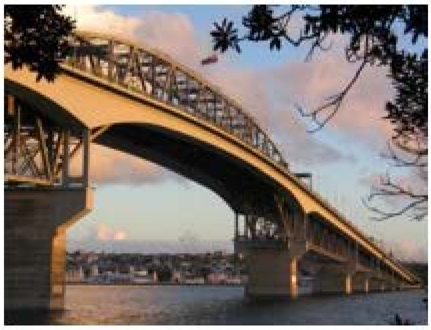
WATER NEW ZEALAND

WATER LOSS GUIDELINES





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WATER LOSS GUIDELINES – WATER NEW ZEALAND

Table of Contents

Preface

These Water Loss Guidelines follow on from the Benchloss New Zealand Manual and Software which was first published in April 2002, then updated in February 2008. These resources are aimed at providing water suppliers in New Zealand with the tools necessary to firstly analyse the level of water losses in a water distribution network and secondly, to move forward in reducing the level of water losses to an appropriate reasonable level for the individual supply.

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Executive Summary

Despite being one of the first countries (in 2002) to produce nationally available standard best practice water balance software based on the IWA methodology, updated in 2008, New Zealand now increasingly lags behind many other countries in using these tools. There is no national requirement in New Zealand to report and publish performance in managing non-revenue water and its components. Although a few water suppliers in the Auckland area have achieved real losses within the top World Bank Institute Band (A), in others the level of losses are still too high, and in many systems it appears that no assessments of losses have yet been made.

Austria – like New Zealand, a country with a high reputation for 'green' environmentally friendly policies – has also recently updated its water balance and performance indicators in line with IWA best practice principles. Although in general water production costs are low, economics only plays a role in the drivers for better management – others drivers are public health, security of supply, ecology and environment. Water loss levels are also the decisive indicator for the condition of the infrastructure system, from large systems down to individual small zones.

These Water New Zealand Water Loss Guidelines are aimed at providing all water suppliers in New Zealand with the means to first assess their water losses, then develop an effective water loss strategy for any distribution system, large or small. They also provide a basis for planning the 'next steps' in managing water losses, starting from any level.

Sections 1 to 6 of the Guidelines, supplemented by Appendices A to H, and the References (many of which will be made available free of charge through a proposed addition to the Water New Zealand website) provide a wealth of technical information to those who may need to use it. At the end of each of Sections 3 to 6, there is a list of bullet points (reproduced in the Introduction) for those readers who need only to know the key aspects of each of these Sections.

The recommended approach to water loss management, outlined in Section 7, is as follows:

Firstly to estimate the level of losses in a network using the calculation methods available (water balance and/or minimum night flow measurements), while understanding the uncertainties around the calculations, and seeking to reduce the level of these uncertainties. Satisfactory metering of system input (bulk water supplied to a network or zone) is fundamental to these calculations. Assessment of the consumption of unmetered residential properties remains an area of uncertainty in water balances that can be reduced by using minimum night flows to assess real losses.

Secondly, having established the level of water losses occurring, it is recommended that leakage targets be set for the system based on guidelines given in Section 6.4, and that budgets for installing monitoring equipment and active leakage control are prepared for approval. Guidance on how to budget for active leakage control, metering and pressure control is provided.

Thirdly, the remaining actions outlined in Section 7 need to be implemented at an appropriate scale in order for set targets to be achieved within an agreed time frame, to reduce and then to maintain water losses at an acceptable level. A description of what is considered to be a basic and an advanced level of implementation of the various actions is included in Table 7.1. This requires ongoing commitment and dedication, and not only of water supply operational staff. It also requires adequate budgets for key ongoing activities; inadequate budgets do not save costs, where leakage is concerned they increase costs.

In summary, there is a need for many New Zealand water suppliers to address water loss management and these guidelines are intended to be a toolbox for those wanting to make progress. Increasingly water suppliers are faced with inadequate treated water supplies, and leakage assessment and reduction must be considered as the first step in providing for future demand.

A summary of some additional resources (manuals and software) is included in the document.

On behalf of Water New Zealand and the Water Services Managers Group, I want to particularly thank Richard Taylor for his commitment and motivation in leading and managing this project, and the Waitakere City Council for supporting him in these endeavours.

Murray Gibb
Chief Executive
Water New Zealand

1.0 Introduction

In 1999/2000, recommendations for a best practice Water Balance and associated Performance Indicators were published by the Water Loss Task Force of the International Water Association (IWA) (Ref. 1). New Zealand was one of the first countries to adopt these recommendations, when in 2002 Water New Zealand (previously known as the New Zealand Water and Waste Association (NZWWA)) commissioned and published the BenchlossNZ software (Ref. 2) and associated User Manual (Ref.3). These provided a standard annual water balance for bulk metering, consumption and water loss calculations, and recommended performance indicators for Non-Revenue Water and real (physical) losses, all based on international best practice.

Benchloss NZ and the Benchloss User Manual were updated in February 2008 (Refs. 4,5), to include several improvements such as the use of minimum default values for smaller components of the Water Balance, and linking of performance to the World Bank Institute banding system. Another software (CheckCalcsNZ, Ref. 6), which does the same type of calculations with some additional information on the World Bank Institute banding system (Ref. 7), and an overview of pressure management opportunities, is also available free of charge to New Zealand Water Suppliers.

BenchlossNZ and CheckCalcsNZ enable Water Suppliers to establish, within calculated confidence limits, the volumes of Non-Revenue Water, Unbilled Authorised Consumption, Apparent (Commercial) Losses and Real Losses occurring in any water distribution system, and associated best practice performance indicators. These performance indicators can be used (Ref. 8) for:

- metric benchmarking (comparison of performance with other New Zealand and international systems, allowing for key system characteristics), or
- process benchmarking (measuring progress towards targets for an individual Water Supplier)

Despite being one of the first countries to produce nationally available standard best practice Water Balance software for the IWA methodology, New Zealand now increasingly lags behind many other countries in using these tools. There is no national requirement in New Zealand to report and publish performance in managing Non-Revenue Water and its components. Although a few Utilities in the Auckland area have achieved real losses within the top World Bank Institute Band (A), in others the level of losses are still too high, and in many systems it appears that no assessments of losses have yet been made.

Austria - another country with a high reputation for ‘green’ environmentally friendly policies – has also recently updated its water balance and performance indicators in line with IWA best practice principles. Although in general water production costs are low, economic aspects only play a role in the drivers for better management. Water loss levels are the decisive indicator for the condition of the infrastructure system, from large systems down to individual small zones. The OVGW W63 Austrian Standard (Ref. 9) gives the following reasons to keep water losses low:

- HYGIENIC (Public Health): each leak represents a risk of contamination by water entering from outside the distribution system
- SUPPLY TECHNIQUES and SUPPLY SAFETY: leakage can lead to quantitative problems (e.g, in situations of peak supply), and can cause decrease in service pressure and lead to customer complaints
- ECOLOGICAL AND ENVIRONMENTAL ASPECTS: water losses contravene recent ecological concepts, and low water losses reduce the energy demand of pumps, treatment stations etc. and therefore reduce CO_2 emissions

- ECONOMIC ASPECTS: in general high water losses cause higher running costs (e.g. energy costs, treatment chemicals, higher maintenance costs); low water losses prevent (or postpone) the exploitation of new resources

Section 7 summarises a recommended approach to a water loss strategy. Table 7.1 lists the typical activities that are considered to be appropriate for New Zealand Water Suppliers operating at a basic level and at an advanced level.

Activity 1: Categorise the Size of System as Large, Medium or Small; identify whether to use ***Water Balance*** and/or ***Minimum Night Flows*** to assess Real Losses.

Activity 2a: If doing a Water Balance - even if this is an approximate first cut attempt using very basic assumptions - identify data deficiencies, use confidence limits to assess uncertainty, arrange for improvements (e.g. to bulk metering) if necessary, calculate real water losses volume and KPIs, including Infrastructure Leakage Index ILI.

Activity 2b: If using Minimum Night Flows: take measurements at time of basic night consumption only, deduct estimate of customer night consumption, calculate KPIs including Snapshot ILI.

Activity 3: Classify current Real Loss management performance using the World Bank Institute Banding System, and check appropriate Activity Priorities.

Activity 4: Investigate Speed and Quality of Repair issues, and address deficiencies.

Activity 5: Active Leakage Control: arrange for regular monitoring of minimum night flows – either by telemetry or regular use of a data logger, or (if limited budget) overnight readings in early spring and late autumn. Set intervention targets in each supply area/zone, preferably based on economic intervention; arrange for active leak detection either using in house resources or a contractor.

Activity 6: **Pressure Management**: ensure that you understand the various benefits of pressure management, and how pressure management might improve management of your system. Check all systems (including gravity systems) for pressure transients. Consider reducing water pressures where this is feasible. Prioritise areas based on multiple criteria (ease of introduction, measured excess pressures, high leakage/burst frequency, etc).

Activity 7: Review the condition of the network and renewal programmes, with particular emphasis on reliable recording of burst frequencies on mains and services. Valve and hydrant condition assessment and renewal programmes may also be necessary.

These activities, carried out in this order, are presented as a cost effective approach to deliver required water loss outcomes.

More detailed technical information is provided, for those who will require it, in Sections 2 to 6, and Appendices A to H. Sections 3 to 6 end with bullet point summaries of Key Points, reproduced below.

Section 2 includes the following:

- a classification (Table 2.1) for categorising New Zealand systems and Zones as Large, Medium or Small, based on number of service connections; with recommendations as to whether Water Balance, or Minimum Night Flows, or both should be used to assess Real Losses, depending upon whether residential customers are metered or not.
- where to find information on analysis of night flows (Appendix A)

- overview comments on the BenchlossNZ 2008 and CheckCalcsNZ software; more detailed information on the 2008 water balance and PI software upgrades can be found in Appendix B
- IWA Standard Water Balance and terminology used in Benchloss and CheckCalcs (Figs 2.1 and 2.2)
- an overview of the Performance Indicators used in Benchloss and CheckCalcs (Table 2.2)
- why %s are unsuitable for assessing operational efficiency of management of Real Losses (see also Appendix C)
- the equation for Unavoidable Annual Real Losses (UARL) and the Infrastructure Leakage Index (ILI)
- the World Bank Institute Banding system for categorising Real Losses (Table 2.3)
- the difference between Metric Benchmarking (for comparisons) and Process Benchmarking (for measuring progress towards targets for an individual Water Supplier)
- recommendation to use ILI for metric benchmarking
- recommendation to use litres/conn/day or kl/km/day for process benchmarking (use litres/service connection/day if connection density 20 per km mains or more, and kl/km/day if less than 20 service connections/km mains)
- the ‘Four Components’ diagram for management of Real Losses (Figure 4.2)
- the additional benefits of pressure management

Section 3 is provided to assist the user to understand the effects of uncertainties in the data. The key points are as follows:

- all water balance calculations include data uncertainties, to a greater or lesser extent.
- the uncertainty can be assessed by including confidence limits in the calculations
- the use of confidence limits can also help to prioritise the most important sources of error in the Water Balance
- for systems where all service connections are metered, the most influential errors are
    1. bulk metering accuracy (water from own sources, water imported and exported)
    2. assessing billed metered consumption during the period of the water balance
    3. assessing customer meter under-registration
- for fully metered systems, confidence limits for Real Losses can be reduced, with care, to around +/- 30 litres/service conn./day for a system with one bulk input meter; multiple bulk input meters will tend to result in a smaller error range
- for systems with unmetered residential service connections, assessment of unmetered residential consumption passing the property line (i.e. property boundary) dominates the sources of error, with bulk metering accuracy some way behind.
- confidence limits for performance indicators are dominated by the errors in calculation of Real Losses, provided reasonable care is taken in assessing number of service connections and average pressures

Section 4 provides practical guidelines for reducing data errors. The key points are as follows:

- reliable bulk metering is fundamental to assessment of Non-Revenue Water and Real Losses
- on-site facilities should be provided for independent checking of bulk meters
- manufacturer’s in-situ testing and Flowmeter Calibration Verification Certificate for a bulk meter is limited when it only relates to electronics and does not guarantee that the meter is recording the actual flow correctly
- the greater the number of bulk meters, the less the uncertainly (Figure 4.1)
- Water Suppliers should aim to reduce uncertainty for bulk metering to better than +/- 2%
- administrative errors for metered consumption volumes may range between +/-0.5% and +/-2%, depending upon the reliability of the billing systems and checking procedures

- Water Suppliers need to be aware of possible errors due to meter lag adjustments and premature water balance, before all relevant meter reading cycles have been completed
- a logical solution to 'Premature Reporting' is to calculate their Water Balance and Real Losses Performance Indicators for a period which ends before the normal Water Year end
- a simple graph of recorded consumption during meter reading cycles, compared with Water Supplied over the same period, can quickly identify the need for meter lag adjustments
- default estimates of retail meter under-registration should be checked by tests on structured samples of retail meters, by type and age and/or accumulated volume
- a consumption monitor based on a 5% random sample of unmetered residential properties may achieve an accuracy of +/- 15% (see also Fig. 4.2)
- wider use of consumption monitors should improve the reliability of estimates of unmeasured residential consumption; geographical location and climate, household occupancy and private supply pipe leakage will be relevant factors
- in the absence of consumption monitors, Water Suppliers with unmetered residential customers should use Table 4.2 for guidance when entering this data in their Water Balance.

Section 5 presents information on assessing Real Losses from Water Balance or Minimum Night Flow calculations, calculating the Performance Indicators, using the ILI to identify performance based on the World Bank Institute Banding System. Key points are as follows:

- for large and medium sized systems, the most basic method of assessing Water Losses is a Water Balance with confidence limits, using BenchlossNZ 2008 or CheckCalcs 2008
- data may be doubtful to start with, but the process of collecting and collating the data will begin to highlight the gaps, and use of confidence limits helps to identify priorities for improving the water balance data.
- in initial calculations, standard defaults should be used for Unbilled Authorised Consumption, Unauthorised Consumption and Customer Meter errors
- where there are large numbers of unmetered residential properties, guidance on estimates of consumption can be taken from metered residential property figures in Table 4.2, allowing for higher losses on private unmetered properties; or a 6-month (winter) water balance can be used to reduce uncertainties in the estimates.
- components of Non-Revenue Water are initially calculated in volume terms but can be converted to dollar equivalents using appropriate valuations for Apparent Losses, Real Losses and Unbilled Authorised Consumption
- snapshot night leakage rates can be derived from night flow measurements and converted to daily snapshot leakage estimates using appropriate Night-Day Factors
- Infrastructure Leakage Index (ILI) is the best PI for making comparisons of Real Losses management performance (Metric Benchmarking)
- ILIs calculated from a Water Balance can be compared to an Australasian data set, and also categorised according to the World Bank Institute Banding System (A to D)
- the WBI Bands provide an internationally applicable description of performance, and a list of relevant leakage management activities appropriate to each WBI Band
- snapshot ILIs can be calculated from night flow measurements, and classified in WBI Bands
- there are several additional useful practical indicators - 'Awareness, Location and Repair' times, Burst Frequency Index (one for mains, another for services) and Rate of Rise of Unreported Leakage

Section 6 - provides practical basic explanations of leakage and pressure management analysis and concepts that are fundamental to effective management of real losses:

- Section 6.1 and Appendix G provide an overview of Bulk Metering and associated problems
- reported mains bursts usually account for less than 10% of Annual Real Losses

- the basic principles of Component Analysis of Real Losses, using the BABE (Bursts and Background Estimates) concept assist understanding of how and where real losses occur
- real loss management deals with limiting the duration of all leaks, however small
  - a toilet leaking for 16 months can lose as much water as a reported mains burst
- all Water Suppliers need to do Active Leakage Control (looking for unreported leaks), at a frequency appropriate to their system characteristics
- night flow measurements in Zones are an excellent way of identifying whether there are any unreported leaks worth looking for
  - but take measurements at times when night consumption is at its lowest
- a practical standard terminology for components of minimum night flows in New Zealand is proposed in Figure 6.5; please use it to reduce misunderstandings and wasted time
- the IWA DMA manual (Ref 24) is an excellent source of information on setting up DMAs
- unavoidable real losses vary widely with average pressure and density of connections in individual Zones; so use Snapshot ILI to set targets for night flow, and then express them in litres/connection/hour if you prefer
- the Economic Intervention concept can be used to rapidly assess appropriate budgets for Active Leakage Control, giving the same results as more complex UK calculation methods
- burst frequencies on mains (per 100 km of mains/year) and on service connections (per 1000 service connections/year) are a good indicator of network condition
  - and if the frequencies are high they may be reduced by pressure management
- pressure management has other benefits – reduction of leak flow rates and some components of consumption - so there is advantage to undertaking pressure management before metering residential customers
- all Zones should be checked for pressure transients – even Zones supplied by gravity
- a rapid overview assessment of possible range of benefits of pressure management can be made with CheckCalcs
- the Pressure Management Group of the IWA Water Loss Task Force is progressing improved methods of detailed predictions of pressure management benefits
- reducing water pressures can impact customer service and fire sprinkler systems so particular care needs to be taken when implementing pressure management
- data from the UK suggests that economic ILIs are likely to be within the range 1 to 3, with lowest values where water is most expensive and supply is actually or potentially limited
- experience from Australia and New Zealand (Auckland region) shows that ILIs close to 1 can be achieved

These Water New Zealand Water Loss Guidelines are aimed at providing all Water Suppliers in New Zealand with the means to first assess their water losses, then develop an effective water loss strategy for any distribution system, large or small. The objective of a water loss strategy should be to reduce the level of real water losses from the water distribution network to an acceptable level based on Public Health, Customer Service, Ecological, Environmental and Economic aspects.

2.0 Background

2.1 Assessing Real Losses for Management Purposes in Large. Medium and Small Systems

Practical approaches to assessing Real Losses for the purposes of effective management differ depending upon the size of the system under consideration, and whether residential customers are metered or unmetered (it being assumed that all significant non-residential customers are metered in New Zealand). The size criteria used in Table 2.1 below to define large, medium and small are considered to be appropriate to New Zealand.

Table 2.1: Practical Approaches for Assessing Real Losses depending upon Size of System

System	Number of Service Connections	Residential customers metered?	Recommended methods for assessing Real Losses
Large	> 10000	Yes	Annual water balance with confidence limits
		No	Annual water balance with confidence limits and Zone night flows or residential consumption monitor
Medium	2500 to 10000	Yes	Annual water balance with confidence limits
		No	Zone night flow measurements to check Water Balance
Small	< 2500	Yes	Zone night flows or/and annual water balance
		No	From Zone night flow measurements

Information on **consumption monitors for unmeasured residential properties** can be found in Appendix D of the BenchlossNZ 2008 Manual (Ref. 5). Estimates of unmeasured residential consumption passing the property boundary, made without the use of consumption monitors, can be substantially in error due not only to actual use of water by residents, but also by small numbers of long-running leaks on the private pipe between the property line (i.e. boundary line) and the buildings. For systems of ‘Small’ or ‘Medium’ size with unmeasured residential properties, it is preferable to also assess Real Losses from Zone night flow measurements rather than to set up a small and possibly unrepresentative consumption monitor.

Sections 3 and 4 of these Guidelines concentrate mainly on Water Balance and Key Performance Indicator calculations with Confidence Limits. Information on **basic interpretation of night flows,** including the calculation of a ‘Snapshot ILI’ (Infrastructure Leakage Index) can be found in Section 5 onwards, and Appendix A of these Guidelines.

2.2 Software: Benchloss NZ and CheckCalcsNZ

The objectives of the BenchlossNZ Software and its associated Manual are to:

- provide a standard terminology for components of the annual water balance calculation
- encourage Water Suppliers in New Zealand to calculate components of Non-Revenue Water, including Apparent Losses and Real Losses, using the standard annual water balance
- promote the use of Performance Indicators suitable for national and international benchmarking of performance in managing water losses from public water supply transmission and distribution systems.

The methodologies used in BenchlossNZ and CheckCalcsNZ draw strongly on relevant aspects of ongoing research and recommendations of the IWA Water Loss Task Force, and experiences in implementing these recommendations in New Zealand and internationally. The more significant modifications included in the 2008 upgrades to these two softwares are summarised in Appendix B.

The two softwares are complementary to each other. Both will produce the same results for Water Balance and Performance Indicator calculations, with confidence limits, if the same data are entered. Availability of CheckCalcsNZ avoided the necessity to make the BenchlossNZ software more detailed than its existing format, and:

- allows the user to calculate System Running Costs, in the 'Running Costs' Worksheet
- compares performance of the system with an Australian/New Zealand data set, and identifies appropriate action priorities for different World Bank Institute Performance Bands A to D, in the 'WBI Guidelines' Worksheet
- provides an overview of pressure management opportunities and probable range of reduction of leak flow rates, new burst frequencies and income from metered customers, in the 'PMOpportunities' Worksheet.

When a Utility is familiar with the basic principles of IWA Water Balance calculations, for fully metered systems and sub-systems the 'CheckCalcsNZ' software should permit easier sensitivity testing of calculations, as well as giving an initial estimate of pressure management opportunities.

2.3 Water Balance

Figure 2.1 shows a simplified IWA standard Water Balance. Water enters as System Input Volume, and becomes either 'Authorised Consumption' or 'Water Losses'. 'Authorised Consumption' can be billed or unbilled. The unbilled portion becomes part of Non-Revenue Water. Water Losses, which form the remainder of Non-Revenue Water, are either:

- 'Apparent Losses'- water used but not paid for (theft, customer meter under-registration)
- 'Real Losses'- leaks, bursts and overflows from the systems of Water Suppliers.

The term 'Unaccounted for Water (UFW) is no longer recommended as the definition of UFW varies widely both within and between countries.

Figure 2.1: A simplified IWA Standard Water Balance

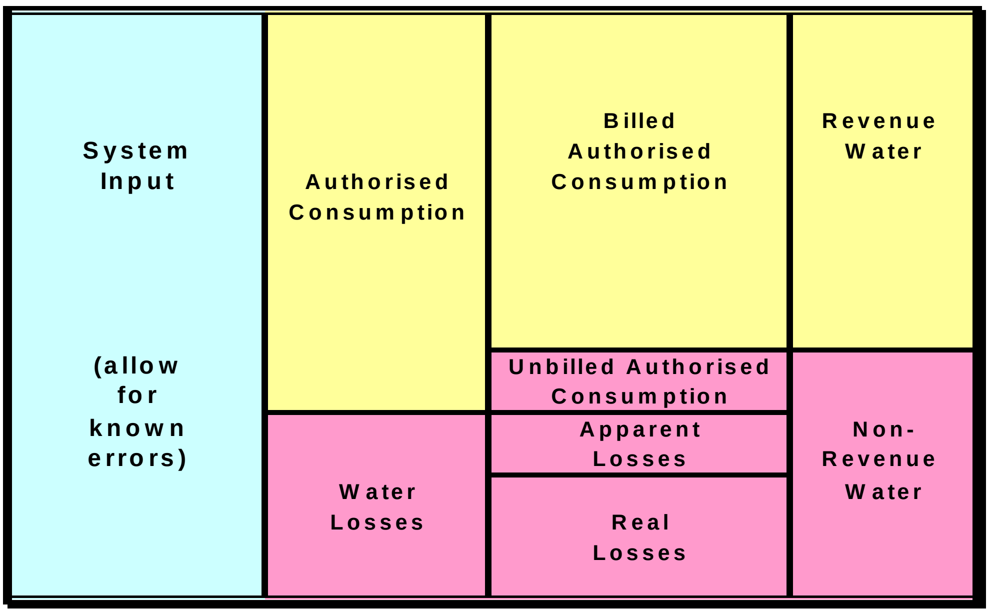


Figure 2.2, which appears on the 'Terminology' Worksheet of both BenchlossNZ and CheckCalcsNZ, with definitions of the individual terms, shows that 'System Input' may consist of two components, 'Own Sources' and 'Water Imported'. 'Own Sources' is the volume of water input to a system from the Water Supplier's own treatment works; or, where no substantial treatment is provided, the volume of water input from the Water Supplier's own sources.

Figure 2.2: Annual Water Balance used in BenchlossNZ and CheckCalcsNZ

Own Sources	System Input	Water Exported	Authorised Consumption	Billed Authorised Consumption	Billed Water Exported to other Systems	Revenue Water
		Water Supplied			Billed Metered Consumption by Registered Customers	
Water Imported	(allow for bulk meter errors)				Billed Unmetered Consumption by Registered Customers	
				Unbilled Authorised Consumption	Metered	Non-Revenue Water
					Unmetered	
			Water Losses	Apparent Losses	Unauthorised Consumption	
					Customer Metering Under-registration	
				Real Losses	Leakage on Mains Leakage and Overflows at Service Reservoirs Leakage on Service Connections up to the street/property boundary	

Figure 2.2 also clearly shows that, if Water is exported to other systems, there can be a significant difference between 'System Input' and 'Water Supplied'. It is also necessary to split 'Billed Authorised Consumption' into 'Billed Water Exported to other Systems' and 'Billed Consumption by Registered Customers (Metered and Unmetered)'.

Non-Revenue Water is then calculated as the difference between:

- o System Input, and Billed Authorised Consumption, or
- o Water Supplied, and Billed Metered and Unmetered Consumption by Registered Customers

Non-Revenue Water is then split into three principal components - Unbilled Authorised Consumption, Apparent Losses and Real Losses. In the New Zealand (and Australian) Water Balances, Unbilled Authorised Consumption and Apparent Losses can be initially estimated using the following default values:

- o Unbilled Authorised Consumption = 0.5% of Water Supplied
- o Apparent Losses: Unauthorised Consumption = 0.1% of Water Supplied
- o Apparent Losses: Customer meter under-registration = 2.0% of Billed Metered Consumption by Registered Customers

Real Losses are then derived as Non-Revenue Water minus Unbilled Authorised Consumption – Apparent Losses. The use of defaults makes it easy to complete an initial water balance. The example shown in Figure 2.3 is for an imaginary New Zealand distribution System with 250 km on mains, 10,000 service connections (all metered), and average consumption of 1000 litres/service connection/day. The water balance volumes are shown in kl/day.

Figure 2.3. Example Water Balance, fully metered system.

Component of Water Balance		Volume kl/day
Water Supplied		11500
Billed consumption	Metered	10000
	Unmetered	0
Non-Revenue Water		1500
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12
	Customer metering errors Default 2.0% of Metered Cons.	204
Real Losses		1227

Colour coding of Cells: Yellow = Data entry, Pink = Calculated values

2.4 Performance Indicators

Performance Indicators are obtained by introducing relevant system parameters to facilitate comparisons between systems of different size and different characteristics. Table 2.2 from the BenchlossNZ 2008 Manual (Ref. 5) shows the five Performance Indicators (PI) considered by Water New Zealand to be most meaningful. Different PI are required for Operational and Financial purposes. The reference numbers shown (e.g. Op27) are those used in the 2nd edition (2006) of the IWA Performance Indicators Manual (Ref. 10).

Table 2.2: Water Loss Performance Indicators in BenchlossNZ and CheckCalcsNZ

Function	Performance Indicator	Notes on appropriate use of this PI	Comments
Operational: Real Losses	**Op27: litres/service conn./ day, when system pressurised**	**Connection density 20/km mains or more**	**Allows for intermittent supply in international comparisons**
Operational: Real Losses	**Op28: m^3/km of mains/ day, when system pressurised**	**Connection density less than 20/km mains**	**Allows for intermittent supply in international comparisons**
Operational: Real Losses	**Op 29: Infrastructure Leakage Index ILI**	**(Lm x 20 + Nc)* should exceed 3000**	**Ratio of Current Annual Real Losses to Unavoidable Annual Real Losses**
Operational: Apparent Losses	**% by volume of metered consumption (excluding Water Exported)**	**Most appropriate PI for Apparent Losses in New Zealand**	**Alternative PIs (% of System Input Volume, litres/conn/day) would favour Water Suppliers with less than 100% customer metering**
Financial: Non-Revenue Water by cost	**Fi47: Value of Non-Revenue Water as % of annual cost of running system**		**Allows separate unit values in cents/Kilolitre for each component of Non-Revenue Water**

* Lm = mains length (km), Nc = number of service connections
Note: Nc and Ns are used interchangeably for number of service connections.

Since the early 1980's it has been recognised that percentages are unsuitable for assessing the operational efficiency of management of real losses (leakage and overflows) in distribution systems. This is because the calculated percentages are strongly influenced by the consumption of water in each individual system, and variations in that consumption. Non-Revenue Water expressed as a % by volume of Water Supplied, although traditionally widely used, also suffers from similar significant problems to % Real Losses when used as a PI. Appendix C provides more information on this topic, in the context of the range of consumption data in New Zealand.

The Financial PI Fi47 in Table 2.2 overcomes this problem by converting components of NRW into dollars, using appropriate valuations, and expressing NRW $ value as a % of annual system running costs (defined in the 'Running Costs' Worksheet in CheckCalcsNZ).

Regarding PIs for Real Losses, the choice between Op27 (litres/service connection/day) and Op28 (kl/km mains/day) depends upon the density of service connections per km of mains. If a well managed system in a developed country has 20 or more service connections/km of mains (Nc/Lm ≥ 20), component analysis usually shows that the majority of the leakage is associated with service connections, rather than mains; so litres/service connection/day (Op27 in Table 2.2) is preferred to kl/km mains/day (Op28, which should be used in systems with Nc/Lm less than 20 service connections/km of mains).

However, neither Op27 nor Op28 take account of three key system-specific factors that have a strong influence on the lowest volume of Real Losses (the 'Unavoidable Annual Real Losses' UARL), achievable in any particular system:

- customer meter location on service connections (relative to street/property boundary);
- the actual density of service connections (per km of mains)
- average operating pressure (leak flow rates vary, on average, linearly with pressure)

By defining the 'Point of Consumption' for service connections in New Zealand as the street:property boundary, for both metered and unmetered properties, the first of these three variable factors is eliminated. However, it is still necessary to allow for the actual density of service connections and average operating pressure when making performance comparisons.

The first IWA Water Loss Task Force developed and published, in 1999 (Ref. 11), the following equation for predicting the UARL for well maintained systems with infrastructure in good condition:

$$\text{UARL (Litres/service connection/day)} = (18 \times Lm + 0.8 \times Nc) \times P$$

where P is the average system pressure in metres (1 metre = 10 kpa)

This equation has proved to be robust when applied internationally over the ten years since 1999; although some Water Suppliers in some countries have achieved these levels of Real Losses (notably Australia, during the recent drought), very few have been able to consistently achieve validated lower levels of Real Losses.

The UARL is used to calculate the Infrastructure Leakage Index (ILI), a non-dimensional performance indicator for operational management of Real Losses. The ILI is the ratio of the Current Annual Real Losses (calculated from the standard Water Balance) to the system-specific Unavoidable Annual Real Losses (calculated from the above equation for UARL). Since 1999, ILIs have been calculated for many hundreds of water supply systems internationally, with values ranging from close to 1, to over 100.

In 2005, the World Bank Institute, with assistance from members of the IWA Water Loss Task Force, developed an internationally applicable Banding System for categorising Real Losses (Ref. 7). The Infrastructure Leakage Index (ILI) is used to categorise operational performance in real loss management into one of 4 Bands, which (for Developed Countries) are as shown in Table 2.3:

Table 2.3 World Bank Institute Bands for Leakage Management in Developed Countries

Band	ILI Range	Guideline Description of Real Loss Management Performance Categories for Developed Countries
A	< 2.0	Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective leakage management
B	2.0 to < 4.0	Possibilities for further improvement; consider pressure management, better active leakage control, better maintenance
C	4.0 to < 8.0	Poor leakage management, tolerable only if plentiful cheap resources; even then, analyse level and nature of leakage, intensify reduction efforts
D	8.0 or more	Very inefficient use of resources, indicative of poor maintenance and system condition in general, leakage reduction programs imperative and high priority

In the BenchlossNZ software, the calculated ILI can be compared to the appropriate WBI Bands on the 'Summary' Worksheet; more details can be found in Appendix J of the 2008 Benchloss Manual (Ref. 5). In CheckCalcsNZ, the WBI Guidelines Worksheet assigns the ILI to the appropriate WBI Band, explains the WBI Banding system in more detail, and compares the system ILI with an Australian and New Zealand data set of ILIs.

Around 2005, the IWA Performance Indicators Task Force began to consider the need to select the most appropriate PIs not only on the basis of Function (Financial, Operational, etc), but also to distinguish (Ref. 8) between:

- **Metric benchmarking** – for more demanding comparisons between Water Suppliers
- **Process benchmarking** –for setting targets and ongoing monitoring of progress towards those targets.

The 2008 Benchloss NZ manual recommends that:

- **Infrastructure Leakage Index** (Op 29) is preferable for **Metric** benchmarking, as it takes account of differences in system specific key parameters (mains length, number of service connections, customer meter location, average pressure)
- **Litres/service connection/day** (Op 27) or **kl/km of mains/day** (Op 28) **(depending upon service connection density)** is preferable for **Process** benchmarking of progress towards reaching target for reductions in Real Losses of a specific Water Supplier

Using the example Water Balance in Figure 2.3, for a system with 250 km of mains and 10,000 service connections, and assuming an average pressure of 50 metres, the Unavoidable Annual Real Losses (UARL) for this system, calculated from the IWA formula in Section 2.4 are:

UARL = (18 x 250 km + 0.8 x 10000 service conns) x 50m = 625,000 lit/day = 62.5 lit/conn/day

As the density of connections (40/km mains) is greater than 20/km, Table 2.3 shows that the Op27 PI of litres/service connection/day is preferred to the Op28 PI of kl/km mains/day.

