IWA/AQUA

First Published in AQUA in December 1999. Corrected Final version with Figures dated 02/09/20

Note to Readers of this paper on LEAKSSuite Library 02.09.20 by Allan Lambert

The term 'Technical Indicator Real Losses' or TIRL was not widely used in the few years after the original publication of this paper in 'AQUA' in 1999. It became more convenient to calculate the ILI as the ratio of volumes of Current Annual Real Losses (CARL) divided by Unavoidable Annual Real Losses UARL.

A Review of Performance Indicators for Real Losses from Water Supply Systems

A.O Lambert[1], Timothy.G. Brown[2] , M. Takizawa[3] , D. Weimer[4]

[1] International Water Data Comparisons Ltd [2] AWWA North American Representative to Water Losses Task Force [3] Tokyo Metropolitan Waterworks, Japan, [4] Neckarwerke Stuttgart AG, Germany

ABSTRACT:

The IWA's Task Force on Water Losses had two key objectives. The first - recommendations for a standard international terminology for calculation of real and apparent losses from water balance – is presented as a Blue Pages (1). As the second - to review Performance Indicators (PIs) for international comparisons of losses in water supply systems – is only briefly mentioned in the Blue Pages, this AQUA paper explains the technical basis for the task Force's recommendations on PIs for real (physical) losses. Traditional PIs were checked against several key local factors that constrain performance in managing real losses. 'Number of service connections' was found to be the most consistent of the traditional PIs over the greatest range of density of service connections and is recommended as the preferred basic traditional Technical Indicator for Real Losses (TIRL). However, TIRL does not take account of several key local factors. To overcome this deficiency, TIRL should be compared with an estimate of Unavoidable Annual Real losses (UARL). An auditable component-based approach is developed and satisfactorily tested for predicting UARL for any system, taking into account the local factors and using international data. The Infrastructure Leakage Index (ILI), calculated as the ratio of TIRL to UARL, is a non-dimensional PI, which enables overall infrastructure management performance in control of real losses to be assessed independently of the current operating pressures; minimum achievable operating pressures are usually constrained by local topography and standards of service.

Key Words: Leakage, Losses, Performance Indicators, Technical Indicator for Real Losses, Unavoidable Annual Real Losses, Infrastructure Leakage Index

INTRODUCTION

The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years, and as a trend over a period of years. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational maintenance activities. The recommended terminology and method of calculation of Real and Apparent losses for international comparisons is explained in the Blue Pages (1). However, once these volumes have been calculated, which performance indicators should be used to decide whether real losses are 'high' or 'low'? And how can rational national and international comparisons be made in a wide variety of different situations?

The objectives of this paper are to:

- identify key local factors which may constrain technical performance in managing real losses
- review the extent to which traditional PIs take account of these key local factors
- identify the preferred basic traditional PI with largest range of application, and its limitations

- propose an auditable component-based methodology for calculating Unavoidable Annual Real Losses (UARL) for any system, taking key local factors into account
- describe the general relationship between UARL and economic leakage levels
- show the derivation of the parameter values used to predict UARL for individual systems
- introduce the Infrastructure Leakage Index (ILI), being the ratio of TIRL to UARL
- test the UARL predictions and ILI calculations against a wide range of international data
- explain how TIRL, UARL and ILI can be used as improved diagnostic performance indicators
- provide examples showing how to calculate TIRL, UARL and ILI

The study uses a reference data set of 27 diverse water distribution systems in 20 countries - Australia, Brazil, Denmark, France, Finland, Germany, Gibraltar, Greece, Iceland, Japan, Maltese Islands, Netherlands, New Zealand, Singapore, Spain, Switzerland, Sweden, UK, USA, and West Bank (Palestine) – together with published data from other international sources listed in the references.

The methodology described here is an improvement of earlier draft versions presented and discussed at workshops and symposia in Portugal, UK, Brazil, USA and Australia, during 1997 and 1998, as the methodology and terminology for UARL and ILI were developed and refined.

REVIEW OF TRADITIONAL PERFORMANCE INDICATORS FOR REAL LOSSES

Key Local Factors Influencing Real Losses

The type of soil/ground can influence the frequencies of leaks and bursts, and the speed with which leaks and bursts become visible at the ground surface. However, correct selection and laying of pipe materials, and modern leakage control methods (e.g. night flows) can reduce these influences significantly.

There are five other local factors which constrain performance in managing real losses, which can vary widely between individual distribution systems - continuity of supply, length of mains, number of service connections, location of customer meters on service connections, and average operating pressure.

