritise the selected areas to tackle the most beneficial areas first

Ensuring that apparent losses are reduced in each zone that is replaced is another important objective of the programme. Apart from the financial loss, illegal connections and inaccurate meters can skew the performance data of a zone and make the real loss appear higher than it actually is. Based on past experience, the relay Contractor faced considerable resistance from the communities in some areas when trying to regularise illegal connections and as a result this work was not successful. Macleod (2012) advised that it will be more practical to make this initiative the responsibility of the Department and therefore they must ensure every connection is metered prior to mains replacement being carried out.

Table 6.4: Phase 4 – Month 25 to 36 - Mains Replacement

Replace all mains 300mm and below and all connection pipes in DMA. Mains above 300mm only to be changed if warranted by assessed real loss rates	After mains replacement, ensure that all meters are located on the property boundaries and are all installed to Manufacturers' recommendations	After mains replacement, check on customer meters in zone and replace all according to meter asset management plan criteria as well as other meters with decreased sales volumes	Log minimum and maximum pressures, optimise prv settings and check all prvs working correctly	Contractor to perform active leak detection during 12 month defect liability period. Minimum levels of leakage and burst frequency must be achieved by Contractor	Maintenance period commences once Contractor has achieved all contractually stipulated performance levels

Larger diameter pipes have a thicker pipe wall, higher structural strength, a lower failure rate and are significantly more expensive to replace. It is therefore advantageous not to assume a blanket replacement policy but to consider each pipe on its merits. The construction contract should allow for testing of any main that is left unchanged to ensure that the new lower loss rates for the zone can be achieved. These rates would be based on the UARL rates in Table 2.7 of 18 litres / km / day / metre pressure and 0.8 litres / connection / day / metre pressure. At the targeted AZP of 42m, this equates to 756 litres / km / day and 33.6 litres / connection / day.

Table 6.5: Phase 5 – Month 37 to 48 - Twelve Month Maintenance Period

Continue to monitor zone real time on an ongoing basis	Recalculate assumed values relating to reduction in burst frequency and reduction in losses for use in the financial analyses	Perform active leak detection when real losses increase	Log minimum and maximum pressures, optimise prv settings and check all prvs working correctly	Contractor to prove status of all valves at end of maintenance period

Table 6.6 details the advantages of this five phase approach.

Table 6.6: Advantages and Disadvantages of the Five Phase Approach

OLD RELAY PROGRAMME	NEW RELAY PROGRAMME
Illegal connections not addressed	Illegal connections to be rectified prior to relay commencing
Sales volume reduced	Greater attention paid to water meters and all old meters and damaged meters to be replaced
Increase in burst rates	Majority of mains in zone will be new and therefore burst rates will reduce. This will be assisted by the reduction of pressure
Insignificant reduction in real losses	Contractor responsible for achieving set targets or penalties to be applied
Savings achieved not sustainable	Monitoring of zone and active intervention by Department to ensure that results are sustained
Department not satisfied with programme or results	Better results will be achieved and communicated to all via internal and external communications programme
Short term demand spike (4km/day) placed on Manufacturers and Contractors causing an increase in prices and reduction in quality	Consistent predictable programme to be implemented and consistent production targets to be set and achieved. This is envisaged to be 1km/day

CHAPTER 6 – SUMMARY

- It is thus clearly evident that leakage was substantially reduced when pressure management was implemented and this reduction can be attributed to the impact of the lowering of the average zone pressure.
- In eight reservoir zones that were monitored before and after mains replacement, the average daily billed metered consumption reduced by 4,7% drop from the baseline billed volumes. This shows that greater attention to consumer meters will be warranted during a mains replacement programme.
- Pressure management and leak detection and repair can be used to substantially increase the economic lifetime of distribution mains.
- Conversely, the impact of loss of institutional knowledge, operational mismanagement and neglect, poor quality of materials and installation and incorrect expenditure will all have a negative impact on the performance of the distribution system.

- A refinement of approach and adapting to local circumstances enabled the benefits of the leak detection and repair programme to be optimised.
- A five stage, 48 month methodology has been developed to mitigate against the previous problems experienced, deal with all relevant issues and maximise the benefits from mains replacement programmes.
- The five phases are Preliminary Investigation, Zone Rectification and Pressure Reduction, Monitoring and Collection of Cleansed Data, Mains Replacement and the Twelve Month Maintenance / Monitoring Period.
- The advantages of the five phase approach are:
    - Illegal connections will be rectified prior to relay commencing
    - Greater attention will be paid to water meters so that billing either remains the same or increases
    - The burst frequency will reduce
    - The Contractor will be responsible for achieving set targets (or penalties will be applied for sub-standard results)
    - The zone will be monitored by the Department to ensure that results are sustained
    - Better results will be achieved and communicated to all via internal and external communications programme
    - A consistent and predictable programme will enable consistent production and quality targets to be set and achieved. This economy of scale will also help to reduce installation cost.

CHAPTER 7 CONCLUSIONS

7.1 OVERVIEW

Inefficient water distribution systems together with an ever-increasing water demand are putting the available water supply under severe strain (Pilcher, 2005). As the distribution networks are in a continual state of deterioration, it is important to monitor the DMA's and take corrective action when appropriate in order to contain the losses. The rate of replacement of the distribution mains, will at best only in the order of 2% per annum, and this is the most expensive and time consuming solution to increase efficiencies. The Utility must continue to actively maintain the other 98% of the system in order to achieve their primary mandate. Sufficient reliable condition data must be collected in order to evaluate the network and make appropriate decisions with regard to the whole life cost, the environment and the public.

7.2 PRESSURE MANAGEMENT

A small increase or decrease in AZP can have a marked impact on the losses and burst frequency. Pressures must be therefore be optimised when improving the performance of a DMA. If this work is conducted prior to mains replacement, it could result in the replacement of the mains being deferred indefinitely as the real losses and burst frequencies reduce with the management of the pressures. If pressure management is conducted as part of the mains replacement programme then the mains will have lower losses and burst frequencies from the outset.

A number of negatives from pressure management must be recognised and dealt with when pressures are lowered.

- The first negative is the reaction from the consumers who have not been educated as to why the municipality is conducting pressure management. They will be used to a certain water supply pressure and when it is lowered, even in some cases from 900kpa to 600kpa, these customers voice their dissatisfaction. The solution to this is the education of the customers and a number of media can be used to achieve this (Street pole notices, newspaper articles, magazine articles, direct mail to the consumers, radio shows, focus groups, public meetings etc.)
- The majority of the consumer demand is independent of pressure (running a bath, filling a boiler, filling a basin or cistern) but some of the demand is related to pressure (showering, garden watering, car washing with hose pipes etc.). When the pressure is lowered the pressure dependent demand will reduce and billed metered consumption

has been observed to decrease by up to 5%. Whilst this reduction in sales has a direct impact on the revenue of the municipality, it is viewed in a positive light from a water conservation perspective. If less water is supplied, the capacity of the supply infrastructure as well as the waste water treatment works will be extended. As South Africa is a water scarce country, this reduction in demand is considered desirable. The consumer will also benefit as they will receive a slightly lower utility bill. Another advantage for the consumer is that their plumbing infrastructure will also last longer and their on-site leaks and bursts will also decrease.

- With the lowering of the water pressure any leak detection which is based on acoustics also becomes more difficult. At lower pressures, the leaks that are detected by geophones, listening sticks, correlators and leak noise loggers become that much more difficult to hear. Hamilton (2012) reported that leak detection in systems with pressures below 200kpa is extremely difficult. The prevalent use of PE and PVC pipe material as opposed to iron and asbestos cement also hinders the leak noise propagation.

7.3 CREATION AND MONITORING OF DISTRICT METERED AREAS (DMA'S)

Farley and Trow (2002) conclude that in order to effectively manage the system, it must be broken up into smaller reservoir areas that can be monitored. This practice will be complimented by the installation of PRV's as each new PRV zone is metered so that it becomes a DMA as well. Apart from reading these meters are read on a monthly basis, areas of interest can be monitored further with the use of flow and pressure loggers. Ultimately, all areas can be monitored real time with the use of radio and GSM technology. The Utility will thus be able to know at any point in time exactly what the flows and losses are in any one area, and this information can be aggregated up to the reservoir area, each of the six operational areas and to the entire system as a whole. Parameters can be set for alarm functionality and the system can also track trends over time so that interventions can be planned accordingly.