Real Losses are: 1227 kl/day, so PI Op27 = 1227000/10000 = **123** litres/service connection/day

Real Losses PI Op29, Infrastructure Leakage Index ILI = 123/UARL = 123/62.5 = **2.0** which is at the boundary between World Bank Institute Bands A and B.

Apparent Losses are:216 kl/day (12 Unbilled Authorised Consumption, 204 customer meter error), which is **2.2%** of Metered Consumption.

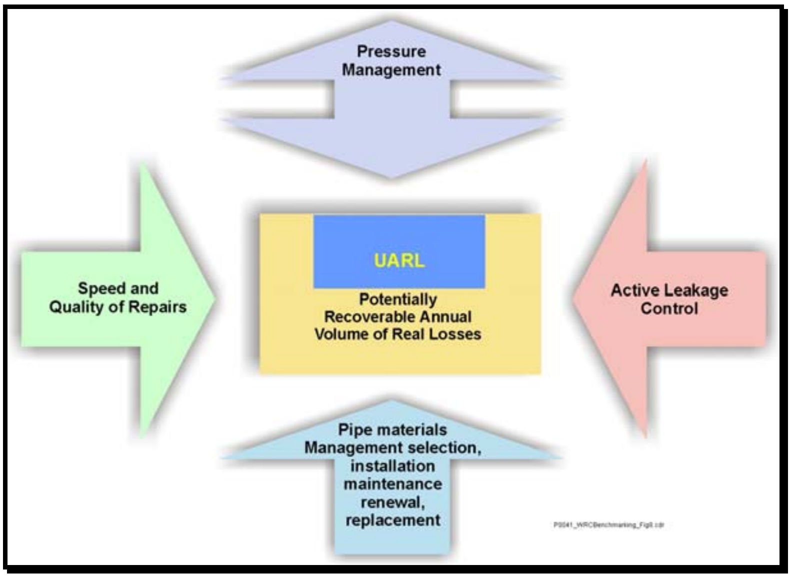
The ILI is clearly superior for Metric benchmarking (comparisons between systems) for Real Losses. However, the reason it is not usually recommended for Process benchmarking (progress towards targets for reduction of Real Losses) is that pressure management will normally be an important part of any real loss reduction strategy. When excess pressures are reduced, both the CARL and the UARL volumes will reduce, so the ILI (=CARL/UARL) may not change to any significant extent.

2.5 Four Components of Real Loss Management

The '4 Components' diagram (**Figure 2.4)** is now widely used internationally to show that effective management of Real Losses for any system requires an appropriate investment in each of four basic activities.

The area of the outer rectangle represents the Current Annual Real Losses volume, which is continually tending to increase as the system gets older, and new leaks and bursts occur. The four complementary leakage management activities (shown as arrows) constrain this increase, but the maximum effect they can possibly have is to reduce the Real Losses as low as the Unavoidable Annual Real Losses (UARL), indicated by the smaller box.

Figure 2.4: The four complementary leakage management activities



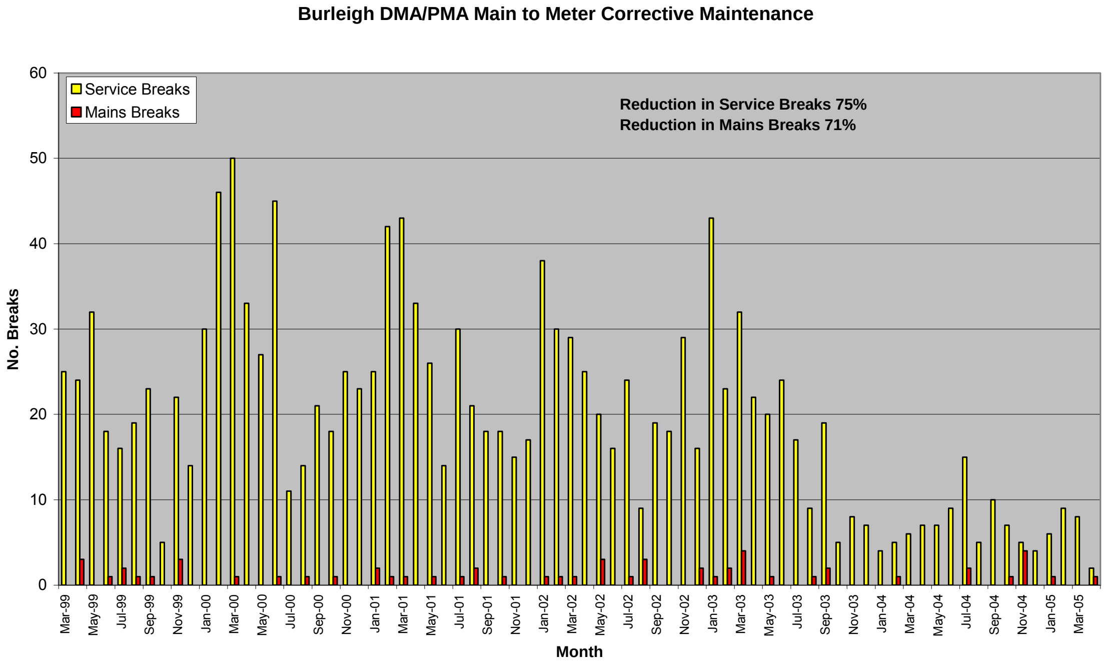
The Infrastructure Leakage Index (ILI) is the non-dimensional ratio of the outer area (CARL) to the inner area (UARL). The ILI measures how effectively the infrastructure activities in Figure 2.4 – speed and quality of repairs, active leakage control and pipe materials management – are being managed at current operating pressure.

Effective management of Real Losses requires the ongoing application (forever!) of all 4 activities to each system, at levels appropriate for that system. A high ILI is a clear indication of insufficient activity in one or more of the four activities. Usually, the two activities with the quickest results and the shortest payback period are:

- 'Speed and Quality of Repairs' – ensure every known leak is repaired promptly and effectively
- 'Active Leakage Control' - finding and fixing unreported leaks; appropriate budgets for economic intervention frequencies can now be easily calculated using 3 basic parameters (Intervention cost; variable cost of water; rate of rise of unreported leakage).

However, if there are excess pressures and pressure transients, in a system, pressure management can be extremely effective in reducing leak flow rates and some components of consumption, and reducing the frequency of new leaks and bursts together with increasing infrastructure life. Immediate substantial reductions in burst frequency and night flows are being achieved in both developed and developing countries. Figure 2.5 shows an example from Australia where the reduction of Zone Inlet pressure of 33% in September 2003 resulted in an immediate 71% reduction in mains breaks and a 75% reduction in service breaks, which have now been maintained for seven years.

Figure 2.5: Example of reduction of mains and service bursts after pressure management



Acknowledgement: Gold Coast Water

A wider international review by members of the IWA Water Loss Task Force Pressure Management Group (Ref. 12) found that, in a sample of 110 pressure management schemes from 10 countries, the % reduction in breaks averaged 1.4 times the % reduction in average pressure. However, % reductions in breaks on mains and services for pressure management in individual Zones varied more widely, from zero in some Zones to more than 3 times the % reduction in average pressure in others. Appendix D, based on Ref. 12, explains how and why this variability can occur.

Benefits and payback periods of pressure management in individual Zones can now be predicted with increasing reliability using appropriate software (for example Ref. 13), leading to the situation where Zones with good potential for effective pressure management can be identified and prioritised. More information on this topic appears in Section 6.5.

3.0 Understanding the Effects of Uncertainties in the Data

3.1 Benefits of Using Confidence Limits in Water Balance and PI Calculations

All data associated with Water Balance and Performance Indicator calculations includes errors and uncertainties. There is no such thing as a 'perfect' calculation. Accepting that there are uncertainties, and trying to quantify them to make rational management decisions, is a recognised part of the IWA methodology, and can in fact be used to help a Water Supplier to prioritise where to concentrate data quality control activities to improve the reliability of the Water Balance calculation, and the performance indicators that are derived from the Water Balance. The example Water Balance in Figure 2.3 will be used to demonstrate this.

3.2 Example Water Balances with all residential service connections metered at property line

The example distribution system has 250 km on mains, 10,000 service connections (Residential and Non-Residential) with an average consumption of 1 kl/day, and an average pressure of 50 metres. The Unavoidable Annual Real Losses (UARL) for this system calculated from the IWA formula in Section 2.4 are 625 kl/day, 62.5 litres/conn/day.

Figure 3.1 shows the simplified Water Balance from with volumes in kl/day, without confidence limits, initially assuming that all service connections are metered at the property line. The estimated components of Non-Revenue Water (Unbilled Authorised Consumption, Unauthorised Consumption and Customer meter error (under-registration) are calculated using the defaults shown, which are New Zealand and Australian national recommended defaults for well managed systems.

Thee Real Losses are 123 litres/service connection/day, and the Infrastructure Leakage Index ILI is 2.0 (= 123/62.5), which is at the upper limit of World Bank Institute Band A.

Figure 3.1: Example Water Balance, fully metered system.

Component of Water Balance		Volume kl/day	Volume litres/conn /day
Water Supplied		11500	1150
Billed consumption	Metered	10000	1000
	Unmetered	0	0
Non-Revenue Water		1500	150
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58	6
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12	1
	Customer metering errors Default 2.0% of Metered Cons.	204	20
Real Losses		1227	123

Colour coding of Cells: Yellow = Data entry, pink = calculated values

But how reliable are the calculated figure for Non-Revenue Water and Real Losses? Should Water Suppliers be concerned about the use of defaults, even for initial calculations? And how can Water Suppliers identify priorities to improve the reliability of the Water Balance, if they cannot assess the reliability of their initial calculations? These problems are solved by attaching confidence limits to each of the volumes entered into the calculation.

Data errors can be systematic, or random, or a mixture of both. For example, if the check calibration of a system input meter shows that it has over-recorded by between 2% and 4%, then there is a systematic error with a best estimate of 3% over-recording of system input volume. There will also be a random error of approximately +/- 1% of the corrected system input volume. Systematic and random errors will exist in all data entered in Water Balance and Performance Indicator calculations.

If systematic errors can be identified and corrected before data are entered in the Water Balance, the remaining random errors are equally likely to be greater than, or less than, the true value. A practical approach for assessing probable random errors in calculated components of NRW, Real Losses and Performance Indicators has been developed using the statistical properties of a probability distribution known as the 'Normal' or 'Gaussian' distribution.

The characteristics of the Normal distribution function are explained in Appendix A of the BenchlossNZ 2008 User Manual, but can be illustrated in a simpler way for the purpose of this Guideline. After entering a 'best estimated' value for each input parameter, the user of either software is offered the option to enter 95% Confidence Limits, as a % value. If the user enters 95% Confidence limits for a data entry item of X%, he or she is effectively saying:

'I think the figure I have entered is probably within +/- X % of the true value'

For example:

'I think the figure I entered for Water Supplied is probably within +/- 3 % of the true value'

'I think the standard defaults I used are probably within +/- 50 % of the true value'

Using the estimated 95% confidence limits entered by the user, BenchlossNZ and CheckCalcsNZ apply routine statistical calculations to calculate 95% confidence limits for derived data, such as:

- the sums or differences of volumes in the water balance (Non-Revenue Water, Real Losses);
- performance indicators which use combinations of items with different measurement units.

Figure 3.2 shows the simplified Water Balance from Figure 3.1 with volumes in kl/day, with 95% confidence limits for data entry volumes of:

- +/- 3% for 11,500 kl/day of Water Supplied
- +/- 2% for 10,000 kl/day of billed metered consumption
- +/-50% for volumes of Unbilled Authorised Consumption and Apparent Losses estimated from the standard defaults

The resulting confidence limits for calculated volumes are:

- +/- 27% for 1500 kl/day Non-Revenue Water
- +/- 34% for 1227 kl/day Real Losses (equivalent to +/- 42 lit./service conn./day, +/- 0.7 ILI)

Figure 3.2: Example Water Balance, fully metered system, ILI = 2.0 with 95% confidence limits.

Component of Water Balance		Volume kl/day	Volume litres/conn /day	95% Confidence Limits +/-
Water Supplied		11500	1150	3.0%
Billed consumption	Metered	10000	1000	2.0%
	Unmetered	0	0	0.0%
Non-Revenue Water		1500	150	27%
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58	6	50%
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12	1	50%
	Customer metering errors Default 2.0% of Metered Cons.	204	20	50%
Real Losses		1227	123	34%

The random errors in the earlier items entered in the Water Balance are all accumulating in the Real Losses. But if the user wishes to narrow the confidence limits, which data entry items are the most influential, and should receive priority attention?

A quick and simple way to answer this question is shown in Figure 3.3. For each 'data entry' Row of the Water Balance, multiply the Volume (kl/day) by the 95% CLs (%); the priorities follow the highest figures that result from doing this.

Figure 3.3: Example Water Balance, fully metered system, ILI = 2.0 with 95% CLs and Priorities.

Component of Water Balance		Volume kl/day	Volume litres/conn /day	95% Confidence Limits +/-	Volume x 95% CLs, kl/d +/-	Priority for action
Water Supplied		11500	1150	3.0%	345	1
Billed consumption	Metered	10000	1000	2.0%	200	2
	Unmetered	0	0	0.0%	0	6
Non-Revenue Water		1500	150	27%		
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58	6	50%	29	4
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12	1	50%	6	5
	Customer metering errors Default 2.0% of Metered Cons.	204	20	50%	102	3
Real Losses		1227	123	34%		

It can now be seen clearly that the 1st priority is to improve the confidence limits for bulk meters measuring Water Supplied, with Billed Meter Consumption the 2nd Priority. Default estimates of Customer metering errors are 3rd priority, some way behind the first two, but the other defaults estimates have low priority.

Suppose now that the Water Supplier makes an effort to reduce the confidence limits for Water Supplied (Bulk Metering) to +/- 2.0%. Figure 3.4 shows that the confidence limits for Non-Revenue Water fall to +/- 20%, and for Real Losses to 26%. But the priorities have not changed.

Figure 3.4: Water Balance, fully metered system, better bulk metering, ILI = 2.0, 95% CLs & Priorities

Component of Water Balance		Volume kl/day	Volume litres/conn /day	95% Confidence Limits +/-	Volume x 95% CLs, kl/d +/-	Priority for action
Water Supplied		11500	1150	2.0%	230	1
Billed consumption	Metered	10000	1000	2.0%	200	2
	Unmetered	0	0	0.0%	0	6
Non-Revenue Water		1500	150	20%		
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58	6	50%	29	4
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12	1	50%	6	5
	Customer metering errors Default 2.0% of Metered Cons.	204	20	50%	102	3
Real Losses		1227	123	26%		

The confidence limits used in Figure 3.4 for bulk metering and billed consumption would only be achievable by Water Suppliers with good metering and sound data checking procedures. The priorities shown are likely to be typical for most New Zealand systems where all customers are metered.

Suppose now that the Water Supplier was achieving Real Losses close to the Unavoidable Annual Real Losses (UARL) of 62.5 litres/service connection/day. After adjusting the 'Water Supplied' in this example calculation from 11500 kl/day to 10885 kl/day to achieve this lower volume of Real Losses, Figure 3.5 shows that the Confidence limits for Real Losses have risen from 26% in Figure 3.4 at an ILI of 2, to 51%.in Figure 3.5 at a lower ILI of 1. So it's clear that the Confidence limits expressed as a % will vary with the level of Real Losses.

Figure 3.5: Water Balance, fully metered system, better bulk metering, ILI = 1.0, 95% CLs & Priorities

Component of Water Balance		Volume kl/day	Volume litres/conn /day	95% Confidence Limits +/-	Volume x 95% CLs, kl/d +/-	Priority for action
Water Supplied		10885	1088.5	2.0%	218	1
Billed consumption	Metered	10000	1000	2.0%	200	2
	Unmetered	0	0	0.0%	0	6
Non-Revenue Water		885	88.5	33%		
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	54	5	50%	27	4
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	11	1	50%	5	5
	Customer metering errors Default 2.0% of Metered Cons.	204	20	50%	102	3
Real Losses		616	62	51%		

In practice, it is more consistent and meaningful, once the calculation has been done, to express the confidence limits for Real Losses in litres/service connection/day, rather than %s, as follows:

- In Figure 3.5, 95% CLs were +/- 51% of 62.5 litres/connection/day = +/- 32 litres/conn/day
- In Figure 3.4, 95% CLs were +/- 26% of 123 litres/connection/day = +/- 32 litres/conn/day

The number of bulk meters can also influence the uncertainty of the Water Supplied volume; the greater the number of bulk meters, the smaller the overall uncertainty in the total calculated system input volume. This aspect is discussed in Section 4.1.

3.3 Example Water Balance with all residential service connections unmetered

Returning to the situation in Figure 3.3, with Water Supplied 11,500 kl/day and bulk meter confidence limits of +/-3%, consider the effect on confidence limits if the residential consumption (assumed to be 9000 out of the 10000 kl/day billed consumption) is not metered, but estimated (based on a random 5% sample) to have confidence limits of +/-15%. Figure 3.6 shows that the confidence limits for Real Losses have now widened to close to +/- 100% and the top priority in the Water Balance is to reduce the confidence limits for the unmetered consumption. For large systems (with more than 10,000 service connections) this could be done by setting up a structured consumption monitor, or splitting the system into Zones with measurements of night flows.

However, referring to Table 2.1 of these Guidelines, it can be seen that for ‘medium and ‘small’ systems, the preferred alternative approach is to set up Zones to measure night flows, as a consumption monitor may need a large % of the properties to be metered if it is to be representative.

Figure 3.6: Water Balance, unmetered residential properties, ILI = 2.0, 95% CLs & Priorities

Component of Water Balance		Volume kl/day	Volume litres/conn /day	95% Confidence Limits +/-	Volume x 95% CLs, kl/d +/-	Priority for action
Water Supplied		11500	1150	3.0%	345	2
Billed consumption	Metered	1000	100	2.0%	20	4
	Unmetered	9000	900	15.0%	1350	1
Non-Revenue Water		1500	150	93%		
Unbilled Authorised Consumption	Default 0.5% of Water Supplied	58	6	50%	29	3
Apparent Losses	Unauthorised consumption: Default 0.1% of Water Supplied	12	1	50%	6	6
	Customer metering errors Default 2.0% of Metered Cons.	20	2	50%	10	5
Real Losses		1411	141	99%		

3.4 Influence of Errors in Parameters used to calculate Performance Indicators

In any calculation of Real Losses Performance Indicators, none of the three parameters used to calculate Real Losses PIs are absolutely reliable.

Mains length should usually be known quite reliably, to within +/- 1% confidence limits, with little chance of systematic error.

As for Number of service connections (Nc or Ns), a frequent error in urban areas is to assume that this is equal to the number of billed properties (or accounts), Np – which can systematically over-estimate the number of service connections up to the property line. For New Zealand conditions, BenchlossNZ suggests that, for fully metered systems, the number of service connections can be assumed as being the number of metered accounts, minus the total of any sub-meters (after master meters, e.g. to shops and flats), plus the estimated number of unmetered service connections. If systematic errors are avoided, the estimate of Nc should usually be within +/- 2%.

For systems where residential properties are not metered, the number of service connections can be counted as being the number of stop taps (tobys) at the property line, or the ratio Nc/Np can be assessed from a representative sample of data.

There are several ways of estimating average pressure. Appendix E reproduces the Appendix from the Benchloss User Manual that describes them. Using these methods, it should be possible to achieve estimates of average pressure to within +/- 5% without large systematic errors.

Because Performance Indicators are calculated using several different units – volumes, number of service connections, mains length (km), pressure (metres) - calculation of % confidence limits is calculated as the square root of the sum of the squared % Confidence Limits for each parameter, while the calculation of confidence limits for ILI is slightly more complex. So the confidence limits for the PI are dominated by the parameter with the greatest % error, And for Real Losses PIs, this is almost always likely to be the confidence limits for the volume of Real Losses (+/-25% or more). Table 3.7 clearly demonstrates this.

Figure 3.7: Real Losses confidence limits dominate the confidence limits for Real Losses PIs

For Density of Conns/km =	40	95% Conf. Limits +/- for		
Parameters used for PI calculations	95% Conf. Limits +/-	ILI	litres/conn/d	kl/km/day
Real Losses annual volume	33.0%	33.4%	33.1%	33.0%
No. of service conns. Ns	2.0%			
Mains Length Lm (km)	1.0%			
Average System Pressure Pav (m)	5.0%			

Given a basic understanding of the uncertainties inherent in Water Balance and Performance Indicator calculations, as explained with examples in Sections 3.1 to 3.4 of these Guidelines, methods of reducing the confidence limits in:

- Bulk Metering
- Billed Metered Consumption and Apparent Losses (Customer Meter under-registration)
- Unmeasured Residential Consumption

are discussed in Section 4 below.

3.5 Summary of Key Points in Section 3

- All water balance calculations include data uncertainties, to a greater or lesser extent.
- The uncertainty can be assessed by including confidence limits in the calculations
- The use of confidence limits can also help to prioritise the most important sources of error in the Water Balance
- For systems where all service connections are metered, the most influential errors are:
    1. bulk metering accuracy (water from own sources, water imported and exported)
    2. assessing billed metered consumption during the period of the water balance
    3. assessing customer meter under-registration

- For fully metered systems, confidence limits for Real Losses can be reduced, with care, to around +/- 30 litres/service conn./day for a system with one bulk input meter; multiple bulk input meters will tend to result in a smaller error range
- For systems with unmetered residential service connections, assessment of unmetered residential consumption (passing the property line) dominates the sources of error, with bulk metering accuracy some way behind.
- Confidence limits for performance indicators are dominated by the errors in calculation of Real Losses, provided reasonable care is taken in assessing number of service connections and average pressures

4.0 Practical Guidelines for Reducing Data Errors

4.1 Bulk Water Metering: Own Sources, Water Imported and Water Exported

If there is no bulk water meters measuring System Input, Water Imported and Water Exported then this is an absolute priority. It is not possible to make any meaningful assessment of losses without some form of bulk metering. A meter capable of measuring the expected range of inflows within +/- 2% accuracy should be installed to manufacturer's specifications, preferably with on-site facilities for checking volumetrically or with a second meter. An insertion probe type device (around +/- 5 to 10% accuracy) is acceptable for occasional measurements but unsatisfactory as a long term installation. As telemetry (SCADA) is another potential source of data error, all bulk meters should have an on-site visual cumulative register which should be used for Water Balance or to check SCADA data.

It is important to realise that a Manufacturer's in-situ testing and Flowmeter Calibration Verification Certificate for a bulk meter is limited when it is only related to electronics and does not constitute a comprehensive check that the meter is recording the actual flow correctly.

If there is only one point of supply to the system with only one meter, then the accuracy of this one meter should be checked and calibrated regularly (once per year). For larger systems with only one source and for bulk metering points for export and import of water, the installation of two meters in series should be considered as a strategy to reduce the uncertainty in the water loss calculations (see below), together with monitoring of night flows.

Where one of the bulk metering components (own sources, or water imported, or water exported) is recorded using more than one bulk meter, the overall uncertainty for that particular bulk metering component is likely to be reduced, assuming that not all meters will under-record or over-record. If, for example, all bulk import meters record approximately similar volumes, the uncertainty of the total is the uncertainty of a single meter, divided by the square root of the number of meters. The greater the number of meters measuring system input, the smaller the overall uncertainty in the total calculated system input volume as shown in Figure 4.1 below. However, if the volumes passing through the input meters are not similar, the reduction in uncertainty will not be as large as shown in Figure 4.1.

Figure 4.1: Showing the relationship between meter uncertainty, number of bulk input meters, and calculated system input volume uncertainty

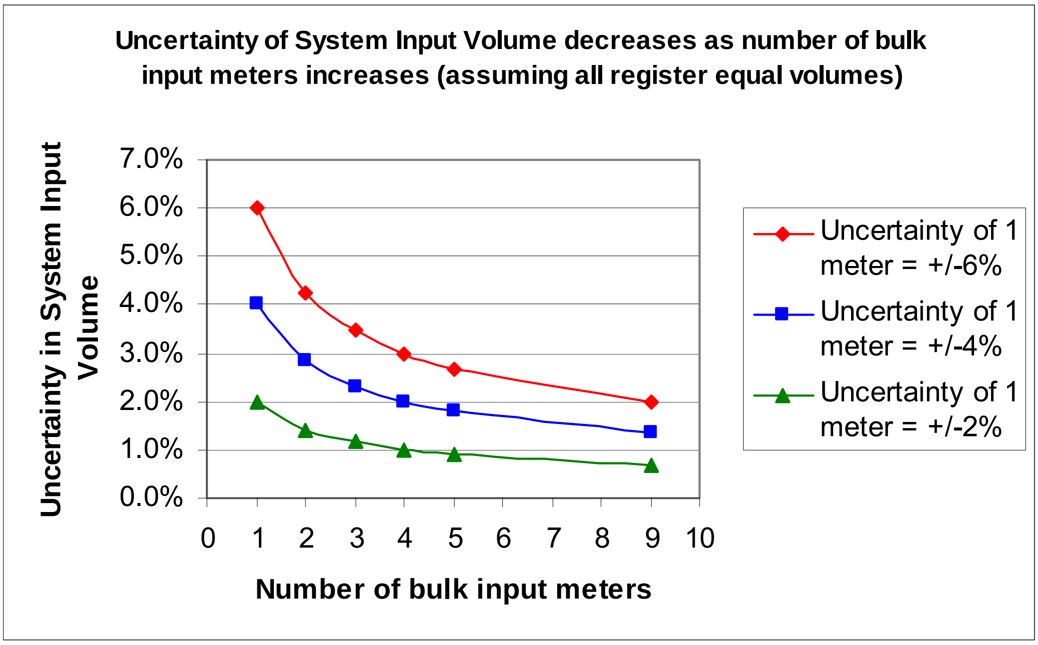


Figure 4.1 shows that, the greater the number of meters used to record the bulk metering input components of the Water Balance (water treatment plant outputs, bulk meter import points) the more reliable will be the overall assessment of 'Own Sources' and 'Water Imported' volumes.

If there are several bulk input meters each with different throughputs and % uncertainty limits, the priority should be to check first those meters that have the largest value of 'Throughput x % uncertainty', in a similar way to the calculations in Tables 3.3 to 3.6.

As a general rule, the 95% confidence limits for each component of Bulk Metering – Own Sources, Water Imported and Water Exported volume should be better than +/- 2% to try to prevent the uncertainty in the water loss calculations becoming very large.

4.2 Metered Consumption and Meter Lag Adjustment

Sections 3.1 to 3.4 of these Guidelines show that, for systems where all customers are metered, assessment of metered consumption during the period of the water balance is likely to be the 2nd largest source of error, after bulk metering.

Where there is universal metering, there will always be some meters where the consumption needs to be estimated due to stopping, damage, no-reads etc. Most billing systems are not designed for retrieval of data for water balance purposes, and investigation usually identifies several sources of potential 'administrative' errors. A range between +/-0.5% and +/-2%, depending upon the reliability of the billing systems and checking procedures, would be a reasonable default range for most Water Suppliers.

Potentially the most serious error is trying to calculate the metered authorised consumption that actually occurred between the two discrete 'dates' at the beginning and end of the 'Water Year' (normally 1st July to 30th June in New Zealand). This scale of this error, known as 'Meter Lag Adjustment' (MLA), will depend on numerous factors as:

- the meter reading frequency (how many times per year),
- the start and finish dates of the meter reading cycle in relation to the Water Year,
- the nature of the reading cycle (rolling reading schedule or other).
- whether there are drought restrictions on consumption at the start or end of the Water Year

Meter lag adjustment calculations are discussed in Appendix F. An example from an Australian system shows that, if quarterly metered consumption volumes from customer meter readings (taken in July-Sep, Oct-Dec, Jan-Mar and Apr-June) are compared with the bulk water volumes supplied during these same 4 calendar quarters, the Non-Revenue Water volume (the difference between the volumes) appears to varies widely from one meter reading cycle to the next, and in some quarters has a zero or even negative value. However, a relatively simple MLA – in the Appendix F example, attributing 50% of the recorded metered consumption in any quarter to the previous quarter, provides a reasonably consistent set of quarterly Non Revenue Water volumes.

In general, New Zealand systems do not experience the multi-year droughts that may occur in large Australian water supply systems, but MLA is still an issue because of seasonal changes in consumption. Large errors in Water Balance calculations due to meter lag can normally be avoided if the problem of Meter Lag Adjustment is acknowledged and appropriately dealt with. However, there is also the problem of Premature Calculations.

In New Zealand, meter reading frequencies seem to be typically 3 months for non-residential properties or large users, and 6 or 12 months for residential properties. So on 30th June, at the end of a Water Year, some of the metered consumption data that occurred during that Water Year may not be available for a further 3, 6 or 12 months. If the Water Supplier is required to provide the Water Balance calculation before all these relevant customer meters have been read, the metered consumption has to be based upon some estimated values (often those for the same period 12 months previously). So MLAs have to be made using partly estimated metered consumption.

If, as in New Zealand, there appears to be no strict national requirement to use a fixed calendar period for the Water Balance, a logical solution to 'Premature Calculations' would be for Water Suppliers to calculate their Water Balance and Real Losses Performance Indicators for an alternative Water Year which ends before the normal Water Year end (30^{th} June), but after the last full set of customer meter readings relevant to the alternative Water Year has been completed and validated.

So, for example, small and medium sized Water Suppliers that can complete meter reading for individual systems or sub-systems in a few weeks, could base the Water Balance period on the mid-point dates of the meter reading cycles. Large Water Suppliers could continue to make MLAs on their rolling reading cycles, but report their Water Balance and Performance data for a Water Year that ends before 30^{th} June.

This flexible approach has been included in a new Water Balance software for Australia (Ref. 14), with the proviso that Water Suppliers using this option are required to draw attention to the fact that a non-standard Water Year has been used to improve data reliability. It is also good practice to record whether a Meter Lag Adjustment has been made or not (this facility is provided on the 'Water Balance' Worksheet in CheckCalcsNZ)

New Zealand Water Suppliers may also wish to classify the method of Meter Lag Adjustment that they use according to Table 4.1, which has recently been developed for Ref. 14.

Table 4.1: Reliability Classifications for Various Methods of Meter Lag Adjustment
Source: WSAA Australian Water Balance Software (Ref. 14)

	Reliability Classifications	Methods of Meter Lag Adjustment considered appropriate for this NPR Classification
A	Based on sound records with adequate procedures	Use of Automatic Meter Reading to identify individual customers' consumption and totalise for defined period of Water Year
		Individual customers' metered volumes apportioned on daily basis using daily Water Supplied, then added to coincide with defined Water Year
B	Mostly conforms to A but some deviations which have minor impact on integrity	Data from customer meter reading cycles are used to apportion recorded consumption volume in cycle to appropriate period in defined Water Year
		Water Balance calculation is based on non-standard Water Year, using mid-dates of meter reading cycles (particularly for smaller systems)
C	Data has significant procedural deviations or extrapolation	Premature Calculations: Water balance calculation with meter lag adjustment is completed before final customer meter readings (relating to actual consumption in Water year) have been completed and validated
D	Unsatisfactory data	No meter lag adjustment is attempted

It is recommended that Water Suppliers develop specifically designed spreadsheets to deal with the meter lag issue as appropriate for their circumstances. Typically this involves understanding meter reading schedules/areas, having a water billing report generated which summarises metered consumption for a given 'reading area' between 'average read dates', interpolating consumption between these 'average read dates' and using this information along with bulk meter readings to assess water loss. Forward assessments of metered consumption in reading areas can also be made to provide for an indicative current water loss calculation.

4.3 Customer Meter Under-Registration

Sections 3.1 to 3.4 of these Guidelines show that, for systems where all customers are metered, under-registration of customer meters is likely to be the 3rd largest source of error.

In New Zealand and Australia, a default value of +/- 2% is recommended for apparent losses due to water meter under-registration. This figure is based on numerous studies which indicate that over time, as the accumulated volume that has passed through them increases, positive displacement water meters 'read slowly' and tend to under-register actual consumption.

Different types of residential meters have different characteristics, and inferential (jet) meters tend to under-record low flows but over-record higher flows as they age. If there are national standards in New Zealand for replacing meters, based on age and/or accumulated volume, and most residential meters in New Zealand are 20mm positive displacement, Class C, then +/- 2% may not be an unreasonable estimate for the under-recording of positive displacement meters.

However, 2% of metered consumption represents a significant volume of water. If water meters are not actually under-registering by 2%, the actual level of real water losses may be less, or more, than calculated in the water balance. Hence it is good practice to carry out a number of meter accuracy tests on a structured sample of meters to reduce the uncertainty regarding the average meter under-registration. In carrying out such tests, the overall meter accuracy should be based on a weighted average of typical consumption rates that represent the typical customer flow profiles.

Table 4.2: Recommended Domestic Meter Testing Procedure using Weighted Average Data

Test Flow Rate	Assumed Usage at Given Flow Rate	Flow Test Result (inaccuracy)	Weighted Result
100 litres/hour	10%	X%	0.10 * X%
600 litres/hour	75%	Y%	0.75 * Y%
1,500 litres/hour	15%	Z%	0.15 * Z%
			Sum of these three numbers gives overall meter accuracy result

Note: It is important that correct signage of test results is used (+ve for over-registration, -ve for under-registration). Information based on a draft Australian Standard.

The default assumption used in BenchlossNZ and CheckCalcsNZ is that customer meter under-registration is 2% of the true volume passing through the customer meters (not 2% of the registered volume). This is because, when customer meters are tested, the under-registration is calculated as a % of the true volume, not the recorded volume, so the correction is always a little larger than (2.04% of the recorded consumption) than users of the software expect it to be.