Note that “number of service connections” should be used in PIs for real losses, rather than “number of properties”. This is because there is no standard international definition of ‘properties’; real losses are calculated up to the first metering point, and in cities the service frequently splits into several separate pipes serving individual domestic or commercial properties after the first metering point.

In approximately half of the 27 systems in the reference data set, customer meters were located close to the edge of the street. In the remainder, customer meters were located up to 30 metres from the edge of the street. Rational PIs for real losses need to allow for such substantial differences.

Density of service connections – expressed as a number per km of mains – varied widely in the reference data set, from 24/km to 114/km, with a median of 47/km, and more extreme values are known to exist. This factor has a major influence on real losses. Note that use of the qualitative terms ‘urban’ or ‘rural’ to imply ranges of connection densities is misleading in an international context – it is recommended that connection densities should always be quoted on a ‘per km of mains’ basis.

Because operating pressures are constrained by local topography and minimum standards of service (to customers or for fire-fighting) average operating pressures vary widely between systems - from 30 metres to over 100 metres (median 45 metres) in the reference data set - and more extreme values are known to exist. Many countries recognise pressure control as a technique for managing leakage, but there are local limits to the lowest acceptable average pressures that can be achieved. The average frequency with which new leaks occur, and rates of flow of individual leaks, are very sensitive to operating pressures. The observed relationship between pressure and leakage rate for individual small sectors of distribution systems varies widely (2,3) because the areas of some types of leakage paths vary with pressure (4). The weighted average relationship for large systems appears to be that leakage rates vary with pressure approximately to the power 1.15, so the simplifying assumption that leakage rate varies linearly with operating pressure is likely to be reasonably satisfactory for performance comparisons of real losses for large systems, except at very high or very low pressures

Continuity of supply is often assumed, but this is not the case in many countries. In situations of intermittent supply, the percentage of time for which the distribution system is pressurised is an important parameter to be included in PIs for real losses. This is easily achieved by expressing the annual volume of real losses as a volume per day 'when the system is pressurised' (w.s.p.). The average operating pressure should also be calculated over the period when the system is pressurised.

Because variations in pressure (and leakage rates) over 24-hour periods are often substantial, it is preferable to express losses derived from annual water balance on a 'per day' basis rather than 'per hour'.

Limitations of Basic Traditional Performance Indicators

The basic traditional PIs for real losses, which are most widely used in different parts of the world to make comparisons of the annual volume of real losses, are:

- % of input volume
- volume lost per length of mains per unit time
- volume lost per property per unit time
- volume lost per service connection per unit time
- volume lost per length of system per unit time (where length of system = length of mains + length of service connections up to point of customer metering)

Traditional PIs for real losses appear to be selected on the basis of the simplicity of calculation, or country tradition, or availability of data for the calculation, or even the PI which produces the best impression of performance. However, the differences can be substantial (5). The proper basis of selection should be the PI that gives the most rational technical basis for comparisons. Table 1 shows the limited extent to which each of the traditional PIs take into account the key local factors (other than ground conditions) which influence real losses.

Table I: Do traditional Performance Indicators for real losses allow for key local factors?

Basic Traditional PI for Real Losses	Continuity of Supply	Length of mains	Number of Service Connections	Location of Customer meters on Services	Average operating pressure
% of Volume input	No	No	No	No	No
Litres/ property/day	No	No	Only if 1 property/conn	No	No
Litres/ Service Connection/Day	No	No	Yes	No	No
M^3/km mains/day	No	Yes	No	No	No
M^3/km of system/day	No	Yes	Possibly	Yes	No

The Traditional PI with the Greatest Range of Applicability

Table 1 shows that real losses expressed as a % of system input does not take account of any of the key local factors; instead, under continuous supply conditions, the average rate of consumption (which is not a primary explanatory parameter) dominates the calculated value (1). If real losses average 100 litres/service connection/ day – which is a good performance for a system with average operating pressures and density of connections – then real losses as % of system input would be:

29% for consumption of	250 litres/conn/d	(e.g. Maltese Islands)
17% for consumption of	500 litres/conn/d	(e.g. UK, Netherlands)
9% for consumption of	1000 litres/conn/d	(e.g. German cities)
2% for consumption of	5000 litres/conn/d	(e.g. Scandinavian city)
1% for consumption of	8000 litres/conn/d	(e.g. Singapore)

Also, considerable confusion is introduced when interpreting % losses data in intermittent supply situations (6). Accordingly, over the last 30 years this measure has consistently been rejected by National Technical Committees - in the UK (3,7), Germany (8) and South Africa (9) – and more recently by the UK Economic Regulator OFWAT (10) and the IWA UFW Task Force (1).