7.4 LEAK DETECTION

In order to get the best results from active leak detection and repair on distribution mains it is concluded that this activity should be conducted in the manner detailed below. The Level 1 to 4 of leak detection is explained in Section 3.4.

1. Examine the water balances and select the worst performing 20% of the reservoir zones.
2. Conduct Level 1 sweeps in these zones and repair all visible leakage.

3. Conduct Level 2 sweeps in the works performing 10% of the reservoir zones. Repeat three or four times and monitor the impact of this activity.
4. Where the losses have not been substantially reduced, conduct step testing to help narrow down the areas in a zone where the losses are the greatest and cover these areas with Level 3 leak detection.
5. Level 4 can be utilised where budget permits.

7.5 MAINS REPLACEMENT

With the exception of mains less than 10 years old and mains greater than 300mm, it is concluded that an optimised approach will be to replace all the water distribution mains in a DMA during a mains replacement programme. On average, this will be 65% of the mains in a zone. This approach will reduce the fruitless expenditure from proving existing water mains and maximise the savings from economies of scale and a consolidated approach. The five phase approach detailed in section 5.2 will maximise the savings from mains replacement.

The development of an efficient methodology to capture and analyse pipe break frequencies would serve as an effective measure to maximise the benefits attributable to mains replacements.

It is concluded that customer metering must be effectively addressed during the mains replacement. Failure to do this will result in a proportion of the hard won (and expensive) reduction in real losses being lost to apparent losses as the sales meter under register the volume supplied. Neil Macleod, (2012) stated that all illegal connections in a zone should be rectified by the water department before the area is handed over to the contractor for mains replacement. It is concluded that all customer metered connections should be relocated outside the cadastral properties to facilitate easy reading of the meters and reduce meter tampering. These meters should also be installed in full compliance with the manufacturers' recommendations.

The minimal sustainable annual cost is found by balancing the Operating Cost and the Capital Cost. In other words, assets must be replaced at the point in time when it becomes cheaper to do so, rather than continue to spend money on their increasing repairs. This will achieve the lowest whole life cost.

7.6 VARIABLES TO BE UTILISED IN THE DECISION SUPPORT SYSTEM

The UK National Faults Database developed by the UKWIR in consultation with all 27 UK water utilities is the most comprehensive faults database. It is therefore concluded that this should be adopted for use by EWS to collect the required fault data. It will be very useful to further develop a spatial link to the GIS so that problem areas can be visually identified. It will be practical to adopt a phased approach with regard to the information that is collected and interrogated. At present, there are a number of areas where the replacement of the water mains will result in excellent returns and these can be analysed with the spreadsheet developed and shown in Tables 3.8 and 3.9. Using very conservative input, it was shown for example in the Ensimbini reservoir zone the Benefit:Cost ratio was 2.6 making the replacement a very viable and attractive option. Over time, staff can be trained, procedures and systems can be implemented to collect and analyse data with greater and greater accuracy and confidence.

The variables to be initially collected to predict benefits are:

1. Real losses per mains length (l/km/day) (Op 28)
2. Water main burst frequency (No./100km/year) (Op 31)
3. Connection burst frequency (No./1000 connections/year) (Op32)

These variables can all be measured in financial terms and return on investment can be calculated. These variables also relate to customer satisfaction and to the efficiency of the system and therefore initially these indicators are sufficient to commence with.

As it becomes increasingly difficult to prioritise one area over another the following data will be required:

• Quality of Service Indicators	Qs10	Pressure of the Supply Adequacy
	Qs12	Continuity of Supply
	Qs14	Interruptions per Connections
	Qs18	Quality of Supplied Water
	Qs21	Physical -Chemical Tests Compliance
	Qs28	Pressure complaints
	Qs30	Water quality complaints
	Qs31	Interruption complaints
• Operational Indicators	Op5	Active Leakage Control Repairs
	Op23	Water Loss per Connection
	Op24	Water Losses per Mains Length
• Water Resource Indicator	Wr1	Inefficiency of use of Water Resources
• Physical Indicator	Ph3	Treated Water Storage Capacity
• Financial Indicators	Fi35	Average Age of Tangible Assets

Non-Revenue Water by Volume (Fi46) and the Infrastructure Leakage Index (Op29) are already calculated and can be used to aid the selection process as well. In time, all 170 performance indicators should be collected.

Analysis can then be extended to consider the risk of failure. This is calculated by multiplying the probability of failure with the consequence of failure.

7.7 METHODOLOGY TO SELECT AREAS TO BE REPLACED

The five phase approach will enable EWS to select zones of interest, improve the zone performance and eliminate false markers. This approach will produce replicable, predictable results and ultimately produce the optimum whole life cost. These decisions will be based on achieving the minimum combination of Capital Expenditure and Operational Expenditure.

As the costs of implementing a predictive planning system are not unsubstantial, it is recommended that the costs and benefits are thoroughly investigated before a decision is made to implement such a system.

Systems in isolation cannot succeed unless they are operated properly. The support of a number of key staff will be required to ensure that the input data used is both accurate and complete, so that the validity of the system output will be reliable.

In order to succeed for any new programme or process to succeed, the endorsement of senior management and the staff will be required. It is concluded that a number of pilots be run initially that are closely monitored. This will assist to refine the procedures and also to monitor and improve upon the vital aspects of the programme. Once it is been proven that this methodology is beneficial, the extra effort will be justified and the operation and support of such a system can be incorporated in the company culture.

7.8 THE CONSTRUCTION OF THE WORKS

There are a number of contracts that can be used and the three primary construction contracts in use in the Civil Engineering Industry are GCC 2010 (General Conditions of Contract), FIDIC (Fédération Internationale Des Ingénieurs-Conseils, which is French for the International Federation of Consulting Engineers) and NEC (New Engineering Contract). Of the three, the NEC3 contract is recommended as it promotes a good working relationship between the parties and it is a clear and simple document that can be used for a variety of work.

It is essential however that the contract includes clear targets for loss reduction. Replacing water mains just so that the average age of the asset decreases or some other random performance target is met is counter-productive. This is the most expensive and disruptive intervention that can be conducted and it is important that operational and financial performance targets are met, as these indicators are the ones that are used to establish if the mains should be replaced or not. If the majority of the mains in a DMA are replaced at one time, then the meter monitoring the flow into the zone can be used to ensure that the minimum loss rates are met. It is recommended that the indicator UARL (Unavoidable Annual Real Loss) is used as an initial target for the contractor to achieve before the mains will be accepted by the client. Over time, this target can be revised so as to ensure that a high degree of quality is achieved by the contractor, whilst at the same time not passing too much risk to the contractor which would have the effect of inflating the cost of the project. By ensuring that a high quality product is constructed, it is felt that there is no reason that these new mains cannot perform satisfactorily for 100 years.

7.9 CHOICE OF MATERIAL FOR NEW WATER MAIN

From the analysis on the choice of pipe material, a framework based on the whole life cost principle has been developed for the engineer to use to determine the most suitable material on a project by project basis. The drivers to be considered are not static and can change for example depending on the area, soil type, oil price and market competition. As more credible local information is gathered it will be easier to reach an optimised decision with more confidence. It is further suggested that local pilot studies could be conducted to assess the performance of these different materials over time.

A multi-criterion decision making tool was developed (Table 3.10 and 3.11) to enable EWS to evaluate the many diverse criteria when deciding upon the most beneficial pipe material. Although marginal and subjective, it has been confirmed that mPVC is still the best material for EWS to utilise for new distribution mains at present.

7.10 REPLACE OR REHABILITATE, TRENCHLESS TECHNOLOGY OR OPEN CUT CONSTRUCTION

The decision of whether to repair or replace will also need to be considered on a whole life cost basis in order to reach the optimum decision over the economic lifetime of the water main. The decision regarding the method of construction can be analysed on a multi-criterion basis so that unlike aspects can be scored and appraised.

