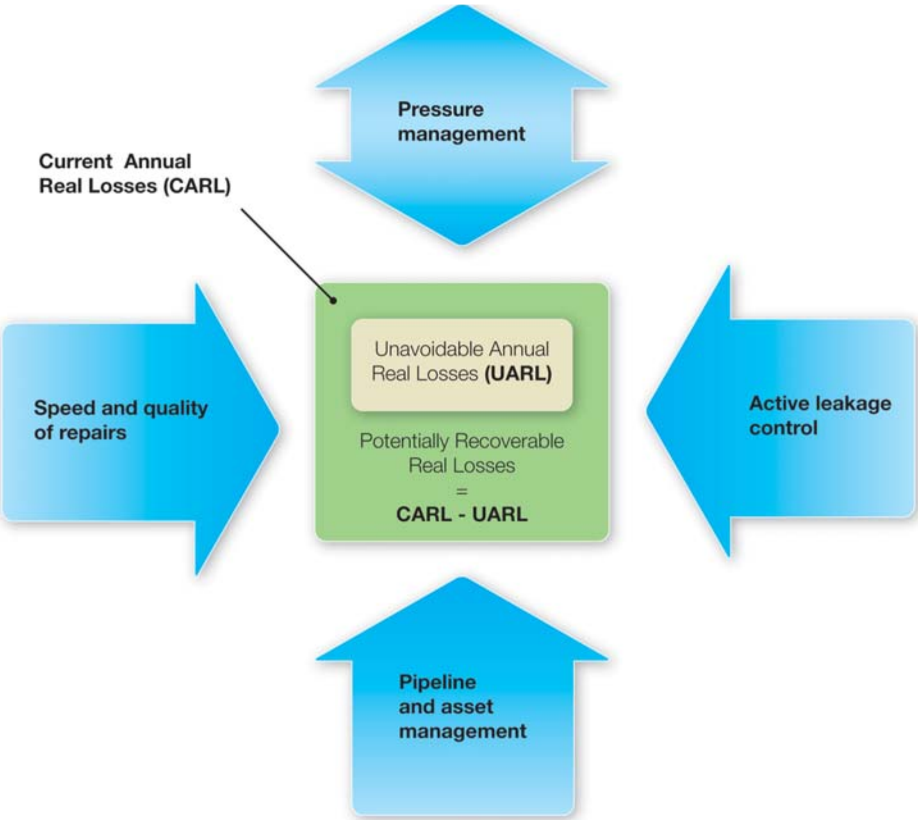
Master Thesis

Mathias H. Kleppen

Optimization of Small Urban Water Services in Developing Countries by Water Loss Management

Literature review with practical examples from Pacific Island countries



Telemark University College

Faculty of Arts and Sciences

Master of Environmental Health

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Photo front/illustration: Four “Pillars” of Real Loss Management (*Source: Trow and Farley, 2006)*

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Abstract

Water is by far our most important natural resource needed to sustain all forms of life on our planet. Today we face depletion and increased scarcity of this precious resource. At the same time there is also a rapid urbanization process going on, - in particular in developing nations. This will put an unprecedented pressure upon the urban water service providers (water utilities) to supply enough hygienically safe water for their customers. Small Island Developing States (SIDS) are no exception to this general trend.

Water losses occur to different degrees in all water supply systems. In developing countries it is not uncommon that half of the water invested in through production and distribution is lost through different types of wastage. There is however methods and techniques that can be applied to reduce the waste of drinking water. This thesis analyses, through an extensive literature review, some of the methods applied on the demand side. As opposed to supply side management that concentrates on major infrastructural investments, the demand side management develops strategies to improve and optimize existing water resources and infrastructure. The term for these strategies applied to Pacific water service providers are Water Loss Management (WLM). WLM could potentially contribute significantly to meet the millennium development goal 7 (specifically target 7c) for the given country.

WLM strategies are known to be data intensive, but many service providers in SIDS do not have an adequate set of data to give a reasonable idea of “what water goes where”. The goal of this research is to find ways to optimize water supply in small urban services in Pacific Island Countries (PIC). It is believed that the most crucial step, from having very little overview to having an improved overview on the supply system, is achievable by starting up WLM initiatives whilst data needs are identified and strategies are implemented to deliver these needs.

Based on the literature review WLM initiatives were implemented and are presented as three different practical examples. Field observations and analysis of the examples emphasizes the understanding of the baseline situation as a critical first step in moving towards an effective WLM program. Suggested strategies and the identification of key factors that influence the implementation of WLM initiatives in PIC are explained.

Key words: water loss management, non-revenue water, small island developing states, urban water services

Definitions and Abbreviations

ALC: Active leakage control (3.3.6)

AUD: Australian dollar

CARL: Current annual real losses (3.4.7.1)

DMA: District metered area (3.4.3)

ELL: Economic level of leakage (3.4.7.4)

FAO: Food and Agriculture Organization

GIS: Geographical information systems (3.4.5)

HDI: The Human Development Index ranks the world's countries according to certain indicators giving an indication on the state of the country. The most recent data are from 2010 and ranks 169 countries into 4 groups; very high, high, medium and low HDI. There are just four PIC ranked in the index and they are all in the group of medium HDI with the exception of Tonga who scores the lowest in the group of high HDI (85). Solomon Islands score a 123rd place. There is no data for Vanuatu and Niue in the 2010 HDI index, but Vanuatu scored a 126th place in the index from 2007. Niue is culturally connected to other Polynesian PIC like Tonga, ranked 99 in 2007, and Samoa, ranked 94 in 2007, but with a much smaller population, gross national product and a higher degree of isolation, it is assumed that Niue would rank lower than Tonga, but higher than Vanuatu (4.1, 4.2 and 4.3).

ILI: Infrastructure leakage index (3.4.7.3)

IWA: International Water Association

JICA: Japan International Cooperation Agency (4.1)

KL: Kiloliter (m^3 = 1000 liters)

l/p/d: Liters per person per day

m: Meter of head (pressure unit). 1 m equals 10 kPa (kilopascal)

MDG: Millennium development goals (3.1)

ML: Megaliter (1000 m^3= 1 million liters)

MNF: Minimum night flow (3.4.1)

NRW: Non-revenue water (3.3.5)

NWD: Niue Water Division (4.3)

NZAID: New Zealand's International Aid and Development Agency (2.1)

NZ$: New Zealand Dollar

PI: Performance indicator (3.4.7)

PIC: Pacific Island Countries (1.1)

PMZ: Pressure management zone (3.4.4)

PRV: Pressure reducing valve (3.4.4)

PVC: Polyvinyl chloride (4.2.1)

PWD: Public Works Department, Vanuatu (4.2)

SBD: Solomon Islands Dollar

SIDS: Small islands developing states (3.2)

SIWA: Solomon Islands Water Authority (4.1)

SMEC: Snowy Mountain Engineer Corporation (4.2)

SOPAC: Pacific Islands Applied Geoscience Commission (2.1)

UARL: Unavoidable annual real losses (3.4.7.2)

UFW: Unaccounted for water (3.3)

UN: United Nations

uPVC: Unplasticized polyvinyl chloride (4.1.1)

VUV: Vanuatu Vatu

WBWC: Wide Bay Water Corporation (2.2)

WDM: Water demand management is an overarching term of efficient use of water and involves the adoption of policies or investment by a water utility to achieve efficient water use by all members of the community (White, 1998). This term was during the work with Pacific utilities narrowed down to the more specific and appropriate term Water Loss Management (WLM), since data collection and strategies to reduce waste became first priority. WLM is the core of this thesis.

WLM: Water loss management entails all the efforts a water service provider make in order to account for all the water that has been invested in through production and distribution, and the methods and techniques to keep losses at a minimum (3.3)

Table of Contents

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Hjartdal, 17th May 2011

Mathias H. Kleppen

Whether you think that you can, or can’t, you are usually right.

Henry Ford

1 Introduction

1.1 Background

Having access to enough safe drinking water is the most fundamental basic need for all human beings. Of the worlds freshwater supplies only a fraction is readily available for consumption by humans.

97 % of the total volume of the world's water is saline, giving only 3,0 % freshwater. Of this total percentage of freshwater around 68,7 % is locked up in glaciers and icecaps, 30,1 % exists as groundwater leaving us with < 1 % found in rivers, lakes and soil moisture (Fig. 1). Therefore we only have relatively easy access to 0.01 % of the world's total water, another 0.01 % being in soil moisture, unavailable for direct human consumption (Grey, 2008).

The much larger potential groundwater supplies can be harnessed to different degrees depending on the aquifer and available technological solutions.

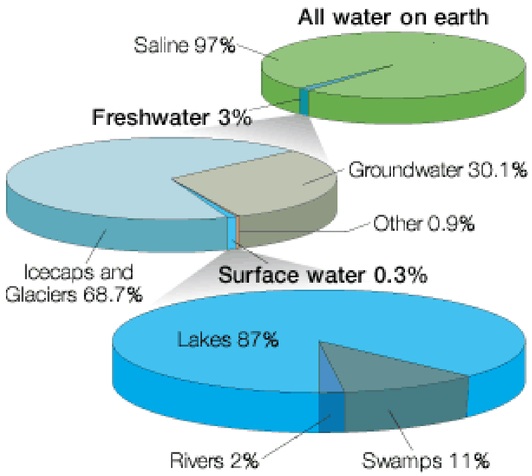

Figure 1: The world's freshwater resources (Source: derived from Gleick, 1997)

Due to the hydrological cycle[1] freshwater is a renewable resource, but it is not distributed evenly in space and time. There may be much precipitation in areas with sparse population and vice versa. The alarming water scarcity in many areas of the world is further exacerbated by population growth, increased standards of living, pollution and climate change, most notably shorter durations of the precipitation seasons and/or an increase in hydrological extremes. Several studies have found that climate change with the projected changes in the

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[1] The U. S. Geological Survey website definition (2011): "The hydrological cycle, also known as the water cycle, describes the continuous movement of water on, above, and below the surface of the Earth. There is no defined beginning or end, since the water cycle is truly a "cycle". Water can change states among liquid, vapor and ice at various places during this cycle and these processes can happen very fast or over millions of years".

global hydrological cycle can lead to a range of effects of great concerns for water service providers, stating that climate change is one of the most influential trends for the future of the drinking water industry (Bates et al., 2008; Danilenko et al, 2010; Liane et at, 2010; Means et al, 2010). The Pacific islands expects to face an increasing variability in rainfall, more cyclone events, accelerated stormwater runoff, increased flood and drought events depending on the location and decreasing water quality with an increasing demand for water. Combined, these impacts are so significant already in many small islands that it hampers the economic development and the health of the people living there (Overmars and Gottlieb, 2009). The expected sea level rise is a particular peril for the atoll nations of Kiribati, Marshall Islands and Tuvalu where the entire population can be deemed “prefugees” (authors definition: people expecting to become environmental refugees within the time span of a generation). The most well known and dramatic example relating to this being the government of Tuvalu’s acknowledgement that the island is “doomed”, and thus they have officially asked Australia and New Zealand for citizenship of Tuvalu’s approximately 11.000 people (Connell, 2003).

About 30 countries in the world are currently regarded as water stressed, of which 20 are absolutely water scarce, defined as <1500m^3/person/year (FAO, 2007). It is predicted that by 2020, the number of water scarce countries will likely reach 35 (Rosengrant et al., 2002). There are several ways of defining water scarcity. In general, water scarcity is defined as “the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully” (FAO, 2007). It is the developing[2] countries that will face the worst crisis and it is estimated that by 2025, one-third of the population of the developing world will face severe water shortages (Seckler et al., 1998). It is also the developing countries that are facing the greatest challenges of “social resource scarcity” and “social adaptive capacity” in order to cope with water stress (Ohlsson, 1999). The terms refer to lack of skills and education in the general population, and weak institutional bodies, governance and legislation. This in turn makes the nation more

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[2] The debate regarding whether or not “high”-, “middle”- and “low income countries” should be used rather than “developed”- and “developing countries” are appreciated, but not relevant in this thesis. In order to have a coherent use of terms throughout the thesis “developing countries” will be attributed the same meaning as “middle and low income countries”.

vulnerable to natural resource scarcity than a nation with the "ingenuity" to plan for- and adapt to, scarcity situations (Homer-Dixon, 1995).

The current world population of nearly 7 billion is projected to reach 10.1 billion in the next ninety years, reaching 9.3 billion by the middle of this century, according to the medium variant of the 2010 Revision of World Population Prospects (UN, 2010). Between 2000 and 2030 it is projected an increase in urban population of 2.12 billion, with more than 95 % of this increase expected to take place in developing countries. The "tilting point" whereby more than 50 % of the world's total population lived in urban areas happened in 2008 (UN, 2008). While the global population has continued to increase rapidly, the amount of available freshwater resources remain constant, though an increasing amount is being polluted by the growing population and rendering less of the resource suitable for human consumption. Human water use increased six fold during the past century (Andresen et al., 1997), and it is estimated that global water withdrawals will further increase by 35% between 1995 and 2020 (Kayaga and Smout, 2006).

Provision of adequate water supply to a burgeoning urban population is a major challenge for the service providers. Additional sources of water are becoming more difficult and expensive to exploit, and there is a substantial investment needed to treat the water into a product suitable for human consumption. Added to these problems are often poor infrastructures, making it difficult to provide clean drinking water on a timely basis. All water distribution systems suffer from leakage, including the ones in developed countries, though not to the extent of most distribution systems in developing countries. Water losses (non-revenue water) average approximately 50 % in developing countries (Kingdom et al., 2006). Other common problems that water operators and service providers in developing countries might face include; poor strategic management, weak financial and operational management, poor staff skills, low funding priority, weak customer service orientation, political interference and little or no independent regulation or oversight (Water Operators Partnerships, 2009). As a consequence optimal use of the available resources is one of the top priority action items for water planners and managers, policy makers and utilities, in order to ensure enough safe drinking water for their customers.

1.2 Problem statement

Many Pacific Island Countries water service providers have problems distributing an adequate water supply since more than half of the water supplied often is lost through leakage and wastage. How can water loss management strategies assist to alleviate this problem?

In the past, development projects in the water supply sector in the Pacific mainly concentrated on the upgrading or extension of existing water supply infrastructure. This *supply* driven approach proved to be very costly for both the donor and the receiving country and did not lead to a safe water supply even for the bigger urban centres in most of the PIC. With more pressure on limited resources, many PIC have realised that the key towards sustainability lies not necessarily in costly infrastructure extension, but rather in the sound management of their existing water supply systems. This is the basis of a *demand* management approach where strategies are developed to improve and optimise existing water resources and infrastructure, and encourage customers to use water efficiently. Economic, environmental and social benefits are achievable with such an approach (SOPAC, 2006).

1.3 Goals and Objectives

The goal of this research is to find ways to optimize water supply in small urban services in the Pacific by water loss management. The research will suggest potential methods and solutions in order to reduce resource waste, and highlight the obstacles faced to do so.

Specific objectives of this research:

1. Based on literature review and practical examples*; suggest strategies* for water loss management programs appropriate to local conditions in PIC.
2. Based on literature review and practical examples; *identify key factors* that influence the implementation of water loss reducing initiatives in small urban water services in PIC.

2 Research methodology

The research methodology applied to this study was divided into two main stages. First stage consisted of a thorough desk study and accounts for around 60% of the workload. The second stage is the results from the actual field work, these practical examples accounts for the remaining 40% of the workload. This division could also be named the theoretical stage and the practical implementation stage. There is always a great interest in seeing if good ideas on paper can be transformed into good results on the ground. The research objectives in this study aims to examine if there indeed is a good correlation between theory and practice when it comes to implementing water loss management strategies.

2.1 Research setting

"A Water Demand Management (WDM) Program for Small Island Countries in the Pacific, 2006 - 2009" was the name given a proposal that was submitted by the Pacific Islands Applied Geoscience Commission (SOPAC), in collaboration with the Pacific Water Association to New Zealand's International Aid and Development Agency. It received the funding in early 2006 and the author of this thesis was hired as a project officer to implement the WDM program. Most of the information presented in this thesis will build on experiences gained throughout the two years as a project officer, while some of the latest data was gathered from a fieldtrip during weeks 12-14, 2010.

2.2 Desk study

The desk study was based upon an extensive literature review, the result of this being chapter 3 of this thesis. By studying various techniques and technologies, methods and concepts of WLM, a foundation for the practical stage was established.

I was also fortunate enough to have the opportunity to follow Wide Bay Water Corporation's WLM course 14 – 28th April, 2008. The course consisted of different theoretical modules combined with practical exercises like testing different leak location equipment and seeing how state of the art pressure management is conducted. An added advantage participating in this course was the meeting with Director Tim Waldron who had extensive previous experiences with WLM in the Pacific region.

2.3 Field study

In this study Niue, Solomon Islands (Honiara) and Vanuatu (Luganville) were picked out to represent three practical examples. The three countries are picked out because work progressed furthest here, and they show different aspects of WLM. Based on this difference chapter 4.1, 4.2 and 4.3 will have a different set up.

The study methods applied during the field study were divided into:

- Discussions with operational staff
- Direct observations
- Implementation of WLM strategies with following analysis/assessment

Having talks with the operational staff to gather information about their water distribution system gave information about the functionality of the system itself and the employees view on issues of concern. It was also a good way to get an overview on their knowledge about water loss causes and effects, and how they thought these best could be solved.

The staff obviously also joined in on the direct observations in the field, since they are the ones with the institutional memory and firsthand knowledge about the system. First we had a look at any available maps of the system. Then observations were made on all critical points in the distribution system, reservoirs were visited and minimum night flow measurements conducted, integrity of valves were checked, pipe repairs were looked at and flow- and pressure tests were conducted.

To see if WLM strategies can assist in reducing waste of water different ideas were put into practice. Since the three water providers in question had very little data on “what water goes where”, a metering and logging effort would get the highest priority. Other focal areas would be general capacity building of the operational and managerial staff in WLM.

3 Literature review

3.1 Millennium Development Goals (MDG)

In 2000 world leaders set ambitious goals to relieve a major portion of humanity from extreme poverty, hunger, illiteracy and disease (UN, 2009). It is relevant to bring this up here as a basis to understand why water loss management is regarded as one of the most important steps to take in order to ensure a safe water supply in developing countries. Water loss management would fall under MDG 7: *Ensure environmental stability*. Target 7c: *Reduce, by half, the proportion of people without sustainable access to safe drinking water and basic sanitation*, the indicator for this being; *proportion of population using an improved drinking water source*. An improved drinking water source could be public tap stands, hand pumps, improved dug wells or springs. Surface water such as rivers and lakes, or dams and unprotected dug wells and springs are referred to as unimproved water sources (Fig. 2). It is estimated that around 1, 2 billion people do not have access to an improved source of water (UN, 2009).

Figure 2: From unimproved (left) to improved (right) water source (Source: Author, 2005).

Figure 2 illustrates the difference between an unimproved and improved water source in Aloi, Uganda, by establishing a sand-filter for water purification and proper collection point.

To meet MDG 7 is a daunting task. If 1, 2 billion is the figure in 2000 there will need to be developed improved services to approximately 220 000 people every day to meet the target in 2015. It is estimated that approximately US$ 20 billion must be invested every year to reach the MDG for basic access to drinking water in developing countries (Kingdom et al., 2006). Urban dwellers in developing countries are more than twice as likely to have access to piped water supply as a person living on the country side. On the other hand urban drift and dwindling local water resources are putting an unprecedented pressure on the water resources of many urban areas. Experiences from the Pacific entails that approximately 20-40% of the water supply, which currently is wasted through leakage, can be reallocated to its intended use by water loss management (information obtained from discussions with operational staff during field work in Cook Islands, Solomon Islands, Marshall Islands, Federated States of Micronesia, Niue and Vanuatu). Thus implementation of water loss reduction methods could potentially bring about significant improvements and be an important part of a country's strategy to meet the MDG 7, target 7c.

3.2 Small Island Developing States

Small Island Developing States (SIDS) are island nations that share similar physical and structural challenges to their development. Most SIDS are isolated to varying degrees, small in land area and with a very limited total population. In general they often have a narrow resource base (fisheries, mining) with fragile land and marine ecosystems that are highly vulnerable to natural disasters. Their economies are open and heavily dependent on trade for national income (Bates et al., 2008). Their growth and development is often further impaired by high transportation and communication costs, disproportionately expensive public administration and infrastructure due to their small size and little to none opportunity to create economies of scale (Overmars and Gottlieb, 2009).

In total 51 Small Island Developing States and territories are included in the list used by the United Nations Department of Economic and Social Affairs in monitoring the sustainable development of SIDS. Apart from the Pacific there are two other groups; the Caribbean and the AIMS which include islands around Africa, in the Indian Ocean, Mediterranean and the South China Sea. In the United Nations they often work combined through the Alliance of Small Island States (AOSIS) (Bates et al., 2008). There are 20 member countries from the Pacific, including Solomon Islands, Niue and Vanuatu which are the practical example countries in this thesis.

3.3 Water loss management (WLM)

Water encompasses a set of different values in different contexts (ecological, economical, social, cultural etc.). We depend upon a steady supply of enough hygienically safe water to be used for drinking, cooking, washing etc. In urban areas there is normally a water service provider that has the responsibility to cater for these needs. They have water as their product to be distributed to the consumers. If water is scarce physical savings will be imperative, if water is abundant, but expensive to treat and distribute, the economical value and potential financial savings from WLM will be of vital importance. Water loss management thus entails all the efforts a water service provider make in order to account for all the water that is being invested in it through production and distribution. The ultimate goal of this effort is to make sure that water losses are kept at a minimum. There will always be a certain amount of leakage to varying degrees in any distribution system, but the key point is to try and get as much as possible of the water supplied to reach its intended users.

Water losses, **non-revenue water** (NRW) and **unaccounted-for water** (UFW) are the most commonly used terms to address the wastage occurring in the supply network. Some definitions of water loss are:

- Water losses = water produced – water billed or consumed (Farley, 2001)
- Water losses = Real losses + Apparent losses (Lambert, 1999)

These definitions basically describe the same, but in this thesis it has been chosen to follow the latter definition from the International Water Associations (IWA) water loss task force methodology and terminology. IWA has been, and is, a leader in developing a standard water balance, international terminology, strategies for water loss reduction and corresponding performance measurement (Brothers, 2003). The IWA approach was used during the field work in the Pacific 2006-2008. The IWA have also defined the components of water losses in a supply network in order to set internationally recognized and consistent standards. This makes it possible to accurately compare performance across national boundaries. The IWA has defined three key water loss components within water supply networks. These are; **authorized consumption**, **apparent losses** and **real losses**.

3.3.1 Authorized consumption (metered and unmetered)

Authorized consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water suppliers and others who are implicitly or explicitly authorized to do so (Trow and Farley, 2006). Authorized consumption includes:

- residential properties
- factories, manufacturing operations
- educational facilities
- local government/council operations and offices
- irrigation of public parks and gardens
- fire fighting and training
- bulk earthworks and dust control
- etc.