Of the remaining basic traditional PIs in Table 1 'number of service connections' is logically preferable to 'number of properties', which can be rejected for reasons previously explained. It might also appear logical to assume that 'length of system' allows for more of the key factors than 'number of connections' or 'length of mains'. However, it was the experience of all the Task Force members, and other experienced practitioners who offered views, that (except at low density of connections) in well-run systems the majority of leaks and bursts (and of the annual volume of real losses) occurs on service connections rather than mains, with most frequent problems in the section of the service connection between the main and the edge of the street.

The Task Force therefore recommended (1) that the basic traditional PI with the greatest range of applicability for real losses, to be referred to as the 'Technical Indicator Real Losses' (TIRL) is:

Litres/service connection/day, when the system is pressurised (w.s.p)

However, the Task Force recommended further interpretation of the calculated TIRL value for an individual system by comparing it with a calculated value for Unavoidable Annual Real Losses (UARL), using a methodology which takes account of the local factors of density of connections, location of customer meters on service connections, and average operating pressure. The component-based calculation of UARL is described in the next section of the paper. The ratio of TIRL to UARL becomes a non-dimensional Infrastructure Leakage Index (ILI), which allows overall infrastructure management performance to be assessed independently of the influence of current operating pressure.

Figure 1 shows values of real losses in litres/service connection/day w.s.p, for each system in the reference data set. Figure 2 shows the values of ILI for each of the systems. The results are discussed later in the paper, after the concept and calculation of UARL has been explained.

Figure 1: Technical Indicator for Real Losses (TIRL) in Litres/Service Connection/day for 27 Water Supply Systems from 20 Countries

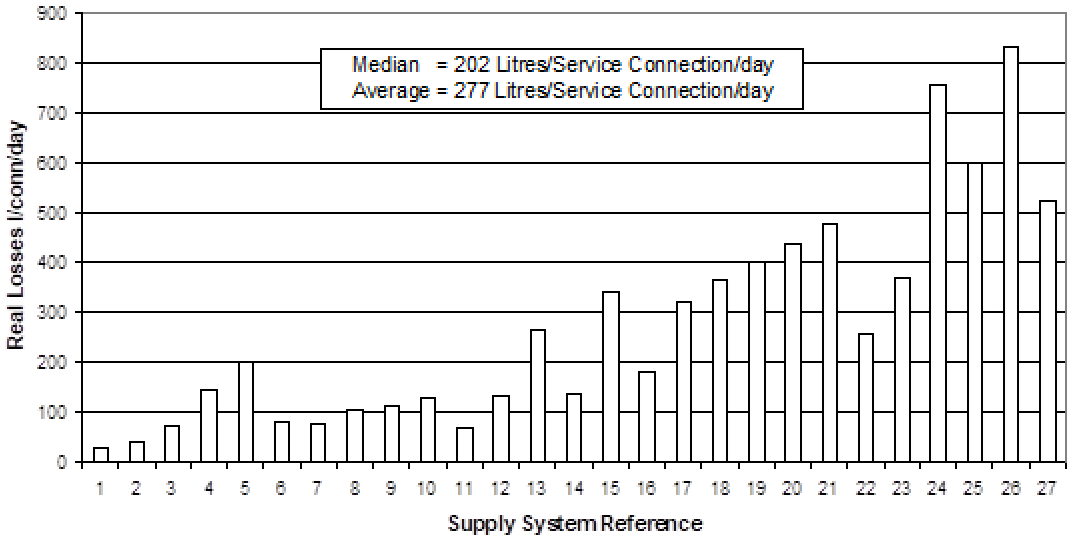
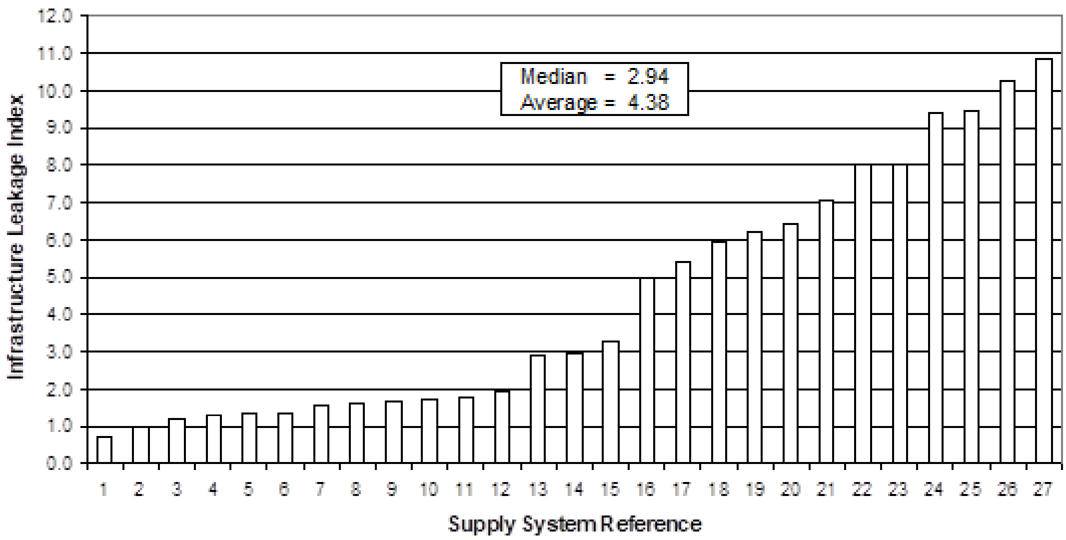