In the example calculations in Figures 3.4 to 3.6, it has been assumed that the confidence limits for the 2% default are +/-50%, i.e. the probable range is within 1% to 3% under-registration.

4.4 Estimating Unmeasured Residential Consumption

In systems where residential customers are not metered, incorrect estimates of unmetered authorised consumption will usually be by far the largest source of error in water balance calculations, even larger than errors in bulk metering

The following is a brief summary of key points from Appendix D of the BenchlossNZ 2008 User Manual deals with this topic in some detail.

At the 'Point of Consumption' (the street:property boundary), the volume of water passing across that boundary into private pipework is the 'Consumption'. 'Consumption' can be considered to consist of 4 principal components:

- Leakage from the underground supply pipe
- leakage from the above-ground plumbing
- indoor use within the buildings
- outdoor use using hosepipes, sprinklers etc

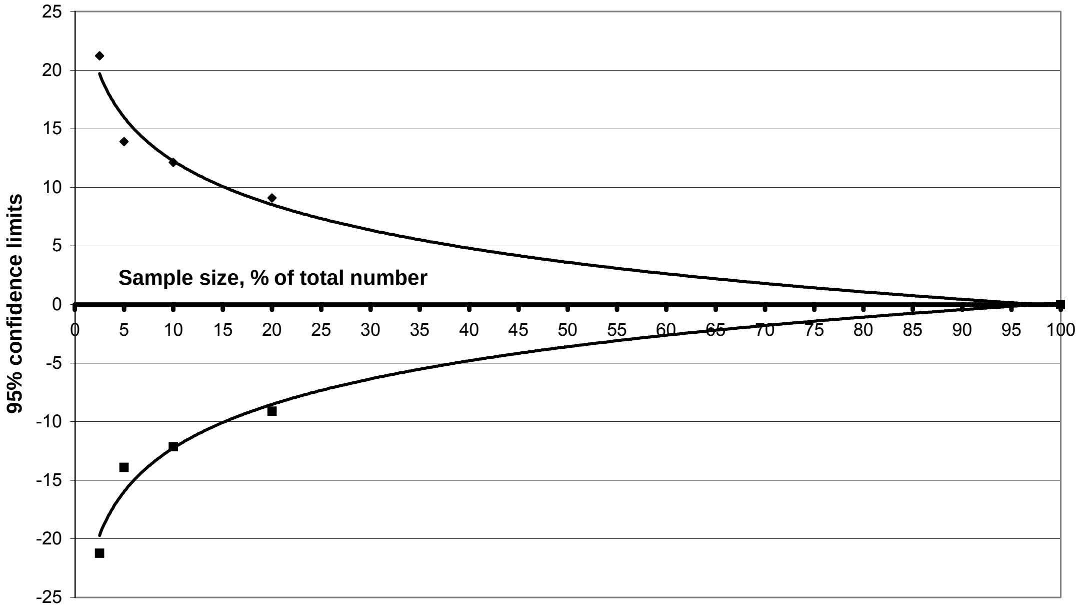
Where there is no metering of residential use, estimates can be made with a consumption monitor. Options are:

- Individual monitor i.e. meter a sample of single houses at the property line
- Small area monitor – sometimes referred to as 'cul-de-sac monitor' using a small bulk meter in a small confined area, in which leakage on the mains and service connections can be kept to a low level, and allowed for.

Problems that present the greatest difficulties in assessing average residential consumption from consumption monitors include significant hidden leaks and outdoor use on a relatively small number of service connections, and variations in residents per property. For random samples (not structured by property type, number of residents etc) large % samples are needed. Figure 4.2 shows a general relationship between 95% confidence limits and size of sample, based on analysis of random selections of 4411 metered residential properties in a South Island city:

- for confidence limits of +/-15%, a 5% random sample appears to be enough
- for confidence limits of +/-10%, a 15% random sample is needed
- for confidence limits of +/- 5%, a 40% random sample appears to be enough

Figure 4.2: % Sample Size vs 95% Confidence Limits, Random samples of Unmeasured Consumption in 4411 Residential Properties in a South Island City.



Because a 40% sample size appears to be needed for a consumption monitor in a small system, to be able to assess residential consumption within +/-5%, it is recommended as being preferable for medium and small systems (less than around 10,000 service connections) to assess Real Losses from Zone night flows, as this will also provide information to assist in pro-active and effective active leakage control.

To assist Water Suppliers with unmetered residential customers, to use an appropriate approximate estimate of unmetered residential consumption in their Water Balance calculations, the data in Table 4.3 have been kindly provided by Water NZ members.

Table 4.3: Per Capita and per property Residential Consumption data, New Zealand

Supply/Area	**Domestic Consumption Litres/person/day**	**Domestic Consumption Litres/property/day**	**Period of measurement (if known)**	**Metered/Unmetered Y/N**	**If Unmetered, number of properties surveyed**	**Other Comments**
North Island						
Whangarei	179	466	2008/09	Y		
Rodney District:						
Hibiscus Coast	165	422	2008/09	Y		based on 2.55 persons/property, single unit residential
Helensville	157	408	2008/09	Y		based on 2.60 persons/property, single unit residential
Muriwai	143	373	2008/09	Y		based on 2.60 persons/property, single unit residential
Warkworth	154	399	2008/09	Y		based on 2.60 persons/property, single unit residential
Wellsford	164	426	2008/09	Y		based on 2.60 persons/property, single unit residential

Supply/Area	Domestic Consumption Litres/person/day	Domestic Consumption Litres/property/day	Period of measurement (if known)	Metered/Unmetered Y/N If Unmetered, number of properties surveyed		Other Comments
Snells/Algies	116	301	2008/09	Y		based on 2.60 persons/property, single unit residential
Auckland Region:						
North Shore City	188	526	2008/09	Y		
Auckland City	160	448	2008/09	Y		
Waitakere City	157	471	2008/09	Y		
Manukau City	168	606	2008/09	Y		
Papakura	199	598	2008/09	Y		
Tauranga City	210	500	2008/09	Y		
Rotorua						
• Eastern urban area	134	545	Jan-Oct 2009	N	14 of 3619	Average h/h occupancy 4.1for sample, 2.9 whole area
• Central urban area	219	643	Jan-Oct 2009	N	15 of 14031	Average h/h occupancy 2.9 for sample, 2.8 whole area
South Island						
Nelson City	175	448	2007/08	Y		
Tasman Region:						
Collingwood	178	488	2008/09	Y	215 meters, seasonal demand	
Kaiteriteri/Riwaka	172	471	2008/09	Y	574 meters	
Motueka	225	616	2008/09	Y	997 meters	
Mapua	239	654	2008/09	Y	768 meters	
Brightwater/Hope	260	713	2008/09	Y	973 meters	
Wakefield	200	547	2008/09	Y	740 meters	
Richmond	249	681	2008/09	Y	5108 meters	
Murchison	266	729	2008/09	Y	301 meters	
Christchurch	291	785	2005-2009	Y		
Dunedin City	229	531	2008/09	N	109 of over 4000	Other monitoring suggests 580 to 600 l/property/day

Supply/Area	Domestic Consumption Litres/person/day	Domestic Consumption Litres/property/day	Period of measurement (if known)	Metered/Unmetered Y/N If Unmetered, number of properties surveyed		Other Comments
Clutha Region:						
Balclutha	508	1040	2008/09	Y		
Benhar	625	1200	2008/09	N	50	Restricted Supply
Clinton	536	1000	2008/09	N	156	Restricted Supply
Kaitangata	827	1801	2008/09	Y		
Lawrence	949	1285	2008/09	N	319	
Milton	700	1359	2008/09	Y		
Owaka	520	867	2008/09	N	196	Restricted Supply
Stirling	453	933	2008/09	Y		
Waihola	519	805	2008/09	N	174	Restricted Supply

Data from a Report (Ref. 15) by OFWAT (the Economic Regulator for England and Wales Water Utiilities) implies that, on average, real losses from unmetered private underground supply pipes are around 46 litres/property day compared to 19 litres/property/day for externally metered residential properties. In England and Wales, residential meters are also usually read every 6 months, but Water Suppliers operate intensive district metering and active leakage control, and also provide free/subsidised repairs or replacements of leaks on private supply pipes.

As New Zealand Water Suppliers do not generally offer free/subsidised repairs, and most do not measure night flows, the allowance for private supply pipe losses on unmetered residential properties should be higher in New Zealand, than in England and Wales. A default figure of 66 litres/property/day was suggested in the example calculation in the CheckCalcs software (see Fig. 5.3). This is around 45 to 50 litres/residential property/day higher than the figures for externally metered residential properties in Table 4.3.

4.5 Summary of Key Points in Section 4

- reliable bulk metering is fundamental to assessment of Non-Revenue Water and Real Losses
- on-site facilities should be provided for independent checking of bulk meters
- manufacturer's in-situ testing and Flowmeter Calibration Verification Certificate for a bulk meter is limited when it only relates to electronics and does not guarantee that the meter is recording the actual flow correctly
- the greater the number of bulk meters, the less the uncertainly (Figure 4.1)
- Water Suppliers should aim to reduce uncertainty for bulk metering to better than +/- 2%
- administrative errors for metered consumption volumes may range between +/-0.5% and +/-2%, depending upon the reliability of the billing systems and checking procedures
- Water Suppliers need to be aware of possible errors due to meter lag adjustments and premature water balance, before all relevant meter reading cycles have been completed
- a logical solution to 'Premature Reporting' is to calculate their Water Balance and Real Losses Performance Indicators for a period which ends before the normal Water Year end
- a simple graph of recorded consumption during meter reading cycles, compared with Water Supplied over the same period, can quickly identify the need for meter lag adjustments
- default estimates of retail meter under-registration should be checked by tests on structured samples of retail meters, by type and age and/or accumulated volume

- a consumption monitor based on a 5% random sample of unmetered residential properties may achieve an accuracy of +/- 15% (see also Fig. 4.2)
- wider use of consumption monitors should improve the reliability of estimates of unmeasured residential consumption; geographical location and climate, household occupancy and private supply pipe leakage will be relevant factors
- in the absence of consumption monitors, Water Suppliers with unmetered residential customers should use Table 4.3 for guidance when entering this data in their Water Balance.

5.0 Reducing Water Loss: Assessing your Losses and Performance

5.1 Assess Current Non Revenue Water Components and Costs from a Water Balance

For medium and large systems, Table 2.1 showed that a Water Balance with confidence limits is the most basic method of assessing Water Losses. Even though the data may be doubtful to start with, the process of collecting and collating the data will begin to highlight the gaps in the data, and the basic use of confidence limits (as shown in Tables 3.3 to 3.6) will help to identify the priorities for improving the water balance data.

In BenchlossNZ 2008, the calculated Current Annual Real Losses (CARL) appear on Rows 79 to 82 of the 'WaterBal' Worksheet, as shown in Figure 5.1.

Figure 5.1: Current Annual Real Losses Calculation by Water Balance, BenchlossNZ 2008

W1g. Current Annual Real Losses (CARL) = Water Losses minus Apparent Losses						
Details	**Example Data**	**This System's Data**	**Units**	**95% Conf. Limits (+/-)**	**Lower Estimate**	**Upper Estimate**
Current Annual Real Losses = Water Losses – Apparent Losses	1598.1	1087.8	10^3m^3/year	15.0%	925.0	1250.6

The Unavoidable Annual Real Losses (UARL) are also calculated, based on the following formula of the 1st IWA Water Loss Task Force (Ref. 11), which takes into account mains length Lm (Km), number of service connections Nc and pressure (Pav, metres):

$$\text{UARL (litres/day)} = (18 \times Lm + 0.8 \times Nc) \times Pav$$

and appear on Rows 58 to 66 of the 'ILI&UARL' Worksheet in BenchlossNZ 2008, as shown in Figure 5.2

Figure 5.2: Calculation of UARL in BenchlossNZ 2008

U3. CALCULATION OF UNAVOIDABLE ANNUAL REAL LOSSES (UARL) for DISTRIBUTION SYSTEM							
Note 7:	Size of System for UARL & ILI Calculations: 20 x Lm + Ns =	16055	which is large enough for UARL and ILI calculations				
Note 8:	Average Pressure =	59	metres, which is large enough for UARL and ILI calculations				
Details	**Calculation**	**Example Result**	**This System's Data**	**Units**	**95% Conf. Limits (+/-)**	**Lower Estimate**	**Upper Estimate**
On mains	18 x Lm x P x 365 x T/10^6	443.48	217.04	10^3m^3/year	5.4%	205.35	228.73
On Service Connections to Street/Property boundary	0.8 x Ns x P x 365 x T/10^6	889.32	266.84	10^3m^3/year	5.1%	253.23	280.44
Total Annual Volume of Unavoidable Annual Real Losses UARL		1332.79	483.88	10^3m^3/year	5.1%	459.15	508.60
UARL in litres/service conn./day when the system is pressurised	Annual Volume of UARL x 10^6 / (Ns x 365 x T/100)	64.7	85.5	Litres/conn./day	5.2%	81.1	90.0

In the CheckCalcs software, the calculations of Current Annual Real Losses and Unavoidable Annual Real Losses both appear on the bottom of the 'Water Balance' Worksheet, as shown in Figure 5.3.

The $ value of the components of Non-Revenue Water (NRW) can be assessed by assigning appropriate $/m^3 valuations against each of the components of NRW, as shown in the lower right hand corner of Figure 5.3. In BenchlossNZ 2008, these conversions to $NZ are done on Rows 35 to 58 of the 'PIComps' Worksheet.

Figure 5.3: Calculation of CARL, UARL and NRW $NZ values in CheckCalcs

'LEAKS' Suite of LEAKAGE EVALUATION and ASSESSMENT KNOW-HOW SOFTWARE										
CheckCalcsNZ - a free software for identifying Leakage and Pressure Management Opportunities										
CheckCalcsNZ	Standard	Version 3a	10th Jan 2008		New Zealand		NZL.000		⊕ ILMSS Ltd	
SHEET IS USED TO CALCULATE NON-REVENUE WATER, CURRENT ANNUAL REAL LOSSES AND UNAVOIDABLE ANNUAL RE										
Colour coding:	Data Entry	Essential Data Entr	Default Values		Calculated Values		Data from another Worksheet			
IWA WATER BALANCE CALCULATIONS for			Anytown			95%	ABC Water			
01/07/1998	to	01/07/1999	365	days	Volume	conf.	Supplementary Checklist relating			
COMPONENTS OF IWA WATER BALANCE					$m^3 \times 10^3$	+/-%	to volumes in calculation			
INPUT FROM YOUR OWN SOURCES					0.0	0.0%	< Corrected for known errors?			No
Water Imported to this system (WI)					6461.7	2.0%	< Corrected for known errors?			No
SYSTEM INPUT					6461.7	2.0%				
Water Exported from this system (WE)					101.0	2.0%	< Corrected for known errors?			No
WATER SUPPLIED to this system (WS)					6360.7	2.0%				
Billed Metered Consumption	14000	Residential Properties (BMCR)			3832.0	2.0%	< Corrected for meter lag?			No
	1714	Non-Residential Properties			1251.0	3.0%	< Corrected for meter lag?			No
Billed Unmetered Consumption	77	Res. Props @	900	lit/prop/d	25.3	20.0%	< Includes	66	lit/prop/d	supply pipe leakag
	42	Non-Res Props @	1500	lit/prop/d	23.0	20.0%	< Includes	66	lit/prop/d	
	Other	Seasonal/Tourists			1.7	30.0%	Value of NRW components			
Billed Authorised Consumption (Metered and Unmetered)					5133.0	1.7%	$/m3		$ x 10^3	
NON-REVENUE WATER (NRW)					1227.7	12.6%	0.16		194	
Unbilled Authorised Consumption			0.50%	of WS	31.8	100.0%	0.30		10	
WATER LOSSES (WL)					1195.9	13.2%	0.15		184	
Unauthorised Consumption			0.10%	of WS	6.4	100.0%	0.70		4	
Customer Meter Errors	Residential		2.00%		76.6	50.0%	0.70		54	
	Non-Residential		2.00%		25.0	50.0%	0.70		18	
APPARENT LOSSES (AL)					108.0	37.8%	0.70		76	
CURRENT ANNUAL REAL LOSSES (CARL)					1087.9	15.0%	0.10		109	
UNAVOIDABLE ANNUAL REAL LOSSES (UARL)					483.5	5.1%	0.10		48	
CURRENT ANNUAL REAL LOSSES (CARL) minus UARL					604.4	27.1%	0.10		60	

Colour coding of Cells: Yellow = Data entry, pink = calculated values, purple = defaults

For your initial water balance calculations, it is recommended to use the standard defaults for Unbilled Authorised Consumption, Unauthorised Consumption, and Customer Meter under-registration (as shown above).

If your system has large numbers of unmetered residential properties:

- it is recommended to use the 'per residential property' data figures of other New Zealand Water Suppliers in Table 4.3 for guidance, remembering to allow for the higher real losses on unmetered supply pipes
- an alternative possibility is to do the Water Balance over the 6 monthly winter period (April to September) when the component of garden watering should be significantly lower and the estimate of unmetered residential consumption lower, but more reliable

The Unit value of Apparent Losses is usually taken as the retail sales price for residential consumption. The Unit Value of Real Losses depends upon local circumstances; e.g. for Water Imported use the variable Bulk Supply charge plus any additional local treatment and power costs. For 'own sources', use the marginal cost/kl of treatment (chemicals) and power, plus (if appropriate) other elements such as capital deferment. Unbilled Authorised Consumption is often valued at the Unit Value of Real Losses

In the example above, the initial best estimate is that this system has:

- Current Annual Real Losses of 1088 Ml/year (3.0 Ml/d) +/- 15%, valued at $109k per year
- Unavoidable Annual Real Losses of 484 Ml/year (1.3 Ml/d) +/- 5%, valued at $48k per year

Using this approach, any New Zealand Water Utility can begin to make an assessment of their volumes of Non-Revenue Water and Real Losses, in both volume and dollar terms, with confidence limits.

An alternative approach to assessing Real Losses from night flow measurements in for small systems, and Zones within larger systems, is described in Section 5.2 below.

5.2 Assess Current Real Losses from Night Flow Measurements

Table 2.1 shows that Zone night flow measurements are recommended for assessing Real Losses not only in Zones of medium and large systems, but also in small systems (those with fewer than around 2500 service connections), and particularly for Zones and Systems with large numbers of unmetered residential properties.

Briefly, the approach, which is explained in Appendix A, is as follows:

- arrange to measure night flows into Zone (permanent/temporary meter, reservoir drop test)
- arrange to measure or estimate an average pressure (AZNP) at night in the Zone at the 'Average Zone Point (AZP)', see Appendix E
- choose a time of year and days of the week when night consumption is likely to be at a minimum, with no use of hosepipes, sprinklers or other exceptional night use
- measure the Minimum Night Flow MNF over 1 hour between 0100 and 0300 hours, together with the Average Zone Night Pressure (preferably over several nights, and use the average values)
- deduct estimate of Customer Night Consumption in litres/connection/hour (assumed as 2.0 litres/conn/hour +/- 40% in the example below)
- calculate Snapshot Night Leakage Rate in m^3/hour, preferably with confidence limits, as shown in Table 5.4

Figure 5.4: Example calculation of Snapshot Night Leakage Rate

STEP 1: CALCULATE SNAPSHOT NIGHT LEAKAGE RATE			09/07/05	to	15/07/05
Number of Service Conns =	3310	Litres/ sec	m^3/ hour	Litres/ conn/ hour	95% Conf. Limits
Length of Mains (km) =	47.00				
when AZNP (metres) =	59.00				
Minimum Night Flow MNF		6.50	23.40	7.07	2.0%
Assessed customer night consumption CNCa		1.84	6.62	2.00	40.0%
Exceptional customer night consumption CNCe		0.00	0.00	0.00	20.0%
Snapshot Night Leakage Rate NLR = MNF - CNCa - CNCe		4.66	16.78	5.07	16.0%

Colour coding of Cells: Yellow = Data entry, pink = calculated values

Using the Snapshot Night Leakage Rate of 16.8 m3/hour, the Snapshot ILI can be calculated as shown in Section 5.4 and Fig 5.12

To convert a night leakage rate in m^3/hour, to an average daily leakage rate in m^3/day, it is necessary to multiply by a Night-Day Factor NDF (see Appendix A), with units of Hours/day, as shown in the example in Table 5.5. The term 'Hour-Day Factor' is also used in the UK.

Figure 5.5: Example Conversion of Snapshot Night Leakage Rate to Snapshot Daily Leakage, using Night-Day Factor

STEP 2: MULTIPLY NIGHT LEAKAGE RATE (NLR) by NIGHT DAY FACTOR (NDF) to obtain SNAPSHOT DAILY LEAKAGE	m^3/ hour	Hours/ day	m^3/ day	95% Conf. Limits
Night Leakage Rate NLR	16.78			16.0%
Night-Day Factor NDF		20.00		5.0%
Snapshot Daily Leakage = NLR x NDF			336	16.8%

Colour coding of Cells: Yellow = Data entry, pink = calculated values

For Zones supplied by gravity, Night-Day Factors typically vary from 18 to 23 hours/day. Zones with pumped or pressure-modulated inflow typically have NDFs ranging from 24 to over 30 hours/day, as pressures at night (and leak flow rates) are then lower at night than during the day.

Zone-specific Night-Day Factors can be calculated by taking pressure measurements at the 'Average Zone Point', using an appropriate FAVAD N1 value (between 0.5 and 1.5) for the pressure: leak flow rate relationship (see Section 6.6). The 'PressCalcs' Standard software (Ref. 13) includes a more comprehensive explanation and Worksheets to define the AZP point, estimate N1 values, and calculate NDFs from pressure measurements at the Average Zone Point.

Using this approach, any New Zealand Water Utility can begin to make an assessment of the Real Losses within individual small systems and Zones, in volume terms, with confidence limits.

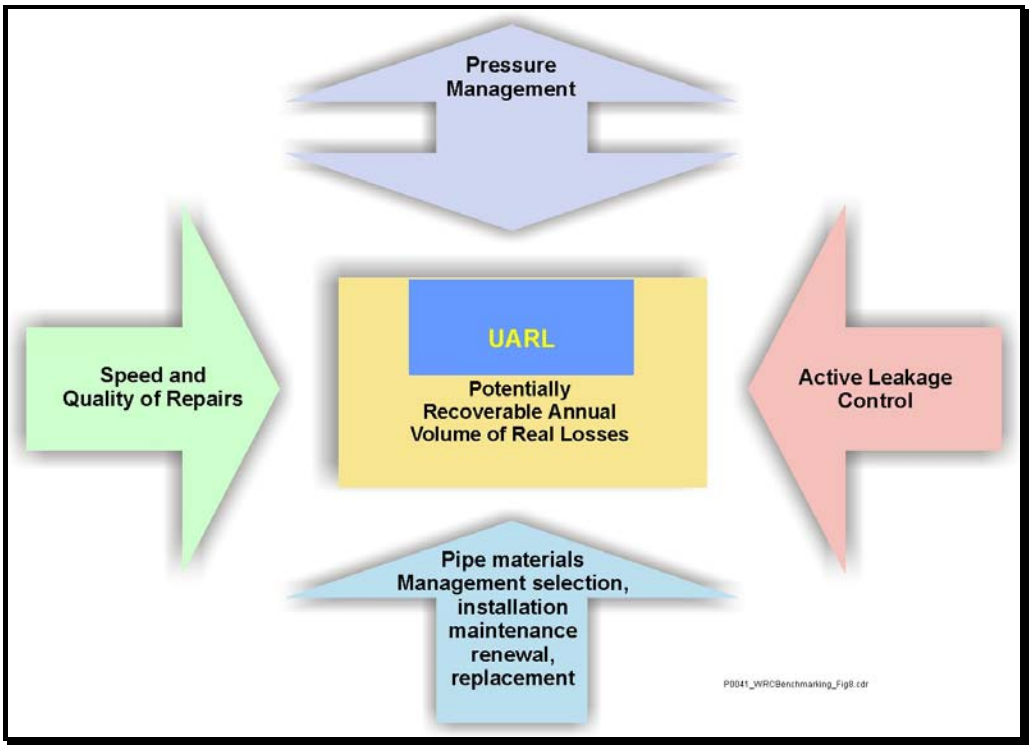
5.3 Compare Real Losses Management Performance using ILI and World Bank Institute Bands

Performance indicators are discussed in Section 2.4 of these Guidelines, where it has been explained that the Infrastructure Leakage Index (ILI) is the best PI for Metric benchmarking (comparisons between systems) of Real Losses management performance. The ILI is the ratio of the Current Annual Real Losses (CARL) divided by the Unavoidable Annual Real Losses (UARL, calculated from the IWA formula in Section 5.1).

Figure 5.6 is a useful diagram, which explains the ILI visually and also shows how Real Losses and ILI are influenced by the four major methods of managing Real Losses. The area of the outer rectangle represents the Current Annual Real Losses volume, which is continually tending to increase as the system gets older, and new leaks and bursts occur. The four complementary leakage management activities (shown as arrows) constrain this increase, but the maximum effect they can possibly have is to reduce the Real Losses as low as the Unavoidable Annual Real Losses (UARL), indicated by the smaller box.

The Infrastructure Leakage Index is the ratio of the outer area (CARL) to the inner area (UARL), and is a non-dimensional number. An ILI close to 1 represents excellent performance in managing Real Losses; whereas an ILI of, say, 5, means that the Current Real Losses are 5 times what would be expected for a well managed system with good infrastructure, at the specified average pressure.

Figure 5.6: The 4 Components Approach to Managing Real Losses



The ILI is preferred for making comparisons between system performance, as the UARL (which is used to calculate the 'best achievable' Real Losses) takes into account the key system-specific factors of number of service connections, mains length and average pressure.

Referring to Figure 5.6, ILI measures how well a Water Supplier is managing the East, South and West arrows (Speed and Quality of Repairs, Pipe Materials management, Active Leakage Control) at the current Operating Pressure. But this should not be taken to imply that the current operating pressure is the optimal operating pressure.

Pressure management will normally be an important part of any real loss reduction strategy. And, when excess pressures are reduced, both the CARL and the UARL volumes will reduce, so the ILI (=CARL/UARL) may not change to any significant extent. Because of this effect, ILI is not normally recommended for Process benchmarking (progress towards targets for reduction of Real Losses). Litres/service connection/day, or kl/km of mains/day are preferred, depending upon whether the system connection density is more than, or less than, 20 service connections/km of mains.

In BenchlossNZ 2008, the calculated ILI (with confidence limits) can be found on Row 36 of the 'Summary' Worksheet, as shown in Figure 5.7.

In the example shown, the ILI has been assessed as being 2.25, which implies (see Columns 4 to 7 of Figure 5.7) that it is within the lower half of World Bank Institute Band B (ILI 2 to <4). The 95% confidence limits are 1.89 (lowest) to 2.60 (highest). The WBI Banding system is explained in Section 2.4. and Table 2.3, and Figures 5.10 and 5.11.

Figure 5.7: Performance Indicators calculated using BenchlossNZ 2008

S3: RECOMMENDED PERFORMANCE INDICATORS

Viewpoint	Level of PI	Performance	World Bank Institute Band (see Note 1) A	B	C	D	PI for this System	Units
Operational Management of Real Losses at Current Pressure	IWA Op27 DoC 20/km or more	Current Annual Real Losses (CARL) when system is pressurised Litres/service connection/day	Less than 171	171 to 342	343 to 684	685 or more	*163* **192** *221*	Litres/ service connection per day
	IWA Op28 DoC<20/km	Current Annual Real Losses (CARL) when system is pressurised m^3/km of mains/day (see Note 2)	Less than 4.7	4.7 to 9.5	9.6 to 18.9	19.0 or more	*4.5* **5.3** *6.1*	m^3 per km of mains per day
	IWA Op29	Unavoidable Annual Real Losses (UARL) for distribution losses Litres/service connection/day (See Note 3)	-	-	-		*81* **86** *90*	Litres/ service connection per day
		Infrastructure Leakage Index (ILI) = CARL /UARL for distribution losses (see Note 4)	Less than 2	2 to < 4	4 to <8	8 or more	*1.89* **2.25** *2.60*	Non-dimensional
Apparent Losses		Apparent Losses volume as % of metered consumption (excluding Water Exported) (See Note 5)					*1.3%* **2.1%** *2.9%*	% of metered consumption
Financial Management of NRW	IWA Fi47	Non-Revenue Water $ value as a % of annual system running cost (See Note 6)					**3.0%**	% of annual system running cost
Additional Calculation for comparison with Fi47		Non-Revenue Water (NRW) volume as a % of Water Supplied volume (See Note 7)	Not reliable for Metric Benchmarking or Process Benchmarking of NRW; shown here for information only				*16.8%* **19.3%** *21.8%*	% of Water Supplied volume

In CheckCalcs NZ, the ILI appears in Row 12 of the 'Performance Indicators' Worksheet, as shown in Figure 5.8, and the value is carried forward automatically to the 'WBI Guidelines' Worksheet, from which Figures 5.9, 5.10 and 5.11 are copied.

Figure 5.8: Excerpt from 'Performance Indicators' Worksheet, CheckCalcsNZ 2008

ABC Water	Anytown	01/07/1998	to	01/07/1999	Density of Conns =	27.7	per km mains

Type of PI	Description of Performance Indicator		95% Conf Limits, +/-%	Comments
Operational management of Real Losses at Current Pressure	IWA Op27: litres/service connection/day	192	15.1%	Litres/conn/day is the better simple PI for this system, with 20 connections/km of mains or more
	IWA Op28: m3/km of mains/day	5.3	15.2%	
	IWA Op29: Infrastructure Leakage Index ILI	2.25	15.9%	The best PI for Operational Management of Real Losses
Apparent Losses	Apparent Losses volume as % of metered consumption (excluding Water Exported)	2.1%	37.8%	The most appropriate simple PI for Apparent Losses in New Zealand
Financial management of Non Revenue Water	Estimated Value of NRW in $ x 10^3	194	12.6%	From 'Water Balance' Worksheet
	Annual Cost of Running this system in $ x 10^3	6500	10.0%	From 'Running Costs' Worksheet
	IWA Fi47: NRW value as % of annual running cost	3.0%	16.1%	A better NRW PI than % by volume
Note: for comparison with Cell F16 only: NRW as % by volume of Water Supplied		19.3%	12.8%	**Not** a recommended PI

Figure 5.9 then compares the calculated ILI to the ILIs for 23 Australasian Water Suppliers.

Figure 5.9: System ILI compared with Australasian Data set, from CheckCalcsNZ 2008

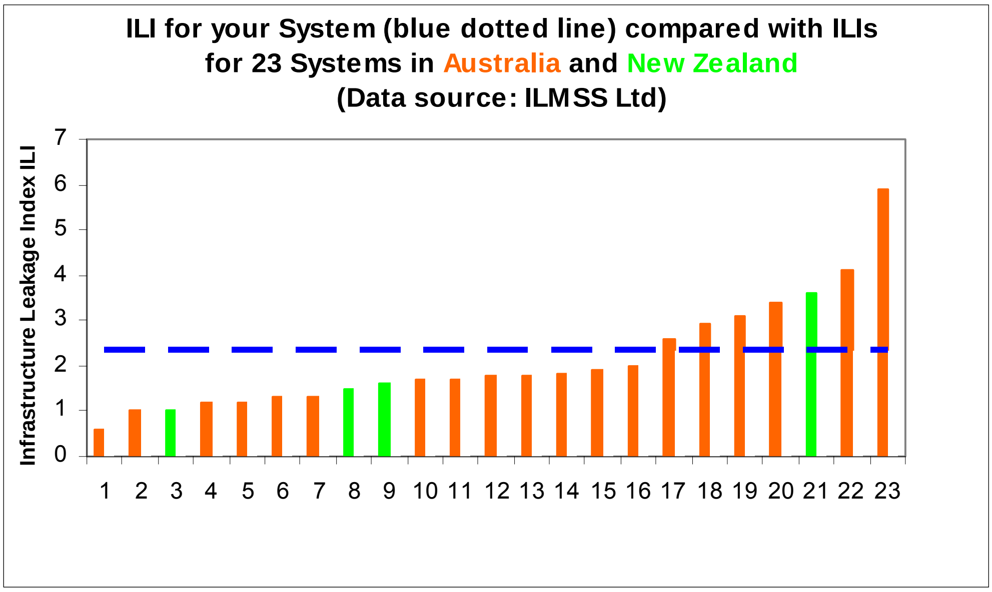


Figure 5.10 then classifies the ILI as WBI Band A, B, C or D, and the 'General Description' (4th column of Fig 5.10) puts the Real Loss performance management into an international perspective.

Figure 5.10: General Description of Meaning of WBI Bands A to D

Developed Countries ILI range	BAND	Calculated ILI for this System	General description of Real Loss Management Performance Categories for Developed and Developing Countries
Less than 2	A		Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement
2 to < 4	B	2.3	Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance
4 to < 8	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
8 or more	D		Very inefficient use of resources; leakage reduction programs imperative and high priority

Source: CheckCalcsNZ 2008

Then, depending upon which WBI Band the performance has been categorised, an overview set of WBI recommendations for appropriate leakage reduction activities are provided for reference.