3.3.2 Apparent losses

Apparent losses consist of unauthorized consumption, and all types of metering inaccuracies (Trow and Farley, 2006). Also data transfer errors and data management errors can be added to this definition. Apparent losses are sometimes referred to as *Commercial losses.*

Apparent losses are water which “disappears” through inaccurate metering and the metering accounting process, lack of metering and incorrect assumptions of unmetered use, theft and illegal use. It can thus be part of either authorized or unauthorized use. The water is not physically lost from the system, but it is never measured or accounted for. These losses cost the utility revenue, but also distort data on customer consumption patterns. If apparent losses are reduced, more revenue will be generated, and better data will be available, by and for the water service provider. Apparent losses include:

- errors in source, production and consumption (household) meters
- theft or illegal use
- unmetered public use (council parks and gardens, cleaning)
- fire fighting and training
- water used in processing (filter back-washing)
- water used in infrastructure maintenance (pipe scouring and reservoir cleaning)
- etc.

3.3.3 Real losses

Real losses are the annual volume lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering (Trow and Farley, 2006) Real losses are sometimes referred to as *Physical losses*.

Real losses are water which physically disappears from the distribution system through problems such as holes, cracks and fissures in pipes, joints and fittings, reservoir overflows and leakage through reservoir floor and walls or through evaporation. This water does not disappear from the hydrological cycle obviously. It is water that the service provider has invested in which does not reach the customer. If real losses are reduced, more water will be available for distribution to customers at a much lower economic and environmental cost than augmentation of supplies. Real losses include:

- background leakage in pipes, joints and fittings
- reported and unreported bursts in pipes
- leakage and overflows from reservoirs
- etc.

3.3.4 Causes of water loss

There are a whole range of factors that are, to varying degrees in space and time, responsible for water loss (Fig. 3). The most common ones being briefly described in the following (Farley, 2001; WBWC course, 2008):

- ***Pressure***. The pressure needed to supply water through the pipe network can in itself cause water loss in several ways through increased leakage as a result of increased pressure; increased burst frequency as a consequence of increased pressure or pressure surges (water-hammer effect); pressure cycling from frequent on/off switching by pumps or faulty pressure-reducing valves (PRV) can cause fatigue in plastic pipes. On the other hand higher pressure will result in more water leaking from holes in the pipeline, creating more sound and thus making leak location easier.
- ***Soil condition and movement***. The soil in which the pipeline is laid influences the pipeline itself. Corrosive soil will deteriorate metallic pipes, changes in moisture content and changes in temperature (freeze-thaw cycles) can lead to soil movement and displacements of pipes, as can obviously earthquakes that appear frequent throughout the Pacific. Vibrations through the soil from traffic loading can also lead to pipe failure.
- ***Poor quality materials and workmanship***. Faulty laying of pipes and incorrect backfilling will cause rapid pipe failure. Storage of plastic pipes in the sun and damage during handling will shorten their durability. On the customers side there will be faulty tap washers, ball valves, poor seals, leaking toilets etc. that causes waste.

- ***Pipe materials and age***. There are several types of pipe materials available for water supply systems (lead, cast- and galvanized iron, copper (housing), different kinds of plastic, asbestos cement and concrete), and they all suffer from different kinds of deterioration that gradually will have a bigger impact with time. When considering the most significant factor creating leakage, age on its own is not necessarily important if the quality of the pipe and workmanship have been good.
- ***Errors in water flow measurements***. Wear and tear on all meters in a supply system can be attributed to environmental factors such as water quality impacts, heat or cold and as seen in the Pacific soil conditions as the bulk meters were often laid directly in the ground. Poor workmanship including lack of proper repair, routine testing and maintenance, or tampering will all lead to errors in flow measurement.
- ***Errors in accounting***. This is relevant when customer accounts exists like in Vanuatu, but not in Niue, and is primarily a result of errors in handling these accounts. These errors can be intentional (corruption) as some people can be deliberately omitted from monitoring records. Accounting data transfer errors and accounting data management errors can occur unintentional due to poorly structured billing and meter reading systems.
- ***Unauthorized consumption***. As discussed previously (2.3.2) this mainly covers theft and illegal use.
- ***Human resources, management and finances***. Lack of skills or incompetence due to lack of training and education can indirectly cause water loss as work is not satisfactorily done. Pilferage and employee’s corruption is also rife in many developing countries. Upper management often does not address water loss and thus create a mindset that can permeate the entire organization. Some utilities might have tight finances thus leaving water losses unchecked and thereby creating even less revenue, – or priorities might simply be given to augmentation of supply instead of focusing on the demand-side.

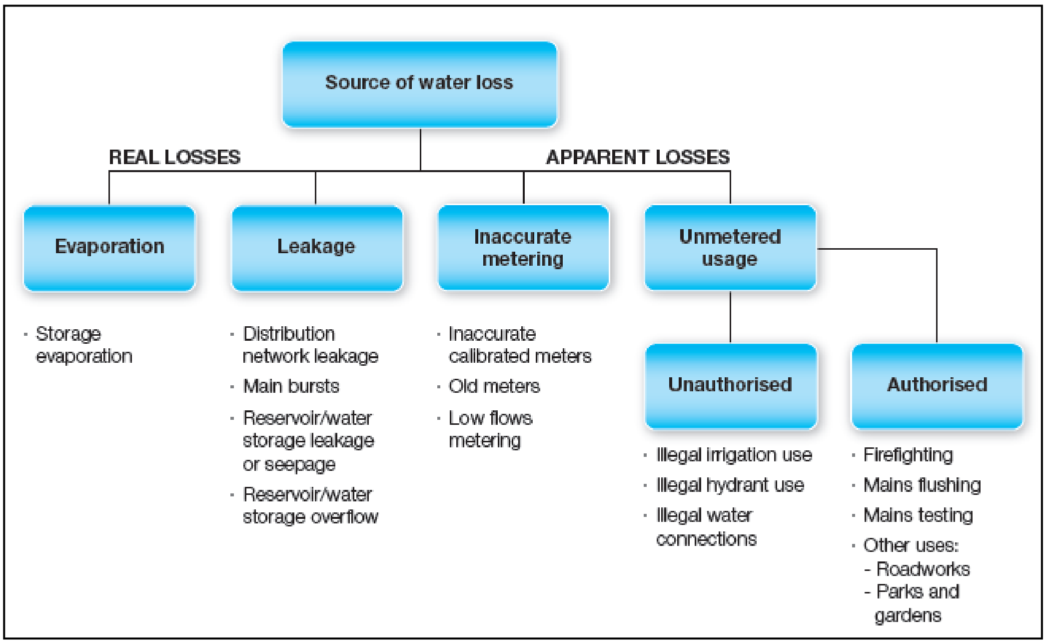

Figure 3: Conceptual model showing the different sources of water loss (Source: Queensland Government, n.d.)

3.3.5 Non-revenue water (NRW) in developing countries

During the literature review it has come clear that non-revenue water (NRW) is the most widely used expression to define water losses. The IWA task force on "water losses", and the task force on "performance indicators", advice to use NRW instead of unaccounted-for water (UFW), because of the widely varying interpretations worldwide of the term UFW (Alegre et al., 2006).

NRW is the difference between the "system input volume", the water supplied into a water supply network, and the volume that is billed to customers. NRW comprises of the three components: *real losses*, *apparent losses* and *unbilled authorized consumption*[3].

As outlined in chapter 1.1 the problems associated with NRW in developing countries are staggering. In the Pacific SIDS the problem is apparent, but varying from being a very serious problem in some countries to becoming under control in others (Burke, 1997 and 1998; Burke and Schötzel, 1998; Schötzel and Bower, 1999; Dawe, 2000 and the World Bank, 2006). It is

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[3] Contrary to real and apparent losses, unbilled authorized consumption does not reflect operational inefficiencies, but rather a public policy decision to allocate water without a monetary compensation (Kingdom et al., 2006). This is currently the case for Niue.

generally acknowledged that NRW in developing countries are very high, still there are in fact very little available data in the literature regarding the actual figures. This is due to several factors were the most obvious is the lack of adequate monitoring systems for analyzing and reporting water losses. The NRW data that do exist is often difficult to obtain and when they are available, they do often contain errors showing a better performance than it is in reality. This is due to the general opinion that high NRW levels is the epitome of a poorly run water utility that lacks the governance, the autonomy, the accountability and the technical and managerial skills to provide reliable service to their customers (Kingdom et al., 2006).

The World Bank has created a database on water utility performance called the International Benchmarking Network for water and sanitation utilities (IBNET). The database contains data from more than 2000 utilities in 85 countries. Fiji, Samoa, Solomon Islands, Tonga and Vanuatu are the only PIC registered in the database, but they contain no data. IBNET found that the average figure for NRW in developing countries is 35%, but the actual figure is probably more in the range of 40-50% (Kingdom et al., 2006). This is again largely due to lack of data in many of the known worst performing utilities, and that it is the better performing utilities that actually report operating data. From experiences during fieldwork in several PIC a rough estimate of 30-60% NRW can be argued. Figure 4 show that 29% of the utilities in the IBNET database have 30-40% NRW. The two upper brackets, ranging from 40% to more than 50% NRW accounts for ca. 35 % of all the utilities, while the lower three brackets - the utilities that perform relatively good - accounts for 36% of the total.

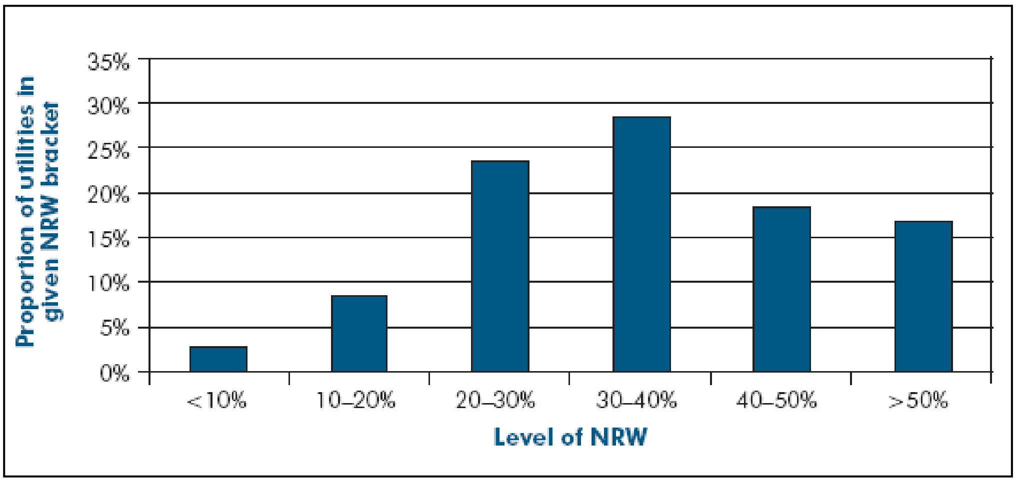
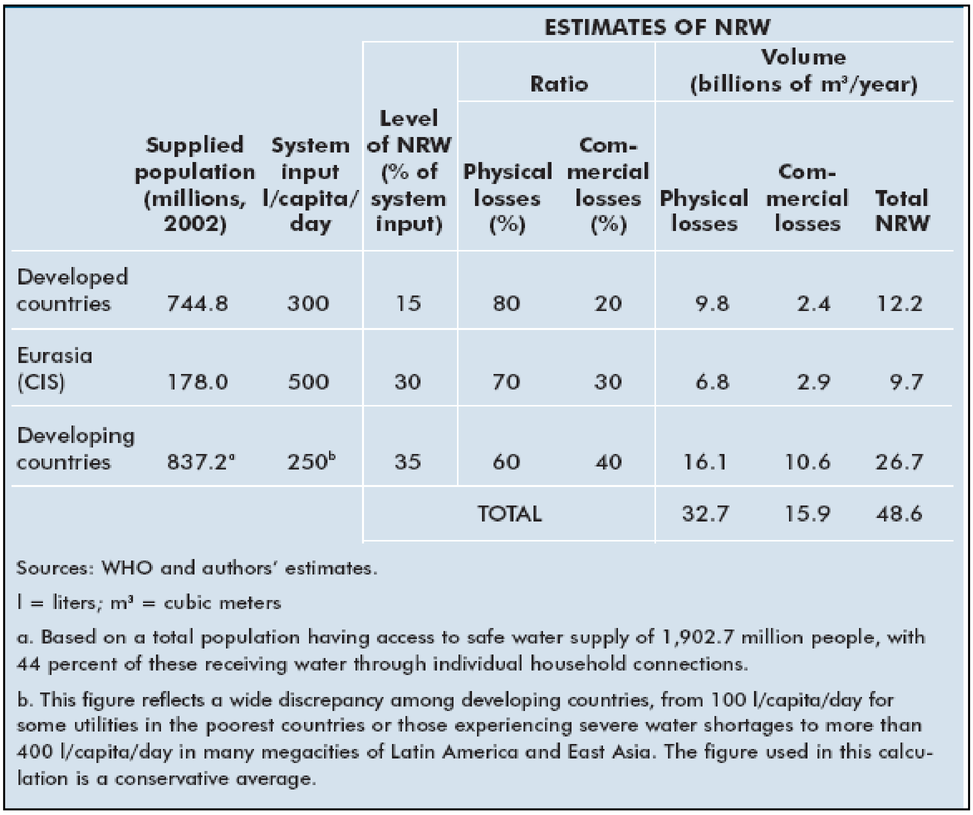


Figure 4: NRW performance by utilities in IBNET database (Source: Kingdom et al., 2006)

The following table 1 is an estimate of the worldwide volume of NRW in urban water supply systems with a breakdown of its components. The figures are developed by the authors of

Kingdom et al. (2006) with population data from the World Health Organization's (WHO) update on the MDG's and a conservative estimate of 35% NRW for developing countries;

Table 1: Estimates of NRW in Developed, Eurasia and Developing countries (Source: Kingdom et al., 2006).



ESTIMATES OF NRW

	Supplied population (millions, 2002)	System input l/capita/day	Level of NRW (% of system input)	Ratio		Volume (billions of m³/year)		
				Physical losses (%)	Commercial losses (%)	Physical losses	Commercial losses	Total NRW
Developed countries	744.8	300	15	80	20	9.8	2.4	12.2
Eurasia (CIS)	178.0	500	30	70	30	6.8	2.9	9.7
Developing countries	837.2[a]	250[b]	35	60	40	16.1	10.6	26.7
			TOTAL			32.7	15.9	48.6

Sources: WHO and authors' estimates.

l = liters; m³ = cubic meters

a. Based on a total population having access to safe water supply of 1,902.7 million people, with 44 percent of these receiving water through individual household connections.

b. This figure reflects a wide discrepancy among developing countries, from 100 l/capita/day for some utilities in the poorest countries or those experiencing severe water shortages to more than 400 l/capita/day in many megacities of Latin America and East Asia. The figure used in this calculation is a conservative average.

The result as seen in table 1 clearly shows the magnitude of the problem with NRW in developing countries. Approximately 16 billion m^3 of treated water physically disappears from the system as real losses, while approximately 11 billion m^3 are delivered to customers for zero revenue. At the same time utilities in developing countries are starved for additional revenues to finance expansion of services, since most of their customer suffers from intermittent supply and poor water quality (Kingdom et al., 2006).

Kingdom et al. (2006) also made an attempt to show what this means in fiscal terms and suggested that water worth around US$ 5 billion is lost every year. This amounts to more than 1/3 of the world total NRW estimated to be US$ 14 billion. Keeping in mind the figure of US$ 20 billion (chapter 3.1) that is needed to be invested every year in order to reach the MDG's, there should be substantial benefits by lowering the amount of NRW. Apparent losses alone amounts to US$ 2.6 billion. This is approximately a quarter of the total yearly investment in drinking water infrastructure for the entire developing world. Real losses alone amounts to approximately 45 million m^3 a day (Kingdom et al. 2006). This would be enough to serve nearly half a billion people with 90 liters of treated water a day.

3.4 Water loss reduction practices

"- *to measure is to know*" and "*what you don't measure you can't manage*" are two well established sayings in the water industry, and in essence they capture what water loss management is all about.

In order to ensure that the best utilization is made of the assets and the water supply itself, it is essential that the water flows are measured within the supply network. The design of the water supply system, and its construction, management, operation and maintenance must be understood and optimized. These issues will vary for each unique water supply system. There are a series of connected techniques, procedures and methods to be applied to get a better understanding of how water losses occur, and how these can be reduced and better managed.

A diagnostic approach, followed by the practical implementation of achievable solutions can be applied to any water company, anywhere in the world, to develop a WLM strategy (Trow and Farley, 2006). There is a general lack of data concerning the water utilities in PIC, and in many cases it is believed that it is not possible to develop, or even start up, a NRW reduction program until detailed analysis of the target and the least cost method of achievement have been studied (Pearson, 2009). Pearson argues further that it is in fact possible to develop a twin track approach of starting on a water loss reduction program whilst data needs are identified and programs are put in place to deliver these needs. This line of thought was also used during the field work in the Pacific.

Other studies on WLM in developing countries have also shown that even without "perfect" data, improvements can be achieved. The following references provide some examples; Kenya, Lesotho, Tanzania and Uganda (Kayaga and Smout, 2007); India & Vietnam (Agrawal, 2008); Ecuador (Beltrán, 2009); Trinidad & Tobago (Fanner, 2009), Indonesia (Iwami, 2009); Papua New Guinea (Makara, 2009); Uganda (Mutikanga et al. 2009b); Namibia (Pietilä and Seppänen, 2009); Nepal (Sharma and Nhemafuki, 2009), Malaysia (Zailan, 2009) and Madagascar (Parker, 2010).

A reasonable way to start up a water loss reduction practice is to prioritize the tasks by posing a few questions about the system characteristics, the production process and the operating practices;

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

(Trow and Farley, 2006).

To answer these questions we go on to the available methods. These comprise of the following;

- Water audit (water balance)
- Meter management
- District metered area (DMA) design and management
- Pressure management
- Leakage monitoring and control
- Mains renewal and control

These are explained in the following chapters 3.4.1 to 3.4.6.

3.4.1 Water audit

The first two questions mentioned, “how much?” and “where from?” can be answered by conducting a systems water audit, often referred to as a water balance (Trow and Farley, 2006). So before starting any form of WLM activity it is important to carry out water audits in order to get an overview on all accountability and management of water, including *metered and unmetered authorized consumption, apparent losses and real losses*. These are the four main components of the water balance. In summary the water audit is a thorough (- or as accurately as possible) accounting of all water into and out of a utility, as well as an in-depth record and field examination of the distribution system. All water supplied is accounted for in the components listed in figure 5, by using either measured or estimated quantities; a cost can then be placed upon the same components in order to assess its financial impact on the water service provider. It is intended that the water audit will determine operational efficiency of the system and identify sources of both water- and revenue loss. Without a proper understanding of the distribution network, WLM initiatives would most likely only yield short-term benefits (Sharma and Vairavamoorthy, 2009).

System input volume	Authorized consumption	Billed authorized consumption	Billed metered consumption	**Revenue water**
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	**Non-revenue water**
			Unbilled unmetered consumption	
	Water losses	Apparent losses (commercial losses)	Unauthorized consumption	
			Metering inaccuracies and data handling errors	
		Real losses (physical losses)	Leakage on transmission lines and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Figure 5: IWA international best practice water balance (Source: Lambert, 2003)

Water auditing is the discipline concerned with quantifying water usage (Sturman et al., 2004), and in the context of WLM there are several different types of auditing procedures to be utilized. Some methods are briefly explained in the following;

(WBWC course, 2008)

- ***Night flow audits for leakage***. At night customer consumption is normally at a minimum. A short-period measurement of inflows to defined, small sectors can provide “snapshot” values of the rate of leakage in that sector. The audit itself also reviews how the utility undertakes the night flow measurement process, including how areas or zones are physically separated and how pressure levels are justified. If it is not possible to accurately define sectors, as is common when first attempting to understand water losses in utilities with poor oversight on their own operations, a *reservoir drop test* can be conducted (Fig. 6). Then the flow from a supply reservoir is measured by recording the fall in the reservoir level over a given time and multiplied by the reservoir cross-sectional area. It is a meaningful first step to understand water losses in the system but the lack of measurement accuracy is a weakness that must be considered.

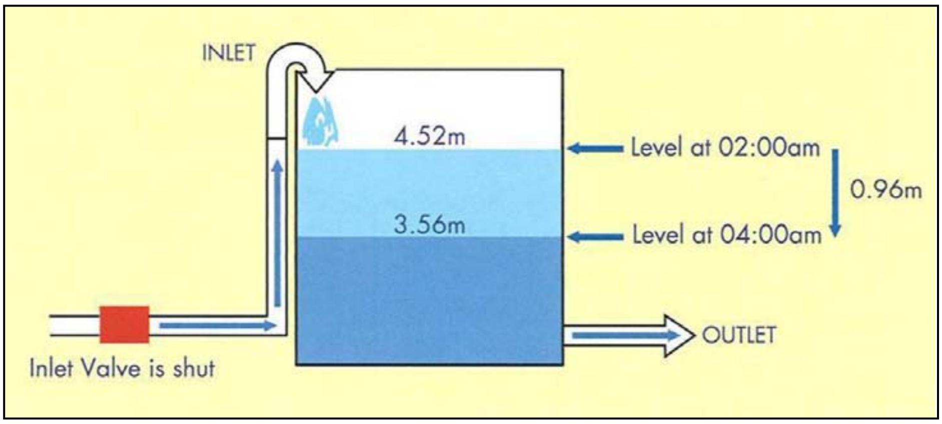


Figure 6: The reservoir drop test (Source: WBWC, 2008)

- ***Reservoir audit for overflows***. This type of audit is a manual inspection of reservoirs to physically check for overflows. This audit is also usually conducted at night when the reservoirs are refilled and overflows can occur without being identified by operators who normally work dayshifts. Overflows normally occur as a result of telemetry failure when the reservoir is full or mechanical errors in simpler stop valves/floats.
- ***System pressure audit***. The system pressure audit is done for strategic and management reasons. It looks at systems design and gives information useful for financial reasons as well as water saving as such. If there is potential for reducing pressure and avoiding pressure surges the flow rates of existing leaks will diminish (reducing background leakage), as well as the annual number of new breaks on the pipelines.
- ***Water audits in businesses and industry***. An annual water audit of businesses and industrial operations identifies where, how and how much water is being used. It also provides the baseline data to develop and implement internal water efficiency programs. This data also need to be known before conducting a reservoir drop test or a night flow audit since industrial users might have high usage also in the night time.
- ***Home water audits***. If there exists incentive based activities to encourage customers to become more efficient, a water utility could conduct home water audits as a service to their customers. Especially where there is a consumption based pricing of water this is relevant, or in cases where water is scarce and awareness programs to make customers understand the "value of water" are implemented.
- ***Meter testing audit***. See 3.4.2.

3.4.2 Water meter management

Water meters are essential in order to collect data needed for efficient management of water losses. Metering link consumption and price (Vairavamoorthy and Mansoor, 2006), and meters are required throughout the distribution network to identify the amount of water harvested, treated, stored, distributed and consumed. Sometimes there is also import and export of water to be measured. In Chapter 3.4.1 we saw that metering is the basis for the water balance, which again is an indicator of operational effectiveness of the distribution system. Since metering is the essential tool in accounting for - and making the best use of - water, it is crucial that the service providers meter their distribution system as fully as possible. Unmetered connections should be kept at a minimum and metering coverage should be maximized in all sectors (Vairamoorthy and Mansoor, 2006). The following types of meters should be installed to measure water use as accurately as possible;

- source or raw water meters
- bulk flow, production or purchase meters
- reservoir outlet meters
- zone meters
- district meters
- industrial, commercial and non-domestic meters
- domestic and residential meters

The list is not exhaustive but contains the most important meters needed also for a service provider in a developing country.