Figure 2: Infrastructure Leakage Index (ILI) Values for 27 Supply Systems in 20 Countries



UNAVOIDABLE ANNUAL REAL LOSSES: CONCEPT AND CALCULATION

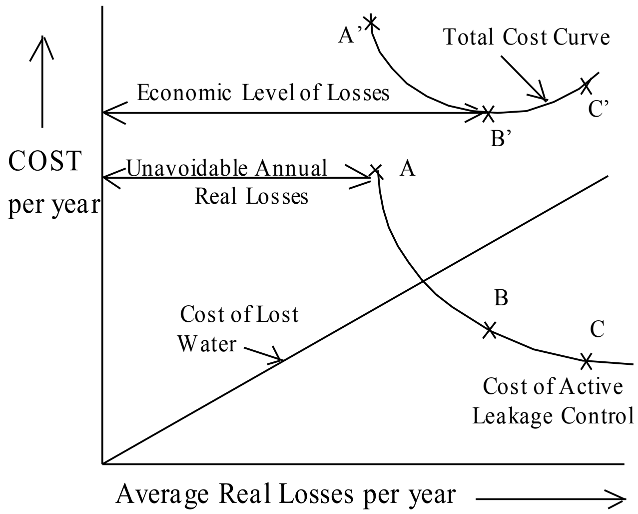
The Concept of Unavoidable Annual Real Losses

Leakage management practitioners recognise that it is impossible to eliminate real losses from a large distribution system. There must therefore be some value of 'Unavoidable Annual Real Losses' (UARL) which could be achieved at the current operating pressures if there were no financial or economic constraints. If the UARL volume for any system can be assessed, taking into account key local factors, then the ratio of Technical Indicator Real Losses (TIRL) to UARL offers the possibility of an improved Performance Indicator for real losses.

Relationship between UARL and Economic Levels of Losses

A simplified economic approach (11) to determining an appropriate intensity of active leakage control for dealing with unreported leaks and bursts is outlined in Figure 3.

Figure 3: Relationship between Unavoidable Annual Real Losses and Economic Level of Real Losses



As the intensity of active leakage control increases (C > B > A), causing the annual cost of leakage control (Y-axis) to increase, the average real losses (X-axis) reduce asymptotically towards some base level, and the annual cost of the lost water decreases as the average volume of real losses falls. The economic level of losses occurs when the Total Cost curve (A'>B'>C'), which is the sum of the cost of lost water and the cost of active leakage control, is at a minimum (Point B' in Figure 3). With simplifying assumptions that:

- infrastructure is in good condition
- point A represents the technical 'state of the art' for intensive active leakage control
- all detectable leaks and bursts are identified and repaired rapidly and effectively

then the real losses for point A correspond to Unavoidable Annual Real Losses (UARL). Actual or economic levels of real losses should always lie at, or to the right of, point A. The Infrastructure Leakage Index – the ratio of actual or economic real losses to UARL - should always exceed 1.0.

