

Water Losses Management and Techniques

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Electronic copies of the International Report, and electronic copies of some of the National Reports, may also be obtained from Allan Lambert at

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Abstract

Since the 1991 IWSA International Report on ‘Unaccounted for Water and the Economics of Leak Detection’, the topic of management of water losses in distribution systems has received increased attention. This International Report seeks to present an overview of the ‘state of the art’ in management of Water Losses, based on the Reports prepared by National Rapporteurs, the recent recommendations of the IWA Task Forces on Water Losses and Performance Measures, and improved concepts for modelling components of leakage and pressure: leakage relationships.

The IWA Task Force recommendations provide overdue clarification and guidance on several issues that have caused persistent problems in quantifying Water Losses and comparing the effectiveness of their management. It is hoped that this Report will assist in the promotion of a more standardised international approach to the definition, assessment, monitoring and management of Non-Revenue Water and Water Losses.

Keywords

Non-Revenue Water, Apparent Losses, Real Losses, Performance Indicators, Benchmarking

INTRODUCTION

During the 1990’s, there have been significant advances in instrumentation for more effective leak detection and location – notably in metering and logging of flows, pressures and leak noises. Improvements in the understanding of pressure: leakage relationships, and in component analysis of Real Losses, and the factors which influence them, have been made. Increasingly, attempts are

made to define the economic level of leakage for individual systems. Yet, despite some encouraging success stories, most water supply systems worldwide continue to experience high levels of water losses, most of which are almost certainly higher than their economic level.

Part of the problem has been the lack of a meaningful standard approach to Benchmarking and reporting of management performance. The IWA Task Forces on Performance Indicators (1) and Water Losses (2,3) have recently produced an International 'best practice' standard for defining and calculating components of water balance, and selecting the most appropriate Performance Indicators for different components of Non-Revenue Water and Water Losses.

This International Report commences with the IWA standard water balance and definitions, as the basic but essential first steps in management of Water Losses. Next, the assessment and management of Unbilled Authorised Consumption – which is part of Non-Revenue Water, but not part of Water Losses in the IWA definitions – is considered. Then follows the assessment and management of components of Apparent Losses.

Volumes of Unbilled Authorised Consumption and Apparent Losses represent water actually used to some purpose, but not paid for; in contrast, Real Losses represent a loss of water resources, at least part of which may be recovered by well-directed leakage management activities. An overview of the major components of a successful Real Losses management policy – Pipeline and Assets Management, Pressure Management, Active Leakage Control, Speed and Quality of Repairs – is given.

Experiences of Pipeline Management, taken from the National Reports, are reviewed first, followed by examples of Pressure Management. A brief outline of recent advances in the understanding and prediction of pressure: leakage rate relationships is provided.

Because assessment of Real Losses is always subject to error, the Report next outlines three methods of assessment – Water Balance, Component Analysis and Night Flow Analysis. Typical results from Component Analysis confirms practitioners' experience that, in most well run systems, the largest volume of Real Losses is associated with service connections rather than mains (for systems with density of connections > 20/km of mains). Component analysis is also used as the basis for deriving an equation for Unavoidable (Technical Minimum) Annual Real Losses (3).

Once the volumes of components of Water Losses have been determined, appropriate Performance Indicators (PIs) can be selected for Benchmarking purposes. The recommended 'best practice' for selection of Level 1 (basic) and Level 3 (detailed) Performance Indicators for Real Losses is outlined. Reasons why %s are not recommended as Operational PIs for Real Losses are explained.

The next section discusses management of the duration of leaks and bursts, through speed and quality of repairs, and active leakage control. Financial Performance Indicators for Non-Revenue Water, and Economic considerations are then reviewed, prior to the Conclusions.

The Report is based principally on the following sources:

- The twenty-two national reports, following, prepared for the 2001 IWA World Congress
- Recent publications of IWA Task Forces on Performance Measures (1) and Water Losses (2,3)
- The International Data set of 27 diverse systems from 20 countries, used by the Water Losses Task Force (3)
- The recent IWSA International Report on Water demand management and conservation including water losses control (4)

DEFINING WATER LOSSES: THE IWA STANDARD TERMINOLOGY

Any discussion relating to water losses must be preceded by a clear definition of the water balance components. In recent years, because of the wide diversity of formats and definitions, many practitioners have identified an urgent need for a common international terminology. Drawing on the best practice from many countries, the IWA Task Forces produced a standard approach for Water Balance calculations (Figure 1), with definitions of all terms involved (1,2).

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage on Service Connections up to point of Customer metering	

Fig. 1. IWA Standard International Water Balance and Terminology

Abbreviated definitions of principal components of the IWA water balance are as follows:

- System Input Volume is the annual volume input to that part of the water supply system
- Authorised Consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- Non-Revenue Water (NRW) is the difference between System Input Volume and Billed Authorised Consumption. NRW consists of:
 - Unbilled Authorised Consumption (usually a minor component of the Water Balance)
 - Water Losses
- Water Losses is the difference between System Input Volume and Authorised Consumption, and consists of Apparent Losses and Real Losses
- Apparent Losses consists of Unauthorised Consumption and all types of metering inaccuracies
- Real Losses are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

Because of widely varying interpretations of the term ‘Unaccounted for Water’ worldwide, the IWA Task Forces do not recommend use of this term. If the term UFW is used, it should be defined and calculated in the same way as ‘Non-Revenue Water’ in Figure 1 (1).

The components of the water balance should always be calculated as volumes before any attempt is made to calculate performance indicators. The separation of Non-Revenue Water into components – Unbilled Authorised Consumption, Apparent Losses and Real Losses – should always be attempted. This is emphasised in the French National Report, and it is encouraging to note that most of the National Reports attempt this separation, to a greater or lesser extent.

Widespread international use of the IWA standard water balance is being encouraged, as the first step in calculating the IWA 'best practice' Performance Indicators. The IWA Standard Water Balance, with minor variations, has already been adopted or promoted by:

- national organisations in Australia (5), Germany, Malta and South Africa
- individual utilities or consultants in Brazil, Canada, Malaysia, New Zealand and USA.

If a well-defined national standard water balance methodology already exists, it is usually relatively easy to re-allocate the components into the IWA standard approach, before calculating the 'best practice' Performance Indicators. If a national standard is being reviewed, as described in the German National Report, adoption of the IWA standard approach is to be encouraged.

In the remainder of this Report, the Author has attempted to reclassify the terminology used in the National Reports into the IWA Standard Terminology. Use of the term 'network' is also avoided; to some it means 'mains', to others it means 'mains and the service connections'. Apologies are offered if any errors that may have been introduced during this process.

ASSESSMENT AND MANAGEMENT OF UNBILLED AUTHORISED CONSUMPTION

Authorised Consumption, in the IWA terminology, includes items such as fire fighting and training, flushing of mains and sewers, cleaning of suppliers' storage tanks, filling of water tankers, water taken from hydrants, street cleaning, watering of municipal gardens, public fountains, frost protection, building water etc. These may be billed or unbilled, metered or unmetered, according to local practice.

Unbilled Authorised Consumption is normally only a small component of the water balance. Wherever feasible, such volumes should be metered. In other situations, simple but effective methods of documenting and estimating such uses are strongly recommended; they often show that volumes of Unbilled Authorised Consumption are unnecessarily high, and can be managed down to lower annual volumes without influencing operational efficiency or customer service standards.

ASSESSMENT AND MANAGEMENT OF APPARENT LOSSES

Apparent Losses consist of Unauthorised Consumption (theft and illegal use) and Metering Errors. Calculations of these volumes are preferably based on structured sampling tests, or estimated by a robust local procedure (which should be defined for audit purposes). Some quoted figures for Apparent Losses in the Country Reports (as % of System Input Volume, SIV) are:

Malaysia	Apparent losses 9% of SIV
Korea	Apparent Losses 9.2% of SIV in 1998, target 3% of SIV in 2011
Australia	Apparent losses 1% to 3% of SIV

However, rather than simply assuming that Apparent Losses are some nominal % of System Input Volume, based on figures for other Utilities, each Utility should attempt to assess and manage the components of Apparent Losses for its own system(s).