The water meters will give information, but all water meters have at the same time considerable measuring limitations. Wear and tear normally leads to under-registration of water consumed and thus increases the amount of apparent loss that leads to revenue loss for the utility. Many service providers in developing countries face problems with intermittent supply, and research have shown that meters function poorly in such systems (Vairamoorthy and Mansoor, 2006). Sudden start and stop of the meter impeller produces an undesirable strain on the mechanics, alternate drying and wetting of the parts is also unwanted since the continued performance of a meter relies upon being in constant contact with water. Intermittent supply can also cause air to enter the system. This air is forced out of consumers connections at the start of supply and cause excessive speeds that affects the working of the meter (Gokhale, 2000), and over-registration of consumption. Other problems reported in numerous studies relate to poor meter quality, poor water quality, use beyond useful life, improper sizing and improper installation (Farley and Trow, 2003). In developing countries in particular it is also relatively common with meter tampering, or that faulty or broken meters are left unchecked (Fig. 7) and not being replaced due to lack of a proper repair and replacement program.

Figure 7: Two examples of troubled zone meters in the Pacific. (Source: Author, 2007)

All meters that are affected by one or more of the above mentioned problems will provide incorrect information and will affect the resulting estimate made in the water balance. Most of the water "lost" to metering errors will appear as apparent losses and cause revenue loss to the service provider. A meter-testing audit would be a useful review of the utilities "meter fleet" to determine accuracy within the fleet. To ensure accuracy, the following meter management steps should be taken;

- ***Correct selection***. There are today a whole range of different meters to be selected for different purposes throughout the distribution system. Meter size is based on the operating conditions like pipe size, the range of flow to be measured, range of pressure it needs to handle and the accuracy needed. Importantly the meter needs to have the lowest anticipated flow within its normal operational area of reading. Water quality factors such as turbidity must also be considered. For the bigger meters that measure the supply the possibility to connect to a logger is beneficial. This will give detailed information of the performance with a temporal resolution that can be decided through the logger-software. Combined with correct selection of meters there is also a need for "customer demand profiling". This profile consists of flowrate data describing water use versus time (Mutikanga et al., 2010). Research by Fantozzi et al., (2010) showed that installation of an unmeasured flow reducer in conjunction with the meter can effectively reduce the water meter under-registration. Having an overall knowledge of the local distribution system in question combined with the meter manufacturer's specifications, and a reliable customer demand profile, will ensure correct meter selection. Unfortunately the pattern of water use in developing countries and its impact on domestic meter selection has not been studied comprehensively or documented, and is therefore not very well understood (Mutikanga et al., 2010).

- ***Correct installation***. A study from Zambia (Gonga and Banda, 2010) showed that installation of water meters is by far the easier part of a metering project. Still it is important that installation are done correctly to ensure correct readings and avoid un-necessary wear and tear of the meter itself, or leakages from connection points. Different installation procedures exist for different meter types, but a rule of thumb is often to keep a 5 times the diameter of the pipe upstream and 3 times the diameter downstream (pers. comm. Bjørnson) free of any obstacles (valves, bends etc.). This is to avoid turbulence that can cause errors in reading. Water industry practice have also shown that the meter should usually be one diameter range less than that of the pipe it is to be installed on. Domestic meters are often many and needs to be easy accessible and easy to read for the meter reader, it should also be sealed so that tampering are reduced and easily seen when it has occurred.
- ***Meter testing and maintenance***. Meter calibration need to be undertaken periodically to assess drift in accuracy. The bulk meter is by large the most important meter since it basically is the instrument to base most WLM decisions upon. It is also the most expensive and most difficult to calibrate meter in the network. Most methods used in developed countries are not suitable in the Pacific since there exists no meter testing beds set up for this job and there is no in-country expertise to use insertion meters. This problem was omitted by the fact that most bulk flow meters were ready for replacement and new ones were installed, or got upgraded with new parts. Small industrial, commercial and domestic meters were calibrated by checking them against a known calibrated meter that the operators carried with them. There were several examples to prove that meter management was not high on the agenda amongst several PIC water service providers. Bulk meters were stuck because of rust debris from the inside of a reservoir, it was found an iron rod inside a bulk meter in another country, some had been incorrectly installed by the consultant and some had basically disappeared under mud and soil.

- ***Replacement***. There are several works that have dealt with the optimum replacement frequency of installed water meters. These works show that replacements should be based upon the meter acquisition and installation cost, the selling price of water, the interest rate of money and the degradation rate of the weighted error. The weighted error of a meter is defined as the combined error at different flows considering the percentage of water that is consumed at each flow rate (Arregui et al, 2010). For our use in the Pacific we simply said that meter replacement should be carried out when the cumulative revenue lost due to meter inaccuracies outweighs the cost to replace the meter itself. When this optimum point for meter replacement occurs can be checked by empirical data from random controls using the calibrated meter. A figure can be constructed for the given utility to see where cost of meter errors is equivalent to the cost of meter replacement (Fig. 8).

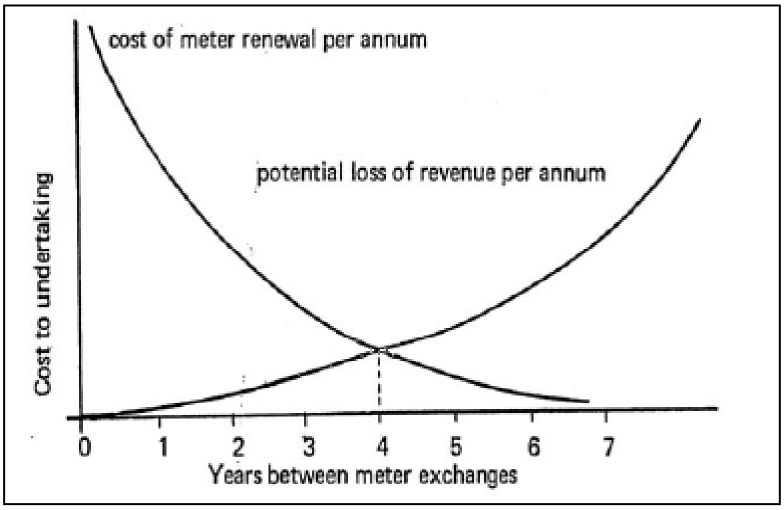


Figure 8: Example on economics of meter exchanges (Source: Coe, 1978)

3.4.3 District metered area (DMA)

The concept of district metered area[4] (DMA) management was first introduced by the British water industry in the early 1980's (Morrison, 2004). A DMA is a section of the overall distribution system that is specifically defined or hydraulically discreet. Ideally it has just one inflow point equipped with a bulk (district) meter (Biedermann et al, 2009). This will tend to

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[4] It is noted that there exists a "verbal battle" in the literature between the use of DMA and the Global Integrated Method, sometimes referred to as the British versus French approach (Biedermann et al, 2009). The work in the Pacific follows terms and definitions used by IWA which means that DMA is the preferred method.

minimize the number of valves which have to be shut to create a discrete area (Trow and Farley, 2006). It is created physically by the closing of valves or, in some cases; it may be defined naturally by the local geography. Creating DMA's are also referred to as *sectorisation* of the supply network and are sometimes done in conjunction with the establishment of pressure management zones (PMZ). Sectorisation is done to get a piece by piece overview of the overall distribution system (Fig. 9). The core of this activity is to measure the flow of water entering and leaving the district or sector. By analyzing this flow, the night flow in particular, a calculation of the level of leakage within the district can be done. This information gives us a clear list on priority of how the different districts perform and where it would be most beneficial to undertake water loss reduction activities. Creating DMA's to monitor water losses has now become one of the most cost-effective and most widely practiced activities to reduce real losses (Farley and Liemberger, 2004). It is still important to take into consideration local factors such as different operating conditions, design of the distribution system, environmental factors, the economy of the utility etc. before embarking upon a DMA program (Brothers, 2009).

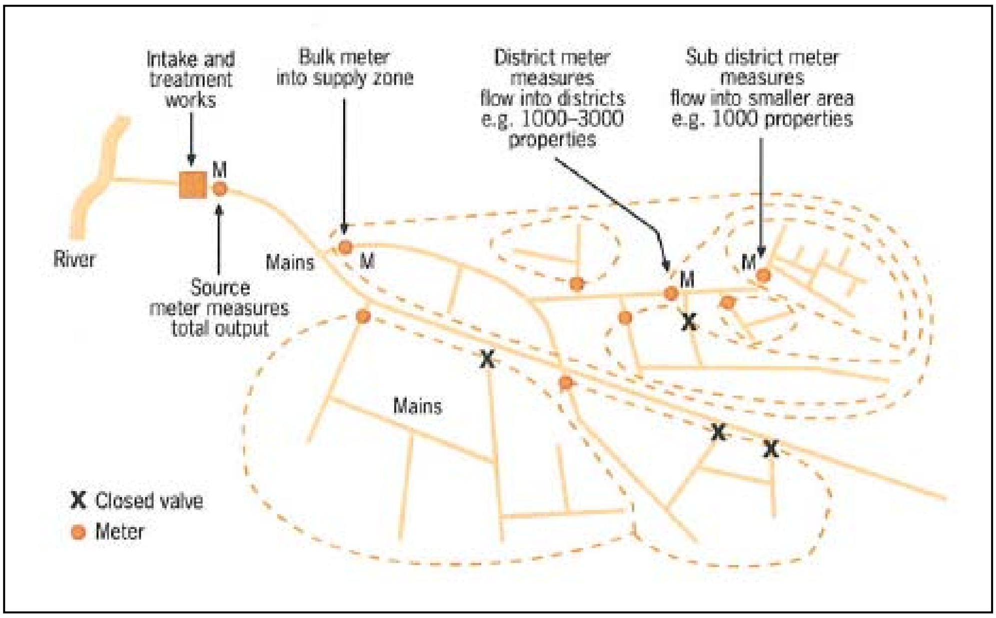


Figure 9: Typical metering hierarchy and DMA options (Source: Farley, 2001)

Dividing a supply network into sectors such as DMA or PMZ, which are then individually managed and monitored on a continuous basis, will give the service provider a better understanding of several important issues like (WBWC course, 2008);

- ***Knowledge of flow and where water supplies are going***. Without the installation of flow-monitoring equipment throughout the distribution system and the separation of sectors, it will basically be impossible for a service provider to know how effectively the system, and areas in it, is operating. Establishing DMA's comes with a cost that has to be compared to the cost of the water volume lost. Each unique water service provider will have their own set of criteria for *economic levels of leakage* (Chapter 3.4.7.3).

- ***Knowledge of potential savings from pressure and flow***. Sectorisation gives utilities the ability to control individual sectors according to their specific conditions and requirements. Once data on flow and pressures for each sector has been captured and analyzed, the potential saving for each one can be calculated. Without this knowledge the ability to gain these potential savings are lost.
- ***Increased knowledge about consumer consumption***. Sectorisation gives the most accurate information about consumer usage patterns within the sub-areas of the distribution network. This information is used to perfecting network analysis models and accurately predicting capital upgrade requirements.
- ***Increased knowledge of how the distribution system works***. Water distribution networks in the Pacific relies heavily upon the institutional memory of the operators, they can have extensive knowledge of the network gained through years of operational experience. Sectorisation allows networks to conclusively prove that all water entering one sector is being measured and identify where equipment is working efficiently or inefficiently. By establishing and later investigating the sectors the field staff will rapidly increase their knowledge of the network.
- ***Pre-planned responses to problems***. Having immediate knowledge of pressures and flows in a sector means that pre-planned responses to emergencies and problems can be instigated promptly and efficiently. It allows the utility to provide customers with a well informed response about the nature of a given problem and what to expect. This again gives a level of reassurance to customers that are not otherwise available.
- ***Economics***. There are several economic benefits from monitoring leakage through sectors. The prime justification of a DMA program is normally focusing on the predicted savings from water loss reduction and the possibility to defer capital expenditure. Extending asset life can significantly reduce cost and by reducing pressure, thus reducing the burst frequency and the subsequent need for repair, this can be achieved. The stabilization of pressure variations will also lead to less material fatigue and increased asset life. In areas where water is scarce there are significant environmental benefits from the deferment of augmenting supplies by a wiser use of the already available resources.

3.4.3.1DMA design

The design of DMA’s is obviously more complicated the bigger the area in question is. However, the overall generalizations that apply for big utilities also apply to the smaller ones. DMA design in developing countries should be planned with practicality, continuity and sustainability being the principle criteria (Loveday and Dixon, 2005). The main question when starting to plan for a DMA program is “where do we start?” Based on institutional knowledge and experiences, the areas with the higher unit cost of water or where the greatest savings can be achieved should be located. Most water utilities today have digitalized maps over their distribution system, if not; like in the case of Luganville, a hard-copy map, schematic or drawing of the network will have to suffice. Before venturing out in the field it is important to get as much information as possible from people that have knowledge about the network, like distribution repair gangs, supervisors, plumbers and main layers if these contractors are still operational in the area. In the Pacific much initial work has been done by overseas consultants that can be contacted to get information if needed. Some of the factors in addition to the available documentation that must be considered and discussed before sectorisation can begin is; topography, number of connections, position of boundary valves and how to test the integrity of the zone. When a plan for the creation of a DMA is hatched an onsite survey is the next step. During this work the following needs to be checked (WBWC course, 2008);

- ***Proposed meter locations***. The location of the district meter has long-term implications for the operational staff, therefore its location needs to be appropriate for their needs as well as for measuring water. It is always beneficial to try and develop a single feed into a DMA for ease of operations and calculations later.
- ***Testing the condition of proposed boundary valves***. As experienced in the Pacific there is not always a correct match between boundary valves on paper and boundary valves in the field. The survey team needs to make sure that they actually exists and the location is known; that they are controlling the water main the plan says they are controlling; that they are the size shown on the plan; that they will shut off the area (s) shown on the plan and control whether they are in good condition or need maintenance or replacement. Boundary valves must be in excellent condition and confidence must be very high that they are not passing any water when closed. If possible natural boundaries should be utilized to minimize the number of valves needed.

- ***Identifying locations of flushing hydrants***. Hydrants for flushing and venting out air need to be located at the extremes of the DMA. Any interruption to flow within the DMA will require action on these hydrants. Hydrants are also useful (necessary) for pressure logging at these extremes where pressure tends to be at its lowest.
- ***Identifying locations of pressure test hydrants***. Within the DMA the highest, furthest and lowest points must be identified. Wherever these positions are, a nearby hydrant needs to be located, or installed, for use as a pressure testing point. Often in the Pacific this was not possible and pressure at municipal tap stands or at private homes were used. This works, but not to the same degree of accuracy as using a hydrant.
- ***Identifying known areas for problems of poor pressure or water discoloration***. Occasionally this is found through determining which water mains are old, corroded or have long lengths of small diameter pipes. Tests on hydrants can be carried out to measure flow and residual pressures and the discoloration can be witnessed from these tests. Again the institutional knowledge will give a lot of information based on the operator's experiences and customer complaints.
- ***Surveying and testing mains where cross connections are suspected***. Often drawings of water distribution systems are wrong. This can be attributed to lack of follow up and control with entrepreneurs that have laid pipes during previous upgrade works. Discussions with people who have worked on the mains can pinpoint areas that need to be tested. This test is carried out onsite using the boundary valves and potentially other critical valves where cross connections might occur. Pressure gauges are placed on hydrants at each side of a valve to be tested and the valve is closed for a short period. One of the gauges should immediately start to fall. If it doesn't a cross connection can be suspected and further investigations are needed.
- ***Survey the entire proposed DMA***. Unless the entire proposed DMA is thoroughly surveyed by taking sample pressure test readings and randomly testing flows from hydrants, local problems will not be identified. The visual inspection often identifies problems where drawings have been misleading, like location and functioning of boundary valves or even new larger consumers that have been connected recently.
- ***Survey staff to gather local knowledge***. Even though this has been a common denominator for all the previous bullet points it is also mentioned as a point on its own because of its importance. In the Pacific there are many water service providers that are totally dependent upon the institutional memory of the employees. This situation, where only certain people understand how parts of the network operate, is

not special for the Pacific but almost endemic in most water utilities. The gathering of the information these people can give is a major benefit for the organization and is useful for the leakage control as well as the general management of the system.

3.4.3.2 DMA management

After the design of the DMA has been decided upon it needs to be tested, or proven. In order to prove a DMA it is necessary to ensure that:

- all meters are functioning correctly.
- the district boundary is “tight”, i.e. closed boundary valves are not passing any water and no boundary crossings have been missed. This can be controlled by a zero-pressure test. The DMA boundary valves should also be clearly marked for identification by all staff, and their status checked regularly.

(Farley, 2001)

After the DMA has been established and proven, all the subsequent work is related to its management, which can be divided into two main parts;

- ***Initial work*** like setting up records and recording procedures; establish a monitoring and detection team, purchase of necessary equipment to allow efficient work and carrying out the initial leak detection and location assessment in each DMA to make sure that existing leaks are repaired. Property counts needs to be done in order to calculate net night flows.
- The next step is the ***routine operations*** that will continue more or less on a continuous basis, largely depending on the economic level of leakage for the given utility. The resulting night flow from the initial work provides a reference value for future target setting; the routine operation is to regularly monitor minimum night flows as an indicator for leakage. The most important tasks to carry out is maintenance of the DMA itself, including keeping property counts up to date and boundary checks to ensure that the integrity of the DMA is maintained; setting up data capture techniques and technology; interpret data to determine if more intensive detection and location effort is required; repair of leak; implementation of pressure management and management of any problems in the DMA.

(Farley, 2001)

3.4.4 Pressure management

Pressure management can be defined as “the practice of managing system pressures to an optimum level of service ensuring sufficient and efficient supply to legitimate uses and consumers, while eliminating or reducing pressure transients and variations, faulty level controls and reducing unnecessary or excess pressures, all of which cause the distribution system to leak and break unnecessarily” (Thornton and Lambert, 2006). Pressure management is a relatively new enterprise in the world of water supply, being recognized in Japan and the UK more than 20 years ago, but not until recently seen as the essential foundation for an effective leakage management strategy in most utilities, both in the developed and developing world. The rate of leakage in a water supply network is a function of the pressure applied by pumps or gravity head, and there exists a physical relationship between leakage flow rate and pressure. This has now been documented through numerous tests both in laboratories and in underground systems (Trow and Farley, 2006). There is also strong evidence that burst rates are functions of pressure as well (Thornton and Lambert, 2006). This evidence now available, and the ever improving reliability with which technical and economic predictions can be made, are such that progressive water service providers can no longer afford to ignore investigating possibilities of pressure management in their systems – it is the foundation for effective leakage management (Thornton and Lambert, 2005).

Pressure management should be an integral part of a well-organized WLM strategy because of its impact on several other aspects;

- If pressure is reduced, the rate of increase in leakage will reduce. Therefore, there is an impact on the level of leak detection resources required.
- The flow rates from all leakage paths (bursts and background leaks) will reduce as shown in figure 10.
- The data used to calculate leakage targets and economic levels of leakage should be revised when pressure management is introduced.
- Reducing pressure may make existing leaks harder to find, because they make less noise, or do not surface.

(Trow and Farley, 2006).

There are presented in the literature a set of key issues that needs to be considered by utilities that wishes to use pressure management as part of their leakage reduction strategy (Lambert, 2003);

- ***The importance of maintaining consistent pressures with minimal variations***. Frequent sudden changes in pressure reduce the average life of pipes. In the extreme cases of intermittent supply situations, new burst frequencies may be 10 times or more what should be expected for continuous supply at the same pressure (Lambert, 2001). Lambert (2001) further states the following message: Avoid frequent pressure changes; wherever possible pump into reservoirs, not directly into distribution mains.
- ***Relationships between pressure and rates of flow from existing leaks***.

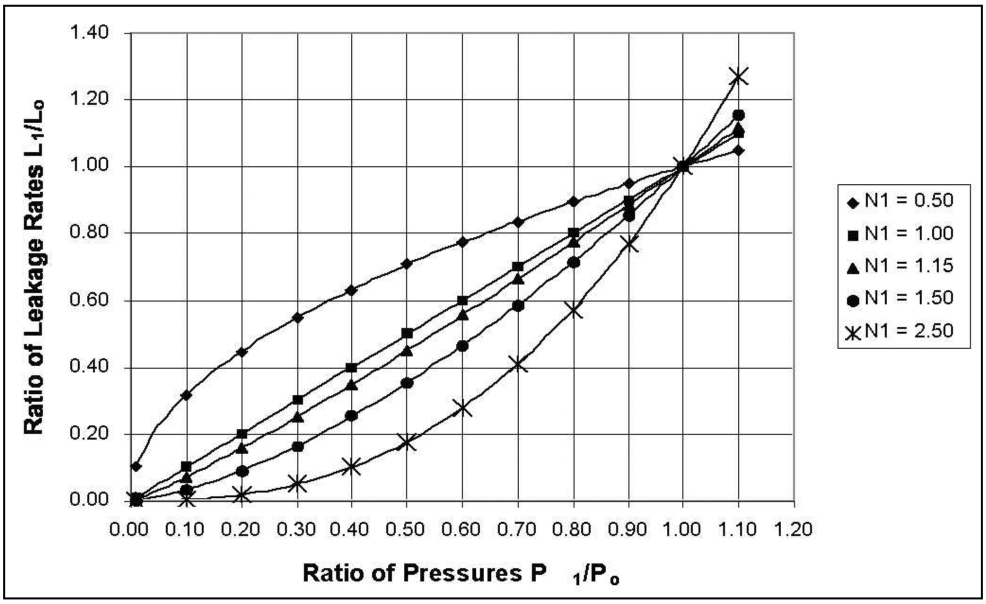


Figure 10: Relationship between pressure (P_1/P_0) and leakage rates (L_1/L_0) for different system specific N1values (Source: Thornton, 2003)

Figure 10 shows the general relationship between pressure and leakage rate for different system specific N1 values, explained below. The hydraulic equation for flow rate (L) through a hole of area A subject to pressure P is:

$$L = Cd \text{ x } A \text{ x } (2gP)^{0,5}$$

Cd is a discharge coefficient and g is the acceleration due to gravity. However, for some types of individual leakage path, Cd and A (and the effective area Cd x A) can be pressure dependent.

For practical predictions of pressure-leakage rate relationships, the IWA best practice equations are;

$$L \text{ varies with } P^{N1}$$

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

Where L_1 and L_0 are leakage levels corresponding to pressures of P_1 and P_0 and N1 is an exponent- for the given system. So, if pressure is reduced from P_0 to P_1, flow rates through existing leaks are also reduced from L_0 to L_1, and the extent of change depends on the system specific exponent N1 (Lambert, 2003).

It is important to note that the ratio of pressures and not the difference in pressures is influential in this predicative equation. The N1 value may vary from 0,5 for "fixed area" leaks to 1,5 or more for "variable area" leaks where effective area varies with pressure. Large leaks from metal pipes will generally have N1 exponents close to 0,5, while small "background" leaks from joints and fittings, and large leaks from flexible non-metallic pipes, usually have N1 exponents of 1,5 or more. From this follows that while N1 values for small individual zones can range between 0,5 and 2,5, the average pressure-leakage rate relationship for large systems with mixed pipe materials is usually close to linear (N1 = 1,0). For quick calculations and small changes in average pressure, the predicted reduction in leakage rate will be N1 times the % reduction in average pressure. For example: a 10% reduction in average pressure for a system with N1 of 1,5 gives a 15% reduction in current leakage rate (Thornton, 2003).