7.11 FURTHER RESEARCH

Further research could be conducted in the following areas to promote a greater level of understanding and possibly influence the current business practices in order to gain greater efficiencies:

- Study the mechanisms of pipe failure / deterioration and make recommendations of what can be done to reduce them
- Recommendations for trunk main condition assessments and replacements
- Pilot study to replace consumer connections only and monitor benefits thereof
- Investigate effects of aggressive soils and water
- Investigate the quality of bedding materials used in pipeline construction and the impact on water drainage and pipe settlement
- Examine the current pressure standards in South Africa that are largely driven by fire fighting to see if there is scope to change the national standards
- Examine the quality of the supplied water to evaluate its potential to increase or decrease the life span of the infrastructure
- Study of the leak detection techniques with a view to improving results on plastic mains operating at lower pressures.

CHAPTER 7 - SUMMARY

- Distribution networks are in a continual state of deterioration.
- It is important to monitor the DMA's and take corrective action when appropriate in order to contain the water losses.
- The replacement of the mains is expensive and time consuming and only impacts a small fraction of the network.
- Sufficient reliable condition data must be collected in order to evaluate the network and make appropriate decisions with regard to the whole life cost, the environment and the public.
- System pressures must be optimised in order to improve the performance of a DMA.
- The negative perceptions and impacts of pressure management must be recognised and dealt with.
- In order to effectively manage the distribution system, it must be broken up into smaller reservoir areas that can be managed. An alternate to this is to create dynamically metered zones.
- The five levels of leak detection detailed in Section 3.4 should be consistently utilised to drive the real losses down.

- With the exception of mains less than 10 years old and mains greater than 300mm, it is recommended that all the mains in a DMA are replaced during a mains replacement programme.
- The five phase approach detailed in section 5.2 will maximise the savings from mains replacement.
- The development of an efficient methodology to capture and analyse pipe break frequencies is essential. The system developed by UKWIR has been well researched and is therefore recommended for this.
- The Faults Data System should also have the capability to link to the GIS so that a "measles map" can be produced for easy identification of problem areas.
- Customer metering must be effectively addressed during the mains replacement or a proportion of the reduction in real losses will be lost to apparent losses.
- All illegal connections in a zone should be identified and rectified by the water department before the area is handed over to the contractor for mains replacement.
- It is recommended that a phased approach is adopted with regard to the information that is collected and interrogated. The variables to be initially collected to predict benefits are:
    - Real losses per mains length (l/km/day) (Op 28)
    - Water main burst frequency (No./100km/year) (Op 31)
    - Connection burst frequency (No./1000 connections/year) (Op32)
- In time, it is recommended that a further 16 indictors are collected / calculated as detailed in section 7.7.
- The NEC3 contract is recommended for the replacement of water mains as it promotes a good working relationship between the parties and it is a clear and simple document that can be flexibly used in a variety of situations.
- It is essential that the construction contract includes clear targets for loss reduction.
- By ensuring that a high quality product is constructed, it is felt that there is no reason that these new mains cannot perform satisfactorily for 100 years.
- It has been confirmed that mPVC is still the best material to utilise for new mains at EWS to use at present.
- Other aspects such as trenchless technology and repair of pipes can be evaluated on an ad-hoc basis using a multi-criterion and whole of life cost assessment.
- Indications of possible further research have been listed.

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INTERVIEWS

Name	Date	Company	Position	Place
Dedekind, Jutta	July 2012	Aurocon Pty Ltd.	AC Main Replacement Project Manager	Durban, South Africa
Anna Fijma,	June 2010	Vitens BV	Senior Asset Manager	Durban, South Africa
Lambert, Alan	March 2013	International Leakage Management Support Services Ltd	Director	London, England
Macleod, Neil	July 2012	eThekwini Water and Sanitation	Head: Water and Sanitation	Durban, South Africa
Maharaj, Rosh	July 2012	eThekwini Water and Sanitation	Manager Finance: eThekwini Water and Sanitation	Durban, South Africa
Moore, Catherine	November 2010	Thames Water PLC	VMR Project Manager	London, England
Melvin Oakes,	November 2010	Seams Ltd	Managing Director	Sheffield, England
Francisco Paracampus	Febraury, 2010	Companhia de Saneamento Básico do Estado de São	Managing Director	Cape Town, South Africa

		Paulo (SABESP)		
Thornton, Julian	June 2011	Thornton International Ltda	Director	Durban, South Africa
Van Den Brink-Bil, Reinders	November 2012	Vitens BV	Asset Manager	Zwolle, The Netherlands

APPENDICES

APPENDIX A - GLOSSARY OF TERMS

(Extract from the USAID Managers NRW Handbook for Africa)

WATER BALANCE DEFINITIONS

All terms used in Figure A.1 are listed in hierarchical order—as one would read the water balance form from left to right. Some of the terms are self-explanatory but are still listed for consistency.

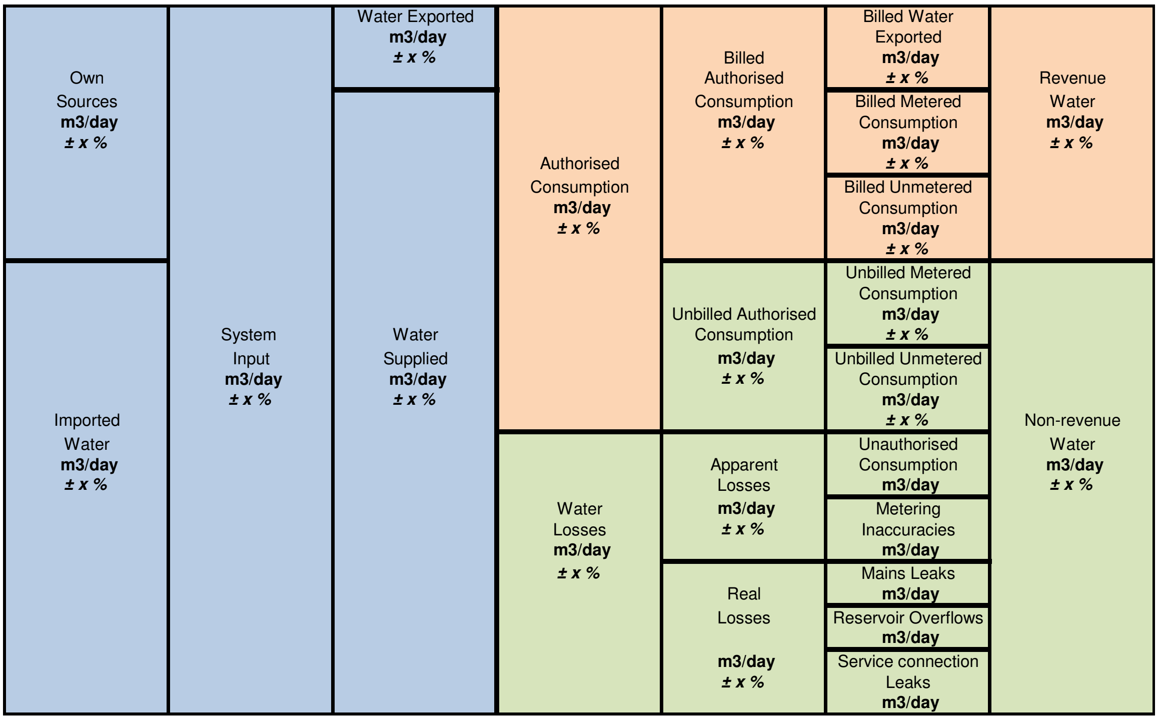

Figure A.1: The IWA Water Balance Diagram

"System Input Volume

The volume of treated water input to that part of the water supply system to which the water balance calculation relates.

Authorized Consumption

The volume of metered and/or un-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so by the water supplier, for residential, commercial and industrial purposes. It also includes water exported across operational boundaries.

Authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered.