Assessment and Management of Unauthorised Consumption

Unauthorised Consumption occurs to a greater or lesser extent in most systems worldwide - the England & Wales estimate (6) is 0.36% of System Input Volume. The Australian, Moroccan and USA National Reports specifically mention this component of Apparent Losses, which is generally associated with misuse of Fire Hydrants and Fire Service connections, and illegal connections.

In Australian, sample metering of normally unmetered Fire Services has identified considerable misuse; this issue is being addressed through an education program. Checking for possible illegal

connections commences with identification of customers with unusually low consumption. In Morocco, metering of fire hydrants is in progress. In the USA, the M36 Audit procedure (7) recommends that Unauthorised Consumption is best dealt with through 'good billing procedures'.

Assessment of Metering Errors

Many users of the IWA standard water balance, including the Author, prefer to correct any known errors to the system input volume at the start of the calculation. This not only reinforces the absolute necessity for regular checks on the accuracy of the system input meters, but also seeks to ensure that the only metering errors in Apparent Losses will be customer metering errors, making the calculated volumes easier to interpret.

Customer Metering Errors include:

- Accounting procedure errors – due to differences between dates of source meter readings and customer meter readings, misread meters, incorrect estimates for stopped meters, adjustments to original meter readings, improper calculations, computer programming errors etc.
- Under or Over-registration of Customer Meters

Several of the National Reports draw attention to the problem of customer meter under-registration.

- Malaysia Customer meters economic life-span 7 to 10 years
10-year meter change expected to limit under-registration to within 5%
- Korea Funds for meter replacements influenced by subsidised charging rates
- Spain (Murcia) Problems with measuring low flow consumption (including housing leakage)
Class B single jet meters tests in houses show average 6% under-registration
- Denmark Customer meters must be approved by spot testing/replaced every 8 years
- Bangkok Customer meter under-registration 2%, customer meter malfunction 2.5%
- Morocco Customer meter under-measurement 10% to 15%
- Germany 'Meter errors at extremely low flows' are now allocated a specific component in the DVGW standard Water Balance documentation

Management of Customer Metering Errors

Management of Accounting Procedure Errors: Many computer-based billing systems are, unfortunately, not designed for efficient retrieval of technical data for water losses studies and calculations. Improved liaison between the Billing and Operational sections of the Utility can minimise such problems. If there are spare 'fields' in the billing system, the use of Global Positioning System (GPS) references for each customer meter location may, in some situations, offer a way of assigning individual meters to individual Sectors. GIS technology also provides the capability to link every customer meter with a service connection.

Management of Customer Meter under/over Recording: the selection of customer meter types and classes (A to D) may be limited by water quality considerations, as well as technical and economic considerations. Economic replacement policies for residential meters based on selective testing programs in the National Reports generally indicate changeover periods between 5 and 10 years. Incorrectly sized commercial meters can result in significant under-registration of consumption, and checks can be made to identify if there are more appropriate meters for individual situations (by occasional monitoring of the actual frequency and range of consumption rates).

Influence of Roof Tanks: When samples of customer meters are tested for accuracy, it is normal to quote the error as a % of the recorded metered consumption. Where customers are served by way of roof tanks, the probability of customer meter under-registration is increased, because of the tendency for a greater part of the consumption to pass through the meter at rates less than the Q_{min} specified for the meter (see Spanish National Report).

This tendency is illustrated in Figure 2, using data from fully metered systems in the Water Losses Task Force International Data Set. Apparent Losses plus Unbilled Authorised Consumption (UAC) for each system are shown as %s of recorded metered consumption. It is unlikely to be a coincidence that the four systems with the highest % values are the only systems where customers are supplied by way of roof tanks. Morocco, which also has roof tanks, also has the highest quoted customer meter under-registration (10% to 15%) in the National Reports.

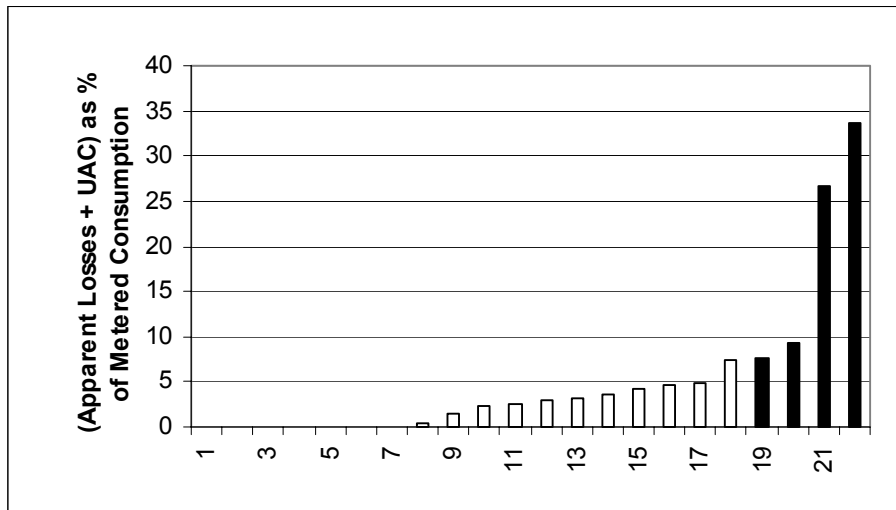


Fig. 2. Apparent Losses and Unbilled Authorised Consumption as % of Metered Consumption, International Data Set ; Systems with Roof Storage Tanks shown in black

Note that, in seven of the 22 systems, no allowance has been claimed for Apparent Losses and Unbilled Authorised Consumption. These are all Northern European systems subject to direct pressure, with types of customer meters that may tend to over-record slightly as they age.

Clearly, it is not going to be valid to make simple comparisons of apparent losses between systems with roof tanks, and systems where the properties are subject to direct mains pressure. The class of customer meter used (A to D), the type of meter (impeller, rotary piston or other types) and the operating pressure (where roof tanks exist) will also influence the lowest achievable volume of apparent losses. Comparisons of meter under-registration for systems with roof tanks is likely to be an important area for practical research over the coming years.

ASSESSMENT AND MANAGEMENT OF REAL LOSSES – AN OVERVIEW

The Four Basic Methods of Managing Real Losses

The assessment and management of Real Losses contains so many elements that it is useful to consider a simplified overview, before going into detail on particular aspects.

In Figure 3, suppose that the area of the large rectangle represents the Current Annual Real Losses, in m³/year, for any specific system. As the system ages, there is a tendency for a natural rate of rise of Real Losses through new leaks and bursts, some of which will not be reported to the Utility. This tendency is controlled and managed by some combination of the four primary components of Real Losses Management: namely:

- Pipeline and Assets Management
- Pressure Management (which may mean increases or decreases of pressure)
- Speed and quality of repairs
- Active Leakage Control, to locate unreported leaks