A Component-Based Approach to Assessing Unavoidable Annual Real Losses

The 'BABE' (Background and Bursts Estimates) (12) approach for calculations of components of real losses, successfully used in a number of specific studies in different countries (including World Bank projects), considers real losses in three categories for modelling and calculation purposes:

- Background losses from undetectable leaks (typically low flow rates and long duration)
- Losses from reported leaks and bursts (typically high flow rates and short duration)
- Losses from unreported bursts (typically moderate flow rates but durations depend on the method and intensity of active leakage control)

Using the BABE technique, it is possible to predict with reasonable overall accuracy, for each individual system, what the average UARL would be for various components of infrastructure at any specified pressure. The simplified components of infrastructure used for this study have been selected for ease of calculation in diverse international situations. Parameters which are required for these BABE calculations are shown in Table 2. No UARL allowance is given for service reservoir leakage or overflows, or for pipework located above ground.

Table 2: Parameters Required for Calculation of Unavoidable Annual Real Losses UARL

Component of Infrastructure	Background (undetectable) losses	Reported Bursts	Unreported Bursts
Mains	Length Pressure Min. loss rate/km *	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Connections, Main to Edge of Street	Number Pressure Min. loss rate/conn*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Connections, Edge of Street to meter	Length Pressure Min. loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration

* at some specified standard pressure

Calculating Components of Unavoidable Annual Real Losses

The parameter values used to calculate the Table 2 UARL components for different sections of infrastructure are based on published international data (summarised in Table 3) for minimum background loss rates, typical burst flow rates and frequencies (13,14,15) for infrastructure in good condition. Average duration assumed for unreported bursts are based on intensive active leakage control, approximating to night flows (or water balance) once per month on highly sectorised distribution networks.

Table 3: Parameters Values Used for Calculation of Unavoidable Annual Real Losses UARL

Infrastructure Component	Background (undetectable) losses	Reported Bursts	Unreported Bursts
Mains	20 litres/km/hr*	0.124 bursts/km/yr. at 12 m^3/hour* for 3 days duration	0.006 bursts/km/yr. at 6 m^3/hr* for 50 days duration
Service Connections to Edge of Street	1.25 litres/conn/hr*	2.25/ 1000 conns/yr. at 1.6 m^3/hour* for 8 days duration	0.75/1000 conns/yr. at 1.6 m^3/hour* for 100 days duration
Service Connections after Edge of Street (for 15m ave. length)	0.50 litres/conn/hr*	1.5/ 1000 conns/yr. at 1.6 m^3/hour* for 9 days duration	0.50/1000 conns/yr. at 1.6 m3/hour* for 101 days duration

* all flow rates are quoted at 50m pressure

The calculated values of UARL for each component of infrastructure, using the Table 3 values, are shown in Table 4. An example of the calculation process, for the average annual losses from Reported Bursts on mains, is as follows:

UARL Component = Burst Frequency x Average Flow Rate x Average Duration
= 0.124 bursts/km/yr. x (12 x 24 hrs) m^3/day x 3 days
= 107 m3/year per km mains at 50m pressure
= 293 litres/km/day at 50m pressure

= 5.8 litres/km/day/m. pressure

It can of course be argued that not all systems with good infrastructure condition would experience the same burst frequencies and average flow rates as assumed in Table 3. However, the 'background' loss components of UARL dominate the calculated values, and sensitivity testing shows that differences in assumptions for parameters used in the 'bursts' components have relatively little influence on the UARL 'Total Losses' values (5^{th} column of Table 4).

Table 4: Calculated Components of Unavoidable Annual Real Losses UARL

Infrastructure Component	Background Losses	Reported Bursts	Unreported Bursts	UARL Total	Units
Mains	9.6	5.8	2.6	18	Litres/km mains/ Day/metre of pressure
Service Connections, meters at edge of street	0.60	0.04	0.16	0.80	Litres/Connection/ day/metre of pressure
Underground pipes between edge of street and customer meters	16.0	1.9	7.1	25	Litres/km u.g. pipe/ Day/metre of pressure

The 'UARL Total' values, in the units shown in Table 4, provide a rational yet flexible basis for predicting UARL values for a wide range of distribution systems, taking into account continuity of supply, length of mains, number of service connections, location of customer meters, and average operating pressure. An example calculation using Table 4 values is shown at the end of the paper.

The Table 4 values can also be presented as a wide variety of equations, look-up tables, graphs and spreadsheets, in any selected combination of metric or imperial measurement units. In the most basic form, UARL in litres/day is

$$UARL = (18 \times Lm + 0.80 \times Nc + 25 \times Lp) \times P$$

Where Lm is mains length in km, Nc is number of service connections, Lp is the total length in km of underground pipe between the edge of the street and customer meters, and P is average operating pressure in metres. This basic equation can be manipulated into many other forms and units, for example into a look-up table (Table 5) or graphs (Figs 4 and 5).