- ***Relationships between maximum pressure and rate at which new leaks occur***. From figure 11 it can be seen that large reductions in new break frequencies can be achieved over a wide range of pressures. Also, the percentage reduction in new breaks usually exceeds the percentage reduction in maximum pressure and can differ significantly for mains and service lines in the same system. Work done in the Byron Bay, Hervey Bay and Gold Coast area of Australia (Mistry, n.d.), and from South Africa (McKenzie and Wegelin, 2002) show similar results.

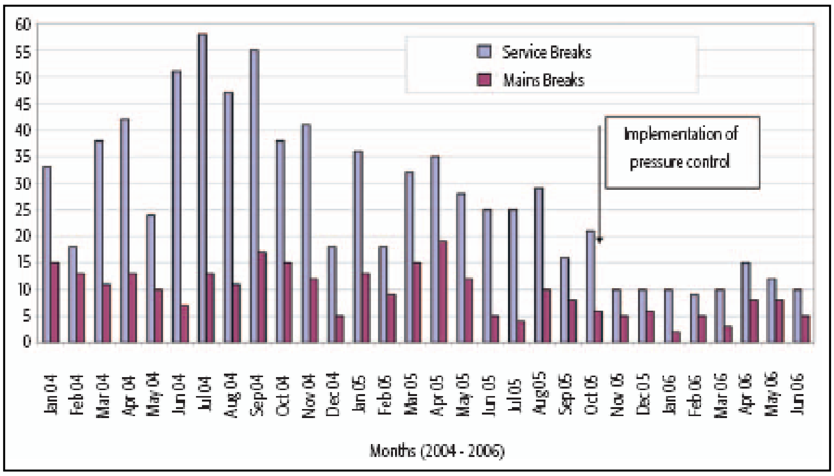


Figure 11: Monthly breaks before and after pressure management, Gracanica (Source: Thornton and Lambert, 2006)

The data making up figure 12 indicates that a unit reduction in pressure will give a 3 or 4 times reduction in burst frequency (Trow and Farley, 2006). It also shows that for systems with a continuous supply, main bursts frequency increases rapidly when pressure exceeds around 35 – 40 m. There is however no unique relationship between maximum pressure and new leak frequency (Lambert, 2003), and it may take several years to obtain good enough data to determine the true benefits of pressure management as a means to reduce bursts.

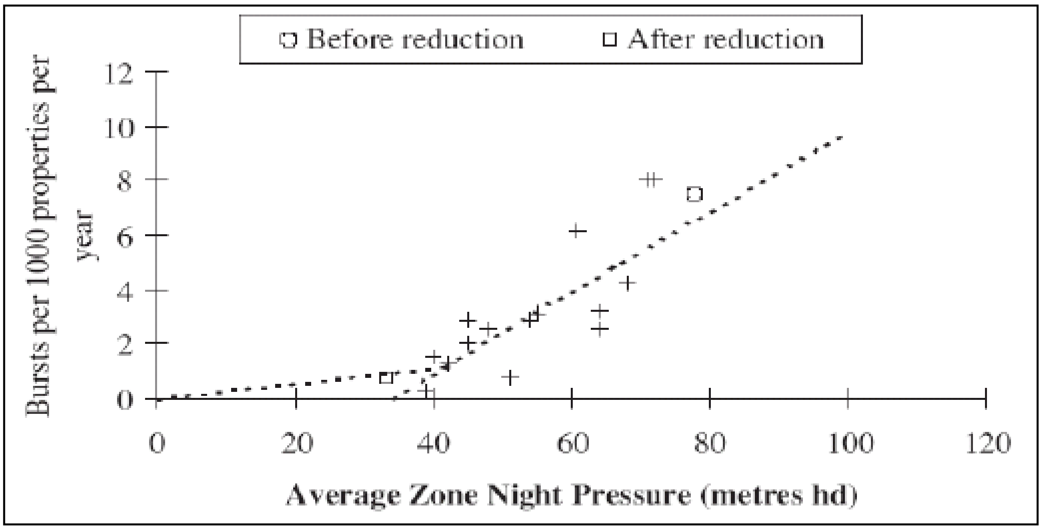


Figure 12: Relationship between Average Zone Night Pressure (ANZP) and burst frequency for a sample of data from one UK water company (Source: Trow and Farley, 2006)

- ***Implementing pressure management***. If no form of pressure control has been implemented from before, like was the case of Luganville in Vanuatu and Niue, the following areas should be investigated to assess the potential for pressure management (WBWC course, 2008);

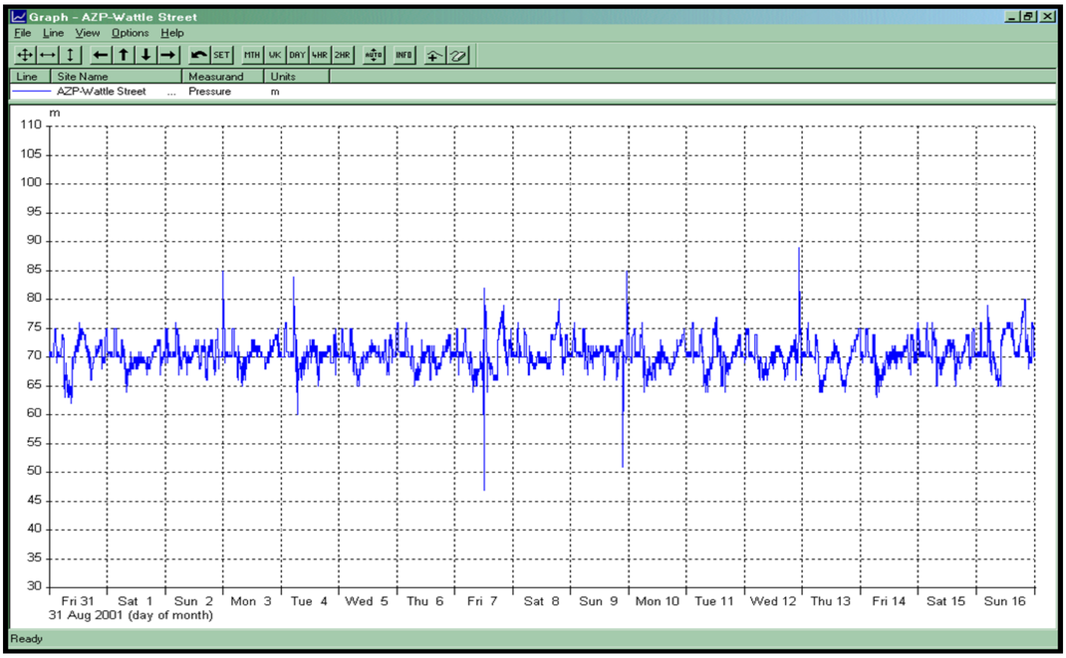
- systems with planned capital expenditure on water distribution, treatment or resources;
- existing systems with pumped inflows;
- areas which have recently experienced water shortages or restrictions;
- reservoir outlets;
- existing DMA's;
- uncontrolled branches on trunk mains;
- multi-feed areas with some or all feeds not pressure controlled;
- areas requiring high day-pressure but low night-pressure;
- new developments or extensions to the existing system, and;
- local knowledge.

The development of pressure management zones (PMZ) is not very different from establishing DMA's as previously discussed, though it doesn't necessarily need to be the exact same. Much of the verification or proving of a DMA must also be carried out for a PMZ. After a potential PMZ has been identified, the boundary of the area should be defined. Basic data on the scheme should then be collected to allow assessment. These data can be found through existing plans, Geographical Information Systems (GIS) if this exists, or through field surveys and should include;

- the number of boundary valves identified
- the number of critical point (s) and elevations
- the pressure reduction potential at maximum flow, using the best estimate of the current minimum pressure at the critical points (s)
- the total number of properties in the PMZ
- the number of identified Pressure Reducing Valves (PRV) sites

(Farley, 2001)

Pump control is often used to manage system pressure by activating and de-activating pumps in accordance with demand for water. With the advent of "*variable speed drive pumps*", pump control can be an efficient method to manage system pressures. "*Fixed speed pumps*" provide a more complicated picture since they can more easily lead to pressure surges through the network. At the very least there need to be a reservoir after the pump. If not, other possibilities should be investigated. Pressure surges or spikes (Fig. 13) cause damage to the distribution network by early material fatigue which in turn leads to breaks. The logical reason for this is when water is pumped at rates higher than necessary into a network, the extra inflow has nowhere to go other than to increase the pressure onto the system until the flow rates from existing leaks (and the creation of some new leaks) provides an escape route for the excess flow.



Line	Site Name	Measurand	Units
———	AZP-Wattle Street ...	Pressure	m

Figure 13: Logger data showing pressure spikes (Source: WBWC, 2008)

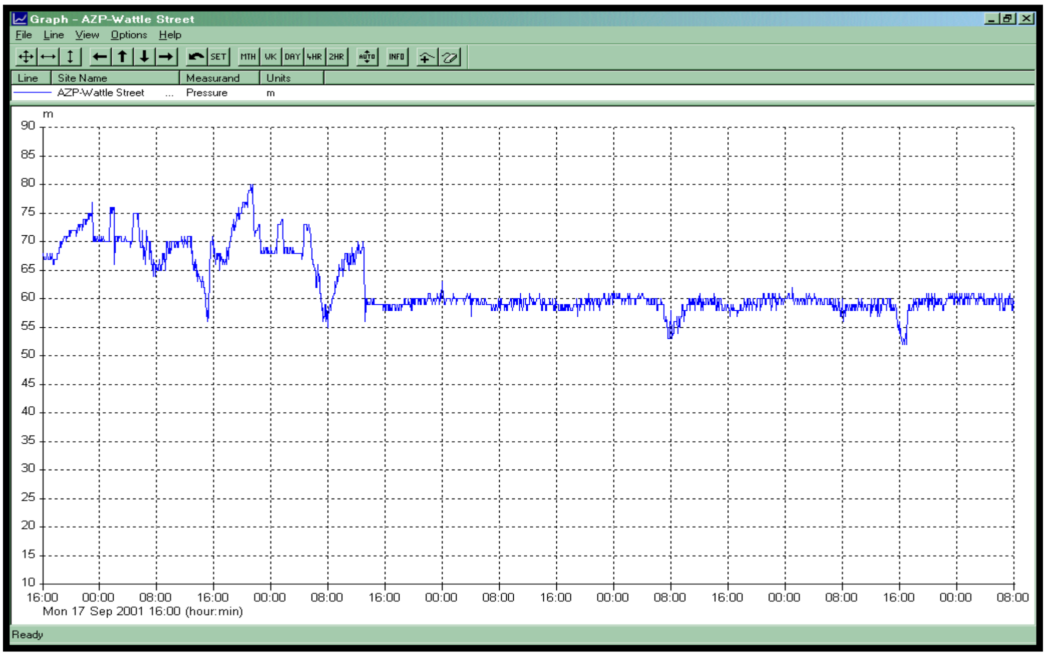
Another technique that are used, but not regarded as good practice, is use of "*throttled system valves*". This technique involves the partially closing of a sluice or a butterfly valve in order to reduce pressure. This is the least efficient method because the headloss changes as the system demand changes. During the night time periods when demand is at its lowest, system pressure will be at its highest and vice versa for the day time. If this is the preferred way of a service provider to control pressure they would be better of investigating the needs for re-designing the system hydraulics.

The traditional method of pressure control in a water reticulation system is through the use of a hydraulically operated control valve. "*Fixed outlet pressure reducing valves*" operate by controlling the fluctuating inlet pressure to provide a fixed outlet pressure. The fixed PRV's are suitable for areas with low frictional head losses and demands that do not vary significantly from season to season or day to day.

"*Time-modulated PRV's*" is the simplest form of advanced pressure control and uses a controller with an internal timer. The pressure is then controlled in time bands according to demand profiles. A demand profile is determined by data logging a week of water flows into the PMZ or DMA and analyzing each 24-hour period in two time slots. The first normally includes periods of peak demand or variable demand and is often identified between 04:00 and 17:00 (this can vary in each unique area). The second time slot is the remaining of the 24 hour period where pressure will increase as a consequence of low demand. These two time periods will then indicate how time-based pressure changes can be used without customers being aware of a change in water pressure. This method is suitable in areas with stable demand profiles and head losses and is usually implemented where there are budget constraints, but still a desire for advanced pressure management.

“*Flow-modulated PRV’s*” provides even greater flexibility and control, but is by far more technically complex. It operates by comparing real time pressure and/or flows to the needs of supplying the minimum pressure at the critical point in the network. It then automatically adjust itself by altering the position of the valve. The objective is to alter the pressure at the inlet point to meet varying demands in the network at different times of the day, thereby maximizing pressure reduction without interfering with customer service standards. This type of pressure control is often the most appropriate form of control for areas with continually changing demand patters and variable head loss.

Figure 14 show a typical profile of steady downstream pressure after commissioning a PRV.



Line	Site Name	Measurand	Units
	AZP-Wattle Street ...	Pressure	m

Figure 14: Steady downstream pressure after commissioning PRV (Source: WBWC, 2008)

The development of equipment used for all arrays of WLM is probably at its “all time high” given the focus on different management techniques, and the need to reduce wastage of freshwater resources in recent years. There are other, more complex ways to managing pressure and leakage, but these goes outside the scope of this thesis since they basically concern bigger urban systems with high costs of employee's and the supplied water itself. However, most flow-modulated controllers can easily be linked with telephone or radio to the critical point in the zone where the minimum pressure is essential. This can be done in developing countries as well and will ease the operations and provide a better control with the pressure management initiative.

3.4.5 Mains renewal and replacement

The general condition of the mains and service lines, and the service reservoirs, are the most significant factor affecting the level of leakage in a water supply network. This was literally seen every day driving to work for a period during the stay in the Pacific. In this case the water utility in Suva, Fiji, was embarking upon an ambitious leakage repair program starting on top of a hill along Mead Road and working their way downwards. As soon as a leak were repaired the pressure would increase enough for a new leak to surface some meters downstream the main, creating new major potholes and degradation of the road above the main. In this case the pipes in the network were simply too worn to get any benefits from a strategy to reduce leakages. All infrastructures naturally deteriorates with time and the most affected in a water supply network, due to various reasons, is the piping. Because of the high cost involved, most pipes are not replaced at a rate that is significant to halt or improve the amount of real losses from the network. This is most certainly the case in many PIC where overseas consultants often have been deployed to construct the distribution system through various funding or development programs, only to be left idle as soon as the initial financial resources have been exhausted. There were also examples of people, making their money from water trucking, tampering with the distribution network and creating “man made” breaks in order to truck more water and make better business for themselves.

An upgrade of the piping infrastructure is more easily justified (in terms of costs) if it can be done in conjunction with the need to meet water quality parameters and customer standards of service (decrease interruptions of supply and maintain minimum pressure standards) simultaneously (Trow and Farley, 2006). The condition of the infrastructure can be assessed in two ways;

- Its propensity to burst. This will be governed by factors such as pressure, ground condition and weather as well as the condition of the mains and service pipe fabric.
- Its propensity to background leakage. This is also governed by pressure.

It is not necessarily so that high burst rates means high background leakage rates and vice versa, so separate investigations have to be done on the two parameters. High burst frequencies tend to be concentrated on small diameter mains with low beam strength, while background leakage is more of a problem on larger diameter mains and service connections (Trow and Farley, 2006).

The primary justification for main renewal and rehabilitation is usually one of the following

- The internal condition of the main is affecting the quality of water running through it. This is often the case with corrosion of cast- or ductile iron pipes, which have no internal protection.
- The internal bore of the main has reduced due to corrosion or a buildup of deposits, so that it is no longer capable of carrying sufficient flow.
- The pipe wall has weakened and is no longer capable of withstanding the internal pressure of water, or it has insufficient beam strength to withstand traffic loading. This is often the case with asbestos cement pipes laid in aggressive ground.
- Some other external factor has resulted in the main being unable to fulfill its current duty. For example: “Crispy” plastic pipes due to long time storage in the sun, wrong handling or backfilling with too coarse material when laying the pipes.

(Trow and Farley, 2006)

If the network is in such a state that mains renewal is to be part of the overall water loss management strategy then it must be appropriately targeted. This includes identification of the mains that are the major contributors to leakage in the system, and then find the best way to replace them. In other words, analyze the DMA data to identify the areas with the highest leakage and make priorities according to their leakage rate. A cost-benefit analysis should be carried out to see whether it is cost effective to replace the main or not. This can be done in conjunction with looking at other potential benefits that would follow a replacement like less spending on continuous repair work and improved customer service. When replacing mains it is essential that the correct pipe material, and specifications are used. Factors such as pressure rating of the pipe material must be carefully considered. It is also important for the utility to ensure appropriate specifications for quality of work, and a follow up plan of contractors so that bedding, surround- and backfilling are done in accordance to these specifications. Added together these mentioned steps are all part of good project management which in itself is vital to secure the wanted outcome of reduced leakage levels.

The Quality Water Project in the region of Drammen (the GVD project) in Norway has developed a new GIS-based tool for selecting pipes in distribution systems that are subject to rehabilitation or renewal (Dupont et al, 2009). It is based upon a multi-criteria selection method that first classifies potential risks in two groups. One defines the criteria for the probability of failure on pipes and fittings, and the other group contains criteria describing the consequence of failure. For each criterion in the two groups, and for all the pipes in the system, a score value between 1 and 6 is applied. Each of these parameters is then multiplied with a weighted factor and the following product is used to calculate two values; "the probability score" and "the consequence score". These two scores are further multiplied with a weighted factor again, and this product is used to calculate "the final rehabilitation score". As an example an old section of the network will have a high probability score that it will leak, but unless it also have a high consequence score i.e. that many people will get affected by a potential burst it may not necessarily get a high rehabilitation score. Thus a tool like this enables the operators to move from the defensive strategy of only selecting the pipes with known high frequency of leakages, to a more proactive strategy where also the pipe's strategic influence in the system is accounted for. In the Pacific not all service providers have software like GIS implemented as part of their operations, but the main part of this multi-criteria selection method is based upon institutional knowledge and the memory of the operators. The scores can be handwritten or in the form of a simple Excel spreadsheet, and pipe sections can be drawn on the schematics with colors implying priority of renewal.

3.4.6 Leakage detection and monitoring

As previously explained water losses do occur in all distribution systems to varying degrees, and we have seen that there are several systematic leakage monitoring and control strategies to reduce wastage that can be applied. However, these methods do not provide the exact location of a leak, neither is it repaired by it. To do so leak detection surveys must be undertaken, and when leakages are found they need to be repaired. Leakages are made up of three components;

- ***Reported leaks and breaks***. These are typically high flow rates at a short run-time since they are usually quickly notified to the utility by customers or easily seen on monitoring equipment.
- ***Unreported leaks and breaks***. These are typically moderate flow rates that can run for a long time. They are usually found by active leakage control i.e. the active search for leakages by the utility leak detection team.

- ***Background leakage*** (mostly joints and fittings). These are leaks with a flow rate too small to be detected if hidden. Generally < 250 l/hour, but since they are often allowed to run continuously they can contribute to the largest leakage figures.

The volume of background leakage can be calculated by data from each DMA and amounts of customer use by the following formulae (WBWC course, 2008);

Volume = (minimum night flow – amount of customer use) / number of connections

The volume of bursts can be assessed by the following formulae;

Volume = average flow rate x average duration x frequency

The volume lost due to leakages (real or commercial loss) depends largely on the characteristics of the pipe network and the leak detection and repair policy (Fig. 15) practiced by the service provider including;

- the pressure in the distribution system
- the frequency and typical flow rates of new leaks and bursts
- the proportion of new leaks that are "reported"
- the "awareness" time (how quickly the loss is noticed)
- the "location" time (how quickly each new leak is located)
- the "repair" time (how quickly it is repaired or shut off)
- the level of "background" leakage (undetectable small leaks)

(Trow and Farley, 2006)

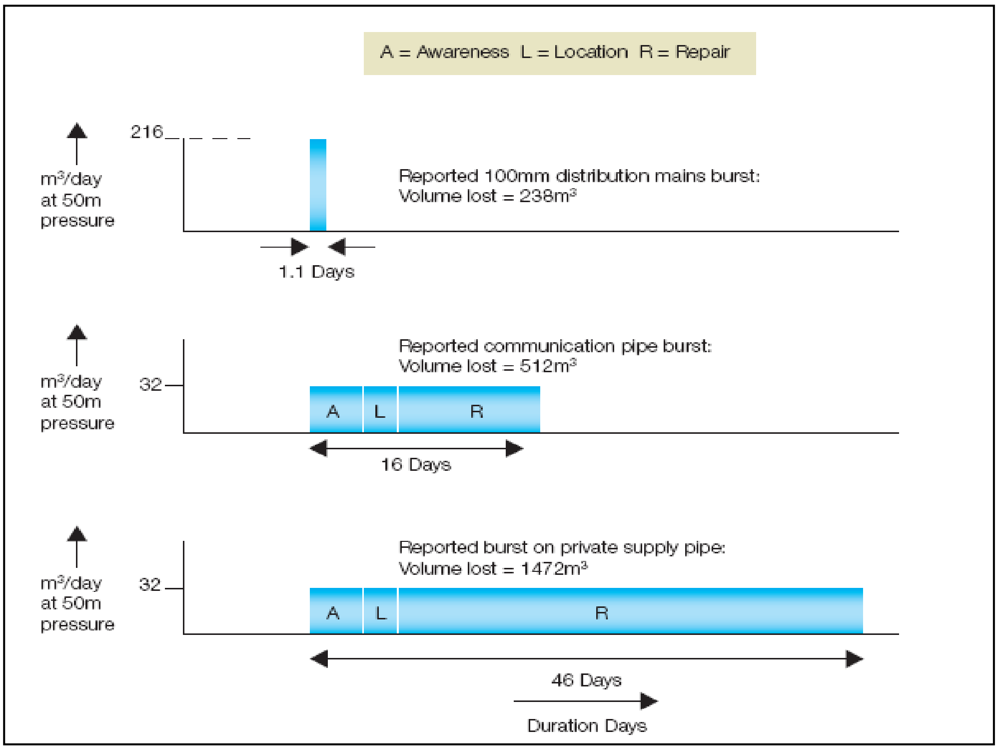


Figure 15: Example of relationship between different types of burst durations and flow rates for reported leakages (Source: Farley, 2001).

Water leaking from a pressurized main emits a sound over a range of frequencies and produces a “hissing” noise. The distribution of frequencies produced by the leak is specific to that particular leak and will depend upon factors such as; the nature of the leak, the size of the hole, pressure, pipe material and the nature of the ground into which the leak is discharging, or whether the ground is waterlogged or not (more are mentioned in Waldron, 2005). The sound of leaking water will travel through the pipe at a velocity which depends on both the characteristics of the water and the pipe material. It can also travel through the ground surrounding the pipe, and as the sound travels away from the leak its character changes slightly. Higher frequencies are lessened with distance and other frequencies may be amplified by cavities in the ground or other underground equipment. Therefore, the leak noise detected will largely depend upon where the sounding takes place. It has been developed data tables showing different frequency bands for different situations and pipe materials, this is information that can be plotted into software accompanying most modern leak detection equipment to ease the operations of finding the leaks.