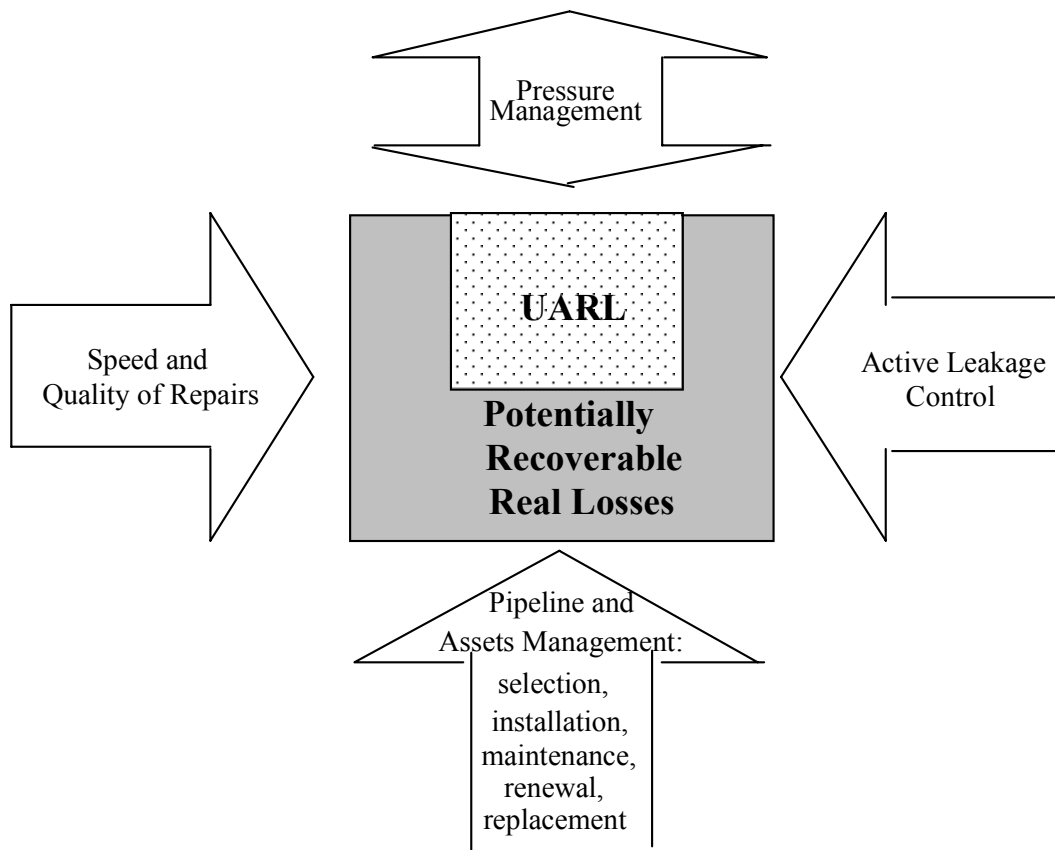


Fig. 3. The Four Basic Methods of Managing Real Losses

The number of new leaks arising each year is influenced primarily by long-term Pipeline Management. Pressure Management can influence the frequency of new leaks, and the flow rates of all leaks and bursts. The average duration of the leaks is limited by the Speed and Quality of Repairs, and the Active Leakage Control strategy controls how long unreported leaks run for before they are located. The extent to which each of these four activities is carried out will determine whether the volume of annual Real Losses increases, decreases or remains constant.

Real Losses cannot be eliminated totally. The lowest technically achievable annual volume of Real Losses for well-maintained and well-managed systems is the Unavoidable Annual Real Losses (UARL), represented by the smaller rectangle in Fig. 3. System-specific values of UARL can be calculated using the component-based methodology (3) developed by the Water Losses Task Force.

The difference between the UARL (small rectangle) and the Current Annual Real Losses (UARL) is the potentially recoverable Real Losses. The ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL) is the Infrastructure Leakage Index (ILI).

The ILI measures how effectively the infrastructure activities in Figure 3 - repairs, active leakage control and Pipeline/Assets Management – are being managed at current operating pressure.

For each of the four activities, there is some economic level of investment and activity, which needs to be calculated or assessed, depending upon the marginal value, in local currency/m³, placed on the Real Losses. Depending upon local circumstances and practice, the marginal value placed on Real Losses may be low – perhaps power and chemicals cost only – or high, and this profoundly influences the economic management policies for controlling Real Losses.

PIPELINE AND ASSETS MANAGEMENT

Infrastructure naturally deteriorates with time, and because of the high costs involved, in most situations it is not being renewed/replaced at a rate which is likely to produce rapid significant improvements in Real Losses. Table 1 lists some aspects of Pipeline Management taken from the National Reports.

Table 1: References in National Reports to Pipeline and Assets Management

Country	References
Malaysia	Major replacement programme for leakage-prone AC mains
Italy	Research into strategic factors envisaged. Service connections more problematical than mains
Korea	Changing old distribution pipes
Japan	Rehabilitation of mains and service lines considered as a preventive measure. Many crack accidents with AC pipes. Mains mostly ductile iron. Service connection pVC, polyethylene and stainless steel.
Finland	Network renovation – specially replacing old corroded steel mains. House connection pipes are estate owners property
France	Not specifically mentioned
Poland	Newly laid systems use ductile iron for trunk lines, more use of plastic pipes
Romania	Mains are over 30-40 years old: 46% AC, 30% uncoated steel, 21% cast iron. Use good materials and good technologies for network repair and rejuvenation
Hong Kong	Mains replacement/rehabilitation for corroded mains and areas with high burst frequencies. Asset management plans to replace 53% of mains in 20 years
Portugal	‘Old age/corrosion’ and ‘construction deficiency’ linked with high break rates
Spain	Distribution system not specifically mentioned; defective plumbing
Norway	Distribution system not specifically mentioned. Leaks on unmetered private lengths of service connections prior to customer meter in house.
Denmark	Rehabilitation programs on 0.8% of pipelines/year. Many older private connection pipes after street boundary in bad condition
UK	Not specifically mentioned. Free/subsidised repair and replacement of leaks on private pipes after street boundary have reduced Real Losses by 18 l/prop/day
Bangkok	Aging distribution pipes; 30% older than 25 years. Target to replace 4% /year
Australia	Not specifically mentioned.
Morocco	Mediocre works construction, old network
South Africa	Maintenance & replacement below optimum. Systems gradually deteriorating, trend likely to continue. Some repairs to leaking private plumbing
Germany	Important statistics on failure rates for mains, fittings and service connections
Hungary	Replace inadequate pipework over 45 years old, aim for 1% of mains. Programme includes changing service connections
USA	Aging infrastructure in urban areas in Eastern states
Taiwan	No specific references

Some points of particular interest are as follows:

- More countries are recognising the need to replace service connections as well as mains
- In many countries, parts of the service connection between main and meter are in private ownership, leading to delays in repairs (longer durations lead to higher Real Losses volumes)
- Pipeline management targets should include service connections, irrespective of ownership
- A pro-active approach to assisting customers to reduce leakage on their private pipes and plumbing systems may be a rational and economically justifiable option.

Several of the National Reports comment on frequencies of new leaks and bursts.

- Finland has ‘quite good and historically consistent’ statistics about pipe breaks
- New leak frequency on French networks is relatively small, generally than 1 per km per year
- In Poland, breakdowns on mains and service connections averages 1.06 per km of pipe per year
- Portuguese break rates on service connections (0.97 to 4.29 per km per year) average 5.5 times the break rates on mains (0.23 to 1.21 per km per year), and that these are ‘5 to 10 times higher than European or North American averages for similar systems’
- The comprehensive German national data base is a useful standard against which new break frequencies in other systems on mains, fittings and service connections can be compared

For systems with pipe materials which are not in good condition, the rate of deterioration, and the rate at which new leaks occur, can sometimes be slowed by some form of pressure management

PRESSURE MANAGEMENT

In some countries it has been recognised for many years that effective management of pressures is the essential foundation for an effective leakage management strategy. The Spanish National Report considers Pressure Reduction to be ‘the preventative measure par excellence’. Table 2 summarises information from the National Reports on the extent to which Pressure management is practiced. The table excludes the UK and Japan, where pressure management has for many years been an intrinsic part of leakage management, but it is not mentioned in the National Reports.