Figure 5.11: Recommendations associated with WBI Bands A to D

WBI Recommendations for BANDS	A	B	C	D
Investigate pressure management options	Yes	Yes	Yes	
Investigate speed and quality of repairs	Yes	Yes	Yes	
Check economic intervention frequency	Yes	Yes		
Introduce/improve active leakage control	Yes	Yes	Yes	
Identify options for improved maintenance		Yes	Yes	
Assess Economic Leakage Level	Yes	Yes		
Review break frequencies		Yes	Yes	
Review asset management policy		Yes	Yes	Yes
Deal with deficiencies in manpower, training and communications			Yes	Yes
5-year plan to achieve next lowest band			Yes	Yes
Fundamental peer review of all activities				Yes

Source: CheckCalcsNZ 2008

So, the ILI calculated from either the BenchlossNZ or CheckCalcs Water Balance can be quickly:

- compared to a national Australasian set of ILIs (Figure 5.9)
- categorised in World Bank Institute A/B/C/D Bands, with performance description (Fig. 5.10)
- assessed for appropriate Real Losses management activities (Figure 5.11).

5.4 Assessing Snapshot ILI and World Bank Institute Bands from Night Flow Measurements

Section 5.2 (and Figures 5.4 and 5.5) showed how Snapshot Night Leakage Rate can be assessed from night flow measurements in a small system or Zone. The Snapshot Night Leakage Rate can also be quickly converted into a Snapshot ILI, then categorised within the World Bank Institute Bands A to D, as shown in Figure 5.12

Figure 5.12: Calculation of Snapshot ILI and WBI Band from Snapshot Night Leakage Rate

STEP 3: CALCULATE SNAPSHOT VALUES OF REAL LOSSES PERFORMANCE INDICATORS			
The Snapshot Daily Leakage is	335.6	m3/day	
	101	litres/connection/day +/-	16.8%
The Snapshot Night Leakage Rate is	16.78	m3/hour at 59 metres AZNP	
The Unavoidable Annual Real Losses are	8.59	m3/hour at 59 metres pressure	
So 'Snapshot' Infrastructure Leakage Index is	1.95	which is in WBI Band	A

In this example, Unavoidable Annual Real Losses UARL is calculated from the formula:

$$\text{UARL } (m^3/\text{hour}) = (18 \times Lm + 0.8 \times Nc) \times AZNP/24/1000$$

Lm = mains length (km), Nc = No. of service connections, AZNP = Ave. Zone Night pressure (m)
So UARL at AZNP = (18 x 47 + 0.8 x 3310) x 59/24000 =(846+2648)x0.00246 = **8.6 m^3/hr**

Calculate Snapshot ILI = Snapshot Night Leakage Rate/UARL = 16.78 / 8.6 = **2.0**

The Snapshot ILI under the WBI Banding System; in this example just within Band A.

'Snapshot' ILIs are a very useful and practical approach for getting a quick estimate of the approximate scale of leakage in small Zones, for providing a cross-check on estimates of ILI from annual Water Balances, and for classifying Real Losses management performance using the WBI Bands A to D.

However, 'Snapshot' ILIs derived from different limited sets of night flows will vary around the annual ILI value, and may even be less than 1.0 soon after an active leakage control intervention, when all detectable reported and unreported bursts have been repaired, and only background leaks (non-visible, non-audible) remain.

So a 'Snapshot' ILI should always be considered as being an approximate value, always treated with caution, and always referred to as a 'Snapshot' value to avoid confusion with the ILI calculated from an annual water balance.

5.5 Other Useful Practical Indicators: Repair Times, Burst Frequencies, Rate of Rise

High and increasing water losses are an indicator of ineffective planning and construction, and low operational maintenance activities (Ref. 16). However, there are some additional indicators now being used or tested by the IWA Water Loss Task Force, that are proving to be useful and practical in analysis of system data, to gain insights into the probable most cost-effective improvements in performance.

Speed and Quality of Repairs: the 'West' arrow of the 4 Components Diagram (Figure 5.6) relates to Speed and Quality of Repairs. The total run time of leaks consists of 3 components:

- Awareness – from when a leak starts, until the Water Supplier becomes aware of it
- Location – the time taken to locate the leak
- Repair – the time taken to repair or shut off the leak

In the absence of night flow measurements, it can be difficult to estimate Awareness times. But all Water Suppliers should keep reliable records on their **Location and Repair times**, for every type of leak. Long running leaks with low flow rates are the largest source of annual Real Losses.

Burst Frequencies: A recent international analysis (Ref. 12) has clearly demonstrated that the burst frequencies on mains and service connections can be significantly reduced in many systems by pressure management – by reduction of pressure transients and excess pressures. Although mains bursts contribute less to annual real losses than many people imagine (usually less than 10% by volume, see Section 6.2), reduction of annual repair costs and extension of infrastructure life are now recognised as key financial drivers for pressure management.

Accordingly, Water Suppliers should record their mains repairs and service connection repairs in formats that permit the calculation of monthly numbers and annual frequencies as follows:

- Mains repairs expressed in number/100 km/year
- Service connection repairs in number per 1000 service connections per year.

Service connection repairs should be subdivided into:

- repairs at the ferrule/main joining point
- repairs on the service line between the main and the stoptap/toby or external meter
- repairs on the stop tap/toby or external meter.

These repair frequencies can then be compared to the reference frequencies for well managed infrastructure in the UARL formula of:

- 13 per 100 km /year for mains repairs
- 3 per 1000 service connections/year for services (excluding stop taps/tobys, meter repairs)

Separate values of a Burst Frequency Index (BFI) can then be calculated for mains, and for services. For example, if the mains burst frequency is 15 per 100 km/year and the service pipe burst frequency is 21 per 1000 service connections/year:

- The Burst Frequency Index for mains is 15/13 = 1.15, which is close to 1
- The Burst Frequency Index for services is 21/3 = 7, which is high.

These two BFIs provide a quick indication of the propensity for bursts in the distribution system, and are valuable (Ref 12) when predicting if pressure management will reduce:

- both mains bursts and service pipe bursts
- mains bursts, but not service pipe bursts
- service pipe bursts, but not mains bursts
- neither mains bursts nor service pipe bursts

Rate of Rise of Unreported Leakage is a parameter that has not traditionally been calculated, but it is one of three parameters (the others are Variable Cost of Water, and Intervention Cost) that can be used (Ref. 17) to quickly calculate the economic frequency of intervention for active leakage control, and the associated budgets.

There are 3 basic methods of assessing Rate of Rise, and calculating Economic Intervention parameters for Active Leakage Control (the 'East' Arrow of 4 Components Diagram (Figure 5.6). See Section 6.4, '*Budgeting for Economic Intervention'* for more information on this topic.

5.6 Summary of Key Points in Section 5

- for large and medium sized systems, the most basic method of assessing Water Losses is a Water Balance with confidence limits, using BenchlossNZ 2008 or CheckCalcs 2008
- data may be doubtful to start with, but the process of collecting and collating the data will begin to highlight the gaps, and use of confidence limits helps to identify priorities for improving the water balance data.
- in initial calculations, standard defaults should be used for Unbilled Authorised Consumption, Unauthorised Consumption and Customer Meter errors
- where there are large numbers of unmetered residential properties, guidance on estimates of consumption can be taken from metered residential property figures in Table 4.2, allowing for higher losses on private unmetered properties; or a 6-month (winter) water balance can be used to reduce uncertainties in the estimates.
- components of Non-Revenue Water are initially calculated in volume terms but can be converted to dollar equivalents using appropriate valuations for Apparent Losses, Real Losses and Unbilled Authorised Consumption
- snapshot night leakage rates can be derived from night flow measurements and converted to daily snapshot leakage estimates using appropriate Night-Day Factors
- Infrastructure Leakage Index (ILI) is the best PI for making comparisons of Real Losses management performance (Metric Benchmarking)
- ILIs calculated from a Water Balance can be compared to an Australasian data set, and also categorised according to the World Bank Institute Banding System (A to D)

- the WBI Bands provide an internationally applicable description of performance, and a list of relevant leakage management activities appropriate to each WBI Band
- snapshot ILIs can be calculated from night flow measurements, and classified in WBI Bands
- there are several additional useful practical indicators - ‘Awareness Location and Repair’ times, Burst Frequency Index (one for mains, another for services) and Rate of Rise of Unreported Leakage

6.0 Reducing Water Loss: Tuning in to the Basic Concepts

6.1 The importance of reliable bulk and district metering

For many New Zealand Water Suppliers it would be surprising if their initial assessment of Real Losses and performance, using Water Balance and/or Night flows, found no deficiencies in bulk metering (and district metering, if there are any district metered areas).

Bulk meters are usually large diameter, and therefore expensive. If installed when treatment plant was built, manufacturer's specifications for older meters may be hard to find. If installed retrospectively, installation specifications are often found to be compromised due to space or cost limitations

However, reliable bulk and district metering is the foundation for water loss management and for an effective water loss reduction strategy. Appropriately specified water meters must be provided and installed, in accordance with manufacturers instructions and best practice, at all main delivery points (such as the outlet of water treatment plants and/or main reservoirs) and bulk metering points.

These meters are essential for the water balance calculation, and may also be usable in some locations for monitoring of night flows in small and medium sized systems. For reliability of low flow measurements, district meters for small systems or zones usually need to be sized smaller than the main in which they are located.

Regular calibration of electronics is normal practice, but this should not be assumed to imply that the meter is recording the correct flows. The meter may be incorrectly sized or of an inappropriate type for the flow profile at the particular location, and facilities for independent flow validation are rarely provided - so regular flow validation is not normally practised. During droughts, bulk meter flows which are much lower than original design flows, or reversal of flows, may occur, leading to under-registration of actual flows.

However, validation of bulk metered volumes is an essential part of Water Balance calculations, and provision of facilities for regular checking of the meters – by volumetric means, insertion meters or duplication of key meters – will reduce uncertainty.

There are many different types of bulk meter - Electro-magnetic, Ultrasonic, Venturi, Dall tube, Orifice plate, Insertion meters, Helix meters, Vortex shedding, Turbine, Propeller etc. All bulk meters are sensitive to distortion of the velocity profile in the mains, to a greater or lesser extent, which is why manufacturers' recommendations on minimum lengths of straight pipe upstream and downstream of the meter (expressed as a number of pipe diameters) should not be compromised. Sensitivity to velocity profile distortion is generally:

- Very High, for insertion meters
- High, for ultrasonic and helix meters
- Medium/Low, for electromagnetic meters

Appendix G (Additional Information on Bulk Metering) briefly summarises some international experiences of Bulk Metering recently presented in Australasia (Refs 14, 19, 20), on:

- Advantages and Disadvantages of different types of Bulk Meters
- Factors affecting accuracy
- Bulk Meter validation options
- Common Issues in Validating Bulk Meters
- Some examples of Errors found when validating bulk meters

- Some basic actions to reduce Bulk Metering Errors

6.2 Speed and quality of repairs, and Component Analysis of Real Losses

The 'West' arrow of the 4 Components approach to managing Real Losses (Figure 5.6) relates to Speed and Quality of Repairs.

Many Water Suppliers throughout the world still believe that if they repair their visible mains bursts quickly, that their leakage management will be acceptably good. There are examples of cities in the Eastern USA and Norway that repair mains bursts quickly (the Norwegian City actually has district metering and night flows) but have ILIs of 10 or more – in other words, they are losing at least 10 times the Unavoidable Annual Real Losses for their system, at its current operating pressure. In both cases, the customer, not the Water Supplier, owns the whole of the service pipe, and is responsible for repairs to leaks on that pipe (which do not generally get repaired quickly or well, if at all).

A quick calculation from a New Zealand Water Supplier with an ILI close to 1.0 shows that reported mains bursts represent only a small proportion (usually less than 10%) of the Current Annual Real Losses in most distribution systems. In this example:

- current annual real losses from the Water Balance are **1,600,000** m^3/year
- there are **400** reported mains bursts on **1200** km of mains/year, or **33 per 100** km/year
  - which is **2.5** times the reference value (13 per 100 km/year) for mains (Section 5.5)
- assumed average flow rate is **600** m^3/day for each mains burst
- if each reported mains bursts runs for **8 hours**, they will lose 600 x 8/24 = **200** m^3/day each
- the annual volume of Real Losses from such bursts will be 400 x 200 = **80,000** m^3/year
  - which is only **5%** of the Current Annual Real Losses

Whilst this simple calculation emphasises the virtue of repairing reported mains bursts quickly, it also clearly shows that in well managed systems such events are only one relatively small component of Real Losses.

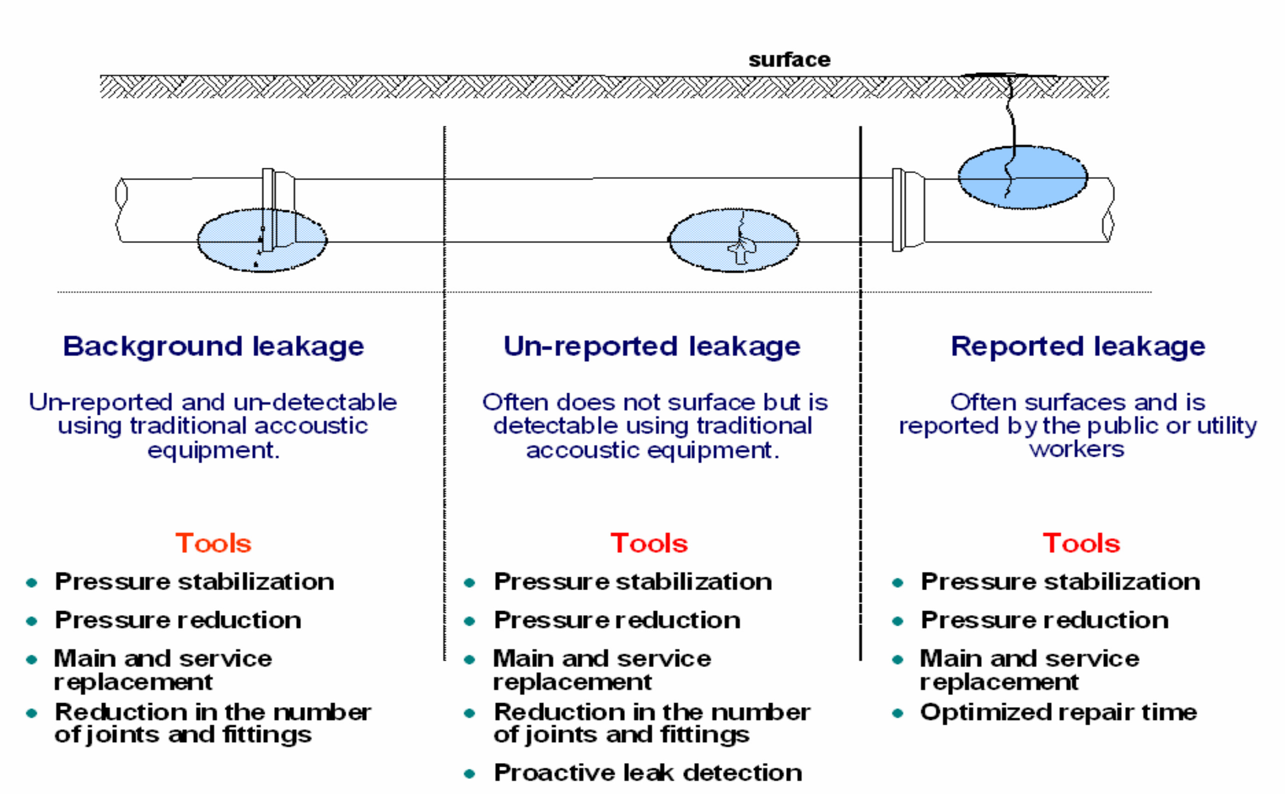
Further evidence comes from France, where Water Suppliers in the Bordeaux region have invested heavily in mains renewals, to the extent that a linear regression through grouped data of numerous Water Suppliers (Ref. 21) shows that Non-Revenue Water (mainly Real Losses) has no discernible component from mains, but still averages 150 litres/property/day.

From these two examples it can be clearly seen that, although rapid repair of reported mains bursts, and investment in good quality mains, are worthy strategies, they will never solve the problem of Real Losses management on their own.

One of the keys to understanding the control of Real Losses is Component Analysis of Real Losses. The BABE (Background and Bursts Estimates) BABE concept (Ref 22) uses auditable assumptions to calculate, from first principles, the components that make up the annual volume of Real Losses. The leaks occurring in any water supply system are considered conceptually in three categories, as shown in Figure 6.1:

- Background leakage – small leaks at joints and fittings, not visible or audible
- Reported bursts – events with larger flows which cause problems and are reported to the Water Supplier;
- Unreported bursts – significant events that do not cause problems and can only be found by active leakage control.

Figure 6.1: Typical characteristics of Background Leakage, Reported and Unreported Leaks



Source: Sabesp (Brazil)

The larger detectable events are usually referred to as bursts, while those too small to be located (if not visible) are referred to as background leaks. The threshold between bursts and background leaks can vary from country to country, depending upon factors such as minimum depth of pipes, type of ground and surface, etc.

In the UK a threshold limit of 500 litres/hour was used in the 1994 Managing Leakage Reports, but advances in technology and other factors suggest that a figure of around 250 litres/hour would be more appropriate in New Zealand.

Using the BABE concept, Table 6.1 below shows other types of leaks that would lose the same volume of water (**200 m^3**) as the mains burst running for 8 hours, in the example calculation above.

Table 6.1: Small leaks can lose as much as large leaks, depending on how long you let them run

Example of leak or burst	Average Flow Rate		Average Run time	Volume lost
	Litres/hour	m^3/day		m^3
Reported mains burst	25,000	600	8 hours	200
Unreported service connection leak	500	12	17 days	200
Reported but unrepaired service leak	100	2.4	12 weeks	200
Leaking valve or hydrant	33	0.8	8 months	200
Leaking Toilet	15	0.4	16 months	200

The simple key to Real Losses management is, therefore, **to manage** and **limit** the **duration** of **all leaks and bursts.** The **frequency** of leaks and bursts is generally not capable of being controlled in the short term, other than perhaps through pressure management (see Section 6.5), or through infrastructure replacement (the most expensive option) in the long term.

The total run time of detectable leaks and bursts (reported and unreported) consists of:

- Awareness – from when a leak starts, until the Water Supplier becomes aware of it
- Location – the time then taken to locate the leak
- Repair – the time then taken to repair or shut off the leak

In the absence of night flow measurements, it can be difficult to estimate Awareness times. But all Water Suppliers should keep reliable records on their **Location and Repair times**, for every type of leak, as long running leaks with low flow rates are the largest source of annual Real Losses.

Once a Water Supplier for a medium or large system starts to record numbers of leaks and bursts, and location and repair times, in a format suitable for Component Analysis calculations, it should be possible within a couple of years to prepare a draft Component Analysis of Real Losses, as in Table 6.2, for comparison with the Real Losses assessed from the Water Balance. Unavoidable Background Leakage (UBL) up to the property line is calculated from an IWA formula (Ref 23):

$$\text{UBL (litres/hour)} = (20 \times Lm + 1.25 \times Nc) \times (P/50)^{1.5}$$

where Lm is mains length (km). Nc is number of service connections (main to property line) and P is the Average Zone Night Pressure (metres)

Table 6.2: BABE Component Analysis Calculation for a New Zealand Water Supplier (2000)

BABE Calculation of Real Losses				
Infrastructure Component	Background Leakage $m^3 x 10^3/yr$	Reported Bursts $m^3 x 10^3/yr$	Unreported Bursts $m^3 x 10^3/yr$	Total $m^3 x 10^3/yr$
Mains	312	149	31	492
Service Conns	915	177	20	1112
Totals	1227	326	50	1604

6.3 Active Leakage Control, with and without Night Flows and District Metering

Active Leakage Control. When a Water Supplier only repairs leaks and bursts that are reported to them, that is known as *Passive Leakage Control.* However, almost all distribution systems experience some leaks and bursts that are not reported. The activity of looking for, finding and repairing such unreported bursts is known as *Active Leakage Control* (ALC), and it is the 'Easterly' arrow of the 4 Components approach to managing Real Losses (Figure 5.6).

The rate at which such unreported bursts accumulate (known as 'Rate of Rise', Refs 17 and 18) varies widely from one system to another, and even within parts of the same systems, depending upon factors such as whether the ground is surfaced or not, the type of soil and underlying rocks, the infrastructure condition, pressure and seasonal factors. Even where rates of rise are small, by international standards, if no ALC policy is in place, the component of real losses from unreported leaks will rise continuously, and will result in annual real losses that increase year on year, and gradual increases in Real Losses performance indicators.

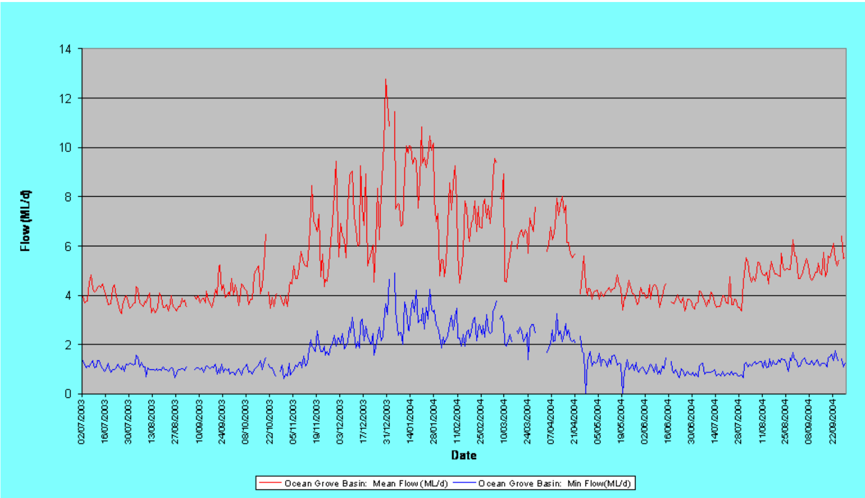
Active Leakage Control consists of managing the duration of unreported leaks by looking for them, finding and repairing them. Although a small proportion of unreported leaks may be visible (usually in inaccessible locations), most unreported leaks do not surface, and have to be detected by sonic means.

The simplest, but most labour intensive method of ALC is to sound every mains fitting and stop tap, or to use correlators and noise loggers, to investigate any sounds that indicate the presence of leaks. Typical costs for an experienced Contractor to do this type of survey are around $NZ 200 per km of mains. This could be a suitable approach for an initial sweep of a medium or large system that has an ILI that is within WBI Bands B, C or D, and has had no ALC activity for several years.

Night Flow Measurements: for small systems, and for medium or large systems that can be split into Zones, night flow measurements are an excellent way of identifying whether there are likely to be any unreported leaks worth looking for. This topic is covered in Appendix A. The following is a brief overview.

In countries such as New Zealand, night flows can vary seasonally to a significant extent. Figure 6.2 shows the annual pattern of daily system inflows, and night flows, in a large DMA (8000 service connections) in Victoria, Australia. Clearly, any attempt to estimate Real Losses from night flows during the summer is going to be invalidated by the large and unknown amount of exceptional night use due to garden watering, late night holiday activities, etc.

Figure 6.2: Annual daily inflows (red) and night flows (blue) in a large DMA in Victoria



In such circumstances, it is clearly preferable to measure and interpret night flow measurements at times of the year when exceptional night use is at a minimum – typically April to October in New Zealand.

Whilst it is preferable to have continuous metering at treatment works outlets and bulk supply points, a comparatively low cost but reasonably effective ALC policy can be commenced by creating temporary metering facilities in small systems (for example, by insertion meters) and taking inflow and pressure measurements for several consecutive nights, one or twice a year, around May and September (an Italian example is given in Ref. 17).

If Zone inflows can be measured continuously for several days, the flow profile will give the first clue as to whether unreported leakage is high, or has risen since the previous measurements. If the night flow is a large proportion of the average daily flow, as in Figure 6.3, then there is likely to be substantial unreported (or unrepaired) leakage. However, if the night flow is only a small proportion of the average daily flow, as in Figure 6.4, then the likelihood of substantial unreported (or unrepaired) leakage is small.

Figure 6.3: Daily flow profile, high leakage Zone

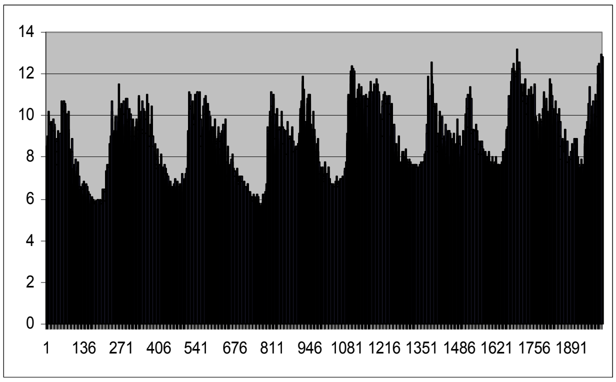
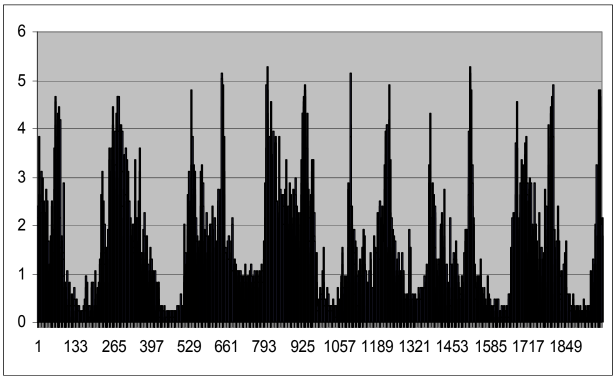


Figure 6.4: Daily flow profile, low leakage Zone



If it is only possible to obtain a [single] small number of night flows, once or twice a year, the approach outlined in Sections 5.2 and 5.4 could be used to obtain a 'Snapshot' night leakage rate, then (if Average Zone Night Pressure is known) convert it to a 'Snapshot ILI' and WBI Band.

For Pressure Management Zones or District Metered Areas with continuous night flow measurements, a more systematic approach to analysis of night flows is recommended, which considers the night flow as a series of components of consumption and leakage, some of which are pressure-dependent.

There is as yet no IWA standard terminology for components of night flow, and the fact that some residential properties in New Zealand are metered, and some are not, is an added complication. However, Figure 6.5 (from an early version of the ALCCalcs software, Ref. 18) shows a suitable practical terminology that New Zealand Water Suppliers are recommended to use, in the interests of standardising terminology. Some of the components of night flow are pressure-dependent, as indicated at the right-hand side of Figure 6.5; the FAVAD concept is explained in Section 6.4.

Figure 6.5: A practical terminology for components of minimum night flows in New Zealand

<table>
<tr><th colspan="4">A PRACTICAL TERMINOLOGY FOR COMPONENTS OF MINIMUM NIGHT FLOWS IN NEW ZEALAND</th><th colspan="2">Pressure-dependent?</th></tr>
<tr><td rowspan="8">Measured Minimum Night Flow</td><td rowspan="3">Night Leakage Rate on mains and service connections up to property line</td><td>Assessed Unreported Leakage</td><td>Assessed Unreported Leakage</td><td colspan="2">Yes, FAVAD N1 usually between 0.5 and 1.5, depends on type of leaks</td></tr>
<tr><td rowspan="2">Background Leakage on mains and service connections up to property line</td><td>On Mains</td><td colspan="2">Yes, FAVAD N1 = 1.5</td></tr>
<tr><td>On Service Connections (Main to property line)</td><td colspan="2">Yes, FAVAD N1 = 1.5</td></tr>
<tr><td rowspan="5">Customer Night Consumption, after property line</td><td rowspan="2">Background leakage on service connections and properties after property line</td><td>On service connections</td><td>Yes, N3 = 1.5</td><td rowspan="5">but N3 = 0 if component of consumption occurs after private storage tank</td></tr>
<tr><td>On leaking toilet cisterns</td><td>Yes, N3 = 0.5</td></tr>
<tr><td>Exceptional Night Use</td><td>Residential and Non-Residential</td><td>N3 usually close to 0.5</td></tr>
<tr><td rowspan="2">Assessed Night Use</td><td>Non-Residential</td><td>N3 usually close to 0</td></tr>
<tr><td>Residential</td><td>N3 usually close to 0</td></tr>
</table>

Source: ALCCalcs software

District Metered Areas: For medium and large systems, where there are a number of Zones with continuous night flow measurements, these may be 'District Metered Areas' (DMAs) or 'Pressure Managed Zones' (PMZs).

The IWA Water Loss Task Force 'DMA Guidance Notes' (Ref 24, 2007) is a comprehensive and free source of information on DMAs, aimed at leakage practitioners who have little or no experience of leakage control using DMAs. It covers:

- Philosophy of leakage control by DMA management
- Scheme design and DMA design
- Establishment of DMAs
- Selecting DMAs for leak detection
- Problematic DMAs
- Glossary and Bibliography
- 6 Appendices: Estimating Night-Day Factors, Estimating Average Pressure, Selecting DMAs for ALC, Night Consumption Estimation (UK experience), the BABE Concept, and Examples of successful DMA implementation.

The following brief notes on District Metered Areas are substantially sourced from the IWA Water Loss Task Force DMA Guidance Notes (Ref. 24)

The design of DMA schemes is very specific to individual networks' hydraulic and water quality conditions and regulations. Typically the design would commence from the trunk mains and extend towards the distribution network. The objective is to separate as much as possible the

DMAs from the trunk system, thus improving the control of the former without affecting the flexibility of the latter. Consequently a key element of this initial review will be to determine local practice or legal requirements regarding flexibility of supply such as satisfying fire fighting capacity etc.

In large and complex networks, DMA management should be introduced as part of an overall plan to monitor the flow from the main sources. In such situations, it might be preferable to divide the network first into larger sectors to identify the leakiest parts of the network. These sectors can then be prioritised for the creation of DMAs.

This initial plan needs careful consideration to determine the boundaries, as this initial design will be crucial to the overall success of the project and its long-term efficiency. In fact, where possible, natural boundaries should be used (rivers, streams and railway lines etc.) to limit the number of valves to be closed. However in a complex network, particularly where the existing pressures are low, it is advisable to use a calibrated hydraulic network model to identify the hydraulic balance points. Small urban and rural networks tend to lend themselves more easily into DMAs, thus eliminating the need for sectors.

Pressure control is an important factor in lowering and subsequently maintaining a low level of leakage in a water network (see also Section 6.6 below). The division of the network into PMZs and DMAs facilitates the creation of a permanent pressure control system, thus enabling reduction of excess pressures, which:

- reduces the flow rates of any existing leaks (including undetectable background leakage)
- reduces the risk of new leaks occurring when existing detectable leaks have been repaired
- prolongs the useful life of the distribution system
- reduces some components of consumption

Pressure control should be incorporated, wherever possible, into the reconfiguration of the system during the design of the DMA scheme.

Most Utilities that operate District Metered Areas effectively on a continuous basis will tell of additional benefits that occur with continuous monitoring of inflows and pressures in PMZs and DMAs, in addition to the rapid identification of both reported and unreported large leaks, and rate of rise of smaller unreported leaks.

These other benefits can be broadly summarised as ‘knowing what is happening in your system’ and include the identification of thefts of water, understanding daily, weekly and monthly consumption patterns, monitoring during operational alterations to supply, and monitoring pressure fluctuations/performance of pressure reducing valves.

There are various opinions on the sizing of District Metered Areas (DMAs). In practice, there will always be a significant variation in size of DMA due to the layout of the existing infrastructure and the need to optimise pressure management. In the UK, DMAs are often sized by the number of properties, where typically a property is supplied by a single customer connection. Consequently, DMAs in urban areas vary between 500 and 3000 service connections.

It has been found that if a DMA is larger than 5000 properties, it becomes difficult to discriminate small bursts (e.g. service pipe bursts) from night flow data, and burst location takes longer. However, the consideration of Rate of Rise of unreported leakage comes into play here. If this Rate of Rise is quite small (as in the large DMA in Figure 6.2, with 8000 service connections, an ILI close to 1.0 and a very low Rate of Rise of unreported leakage), the case for subdivision into smaller permanent DMA.s may be hard to justify purely on grounds of identifying unreported leaks.

However where appropriate, large DMAs can be divided into smaller temporary DMAs by closing additional valves so that each sub-area is fed in turn through the DMA meter for leak detection activities. In this case, the cost of any extra valves required should be taken into account at the DMA design stage.

A typical installation of a water meter and pressure reducing valve is shown in Appendix H.

Indicative costs for these types of installations are given in the table below:

Table 6.3: Indicative costs for water meter and pressure reducing valve installation

Refer Appendix H for Typical Installation Details	Indicative Cost for 100mm Pipeline (as Appendix H) 80mm PRV, Meter, Strainer	Indicative Cost for 150mm Pipeline (as Appendix H) 100mm PRV, Meter, Strainer
Two chambers with lids, drainpipes etc	12,000	12,000
Pipes, fittings and line valves (excludes bypass)	3,000	6,000
Pressure Reducing Valve	2,300	3,000
Water Meter	1,200	1,500
Strainer	400	500
Total	**$ 18,900**	**$ 23,000**

Note: Costs in 2009 NZ$

6.4 Setting Leakage Targets for Zones, and Budgeting for Economic Intervention

Setting Leakage Targets for Zones: for distribution systems with more that 20 service connections per km of mains (which probably comprise most New Zealand distribution systems) the majority of unreported leakage is likely to be associated with service connections, and so simple targets can be set in litres/service connection/hour. If the majority of unreported leakage is found to be on mains, then the target could be set in litre/km of mains/hour. However, these simple indicators take no account of system pressure. Figure 6.14, in Section 6.6, shows how minimum night flow in a relatively high leakage Zone in Brazil changes significantly with pressure.