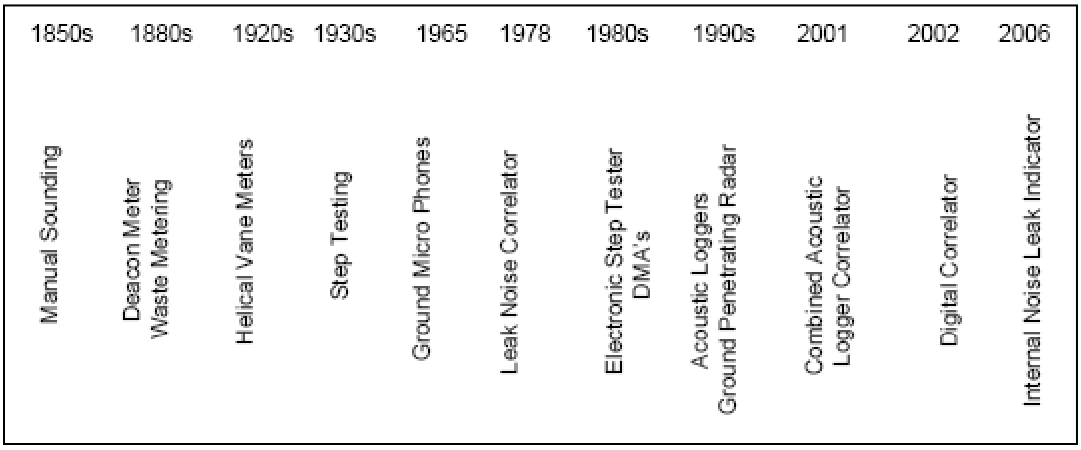


Figure 16: Development of leakage detection technology timeline (Source: Pilcher, 2003)

Leak detection is about “narrowing down” and hopefully pinpointing, or at least localizing the section of the network, where there are one or more leaks. While the reported bursts are easy to find a more proactive leak detection effort is needed to find unreported leaks and bursts. This is called Active Leakage Control (ALC) and can best be described as a “proactive strategy to reduce water loss by the detection of non-visible leaks using highly trained engineers and technicians using specialized equipment followed by the prompt repair of leaks” (Pilcher, 2003). There are several techniques and equipment (Fig. 16) developed for this purpose and the most common ones are;

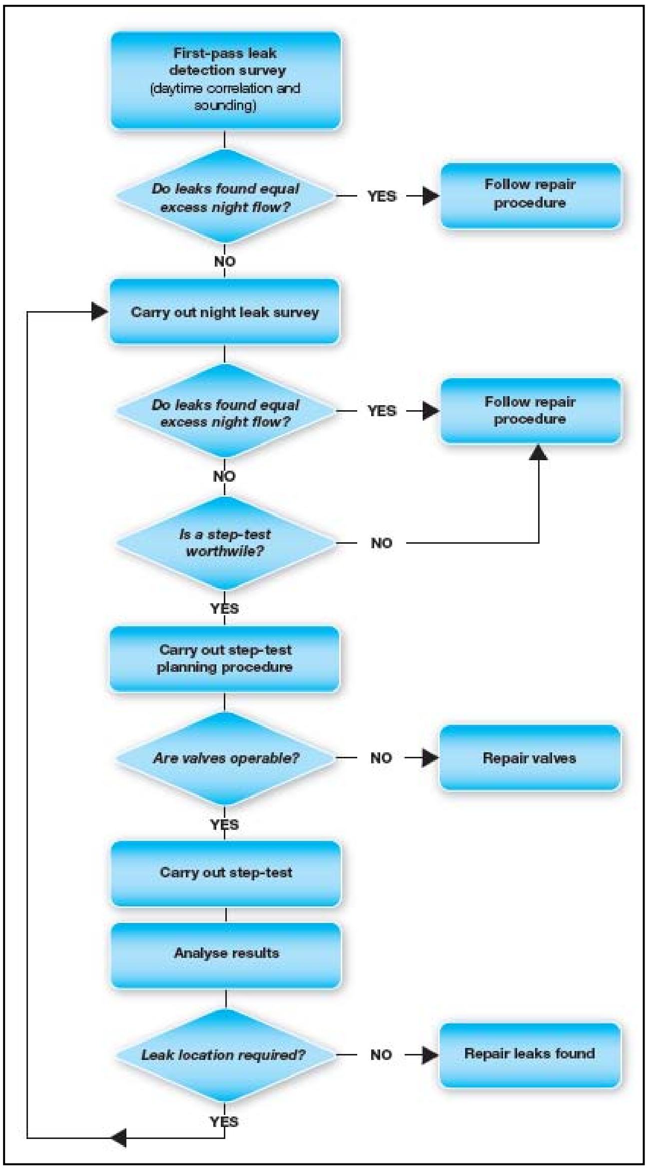
- ***Sounding*** (listening sticks and geophones, Fig. 17). Sounding is the principal method used for locating leaks. This is because of its low cost of equipment and the fact that many leaks are found using this method given that the operator have a “trained ear” for locating leaks. This method involves listening to each main fitting and service connection stop-taps in a zone or area suspected to leak, to determine if there is a noise that actually could be a leak. The effectiveness of this depends on the operators experience, level of hearing and the environment. From the author’s own experiences it is difficult for an un-trained ear to hear the difference between a leak noise and other noises on the network, or even ambient noise in the overall environment like traffic or wind. Sounding at night can alleviate this problem since there is less ambient noise and the pressure is at its highest due to low demand giving a louder leakage noise.

Figure 17: Listening stick (left) and Geophones (right) (Source: Author, 2006)

- ***Correlation surveys*** (leak noise correlation). Most leak detection methods utilize equipment for detecting the intensity of noise in order to find the leak. The leak noise correlator work on a different principle. Given that a leak noise can be detected, a correlator will measure the transmission speed of that noise along the water pipe, based on the type of material. Normally the correlator equipment consists of two transducers (microphones or sensors) that are magnetically attached to the water main, usually at fittings, these listen for sounds and transmits their data via a radio link transmitter to the correlator itself. The correlator usually consists of a screen built into a computer-based device that correlates all data and measures the speed of noise transmission between the correlators. The time delay, or the difference between the times that the leak noise reaches the two different transducers is measured, and the accurate position of the leak can be computed. Correlators are expensive to purchase , and not the most effective overall survey tool for a water distribution network, but they are the best available method for locating leaks if it has already been proven that there is a leak somewhere in a given area.
- ***Acoustic logger*** (noise loggers). This equipment provides a relatively cost efficient methodology to find leaks, and is rapidly being accepted by utilities worldwide including developing countries. The loggers cause no disruption to supply, more loggers can be deployed according to needs using the same software in one computer, they are easy to deploy and recover, they operate automatically so no night work is

required, they can indicate leaks from a short time of logging and be easily moved around the network, and the often expensive network investment to establish step tests is avoided. The level of noise heard by the logger is stored in its memory, and those loggers within audible range of a leak will register a relatively higher level and lower statistical variance (spread) of noise, compared to other loggers that only record random events. This data is downloaded to a computer and the results are analyzed statistically and displayed in a graphic format for each logging period. Loggers only indicate where the leak might be and correlation or sounding needs to be done in that area to pinpoint the leak. Acoustic logging technology has recently been combined with correlation technology. This gives the loggers the possibility to inter-correlate between them and find the point(s) with the highest probability for leaks in the given sector where loggers are deployed. Improved efficiency and a subsequent reduction in operational cost follows by getting this activities into one (Pilcher et al., 2007).

- ***Step testing***. Step testing (Fig. 18) is an indirect method of leak detection that measure water flow in discrete areas. The flow in each section is measured during the anticipated minimum night flow (MNF) period, if there is a significant drop in the MNF when a particular section is closed off it indicates that there may be a leak. This methodology has been widely used for a long time though new innovations might make it less suitable in the future. The step test puts high demands on the integrity of a DMA and the valves in the system. Service providers in the Pacific often have networks where it is unknown if the valves close clockwise or anti-clockwise, or if they close properly at all. On the positive side, doing a step test can improve the operators knowledge about their network significantly and this in itself might be a good reason for going through with it, in addition to step tests being a good method for detecting leaks. Pilcher et al., 2007 presents two different methods of step tests; "*the isolation method*" and "*the close and open method*". Farley, 2001 also includes a 3rd option; "*the backfeed method*".



The isolation method involves the successive closing of valves starting from the furthest point from the (district) meter and working your way back to the meter by shutting valves in sequences. The areas downstream of the closed valves are without water during the test. Arriving back at the meter the flow should drop to zero if there are no leakage. Potential leaks can be found by this method, but the disadvantage is that the system is partly de-pressurized for some time with the associated risk of backsiphonage and the risk of infiltration by ground water (Pilcher et al., 2007).

Figure 18: Typical leak detection and location procedure (Source: Farley, 2001)

The close and open method involves closing valves to isolate each individual step and once the reduction of flow has been recorded the valves are reopened. This method provides less inconvenience to any night time water users, but if a leakage or burst is identified care must be taken when restoring the supply to avoid aerated and murky water.

In figure 18 a typical leak detection and location procedure is presented. Where the flow chart says step test we remember that this can potentially be done by deploying loggers as an alternative approach. What would be the most appropriate will largely depend on available equipment, the state of the distribution network and the level of operator skills and knowledge.

3.4.7 Performance measures

Performance indicators can be a very helpful tool to assess the performance of water service providers with regards to control of water losses. As we have seen from the previous it is clear that water losses are a direct measure of how well a distribution system is performing and being operated and maintained. Once these water losses have been calculated or estimated there would be a need for some performance indicators (PI) to decide whether these losses are "high" or "low" (Lambert et al, 1999). This has been one of the main tasks of the IWA's Task Force on Water Losses. Much of the methodology and terminology was developed during the late 90's, and a reference data set derived from 27 diverse water distribution networks from 20 countries was published by Hirner and Lambert (2000). From this initial publication until today there have been published a vast amount of literature on the subject and the PI's have been refined to suit different circumstances better as more research have become available. Some of the most central articles would be; Lambert (1999); Lambert et al. (2001); Lambert and McKenzie (2002); Liemberger and McKenzie (2003); Lambert and Fantozzi (2005); Lambert and Lalonde (2005); Thornton and Lambert (2005); Liemberger et al. (2007) and Fantozzi et al. (2010). Liemberger and McKenzie (2005) and Mutikanga et al. (2009a) and (2009b) are especially relevant for developing countries.

We have seen that there are different ways of managing and measuring water loss, where the water balance/audits and minimum night flow measuring was used during the work in the Pacific after the "best practice" advice of the IWA. When the water loss has been measured as accurately as possible there are technical indicators available to express the level of leakage. The IWA recommends the following indicators to evaluate the technical condition of a water supply network; the infrastructure leakage index (ILI: 3.4.7.3) and the economical level of leakage (ELL: 3.4.7.4). These two are determined based on the relationship between the current annual real losses (CARL: 3.4.7.1) and the unavoidable annual real losses (UARL: 3.4.7.2).

There are also five other key local factors that have an impact when trying to measure performance at a water utility, and these can vary significantly between different service providers in different environments. The IWA have through their research on the subject come up with some best practice recommendations on this as well. "***Number of service connections***" should be used as a PI for real losses rather than "number of properties", the density of service connections should be expressed as "***number per km of mains***". Pressure can vary widely and the "***average operating pressure***" or the median value of the measurements should be used. Experiences of the IWA show that leakage rate varies with pressure approximately to the power1.15, so a simplified assumption that leakage rate varies linearly with operating pressure is likely to be satisfactory for performance measures in larger systems, not the ones with either very high or very low pressures. Where there are problems with intermittent supply, the IWA have met this by expressing annual volume of real losses as a volume per day “***when the system is pressurized***”. The variations in pressure and the accompanying leakage rates are often significant over a 24 hour period, therefore it has been advised to express losses derived from the annual water balance on a “***per day***” basis rather than “per hour” (Lambert et al., 1999).

3.4.7.1Current annual real loss (CARL)

CARL is the total water loss from the distribution network, up to the point of measurement of customer use (service line meter), as calculated in the water balance excluding the apparent losses and authorized consumption (WBWC course, 2008).

CARL = System input – (Authorized consumption + Apparent loss)

Where:

System input is the supply into a network to which the annual water balance relates, allowing for known errors.

Authorized consumption and apparent losses are explained in chapter 3.3.1 and 3.3.2.

If it is difficult to obtain reliable figures on real losses it can be estimated. The CARL is equal to the NRW, since apparent losses normally take up a smaller volume of the total losses.

3.4.7.2 Unavoidable annual real loss (UARL)

Since it is virtually impossible to have a water distribution network entirely free of leakages, there will at one point be impossible to reduce the rate of water loss any further. This is the rationale behind the UARL. If the UARL volume for any system can be assessed, taking into account the key local factors, then the ratio of CARL to UARL offers the possibility of a PI for real losses (Lambert et al., 1999). The UARL thus represents a theoretical reference value representing the lower technical limit of leakage reduction that can be achieved.

In its most basic form the equation is as follows:

UARL = (18 x Lm + 0.80 x Nc + 25 x Lp)

Where:

UARL is in liters pr. day

Lm is the length of mains in kilometers

Nc is the number of service connections (main to meter)

P is the average operating pressure at average zone point in meters head

Lp is the length of unmetered underground pipe from street edge to customer meters (km)

This equation is based on an average length of pipe from the water main to the customer meter of 10 m. The Lp term is therefore only used in cases where the customer meter is installed in excess of 10 meters from the water main. In some countries the meters are located on the street edge i.e. close to the water main and the equation can then be simplified to;

$UARL = (18 \times Lm + 0.80 \times Nc) \times P$

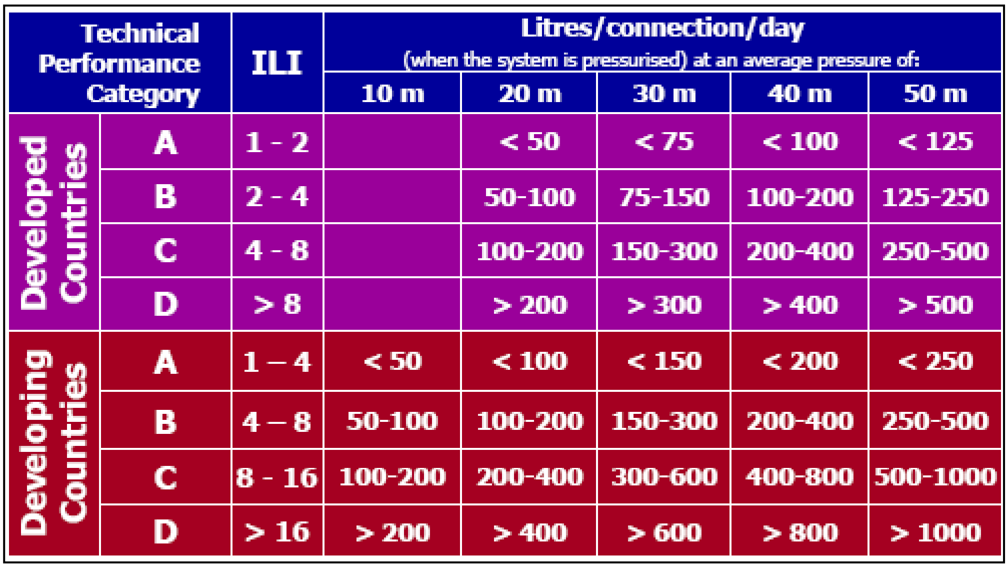
(Lambert et al., 1999; McKenzie and Wegelin, 2002).

3.4.7.3 Infrastructure leakage index (ILI)

The ILI is a dimensionless ratio calculated simply as CARL/UARL. The ILI is the IWA “best practice” Level 3 (Detailed) Performance Indicator for Operational Management of Real Losses (Alegre et al, 2000). If the ILI for a supply network is, for example 5.0, this would mean that the CARL is assessed to be around 5 times as high as the UARL for a system with this length of mains, number of connections and customer meter location, under the same pressure management regime (Lambert et al, 1999). If there are no changes made to the operating pressure options to reduce CARL by around 1/3 still exists, the additional changes in real losses will result from changes in the pressure management regime (Lambert et al, 1999). In practical terms this means that the higher the ILI, the poorer is the performance of the distribution network, while an ILI close to 1.0 would mean “world-class” management ensuring that real losses were continuously kept to the “unavoidable” or “technical minimum” value at current operating pressures.

There are however some problems using the ILI in developing countries since they are based upon data for well managed systems in the developed world. Many countries in the developing world still use the PI %NRW. This PI is rather misleading because the % value is strongly influenced by consumption which has nothing to do with the efficiency of managing water losses. Problems associated with apparent losses is to a great extent a larger problems in developing countries as opposed to the developed ones, and the UARL itself might be less relevant in areas where visible leaks are significant but still takes a long time to be repaired. Liemberger and McKenzie (2005) suggests a “look-up” table (Tab. 2) that accounts for these differences in operating practices still based on the ILI to help address these issues. This allows a first simple assessment using liters per connection per day in combination with the approximate average pressure:

Table 2: Proposed use of ILI as PI in developed and developing countries (Source: Liemberger and McKenzie, 2005)



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

In table 2 different ILI ranges have been provided for developing and developed countries. The table attempts to classify the leakage levels within the water utilities into four categories based on the ILI values as follows:

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

(Liemberger and McKenzie. 2005)

Since the vast majority of water service providers in the developing world will have ILI values exceeding the upper limit of 16, reducing real losses to below 16 will be a starting point. As soon as utilities start to introduce ALC, carry out flow and pressure measurements, and improve overall data quality the bandwith of the ILI will dramatically be reduced. Often leakage reduction will also lead to an improved supply situation and pressure increases that will make the calculation of the UARL more accurate (Liemberger and McKenzie, 2005).

3.4.7.4 Economic level of leakage

The ELL is defined as “the level of leakage at which any further reduction would incur costs in excess of the benefits derived from the savings” (Lambert and Lalonde, 2005). The current thinking on ELL is that each and every activity aimed at reducing leakage follows the “*law of diminishing returns*”, meaning “the greater the level of resources employed, the lower the additional marginal benefit which results” (Pearson and Trow, 2005). The ELL is set within the context of the supply-demand balance for water. For example; a reduction in leakage will directly lead to a reduction in water treated and potentially pumped for supply and consequently this may reduce capital expenditure in the planning period for new water supply schemes. Operating at the ELL thus means that the total cost of supplying water to the customer is minimized and the utility is operating efficiently (Fig. 19).

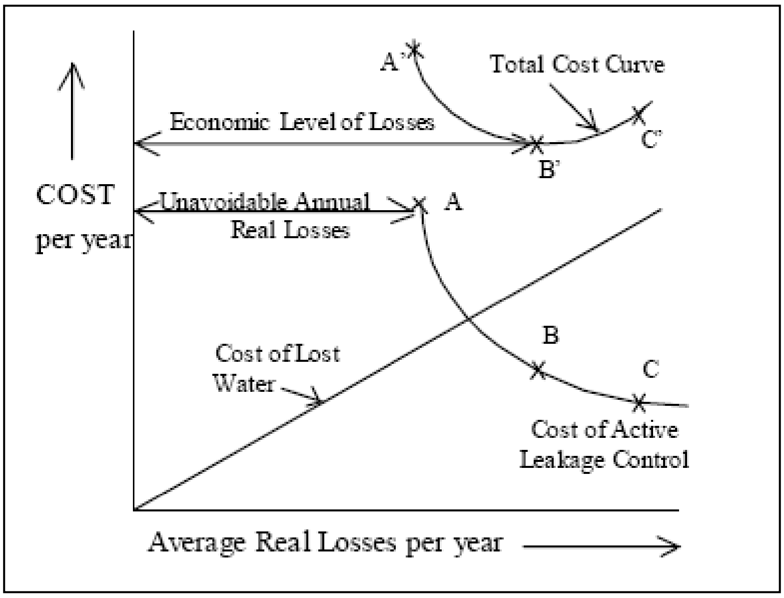


Figure 19: Relationship between UARL and ELL (Source: Lambert et al, 1999)

The calculation of the ELL for an area starts with establishing the current situation in regards to leakage. The current level of leakage is ascertained for the whole system (trunk mains, distribution mains and service pipes). Then a review of the future or alternative options for leakage reduction is carried out. This is done by considering existing and new policy and technology options for leakage/pressure/meter management, mains replacement and DMA design. For each of these, the cost of implementing the options is calculated. Then a family of leakage/cost relationships are developed, and considerations can be done to which of these options will be implemented to reach the various target levels of leakage (points A, B and C in figure 19).

Figure 19 above further explains the concept and presents a simplified economic approach to determine an appropriate intensity of ALC for dealing with unreported leaks and bursts. As the intensity of ALC increases (C > B >A), causing the annual cost of leakage control (Y-axis) to increase, the average real losses (X-axis) reduce asymptomatically towards some base level, and the annual cost of the lost water decreases as the average volume of real losses falls. The ELL occurs when the total cost curve (A’ > B’ > C’), which is the sum of the cost of lost water and the cost of ALC, is at a minimum (point B’). With simplifying assumptions that;

- the infrastructure is in good condition;
- point A represents the technical “state-of-the-art” for intensive ALC;
- and, all detectable leaks and bursts are identified and repaired rapidly and effectively.

Then the real losses for point A correspond to UARL. Actual or economic levels of real losses should always lie at, or to the right of, point A. The ILI – the rate of CARL/UARL will always exceed 1.0 (Lambert et al., 1999)

3.4.8 Water loss management strategies

Throughout chapter 3.4 different water loss reduction practices has been outlined. A strategy can be applied to any water distribution network using all or parts of these reduction practices to varying degrees suited the unique utility in question. The key to developing a water loss strategy is to gain a better understanding of the reasons for losses and the factors which influence them. Then techniques and procedures can be developed, and tailored to the specific characteristics of the network and local influencing factors, to tackle each of the causes in order of priority. To start up with the development of a water loss strategy it can be helpful going through a step by step process as described in figure 20. Once some thought have been given to these different factors a unique strategy for the particular needs of the service provider can be developed. As the work to reduce water losses proceeds the strategy might need to be refined or partially re-defined, so some level of “headroom” and flexibility must be applied. Vermersch and Carteado (2010) takes this thinking one step further in their article “An Overall Dynamic Approach in Water Loss Management”, stating that many action plans for reducing NRW fail for various reasons, one of the main reasons being that there is not enough consideration of the dynamic nature of water losses, the interactions between the different types of losses and, in some cases, the migration of one category of loss into another one. This can be visualized by an example taken from the same article. In this case not all service connections are metered. This is quite usual especially in low income areas that are not under regulatory control, or in the case of Niue where the government provide water for free. It is frequent that the levels of water losses are attributed to leakage and the poor state of the supply network. The issue of apparent loss is underestimated for management or political reasons and priority might be given to a leak detection operation. The result might be that the intended effect is not the expected one. Fixing leaks in the network leads to better pressure of service and increased consumption and wastage by the unmetered users. The savings of real losses are automatically transformed into apparent losses by underestimating the customer’s consumption without any financial advantage for the water service provider (Vermersch and Carteado, 2010). It is imperative to be aware if this sort of dynamics when embarking upon any intervention to reduce water losses.