Table 2: References in National Reports (other than Japan and UK) to Pressure Management

Country	References to pressure management
Malaysia	Install break pressure tanks or pressure reducing valves to control very high pressures. Leakage in the distribution system is proportional to water pressure
Italy	Identifying water pressures to reduce damages to materials under normal use
Korea	Not specifically mentioned
Finland	Managing pressure is not used to reduce leakage
France	Not specifically mentioned
Poland	Real losses influenced by end-system water pressure
Romania	Development... to control pressure values in the distribution system
Hong Kong	Flow-modulated pressure reducing valves in areas with unduly high pressure
Portugal	Intended flow and pressure telemetered data in EPAL
Spain	Pressure reduction is the preventative measure par excellence
Norway	Leakage very much dependent on pressure. Existing pressure zones; possibility of reducing pressures, introducing new pressure zones, modulated pressure control.
Denmark	Use of pressure zones, pumping heads kept as low as possible
Thailand	Plan for zoning system to check flows and pressures
Australia	Systems generally operate at high pressures. Research into pressure management.
Morocco	Strong pressure
South Africa	Pressure management receiving considerable attention in recent years. Pilot studies in major cities and many completed projects (e.g. 60 smart PRVs in Johannesburg)
Germany	Leakage rates change with pressure much more than would be predicted by the theoretical ‘square root’ relationship. Leakage targets set for customary 3 to 5 bar average supply pressure. Pressure management not normally used for loss reduction
Hungary	Not specifically mentioned
USA	Pressure management not widely practised. Recommended to allow for pressure in performance comparisons, and to further the science of pressure management.
Taiwan	Not specifically mentioned

Some National Reports seem to consider Pressure Management as consisting only of sectorisation or installation of Pressure Reducing Valves (PRVs), but in practice pressure management for leakage management also includes minimising the range and frequency of surges, and level and overflow control at storage reservoirs.

Probably the most important aspect of pressure management, in relation to leakage management, is the control of surges and rapidly fluctuating pressures. Systems with intermittent supply situations, (or direct pumping into mains) usually experience these effects to a greater degree than gravity-fed systems, and are often found to have unusually high frequencies of new leaks and bursts.

The benefits of Pressure Management, in its widest sense, are:

- extension of the life of the distribution infrastructure
- reduction of new burst frequencies on distribution mains and service connections
- reduction of flow rates of all leaks and bursts present in the system at any time
- reduction of new leaks on private pipes and overflows at private storage tanks
- reduction of some components of consumption subject to direct mains pressure

Numerous successful pressure management projects have been implemented in Brazil, Denmark, Cyprus, Hong Kong, Israel, Japan, Malaysia, Malta, South Africa, Spain, Taiwan and UK. Italy, Romania, Portugal, Norway, New Zealand, Thailand, Australia and USA appear to be aware of the potential for pressure management benefits, but numbers of actual projects seem relatively small.

Concerns are sometimes expressed about the impact of pressure management on dealing with fire service requirements and insurance claims, or the potential loss of revenue from metered customers. Each case must be carefully considered, but this requires an understanding of the technical issues, and predictions of the savings (8), for a rational benefit:cost analysis..

As the diverse relationships between operating pressure and the flow rates from existing leakage paths are not widely understood, a brief outline is provided below. For further details see Ref. (9)

Pressure: Existing Leak Rates Relationships

Japanese and UK research data on pressure:leakage rate relationships have been reconciled with other test data worldwide using the FAVAD (Fixed and Variable Area Discharges) concept (10). The velocity of a leak varies with the square root of pressure and a Coefficient of Discharge (Cd); but FAVAD also recognises that the effective area of some leakage paths – Cd x A – may vary with pressure. The simplest versions of the FAVAD equation are

Leakage Rate L (Volume/unit time) varies with Pressure^{N1} or $L_1/L_0 = (P_1/P_0)^{N1}$

Fig. 4 shows relationships between Ratio of Pressures (P_1/P_0), Ratio of Leakage Rates (L_1/L_0) and N1. The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. Japanese practice has been to assume an average N1 value of 1.15, based on the weighted average of a range of tests with N1 values between 0.63 and 2.12 (11).

N1 values can be calculated from tests on Sectors at night; values derived for sectors in the UK, Brazil and Malaysia have shown that N1 generally varies between 0.50 and 1.50, with occasional values between 2.0 and 2.5. Small undetectable leaks at joints and fittings (known as 'Background' leakage) typically has N1 values around 1.50, as do larger leaks and bursts on plastic pipes. Detectable leaks and bursts on metal pipes normally have N1 values close to 0.50.

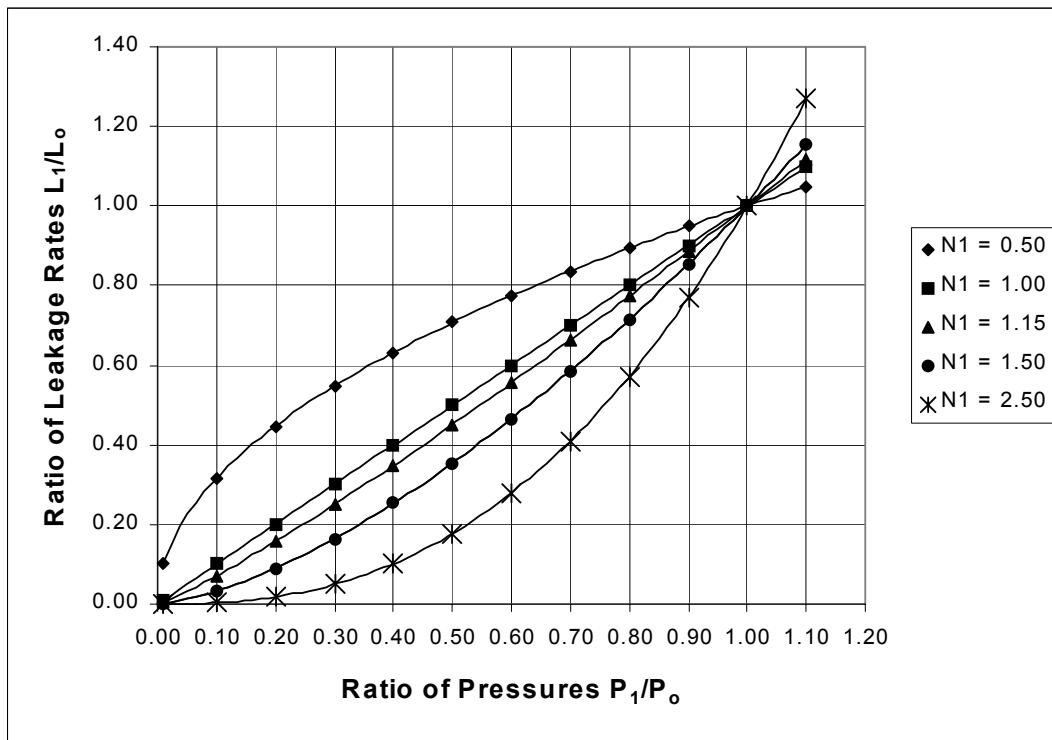


Fig. 4: General Relationships between Pressure and Leakage Rates using the N1 Approach

ASSESSING REAL LOSSES

Assessing Real Losses from Water Balance

This is the most basic and widely used method. The volume of Real Losses (Fig. 1) is assessed as the component remaining after Authorised Consumption and Apparent Losses volumes have been calculated, and deducted from System Input Volume.

Volumes of Real Losses calculated from a ‘Top-Down’ Water Balance are always subject to some calculation error, because of errors in the individual components. Some of the most recent recent international applications of the IWA Standard Water Balance include the facility to calculate the 95% confidence limits for the assessed volume of Real Losses, given 95% confidence limits for the other volumes entered in the water balance.