Table 5: UARL values in litres/service connection/day, for customer meters located at edge of street
'Add-on' values for underground pipes distant from edge of street shown at foot of table

Density of Connections (per km mains)	Average Operating Pressure in Metres				
	20	40	60	80	100
20	34	68	112	146	170
40	25	50	75	100	125
60	22	44	66	88	110
80	21	41	62	82	103
100	20	39	59	78	98
Add on, for each metre of pipe (per connection) between edge of street and customer meter	0.5	1.0	1.5	2.0	2.5

UARL values for each individual system can be read off or interpolated from Table 5. For example, a system with connection density 40 per km mains at 60 m. average pressure has a UARL of:

- 75 litres/service connection/day for customer meters located at the edge of the street

- 90 (=75+1.5 x 10) litres/conn/day for meters located 10 m. from the edge of the street

Table 5 demonstrates very clearly why it has previously proved impossible to quote a reliable single value for unavoidable real losses, even when the best of the traditional performance indicators is used, because of the wide range of local key factors experienced internationally.

Graphical Presentation of UARL Predictions

To demonstrate important features of relationships between UARLs and local key factors, and to test the validity of the UARL predictions, the Table 4 'Total Losses' values have been used to produce graphs where the X-Axis value is density of service connections (per km of mains) and the Y-Axis is the UARL value in :

- litres/service connection/day/metre of pressure (Figure 4)
- litres/km of mains/day/metre of pressure (Figure 5)

The 3 lines on each of Figs 4 and 5 show the UARL losses on mains only (bottom line), on mains plus service connections for customer meters located at the edge of the street (middle line), and (upper line) on mains plus service connections where there are 15 metres of underground pipe (per service connection), between the edge of the street and the customer meter. So, for example, for a system with density of connections of 70 per km mains, the UARL values can be read off from Figures 4 and 5 as:

- 1.06 litres/conn/day/m. pressure, or 74 litres/km mains/day/m. pressure, for customer meters located at the edge of the street
- 1.43 litres/conn/day/m. pressure, or 100 litres/km mains/day/m. pressure, for customer meters located 15 metres from the edge of the street

The ratio of these figures, which is 1.35, is very close to the ratio of values for real losses published by OFWAT (10) in England & Wales for customer meters at, or around 15 from, the edge of the street, for an average density of connections of 70 per km of mains. Further tests of the validity of the UARL predictions are described below.

Figure 4: Unavoidable Annual Real Losses in Litres per Service Connection per Day per Metre of Pressure, vs Density of Service Connections

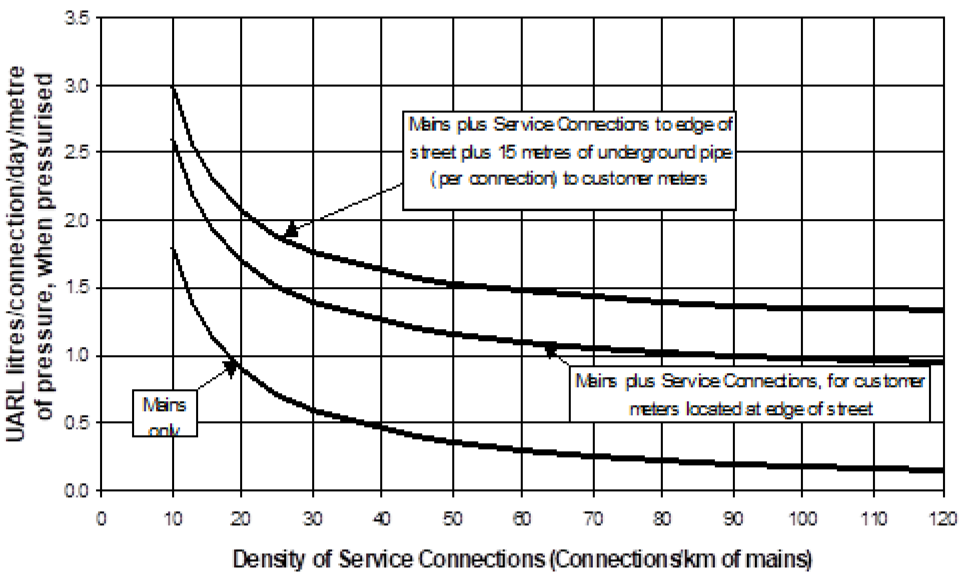
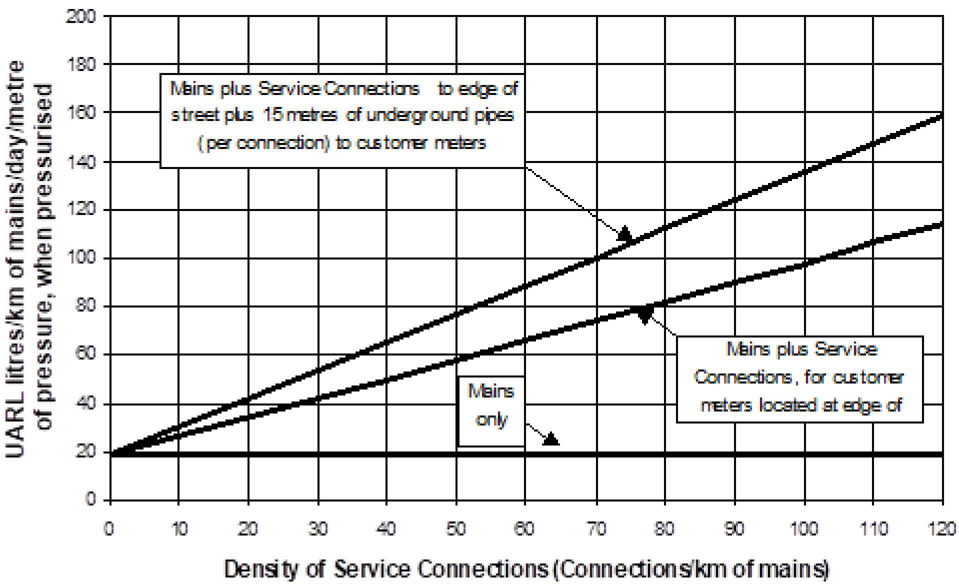