The Unavoidable Annual Real Losses (UARL), which is used to calculate the Snapshot ILI from minimum night flows (see Section 5.4) increases:

- as the Average Zone Night Pressure (AZNP) increases
- as the density of connections (DC) increases.

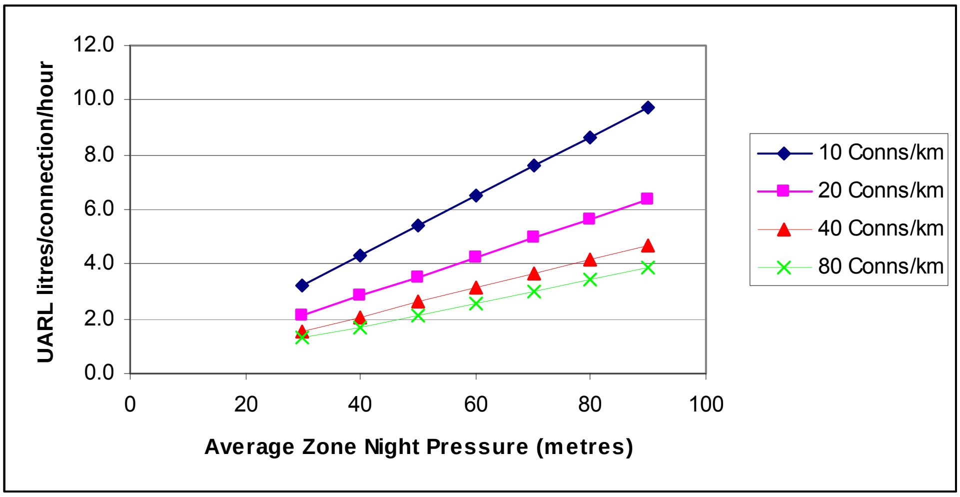
The UARL in litres/service connection/hour can be calculated from the equation:

$$\text{UARL (litres/connection/hour)} = (18/DC + 0.8) \times AZNP/24 = (0.75/DC + 0.0333) \times AZNP$$

Figure 6.6 shows that the UARL in litres/service connection/hour can vary widely, from:

- 1.5 litres/connection/hour at 80 connections/km and 30 metres pressure, to
- 10 litres/connection/hour at 10 connections/km and 80 metres pressure

Figure 6.6: Variation of UARL in litres/connection/hour with Average Zone Night Pressure and Density of Connections



Given the wide variation in connection densities and pressures in New Zealand, use of the same fixed target value in litres/service connection/hour for all Zones is not a reliable strategy. Instead, Zone targets could be set in terms of a Snapshot ILI (as occurs in Malta, Ref 25), recognising that the Snapshot ILI might fall to 1.0 or even slightly less than 1.0 immediately following an intervention to find and repair all detectable leaks.

If New Zealand Water Suppliers prefer to continue to express targets in terms of litres/connection/hour, the targets based on Snapshot ILIs can easily be converted to litres/service connection/day for each individual Zone, as shown in the following example:

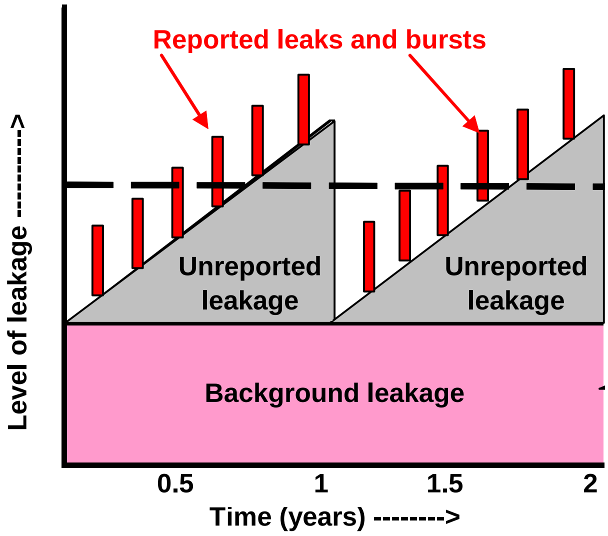
- Suppose target Snapshot ILI for all Zones = 2
- Zone A has DC of 40 and AZNP of 45; UARL = (0.75/40 + 0.0333) x 45 = 2.3 litres/conn/hour
- Target night leakage for Zone = Snapshot ILI x UARL = 2 x 2.3 = 4.6 litres/conn/hour
- Add 2 litres/connection/hour for customer night consumption, target MNF = 6.6 litres/conn/hour.

Then repeat calculations for Zones B, C, D, etc.

For a typical urban water supply, one would expect a target for ‘Real Water Losses’ to fall within the range of 75 to 150 litres/connection/day, but the figures also need to be expressed as an ILI to ensure that a low value in litres/service connection/day is not the result of favourable operating conditions (lower pressures and higher density of connections).

Budgeting for Economic Intervention: Where Water Suppliers have previously not undertaken Active Leakage Control, there is usually a problem with obtaining a revenue budget allocation to get started. It is also necessary to recognise that ALC is not a one-off activity, as the unreported leakage will continue to rise after the first intervention has taken place, and further regular interventions will be needed. Figure 6.7, from Ref 26 shows this diagrammatically.

Figure 6.7: Variation of Components of Real Losses with Time and ALC Interventions



SourceL Fantozzi & Lambert (2007)

If the Rate of Rise of unreported leakage (the slope of the grey triangles in Figure 6.7) can be estimated, even approximately, then the Economic Intervention frequency occurs when the $ value of the lost water in the grey triangle equals the cost of the intervention (CI) to detect the unreported leaks. This Economic Intervention Concept (Refs. 17, 26) can then be used to assess the economic frequency of intervention, and the annual budget requirements for each Water Supplier (excluding repair costs).

There are 3 quick methods for assessing Rate of Rise (RR) in m^3 per day, per year:

- for Water Suppliers not currently doing ALC:
  - increase in annual System Real Losses from successive annual water balances
- for Water Suppliers currently doing ALC or measuring night flows:
  - analysis of leaks found between successive interventions
  - increase in night flows from one Spring or Autumn to the next

The 2 other parameters needed for the calculation are:

- Cost of an Intervention CI : in $, or $/service connection, or $/km of mains
- Variable Cost of lost water CV : $/m^3$

If Intervention Cost CI is in $, Variable Cost CV is in $/m^3$ and RR is in m^3/day, per year:

Economic Intervention Frequency EIF (months) = $\sqrt{(0.789 \times CI/(CV \times RR))}$ ....(1)
Economic Percentage of system to be surveyed annually EP (%) = 100 x 12/EIF............(2)
Annual Budget for Intervention (excluding repair costs) ABI ($) = EP% x CI.....................(3)
Economic Unreported Real Losses EURL (m^3) = ABI/CV ....(4)

A simple calculation for a system with 10,000 service connections and 250 km of mains is shown below:

- unreported leakage rises (RR) by 200 m^3/day in a year (20 litres/connection/day/year)
- variable cost of Water CV = 0.5 $/m^3$
- cost of a whole system intervention CI (excluding repairs) = $200/km = 200 x 250 = $50,000

Economic Intervention Frequency (months) = $\sqrt{(0.789 \times CI/(CV \times RR))}$ = 20 months
Economic Percentage of system to be surveyed annually EP (%) = 100 x 12/EIF = 60%
Annual Budget for Intervention (excluding repair costs) ABI ($) = EP% x CI = $30,000/year
(equivalent to $3/service connection/year)
Economic Unreported Real Losses EURL (m^3) = ABI/CV = 60,000 m^3/year (16 litres/conn/day)

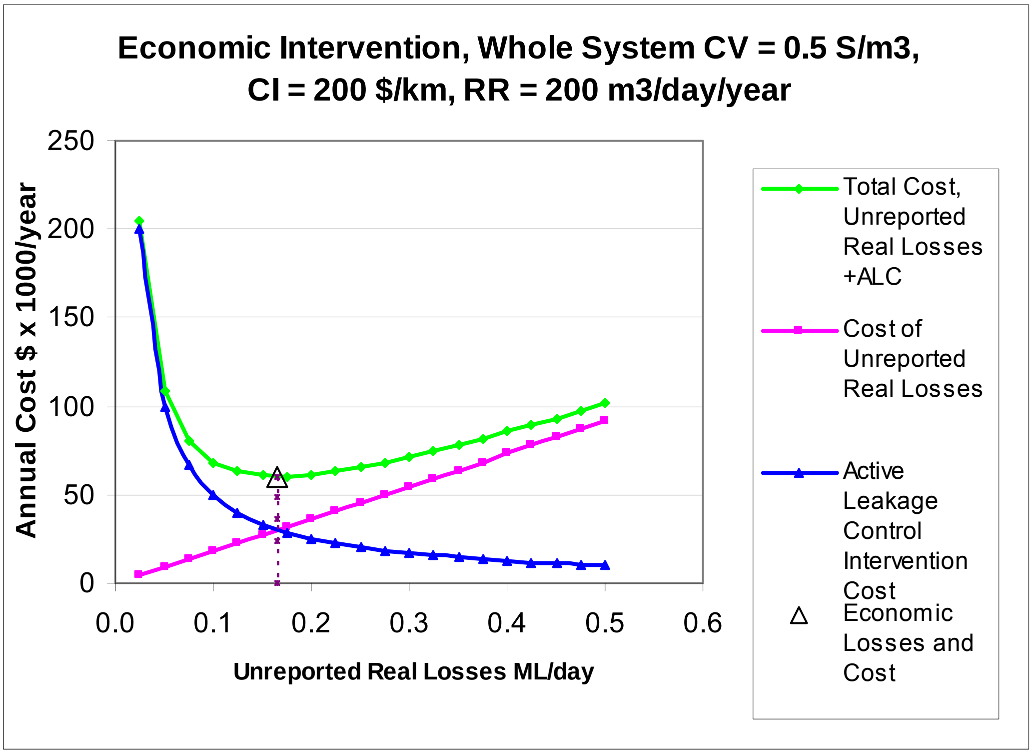
The ALCCalcs software (Ref. 18) is designed for these calculations, and the same calculation as done manually above is shown in Figure 6.8, with confidence limits.

Figure 6.8: Calculation of Economic Intervention Parameters using ALCCalcs software

Data entry	Calculated values	Data from another Worksheet		
Step 1: Enter Country, Currency, Volume Units, Utility and System				
Country	New Zealand	Currency = NZ$	Volume units =	m^3
Utility	Anytown Water Council	System	Whole System	
Step 2: Enter mains length & number of service connections				Conf. limits+/
Length of mains	250.0	km		1.0%
Number of service connections	10000			2.0%
Step 3: Enter key parameters for calculations (CV, CI, RR)				Conf. limits+/
Variable cost of water CV =	0.500	NZ$/ m^3		10.0%
Full system intervention cost CI (excluding repair costs) NZ$/km =	200	50000	NZ$	10.0%
Natural Rate of Rise of unreported leakage RR	200.0	m^3/day in a year		25.0%
	20.0	litres/conn/day per year		
	1.00	m^3/km mains/day/year		
and is categorised as being	Low			
Step 4: Review calculated figures for Economic Intervention				Conf. limits+/
Economic Intervention every	19.9	months		4.0
Economic Percentage checked	60%	of system per year		12%
Annual Budget for Intervention	30.2	Thousand NZ$		6.1
	3.0	NZ$/conn/year		0.6
Economic Unreported Real Losses	60.4	Thousand m^3/year		12.3
	16.6	litres/service conn./day		3.4
	0.66	m^3/km of mains/day		0.13
Step 5: Complete the Audit trail for the calculation				
Name	A.N.Other	Date	2nd Dec 2009	
e-mail	Anyone@anywhere.com			

This approach uses the same basic methodology as the more complex methods developed in the UK during the 1990's, as can be seen from Figure 6.9, which is one of the graphs produced with the ALCCalcs calculations in Figure 6.8. However, it is much easier to apply using the 'Rate of Rise' concept. Because the predictive equations are based on square root functions of RR, CI and CV, the results are not highly sensitive to moderate variations in estimating these parameters (particularly Rate of Rise, RR).

Figure 6.9: Graph from ALCCalcs software showing Economic Intervention Concept



Source: ALCCalcs software

It should be noted that, at the economic intervention frequency, the Annual Budget for Intervention $30k in the above example) will be the same as the value of the water lost from unreported leaks. If the intervention frequency actually used in more frequent, or less frequent than the Economic Intervention Frequency, this is false economy as the sum of the value of water lost + annual intervention cost will be above the minimum total for the Economic Intervention Frequency.

Once the budget for Economic Intervention Frequency has been assessed for the whole of a Water Supplier's system, the same basic equations can be applied to each individual Zone within the system to determine the Economic Intervention Frequency for each individual Zone.

6.5 Network Condition and burst frequency

Burst Frequencies: are a good indicator of Network Condition. Accordingly, Water Suppliers should record their mains repairs and service connection repairs in formats that permit the calculation of monthly numbers and annual frequencies as follows:

- Mains repairs expressed in number/100 km/year
- Service connection repairs in number per 1000 service connections per year.

Service connection repairs should be sub divided into:

- repairs at the ferrule/main joining point
- repairs on the service between the main and the stoptap/toby or external meter
- repairs on the stop tap/toby or external meter

Some types of pipes have relatively high burst frequencies – for example, small diameter cast iron and fibre-cement mains appear to be particularly prone to failure by ring cracks. Until recently, it was widely considered that the only solution to an increase in burst frequencies on particular sections of mains or services was to replace these assets; but pipe replacement is by far the most expensive of the '4 Components' approach in Figure 5.6 (in terms of $ spent per kl saved).

However, the Pressure Management Group of the IWA Water Loss Task Force has now clearly identified many Zones world-wide (Ref 12, 2006) where burst frequencies on mains and or service connections have been significantly reduced by pressure management. This has resulted in an international resurgence of interest in pressure management – which previously tended to be cost-justified only on the value of the reduction in leak flow rates.

When pressure management is introduced, in some Zones both mains and service bursts are reduced (see Fig 2.5). In other Zones, either mains or service bursts are reduced, but not both.

The latest WLTF Pressure Management Group method for predicting if either, or both, or neither, will reduce is outlined in Appendix D. The starting point is to compare actual repair frequencies (for, say two years prior to possible implementation) with the reference frequencies for well managed infrastructure in the UARL formula of:

- 13 per 100 km /year for mains repairs
- 3 per 1000 service connections/year for services (excluding stop taps/tobys, meter repairs)

Separate values of a Burst Frequency Index (BFI) can then be calculated for mains, and for services. For example, in Wide Bay Water (Australia) (Figures 6.10 and 6.11), before implementation of pressure management, the mains burst frequency was around 12 to 15 per 100 km/year, close to the UARL frequency of 13 per 100 km/year; but the service pipe burst frequency was 31 to 34 per 1000 service connections/year (around 11 times the UARL frequency of 3 per 1000 service connections/year).

Figure 6.10: Mains burst frequencies

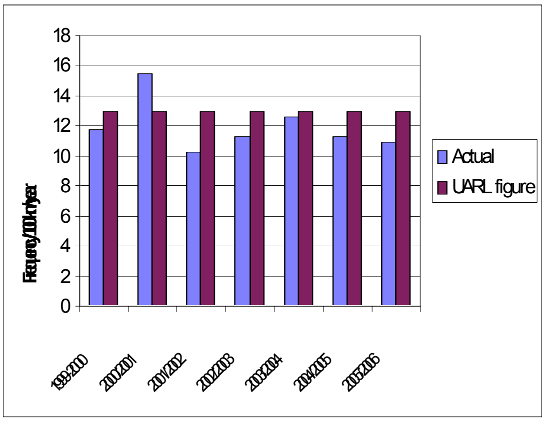
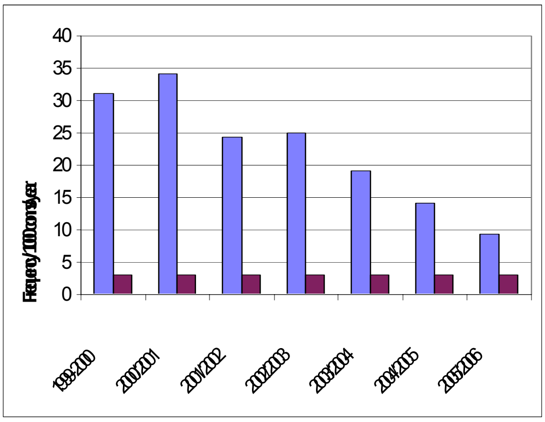


Figure 6.11 Service connection burst frequencies



The high BFI for service connections was a good predictor that, with pressure management, service connection bursts would reduce significantly (which they did). The low BFI for mains was also a good indicator that mains burst frequency would hardly be affected by the pressure management.

A quantitative prediction method of bursts reduction is under ongoing review by the Pressure Management Group of the Water Loss Task Force, and is being tested and improved as reliable data increasingly becomes available (Ref. 13).

One of the immediate practical benefits of reductions in burst frequencies is that some resources in operational budgets for repairs costs, out of hours work costs, manpower etc are immediately freed up for other uses

Although mains burst frequencies in Fig. 6.10 did not change significantly (because they were in good condition as indicated by their BFI being close to 1), the prediction method in Appendix D implies that their working life will have been increased. A methodology to value this benefit is currently being investigated by the Pressure Management Group of the Water Loss Task Force.

6.6 The many influences of Pressure Management

Pressure Management has been defined (Ref 12) as

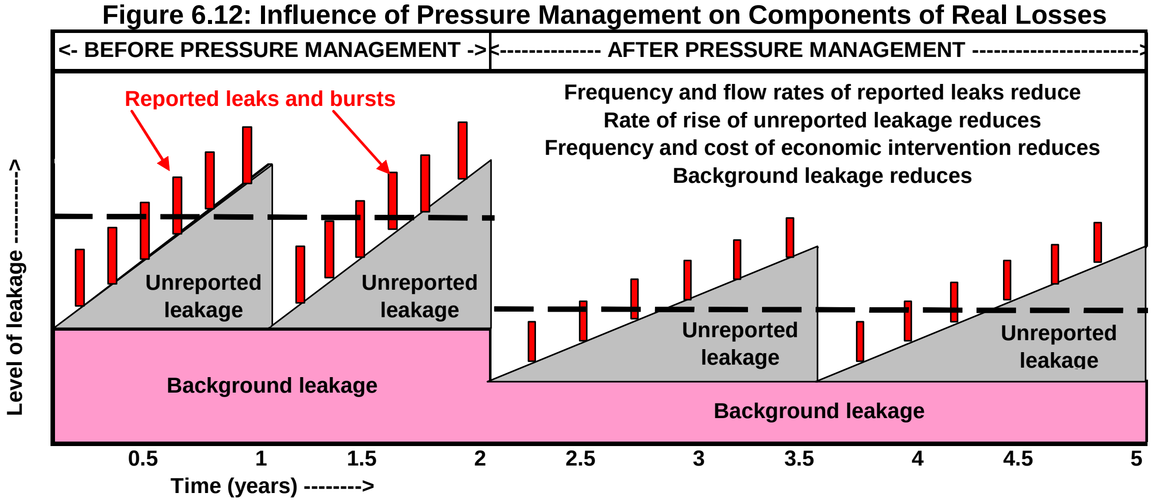
The practice of managing system pressures to the optimum levels of service ensuring sufficient and efficient supply to legitimate uses and consumers, while reducing unnecessary or excess pressures, eliminating transients and faulty level controls all of which cause the distribution system to leak unnecessarily

Pressure management has the following benefits:

- reduction of existing and future leak flow rates, and some components of consumption
- possible reduction of new burst frequency, and/or extension of infrastructure life

Figure 6.12 (which can be compared with Figure 6.7) shows how implementing of pressure management can be effective in reducing all the components of Real Losses.

Figure 6.12: Influence of Pressure Management on Components of Real Losses



Source: Fantozzi and Lambert, 2007

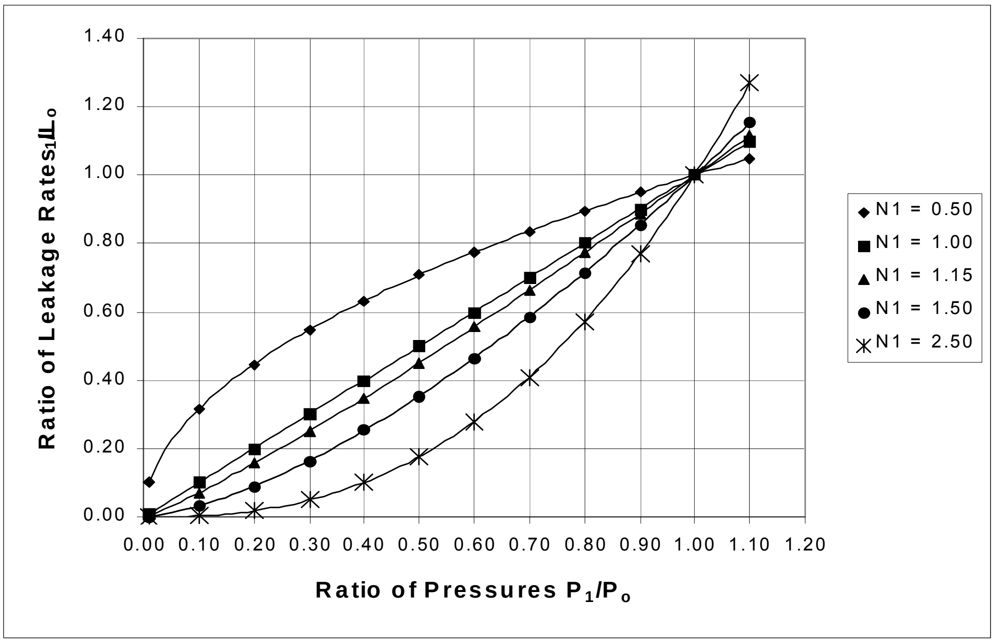
All of these influences can now be predicted, with increasing reliability (Ref. 13).

Predicting changes in leak flow rates The most 'Best Practice' form of equation for pressure: leak flow rate relationships is based on a simplified version of the FAVAD (Fixed and Variable Area Discharges) concept (Ref. 27), using the equation:

$$\text{Leak flow rate L varies with } P^{N1} \quad \text{and} \quad L_1/L_0 = (P_1/P_0)^{N1}$$

As shown in Figure 6.13 if the average pressure is reduced from P_0 to P_1, flow rates through existing leaks change from L_0 to L_1, and the extent of the change depends on the ratio of average pressures and the exponent N1. Higher N1 values represent leaks where flow rate is more sensitive to pressure.

Figure 6.13: FAVAD Equation shown as a graph



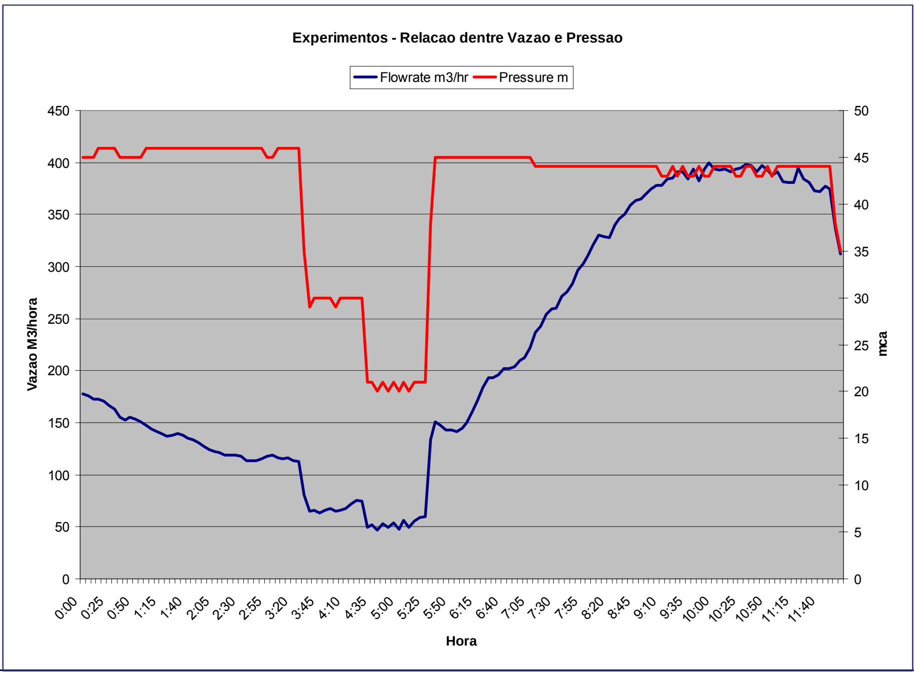
Source: PressCalcs software

Tests on systems and pipe samples have shown that different kinds of leaks have different N1 exponents:

- for background leakage, and splits on flexible pipes, N1 is usually close to 1.5
- for detectable leaks and bursts on rigid pipes (corrosion holes, ring cracks etc) N1 = 0.5

Figure 6.14 from Brazil, shows an N1 test. When night flow stabilises, pressure is reduced in steps, and the night flow reduces with each step. After deducting estimates for night consumption, the three night leakage rates can be compared with the three Average Zone Night Pressures, and the N1 values calculated.

Figure 6.14: Example of an N1 Test (Brazil). Pressure in red, night flow in blue

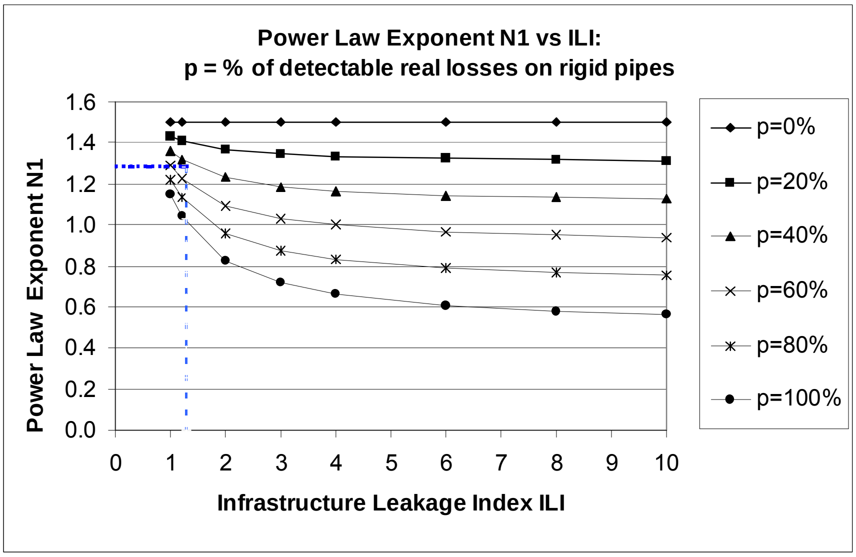


Drawing on a international test data, the IWA WLTF Pressure Management Team has developed and tested the prediction method for N1 shown in the equation below, and Figure 6.15, the upper line for 100% flexible pipe materials (p = 0%) is assumed to be constant at 1.5, whatever the ILI. The lower line for 100% rigid pipe materials was calculated assuming N1 = 1.5 for unavoidable background leakage for infrastructure in good condition, and N1 = 0.5 for detectable leaks in rigid pipes. Intermediate lines are based on the empirical equation:

$$N1 = 1.5 - (1 - 0.65/ILI) \times p/100$$

So, for example, if ILI = 1.3 and p = 43%, the predicted N1 is around 1.3.

Figure 6.15: Predicting the N1 exponent using ILI and % of detectable real losses on rigid pipes



Predicting changes in some components of residential consumption also uses the Favad concept, but with an exponent N3. The consumption is split into 'in-house' and 'outside' components.

- for 'Outside' components, N3 is 0.5 for hoses and sprinklers, 0.75 for seepage and weeper hoses, and (obviously) zero for swimming pools.
- For 'in-house' consumption, N3 is less (usually in the range 0 to 0.1) and depends upon a number of specific factors

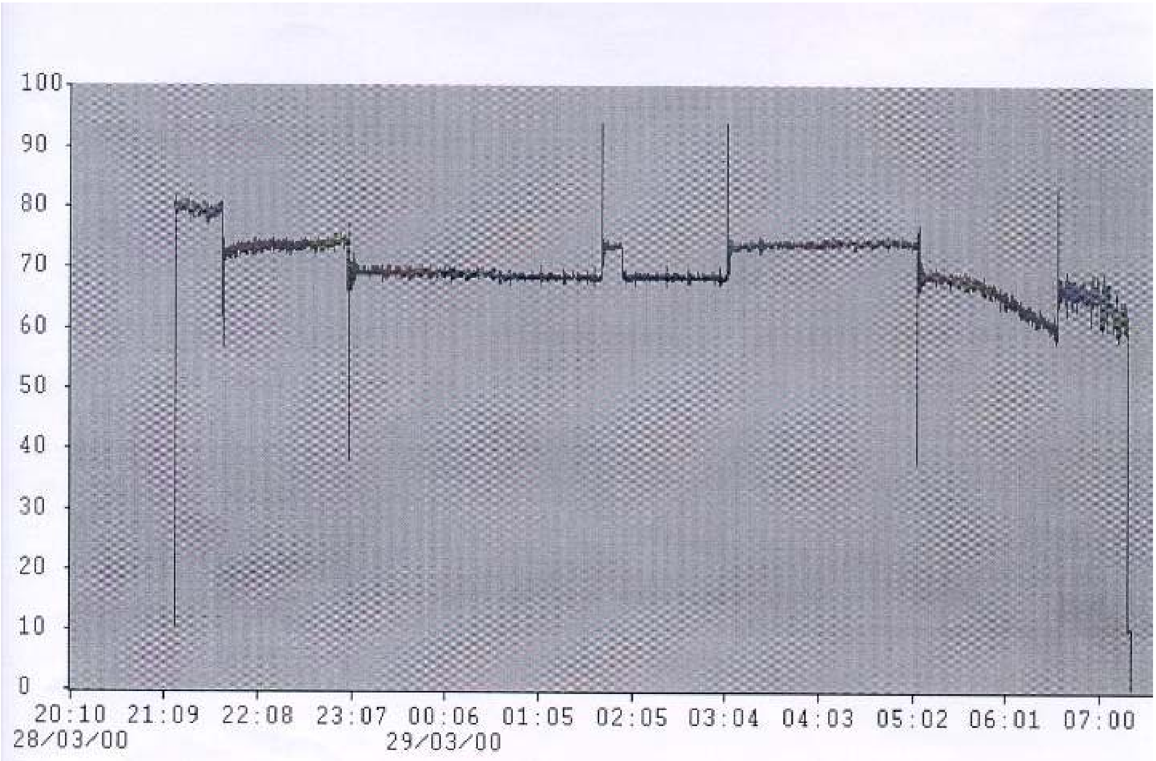
This method is used to predict changes in income from metered customers. Note that, if a Water Supplier is considering introducing Pressure Management and metering residential customers for the first time, there is merit in doing the pressure management first as there will be no significant change in income if residential consumption reduces.

Predicting changes in burst frequencies has been explained in Section 6.5 and Appendix D. However, there is one simple test that every Water Supplier should do. The largest reductions in bursts from pressure management have been associated with pumped systems, with pressure transients, which can add 20 or 30 metres to normal maximum pressures.

So check for the presence of pressure transients and surges in all Zones, even those supplied by gravity. This is because customers are sometimes the cause of transients (pumps switched on and off, sudden closures of valves).

Set a pressure logger somewhere in the Zone for 1 week, recording at 1 second intervals. The results can sometimes be surprising (Figure 6.16), as most pressure loggers are set to record the average pressure over 5, 10 or 15 minutes, and would not show the presence of transients.

Figure 6.16: Pressure transients in a Zone with pressure booster pumps



Simplified and Detailed Predictions of the Effects of Pressure Management:
The 'PMOpportunities' Worksheet in CheckCalcs provides an initial overview of the possible rage of changes in leak flow rates, burst numbers and residential consumption. The purpose of this is so that Users can see that predictions of all three effects are possible, and to see if they are interested to look into Pressure Management opportunities further.

Figure 6.17: Excerpt from 'PMOpportunities' Worksheet, CheckCalcs software.

Step 1:	Check for presence of surges by recording sample pressures in system at 1-second intervals.
Step 2:	Assess probability of Pressure Management opportunities based on type of supply (gravity or pumped) and average pressure

			Type of System	Average Pressure	Probability
ABC Water			Gravity supply	Less than 30 metres	LOW
Anytown				30 to 40 metres	MODERATE
Average System Pressure Pav is	58.9	metres		40 to 60 metres	MEDIUM
System is supplied principally by gravity with	Continuous supply			More than 60 metres	HIGH
Using this information, and the assessment method shown, the probability of pressure management opportunities for this system can be provisionally categorised as	MEDIUM		Direct pumping	All	HIGH
			Intermittent Supply	All	HIGH

Step 3: Predict possible changes in leak flow rates, frequency of new bursts and repair costs, and residential consumption, for change in pressure

			Probable range of predicted changes:	Lower	Average	Upper
Assumed change in average system pressure	-5.00	metres				
Assumed % change in Pav	-8.5%		% change in current leak flow rates	-4%	-8%	-12%
% of annual residential consumption outside property	30%		% change in new burst numbers and annual repair costs	-6%	-12%	-24%
Do customers have private storage tanks? (Yes/No)	No		% change in residential consumption	-0.3%	-0.8%	-1.3%

An appropriate software for gaining a better understanding of the various principles, and making System and Zone-specific predictions of Payback Periods taking all three effects into account, is the PressCalcs software (Ref. 13)

Predicting changes in infrastructure life is being investigated by the Pressure Management Group of the Water Loss Task Force.