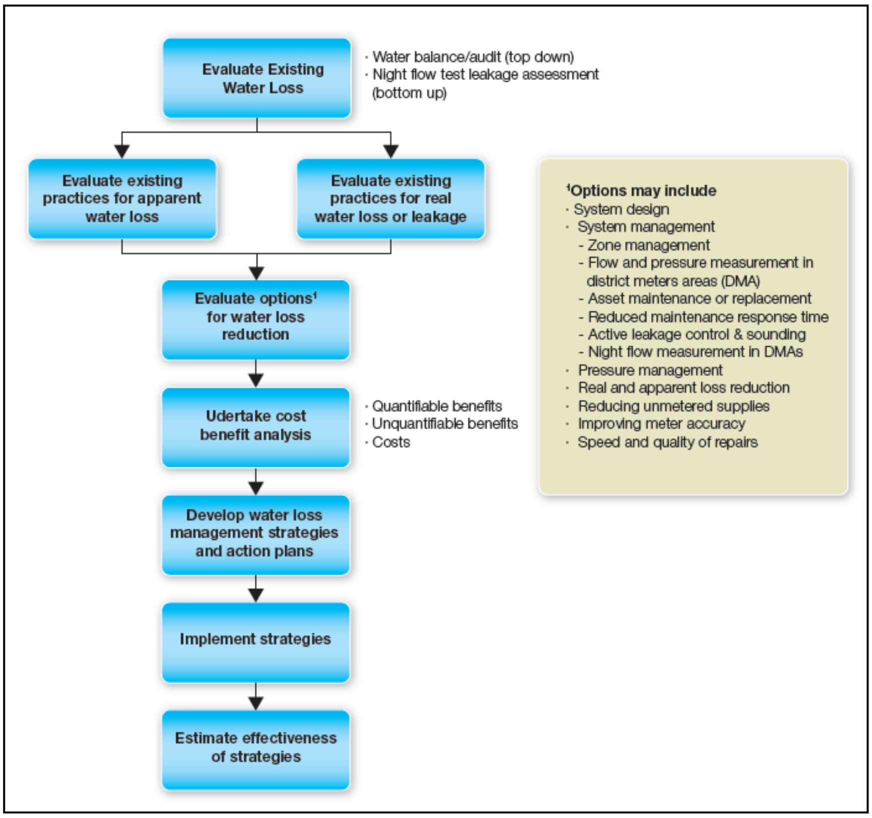


Figure 20: Water loss management process (Source: Queensland Government, n.d.)

3.4.8.1 Interventions for real loss and apparent loss

The interventions needed to reduce real and apparent losses can be employed to any supply network and will be based upon the various practices outlined in chapter 2.4. Every water supply network has a unique set of reasons for their losses, and degrees of the different losses. Thus each service provider will have their own unique possible solution. The interventions for real and apparent losses can be presented in a conceptual model sometimes referred to as “the four pillars of leakage management” when we look into real loss management (Trow and Farley, 2006). From this it has also been derived a similar model for apparent loss interventions. During work in the Pacific we simply referred to these two similar theories as "squeezing the box". The reason for this can be intuitively understood by looking at the conceptual model where there are four different primary interventions methods trying to squeeze the CARL box to become as close as possible to the UARL box. In the case of apparent losses the goal is to squeeze the existing apparent losses as close to the unavoidable apparent losses as possible.

- **Interventions for Real Losses**

  The four main intervention methods for real losses are presented in figure 21. Any water supply system deteriorates over time, and a natural rate of rise of real losses through leaks and breaks are to be expected. In an attempt to try and minimize this tendency towards increased wastage a combination of the four primary intervention methods can be utilized. These are;

  - Pressure management (increases or decreases of pressure)
  - Active leakage control
  - Speed and quality of repairs
  - Pipeline and asset management

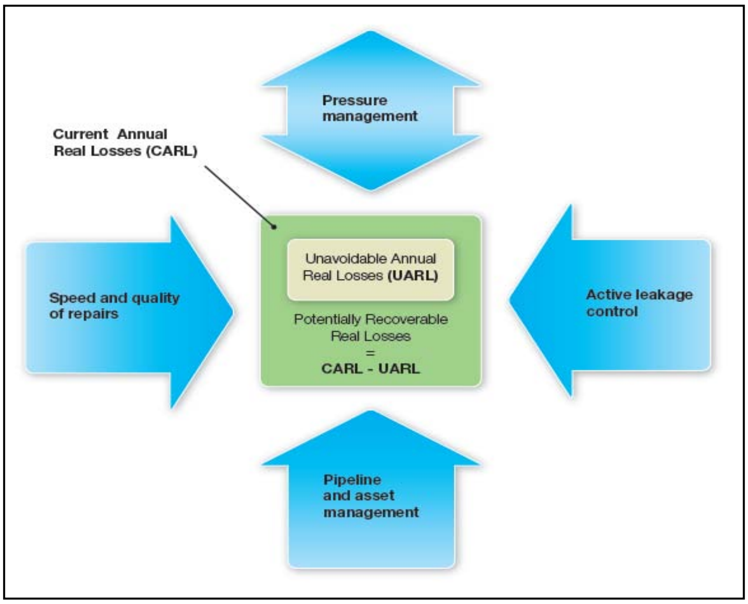


Figure 21: Squeezing the box of real losses (Source: Trow and Farley, 2006)

These four "pillars" all interact to different degrees in any water utility. Pressure management is the only arrow that goes both ways because it can reduce the frequency of new leaks, and reduce the flow rates of all excising leaks and breaks, by reducing the pressure. On the other hand the opposite will happen if pressure is increased, leading to an increase in real losses. Active leakage control is needed to find unreported leaks, and reduce the duration of how long these leaks can run. The frequency of leaks and the number of new leaks that will occur is primarily a factor of how the pipeline and assets are managed in the long-term. The speed and the quality of repairs will reduce the average run time of leaks. Depending on how these activities are carried out the real losses of a water service provider will increase, remain constant or decrease.

- **Interventions for Apparent Losses**

The same overall principles that have been described in the previous on interventions for real loss apply to apparent loss as well (Fig. 22). The major objective is to work on all four components of apparent water loss in an effort to reduce this type of wastage down towards the economic level (Rizzo et al., 2004). The interventions focus on unauthorized consumption and all forms of technical and administrative inaccuracies linked to metering of consumers.

The four components that make up the IWA‘s water loss task force’s strategy of controlling apparent loss is;

- Meter under-registration,
- Meter reading errors,
- Errors in managing metered consumption data
- Water theft

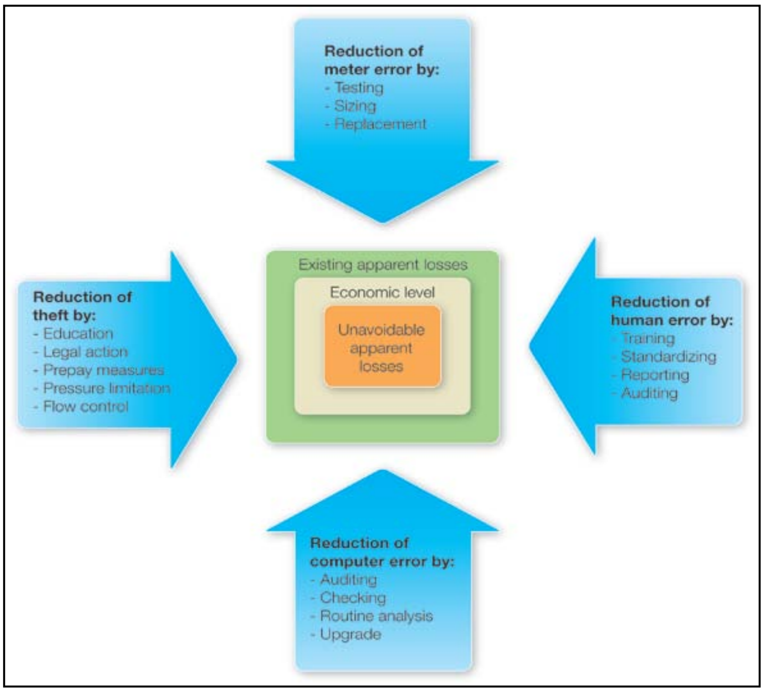


Figure 22: Squeezing the box of apparent losses (Source: WBWC, 2008)

In figure 22 the additional element of economic level of loss (ELL) is included. This way of presenting the conceptual model could also be applied to figure 21. These two models are used a lot in the literature, and it varies whether the ELL component is included or not.

3.4.8.2 Wrap up literature review

Water loss management is a set of methodologies, techniques and technology in progressive development today. What has been described in the previous literature review is by no means “everything” that water loss management consists of. It has been narrowed down to the most central theories and to what was necessary to develop WLM strategies for PIC service providers.

4 Practical examples - Results and discussions

The previous literature review gave answers to the thesis' problem statement by presenting potential methods and solutions to reduce waste of water resources by water loss management. It also serves as the basis for answering the specific research objectives. Chapter 4 presents the results achieved by implementing water loss management strategies in three different Pacific Island countries. It is based upon the specific research objectives and will highlight the different strategies themselves, and the key factors that influenced the implementation of these strategies to reduce waste of drinking water.

Different utilities face different challenges, and their operational staff will have different levels of knowledge. The examples vary widely in many respects; in terms of sizes, topographic conditions, supply situations, network conditions, connection densities etc. Honiara and Luganville are truly urban areas, while Niue would better fit the term peri-urban. Because of this it is vital that WLM strategies are tailored for the service provider in question, and that the strategies are understood and possible to grasp by the operational staff. The examples provided in the following will show that WLM strategies, even in the simplest form, inevitably can be a step towards a more efficient resource use. And by that also be a part of meeting the MDG 7. Still, it is not necessarily so that it is easily implemented. The obstacles faced to do so might be as interesting to understand as a success story. It is hoped that experience gained from working in these countries will be valuable for future non-revenue water reduction activities in other SIDS.

4.1 Example 1 – Honiara, Solomon Islands

Solomon Islands is a country consisting of several small and medium sized islands in the South Pacific Ocean, East of Papua New Guinea (Fig. 23). It has a total of 28,896 km^2 land area. The terrain is mostly rugged mountains with some low lying coral atolls. The climate is fairly stable with few extremes of temperature and rainfall except for tropical monsoons. Approximately 570,000 people live in the country with a growth rate at 2.2 %. The life expectancy of the total population is 74 years, while the infant mortality rate is 18 deaths/ 1000 live births. Around 19% of the total population lives in urban areas, with an urbanization of 4.2% annual rate of change, 2010-2015 estimate (CIA, 2011). The country rank 123 on the 2010 HDI.

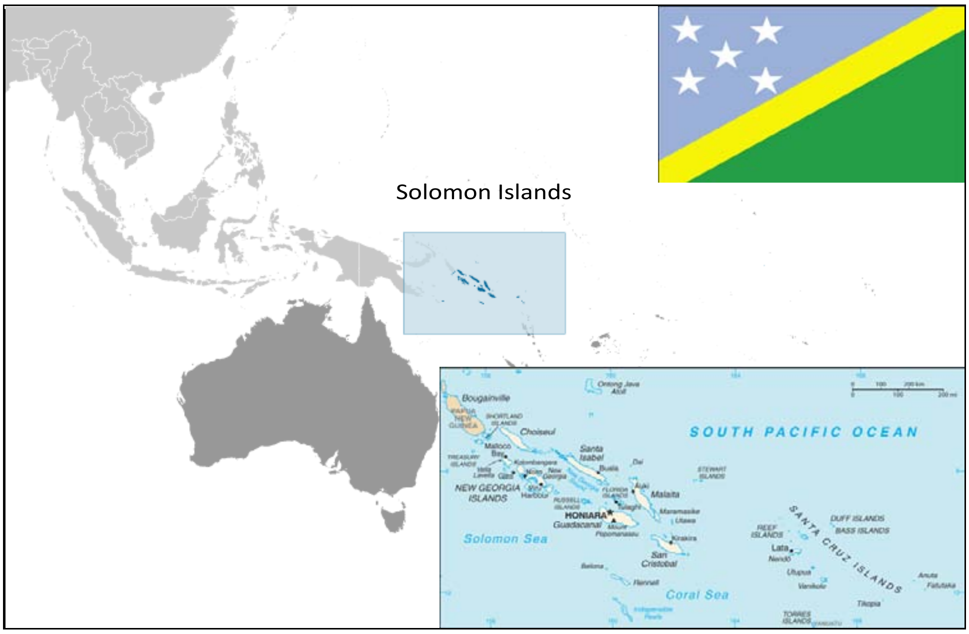


Figure 23: Solomon Islands location and flag (Source: CIA, 2011)

Previously during the 80's the Water Unit under the public works department had a fully functional Waste Control Group (leakage group). However, the group slowly declined as the Solomon Islands Water Authority (SIWA) took over from the Water Unit in 1994. Today SIWA no longer has a functional leakage group although attempts were made during the late 90's to revive the team. Under the JICA-funded project "The Study for Rehabilitation and Improvement of SIWA's Water Supply and Sewerage Systems", NRW ratio in 2004 was determined as 42.6%. The leakage survey was conducted using 10 model blocks and an average leakage ratio of 47.4% was obtained and refined to 40% as the actual leakage. From the JICA study the establishment of a leakage team was recommended (Booth et al., 2006). "The recommendation is in line with the proposed program and by SOPAC for a Demand Management Program and provides an opportune time for SIWA to utilize expertise and assistance provided under the program" (pers. comm. Andresen). One of three main outputs of the WDM program was "Water demand management teams established, trained and functioning with increased capacity within each participating utility". A major component of the program was the development of skills and thus the need for in-country training and hands-on problem solution in the different subjects comprising WLM. Based upon needs identified through the scoping mission in October 2006, WLM strategies were implemented during the period 29th July – 2nd August 2007.

A WLM team was established through correspondence with the SOPAC country focal point before arrival in Honiara, and consisted of 6 SIWA staff at different levels in the organization.

4.1.1 Site investigations

The system in question relies on groundwater supplied by two boreholes pumping approximately 50 ML of water per month to a receiving tank before pumping to two reservoirs. The first reservoir, Tuvaruhu Tank, is approximately 70 m^3 supplying water to 90 connections. The main reservoir, Lower Western Kola Tank, is supplied via a 3 kilometer, 150 mm uPVC main. This reservoir is 460 m^3 and supplies approximately 350 customers including the business centre of Chinatown and the National Referral Hospital (Honiara Hospital), which is one of the largest water users in Honiara. The total metered average monthly water consumption is 24 ML. Average power consumption is 20,000 kilowatt hours per month (pers. comm. Andresen).

A site investigation was conducted immediately after arrival in Honiara, first through a look at the area in MapInfo, then later in the field. Potential sites for flow and pressure loggers were identified and based on this, loggers were deployed throughout the system as shown in figure 24. Training and practical exercises on setting up the loggers where given to the SIWA team.

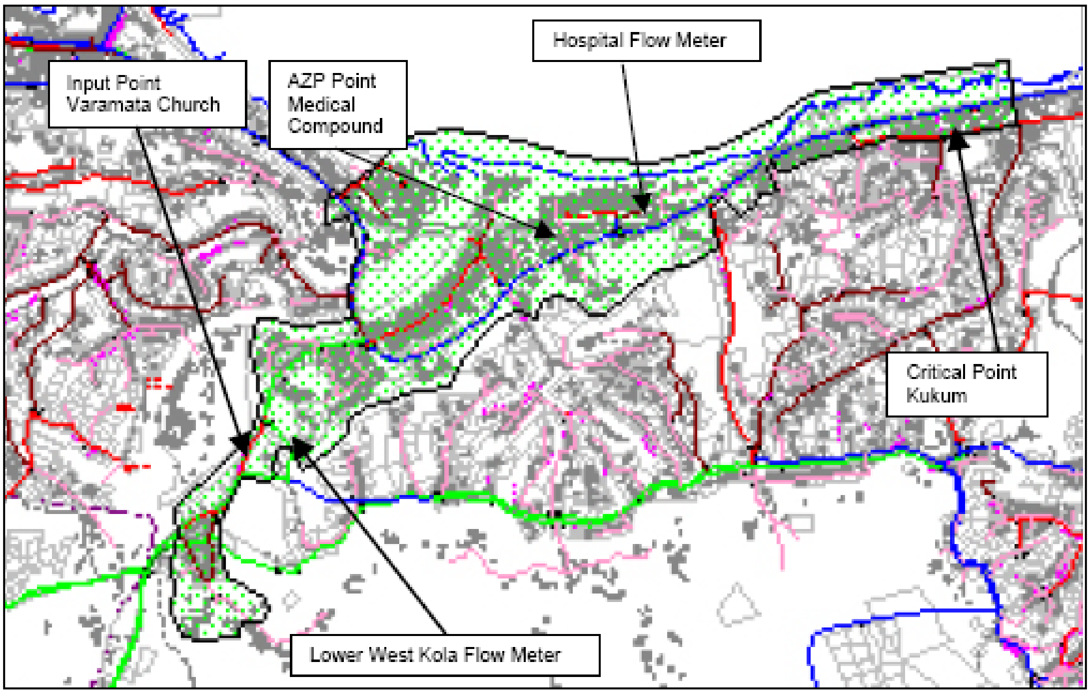


Figure 24: Pressure and flow meter logging locations at the Lower West Kola DMA (Source: MapInfo software by Pankaj Mistry on behalf of SIWA, 2007)

The Lower West Kola Supply system is the main part of what is called the Tuvaruhu pumped water supply system in Honiara, and was identified as a priority area by the SIWA Team Leader, during the 2006 scoping mission. The Honiara Hospital is the biggest customer in the area, but it was shown that one out of two water meters feeding into the hospital were clogged up and therefore creating no revenue for SIWA. Servicing of the meters was carried out. Following servicing, results from the loggers indicated that the meters were working satisfactorily.

Honiara Hospital average flow rate: 4.0 liters/second, 14.4 m^3/hour or 345.0 m^3/day

Half of this water flow has not been accounted for during an unknown duration of time where the meter measuring the laundry area and accommodation for nurses has been out of order. This equates to a potential revenue loss of Solomon Island Dollar (SBD) 828 per day (based on the commercial customer rate of $2.40 a kilolitre), or SBD 24,840.00 per month.

4.1.2 Flow meter, MNF and data logger analysis

After downloading the first set of data it was clear that something out of the ordinary was happening in the system (Fig. 25). Almost no flow in the night indicated a very good system with close to no leaks. There was however no reason to believe this was truly the case based upon previous reports and the age of the system, so other options were scrutinized further. Pressure loggers showed very low pressure, average 8 m throughout the system, and the same only 300- 400 m from the tank where an expected pressure should be around 40-45 m. This pressure drop might be explained from the fact that the 200 mm pipe at this location is cast iron and embedded in coral rock that contains high levels of corroding agents leading to holes, with subsequent leaks, which might not be seen because of the highly permeable ground. As important are the likely lime deposits decreasing the diameter on the inside of the pipe from the “hard water” pumped through it. On top of this the old tank did shed big amounts of debris through corrosion into the pipe system before it was replaced. This type of debris clogged up one of the hospital meters and indicated that there might be a collection of this somewhere in the 200 mm pipes as well, most likely where there are other obstructions like a valve or a t-coupling.

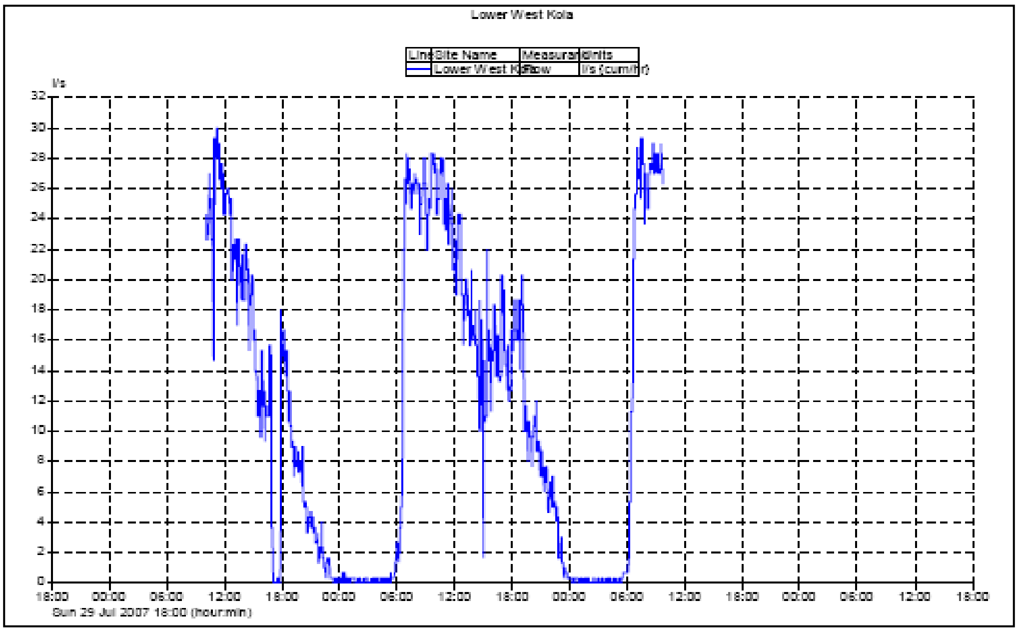


Figure 25: Lower West Kola flow regime. Liters per second (l/s) on the Y-axis, time on the X-axis (Source: Pmac software fieldwork, 2007)

As there had been no power cuts during the night in the initial logging period, there were no extremes in data due to such an event. The integrity of the 200 m cast iron pipe feeding from the tank 300 m towards the first t-coupling was tested by closing the valve before the T and monitoring that the meter actually stopped. However this was not entirely reliable due to two factors – one being that the water meter was too big in size compared to the pipeline it was measuring, and secondly; - the meter was also placed on a rather steep hillside. These factors could allow flow that the equipment would not detect.

Water industry practice has shown that usually the size of the meter is one diameter less than the size of the pipe it is to be installed on. In this case that means a 150 mm meter since it is a 200 mm pipe. The WDM program delivered a 150 mm water meter. Due to lack of information from cargo companies and travel agencies it was not possible to get the water meter on the flight as planned. Max weight per unit cargo was 32 kg, while the 150 mm meter was heavier than that. This serves as an example on challenges one can expect in developing countries that would most likely not happen in developed countries. The meter eventually arrived 2nd August 2007. It was supposed to be installed later by SIWA at a more suitable site than the current one (Fig. 26).

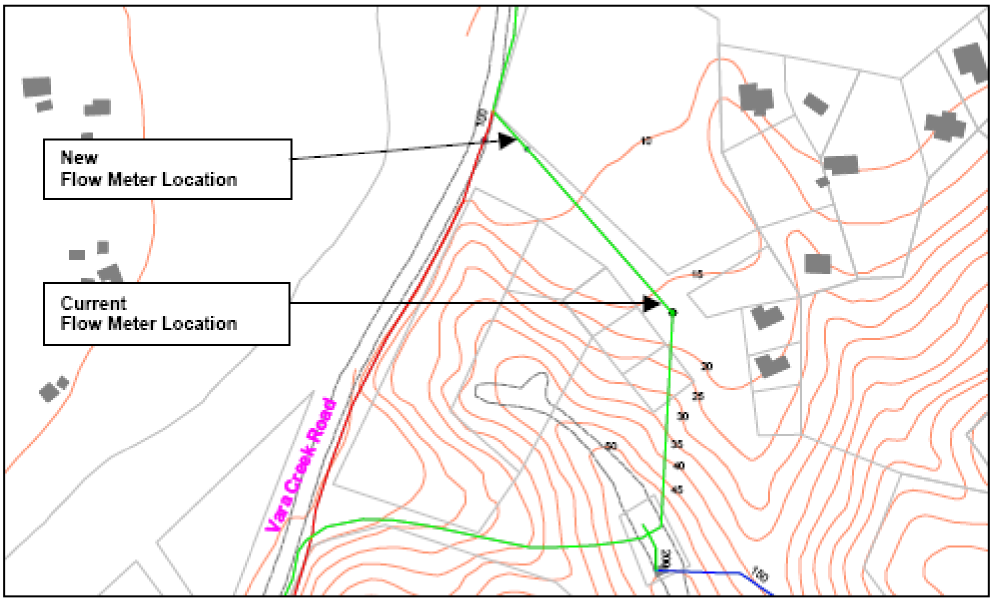


Figure 26: New flow meter location (Source: MapInfo software by Pankaj Mistry on behalf of SIWA, 2007)

The current 200 mm meter is placed where the pipe is running down a rather steep hill. So, in addition to being too big to create the proper flow regime through the meter to enable accurate reading, a lot of water might run through the impeller without making this turn to register the flow. By installing an appropriately sized 150 mm meter on the flatter area the pipe will be filled with water and the reading will be accurate. An added benefit by installing the new meter at the correct site is the opportunity to take a pipe sample to investigate the inner diameter of the pipe. The obstruction that is causing the dramatic pressure fall should be located during this replacement work.