Water Losses
The difference between System Input and Authorized Consumption. Water losses can be considered as a total volume for the whole system, or for partial systems such as transmission or distribution schemes, or individual zones. Water Losses consist of Physical Losses and Commercial Losses (also known as Apparent Losses)

Billed Authorized Consumption
Those components of Authorized Consumption which are billed and produce revenue (also known as Revenue Water). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Unbilled Authorized Consumption
Those components of Authorized Consumption which are legitimate but not billed and therefore do not produce revenue. Equal to Unbilled Metered Consumption plus Unbilled Unmetered Consumption.

Commercial Losses
Includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use).

Physical Losses
Physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer use. In metered systems this is the customer meter, in unmetered situations this is the first point of use (stop tap/tap) within the property.

Billed Metered Consumption
All metered consumption which is also billed. This includes all groups of customers such as domestic, commercial, industrial or institutional and also includes water transferred across operational boundaries (water exported) which is metered and billed.

Billed Unmetered Consumption
All billed consumption which is calculated based on estimates or norms but is not metered. This might be a very small component in fully metered systems (for example billing based on estimates for the period a customer meter is out of order) but can be the key consumption component in systems without universal metering.

Unbilled Metered Consumption

Metered Consumption which is for any reason unbilled. This might for example include metered consumption by the utility itself or water provided to institutions free of charge, including water transferred across operational boundaries (water exported) which is metered but unbilled.

Unbilled Unmetered Consumption
Any kind of Authorized Consumption which is neither billed nor metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc

Unauthorized Consumption
Any unauthorized use of water. This may include illegal water withdrawal from hydrants (for example for construction purposes), illegal connections, bypasses to consumption meters or meter tampering.

Revenue Water

Those components of Authorized Consumption which are billed and produce revenue (also known as Billed Authorized Consumption). Equal to Billed Metered Consumption plus Billed Unmetered Consumption.

Non-Revenue Water

Those components of System Input which are not billed and do not produce revenue. Equal to Unbilled Authorized Consumption plus Physical and Commercial Water Losses.

(Unaccounted-for Water)

Because of the widely varying interpretations and definitions of the term 'Unaccounted for Water', it is strongly recommended that this term be no longer used. It is equivalent to 'Water Losses' in the Water Balance diagram

Background Leakage

Background leakage (also called background losses) are individual events (small leaks and weeps) that will continue to flow, with flow rates too low to be detected by an active leakage control campaign unless either detected by chance or until they gradually worsen to the point that they can be detected. As the term is nearly untranslatable, it is often referred to as "unavoidable losses". The level of background leakage depends on the overall infrastructure condition, the pipe material(s) and the soil. It is furthermore heavily influenced by pressure (N1=1.5 or even higher).

Bursts

Events with flow rates greater than those of background losses and therefore detectable by standard leak detection techniques. Bursts can be visible or hidden.

Reported Bursts

Reported Bursts are visible leaks that are brought to the attention of the water utility by the general public or the water supply organization's own operatives.

Unreported Bursts

Unreported bursts are those that are located by leak detection teams as part of their normal everyday active leakage control duties. These breaks go undetected without some form of active leakage control.

Active Leakage Control (ALC)

ALC is the policy a water utility implements if it decides to pro-actively search for hidden leaks. ALC in its most basic form consists of regular sounding (e.g. listening to leak noise on fire hydrants, valves and accessible parts of service connections (e.g. stop cock) with listening sticks or electronic devices.

Leak Duration

The length of time for which a leak runs consists of three separate time components - awareness, location and repair time.

Awareness Time

Awareness Time is the average time from the occurrence of a leak until the water utility becomes aware of its existence. The awareness time is influenced by the type of applied ALC policy.

Location Time

For reported bursts, this is the time it takes for the water utility to investigate the report of a leak or break and to correctly locate its position so that a repair can be carried out. For

Unreported bursts, depending on the ALC method used, the location duration may be zero since the burst is detected during the leak detection survey and therefore awareness and location occur simultaneously.

N1 Factor
The N1 Factor is used to calculate pressure/leakage relationships:

Leakage Rate L (Volume/unit time) varies with Pressure N1 or L1/L0 = (P1/P0) N1

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. N1 Factors range between 0.5 (corrosion holes only in metallic systems) and 1.5 with occasional values of up to 2.5. In distribution systems with a mix of pipe materials, N1 values might be in the order of 1 to 1.15. Therefore a linear relationship can be assumed initially until N1 Step Tests are carried out to derive better data.

N1 Step Test
The N1 Step Test is used to determine the N1 value for areas of the distribution network. Inflow to the area as well as pressure at the Average Zone Point are recorded. During the test supply pressure into the area is reduced in a series of steps. This pressure reduction together with the corresponding inflow reduction forms the basis for the calculation of N1.

Pressure Step Test
Equivalent to N1 Step Test.

Average Zone Point (AZP)
The AZP is the point in a certain zone or area of the distribution network which is representative for the average pressure in this particular part of the distribution network.

BABE Concepts
The Bursts And Background Estimates (BABE) concepts were developed by the UK National Leakage Initiative between 1991 and 1993. The concepts were the first to model physical losses objectively, rather than empirically, thus permitting rational planning management and operational control of strategies for their reduction.

Leakage Modelling

Leakage modelling is a methodology to analyze 24h inflow and pressure data of a hydraulically discreet part of the distribution system. Using the N1 pressure:leakage relationship principles and the results of the N1 Step Test the measured inflow can be split into:

Equivalent Service Pipe Bursts (ESPBs)
The number of ESPBs is an indication of how many hidden leaks can be expected in a certain part of the distribution network. It is calculated by dividing the volume of excess (or hidden) losses by the volume of water lost through an average service pipe burst.

Hidden Losses (Excess Losses)
Physical loss component analysis is used to determine the part of physical losses which is in "excess" of all other leakage components. The volume of Hidden (Excess) Losses represents the quantity of water lost by "hidden" leaks that are not being detected and repaired with the current leakage control policy.

District Metered Area (DMA)
A discrete zone with a permanent boundary defined by flow meters and/or closed valves.

Night Flow Test (NFT)
Zone inflow and pressure measurement carried out during night hours, usually between 02:00 and 04:00 hours to measure Minimum Night Flow and corresponding Average Zone Night Pressure.

Average Zone Night Pressure (AZNP)
The AZNP is the average pressure during (low consumption) night hours measured at the Average Zone Point.

Minimum Night Flow (MNF)
The Minimum Night Flow (MNF) in urban situations normally occurs during the early morning period, usually between around 02:00 and 04:00 hours. The MNF is the most meaningful piece of data as far as physical loss levels are concerned. During this period, consumption is at a minimum and therefore physical losses are at the maximum percentage of the total flow. The estimation of the physical loss component at Minimum Night Flow is carried out by subtracting an assessed amount of Minimum Night Consumption for each of the customers connected in the zone being studied.

Minimum Night Consumption
Minimum Night Consumption is part of the Minimum Night Flow and is normally composed of three elements:

Household night use

Non-household night use

Exceptional night use

Net Night Flow
Net Night Flow is the difference between Minimum Night Flow and Minimum Night Consumption and is equivalent to Night Leakage

[Net Night Flow] = [Minimum Night Flow] - [Minimum Night Consumption]

Infrastructure Leakage Index (ILI)
The ILI is a measure of how well a distribution network is managed (maintained, repaired, rehabilitated) for the control of real losses, at the current operating pressure. It is the ratio of Current Annual volume of Physical Losses (CAPL) to Minimum Achievable Annual Physical Losses (MAAPL). Minimum Achievable Annual Physical Losses (MAAPL) is called "Unavoidable Annual Real Losses (UARL)" by the International Water Association

ILI = CAPL / MAAPL
Being a ratio, the ILI has no units and thus it facilitates comparisons between countries that use different measurement units (metric, U.S., or imperial).