Implementing Pressure Management Schemes
Reducing water pressures can impact customer service and fire sprinkler systems, so particular care needs to be taken when implementing pressure management. The following measures are recommended, based on experience:

- Identify fire sprinkler systems in the area to be affected, and establish whether or not the systems are likely to be non-compliant after the pressure reduction. Depending on the policy of the Water Supplier, the response to property owners can range from 'our legal opinion is that there is no obligation to maintain water pressures above a minimum service level (of between 200kPa and 300kPa)', to the Water Supplier working proactively with the property owner and fire contractor to resolve issues before they arise. The latter is considered to be a responsible approach and is recommended. A customer can argue that if the Water Supplier is implementing these measures to reduce costs, then the cost of making initial changes should be considered in a cost/benefit analysis (i.e. the long term savings should justify initial costs). The cost of installing pumps for fire sprinkler systems is high (typically more than $60,000 with diesel backup power supply) and hence the initial assessment of sprinkler systems should be carried out at an early planning stage. The issue of fire sprinkler system compliance is likely to be the most problematic in implementing pressure management, and options for areas with a high density of fire sprinkler systems may be limited.
- A communications strategy is necessary, as customers will notice changes when pressures are adjusted. This typically comprises public notices and a letter drop to all property owners advising of the changes and the benefits of pressure management. Some impacts, such as the performance of hydraulic disabled person lifts, or other hydraulically operated equipment are often difficult to pre-empt.
- Monitoring of pressures in the network immediately before, during the transition, and after adjusting pressures is essential.
- Pressures should be reduced gradually and in stages over a number of days or weeks so that impacts can be dealt with in a managed way. A plumber should be on hand to adjust showers (which are an essential customer requirement), as some showers will be adversely affected.

Further useful information on implementing pressure management is included in the paper by Pilipovic and Taylor (2002) entitled 'Pressure Management in Waitakere City – A Case Study', a copy of which is provided in Appendix I.

6.7 Economic level of leakage

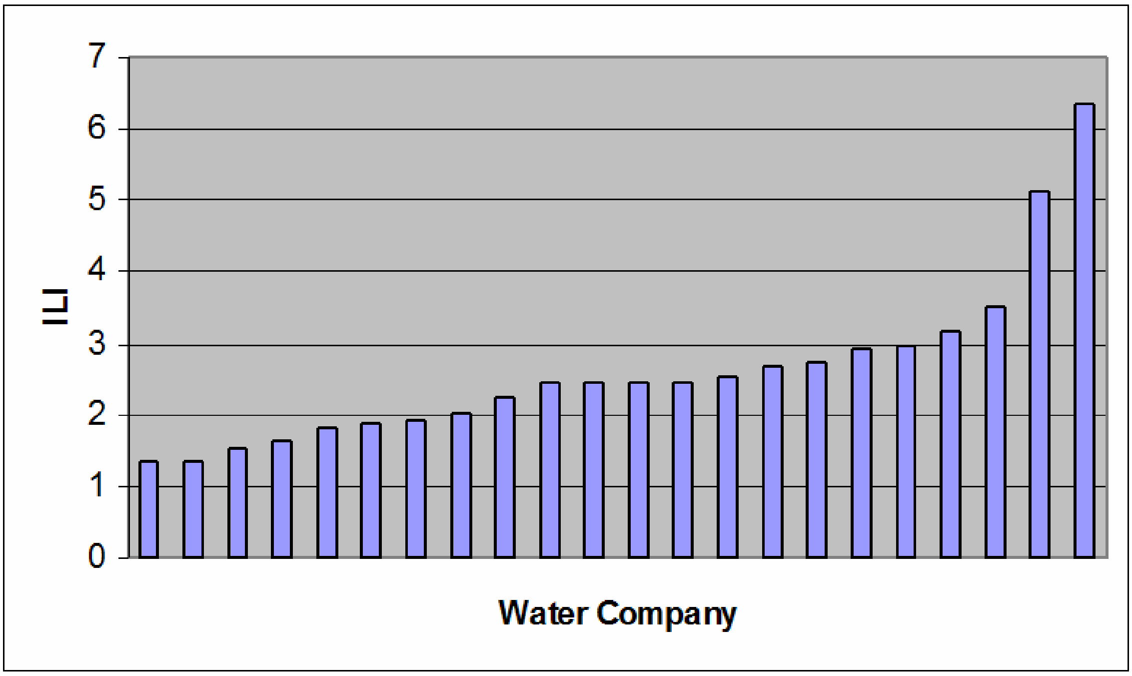
Economic level of leakage (ELL) was a concept mainly developed in England and Wales during the period 1994 to 1998. The Water Companies – many of which had been privatised in 1990 – were required to demonstrate to the Economic Regulator (OFWAT – Office of Water Services - that they had achieved economic leakage levels, using 'robust' methodologies.

The basics of the two main methodologies used first appeared in one of the 1994 UK Leakage Control Initiative Reports (Ref. 28). Both methods were based on the concept of minimising the sum of Cost of Intervention and Cost of Lost Water, and were mainly concerned with assessing the Economic Intervention Frequency for Active Leakage Control (the right hand arrow of the 4 Components diagram), see Figure 6.9. One approach was based on modelling of BABE components, the other was an empirical curve fit to night flows. Neither could be easily applied at both System and Zone level.

By 1998, most England and Wales Companies had demonstrated, to the satisfaction of OFWAT, that they had achieved Economic Leakage levels. The ILIs for England and Wales Companies in 2002 are shown in Figure 6.18. All but the two Companies with the highest ILIs are considered to have achieved Economic Leakage Levels. Their ILIs range from 1.3 to 3.3, and:

- Companies with the lowest ILI are those where water is scarce and relatively expensive
- Companies with the lowest ILI are those where water is more plentiful and relatively cheap.

Figure 6.18: ILIs for England & Wales Water Companies, 2002-03



Source: UK Environment Agency

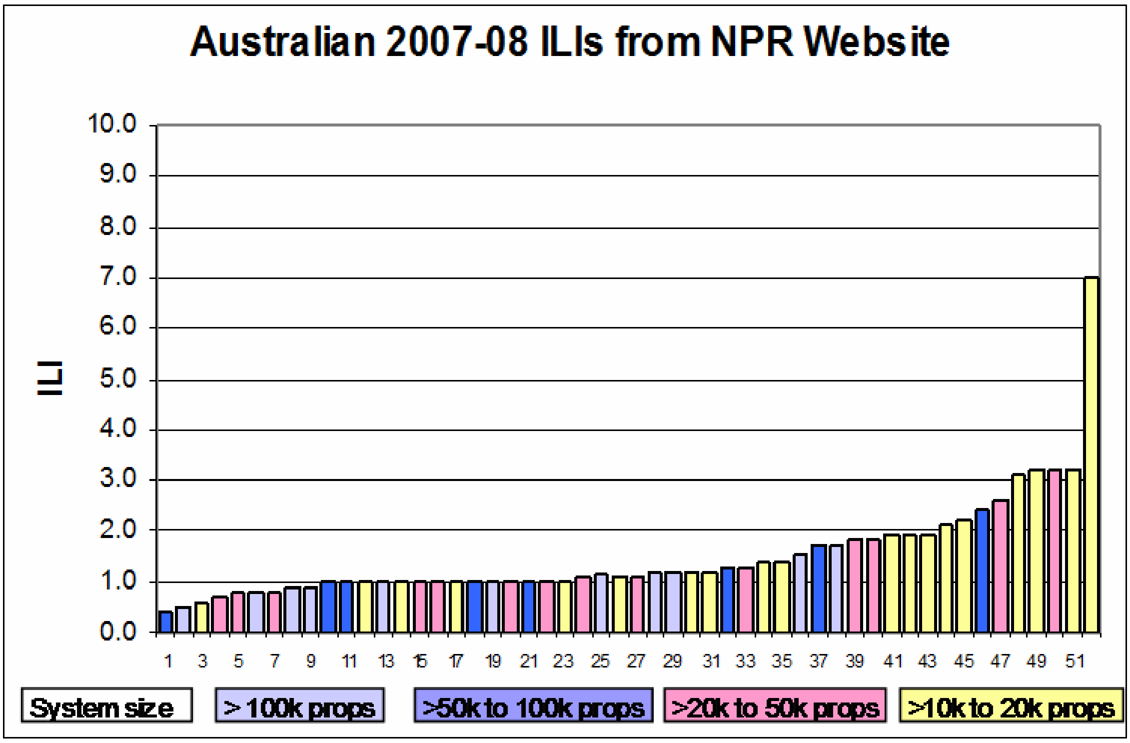
A broad provisional conclusion to be drawn from this England and Wales data is that in a developed country, Economic ILIs of up around 3 are roughly appropriate for a Water Utility with plentiful and cheap supplies, but where there are shortages and water is scarce, ILIs should be close to 1.0.

Recent experiences in Australia and New Zealand also suggest that, where water is scarce (or potentially scarce) and therefore expensive, Water Suppliers should be achieving ILIs close to 1.

ILIs from the 2007-08 Australian National Performance Report (Ref 29), shown in Figure 6.19, show that, following five years of severe drought, a majority of Australian Utilities (including all the large cities) are achieving ILIs close to 1, but that a few (mostly in the wetter North and North-East) have ILIs around 3. Several of the lowest ILIs have been checked and found to be under-estimates, due to problems of measuring such low levels of leakage (many of which have been discussed in Sections 3 and 4 of these Guidelines).

The Real Losses in most Australian that provide data to the National Performance Report (Ref. 29) are now so low that the new WSAA Water Balance software (Ref. 14), has split WBI Band A into two – Band A1, for ILI less than 1.5, and Band A2, for ILIs 1.5 to 2.

Figure 6.19: ILIs in Australian Water Utilities, 2007-08



In New Zealand, in the greater Auckland region, where water is also relatively scarce and relatively expensive, most of the Distribution Utilities are now achieving ILIs in the range 1.0 to 1.5.

Regarding the broader topic of assessment of Economic Leakage Levels, it is now very clear from the work of the IWA Water Losses Task Force that it is not sufficient to simply calculate an Economic Intervention Frequency for Active Leakage Control at current pressures, and then to claim this is an Economic Leakage Level. It is also necessary to look for opportunities for pressure management, and to bring the effect of such activities into the calculations, as indicated in Figure 6.12.

Software to do such calculations (ELLCalcs, Ref. 30) is being used in Canada (Ref. 31). However, in New Zealand, there are relatively few Water Suppliers whose data and practices are robust enough for such analysis at present. So the emphasis for the next few years should be to understand and apply principles of Economic Intervention for Active Leakage Control, and to seek opportunities for Pressure Management with relatively short payback periods.

6.8 Key points from Section 6

- Section 6.1 and Appendix G provide an overview of Bulk Metering and associated problems
- reported mains bursts usually account for less than 10% of Annual Real Losses
- the basic principles of Component Analysis of Real Losses, using the BABE (Bursts and Background Estimates) concept assist understanding of how and where real losses occur
- real loss management deals with limiting the duration of all leaks, however small
    - o a toilet leaking for 16 months can lose as much water as a reported mains burst
- all Water Suppliers need to do Active Leakage Control (looking for unreported leaks), at a frequency appropriate to their system characteristics
- night flow measurements in Zones are an excellent way of identifying whether there are any unreported leaks worth looking for
    - o but take measurements at times when night consumption is at its lowest

- a practical standard terminology for components of minimum night flows in New Zealand is proposed in Figure 6.5; please use it to reduce misunderstandings and wasted time
- the IWA DMA manual (Ref 24) is an excellent source of information on setting up DMAs
- unavoidable real losses vary widely with average pressure and density of connections in individual Zones; so use Snapshot ILI to set targets for night flow, and then express them in litres/connection/hour if you prefer
- the Economic Intervention concept can be used to rapidly assess appropriate budgets for Active Leakage Control, giving the same results as more complex UK calculation methods
- burst frequencies on mains (per 100 km of mains/year) and on service connections (per 1000 service connections/year) are a good indicator of network condition
  - and if the frequencies are high they may be reduced by pressure management
- pressure management has other benefits – reduction of leak flow rates and some components of consumption - so there is advantage to undertaking pressure management before metering residential customers
- all Zones should be checked for pressure transients – even Zones supplied by gravity
- a rapid overview assessment of possible range of benefits of pressure management can be made with CheckCalcs
- the Pressure Management Group of the IWA Water Loss Task Force is progressing improved methods of detailed predictions of pressure management benefits
- reducing water pressures can impact customer service and fire sprinkler systems so particular care needs to be taken when implementing pressure management
- data from the UK suggests that economic ILIs are likely to be within the range 1 to 3, with lowest values where water is most expensive and supply is actually or potentially limited
- experience from Australia and New Zealand (Auckland region) shows that ILIs close to 1 can be achieved

7.0 Recommended Water Loss Strategy

A recommended water loss strategy is summarised in the table below. The order of the items in the left hand column of the table is the order which is generally likely to be the most cost effective in achieving reduction of Real Losses. The table describes typical activities required of Water Suppliers operating at a basic level and at an advanced level.

Table 7.1: Recommended Water Loss Strategy

Activity	Basic	Advanced
Activity 1: Categorise Size of System	• Categorise your System(s) as Large, Medium or Small, using Table 2.1 • Identify the Recommended Method(s) for assessing Real Losses, either Water Balance and/or Minimum Night Flow Measurements	
Activity 2a: Water Balance calculation of Real Water Losses and Performance Indicators, including Infrastructure Leakage Index ILI, preferably with confidence limits, using BenchlossNZ 2008 or CheckCalcsNZ software.	• Be aware of high uncertainty in main components of water balance such as system input, authorised consumption and customer meter under-registration. • For unmetered connections, assumptions made regarding consumption, not based on any monitoring data, will have the largest uncertainty • Use standard defaults for Unauthorised Consumption, Unbilled Authorised Consumption, and customer meter under-registration.	• Reduced level of uncertainty limits for the following: − System input meters accurate (and preferably multiple). − For metered systems, meter lag effects carefully considered and Meter under-registration (accuracy) checks have been carried out to justify percentage under-registration figure(s) used. − For unmetered systems, a soundly based 'monitoring' programme has been carried out. − Unbilled Authorised Consumption (system flushing etc.) is metered or assessed.
Activity 2b: Minimum Night Flow measurements (MNF).	• Large open network. • Occasional datalogging. • Use of insertion flow meters. • Reservoir drop tests. • Assess the Snapshot ILI	• Network divided into District Metered Areas (DMAs). • Calibrated water meters supplying DMAs. • Continuous on-line monitoring. • Automatic reporting on MNF. • Economic Intervention Policy
Activity 3: Classify current performance using World Bank Institute Banding System	• Classify ILI or Snapshot ILI in WBI Band A, B, C or D using Figure 5.10 • Check appropriate Activity Priorities using Figure 5.11	• Classify ILI or Snapshot ILI in WBI Band A, B, C or D using Figure 5.10 • Check appropriate Activity Priorities using Figure 5.11
Activity 4: **Investigate Speed and Quality of Repairs.**	• Slow, random response to reported faults, including reported and unreported leaks. • Failure to repair difficult leaks, smaller leaks on Utility system • Failure to ensure leaks on unmetered private service pipes are repaired	• Monitored, timely response to all reported faults and unreported leaks on Utility infrastructure. • Optimised resources for maintenance work. • Options for improved maintenance, including methods and materials, are continually examined to reduce leakage volumes. • Ensures leaks on unmetered

Activity	Basic	Advanced
		private service pipes are repaired
Activity 5: Active Leakage Control.	• Random interventions, usually after problems have occurred. • Untargeted acoustic leak detection. • Use of basic technology (acoustic listening only). • Unreported leaks with long run times • No annual budget for regular leak detection	• Timely intervention if high MNFs develop quickly. • Leak detection targeted in DMAs with high MNF. • Use of step testing or splitting of zones to establish high leakage precincts. • Use of wide range of equipment acoustic listening sensors, noise loggers including correlators. • Economic intervention frequency and annual budget have been established for network.
Activity 6: Pressure Management.	• No assessment of average pressure in System and Zones • No checks for pressure transients • Benefits of pressure management not understood or accepted • Largely open network with no pressure zoning; excess pressure may be well above minimum standard of service. • No use of pressure reducing valves or transient control.	• Each DMA operating at 'adequate' but not excessive pressure. • Use of transient control, network sectorisation and PRVs (flow modulating where appropriate.) • Optimum pressure regime for network –if not, further pressure management targeted at Zones with high leakage and high burst frequency on mains and service connections.
Activity 7: Infrastructure Condition and Break Frequency.	• No asset condition information gathered. • Frequencies of repairs on mains and mains fittings not calculated • Frequency of repairs on service connections not calculated • Network renewal programme if any, randomly developed.	• Network faults systematically recorded. • Break frequencies on mains, and on services, compared to international reference values • Renewal programme developed based on condition information and network fault information. • Renewal policy developed and included in Asset Management Plan.

Hence a recommended approach would be as follows:

Activity 1: Categorise the Size of System as Large, Medium or Small using Table 2.1, and identify whether to use Water Balance and/or Minimum Night Flows to assess Real Losses using

Activity 2a: If doing a Water Balance - even if this is an approximate first cut attempt using very basic assumptions:

- identify deficiencies in the data used for water balance volumes
- use confidence limits to assess calculated Real Losses volume and uncertainty
- arrange for improvements (e.g. to bulk metering) if necessary
- calculate real water loss KPIs, including Infrastructure Leakage Index ILI

Activity 2b: If using Minimum Night Flows:

- take the measurements at times of basic night consumption only
- deduct an appropriate estimate for customer night consumption (this will be higher for unmetered residential properties)
- remember to assess the average system pressure at the time the MNF is measured
- calculate the real water loss KPIs, including Snapshot ILI

Activity 3: Classify current Real Loss management performance using the World Bank Institute Banding System (Figure 5.10), and check appropriate Activity Priorities using Figure 5.11

Activity 4: Investigate Speed and Quality of Repair issues, and address deficiencies

Activity 5: Active Leakage Control: arrange for regular monitoring of minimum night flows – either by telemetry or regular use of a data logger.

- if very limited budget, take overnight readings in early Spring and late Autumn
- splitting of zones may be an option to monitor water loss in smaller areas
- set intervention targets in each supply area/zone, preferably based on economic intervention
- arrange for active leak detection either using in house resources or a contractor.

Activity 6: Pressure Management: ensure that you understand the various benefits of pressure management, and how pressure management might improve management of your system.

Check all systems (including gravity systems) for pressure transients.

Consider reducing water pressures where this is feasible. Prioritise areas with:

- single feed and few (preferably zero) boundary valves
- little or no impact on fire sprinkler systems
- high burst frequencies (mains and/or services)
- high leakage and high rates of rise of unreported leakage
- pressures at critical points in system substantially in excess of the minimum standard of service

Activity 7: Review the condition of the network and renewal programmes, with particular emphasis on reliable recording of burst frequencies on mains and services. Valve and hydrant condition assessment and renewal programmes may also be necessary.

8.0 Resources

It is the intention to assemble as many as possible of the References to these Guidelines on a single website in New Zealand, which would be accessible free of charge to anyone wishing to obtain copies.

In the case of software mentioned in these Guidelines, copies may be obtained as shown in Table 8.1 below.

Table 8.1: Software and Associated Manuals

Manuals	**Functions**	**Available From**
Benchmarking of Water Losses in New Zealand (Feb. 2008)	Includes User Manual for BenchlossNZ2008V2a	Water New Zealand
Water Loss Guidelines, Version 1a, February 2010	For planning 'Next Steps; in managing Real Losses	Water New Zealand
Software		
BenchlossNZ2008V2a (Feb 2008)	Water Balance and Performance Indicator Calculations	Water New Zealand (included with the manual)
CheckCalcsNZV3a (Feb 2008)	Check on Leakage and Pressure Management Opportunities, including Water Balance and PI Calculations	Free to New Zealand Water Utilities, from Wide Bay Water Corporation/ILMSS Ltd
PressCalcsV4a (Dec 2009)	Explains concepts used to predict influences of pressure management, with calculations	Wide Bay Water Corporation/ILMSS Ltd. Utility Site Licence
ALCCalcs V4b (Dec 2009)	Explains concepts used to assess Economic Intervention frequencies and budgets, with calculations	Wide Bay Water Corporation/ILMSS Ltd. Utility Site Licence
ELLCalcs V3a (June 2009)	For calculation of Short-Run Economic Leakage Level, with and without pressure management	Wide Bay Water Corporation/ILMSS Ltd. Utility Site Licence
NLRx NDFCalcs	Used for assessing Night Leakage Rate, Daily Real Losses and Snapshot ILI from night flows	Wide Bay Water Corporation/ILMSS Ltd. Utility Site Licence
IWA Publications		
District Metered Areas (DMA) Guidance Notes (February 2007 Version 1)	Covers the design of DMAs, analysis of flow measurement, prioritising of leak location from DMA data, management of DMAs, and case studies.	Available free from Water New Zealand website.
Pressure Management Guidance Notes – Due in late 2010		To be available free from Water New Zealand website.

9.0 References

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5. **User Manual for the BenchlossNZ software Version 2a (Feb 2008).** NZWWA.

6. **CheckCalcsNZ V3a software for Water Loss and Pressure Management Opportunities, including Water Balance and PI calculations (Jan 2008)**. ILMSS Ltd / Wide Bay Water Corporation

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12. **Thornton, J and Lambert A (2007): Pressure management extends infrastructure life and reduces unnecessary energy costs.** Water Loss 2007: Conference Proceedings 2007', Bucharest -Romania, 23-26 Sept 2007. ISBN 978-973-7681-24-9. Paper 51, Volume 2, pp 511-521.

13. **PressCalcs V4a (Dec 2009). Software with concepts used to predict influences of pressure management**. ILMSS Ltd / Wide Bay Water Corporation

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without Pressure Management. IWA 'Leakage 2005' Conference, Halifax. Proceedings published by World Bank Institute.

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19. **Vermersch, M (2008). Apparent Losses Part 2, Metering Losses and Unauthorised Consumption.** Power Point presentation at Wide Bay Water MasterClass ‘WaterLoss Australia 2008’ Brisbane/Sydney/Melbourne Nov 2008.

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30. **ELLCalcsV3a, June 2009 Software for calculation of Short-Run Economic Leakage Level, with or without pressure management.** ILMSS Ltd / Wide Bay Water Corporation

31. **Fanner, P and Lambert, A.O (2009). Calculating SRELL with Pressure Management, Active Leakage Control and Leak Run-Time Options, with confidence limits.** Proceedings of IWA Specialist Conference 'Water Loss 2009" , Cape Town, South Africa, April 2009.

APPENDICES

APPENDIX A: Using Night Flow Data To Assess Real Losses

(this is substantially the same as Appendix J of the Benchloss 2008 User Manual, Ref. 5)

A1: USING NIGHT FLOW DATA TO ASSESS REAL LOSSES

In the BenchlossNZ 2008 and CheckCalcsNZ software, Real Losses are assessed from an annual Water Balance. However, the estimate of Real Losses that result may have wide confidence limits, particularly for partially metered systems where there are large uncertainties in estimates of unmeasured residential consumption (including supply pipe losses).

Night flow measurements can also be used to provide an alternative assessment of Real Losses, particularly in small districts where not all properties are metered. This Appendix is an introduction to the general concepts of assessing Real Losses in small systems.

Measurement and analysis of night flows from small systems, or sub-systems within a larger distribution system, is also a practical and effective way to identify:

- the presence of significant amounts of detectable leakage
- changes in leakage
- priorities for leak detection activities.

For the purpose of this Appendix, systems where night flows are measured will be referred to as District Metered Areas (DMAs), whether the night flow is measured continuously or only occasionally.

The easiest way to identify distribution DMAs with high leakage is a visual check on the 24-hour flow and pressure profiles. DMAs where the night flow is consistently a high proportion of the average inflow (**Figure A1**) will generally have higher leakage, and be a priority for active leak detection.

In contrast, DMAs where the night flow is only a low proportion of the average inflow **(Figure A2)** will generally be those with lower leakage, and not such high priorities for active leak detection.

Fig. A1: Weekly inflows, high leakage DMA

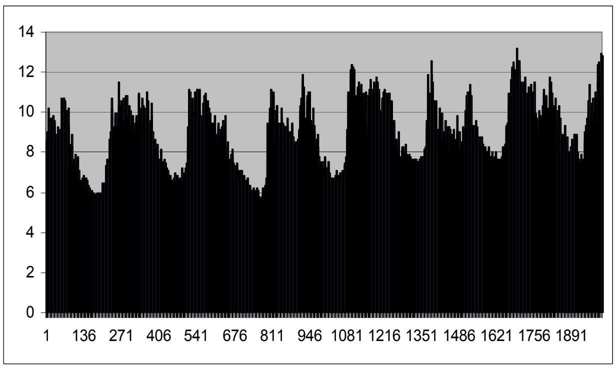
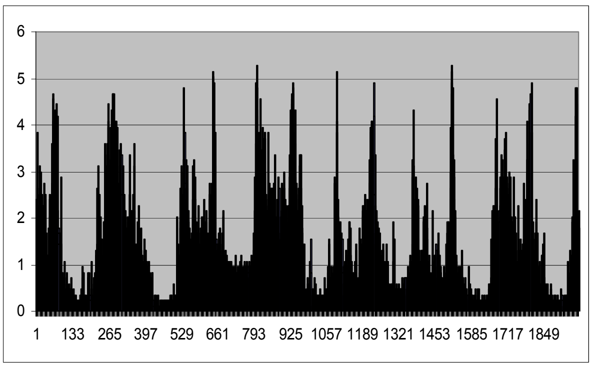


Fig. A2: Weekly inflows, low leakage DMA



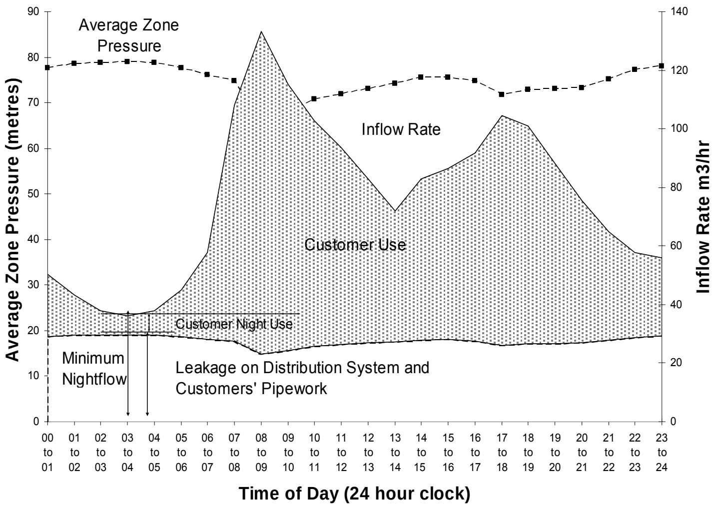
Visual inspection of graphed flow and pressure data is always the first and most important step in any analysis of DMA data, and an important aspect of data quality control, prior to more detailed analyses.

A2 THE INFLUENCE OF PRESSURE VARIATIONS, AND NIGHT-DAY FACTORS

Figure A3 shows a 24-hour profile of inflow and average Zone Pressures for a DMA supplied by gravity. In the early hours of the morning (normally sometime between 1 am and 4 am) customer night use is at a minimum, and leakage is at a maximum because of the higher average pressures at night.

If an estimate can be made of the customer night use, at the time of minimum night flow, then what remains is leakage. However, this leakage is not only on the water supplier's distribution system, but also on the customers' private supply pipes and plumbing systems.

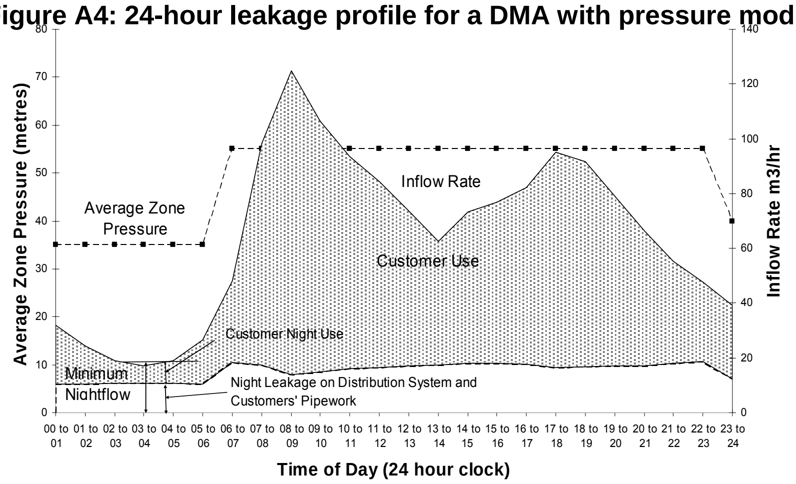
Figure A3: 24-hour leakage profile for a DMA supplied by gravity



It can also be seen from **Figure A3** that, as customer use and inflow vary over the 24 hours, the average pressure in the system changes, and (because leak flow rates change with pressure) the leak flow rates also change. So in the case of a DMA supplied by gravity, it can be seen from **Figure A3** that the average leakage over 24 hours will be less than 24 times the leakage at night (in m^3/hour).

In contrast, **Figure A4** shows a 24-hour profile of inflow and pressure for a DMA supplied with modulated pressure control (or by pumping) where average pressure at night is less than that during the day. In this situation, it can be seen that the average daily leakage will be more than 24 times the leakage at night (in m^3/hour)

Figure A4: 24-hour leakage profile for a DMA with pressure modulated input.



To convert a night leakage rate in m^3/hour, to an average daily leakage rate in m^3/day, it is necessary to multiply by a Night-Day Factor NDF, with units of Hours/day. The term 'Hour-Day Factor' is also used in the UK.

Night-Day Factors can be assessed by taking pressure measurements at the 'Average Zone Point' in a DMA, using an appropriate FAVAD N1 value (see Section 6.6 of the Water Loss Guidelines). The 'PressCalcs' Standard software (Ref. 13) includes a more comprehensive explanation and Worksheets to define the AZP point, estimate N1 values, and calculate NDFs from pressure measurements at the Average Zone Point.

For DMAs supplied by gravity, Night-Day Factors typically vary from 18 to 23 hours/day. DMAs with pumped of pressure-modulated inflow typically have NDFs ranging from 24 to over 30 hours/day.

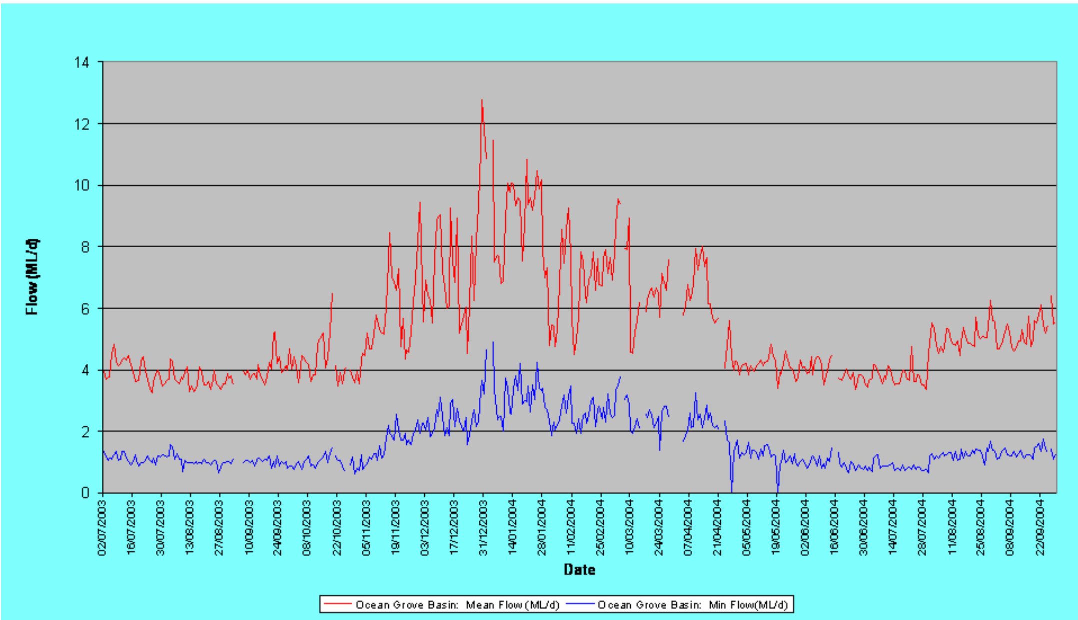
It will be evident from the above that pressure has a major influence on the leakage component of night flows, and that reconciliation of night leakage rates with Real Losses calculated from an annual water balance needs an understanding, and proper application, of the principles involved.

A3 'SNAPSHOT' ESTIMATES OF REAL LOSSES

However, it is possible to get 'Snapshot' estimate of real losses from night flow measurements. To do this, it is first necessary to select an appropriate time of year, when the only components of night use are the aggregations of small individual customer night use (e.g. toilet flushing). **Figure A5** shows the annual pattern of daily system inflows, and night flows, in a large DMA in Australia. Clearly, any attempt to estimate Real Losses from night flows during the summer 6 month period is going to be invalidated by the large and unknown amount of exceptional night use due to garden watering, late night holiday activities, etc.

In such circumstances, it is preferable to take and interpret night flow measurements at times of the year when exceptional night use is at a minimum – typically April to October in New Zealand (times will vary between North and South Island).