SIWA were notified about the following: “If there is in fact a physical obstruction in the area identified care should be taken when clearing this out. Increased pressure from 8 m to 30-40 m will most likely lead to increased amount of background leakage, consumption and burst frequencies”.

Solution 1:

In the first instance it was recommended that a series of pipe samples be taken from the 200 mm pipe, with work commencing from the flow meter location every 30 to 40 m. And continuing at every major tee off up to the bridge at the Honiara river, where the mains tee off over the bridge and into China Town. This will give a good indication of the state of the internal surface of the pipe.

Solution 2:

It was also recommended that pressure-tapping points be installed every 20 m from the flow meter. These should then be logged for pressure for a minimum of 24 hours – if there was a restriction between the loggers, a significant pressure drop should be recorded by the loggers. This will easily determine where the restriction is, and the methodology should be conducted along the major pipeline that feeds the DMA.

4.1.3 Sectorisation and creation of DMA

Using the existing drawings on MapInfo as a base, and onsite inspections for verification, a DMA of the Lower Western Kola supply area was created. The MapInfo documentation, topography, number of connections, position and integrity of boundary valves and the tests of the zones integrity, all make up the basic steps before going back to the MapInfo drawing board to establish the boundary (Fig. 24). The appointed MapInfo officer in SIWA had already received training through other SOPAC programs, and more training was received through the expertise of Pankaj Mistry from WBWC during the period of field work. Pankaj demonstrated how to retrieve information on pipe lengths, number of connections and buildings by using the specialized functions within MapInfo. Training was also given on adding colors to different pipe diameters in the network i.e. 100 mm mains would show up red, whilst 150 mm would show up blue etc. This is a good methodology to apply since it minimizes mistakes on pipe diameters when viewing data on the screen. In addition, MapInfo provides a tool whereby labels can be inserted onto the base data and these in turn can be created into their own layers. Since MapInfo can contain all information about a water supply network, its use are very helpful in WLM and can form the key base in design and implementation of creating DMA’s and PMZ’s, given there are personnel who can work it properly.

The main challenge in creating the DMA proved to be the integrity of the boundary valves. Though several of the staff at SIWA, one of the seniors in particular, had extensive institutional memory on the systems design, a significant amount of confusion was found with respect to the state of the systems valves. No one could say for certain if they were open or closed, or if they were functional or broken. There were also different types of valves, some closing clockwise, others anti-clockwise. A valve was located in the Kukum area (critical point) that was destroyed by roadwork. This was replaced the same day by SIWA staff. The WDM program had stocked SIWA with excellent acoustic leak detection equipment and training was provided on the use of this while working through the network doing boundary valve investigations. The importance of testing the boundary valves and incorporating information about them into the MapInfo software, as part of the asset management of the utility were stressed. The survey team from SIWA went around the whole network performing hands-on testing of the valves to prove:

- That they actually exist and the location is known and accurate;
- That they are controlling the water main the plan says they are controlling;
- That they are the size shown on the plan;
- That they will shut off the area/s identified in the plan;
- Whether they are in good condition or need replacement, and;
- That the direction on every valve is marked since there is a mix of types in the system.

This exercise served as a “wake-up call” for several of the operational staff in SIWA. Firstly it demonstrated a vulnerability concerning network knowledge. Secondly it proved that it does not necessarily need to be a massive undertaking to significantly improve the overall knowledge about the network. It was advised that SIWA would continue to do this type of field investigations and note their findings for later reference.

4.1.4 Outcome of WLM implementation

The strategy applied in Honiara was based upon reviving the previous Water Unit that had been active doing WLM in the 80’s. A team were established that would be either introduced to WLM strategies, or receive a reminder of “rusty” skills. Leak detection equipment was supplied, and training in the use of the equipment was given. The field investigations proved the point of having knowledge about the system, and how to locate problem areas in a systematic manner. The financial benefits of WLM were proven by the small example of repairing the hospital meter. Further it was successfully proven that in order to have understanding about your network you need to have data collection facilities, like functional meters and loggers, in place. In addition to this it was also proven that you can create an improved overview of the network also by simply walking from valve to valve and control how they function. This is important knowledge and it was explained how this information could be implemented into the MapInfo database for later reference. SIWA were also introduced to how a DMA is established, and how this can ease the work of locating and repairing leaks, and eventually provide better service for the customers while at the same time saving money for the utility. These key factors would have been the core part of an initial WLM strategy in Honiara, but there are also other factors that did not provide the results that were hoped for.

Even though the effectiveness of different WLM initiatives got demonstrated during the scoping mission SIWA did not follow up on this. The bulk flow meter that would have given good data on the outflow from the Lower West Kola Tank was still sitting idle in the warehouse one year later. Neither had any active leakage detection effort been implemented on a continuous basis. There can be several reasons for this, the main factor being the promised multimillion dollar project from JICA for the rehabilitation and improvement of Honiara’s water and sewerage systems. The expectations to this project resulted in some degree of apathy amongst the operational staff and upper management. Having an ongoing WLM strategy on a very old and worn out infrastructure seemed unnecessary if there would be a total upgrade in just a few years time. Honiara has also been plagued with ethnic tension and riots where much of the infrastructure has been damaged. The utility lack enough skilled operators and resources, and the ones employed has low salaries. Combined these effects might give a feeling of helplessness. It is very challenging to work pro-actively in such an environment, and the back-log of things that should have been done will easily grow out of the capabilities inherent in the utility. Kick starting a WLM effort and demonstrating the gains acquired by the different strategies might be proven on a short mission, but without strong will and leadership within the utility such work might easily be set aside as soon as the consultant or development aid worker has left the country. Communication in the Pacific is a challenge as many public utility offices do not have good internet access or even their own computers. The international aid in itself can also pose challenges as there are few people in the upper management of the service providers that need to cater for a multitude of different projects. Where this is the case it is usually the project with the most available funding that get priority. The effectiveness of implementing WLM strategies was never the less proven qualitatively by the work done in the field, though it never progressed far enough to show clear quantifiable results.

4.2 Example 2 – Luganville, Vanuatu

Vanuatu is a country consisting of more than 80 islands with a total landarea of 12,189 km^2. Port Vila is the capital, while the main urban centre on the largest island of Espiritu Santo is Luganville (fig. 27). The climate is tropical with moderate southeast trade winds from May to October, moderate rainfall from November to April, with a risk for cyclones from December to April. The terrain is mostly made up of mountainous islands of volcanic origin with narrow coastal plains. 225,000 people live in the country. Life expectancy at birth is 65 years, and there is an infant mortality rate of 46.85 deaths/1000 live births. 26% of the total population lives in urban areas that have an estimated urbanization of 4.2% annual rate of change, 2010 – 2015 (CIA, 2011). Vanuatu ranks 126 on the 2007 HDI.

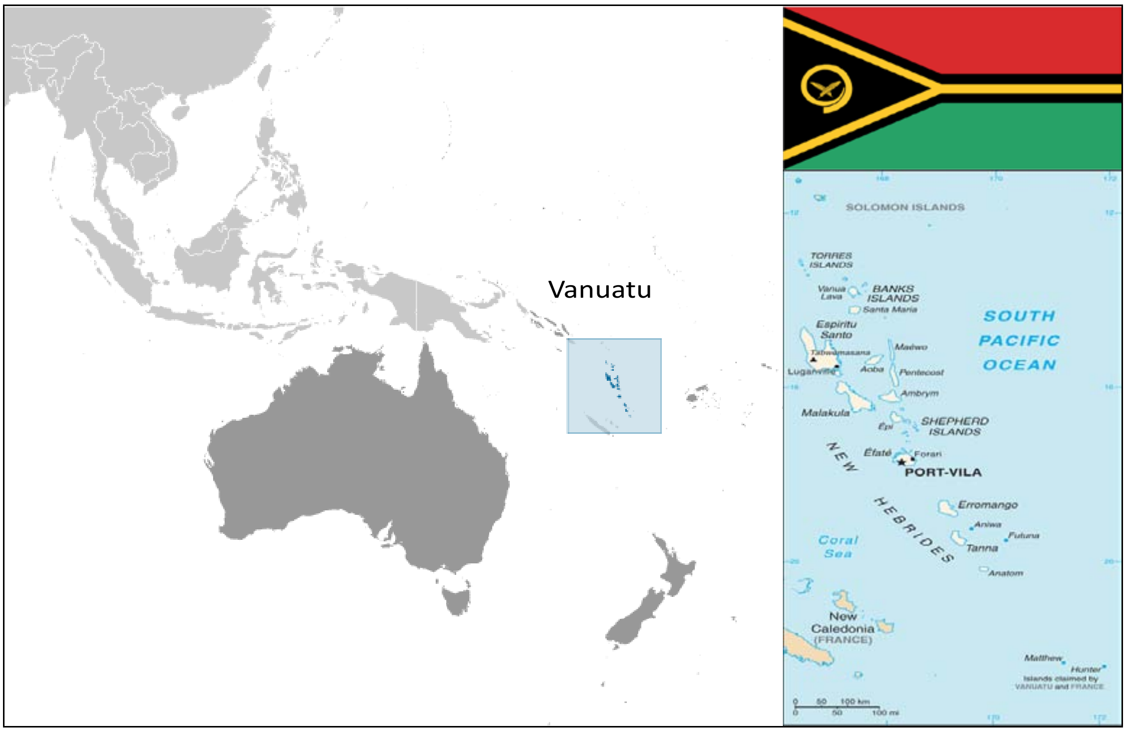


Figure 27: Vanuatu location and map (Source: CIA, 2011)

Based upon previous request and needs identified by the Director of Department of Geology, Mines and Water Resources, a scoping mission to Luganville was conducted during February 2008. During this mission fact finding and data collection on current systems performance were key in order to plan and prepare for further WLM initiatives in Luganville. Findings from the scoping mission are presented in the following.

Beforehand there had been established a WLM team consisting of the Public Works Department's water supply section operational staff. A visual overview of the supply area is shown in figure 28.

4.2.1 Site investigation

Figure 28: Location of main water infrastructure in Luganville (Source: Google Earth, 2010).

From the initial discussions with the WLM team it became clear that there where many opportunities for improvements of the reticulation system in Luganville. Some of the main issues of concern were;

- No MapInfo or similar software. The only overview on the network where one copy of the system schematics done by SMEC International, Australia, in 1999. An example is seen in figure 29.
- Defect or unreliable bulk flow meters
- No leakage estimates or knowledge on how to do a manual leakage estimation
- No good quality leak detection equipment
- No PVC pipe detector though parts of the system had a recent upgrade to new PVC pipes
- No overview on pressures throughout the system
- No overview on integrity of valves
- Uncertainty regarding reservoir sizes, pumping rates and kilometers of mains
- No laptop computer, only two desktops whereby one would be used as the Access database for billing.

Having established a lack of equipment and knowledge of WLM it must be said that the best asset at PWD would be the staff. There was a very positive attitude and interest in improving skills in WLM. This impression was further strengthened by a tidy pumping station, warehouse and office environment, and by the fact that people in general were happy about the service provided by PWD. Especially the rapid restoration work done after a 7.2 magnitude earthquake that hit 1st August 2007 and destroyed parts of the supply system, were appreciated.

4.2.2 Metering

The Luganville water supply system was built by American soldiers during the World War II in 1942. The water is sourced from a concrete lined well in a natural spring to the pumping and treatment plant at Sarakata. From here it is pumped uphill to the storage reservoirs of Sarakata (~1100 m^3) and Chapui (~1500 m^3), which then gravity feeds back into the supply area.

The flow to Chapui is metered within the pumping station. This150 mm meter is read and data are recorded for future reference. The flow to Sarakata is not metered, but estimates are based upon recorded pumping times and pump capacity. There were no inlet meters on the reservoirs. On the outlet of the Sarakata reservoir there were two 150 mm bulk flow meters. The first would measure the total flow, while the second would measure the main going further to the central area after another main had branched off to the western supply area (Solway Township). The first were placed correctly on the main, but out of order. The other was placed immediately behind a valve that regulates the tee junction in front of it. Though registering, it would not be correct due to wrong location and wrong size. A water meter needs a uniform current to measure correctly, the valve and tee in front of it will give a turbulent flow and resulting errors in reading. The size of the meters should have been one down from the pipe size i.e. 100 mm, not 150 mm. The bulk flow meter that was in disrepair was fixed during the follow up mission and logged. There was no bulk flow meter on the outlet of the Chapui reservoir.

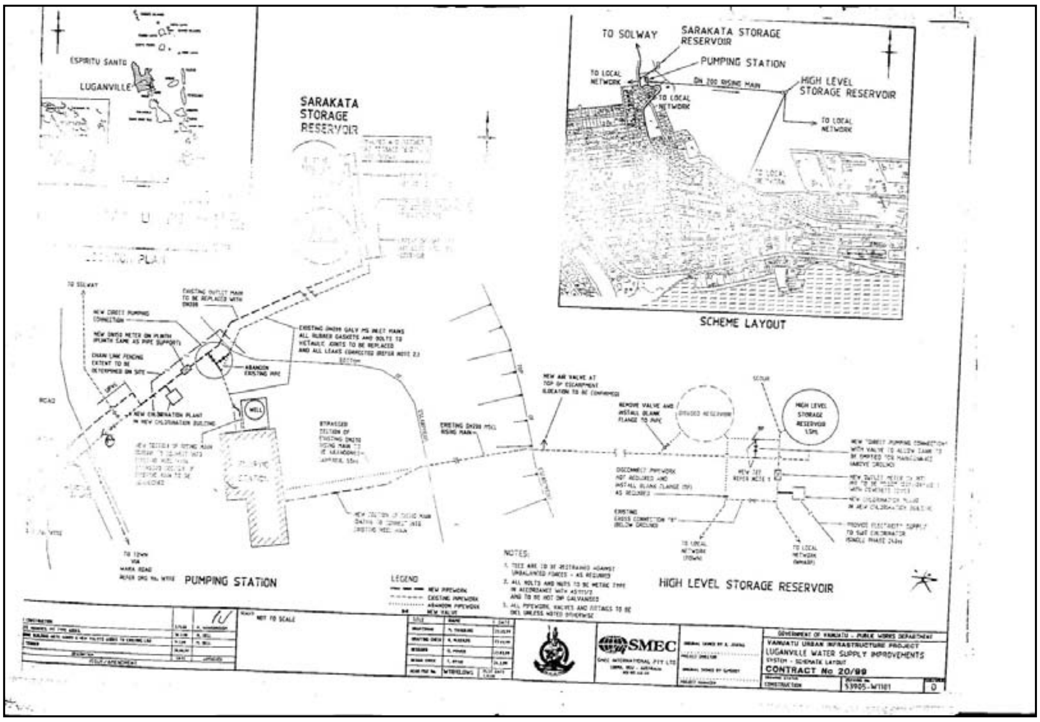


Figure 29: Scan of system schematics (Source: Author, PWD office wall, 2008).

In Luganville all customers are metered. In 2008 there were registered 3142 connections. These meters are being read manually and noted in a logbook every quarter before punched into the database. This is a very positive feature for the purpose of efficient WLM. However, after checking random meters of both domestic and industry customers, it came clear that there was potentially several defunct meters in the system. This would cause revenue loss to the service provider. As an example there was found many domestic connections with a yearly consumption of 10 – 20 m^3/year, compared to the average that was calculated to be in the area of 186 m^3/connection/year. This estimate was based upon averages from samples in the billing logbook. The easiest way to solve this problem would be for the PWD staff to analyze their logbook and note down very low meter readings and then go to this location to find the reason. Replace or repair the meters, and also invest in two new 80 mm meters for the biggest industrial customers; the Abattoir Company and the hospital since these customers also showed low water usage compared to what would be expected. Another major challenge in order to use customer metering data as a tool for WLM is the very high amount of disconnected meters. Of the 3142 connections 1420 have been disconnected because of non-payment and other reasons. Due to this fact and that people will find other ways to tap into the reticulation system, a relatively high amount of unauthorized consumption would be expected. If we use the figure of 186 m^3/connection/year x 1420 disconnected domestic meters we have approximately 264 ML lost through unauthorized consumption. This figure is obviously not accurate, but would give an indication of the water losses caused by unauthorized consumption. What is more important in the initial stage is to get a figure on the total amount of NRW. The real losses normally contribute the most to the NRW quantity. This is explained in the following.

4.2.3 MNF estimate by reservoir drop test

There was no leakage estimates done by PWD staff, so training on how to perform MNF determination by reservoir drop tests were done in the night for both Sarakata and Chapui reservoirs. A reservoir drop test is the most reliable method of measurement of a service reservoir without an outlet meter as explained in chapter 3.4.1. Though giving a fair assumption it is not an accurate science, and should only be used as a substitute for bulk meters when there is no alternative. Together with an available measurement done by SMEC in 1999 the following comparison could be done (Tab. 3);

Table 3: Comparisons of estimated MNF (Source: Author and PWD staff, 2008)

Estimated Minimum Night Flows (m^3/hour)		
	SOPAC 2008	SMEC 1999
Sarakata reservoir	67	46.8
Chapui reservoir	72	50.4

From the table we see there is a relationship between the different measurements. Multiplying the figures from 2008 with 0,7 gives approximately the 1999 figures. This could be a coincidence, but more likely it would indicate that there has been a steady degradation of the whole system without any particular area being better or worse than the other. A result like this would be expected if the supply system is left basically unchecked and no planned maintenance work is conducted.

Using figures from the scoping mission in 2008 there is a potential leakage of 1,218 ML/y (67 m^3/h + 72 m^3/h = 3336 m^3/d x 365 d = 1,218 ML/y), compared to the 1766 ML/y total water supplied (pers. comm. PWD staff). The rate of potential leakage within the Luganville urban water supply system would then be approximately 69%. This is very high, but confidence that the figure is not very far off the mark was given by the fact that the leakage rate in 1999 was estimated by SMEC at around 65% (pers. comm. PWD staff).

In Luganville the chargeable rate to customers were 0,58 VUV/m^3 in 2007 (VUV is the Vanuatu currency “Vatu”). So with the figures we have that the utility would lose 1,218,000

m^3/y x 0,58 VUV/m^3 = VUV 633,360 per year in potential revenue. But a bigger cost for the service provider would be electricity needed for pumping water. The power supply bill for 2007 amounted to VUV 22 mill. If this is divided by the total amount of supplied water we get 12,5 VUV/m^3. In addition there is also a cost of 2,5 VUV/m^3 for chlorination used in the water treatment. Again if we calculate this figures with the MNF based leakage estimate we have that PWD are paying VUV 15,225,000 for power to pump water that do not reach their intended users, and VUV 3,045,000 in “wasted” disinfectant.

4.2.4 Pressure management

One main reason for the major amount of NRW in Luganville can be attributed to rather high system pressure seen in conjunction with a network at the end of its operational life. This is quite unusual in developing countries that more often face problems with too low pressures and intermittent supply. But an average rate of two mains bursts a week and up to around 10 breaks on service lines a week is a good indication that pressure is higher than the network can cope with. A field trip around the system was undertaken during the scoping mission to check pressures and flow (Tab. 4) at different hydrants and households while at the same time checking the integrity of the boundary valves, and looking for potential sites to install pressure reducing valves. This because there was a suspicion that pressures were high, even before measuring it, based on the high leakage/bursts rate.

Table 4: Point pressure and flow tests in Luganville (Source: Author and PWD staff, 2008)

Location	**Pressure - Connection type - Max flow (m^3/h)**
St. Michaels point (western critical point)	31m - household – not measured
Coral keys	30m - hydrant - 30
Abattoir/Santo Engineering	32m - hydrant - 55
PWD office	30m - household – not measured
Hotel Santo/Unity park	40m - household- not measured
Solway (Sarakata floodplain)	32m - hydrant - 34
Main warf	80m - hydrant - 55+
Property behind police station	68m - household – not measured
At the only booster pump (northern critical point)	14m - hydrant -22
WMF compound	42m - hydrant - 25
Hoom subdivision, Lot 44	44m - household – not measured
Pekao Int. national airport (eastern critical point)	42m - hydrant - 22

As an example; minimum pressure that a water utility in Queensland, Australia, is obliged by law to provide its customers is 22 meters (pers. comm. O’Halloran). If this was set as a target in Luganville the average pressure in the system would drop by approximately 50% allowing for reduced background leakage and burst rates on both mains- and service connections. It must be noted that the many factors influencing the effect of pressure management on burst frequency reduction attributable to pressure reduction, can only be based on reductions achieved in similar systems in similar geographical locations. What we can say for certain is that there will be *some* reduction in burst frequencies and background leakage when system pressures are reduced.

4.2.5 Outcome of WLM initiatives

From the previous we see that the water service provider achieved greater insights into their system performance by simple WLM methods. This in itself is possibly the most important step in the right direction, giving the operational staff more confidence and understanding about their system, as opposed to the “business as usual”, working ad-hoc on repairs and maintenance of the network. However, there is still a long way to go in order to actually improve the performance of the network. Some suggested strategies were discussed with the PWD team and WBWC specialists and are presented in order of priority;

Priority 1 would be proper bulk flow metering. Without better data on flows it is difficult to develop a reasonable accurate water balance. The water balance is an important tool showing what water goes where. As a minimum it should be installed a meter on the bulk line feeding the Sarakata reservoir, providing accurate figures on water supplied. The outlet of the Chapui reservoir is also in need of a bulk flow meter. Together with the improvements in bulk flow metering a major repair/replace effort should be conducted throughout the systems customer meters. The cost of improved bulk flow metering would amount to around VUV 950,000,- (April 2011 value) while the cost of upgrading domestic and industrial metering would depend on how many can be repaired and how many needs replacement.

Priority 2 would be to create DMA’s. The installation of bulk meters would enable the creation of three DMA’s. This would further allow staff to gather minimum night flow data from these areas and provide the following benefits:

- A planning tool to assist with identifying areas of highest leakage thus allowing leak detection resources to be deployed more effectively.
- The facility to monitor DMAs to estimate the savings produced by leak detection activities and associated repair programs.
- The facility to monitor future leakage levels (left alone leakage will always increase corresponding to the “natural rate of rise”).