Minimum Achievable Annual Physical Losses (MAAPL)
Physical Losses cannot be totally eliminated. The volume of Minimum Achievable Annual Physical Losses represent the lowest technically achievable annual volume of Physical Losses for a well-maintained and well-managed system. The standard equation for calculating MAAPL for individual systems was developed and tested by the IWA Water Losses Task Force. It allows for:

background leakage—small leaks with flow rates too low for sonic detection if non-visible

reported leaks and breaks—based on average frequencies, typical flow rates, target average durations *unreported leaks and breaks—based on average frequencies, typical flow rates, target average durations*

pressure/leakage rate relationships (a linear relationship being assumed)

The MAAPL equation requires data on four key system-specific factors:

- *Length of mains (all pipelines except service connections)*
- *Number of Service Connections*
- *Length of service connection between property boundary and customer meter. (Note: this is not the same as the total length of the service connection. Losses on the service connection between the tapping point at the main pipeline are included in the allowance per service connection. The additional allowance for length of connections on private land was included to take the longer leak run-times in situations were visible leaks would not be seen by public into account."*

APPENDIX B – THE IWA PERFORMANCE INDICATORS

Table B.1: The IWA Water Resource Performance Indicators (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
WR 1	**Inefficiency of use of Water Resources (%)**	**Percentage of water that enters the system and is lost by leakage and overflows up to the point of customer metering.**	**Y**	**Y**
WR 2	Water Resources Available (%)	Percentage of available water that enters the system.		
WR 3	Own Water Resources Available (%)	Percentage of available water that enters the system.		
WR 4	Reused Supplied Water (%)	Percentage of water entering the system that is reused.	Y	
Totals			**2**	**1**

Table B.2: The IWA Physical Performance Indicators (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
Ph1	Treatment Plant Utilisation	Maximum percentage of the daily capacity of the existing treatment plants that were used	Y	
Ph2	Raw Water Storage Capacity (days)	Capacity of raw water reservoirs per unit volume of daily system water input.	Y	
Ph3	**Treated Water Storage Capacity (days)**	**Capacity of transmission and distribution service reservoir per unit volume of system water input.**	**Y**	**Y**
Ph4	Pumping Utilisation (%)	Percentage of the maximum pumping capacity (that can be simultaneously) that was actually used.		
Ph5	Standardised energy consumption (kWh/m³/100m)	Average pumping energy consumption in the system per 1m³ at 100m of head.	Y	Y
Ph6	Reactivate Energy Consumption (%)	Percentage of the maximum pumping capacity (that can be simultaneously) that was actually used.		
Ph7	Energy Recovery (%)	Percentage of the total energy consumption for pumping that is recovered by the use of turbines of reverse pumps.		
Ph8	Valve Density (No./km)	Number of isolating valves per unit of distribution mains length.	Y	
Ph9	Hydrant Density (No./km)	Number of hydrants per unit of distribution mains length.	Y	
Ph10	District Meter Density (No./1000 Service Connections)	Number of district meters per thousand of service connections.	Y	Y
Ph11	Customer Meter Density (No./Service Connections)	Number of direct customer meters per service connection.		
Ph12	Metered Customers (No./customer)	Number of direct and bulk meters per customer		
Ph13	Metered Residential Customers (No./customer)	Number of residential-equivalent customer meters per residential customer.		
Ph14	Automation Degree (%)	Percentage of control units that are automated.		
Ph15	Remote Control Degree (%)	Percentage of control units that are remotely controlled.		
Totals			**7**	**3**

Table B.3a: The IWA Operational Performance Indicators (Part 1/2) (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
Op1	Pump Inspection (-/year)	Rates of pumps inspected per year, assessed in terms of nominal power.	Y	
Op2	Storage Tank Cleaning (-/year)	Rates of storage tank cells cleaned per year, assessed in terms of volume.	Y	
Op3	Network Inspection (%/year)	Percentage of network inspection per year, assessed in terms of length.	Y	
Op4	Leakage Control (%/year)	Percentage of mains length subject to active leakage control.	Y	Y
Op5	**Active Leakage Control Repairs (No./100km/year)**	**Number of leaks detected and repaired due to active leakage control per unit of main length.**	**Y**	**Y**
Op6	Hydrant Inspection (-/year)	Rates of hydrants inspected per year.		
Op7	System Flow Meters Calibration (-/year)	Rate of system flow meter calibration per year.	Y	
Op8	Meter Replacement (-/year)	Rate of flow meter replacement per year.	Y	Y
Op9	Pressure Meter Calibration (-/year)	Rate of pressure meter calibration per year		
Op10	Water Level Meter Calibration (-/year)	Rate of water level meter calibration per year.		
Op11	On-line water quality monitoring equipment calibration (-/year)	Rate of on-line water quality monitoring instrument calibration per year.		
Op12	Emergency Power System Inspection (-/year)	Rate of power systems inspections per year assessed in terms of nominal power.		
Op13	Signal Transmission Equipment Inspection (-/year)	Rate of signal transmission units inspection per year.		
Op14	Electrical Switchgear Equipment Inspection (-/year)	Rate of electrical switchgear units inspection per year.		
Op15	Vehicle Availability (No./100km)	Number of vehicles available daily, on a permanent basis, on average, for field works in operation and maintenance activities per 100 km of mains	Y	
Op16	Mains Rehabilitation (%/year)	Percentage of mains length rehabilitated per year.	Y	Y
Op17	Mains Renovation (%/year)	Percentage of mains length renovated per year.	Y	Y
OP18	Mains Replacement (%/year)	Percentage of mains length replaced per year.	Y	Y
Op19	Replaced Valves (%/year)	Percentage of mains valves replaced per year.	Y	Y
Op20	Service Connection Rehabilitation (%/year)	Percentage of service connection replaced or renovated per year.	Y	Y
OP21	Pump Refurbishment (%/year)	Percentage of pumps that were subjected to overhaul per year, assessed in terms of nominal power.	Y	
Op22	Pump Replacement (%/year)	Percentage of pumps replaced per year, assessed in terms of nominal power.	Y	
Op23	**Water Loss per Connection (m^3/connection/year)**	**Total (apparent and real) losses, expressed in terms of annual volume lost per service connection. This indicator is adequate for urban distribution systems.**	**Y**	**Y**
Op24	**Water Losses per Mains Length (m^3/connection/year)**	**Total (apparent and real) losses, expressed in terms of annual volume lost per mains length. This indicator is adequate for bulk supply and low service connection density distibution systems.**	**Y**	**Y**
Op25	**Apparent Losses (%)**	**Percentage of the water provided to the system (system input volume minus exported water) that corresponds to apparent losses. This indicator is adequate for urban distribution systems.**	**Y**	**Y**
Op26	Apparent Losses per system input volume (%)	Percentage of the water entering the system (exported water inclusive) that corresponds to apparent losses. This indicator is adequate for bulk supply and low service connections density distribution systems.	Y	Y
Op27	**Real Losses per Connection (l/connection/day when system is pressurised)**	**Real losses, expressed in terms of the average daily volume lost per connection. This indicator is adequate for urban distribution systems.**	**Y**	**Y**
Op28	**Real Losses per Mains Length (l/km/day when system is pressurised**	**Real losses, expressed in terms of the average daily volume lost per mains length. This indicator is adequate for bulk supply and low service connection density distribution systems.**	**Y**	**Y**
Op29	**Infrastructure Leakage Index (-)**	**Ratio between the actual real losses and an estimate of the minimum real losses that could be technically achieved for the system operating pressure, average service connection length and service connection density.**	**Y**	**Y**
Op30	Pump Failures (day/pump/year)	Average number of days per year system pumps are out of order.	Y	
Op31	**Mains Failure (No./100km/year)**	**Average number if mains failures per 100km of mains and per year.**	**Y**	**Y**
Op32	**Service Connection Failures (No./1000 connections/year)**	**Average number of service connections failures, expressed per 1000 connections and per year.**	**Y**	**Y**
Op33	Hydrant Failures (No./1000/hydrants/year)	Average number of hydrant failures, expressed per 1000 hydrants and per year.		
Op34	Power Failures	Average number of hours per year pumping stations are out of service due to power supply interruption.		