Figure 5: Unavoidable Annual Real Losses in Litres per Km of Mains per day per Metre of Pressure, vs Density of Service Connections



TESTING THE VALIDITY OF THE UARL PREDICTIONS

Comparisons of UARL Predictions with Ranges of 'Unavoidable Losses'

Examples of previously published values for 'Unavoidable Losses' are:

- USA, 2.4 to 7.1 m3/km/day (1000 to 3000 US Gallons/mile/day) (16)
- Germany, 1 to 5 m3/km/day depending on ground type, for Density of Connections between 35 to 50 per km (7)
- France, 1.5 to 7 m3/km/day for 'rural' to 'urban' situations (17)

The wide ranges and limiting constraints of these figures have severely limited their application to specific situations outside their country (or region) of origin. In the international reference data set, individual density of service connections varied from 24/km to 114/km. 'Urban' connection densities for German cities (around 45/km) were around twice those of Scandinavian cities, half of those for Japanese/Brazilian/UK cities, but similar to the values for the most rural of the England & Wales Water Companies.

Assuming typical operating pressures between 30 and 60 metres, customer meters at an average of 7.5 metres from the edge of the street, and density of service connections typically between 20 to 100 per km mains, Figure 5 can be used to show that the typical range of UARL values, in m3/km mains/day, are close to published ranges for 'unavoidable losses' in USA, Germany and France.

Lower (at 20 Conns/km): 37 l/km/day/m x 30m pressure = 1.1 m3/km/day
Upper (at 100 Conns/km): 117 l/km/day/m x 60m pressure = 7.0 m3/km/day

However, the UARL approach has the advantage that it gives a specific value for 'unavoidable losses' for each system depending upon its own local environment factors. The next test uses this feature.

Comparison of UARL Values for Four Well-Managed Systems

Four supply systems requiring active leakage control were selected from the reference data set- two from the Asia Pacific region, and two from Western Europe. Each has a good national and international reputation for technical leakage management with sectorised networks. The systems (Table 6) cover a diverse range of operating pressures, density of connections and customer meter locations. If the true leakage management performance of these four systems – which should be similar – is assessed in terms of traditional PIs, the rank orders are different for each PI, and the values range from:

- 70 to 146 litres/service connection/day.
- 2.8 to 6.8 m3/km/day
- 1% to 23%. of system input volume

If the UARL predictions are reasonably representative, and the ratio of TIRL/UARL (the Infrastructure Leakage Index) is a reliable PI of overall infrastructure leakage management at current operating pressures, the ILI values in Table 6 should all be moderately greater than 1.0, and reasonably similar to each other. The actual values of Infrastructure Leakage Index in Table 6 pass this test. The variation (approximately +/- 20%) from the average value ILI of 1.51 is well within the likely range of error in assessing real losses from Water Balances on systems with low levels of real losses (1).