Figure A5: Annual variation of daily inflows and night flows in a Victoria DMA



Looking again at **Figures A3 and A4**, it can be seen that, when estimated customer night use is deducted from minimum night flow, the leakage remaining includes leakage on customers' supply pipes and plumbing systems after the property line. So to estimate the leakage rate on the water supplier's mains and service connection up to the property line, an estimate of leakage after the property line needs to be made.

Given the widely different conditions between different DMAs and small systems in New Zealand depending upon length of supply pipes Lp, night pressure, and whether residential customers are metered or not, estimates of 'customer leakage at night' can be expected to vary widely; the influence of toilet cistern leaks can also be significant. If customer night use and customer leakage are aggregated, values of 'Customer night consumption' are likely to be of the order of:

- 1.5 to 2.0 litres/conn/hr for single service connections to single metered residential properties
- 2 to 2.5 litres/conn/hr for unmetered residential properties
- 10 litres/conn/hr or more in some rural areas. Guidance on the most appropriate figure to choose for night consumption in individual Zones normally requires a more detailed approach to component analysis, which is outside the scope of this relatively brief Appendix.

However, once an estimate of the assessed Customer Night Consumption has been made, a 'Snapshot' estimate of Night Leakage Rate on the water supplier's infrastructure can be made using **Step 1** of the ILMSS software **NLRxNDFCalcs,** see **Figure A6.** Confidence limits are a useful feature of this calculation.

Figure A6: Estimation of Snapshot Night Leakage Rate (from NLRxNDFCalcs software)

STEP 1: CALCULATE SNAPSHOT NIGHT LEAKAGE RATE			09/07/05	to	15/07/05
Number of Service Conns =	3310	Litres/ sec	m^3/ hour	Litres/ conn/ hour	95% Conf. Limits
Length of Mains (km) =	47.00				
when AZNP (metres) =	59.00				
Minimum Night Flow MNF		6.50	23.40	7.07	2.0%
Assessed customer night consumption CNCa		1.84	6.62	2.00	40.0%
Exceptional customer night consumption CNCe		0.00	0.00	0.00	20.0%
Snapshot Night Leakage Rate NLR = MNF - CNCa - CNCe		4.66	16.78	5.07	16.0%

The Snapshot Daily Leakage can then be used to calculate Snapshot values of the Real Losses Performance Indicators, as in **Figure A7**.

Figure A7: Estimation of Snapshot Real Losses Performance Indicators, NLRxNDFCalcs

STEP 3: CALCULATE SNAPSHOT VALUES OF REAL LOSSES PERFORMANCE INDICATORS			
The Snapshot Daily Leakage is	335.6	m3/day	
	101	litres/connection/hour +/-	16.8%
The Snapshot Night Leakage Rate is	16.78	m3/hour at 59 metres AZNP	
The Unavoidable Annual Real Losses are	8.59	m3/hour at 59 metres pressure	
So 'Snapshot' Infrastructure Leakage Index is	1.95	which is in WBI Band	A

Any calculation of ILI which is not based on an annual water balance can only be regarded as an indicative value. This is because 'Snapshot' ILIs derived from different limited sets of night flows will vary around the annual ILI value, and may even be less than 1.0 soon after an active leakage control intervention, when all reported and unreported bursts have been repaired, and only background leakage remains. So a 'Snapshot' ILI should always be considered as being an approximate value, always treated with caution, and always referred to as a 'Snapshot' value to avoid confusion with the ILI calculated from the annual water balance.

However, 'Snapshot ILIs' are a very useful technique for assessing the scale of Real Losses when Systems and Zones are first being investigated.

In summary, this Appendix has only sought to outline the methods by which Real Losses can be estimated from night flow measurements. The IWA Water Loss Task Force DMA Guidance Notes (Ref. 24) provide more information, and can be downloaded free of charge from the IWA Water Loss Task Force Website www.iwaom.org/wltf.

APPENDIX B: Significant Modifications to BenchlossNZ and CheckCalcsNZ 2008 Upgrades

The more significant modifications included in the 2008 upgrades to these two softwares may be briefly summarised as follows:

- inclusion of 'Water Supplied' in the Water Balance terminology and calculations
- inclusion of recommended guideline default values (as percentages of Water Supplied) for initial estimates of Unbilled Authorised Consumption and Unauthorised Consumption
- inclusion of recommended guideline default values (as percentages of metered consumption) for initial estimates of Customer Meter Under-registration
- updating references for some performance indicators following publication of the 2nd Edition (2006) of the IWA Performance Indicators Manual
- introducing '% of metered consumption' as an operational performance indicator for Apparent Losses.
- replacing the 2002 'typical ranges' for Real Loss Performance Indicators (Excellent, Good/Fair, Below Average) with World Bank Institute Banding System (A,B,C,D)
- introduction of lower limits (in terms of number of service connections and length of mains) for validity of Unavoidable Annual Real Losses (UARL) and Infrastructure Leakage Index (ILI) calculations

The BenchlossNZ User Manual is a comprehensive reference document covering the following topics:

- Introduction to Benchmarking of Leakage
  - Problems with percentages as Performance Indicators
  - Making progress
  - Benchmarking of Water Losses – a rational approach
- Some Detailed Considerations
  - Assessing accuracy of Water Balance and Performance Indicator calculations
  - Examples of water reticulation layouts in New Zealand
  - Estimating underground supply pipe leakage
  - Estimating unmetered residential consumption
  - Allocating minor components in the Water Balance
  - Estimating Unbilled Authorised Consumption
  - Estimating Apparent Losses
- Outline of the BenchlossNZ Software
  - Hardware and software requirements
  - Installing BenchlossNZ
  - Overview of the software
  - The individual Worksheets
  - Input Data requirements
- Using Benchloss
  - Explanation is given of using each of the 11 Worksheets shown in Table 2.2.
- References
- Technical Appendices
  - A: Assessing the accuracy of Water Balance & Performance Indicator calculations
  - B: Terminology used for water reticulation systems

- C: Estimating underground supply pipe leakage on private pipes
- D: Consumption monitors for unmetered residential properties
- E: Allocating specific components to the water balance
- F: Estimating apparent losses
- G: Introduction to BABE and FAVAD concepts, and calculation of Unavoidable Annual Real Losses (UARL)
- H: Calculating Average Pressure in Distribution Systems
- I: Printout of Benchloss Version 1a Worksheets
- J: Using Night Flow Data to assess Real Losses
- K: Overview of the CheckCalcsNZ software

The BenchlossNZ software and Manual is available directly from Water New Zealand. The CheckCalcsNZ software (CheckCalcsNZ) is also available free to New Zealand Water Suppliers on request from Wide Bay Water Corporation. Table B.1 shows the Worksheets in BenchlossNZ and CheckCalcsNZ, both of which are Excel Workbooks with a similar number of Worksheets, the majority of which are ‘Information’ Worksheets and five of which, in each case, are for Data Entry.

Table B.1: Listings of Worksheets in BenchlossNZ2008 and CheckCalcsNZ2008

WORKSHEETS in BENCHLOSSNZ 2008		WORKSHEETS in CHECKCALCsNZ2008	
INFORMATION WORKSHEETS	DATA ENTRY WORKSHEETS	INFORMATION WORKSHEETS	DATA ENTRY WORKSHEETS
Licence		Licence	
Introduction		Intro	
	INF&UARL	4Comps	
Terminology		Terminology	
	Consumption		System Info
	WaterBal		Water Balance
WBComponents			Running Costs
	PICalcs		Performance
Summary		WBI Guidelines	
	COMPData		PMOpportunities
Why Not %s		LEAKSSuite software	
		Twin Track	

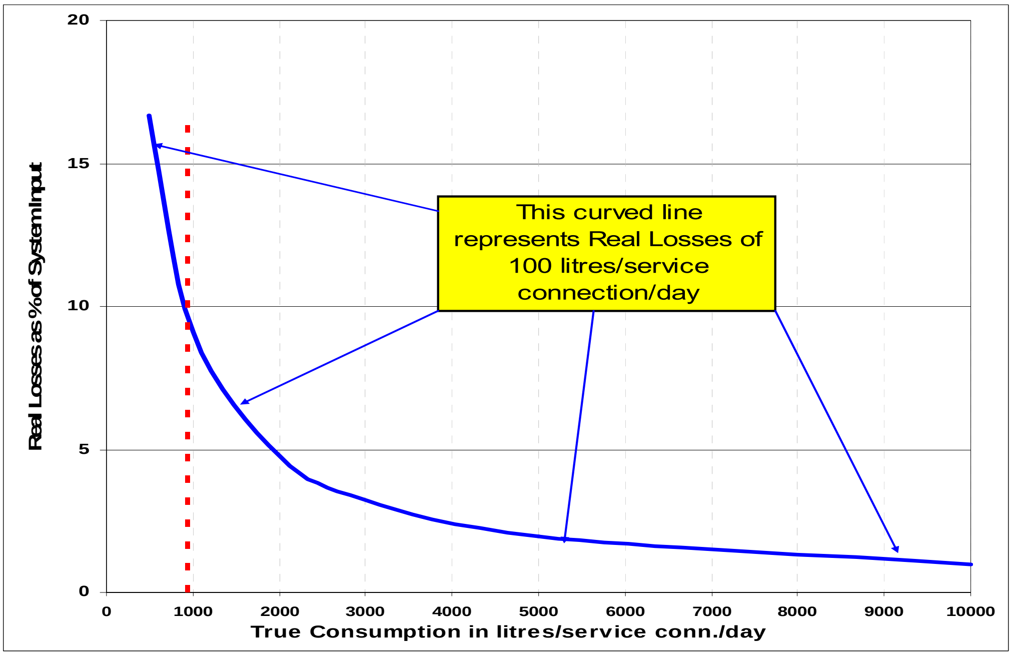
APPENDIX C: Why %s by volume are not suitable Performance Indicators for Real Losses

Since the early 1980's it has been recognised that percentages are unsuitable for assessing the operational efficiency of management of real losses (leakage and overflows) in distribution systems. This is because the calculated percentages are strongly influenced by the consumption of water in each individual system, and variations in that consumption.

The influence of consumption, and changes in consumption, can be seen in Figure C.1. If Real Losses (curved line) are 100 litres/service connection/day, and True Consumption (including apparent losses) varies as shown on the X-axis, the % Real Losses vary from 17% in systems with low consumption/service connection, to 1% in systems with high consumption per service connection (such as Singapore).

In New Zealand, typical consumption ranges from 500 litres/service connection/day in the south of South Island to over 3000 litres/service connection/day in some urban sub-systems systems with industry. Real Losses of 100 litres/service connection day expressed as a % of Water Supplied (= Real Losses + True Consumption) will vary from 17% to 3%, not because of better or worse leakage management performance, but simply because the higher consumption appears to reduce the Real Losses when they are calculated as a % of volume of Water Supplied.

Figure C.1: Influence of Consumption on Real Losses expressed as % of Water Supplied



At a typical North Island urban consumption of around 1000 litres/service connection/day (the broken vertical line on Figure C.1), % Real Losses are very sensitive to small changes in consumption. If customer-side demand management activities or drought restrictions or seasonal factors significantly decrease consumption, the percentage Real Losses by volume will increase despite the fact that the volume of Real Losses remains unchanged or is even reduced.

Non-Revenue Water expressed as a % by volume of Water Supplied, although traditionally widely used, also suffers from similar significant problems to % Real Losses when used as a PI.

So '% by volume', although it is calculated and shown in both BenchlossNZ and CheckCalcsNZ, is no longer recommended as a meaningful performance indicator for Real Losses or Non-Revenue Water.

APPENDIX D: Explaining reductions in bursts following pressure management.

Source: IWA Water Loss Task Force Pressure Management Group, paper by Thornton & Lambert, 2007 (Ref. 17)

The conceptual approach currently being used by the Pressure Management Team of the WLTF, in attempting to develop an improved practical understanding of pressure/break frequency relationships, is shown in the following series of figures.

In Figure D.1, the X-axis represents system pressure and the Y-axis represents failure rates. When a new system is created, mains and services are normally designed to withstand maximum pressures far greater than the range of daily and seasonal operating pressures for a system supplied by gravity. The system operates with a substantial factor of safety, and failure rates are low. Even if there are pressure transients in the system (Figure D.2), the maximum pressures do not exceed the pressure at which increased failure rates would occur.

Figure D.1: New system supplied by gravity operates well within design maximum pressure

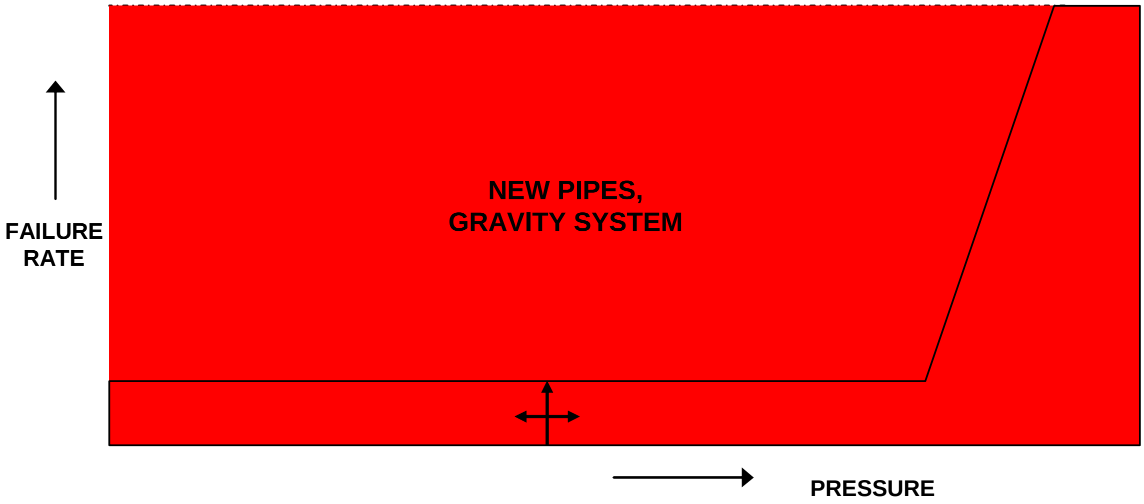
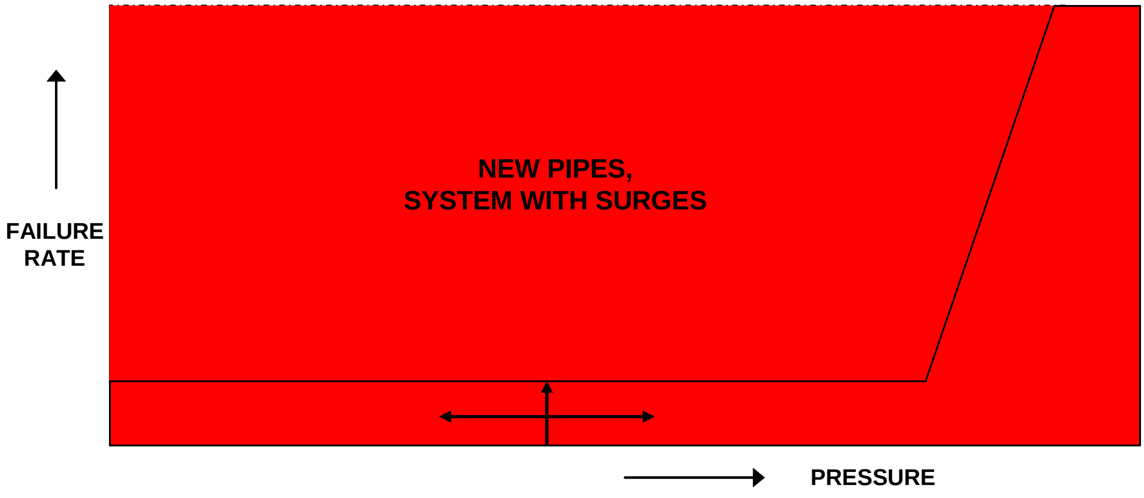
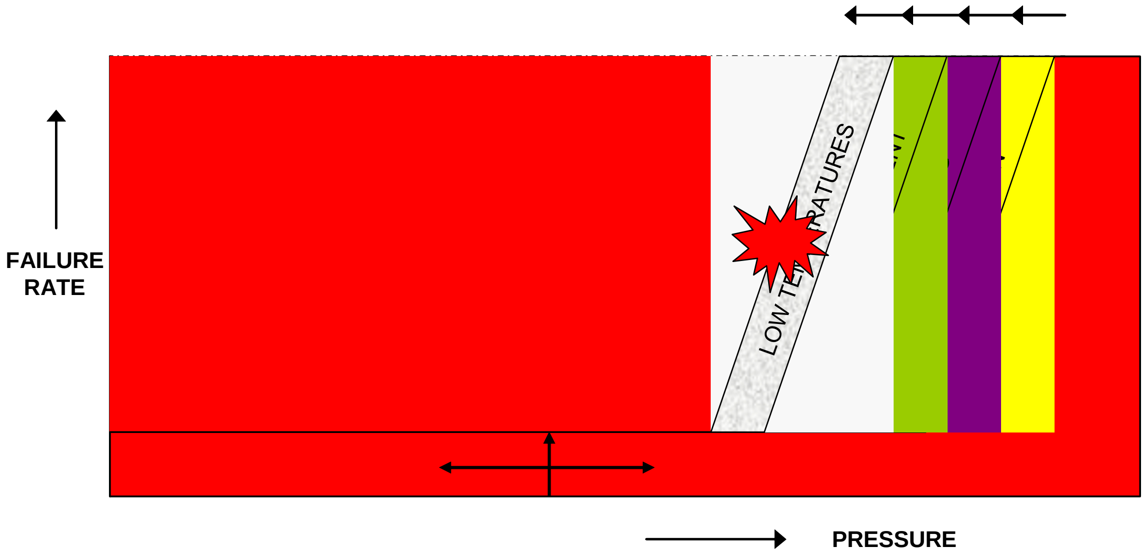


Figure D.2: New system with surges also operates well within design maximum pressure



As the years pass, adverse factors based on age (including corrosion) gradually reduce the pressure at which the pipes will fail (Figure D.3). Then, depending upon local factors such as traffic loading, ground movement and low temperatures (which will vary from country to country, and from system to system), at some point in time the maximum operating pressure in the pipes will interact with the adverse factors, and break frequencies will start to increase. This effect can be expected to occur earlier in systems with pressure transients or re pumping, than in systems supplied by gravity.

Figure D.3: Combination of adverse factors (including surges) cause increased failure rates

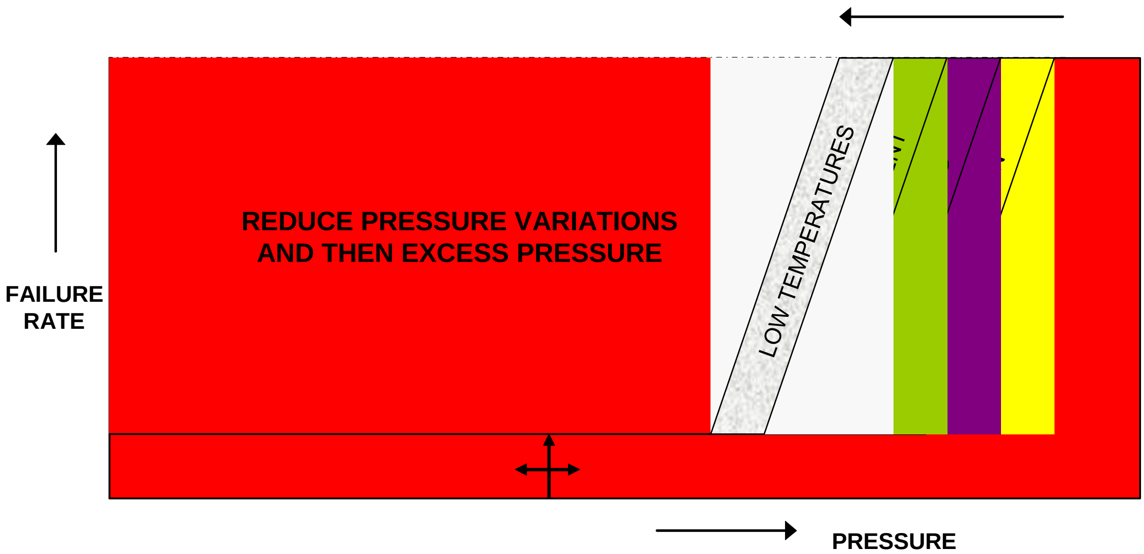


If the system is subject to surges or large variations in pressure due to changing head loss conditions, then introduction of surge control or flow or remote node pressure modulation may be expected to show a rapid significant reduction in the new break frequency. The average pressure in the system is unchanged, but the reduction of surges and large variations means that maximum pressures do not interact to the same extent with the adverse factors.

If there is excess pressure in the system at the critical point, over and above the minimum standard of service for customers, then permanent reduction of the pressure by installation of pressure management (PRV, sub-division of large Zones, etc) will move the range of operating pressures even further away from the pressure at which combinations of adverse factors would cause increased frequency of failure.

Figure D.4 shows the effect of reducing surges and variations in pressure and then reducing excess pressure.

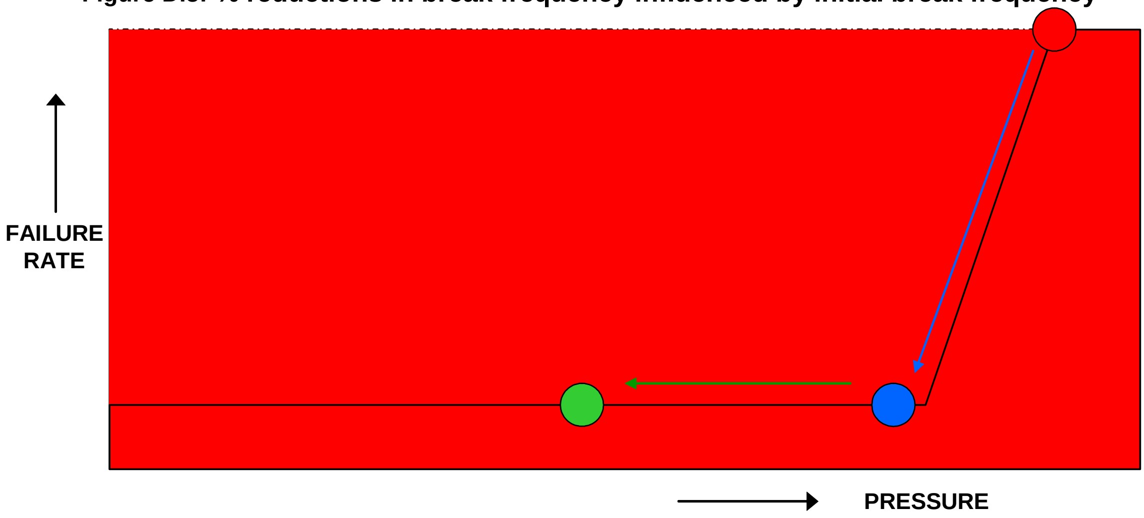
Figure D.4: Reduction of surges and variations and reducing excess pressure limits interaction with adverse factors and increases factor of safety



A hypothesis as to why mains and/or service connections in some systems show large % reductions in new break frequency with pressure management, but in others the % reduction is only small, can be proposed using this concept.

- If, before pressure management, there is already a relatively high break frequency (Red Point in Figure D.5), then a relatively small % reduction in pressure may cause a large % reduction in new break frequency (towards Blue Point).
- But if there is already a relatively low break frequency before pressure management (Blue Point in Figure D.5), then any % reduction in pressure (from Blue Point to Green Point) should have little effect on new break frequency, but will create a greater factor of safety and extend the working life of the infrastructure.

Figure D.5: % reductions in break frequency influenced by initial break frequency



APPENDIX E: Methods of Calculating Average Pressure in Distribution Systems

(Copied from Appendix H of Benchloss 2008 User Manual)

E1. A SYSTEMATIC APPROACH TO CALCULATING AVERAGE PRESSURE

As pressure is a key parameter in modelling and understanding leakage, it is worthwhile to adopt a systematic approach to its calculation. The procedure is as follows:

- For each individual zone or sector, calculate the weighted average ground level;
- Near the centre of the zone, identify a convenient pressure measurement point which has the same weighted average ground level – this is known as the **Average Zone Point**;
- Measure the pressure at the Average Zone Point, and use this as the surrogate average pressure for the Zone.

AZP pressures should be calculated as average 24-hour values; night pressures at the AZP point are known as AZNPs (Average Zone Night Pressures).

For relatively small sectors with well-sized mains in good condition, with reliable information on average Zone inlet pressure at a single inlet point, preliminary estimates of average pressure can be made as follows:

- Measure or estimate the average pressure at the Inlet Point to the zone or sector, and estimate the average zone pressure taking into account the difference in datum levels between the Inlet Point and the AZP point, assuming no frictional loss.

To obtain Average Pressure for aggregations of Zones, calculate the weighted average value of pressure using (preferably) number of service connections in each zone.

If Network Analysis models are not available, the approach used in part H2 of this Appendix should be followed. If Network Analysis models are available, follow the approach in part H3.

E2. AVERAGE ZONE PRESSURES WHERE NO NETWORK MODELS EXIST

E2.1 Calculate Weighted Average Ground Level for Each Sector

Split the distribution system conceptually into sectors defined by pressure management zones or district metered areas; break the system down into the smallest areas for which average pressures may be required.

Next, for each sector, superimpose a plan of the distribution system over a contour map, preferably with 2-metre intervals. Allocate to each contour band one of the following infrastructure parameters (parameters are in order of preference):

- Number of service connections;
- Number of hydrants;
- Length of mains.

Whichever infrastructure parameter is selected, the weighted average ground level can then be calculated as shown in **Table E1** below.

Table E1: Example calculation of weighted ground level

Contour Band (m)			Number of Service Connections	Contour Band Mid Point * Number of Connections
Lower Limit	Upper Limit	Mid-Band		
2.0	4.0	3.0	18	54
4.0	6.0	5.0	43	215
6.0	8.0	7.0	40	280
8.0	10.0	9.0	41	369
10.0	12.0	11.0	63	693
12.0	14.0	13.0	70	910
14.0	16.0	15.0	41	615
16.0	18.0	17.0	18	306
18.0	20.0	19.0	12	228
20.0	22.0	21.0	8	168
22.0	24.0	23.0	3	69
24.0	26.0	25.0	0	0
Totals			**357**	**3907**

Weighted Average Ground Level = 3907 / 357 = 10.9 m

E2.2 Measure or Calculate Average Zone Pressure

Obtain the average pressure at the Average Zone Point in the following manner:

- Measurements over a period of one year;
- Preliminary estimate based on average Inlet pressure adjusted for difference in ground levels between Inlet Point and AZP.

Example: In the sector data in **Table E1**, the average inlet pressure at a service reservoir is 1.5 metres below the overflow level (which is 65.0 metres above mean sea level - amsl).

- The average inlet pressure is therefore (65.0 – 1.5) = 63.5 m amsl ;
- The ground level at the AZP point is 10.9 m amsl;
- The average zone pressure is therefore estimated as (63.5 – 10.9) = 43.6 m.

E2.3 Calculate Weighted Average Pressure for Aggregation of Zones

The weighted average pressure for sectors of a distribution system, consisting of aggregations of individual zones with different average pressures, is obtained by calculating a weighted average for all the zones. If possible, the Number of Service Connections should be used as the weighting parameter (if not available, use length of mains or number of hydrants). An example calculation is shown in **Table E2**.

Table E2: Example calculation of weighted ground level

Area Reference	Number of Service Connections	Average Zone Pressure	Number of service Connections * AZP
A	420	55.5	23 310
B	527	59.1	31 146
C	443	69.1	30 611
D	1352	73.3	99 102
E	225	64.1	14 423
F	837	42.0	35 154
G	1109	63.7	70 643
H	499	56.3	28 094
I	1520	57.0	86 640
	6932		**419 122**

Weighted average pressure for the whole area = 419,122/6932 = 60.5 metres

E3. AVERAGE ZONE PRESSURES USING NETWORK MODELS

E3.1 Calculate Weighted Average Ground Level for Each Sector

Because each node of a Network Analysis Model will normally have a number of properties, a datum ground level, and an average pressure value, it is relatively easy to calculate the weighted average pressure for all the nodes in the model (or any defined part of it).

It is worthwhile, however, to ensure that a weighted average ground level, and an AZP point are defined for each zone/sector, as these will occasionally be required for test measurement.

APPENDIX F: Meter Lag Calculations: Methods and Examples

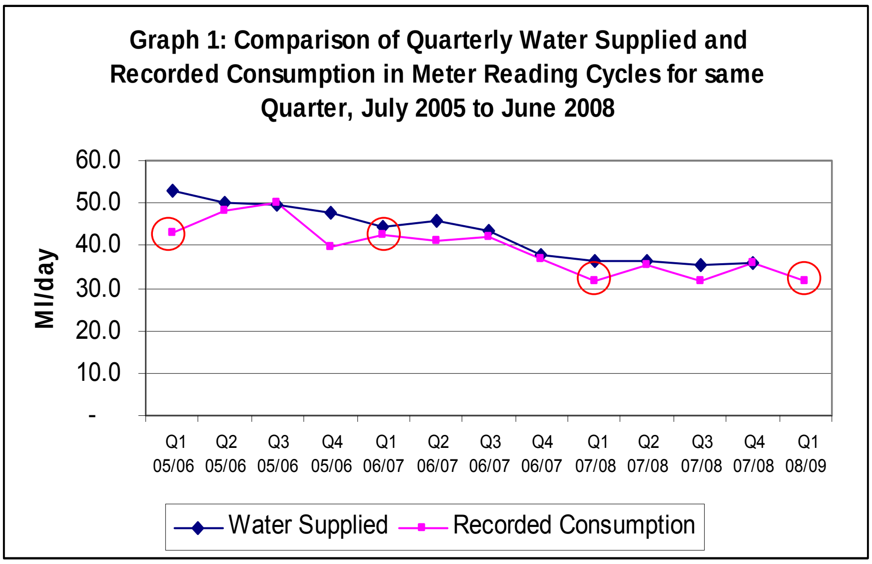
F1: WHAT ARE METER LAG ADJUSTMENTS; WHY ARE THEY NEEDED?

In Water Balance calculation, the bulk metered volume of 'Water Supplied' should be compared to the actual consumption volume over a 12-month 'Water Year' which, in New Zealand, normally runs from 1st July to 30th June inclusive.

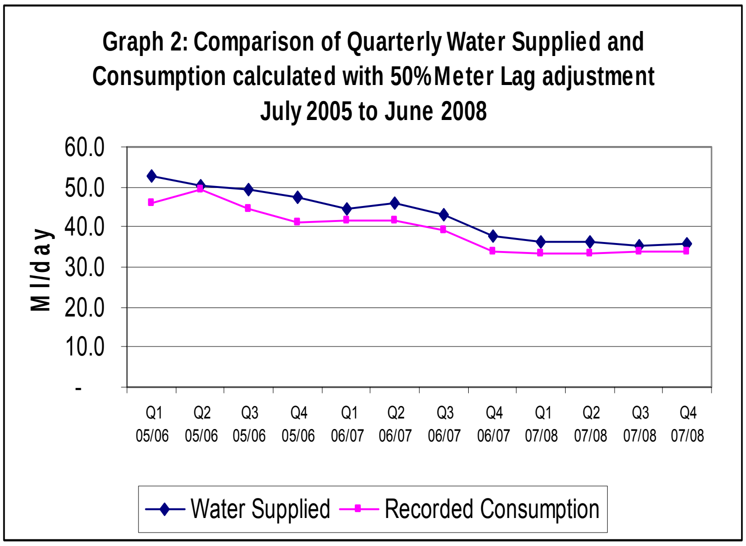
In New Zealand, meter reading frequencies for residential properties seem to be typically every 6 or 12 months, and every 3 months for non-residential properties or large users. In large systems, Water Suppliers tend to operate a rolling reading cycle. In medium and small systems, or those with several smaller Water Supply Systems, the meter reading cycle for each individual system may be completed in a few weeks. With smart metering and automatic data collection, the meter reading cycle can be completed in a few days, although there will usually remain some reading and billing queries to be resolved.

The effect of failure to make a 'meter lag' adjustment can be simply demonstrated from the following Australian example. The first meter reading cycle commences on the 1st day of a new Water Year (1st July), takes 3 months to complete, and there are 4 meter reading cycles per year.

Graph 1 shows quarterly data (in Ml/d) for Water Supplied and Recorded Metered Consumption over the period 2005 to 2009, with some seasonal variation and a general reduction due to imposition of drought restrictions. If no meter lag calculation is attempted, in some quarters the metered consumption recorded in the quarter equals or even exceeds volume of water entering the system in that quarter. So the Non-Revenue Water (the difference between the two lines) appears to be highly variable from one meter reading cycle to the next, and in some quarters has a zero or even negative value



In Graph 2, a simple meter lag adjustment has been made by attributing 50% of the consumption recorded in each billing cycle to the previous billing cycle period. Although there were some irregularities in 2005/06, the Non-Revenue Water (the difference between the Quarterly Water Supplied and the recorded consumption with a simple meter lag adjustment) is seen to be reasonably consistent.



At the very low levels of Non-Revenue Water and Real Losses currently being achieved in Australia, the difference in calculated Real Losses between making, or not making, a Meter Lag Adjustment (MLA), can be very large (over 100%) in years when there is a large difference between the recorded consumption in Q1 for successive years.