Table B.3b: The IWA Operational Performance Indicators (Part 2/2) (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
Op35	Water Point Failures (No./water-point/year)	Average number of failures per water point and per year.		
OP36	Customer Reading Efficiency (-)	Ratio between the effective meter readings and the total number of readings of all the customers meters were read according to the pre-established frequency.	Y	Y
OP37	Residential customer reading efficiency (-)	Ratio between the effective residential meter reading and the total number of readings if all the residential customers meters were read according to the pre-established frequency.	Y	Y
Op38	Operational Meters (%)	Percentage of the customer meters that are installed that are not out-of-service.	Y	Y
Op39	Unmetered Water (%)	Percentage of system input value that is not accounted for as metered consumption.	Y	Y
Op40	Tests Carried Out (%)	Percentage of treated water tests required by applicable standards or legislation that are carried out.	Y	
Op41	Aesthetic Tests Carried Out (%)	Percentage of aesthetic test of treated water required by applicable standards or legislation that are carried out.		
Op42	Microbiology test carried out (%)	Percentage of microbiology test of treated water required by applicable standards of legislation that are carried out.	Y	
Op43	Physical-Chemical test carried out (%)	Percentage of Physical-Chemical test of treated water required by applicable standards or legislation that are carried out.	Y	
Op44	Radioactivity Test Carried Out (%)	Percentage of radioactivity test of treated water required by applicable standards or legislation that are carried out.		
Totals			**32**	**21**

Table B.4: The IWA Quality of Service Performance Indicators (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
QS1	Household and business supply coverage (%)	Percentage of existing households and businesses that are connected to the public network.	Y	Y
QS2	Building Supply Coverage (%)	Percentage of existing buildings that are connected to the public network.		
QS3	Population Coverge (%)	Percentage of resident population that is served by the undertaking.		
QS4	Population Coverage with Service Connections (%)	Percentage of the resident population that is served through service connections.	Y	Y
QS5	Population Coverage with public taps or standpipes (%)	Percentage of the resident population that is served through public taps or standpipes.	Y	Y
QS6	Operational Water Points (%)	Percentage of existing water points that are not out of service.		
QS7	Average Distance from Waterpoints to households (m)	Average distance between water points and the respective far-most households.		
QS8	Per capita water consumed in public taps and standpipes (l/person/day)	Ratio between the volume of water supplied by public taps and standpipes and the population they supply.	Y	Y
QS9	Population per public tap or standpipe (person/tap)	Average number of persons served by public tap or standpipes.	Y	Y
QS10	**Pressure of the Supply Adequacy (%)**	**Percentage of the delivery points (one per service connection) that receive and are likely to receive adequate pressure.**		**Y**
QS11	Bulk Supply Adequacy (%)	Percentage of delivery point that are supplied at any time according to the target flow, volume and/or pressure.	Y	Y
QS12	**Continuity of Supply (%)**	**Percentage of hours when the (intermittent supply) supply system is pressurised.**	**Y**	**Y**
QS13	Water Interruptions (%)	Average percentage of hours each person served is subjected to water interruptions.	Y	Y
QS14	**Interruptions per Connections (No./1000 connections/year)**	**Average number of interruptions per service connection per year.**	**Y**	**Y**
QS15	Bulk Supply Interruptions (No./delivery points/year)	Average number of interruptions per delivery point per year.	Y	Y
QS16	Population Experiencing Restrictions to Water Services (%)	Average percentage of hours each served person experienced restrictions to water services.	Y	Y
Q17	Days with Restrictions to Water Services (%)	Percentage of days within restrictions to water services.	Y	Y
QS18	**Quality of Supplied Water (%)**	**Percentage of the total number of treated water tests performed that comply with the applicable standards or legislation.**	**Y**	**Y**
QS19	Aesthetic Tests Compliances (%)	Percentage of the total number of aesthetic tests of treated water performed that comply with the applicable standards or legislation.	Y	Y
QS20	Microbiology Test Compliance (%)	Percentage of the total number of microbiology tests of treated water performed that comply with the applicable standards or legislation.	Y	Y
QS21	**Physical -Chemical Tests Compliance (%)**	**Percentage of the total number of physical-chemical tests of treated water performed that comply with the applicable standards or legislation.**	**Y**	**Y**
QS22	Radioactivity Test Compliance (%)	Percentage of the total number of radioactivity tests of treated water performed that comply with the applicable standards or legislation.		
QS23	New Connection Efficiency (days)	Average time spent from customer requests until the availability of the water service, for existing service connection assets.	Y	
QS24	Time to Install a Customer Meter (days)	Average time spent from customer requests for the installation of newly fitted water meters until the availability of the services.		
QS25	Connection Repair Time (days)	Average time spent repairing service connections.	Y	
QS26	Service Complaints per Connection (No. complaints/1000 connection/year)	Average number of complaints of quality of service per 1000 service connections and per year. This indicator is adequate for distribution systems.	Y	Y
QS27	Service Complaints per Customer (No. complaints/customer/year)	This indicator is adequate for bulk supply and low service connection density distribution systems.	Y	
QS28	**Pressure Complaints (%)**	**Percentage of service complaints regarding pressure problems.**	**Y**	**Y**
QS29	Continuity Complaints (%)	Percentage of service complaints regarding continuity problems.		
QS30	**Water Quality Complaints (%)**	**Percentage of service complaints regarding water quality problems.**	**Y**	**Y**
QS31	**Interruption Complaints (%)**	**Percentage of service complaints regarding interruption problems.**	**Y**	**Y**
QS32	Billing Complaints and queries (No./customer/year)	Average number of billing complaints and queries per customer and per year.	Y	Y
QS33	Other Complaints and Queries (No./customer/year)	Average number of other complaints and queries per customer and per year.	Y	Y
QS34	Response to Written Complaints (%)	Percentage of written complaints responded to within the target time.		
Totals			**25**	**23**

Table B.5a: The IWA Financial Performance Indicators (Part 1/2) (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
Fi1	**Unit Revenue (R/m³)**	**Revenue per cubic meter of authorised consumption.**	**Y**	**Y**
Fi2	Sales Revenue (%)	Percentage of revenues coming from sales.	Y	
Fi3	Other Revenues(%)	Percentage of revenues not coming from sales.	Y	
Fi4	Unit Total Cost (R/m³)	Total costs (running and capital) per cubic meter of authorised consumption.	Y	
Fi5	Unit Running Costs (R/m³)	Running cost per cubic meter of authorised consumption.	Y	
Fi6	Unit Capital Costs (R/m³)	Capital cost per cubic meter of authorised consumption.	Y	
Fi7	Internal Manpower Costs (%)	Percentage of the running costs corresponding to the internal manpower.	Y	
Fi8	External Service Costs (%)	Percentage of the running costs corresponding to the external services.	Y	
Fi9	Imported (raw and treated) Water Costs (%)	Percentage of the running costs corresponding to imported water.	Y	
Fi10	Electrical Energy Costs (%)	Percentage of the running costs corresponding to electrical energy.	Y	
Fi11	Other Costs (%)	Percentage of the running costs corresponding to other costs not considered in Fi7 to Fi10.	Y	
Fi12	General Management Functions Costs (%)	Percentage of the running costs corresponding to running cost of general management costs.		
Fi13	Human Resources Management Functions Costs (%)	Percentage of the running costs corresponding to running cost of general management costs.		
Fi14	Financial and Commercial Functions Costs (%)	Percentage of the running costs corresponding to running cost of financial and commercial functions.		
Fi15	Customer Service Functions Costs (%)	Percentage of the running costs corresponding to running cost of customer service functions.		
Fi16	Technical Services Functions Costs (%)	Percentage of the running costs corresponding to running cost of technical service functions.		
Fi17	Water Resources and Catchment Management Costs (%)	Percentage of the running costs corresponding to running cost of the water resources and catchment management.		
Fi18	Abstraction and Treatment Costs (%)	Percentage of the running costs corresponding to running cost of abstraction and treatment.		
Fi19	Transmission, Storage and Distribution Costs (%)	Percentage of the running costs corresponding to running cost of transmission, storage and distribution.		
Fi20	Water Quality Monitoring Costs (%)	Percentage of the running costs corresponding to running cost of water quality monitoring.		
Fi21	Meter Management Costs (%)	Percentage of running costs corresponding to running costs of meter management.	Y	
Fi22	Support Services Costs (%)	Percentage of the running costs corresponding to running cost of support services.		
Fi23	Depreciation Costs (%)	Percentage of the capital cost correponding to depreciation costs.	Y	
Fi24	Net Interest Costs (%)	Percentage of capital costs corresponding to net interest costs (i.e. difference between interest expenses costs and interest income)	Y	
Fi25	Unit Investment (R/m³)	Cost of investment (expenditures for plant and equipment) per cubic meter of authorised consumption.	Y	
Fi26	Investments for New Assets and Reinforcements of Existing Assets (%)	Percentage of the cost of investments corresponding to investments in new assets and reinforcements of existing assets.	Y	
Fi27	Investments for Assets Replacements and Renovations (%)	Percentage of the costs of investments corresponding to investments for asset replacements and renovations.	Y	
Fi28	Average Water Charge for Direct Consumption (R/m³)	Water sales revenue from residential, industrial and other customers (exported water excluded; public water taxes excluded) per cubic meter of authorised consumption, exported water excluded.	Y	
Fi29	Average Water Charges for Exported Water (R/m³)	Water sales revenue from exported water (excluding public water taxes) per cubic meter of exported water.	Y	
Fi30	Total Cost Cover Ratio (-)	Ratio between the total revenues and the total costs.	Y	