The disadvantages for relying only on Water Balance for assessment of Real Losses are:

- Water Balance gives no indication of the individual components of Real Losses, or how they are influenced by Utility policies.
- Water Balance normally covers a 12-month retrospective period, so it has limited value as an ‘early warning’ system for the occurrence of new unreported leaks and bursts

For these reasons, Real Losses should preferably also be assessed by additional methods, namely:

- Component Analysis of Real Losses
- Analysis of night flows

Component Analysis of Real Losses

The general principle of assessing some components of Real Losses from repair statistics is well known. Annual numbers of repairs are assumed to represent the annual number of new leaks and bursts; these are then classified into different categories, with different typical flow rates. If average duration of each category of leak or burst is logically assessed, then the annual volume lost from

different categories can be assessed. In 1993, an internationally applicable overview concept known as ‘Background and Bursts Estimates’ (BABE) was developed from this basic building block, for calculating components of Real Losses based on the parameters which influence them.

In BABE analyses, components of Real Losses are considered to consist of:

- Background leakage at joints and fittings, flow rates too low for sonic detection if non-visible
- Reported leaks and bursts – typically high flow rates but short duration
- Unreported leaks and bursts – moderate flow rates, average duration depends on method of active leakage control

By considering average duration of detectable leaks and bursts to consist of three components – Awareness, Location and Repair time – these concepts can be used to model any Utility policies and standards of service. Typical burst flow rates are specified at a standard pressure, and adjusted to actual pressure using appropriate assumptions for FAVAD N1 values. The typical parameters which would be assumed to influence components of Annual Real Losses in different parts of the infrastructure are shown in Table 3.

Table 3: Parameters used for calculating Components of Annual Real Losses

Component of Infrastructure	Background (undetectable) leakage	Reported Bursts and Overflows	Unreported Bursts and Overflows
Mains	Length Pressure Min loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Reservoirs	Leakage through structure, % of capacity/day	No. of reported overflows/yr Average flow rate Average duration	No. of unreported overflows/year Average flow rate Average duration
Service Connections, Main to Property Boundary	Number of Service Connections Pressure Min loss rate/conn*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Connections after Property Boundary	Length Pressure Min loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration

* at some standard pressure, later corrected for actual pressure using FAVAD

Where do the Largest Components of Real Losses Occur?

Analyses of components of Real Losses assist in identifying where the largest components occur in any individual system, and how these components are influenced by Utility policies.

The large number of joints and fittings on service connections between the main and the edge of the street result in a relatively high value for background leakage in this part of the infrastructure. Also, studies of new burst frequencies on mains and services such as Figures 5 and 6 of the German National Report, and Table 2 of the Portuguese National Report, show that the frequency of new bursts, per km of pipe, is several times higher on service connections than on mains. Although average burst flow rates are higher for mains than for service connections, when typical proportions of unreported bursts, and average durations of different types of bursts, are taken into account, it is

evident that in most systems the largest volume of Annual Real Losses generally occurs on service connections. This accords with most operational experience world-wide.

There will of course be some systems where the greatest proportion of Real Losses will be associated with the mains, rather than the service connections. The Water Losses Task Force calculated that, in well managed systems, this 'break-point' occurs when the density of connections is around 20 per km of mains, and this figure has implications for the choice of the most appropriate Performance Indicators.

There are many different situations regarding ownership and maintenance responsibility of service connections, which can have a major influence on the annual volume of Real Losses. For example, in Finland, Japan, Norway, and parts of USA, the whole of the service connection, from the main to the customer meter, is the customers' responsibility, and customer meters can be located anywhere from the street/property boundary to 30 metres or more after the boundary.

In many systems, the customer meter is located close to the street/property boundary, and the service pipe between the main and the customer meter is owned and maintained by the Water Utility. Where the customer meter is located some distance after the street/property boundary, the leakage on the private pipes between the street/property boundary and the customer meter becomes an additional component of calculated Real Losses. Detailed Performance Comparisons therefore need to allow for customer meter location.

Unavoidable Annual Real Losses

The Water Losses Task Force developed a system-specific equation (3) for the lowest technically achievable Real Losses, for well managed infrastructure in good condition. Substituting appropriate parameter values in Table 3 for a well-managed system with infrastructure maintained in good condition, the following components of UARL were obtained.

	On mains:	18 litres/km mains/day/metre of pressure
Plus	On service connections,: (up to property boundary)	0.8 litres/service connection/day/metre of pressure
Plus	On service connections (property boundary to customer meter)	25 litres/km/day/m of pressure

UARL is a useful concept as it can be used to predict, with reasonable reliability, the lowest technically annual real losses for any combination of mains length, number of connections, customer meter location and average operating pressure – assuming that the system is in good condition with high standards for management of Real Losses. UARL is also used in the calculation of the Infrastructure Leakage Index.

Figure 5 shows how the UARL varies with the Density of Connections (per km of mains). If UARL is expressed in m³/km of mains/day/metre of pressure (right hand axis), the UARL value rises rapidly as Density of Connections increases; the value at 120 connection/km being over 3 times the value at 20 connections per km. This means that when Real Losses are expressed 'per km of mains', it is only possible to compare performance (or set targets) for systems within specified narrow bands of Density of Connections (as in Figure 3 of the German National Report).

Alternatively, if UARL is expressed in litres/service connection/day/metre of pressure (left hand axis), the UARL value is almost constant for a wide range of Density of Connections from 60 per km upwards, at 1.0 litres/service connection/day/metre of pressure (+/-10%). As Density of Connections decreases from 60 to 20 per km of mains, the UARL in these units rises by around 50%, and this measure is not recommended for connection densities less than 20 per km of mains.

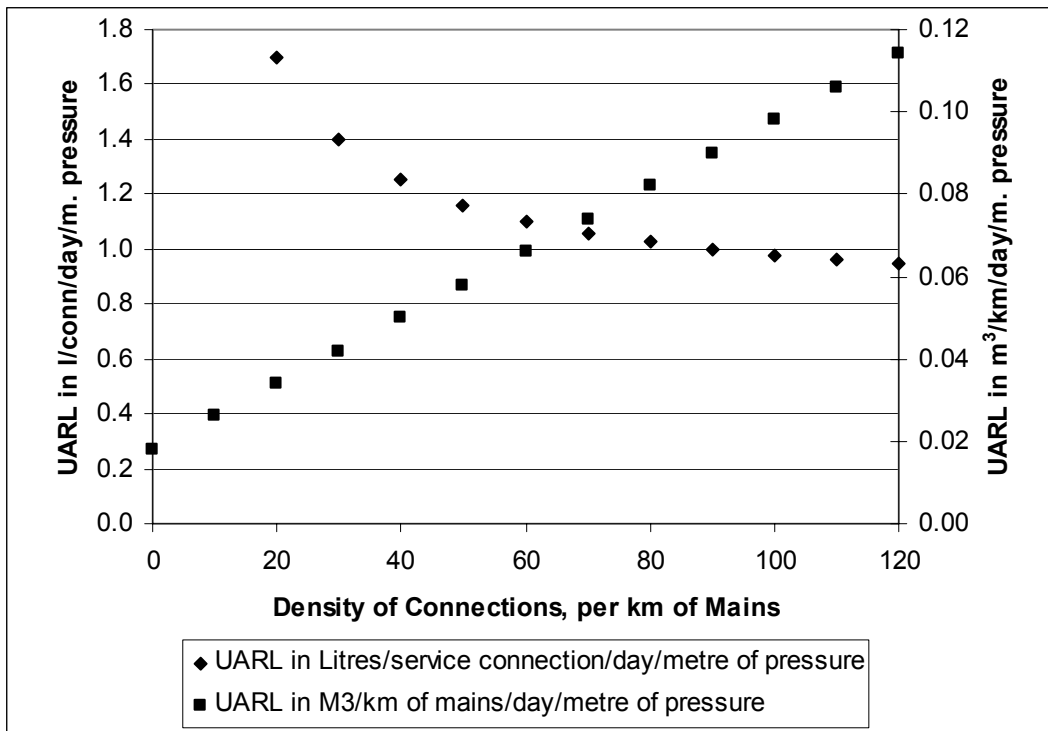


Fig. 5: Unavoidable Annual Real Losses vs. Density of Connections, for Customer Meters located at street/property boundary

Assessing Real Losses from Continuous Night Flows

Night flows measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of unreported leaks and bursts; this activity is discussed in the ‘Managing the Duration of Leaks’ later in the Report.