In general, New Zealand systems do not experience the multi-year droughts that may occur in large Australian water supply systems, and so large errors in Water Balance calculations due to meter lag can normally be avoided if the problem of Meter Lag adjustment is acknowledged and appropriately dealt with.

APPENDIX G: Additional Information on Bulk Metering

There are many different types of bulk meter - Electro-magnetic, Ultrasonic, Venturi, Dall tube, Orifice plate, Insertion meters, Helix meters, Vortex shedding, Turbine, Propeller etc. All bulk meters are sensitive to distortion of the velocity profile in the mains, to a greater or lesser extent, which is why manufacturers' recommendations on minimum lengths of straight pipe upstream and downstream of the meter (expressed as a number of pipe diameters) should not be compromised. Sensitivity to velocity profile distortion is generally:

- Very High, for insertion meters
- High, for ultrasonic and helix meters
- Medium/Low, for electromagnetic meters

Each of these meter types has its own particular advantages and disadvantages. Some of these (from Ref 19) are shown in the Table below.

Advantages and Disadvantages of different types of Bulk Meters

Type of Bulk Meter	Advantages	Disadvantages
Ultrasonic (transit time)	High accuracy, linear response	High sensitivity to flow distortion
	Great reliability. No mobile parts subject to wear	Need for electric supply
	Small head loss	Not suitable for billing (this may change with new standards)
	Moderate cost	
Electromagnetic	High accuracy, linear response	Need for electric supply
	Great reliability. No mobile parts subject to wear	Needs protection against electrical storms; subject to failure from lightning strikes
	Small head loss, low operation cost	Not suitable for billing (this may change with new standards)
	Medium/low sensitivity to flow profile distortion	
Insertion	Low cost, especially for large diameters	Low measurement reliability compared to other technologies
	A single insertion probe can be used at different locations	Very sensitive to distortion of velocity profile
	Can be used in water with suspended solids	Need to drill a hole in the pipe
	Small head loss	Narrow range of measurement
Horizontal Helix Meters	Usable in difficult working conditions	Error curve is sensitive to velocity profile quality.
	Wide measuring range	Use of tranquilising lengths of pipe upstream of meter may be necessary
	Metering module can be replaced in existing casing	Low sensitivity for low flow rates
	Can be installed in virtually any position	Impact of large suspended solids may damage the metering module; the use of stone strainers is recommended
	Pulse emitters can be attached to flow totalisers	

Regular calibration of electronics is normal practice, but this should not be assumed to imply that the meter is recording the correct flows. The meter may be incorrectly sized or of an inappropriate type for the flow profile at the particular location, and facilities for independent flow validation are rarely provided - so regular flow validation is not normally practised. During droughts, bulk meter flows which are much lower than original design flows, or reversal of flows, may occur, leading to under-registration of actual flows.

Other factors affecting bulk meter data accuracy (Ref. 20) include:

- Changes to Meter Geometry: caused by Corrosion and Corrosion products, other deposits and debris, and mechanical wear.
- Installation problems pipework configuration upstream or downstream of the meter, mis-alignment, and meters not running full.
- Signal Processing Errors, which can be caused by Span Errors (when setting up or checking the meter) and other calibration factors.
- SCADA systems involve manipulation of data during transmission and possible data loss when SCADA systems are not operating

Validation of bulk metered volumes is therefore an essential part of Water Balance calculations.

Bulk Meter Validation Options (Ref. 20) include:

- <u>Volumetric tests,</u> involving drawing down an upstream tank or clear well, or filling a downstream tank, are a good practical option, if possible.
    - o the tank must be large enough to provide the test accuracy required - what is the resolution for a 1mm difference in level?
    - o the measured level drop needs to substantially exceed the potential measurement error of the water level measuring equipment
    - o the tank must be capable of being isolated for a sufficiently long period to provide the accuracy required
    - o a static test must be conducted on the tank to check for leakage / valves passing
    - o for accurate measurement of tank dimensions and water depth, use an ultrasonic level sensor or high accuracy pressure transducer
- <u>Mass Balances</u> are a useful first step, for multiple sets of meters around treatment works (raw water, process water meters, output meters etc)
    - o temporary meters may be needed on any pipes not normally metered
    - o if inconsistencies are found in the mass balance, further investigation is necessary.
    - o mass balances can also be used to check for inconsistencies between two bulk meters in series, where water is exported from one system to another; or between groups of bulk meters, for example on transmission mains
- <u>Test Meters in Series</u>: Insertion meters
    - o do not locate insertion meters within 50 pipe diameters of pumps, fittings or bends
    - o above DN600, double these distances to try to offset possible swirl problems
    - o above DN1200, distances should be further increased; use 2 plane data probes or a minimum of two pairs of ultrasonic meters
    - o always determine the velocity profile, experience shows that it is rarely uniform
    - o always undertake the test with the insertion meter at the pipe centreline
- <u>Test Meters in Series</u>: Clamp-on Ultrasonic meters
    - o Minimum distances from pumps, fittings or bends as for Insertion Meters; use a minimum of two pairs of ultrasonic meters above DN1200
    - o always measure pipewall thickness using ultrasonic tool, and always use silicon grease to ensure good contact
- <u>Portable Test Rigs</u> may be used for checking small bulk meters

Common Issues in Validating Bulk Meters (Ref. 20) include:

- Data Chain Analysis: test across the normal operating range of the meter, using 3 flow rates if operationally possible
  - record local (and remote) integrator readings at start and end of each test
  - log meter output (4-20mA / pulse) from primary sensor
  - obtain data for period of test from SCADA and compare with on-site readings to check if SCADA has introduced additional errors
- Conclusions of Bulk Meter Validation Test: calculate the error range of the validation method; if recorded bulk meter flows during the test are:
  - within this error range, the bulk meter is deemed to be OK.
  - outside this error range, assume the bulk meter has a systematic error, correct recent recorded volumes, take appropriate action.

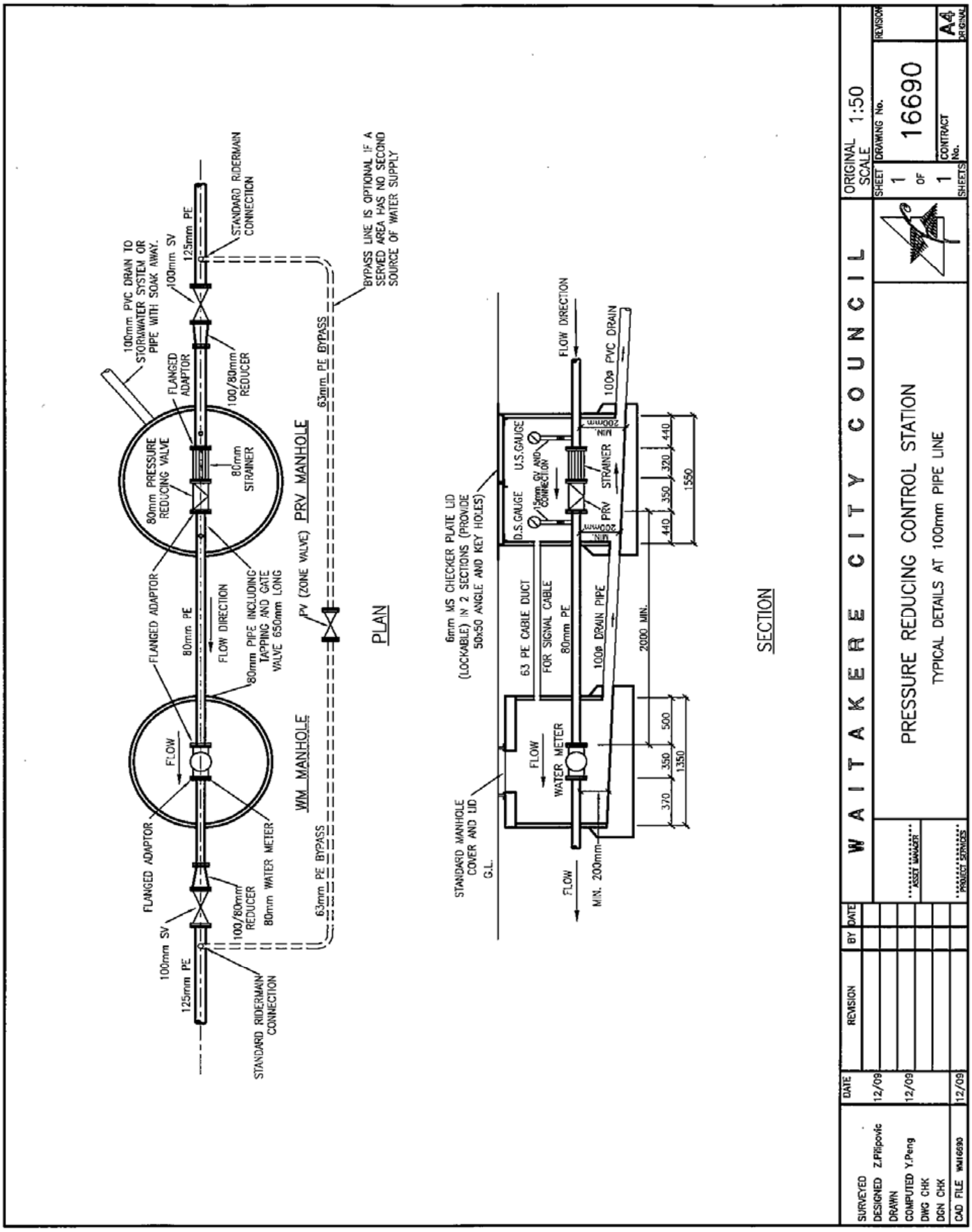
Some examples of Errors found when validating bulk meters include:

- main meter from treatment works over-sized for drought flows; mass balance and volumetric test indicate under-reading of 1% to 4%. SCADA volumes 1.7% higher than on-site readings
- two ultrasonic meters at a treatment works: one using incorrect configuration file; when corrected, one under-reading by 3.3%, the other by 4.8%, based on volumetric tests.
- Buried meter recording flows when no flows passing through it; over-reading by 16% to 20%, suspected due to water ingress.
- Open by-pass at one export point; bi-directional flows at another, correctly recorded by meter but billing system configured to calculate forward flows only
- An unmetered import point had been opened in an emergency, but not closed afterwards.

Some basic actions to reduce Bulk Metering Errors (Ref. 20) include:

- find, and retain in an accessible location, manufacturer's specifications and accuracy data for all bulk meters
- record if bulk meters are not installed in accordance with manufacturers instructions (or current best practice), with photographs
- provide on-site validation facilities to facilitate volumetric checking of bulk meters at least once per year
- carry out regular (approximately monthly) mass balances where possible, to identify changes and inconsistencies
- identify and limit locations where bi-directional flows may occur, or bulk meter by-passes may be left open.
- ensure that all bulk meters have a cumulative register on-site, with an emergency power supply in case of temporary loss of power
- always use the bulk meter cumulative register readings for water balance calculations (or ensure SCADA data correspond with them)
- the accuracy of 1 bulk meter, correctly selected/sized/installed/maintained, should not be assumed to be better than +/- 2%.
- if more than one bulk meter supplies a system, the random error of their total volume should decrease with the number of meters.

APPENDIX H: Typical Installation of a Water Meter and Pressure Reducing Valve



APPENDIX I: Pressure Management in Waitakere City – A Case Study

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ABSTRACT

In 1996, as part of Council's Water Cycle Strategy, a pressure standardisation programme to permanently lower the average supply pressure citywide was implemented with the aim of reducing water loss and water use. The experience gained during the 1994/95 Auckland water shortage had confirmed that there was considerable scope to reduce pressures in many areas.

Since 1996 water pressures have been reduced in over 60% of the reticulated area of the city, with the average pressure reduced from 710kPa to 540kPa. As a result of this programme water loss from the network has been reduced, there has been a reduction in the frequency of mains breaks and it is likely that the life of water pipeline assets has been extended. Furthermore both pressure and demand management initiatives have reduced per capita water use in the city by more than 10%.

A network computer model was used as a design tool to check the network under various pressure regimes and cost benefit analyses were carried out for various design scenarios. Fire sprinkler systems were checked as part of the design process. Minimum service standards were not reduced and in some cases pressures were actually increased. This paper covers the various aspects of the design, the implementation and the results of the pressure standardisation programme.

KEY WORDS

Pressure management, leakage, demand management, pressure reducing valve (PRV), modelling

Introduction

Waitakere City Council's water business unit (EcoWater Solutions) purchases water from Auckland's bulk supplier (Watercare Services Ltd) to supply residents and businesses in the city. Bulk water is metered at 28 bulk supply points. All consumption is metered with currently around 59,000 connections made up of residential (79%), industrial/commercial (15%) and agricultural (6%) users. The network comprises 1267km of water mains ranging in size from 50mm to 375mm. Approximately 60% of the mains are asbestos cement, 30% PVC and the balance are polyethylene, steel, galvanised and cast iron.

In late 1995 Waitakere City Council combined its "Eco city" philosophy with the lessons learnt during the 1994/95 Auckland water shortage to develop a Water Cycle Strategy that promoted sustainable water management solutions at a local level. During the water shortage pressures were reduced as an emergency measure. In 1996, as part of the Water Cycle Strategy, it was decided to implement a programme to permanently lower the average supply pressure citywide to reduce water loss and water use. The water shortage had confirmed that there was considerable scope to reduce pressures in many areas as existing pressures were often well in excess of 300kPa.

Since 1996 water pressures have been reduced in approximately 60% of the reticulated area of the city with the average pressure reduced from 710kPa to 540kPa. Pressures were altered for 35,000 consumers, and in most cases pressures were reduced by between 150 and 500kPa. Pressure fluctuations were also reduced in many areas as a result of the programme. Water loss from the network and the frequency of mains breaks have significantly reduced as a result of the programme and it is also likely that the life of water pipeline assets has been extended. With advanced pressure management techniques, future upgrading works may also be deferred as pressures can be increased only during periods of high demand. As a greater number of smaller sub zones can now be managed and monitored, leak detection activities are more focussed. Pressure and demand management initiatives have reduced per capita water use in the city by more than 10%.

Design work and implementation was carried out in house by water engineering staff. A network model was used as a design tool to check the network under various pressure regimes, and cost benefit analyses were carried out for the different scenarios. Minimum service standards were not reduced. In some cases zone boundaries were altered and in a few small areas pressures were increased to improve service. The impact of reduced pressures on fire sprinkler systems was considered and affected systems dealt with individually. This paper covers the various aspects of design and implementation of the pressure standardisation programme, and the main results.

Background

The detrimental effect of excessive and unstable pressure in the water supply system on network assets has been recognized in many countries since the early 1980's. The problem can be likened to high and fluctuating blood pressure in the human body. Since 1980 a number of research activities at a national level have been carried out, for example, in the UK (Ref 1), and pressure management case studies have been analysed in the UK, Japan, Brazil, and Malaysia (Ref 2). Awareness of pressure management and its effects on network assets is now much more acknowledged then previously and a new water supply discipline, pressure management, has developed. In many water authorities, pressure management is widely accepted as having benefits in:

- Demand Management - Less consumption from pressure related uses of water;
- System Deterioration - Extended useful life of infrastructure;
- Water Losses - Reduced leakage and fewer new leaks;
- Maintenance costs - Reduced frequency of main breaks;
- Customer service - Better service due to less water supply interruptions.

The UK Water Research Centre and Japan both developed average relationships between leak flow rate and system pressure around 1980. The FAVAD concept, developed in 1994 by John May in the UK, has proved to be the most reliable approach, and further work carried out since 1994 by the IWA Water Loss Task Force has confirmed the N1 exponent in the FAVAD relationship is dependent on the type of pipeline materials; Figure 1 below (refer Ref 2) shows a range of pressure/leakage relationships relating to various N1 values. There is now a good understanding of the way networks respond to pressure changes. Our experience has proven that an N1 value of 1.5, which relates to high pressure systems with predominantly non-metallic pipe materials without significant leakage, applies particularly well to the reticulation in Waitakere City.

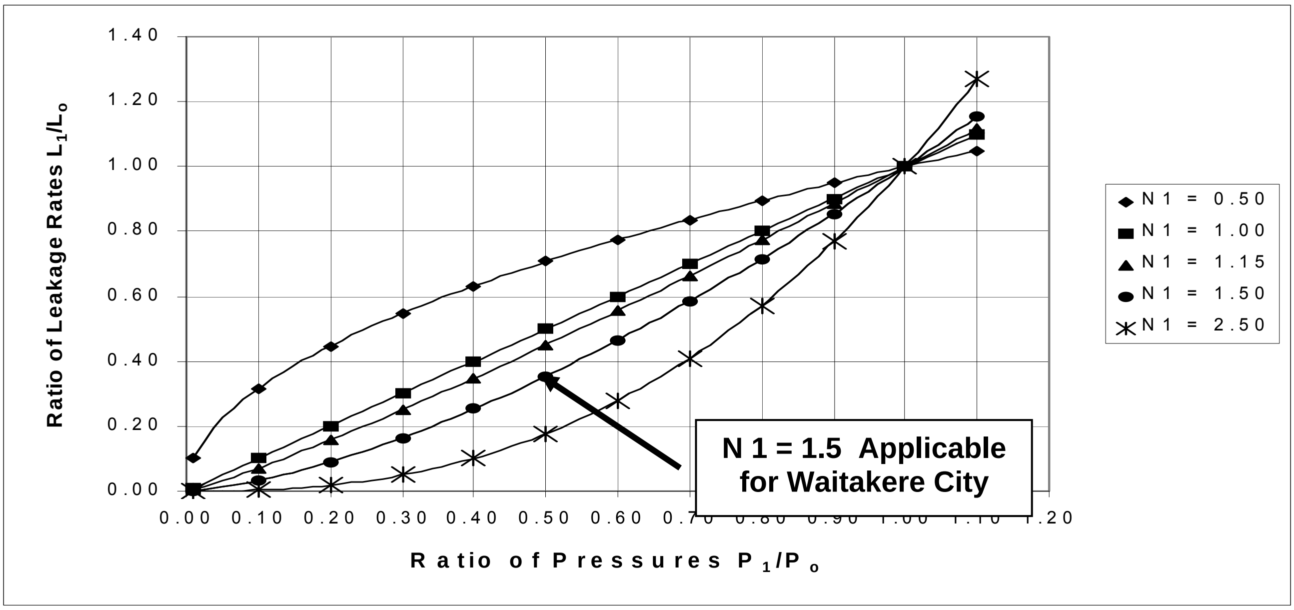

Figure 1: Relationship between System Pressure and Leakage

PILOT ZONE INVESTIGATIONS

The first stage of the programme was designed as a trial exercise in a pilot area, as there appeared to be no previous experience in comprehensive pressure management projects in New Zealand. Massey East Zone, with 1,250 connections, was selected for the detailed network investigations. The area was split into a lower and an upper sub-zone. In the lower zone the pressure was reduced by 500kPa while in the upper zone pressures were reduced 200kPa. The results from the pilot investigation confirmed expectations. Over the period, the average minimum night flow, as an indicator of losses, was reduced from 1.2 l/s to 0.6 l/s and the total water demand reduced by up to 14%. Only five customers complained about low pressure, all relating to problems with hot water pressure and showers. A plumber at Council's cost quickly remedied these problems.

DESIGN CRITERIA

DELIVERY STANDARDS

The aim of the programme was to reduce the average supply pressure across the city but maintain the current minimum service standard of 250kPa pressure and 25 litres/minute flow measured at the meter. For design purposes 300kPa residual pressure was required under peak demand and 100kPa for background use plus fire flows.

It was also necessary for compliant fire sprinkler systems installed prior to 1996 to remain compliant after the pressure adjustments. This was a responsible approach rather than a legal requirement. A calibrated network model was used to analyse various pressure management options and to check that the supply to critical points was not compromised.

SELECTION AND DEVELOPMENT OF PRESSURE ZONE AREAS

The main urban areas of Waitakere City and the northern part of the city i.e. Henderson, Hobsonville, Whenuapai, Lincoln, Swanson, Te Atatu, Kelston, New Lynn, Glen Eden, are relatively low lying and border onto the upper reaches of the Waitemata Harbour. These areas were typically supplied directly via the Watercare trunk water mains with a static pressure of 115m (HGL) and daily pressure fluctuations between 95 and 115m(HGL). Thus improvements could be achieved by implementing pressure management, firstly by the permanent rezoning of existing areas where the HGL could be reduced from 115m to 65m or 75m, and secondly, by optimising pressure regimes. As a first step pressure reducing valves with basic fixed outlet pressure characteristics were installed, as the water supply zones were comparatively small. The use of time variable and flow compensating valves was seen as an enhanced option for a future development.

An overview of the system rezoning pressure reduction for four supply zones / sub – zones is given in Table 1.

HYDRAULIC SURVEY AND MODELLING

A hydraulic survey using solid-state pressure loggers to monitor performance was recognized as an essential step prior to the introduction of pressure reductions. Initially pressure loggers were used to calibrate the network model and to record the pressures occurring prior to implementation of the pressure standardization programme. Prior to making changes to the network, and during the implementation phase of the programme, pressure loggers were used to closely monitor the changes and to verify pressures at the supply points, the furthest points in the zone and the highest points (the critical points), as well as for analysis of PRV performance.

A dynamic hydraulic model (WesNet / InfoWorks WS) was used for analysing how the network would respond to a change in pressure regime, for designing the pressure standardization programme and for operational and planning needs. Separate models were developed and calibrated for each distribution zone but the intention is to combine these into a global model as a further enhancement to the modelling. To create the model geometry for each zone GIS graphical files in CGM form were imported and nodes and pipes traced directly over background GIS maps. In total the models have 2,502 nodes and 2,909 pipes with a combined length of 668.1 km. Demand is modelled by defining a demand block (a nodal polygon) as the unit of demand modelling. All elements of the network including pumps, supply points, reservoirs, and pressure control valves were modelled to match actual operating conditions.

The models are very stable and the “goodness of fit” between the computed and measured results is generally in the order of 5 %. Models for the entire Waitakere City water supply system were completed 'in house' over a period of 9 months.

Table 1: Summary of Pressure Reduction in Water Supply for Zones 4, 5, 6 and 15.

No.	SUPPLY ZONE and Sub Zone	Initial Maximum Pressure	Reduced Max. Pressure	Pressure Reduction	Reduced Daily Pres. Fluctuations	Number of Connections
		m	M	m	m	
4	**LINCOLN – SWANSON**					7.300
	Lincoln-Swanson Central *Sub Zone*	115	75	40	20	4,900
	Massey Reservoir *Sub Zone*	115	100	15	20	1,900
	Simpson Rd *Sub Zone*	115	100	15	25	500
5	**TE ATATU – KELSTON – GLENDENE**					7,000
	Te Atatu Peninsula *Sub Zone*	100	65	35	25	3,100
	Te Atatu South	100	75	25	20	3,000
	Kelston *Sub Zone*	100	65	35	10	900
6	**HENDERSON**					5,800
	Henderson Central *Sub Zone*	115	75	40	20	4,700
	View Rd *Sub Zone*	115	95	20	20	900
	Pine Ave. *Sub Zone*	115	90	25	25	200
15	**WEST HARBOUR**					3,000
	West Harbour Upper Sub Zone	115	95	20	15	1,700
	West Harbour *Lower Sub Zone*	115	65	50	15	1,300

PROGRAMME IMPLEMENTATION

EQUIPMENT SELECTION AND INSTALLATION

The results of the hydraulic survey and network modelling were used in selecting and sizing pressure-reducing valves, water meters etc for each site. The standard installation consisted of a strainer and PRV installed in one chamber, and the water meter installed in a separate downstream chamber. The pressure standardisation programme involved bringing back into service 15 existing PRV's at bulk supply points and the installation of 22 new PRV's.

METHODOLOGY

Once the pressure reducing valves were installed, the pressure reduction exercise was usually carried out in two steps. Firstly, pressure was reduced half way to the target level and a few days later the pressure was adjusted to the final level. Over this period, data loggers recorded inlet and outlet pressures at the PRVs and pressure at critical points in the zone. In the majority of cases the implementation of the programme was carried out smoothly without any significant operational difficulties. Furthermore there have been no significant reticulation problems during subsequent summers when temperatures have been high and demand at record levels.

The implementation of the entire pressure standardisation programme (35,000 properties) was carried out with only 1% of affected customers contacting council with a pressure related complaint. Half of these complaints were attributable to customer's internal plumbing problems such as hot water cylinders and showers. A plumber quickly resolved these problems (often only adjustment) at council's expense. Some problems took longer to resolve. Problems with plumbing systems and inadequately sized pipes or highly encrusted private galvanized pipes became evident at lower pressures. In some cases the pipe for a new private line was supplied free. Council staff rectified any service connection problems (restricting flow to the meter) at Council's cost.

Problems in the distribution system were mainly caused by poor PRV performance, e.g., cyclic pressure fluctuations, unstable pressures irrespective of demand, pressure drops during peak demand and valves performing as a direct ratio valve rather than as a pressure-reducing valve. In one or two cases the PRV failed and there was a sudden return to original pressures, which had a very undesirable effect on the network. Other problems encountered were due to faulty valves, one left-hand valve, and ordinary valves being left off instead of being turned on after maintenance.

CUSTOMER RELATIONS AND FIRE SPRINKLER SYSTEMS

An important aspect of the programme was dealing with customer relations. The programme was communicated as a 'pressure standardisation programme' whereby pressures were being standardised across the city. Notification of the programme and a speedy response to any customer complaints arising from changes in operational pressure was essential. A letter with information about planned activities and a pressure standardisation brochure were delivered to all affected customers. Every customer complaint was followed up promptly and investigated by taking flow tests at the meter, the house tap and a pressure test at the nearest hydrant. Appropriate action was taken to ensure there were no outstanding problems.

To ensure fire sprinkler systems remained compliant after the pressure changes were made a specialist fire engineer was engaged to access the impact of reduced pressures on 70 fire sprinkler systems within the city. Where a problem was envisaged for a particular system the network model was used to confirm final pressures at the location and then the designer of the system was engaged by Council to identify the most cost effective means of overcoming the problem. Some reticulation improvements and upgrading of internal sprinkler installations were carried out and funded by Council to overcome such problems.

COST BENEFIT OF THE PROGRAMME

The capital cost for the programme was $850,000 spread over three financial years. This expenditure covered the cost of installing 22 new pressure control sites, laying a few new short pipelines, road crossings, installing new valves, fire system consultants, modifications to existing fire sprinkler systems, plumbing costs and public notification. The key benefits of programme are summarised below.

- Less water consumption per capita largely a result of a reduction in pressure dependent usage, e.g. showers, garden hoses etc. Per capita water consumption in Waitakere City has reduced by more than 10 % since 1992/93 due to the introduction of various demand and pressure management techniques. Pressure management however, is known to be largely responsible for the overall per capita reduction (Ref 3). It has been estimated that the quantity of wastewater per capita has also reduced by approximately 4% - 5%. One percentage of wastewater volume represents a cost to Waitakere City of approximately $100,000 per year.
- Less frequency of major breaks (i.e. major breaks on a water main or saddle) as shown in Figure 2. In 2000 / 01 the average number of breaks per month was 48 (or 10 breaks per 1,000 connections). Prior to 1996 the average number of breaks per month was more than 65 (or 15 breaks pre 1,000 connections). Less breaks means

reduced maintenance costs and less supply interruptions and consequently improved customer service.

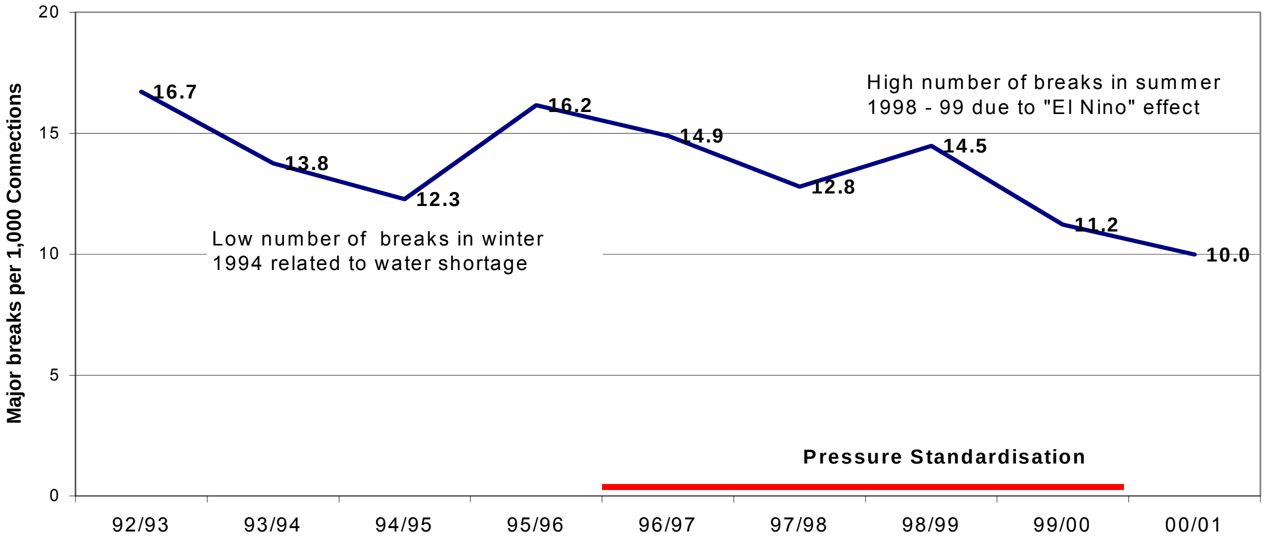

Figure 2: Waitakere City – Number of Major Breaks per 1,000 Connections Per Annum

- Less water losses. The non-revenue water loss reduced from 14.7 % by volume for the 12 months ending June 1996 to 10.5 % for the 12 months ending June 2001 (Figure 3). Reducing water losses by one percentage point represents an annual saving to Waitakere City of $ 65,000, i.e. the 4.2% reduction represents a total saving of $273,000 per annum.

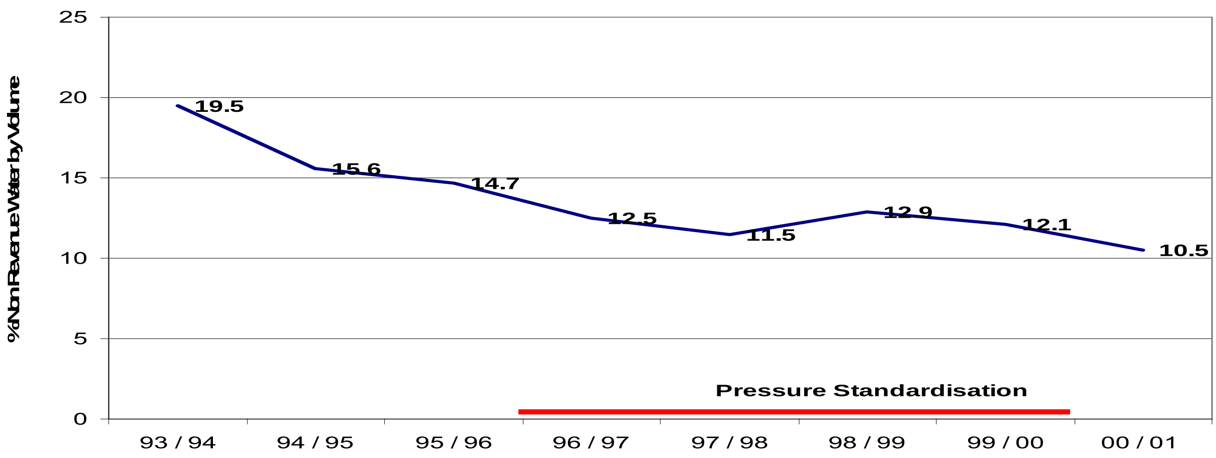

Figure 3: Waitakere City – Water Losses, % Non revenue Water By Volume

- More efficient leak detection is now possible as 14 new sub zone areas with 22 control points (meters) are now monitored, some using telemetry. This means that the awareness time of unreported leaks is reduced with significant cost savings.
- The life expectancy of water network assets, where pressures have been reduced and pressure fluctuations minimised, has probably been extended by 10 to 20 years

- Less capital expenditure for future upgrading of the system. Savings in capital upgrading costs to meet population growth is now possible as existing surplus upstream pressure at control points can be used to increase the capacity of the system by simply converting the fixed pressure PRV's to flow modulating PRV's
- One benefit often overlooked is that private plumbing systems are subjected to a reduced pressure, which in turn reduces faults on private water systems.

A very simple but conservative overall cost benefit for the programme gave a payback period of 3.3 years. This ignores the financial benefits of deferred capital works, reduced wastewater volumes and extended life of assets etc.

CONCLUSIONS

For water supply authorities the continuous improvement and development of operational network management is essential to gain the greatest efficiencies in water distribution. Initial results of the pressure standardisation programme in Waitakere City have confirmed that pressure management is a significant operational technique that can be used to great advantage with many benefits. The fact that Waitakere City is supplied by a bulk supplier (Watercare Services Ltd) via 28 bulk supply points supplying 17 discrete water supply zones meant that pressure reduction was perhaps easier to accomplish than for other water utilities, however it is evident that the benefits of pressure management are too great to be ignored by any water supplier. The benefits of the programme as outlined above are robust and will generate ongoing financial benefits.

ACKNOWLEDGEMENTS

Waitakere City Council has pursued a progressive approach towards sustainable water management and how this can be achieved at a local level. This paper outlines one of the achievements resulting from this strategic direction. The writers would like to thank Waitakere City Council for being a progressive city and EcoWater management staff for their strong support in the implementation of the pressure standardisation programme.

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