Table B.5b: The IWA Financial Performance Indicators (Part 2/2) (Alegre, 2006)

Abreviated Name	Performance Indicator	Description of Performance Indicator	Useful System Indicator	Useful DMA Indicator
Fi31	Operating Costs Coverage Ratio (-)	Ratio between the total revenues and the running costs.	Y	
Fi32	Delay in Accounts Receivable (days equivalent)	Ratio between the accounts receivable from drinking water and the sales revenues		
Fi33	Investments Ratio (-)	Ratio between the investments subjected to depreciation and the depreciation costs.		
Fi34	Contribution of Internal Sources to Investment = CTI (%)	Percentage of total investments that are financed by the cash flow.		
Fi35	**Average Age of Tangible Assets (%)**	**Percentage of the historical value of tangible assets that corresponds to depreciated historical value of tangible assets.**	**Y**	**Y**
Fi36	Average Depreciation Ratio (-)	Ratio between the depreciation costs and the historical value of tangible assets.	Y	
Fi37	Late Payment Ratio (-)	1 minus the ratio between the annual debt from customers and the amount billed.		
Fi38	Inventory Value (-)	Ratio between the value of overall inventory at the end of the fiscal year and the operating revenues.		
Fi39	Debt Service Coverage Ratio = DSC (%)	Percentage of the financial debt service that corresponds to cash-flow.		
Fi40	Debt Equity Ratio (-)	Ratio between total debt and the shareholders' equity.		
Fi41	Current Ratio (-)	Ratio between current assets and current liabilities.	Y	
Fi42	Return on Fixed Assets (%)	Percentage of the historical value of tangible assets, deducted from the depreciated historical value of tangible assets, that corresponds to operating income.		
Fi43	Return on Equity (%)	Percentage of the shareholders' equity corresponds to net income (after interest payments and taxes).		
Fi44	Return on Capital Employed (%)	Percentage of the total assets that corresponds to operating income (EBIT) (deducted from related taxes).		
Fi45	Assets Turnover Ratio (-)	Ratio between the sales revenues and total assets.		
Fi46	**Non-Revenue Water by Volume (%)**	**Percentage of the system input volume that corresponds to non-revenue water.**	**Y**	**Y**
Fi47	Non-Revenue Water by Cost (%)	Percentage of the system input volume that corresponds to the valuation of non-revenue water components.	Y	
Totals			**26**	**3**

APPENDIX C – FAULT DATA

The fault data collected by Dutch Water Utility Evides BV and the UK National Faults database are shown in Table C.1.

Table C.1: Fault Data Collected by Evides BV

ID	Name	Type	Length
1	Awareness time	String	20
2	Location time	String	20
3	Repair time	String	20
4	Duration to repair the fault	String	20
5	Plumber assigned	String	20
6	Fittings used for fixing the fault	String	50
7	Cost of repair	String	20
8	Estimated rate of leakage	String	20
9	Last fixer of the fault on the section	string	20
10	Date of last fault for the section of the pipeline	string	20
11	Frequency of bursting	String	20
12	Nature of fault	String	30
13	Mode of failure	string	30
14	Size of the fault	String	20
15	Possible cause of the fault	string	20
16	Point of fault	String	20
17	Function of the pipeline	String	20
18	Depth of pipeline	Integer	10
19	Material	string	20
20	Diameter	Integer	10
21	Construction year of the pipeline	string	20
22	Construction date of the pipeline	string	20
23	General condition of the pipe	String	20
24	Average zone night pressure	Integer	20
25	Average pressure	Integer	20
26	Recommendation	string	30
27	General Remark	String	20

Table C.2: Nature of Fault Data Collected by Evides BV

12	**Nature of fault**
	Burst pipe
	Broken pipe
	Leaking Valve
	Underground leak
	Leaking Meter
	Multi broken pipe
	No water
	Leaking pipe
	Low pressure
	Heavily leaking pipe

Table C.3: Mode of Failure Collected by Evides BV

13	**Mode of failure**
	Longitudinal
	Circular (Circumferencial)
	Hole/ Pit
	Joint
	Broken pipe
	Unclassified

Table C.4: Size of Fault Collected by Evides BV

14	**Size of the fault**
	Small
	Medium
	Large
	Broken pipe

Table C.5. Point of Fault Collected by Evides BV

16	**Point of fault**
	On the joint
	Along the pipeline
	Valve point
	etc

In order to allow different UK utilities to participate on the level that they desire, the data has been divided into three categories (Essential, Preferable and Desirable) as shown in Table C.6.

Table C.6: Job Management Information Collected in the UK National Faults Database (UKWIR 2003b)

Essential	Preferable	Desirable
Code for type of activity	Boundary information- District Metered Area, Water Supply Zone	Repeat visit
Failure date and/or repair date	Category of initiator of original work order	Repair technique
Address or Unique Street Identifier (to link to GIS)	Surface classification	Resource group

Table C.7: Field Reporting Information Collected in the UK National Faults Database (UKWIR 2003b)

Essential	Preferable	Desirable
Grid reference, Address, Unique Street Identifier or Unique Pipe Identifier	Boundary information- District Metered Area, Water Supply Zone and Company	Condition
Diameter and units	Failure type	External point loads
Material Type	External protection	Depth
Failure date and/or repair date	Internal protection	
	Soil type	
	Surface classification	

Table C.8: Asset Inventory Data Collected in the UK National Faults Database (UKWIR 2003b)

Essential	Preferable	Desirable
Unique Pipe Identifier	Class/ SDR/Pressure rating	Manufacturer
Diameter and units	Boundary information- District Metered Area, Water Supply Zone and Company	Specification (eg BS,EN)
Year of installation	Subsidary material type	Joint type
Material type	External protection	
Length	Internal protection	
	Soil type	
	Surface classification	

APPENDIX D – PIPE GRAVEYARD PHOTOS

The photos below were taken by Julian Thornton during a visit to the "pipe graveyard" at the EWS Mobeni Depot. They have been included to show some of the common failures that are experienced with PVC, AC and Cast Iron mains.