However, continuous night flows can also be used for assessing Annual Average Real Losses. Night flows in individual Sectors must be measured continuously throughout the year. Customer night consumption must be assessed and deducted, and the average night leakage (in m³/hour) must be multiplied by a ‘Night-Day Factor’ which depends upon the 24-hour variation of average pressure in the sectors.

The Economic Regulator (OFWAT) for England and Wales requires Water Companies to calculate Annual Real Losses by this ‘bottom-up’ method, as well as using the ‘Top-down’ Water Balance. Both methodologies are also used in Malta.

PERFORMANCE COMPARISONS FOR REAL LOSSES

The Best Practice Basic Performance Indicator for Operational Management of Real Losses

The ‘Manual of Best Practice’ for Performance Indicators (1) contains 133 different Performance Indicators for different functions - Water Resources, Personnel, Physical, Operational, Quality of Service, Financial Indicators. Each function can also have up to 4 Levels of Indicators, according to their importance as management tools. Level 1 (basic) PIs provide a general management overview of efficiency and effectiveness.

The recommendation for the ‘Best Practice’ Level 1 Performance Indicator (Op24) for Operational Management of Real Losses recognises that:

- % of input volume is too strongly influenced by consumption, and changes in consumption, making it unsuitable for this purpose

- ‘per billed account’ or ‘per property’ should not be used, as some service connections supply multiple billed properties, yet there is only one service connection with potential to leak
- the choice of ‘per service connection’ or ‘per km of mains’ as a scaling factor depends upon the density of connections for the system under consideration

Figure 6 shows this selection process for IWA PI Op24 in the form of a decision diagram. As most distribution systems have density of connections > 20 per km of mains, ‘per service connection’ should logically become the predominant basic operational PI for Real Losses in future.

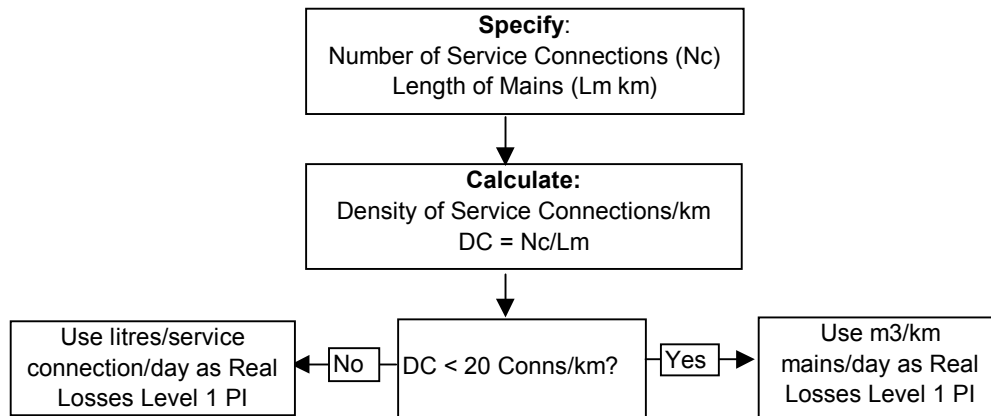


Fig. 6. Process to determine Level 1 PI for Operational Management of Real Losses

In the case of systems subject to intermittent supply, Op24 is expressed as ‘litres/service connection/day when the system is pressurised’. The annual volume of Real Losses is divided by the equivalent number of days that the system is pressurised, rather than by 365 days.

Fig. 7 shows the values of Op24 for the Water Losses Task Force International Data Set (3).

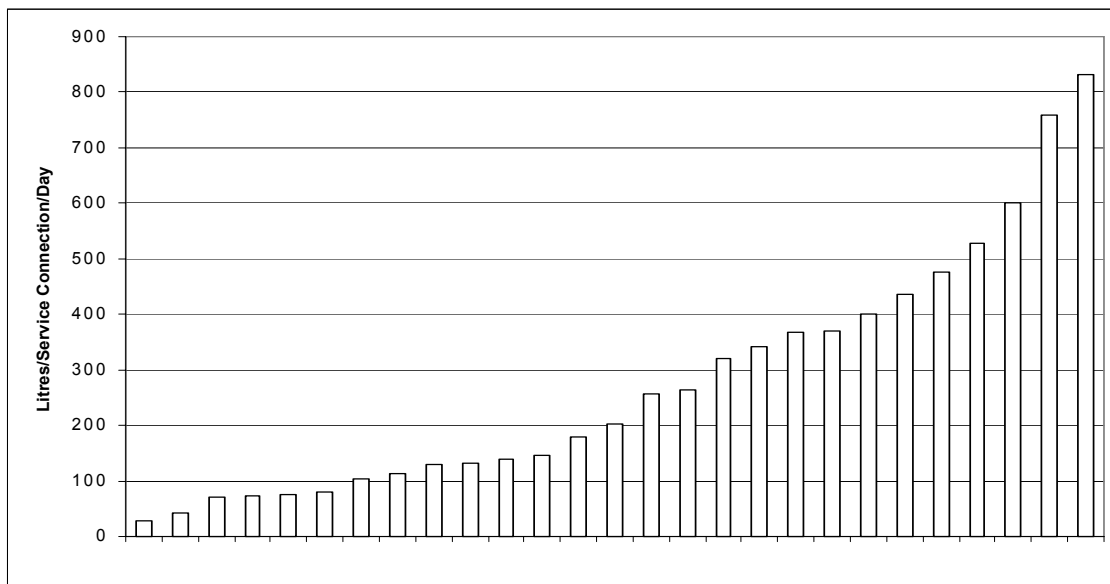


Fig. 7. Real Losses in Litres/service connection/day for International Data Set Systems

Comparatively few of the National Reports provided the data in this form, but it is hoped that more Utilities will use this measure as an additional PI for Real Losses in future.

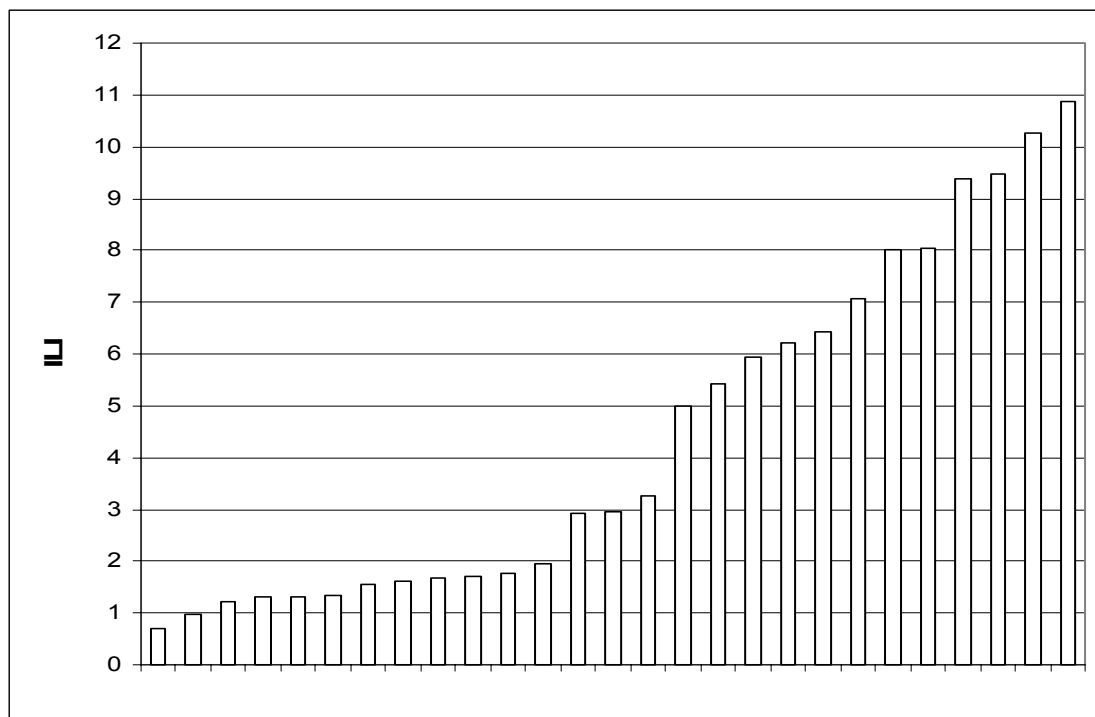
- The Malaysian Report, Table 3.1, infers values for Pilot areas between 297 and 681 litres/service Conn./day before leakage control, falling to between 109 and 711 after leakage control.
- The Portugal Report, Table 1, quotes Non-Revenue Water for 20 Water Companies ranging from 74 to 461 litres/property/day
- The Australian National report quotes an average figure of 137 litres/service connection/day for their Urban water industry.
- Data extracted from Ref. 5 showed values of Distribution Losses (to the street/property boundary) for English and Welsh Companies ranging from 78 to 223 litres/property/day (average 105), with an additional average of 38 litres/property/day on private pipes after the street/property boundary.