It is envisaged that a new bulk meter installed at the outlet of the Chapui Reservoir will also act as the DMA meter for the Chapui District Metered Area. Similarly the existing meter on the feed from the Sarakata Reservoir will act as the DMA meter for the Sarakata DMA. A third meter should be installed on the St. Michel side of the main bridge just before the water main splits into two separate feeds. By doing it this way it will be possible to create three DMA's without the need and costs associated with establishing new pipes and valves.

Priority 3 would be to reduce pressure in the system. This is done by installing pressure reducing valves (PRV) at designated points. Three areas fit for installation was located with the assistance of WBWC specialists. This would reduce the overall pressure for the whole system, and come at the cost of around VUV 760,000,- (April 2011 value) in addition to shipment and installation. After pressures are reduced, staff should draw up a new pumping timetable based on the reduced pumping requirement. This timetable should not allow the reservoirs' water levels to increase beyond one meter below the overflow point and would thus eliminate water loss due to reservoir overflow.

Priority 4 would be active leakage control (ALC). The key to further improvement in the Luganville water system lies in the strategy of using the initial financial savings gained from pressure reduction to fund further water loss reduction activities. ALC activities will in turn further reduce electrical costs associated with pumping water, thus freeing more funds. This strategy can reverse the current downward cycle of under-resourced asset maintenance and management which results in further losses and asset degradation, rather leading to an upward spiral of savings, reinvestment and continuous improvement. In order for this strategy to be fully effective the water system maintenance staff needs to be proficient in using electronic sounding equipment. Unlike Niue and Solomon Islands the work never progressed far enough to prove the gains made by ALC activities, but this is from experience one of the easier strategies to implement as long as there are good equipment available and operational staff are using it often enough to maintain a "trained ear".

A key factor suggesting why there had been so little attention given to WLM in the past might be attributed to lack of knowledge. But with a team that was interested and had a strong desire to learn WLM methods it was possible to move from almost no data to having a much better overview on the supply network. The exercises done during the scoping mission gave, through a simple water audit, answers to how much non-revenue water the utility currently have, how much this means in fiscal terms and what can be done to improve the situation. This was a fundamental step towards improved resource management. The operational staff is now able to investigate NRW themselves by reservoir drop tests, and there is improved knowledge of the systems flow and pressure regime. Increased attention is given to customer metering and this will eventually decrease the amount of unauthorized consumption. The cost calculations will make it easier for the managerial staff to seek funding from the government since they now have figures to present that can be proven, not only assumptions.

The operational staff is also set up for a more proactive attitude towards solving problems. In the past most repairs where ad-hoc, while now they have the knowledge to understand and prioritize what methods to be applied. Knowledge is one key factor, but you also need the equipment to actually get the job done. The PWD are now stocked with leak detection equipment that they can use for active leak detection. They have also been supplied with the necessary equipment to establish bulk metering, and by that getting even better data on supply and leakage rates (pers. comm. Giles-Hanssen). The progress so far also proved the fact that WLM initiatives are low-cost compared to the supply driven approach whereby major infrastructural investments normally are required. There were no major obstacles in implementing WLM initiatives in Luganville, but inherent in any water utility, be it in developed or developing countries, there are a constant need for funding to make the necessary improvements. Vanuatu is a relatively poor country and the funding of PWD does not correspond to the needs. Neither is there money enough to employ enough skilled staff. This is a limiting factor on how much work that realistically can be done. With many breaks on both mains and service lines the PWD team are often bound up to “emergency” repair work instead of being able to proactively do prioritized maintenance work to avoid such incidents.

4.3 Example 3 – Niue

Niue is one of the world’s smallest nations, both in land area and population size. It is also one of the most isolated, being a lone raised coral atoll island East of Tonga and South of Samoa. (Fig. 30). With a land area of 260 km^2 the whole country is almost half of Oslo municipality (454 km^2). The climate is tropical modified by southeast trade winds. Cyclones like Heta in 2005 inflicted severe damage on the country. Waves pushed up the 20-40 m steep limestone cliffs that surround the islands central plateau and washed the hospital, resort hotel, casino and several private houses off their foundation and onto the ocean. It is estimated that the population will be around 1300 in mid 2011, with a negative annual growth rate of -0,032%. 38% of the total population is said to be living in urban areas, with a negative annual rate of – 1.3% (CIA, 2011). The country is estimated to rank around 100 on the HDI, based upon ranks of comparable countries like Tonga and Samoa.

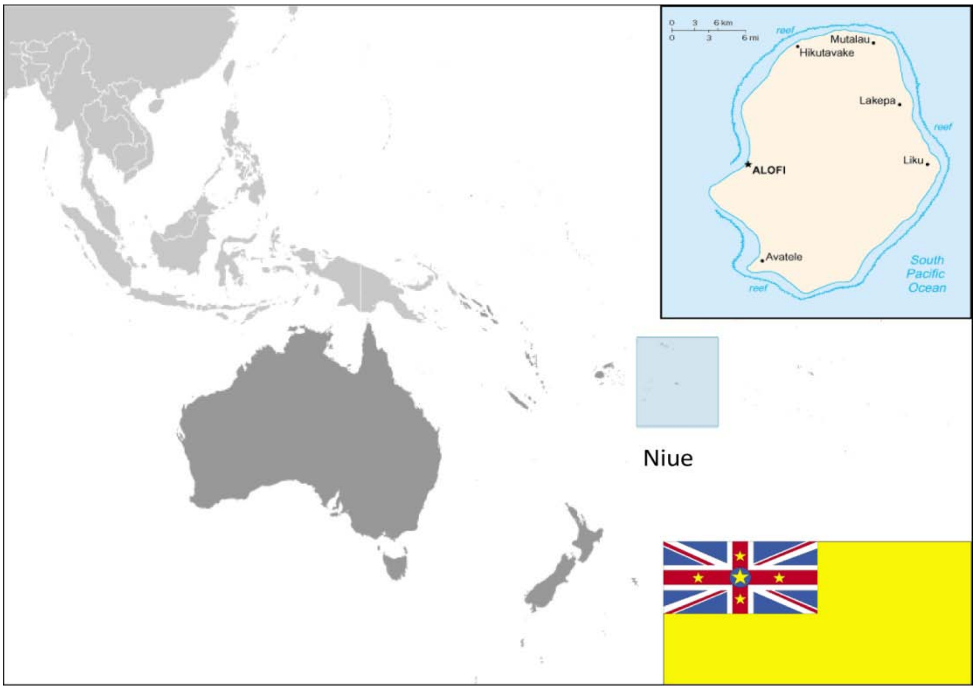


Figure 30: Niue location and flag (Source; CIA, 2011)

4.3.1 Site investigation

The first mission to Niue was conducted during November 2006. The manager of the Niue Water Division (NWD) is very proactive in securing a safe and sustainable water supply to the people of Niue. During the preparation to the initial scoping mission it became clear that Niue have had their “fair share” of a variety of development projects. That in itself would not be uncommon in the Pacific, but in regards of water management most of the funding had been geared towards “enabling activities”, like plain information collection, capacity building, and the creation of policies and action plans. Both the Director of the Public Works Department and the NWD Manager made clear that a more hardware based project was needed in order to get a better understanding of the islands water supply network. The water supply infrastructure consists of a groundwater bore with a submersible pump from where water is pumped to a reservoir, and from there either gravity fed or pumped directly to the customers. A total of 16 villages or distribution zones, including the town area of Alofi have this type of set-up. Because of this it would be very easy to create District Metered Areas (DMA) in Niue, simply by letting one village be one DMA, and the bulk flow meter would also act as the district or zone meter.

4.3.2 Metering and logging

There were bulk flow meters on the outlet of the reservoirs, but it had not been common practice to take readings of these meters. Water use had rather been related to the electricity bill for groundwater pumps and surface booster pumps. These figures were rough estimates, but during a monitoring time of 6 years the manager had noted a steady increase, especially the last 2 years (2005-2006), in electricity consumption. During this time the island population remained virtually unchanged at around 1800 people, so either this was a sign of increased water consumption or an increase in leakage.

When inspecting the old bulk flow meters they were found to be out of order or to be difficult to read. From earlier work done by SOPAC (Dawe, 2000) it was found that the per capita consumption of the people in Hakupu were 1738 l/p/d, while the people in Makefu and Alofi South used around 30 liters each per day. These figures were both completely erroneous and showed the need for bulk flow meter replacement. The WDM program supplied NWD with bulk flow meters and flow/pressure loggers. A laptop computer containing software to read the logger data were also supplied together with training in how to operate this equipment. During a field mission in June 2006 installation of the meters and loggers commenced at 12 out of the 16 villages, and the first findings from the logger readings are seen in table 5:

Table 5: Night flow readings from loggers 4th June 2007 (Source: Author and NWD staff)

Village - Pop. served	**l/s**	**l/h**
Hakupu – 162	0,2	720
Avatele – 164	0,4	1440
Lakepa – 72	0,2	720
Liku – 62	0,2	720
Mutalau – 81	0,2	720
Paliati (Alofi North) – 427	1,5	5400
Tapeu Airport	0,5	1800
Tapeu (Alofi South) – 609	0,8	2880
Tuapa – 196	1	3600
Vaieia Talomai - 59	0,6	2160
Total		**~ 20 m³/h**

This initial exercise already proved the usefulness of logging data since it made it clear for the service provider what areas to prioritize for further investigations. The following recommendations could be given; **1)** Investigate the high night-time consumption from the Paliati Alofi North source. This tank is feeding the wharf and there might have been cleaning out of fish boats or processing in the factory to account for this, if not – investigate, detect and repair leaks. **2)** Tuapa tank that is also feeding into Namukulu area is showing signs of leakage or small burst in the supply lines – investigate, detect and repair leaks. **3)** Follow the same action for Vaieia Talomai. **4)** 0.5 l/s for the airport supply line is too high since there is close to no activity there apart from once a week – investigate, detect and repair. Alofi South have a high minimum night flow (0.8 l/s), this might be because of many households and more activities at night time (bathroom, shower, toilets), but it would still be advisable to perform leak detection in the area.

4.3.3 Leak detection

Water use in Niue has been estimated to 278 l/p/d (Green, 1999), which is close to typical demands in most developed countries. In terms of rural village supply in the Pacific, this demand is quite high, but for semi-urban reticulation systems the value is quite typical. The public water supply in Niue has avoided major investments or full-scale upgrades since it was first established. There are two main reasons for this;

- The population of Niue has decreased because of migration mainly to New Zealand.
- A house-to-house leak detection and maintenance program started in 1997, and reduced water consumption by half between the start and the end of the program in 1999.

Before this leak detection effort the water supply was in serious difficulty. Mismanagement and lack of maintenance led to water supply being unreliable. The demand exceeded supply. Even with pumps working on full capacity, there was insufficient water reaching many end-line consumers, and storage tanks would remain empty (Green, 1999).

This problem were on the rise again due to lack of funding to keep the leak detection effort ongoing from 1999 and onwards. To counter this challenge new leak detection equipment were provided to NWD, and training in the use of this was given during the scoping mission in 2007. The equipment consisted of an acoustic listening stick and ground microphone, and had earlier been tested and found to be the best for the "untrained ear". In simple terms the test had been done by an impartial acoustics specialist hired by WBWC to find the best equipment amongst all the different suppliers of leak detection equipment.

During the exercises with the operational staff from NWD we found the equipment to be efficient from the beginning in locating leaks. This was due to two factors; firstly the operators had some previous experience, although from many years prior, and secondly because the mains are laid very near the surface of the ground. Often no more than half a meter deep, and thereby creating noise that is easily picked up by the microphone. Finding the mains in the first place could be a bigger challenge, but this was solved by providing pipe tracing technology. NWD was stocked with an active frequencies pipe and cable locator, detectable fibre rod (100 m) that goes into the plastic pipes, and a metal detector for metallic pipes. Using this technology it proved easy to find were the pipes were located in addition to prove inter sector linkages in the network. The sequence of pictures below (Fig. 31) show the team finding a leak that we estimated to be around 3,5 liters per minute. That equals 5 m^3 per day, or 150 m^3 per month in real loss.

Figure 31: Leak detection exercise in Niue (Source: Author, 2007)

According to the NWD manager the leak detection effort has been ongoing ever since, and new leaks are proactively located and repaired. With this improvement to the network itself it is now planned to move over to repairing leaks that occur on service lines and in-house appliances. Funding has been granted through the WDM program and is planned to be started during 2011 (pers. comm. Giles-Hanssen).

4.3.4 Water audit, economic benefits and ILI

The objective of the evaluation of the Niue water supply system was to collect information, (Tab. 6) to demonstrate the economic and environmental benefits of WLM strategies. The actions necessary to achieve this objective were;

- Undertake a water audit as soon as data became available;
- Estimate the volume of water losses attributable to leakage;
- Make recommendations for the sectorisation of the network;
- Highlight the financial benefits from reduced water loss;
- Recommend appropriate strategies to achieve further reduction in real loss.

After meters and loggers had been installed, and operated by NWD for a period from 30th June 2006 to 1st July 2007, the following data were provided by the NWD Manager;

Table 6: Water audit data Niue (Source: Compiled by Author/WBWC, 2007)

	Data title	Data	Data source
1*	Total length of mains (km)	51.2	NWD
2*	No. of service connections	579	NWD
3*	Average operating pressure (m)	30.4	WBWC estimation from average data in each village communicated with NWD
4*	System input (KL)	274,000	WBWC estimation using 2 months collected data from meters installed after each tank associating to a 12 months average value
5	Water exported	0	NWD
6	Metered residential	0	No customer metering
7 & 8*	Unmetered residential (KL) & Unmetered non-residential (KL)	180	WBWC estimation based on 1,805 inhabitants and a consumption of 273 l/capita/day communicated by NWD
9	Marginal cost of water production (NZ$/KL)	0	No water treatment
10*	Selling price of water (NZ$/KL)	0.71	No tariff applied, all absorbed by Niue Government. WBWC estimate based on the annual cost and production
11	Annual cost of running the water supply system (NZ$)	206,503	Budget review August 2006, and 2006-2007 Total Budget communicated by NWD

Rows indicated with an asterisk * are essential, but an attempt to complete all fields should be made indicating estimated data. NZ$ = New Zealand Dollar, currency used in Niue.

The water system input value (KL) is quite accurate as its estimation comes from metered data. As consumption is not recorded using household meters at each connection, the figure given for residential and non-residential water use is an estimate made by WBWC.

Consumption per connection is calculated by dividing the total volume of water delivered into the system by the number of connections;

274 ML/year divided by 579 connections = 473 KL/connection/year

This equates to a water supply of 1297 liters/connection/day. The figures used for authorized consumption is an estimate, provided by PWD, based on 1805 inhabitants and a per capita consumption of 273 liters per day.

Figure 32 shows the basic components of the Niue water supply system expressed as a percentage of total water supplied,;

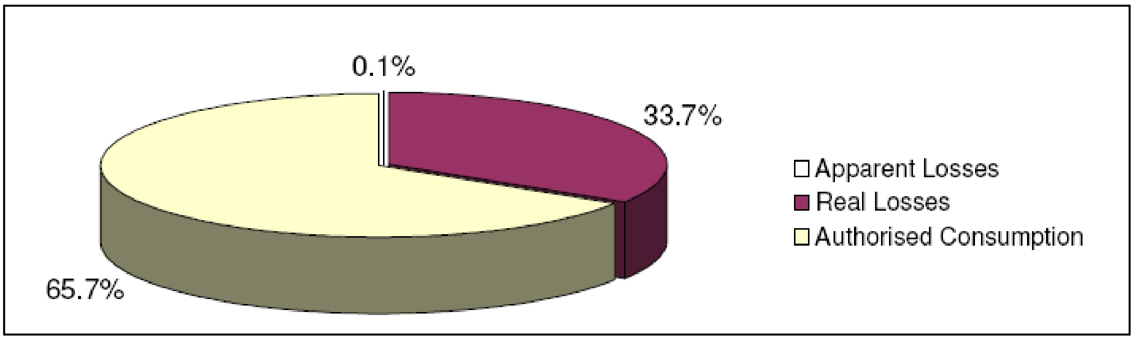


Figure 32: Components of water supplied (Source: WBWC, 2007)

Apparent loss is unauthorized consumption (mainly theft), inaccuracies in customer meters and errors in meter data transfers. As water is not metered or charged for, there is unlikely to be any theft. In addition there were at this stage only new bulk flow meters that were being read by loggers. As a consequence apparent loss was set to nil. The figures for CARL and UARL are calculated by WBWC.

Based upon this data it was also interesting to calculate the infrastructure leakage index (ILI). There is an average density of connections of 11,3 per kilometer of main with an average operating pressure of 30,4 m. The average operating pressure was estimated using the average value for each village based upon the pressure logger data. The ILI for the supply area was as follows;

The UARL is 15ML or 73 liters/connection/day.

The ILI is calculated by dividing the current annual real losses (CARL) by the unavoidable annual real losses (UARL): 92ML/15ML = ILI of 6.1

An ILI of 1.0 would show that the losses within the infrastructure match the best possible result for the condition of the network. The ILI in Niue of 6.1 would mean that the CARL is assessed to be around 6 times as high as the UARL for this particular system. This further suggests that there is a six fold theoretical potential of improvement.

The value of water losses can be calculated at the cost of production or at the retail cost to the consumer. In Niue there is no charge for domestic consumption. Financial savings resulting from reduced water losses will therefore be found in reduced production and supply cost. Electricity is the single biggest cost that is directly linked to the volume of water produced. Other significant costs are fixed and therefore not responsive to variations in the volume of water produced. Table 7 shows an assessment based on savings in electricity costs gained by reducing 50% of the CARL;

Table 7: Financial savings from reduced electricity consumption (Source: WBWC, 2007)

Annual water supply (ML)	274
Total electricity cost 2006/2007 (NZ$)	104,000
Annual electricity cost per ML supplied (NZ$)	379.56
Potential annual savings from ALC (ML*)	52
Potential annual financial savings (NZ$)	19,737

*Based on detecting and preventing 50% of CARL

The yearly budget allowance to NWD in 2007 for operations and maintenance after pumping costs, salaries, land lease and administration costs are deducted where approximately NZ$ 30,000,- (pers. comm. Siohane). The potential financial savings of nearly NZ$20,000,- through reduced leakage are therefore significant for the utility.

4.3.5 Awareness raising

Awareness raising aimed at all levels of stakeholders, from the general public to the politicians, should be an integral part of a WLM initiative. It was hoped that consumers would appreciate the value of water if they were presented to the efforts made by NWD in order to provide enough, clean water to the public. The politicians is also in need of some “water education” as they often do not have the understanding needed to provide sufficient funding to keep the water supply infrastructure from deteriorating. During the first mission in Niue this was met through different initiatives, first through a meeting with all relevant top-level politicians. The current status of the water supply network where presented together with the plans and possibilities for upgrades. The scope for reduced power bills were naturally of great interest to the politicians, but they were also interested in further data collection and monitoring as part of their overall resource security.

The second meeting was held at the Ministry of Education. From the meeting it became clear that there had previously been quite a broad focus on water resources awareness in the school curricula on the island. Funding had ceased and continued awareness raising had therefore been disrupted. The Ministry representative explained there was in-house capacity to translate any existing water awareness material into Niuean language and/or adapting it to the Niuean setting. At this stage it was agreed that the Ministry of Education would set up a preliminary budget on water awareness raising through the school curricula, while the WDM program would liaise with other relevant SOPAC programs in Niue to secure funding. The water awareness aimed at schools are now established and running (pers. comm. Siohane).

It was also important to show the people of Niue that NWD takes their responsibility serious. To make the department a bit more visible a new logo were designed during the scoping mission. It had the combined shape of a traditional Polynesian fish hook and water droplet as seen in figure 32. During the installation of bulk flow meters and loggers the national television station was invited to come and make a news bulletin about the work NWD do. This resulted in a 10 minute long field interview where NWD were given the opportunity to explain about the infrastructure and their ongoing upgrades in order to secure the people of Niue a safe and sustainable water supply.

Figure 32: Niue NWD logo and creation of news bulletin (Source: Author, 2007)

4.3.6 Outcome of WLM initiatives

WLM efforts in Niue had come to a halt because of lack of funding. Much of the data collection infrastructure was worn out and in disrepair. Neither was there equipment to carry out active leakage control leading to the typical passive management of only repairing leaks after they cause supply disruption, or visually appear on the ground. The NWD now enjoys a much improved knowledge in WLM. This is basically thanks to the strategy of data collection by meters and loggers being deployed for every village. Since the village with its associated water supply infrastructure is a natural DMA, efforts in order of priority based upon leakage data for each DMA can be implemented pro-actively. According to the NWD manager the operational staff has used the leak detection equipment to conduct active leakage control throughout the island, starting with the areas with the highest leakage rates. By doing this the NWD also have figures to prove the economic benefits from the WLM effort. The work so far has released more funding, both from the donor community and the government, and some of this is planned to finance new household leak detection and repair efforts (pers. comm. Siohane).

The results presented in this example gives a fair assumption on “what water goes where”, but the data is far from perfect. In order to achieve full knowledge of the system it would be necessary to install inlet flow meters between the bores and the reservoir where possible, and meter all household connections. The NWD have calculated this to a cost of approximately NZ$ 70,000,-. SOPAC through the WDM project can provide the funding for this effort and there are plans for implementation during 2011 (pers. comm. Giles-Hanssen).

The WLM strategies implemented in Niue proved both environmental and economic benefits from user friendly and relatively cheap equipment. With very limited human resources being one of the main obstacles to improved water resources management in Niue, strategies to improve effectiveness and systems knowledge is important. NWD only have 3 operational staff in addition to the manager. But with the help of data gathered from each DMA their effort can be planned and effective, saving time and money for the service provider and improving customer service by avoiding disruptions of supply.

5 Conclusion

Based on the literature review and assessment of the practical examples, the following conclusion can be made;

There exist several methods and techniques that can reduce the wastage of drinking water if implemented. These different WLM strategies can significantly contribute to the optimization of small urban water services, and by that reducing the need for expensive infrastructural investments. The results described in the practical examples also confirm the assumption that WLM initiatives can be implemented successfully even without perfect data, if the approach of gathering data is an integral part of the overall WLM program.

Some key factors impinge upon the successful implementation of WLM strategies. These constraints can be;

Lack of data and information systems; insufficient or inoperative equipment; poor maintenance of equipment; limited technical expertise; weak institutional bodies; sometimes demoralized and unmotivated staff; insufficient knowledge or training opportunities; lack of finances because there are no national long term planning and commitment, or an inadequate share of the national annual budget is provided to the water utilities; no value given to water or the establishment of a proper tariff; political instability. The need for demand side solutions are sometimes scaled down in competition with supply side solutions, even though WLM is an fundamental part of the overall management of water supply, and major savings can be achieved with a limited budget.

On the other hand several key factors that support the efficiency of WLM strategies were demonstrated;

Installation of flow monitoring equipment, and simple water auditing, gives the service provider knowledge of flow, and where water supplies are going. Establishment of DMA’s and pressure logging gives further knowledge of the potential savings that can be made. The increased knowledge about how the distribution system works results in the possibility to have pre-planned responses to problems. Active leakage control and prompt repairs, if possible in conjunction with pressure management, leads to less wastage. This in turn have a positive impact on the economy of the service provider. Financial resources can be re-directed to other WLM initiatives, and an upward spiral of savings and further improvements to the supply network can be achieved. Environmental benefits from the deferment of augmenting supplies, by making the most of what is already available, are achievable with such strategies.

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