Figure D.1: Some of the mPVC pipes dumped at the Depot

Figure D.2: Pressure burst on a mPVC main

Figure D.3: Longitudinal Pressure burst on an mPVC pipe

Figure D.4: Pin hole failure on a PVC tee

Figure D.5: Longitudinal pressure burst on an AC pipe

Figure D.6: Ring fracture on an AC pipe caused by settlement

Figure D.7: Hole failure in an AC pipe

Figure D.8: AC pipe collar failure

Figure D.9 AC pipe degraded through soft water attack

Figure D.10 AC collar failure due to faulty rubber seal

Figure D.11: Pipe tuberculation in an unlined cast iron pipe

Figure D.12: Pipe failure due to corrosion at pipe wall

APPENDIX E – THAMES WATER VICTORIA MAINS REPLACEMENT (VMR) PROGRAMME

Information Received From Interview with Kathryn Moore – Senior Contracts Manager - VMR Programme

DATE – 15 November 2010

PLACE - London

Thames Water is the water utility that provides water to central London in the United Kingdom. In terms of number of connections and mains lengths it is approximately three times the size of the eThekwini system. Thames water supply 2100Ml/day to consumers and eThekwini supplies 860Ml/day and this is a factor of 2.4. Interestingly, the leakage volume is 2.7 times the volume lost in eThekwini (654 Ml/day vs. 240 Ml/day). The UK is very advanced in terms of the monitoring and control of NRW and therefore it was considered prudent to investigate how these utilities approach mains replacement. The reduction of leakage is a priority for the Utility and weekly meetings are held to examine all activities to monitor and reduce leakage. Leakage is measured per DMA and this is summarised per area (Central North, Eastern North, West, Central South and Eastern South). These five areas are then aggregated so that the volume of leakage is monitored on a daily basis. The utility is held responsible for achieving leakage targets by the regulator Ofwat and severe penalties are imposed if targets are not met. The reduction of leakage at Thames Water is tackled through a multi-pronged approach being monitoring, active and reactive mains repair, reticulation mains replacement (VMR), a network improvement programme, a trunk main leakage reduction programme, district metering and pressure management, bulk meter management, commercial logger availability and maintenance and Pumping optimisation.

- Significantly, individual mains are not prioritised for replacement. If the kpi's of the zone flag it for replacement, the whole zone is replaced. The exception to this is mains greater than 300mm and mains that are less than 10 years old. Where mains are left in the ground, these mains are step tested and a flow balance is conducted on these individual mains. The contractors are incentivised to find and repair leaks on the mains that are not scheduled for replacement.

- The number of recorded bursts can also trigger mains to be replaced. This value is set at three to 5 bursts per annum per 100 metres. Another reason that mains can be replaced is from the poor result from non-destructive testing. If the cost of controlling the leakage to a given level becomes excessive, the mains are flagged for replacement and lastly, risk is also taken into account when prioritising the mains for replacement.
- The district metered areas (DMA's) used to be 10000 connections in size and this has now been reduced to 2000 connections. 40% of the system is under PRV control and the minimum pressure is set to result in a pressure of 10m at the customers tap at the critical point. It is common for customers to fit their own tanks and pumps to raise their own internal pressure.
- Many consumer connections are not metered and this is being undertaken during the replacement programme so that, on completion, an accurate water balance can be calculated.
- DMA's are monitored using battery powered magnetic flow meters and these are monitored on-line, real time by the use of GSM and SCADA. A programme called Netbase is used to store all the logged flow data.
- Zone integrity is important in order to keep the water balance information correct. A device called Wizkey is used to operate and record the status of all boundary valves.
- The threshold to determine if a zone must be replaced or not is a simple one. If the Real Losses in a DMA exceed 0.06ML/km/day, it is flagged as a candidate for replacement. This is approximately three times higher than the UARL.
- The price of water used in the optimisation routines is the cost to produce new water. This new water is produced by Desalination and is approximately £1m/Ml. The selling price is 10p/kl which is similar to the tariffs charged by eThekwini.
- Sahara leak detection technology is used to search for leaks on the trunk mains.
- The cost of replacing the existing mains varies from £350 to £500 / metre.
- A strong governing contractual condition for the main layers is that they are bound to leakage targets. This moves the risk to the contractor and ensures that a high quality of installation is achieved. The benefit for the utility is that they are thus guaranteed to achieve the predicted return on investment.
- Much of the existing system is made up of iron and many water complaints are received related to this material.
- The staff compliment at Thames Water is approximately 3500 and 10% of these staff members are dedicated to reducing leakage.
- From a design perspective, the length of mains in the zones varies from three to ten kilometres. It is preferred to have a zone fed by multiple feeds. All mains are redesigned

in a zone taking demand (current and future) into account and the pressures are also optimised in each zone. All communication pipes are replaced when the mains are replaced. Contractors are awarded packages of approximately 100km and a two year contract period is given for the programme. Over the last three years the VMA has replaced 200km per annum. The contractor is responsible for maintaining the system for 10 years after the mains are replaced.

APPENDIX F - EWS WASTE WATER TREATMENT WORKS WATER BALANCE

Wastewater Treatment Works	Volumes (Ml/Annum)				E. Water In : Sewer Out = C / A
	A. Inflow at Works	B. Billed Metered Consumption: Total	C. Billed Metered Consumption: To Sewer	D. Difference = A - C	
Amanzimtoti	9 235	11 564	8 803	432	0.95
Cato Ridge	109	276	74	36	0.67
Central	25 536	15 043	13 467	12 069	0.53
Craigieburn	599	157	148	450	0.25
Dassenhoek	988	1 390	840	147	0.85
Fredville	182	358	96	87	0.52
Genazzano	512	612	578	-65	1.13
Hammarsdale	2 741	2 815	2 201	540	0.80
Hillcrest	328	1 023	410	-82	1.25
Isipingo	5 362	4 119	4 010	1 352	0.75
Kingsburgh	1 884	3 194	1 888	-4	1.00
KwaMashu	19 462	17 867	16 489	2 973	0.85
KwaNdengezi	554	683	560	-6	1.01
Mpumalanga	862	2 088	1 112	-250	1.29
New Germany	464	1 793	1 654	-1 189	3.56
Northern	23 086	25 530	23 314	-228	1.01
Southern	59 593	50 806	47 010	12 583	0.79
Tongaat Central	3 264	3 572	2 838	426	0.87
Umbilo	5 236	4 679	3 948	1 288	0.75
Umdloti	396	187	123	272	0.31
Umhlanga / Phoenix	12 540	10 722	10 255	2 286	0.82
Umhlatuzana	4 067	5 011	3 816	251	0.94
Umkomaas	204	912	727	-523	3.56
Verulam	2 111	2 955	2 306	-196	1.09

Table F.1: EWS Water Treatment Works Water Balance

APPENDIX G – CHANGES TO EWS OPERATIONS

Apart from the recommendations made throughout this text, the following points are also raised as they have potential to improve the efficiency of the Utility.

- Current Operations
  - Make plumbers accountable for repairs
  - Drastically increase the active leak detection
  - Increase the communication messages to encourage the public to report leaks
  - Explore an incentive scheme to reward communities for helping to reduce water losses.
- Fault data collection
  - Adopt the UK standard (UKWIR, 2003a and 2003b) for fault data so that the correct data is recorded in a standard fashion
  - Encourage other utilities in South Africa to do the same and share data with them
  - Share the fault data internationally to increase knowledge of failure trends and how to mitigate against these failures.
- Mains replacement software
  - Starting with a simplistic approach, collect the data in a reliable manner
  - Study the available software programs available in the market and purchase for use at EWS. This software must be able to run with the initial data, but also be able to incorporate the future needs as the Utility matures. The software must be able to conduct the iterative calculations based on the achieved savings to refine decision making process
  - Full time staff should be dedicated to this function and report to the Asset Manager.
- Construction of new and replacement mains
  - Consumer connections must always be replaced along with the new main
  - The newly constructed main and together with all the connection pipes are to be pressure tested to ensure that they are leak free

    - The design of these mains must facilitate the operations and maintenance activities that will be required. Lower design pressures, valves to facilitate step testing and bulk meters are a must. In particular, as leak detection is becoming increasingly difficult on plastic mains at low pressures, the design engineer must modify the design standards to facilitate the early warning and location of leaks in the future.
- The finance department and senior management must take cognisance of the implications and requirements of the mains replacement programme and accommodate the funding thereof in the tariff model. Normally, capital works are funded from loans. In this case however, it is recommended that the full cost of the annual mains replacements is supported by the tariff as it is an expense that will occur every year.