A Better PI for Operational Management of Real Losses

The Level 1 PIs of ‘per service connection’ and ‘per km of mains’ provide basic comparisons of performance, but they are strongly influenced by differences in Density of Connections, customer meter location and average pressure. Level 3 (detailed) PIs include specific details such as these.

The Level 3 PI for Operational Management of Real Losses is the Infrastructure Leakage Index (ILI), which is the ratio of the Current Annual Real Losses (CARL) to the Unavoidable Annual Real Losses (UARL), see Figure 3. The basis of calculation of the UARL (3) makes due allowance for length of mains, number of service connections, location of customer meters and average operating pressure. The ILI measures how effectively the three infrastructure activities in Figure 3 – speed and quality of repairs, active leakage control and pipe materials – are being managed, at the current operating pressure.

Figure 8 shows calculated values of ILI for the International Data Set. Values close to 1.0 represent near-perfect technical management of real losses from infrastructure, at actual operating pressures.



Problems with Percentages

Technical groups in Germany (DVGW) and the UK have, for many years, drawn attention to the undue influence of consumption, and changes in consumption, when Water Losses are expressed as a % of System Input Volume. The UK Economic Regulator (OFWAT) and the South African Bureau of Standards have more recently decided against continued use of %s for making performance comparisons of Real Losses, a view endorsed by the IWA ‘Best Practice’ Report (1). The undue influence of consumption, and changes in consumption, is demonstrated in Figure 9. The X-axis shows the consumption per service connection per day, ranging from as low as 250 l/Conn./day (Malta) to over 8000 l/conn./day (Singapore). The curved line represents Real Losses of 200 litres/service connection/day (the average of the International Data Set). Depending upon the consumption per service connection, the same volume of Real Losses could, in % terms, be anything from 44% to 2.4%. When consumption decreases, seasonally or annually, or due to demand management measures, the % Real Losses increases even if the volume of Real Losses remains unchanged. When consumption increases, the opposite effect occurs. Figure 3 of the Polish National Report demonstrates the same conclusion as Figure 8, namely that % Real Losses decrease rapidly as System Loading (in m3/km mains/hour) increases.

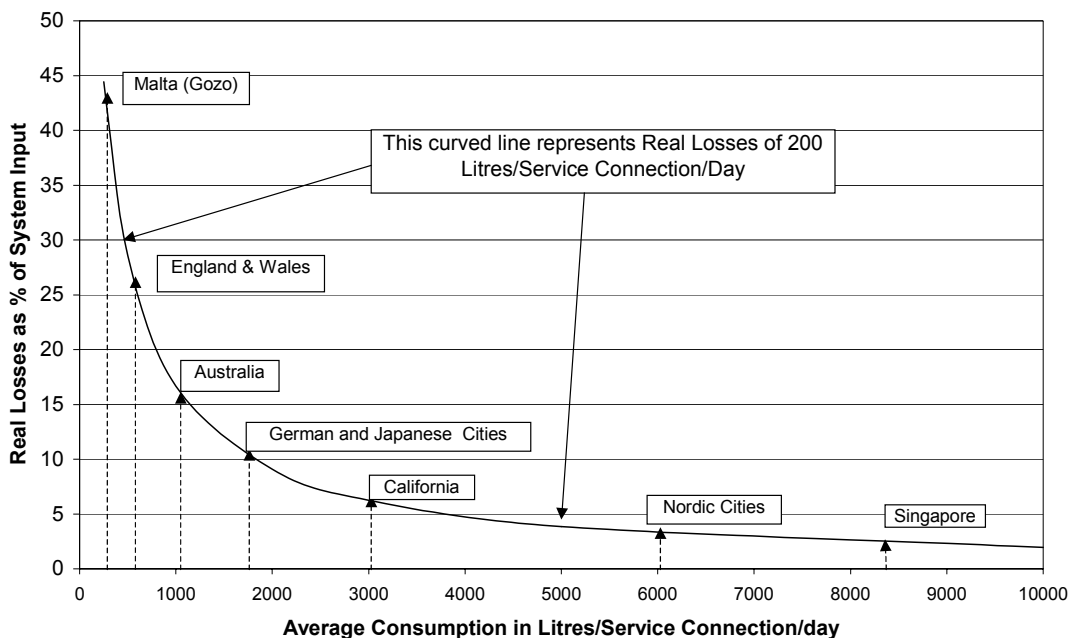


Fig. 9. The Influence of Consumption on Real Losses expressed as % of System Input Volume

There are also problems of interpreting % Real Losses in intermittent supply situations, and auditing future targets for Real Losses stated in % terms.

MANAGING THE DURATION OF LEAKS AND BURSTS

Referring to Figure 3, Pipeline Management and Pressure Management (together with climatic variations and activities of other Utilities) are the prime factors that influence the number of new leaks and bursts that will occur in any system each year. Where these numbers are high, reductions usually take many years of well-targeted investments – although where excess pressures or frequent surges occur, pressure management can often decrease these numbers noticeably. The majority of the new leaks and bursts will usually be ‘reported’ events, brought to the attention of the Utility as a result of supply failures, low pressure, or visible leaks.

The remainder will be ‘unreported’ events that will need to be identified by some method of active leakage control. So, in the simplest terms, Active Leakage Control represents the management of the duration of unreported leaks. There are several different methods of Active Leakage Control, and many different levels of activity for each method. Selection of the most appropriate method and level of activity for an individual supply system becomes a matter of efficiency and economics, given that the numbers of new unreported leaks and bursts from one year to the next is unlikely to vary greatly in the short term.

This type of analysis can be assisted by considering the average duration of particular types of leaks to consist of 3 components :

- ‘Awareness’ from the start of the event to the time the Utility is aware that a new leak exists
- ‘Location’, the time taken to locate the event once the Utility is aware of it
- ‘Repair’, the time taken to repair or shut-off the leak or burst once it has been located

Using the above approach, the average duration of any type of unreported leakage event can be assessed, and related to any particular Active Leakage Control policy or level of activity, or standards of service. As a simple example, if a system is subject to inspection by regular sounding of all mains fittings and service connections once per year, the average ‘Awareness + Location’ duration will be six months, and the average repair time will depend upon the Utility’s standard of service target times for particular types of repairs.

The more sophisticated Active Leakage Control methods consist of some initial ‘screening’ method for ‘Awareness’ of new unreported leaks in a system or a part of the system. The tried and tested methods of inflow measurements to permanent or temporary sectors, are (with examples):

- comparisons of inflow volume against metered consumption (Australia, South Africa, USA)
- continuous night flow measurements – sectors monitored manually, with loggers or by SCADA systems (England/Wales; parts of Norway, Thailand, Australia, Morocco, Germany)
- occasional night flow measurements – Malaysia, Hong Kong, parts of Portugal, Denmark, South Africa, Japan (block system).
- intermittent daytime measurements – zero-consumption method (Germany) for direct-pressure systems

The recent advent of leak noise loggers is an alternative method for permanent or temporary preliminary screening for ‘awareness’ of unreported leaks; an example of use of this new technology is described in the Special Contribution from Spain. Leak noise loggers are also used for ‘location’ as an alternative to step-testing and use of correlators when narrowing down the search areas for individual leaks. More traditional methods – correlators and geophones are then used for pinpointing the leaks.

Once leaks are located – whether they are reported or unreported events – the ‘Repair’ element of the overall duration should be monitored against realistic target times.

Methods for assessing the economic level of specific active leakage control methods are mentioned in the Norwegian, UK and Taiwan National Report. Some of these methods require a knowledge of the numbers of new unreported leaks each year – which can only be truly known once intensive active leakage control has been implemented for several years. A more flexible and less data hungry methodology, known as Economic Intervention, based on tracking of natural rate of rise of night flows and/or Real Losses, is currently under development and testing in Malta and South Africa.

FINANCIAL AND ECONOMIC CONSIDERATIONS

Financial Performance Indicators

The IWA 'best practice' Level 1 Performance Indicator for Non-Revenue Water is

Volume of Non-Revenue Water as a % System Input Volume (Fin 36, Ref 1)

Table 4 lists references to % NRW by volume in the National Reports. However, lists of % NRW such as Table 4 - or Table 3.4 in Ref. 12, which shows % NRW varying from 4% to 75% - provide no explanation of the reasons why one figure may be 'high', and the another figure 'low'. These reasons include the following:

- % Apparent Losses are influenced by whether systems have roof tanks or not (Figure 2)
- Average operating pressures vary from less than 20 metres to over 100 metres, and average leakage rate varies almost linearly with pressure (Fig. 4)
- % Real Losses are greatly influenced by the average consumption (Figure 8)
- economic NRW management policies depend upon the cost and availability of water
- Density of connections varies from less than 20 to over 100 per km of mains
- Some NRW estimates includes Real Losses on customers private pipes, because on customer meter locations
- Intermittent supply reduces the % of time the system is pressurised

Table 4: References in National Reports to NRW as % of System Input Volume

Note: because of different calculation criteria used, NRW figures are not necessarily comparable

City or Country	Current NRW %	Targets Mentioned
Malaysia	36.4	NRW 25% in 2005
Italy	30 to 40	'Acceptable' Long-term NRW 15%
Korea	29.3	NRW 15% in 2001
Japan		Real Losses 5% to 10%
Finland	12 to 25	NRW under 10%
France rural	10 to 40	Lowest compatible with economic balance
France urban	10 to 30	
Poland	<10 to >20	System-specific based on consumption (Fig 3)
Romania		Real Losses 15% to 20%, next 10 to 20 years
Hong Kong	30.5	Real Losses 16% in 20 years time
Portugal	18 to 58	Not stated
Murcia, Spain	9.7	Not stated
Norway	40	NRW less than 20% would not be economic
Denmark	7.6	NRW < 10%, tax of 5 Kr/m ³ if above this
Bangkok, Thailand	38.8	NRW not to exceed 30% in 2004
Hungary	24	Not stated
USA	5 to 37	Target systems with NRW >10%
Taiwan Province	23.1	Not stated
Taipei, Taiwan	41.8	Not stated

NRW (or UFW) has, for many years, been quoted only or principally in % terms. Accordingly many non-specialists, including politicians and the media, incorrectly believe that this is the most meaningful measure of performance for NRW and all its components. So targets are often set, or suggested, at National level in % terms. Whilst this is undoubtedly better than setting no targets at all, it discriminates against Utilities with low consumption (low system loading), higher than average operating pressures (due to topography), and NRW calculations which include leakage on customers' private pipes.

However, in some countries – England & Wales, Germany, South Africa, Malta – the national organisations responsible for assembling NRW figures have taken a specific decision not to use %s in future. In England & Wales, which has probably the most stringent independently audited regulatory reporting procedures in the World, mandatory targets for Real Losses are set by the Economic Regulator (6) in terms of average volume per day for each Utility, based on analysis of economic leakage levels. Performance statistics are reported and published in detail, in Volume/day and in terms of ‘per property/day’ and ‘per km mains/day’.

The IWA Task Forces have also recommended a Level 3 Financial Performance Indicator for Non-Revenue Water. For the calculation of this PI (Fi37 in Ref. 1), the volumes of each of the main components of NRW is assigned a valuation in local currency/m³, appropriate to local circumstances, and the value of the NRW component expressed as a % of the annual cost of running the system.

Economic Considerations

In recent years there has been substantial technical progress in methodologies to calculate economic levels of pipe materials investment, pressure management, active leakage control and speed and quality of repairs. However, the application of these methodologies has been limited by the problem as to how an appropriate valuations on Real Losses in different circumstances. In many cases, unless the water is purchased as a bulk supply, or supplies are limited, Real Losses have been valued only at the short-run marginal cost of production (power and chemicals).

This situation is changing. The UK Economic Regulator now insists that the England & Wales Water Companies should base their policies on long-run marginal cost, including capital deferment costs. In Denmark, a tax is levied on Water Utilities if NRW exceeds 10%. Environmental issues are likely to have an increasing influence on leakage management policies in Australia.

As natural water resources become scarcer, higher values will be placed upon source waters, leading inevitably to greater investment in management of Real Losses. Selection of the most appropriate combination of management techniques for individual situations will be a considerable challenge to the International Water Industry.

CONCLUSIONS

- Although the management of Water Losses is receiving increased attention internationally, many systems have Non-Revenue Water which is higher than a desirable or economic level
- The National Reports use different terminology, different calculation methods, and a variety of Performance Indicators, which limits the possibilities for benchmarking of true performance
- The recommendations of the IWA Task Forces on Water Losses and Performance Indicators now provide ‘best practice’ guidance on these matters
- Non-Revenue Water should always be split into components for more detailed analysis
- Comparisons of Apparent Losses should differentiate between systems with and without roof tanks, because of their influence on customer meter under-registration
- Comparisons of Real Losses should not be based on % of System Input Volume
- Pipe Materials Management is not receiving adequate attention or funding in many systems
- ‘Best Practice’ choice of the basic PI for Operational Management of Real Losses – ‘per service connection’ or ‘per km of mains’ depends on the density of service connections/km of mains.
- The Infrastructure Leakage Index is a new detailed PI for Real Losses, which measures the ratio of Current Annual Real Losses to system-specific Unavoidable Annual Real Losses

- Pressure Management is receiving increasing attention as an effective means of Leakage Management; the basic understanding of pressure:leakage rate relationships has improved
- Technical and economic calculations are now possible for most aspects of NRW management
- Component analysis of Real Losses offers greater insights into where components of Real Losses occur, and how they may be better managed
- Service connections generally produce the largest component of Annual Real Losses Volume
- A more pro-active approach to minimising leakage on private pipes is noted in some countries
- Options for Active Leakage Control can be compared in terms of how they influence the average duration of unreported leaks (awareness, location and repair times)
- Leak Noise Loggers provide a valuable addition to traditional Active Leakage Control methods
- Targets are increasingly being set at National Level for NRW or its components
- The value assigned to marginal costs of Real Losses is likely to increase, resulting in more intensive investment in NRW management

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