Table 6: Infrastructure Leakage Index (ILI) values for well-managed systems in four countries

Supply System	Connection Density per Km mains	Location of Customer Meters (ES = edge of street)	Average Pressure Metres	Unavoidable Annual Real Losses UARL Litres/conn/day/	Technical Indicator Real Losses TIRL litres/conn/day/	ILI = TIRL / UARL
A	86	ES	39	39.4	69.9	1.77
B	47	ES + 30m	57	111	146	1.31
C	38	ES + 10m	40	60.9	73.8	1.21
D	39	ES + 11m	40	61.3	107	1.75

OTHER ASPECTS OF UARLs

What does the UARL approach tell us about traditional Performance Indicators?

The shape of the lines in Figure 4 show that for a wide range of values of connection densities (30 to over 100), the UARL in litres/conn/day/m pressure is within +/- 15% of the value at the median connection density of 47 per km in the reference data set. This is because, at connection densities greater than around 20 per km, over 50% of the UARL occurs on service connections rather than mains. Conversely, the UARL in litres/km mains/day /m of pressure (Figure 5) varies widely over the whole range of connection densities.

Figures 4 and 5 provide strong technical support for the Task Force recommendation (initially based on experience world-wide) that 'per service connection' is preferable to 'per km mains' as a basic technical PI for real losses for international comparisons, for a large range of connection densities exceeding 20 per km. UARL losses which are expressed 'per km of system/day/m of pressure' (18) can also be seen to be slightly less consistent than on a 'per service connection' basis.

Situations where UARL calculations are unlikely to be valid

The basic assumptions used in the UARL predictions may break down in situations where intensive active leakage control to locate unreported leaks is not possible, or not necessary. For example, in situations where pressures are significantly less than around 20 metres, sonic detection of hidden leaks may not be possible with some pipe materials and some depths of cover.

In some types of soil, where all significant new leaks and bursts become rapidly visible at the ground surface, the Table 4 values will inevitably over-estimate the attainable level of UARL where there is good infrastructure and rapid good quality repair of all visible leaks and bursts. For example, in the German DVGW technical recommendations (8), sandy soils have the lowest 'lower limit' for losses.

CALCULATING AND INTERPRETING THE RECOMMENDED PERFORMANCE INDICATORS

Recommended calculation procedure

The systematic step-by-step procedure for calculating recommended performance indicators for real losses is detailed in Ref. 1. Current Real Losses are calculated as an annual volume (m3/year), then expressed in m3/day when the system is pressurised, then in terms of the Task Force's recommended Technical Indicator for Real Losses TIRL – Litres per service connection per day w.s.p.

Next, the Unavoidable Annual Real Losses (UARL) are calculated at the current operating pressure for up to three components of infrastructure (depending on customer meter location). The Infrastructure Leakage Index (ILI) is then calculated as the ratio of TIRL to UARL. Simplified examples of these calculations are shown at the end of the paper.

Interpreting the TIRL, UARL and ILI values

<u>The Technical Indicator for Real Losses (TIRL) in Litres per connection/day w.s.p</u> – is the traditional basic performance measure with the greatest range of applicability. However, individual values of TIRL may still be influenced by operating pressure, location of customer meters and low density of connections. Figure 1 shows the values of TIRL for the 27 systems in the reference data set, which vary from 29 to 832 litres/connection/day w.s.p. – a range of 28 to 1.

<u>The Unavoidable Annual Real Losses (UARL)</u> is a prediction of what the real losses would be for any specific system if all infrastructure was in good condition, with intensive 'state of the art' active leakage control, and all detectable leaks and bursts are repaired quickly and effectively. It takes account of length of mains, number of service connections, location of customer meters, continuity of supply, and average operating pressures (when the system is pressurised) between 20 and 100 metres. It is not necessarily economic to achieve the UARL. The ability to calculate reasonably reliable values of UARL has several applications in leakage management studies, but this paper considers only performance indicators. The UARLs of the reference data set vary from 32 to 153 litres/connection/day w.s.p. – a range of 5 to 1.

<u>The Infrastructure Leakage Index (ILI)</u> is the ratio of the Technical Indicator Real Losses (TIRL) to the value of UARL calculated for current pressures and continuity of supply. It is a non-dimensional Performance Indicator of the current overall management of the infrastructure for leakage control purposes. The greater the amount by which the ILI exceeds 1.0, the greater the potential opportunity for further management of real losses by infrastructure management and maintenance, more intensive active leakage control, or speed and quality of repairs. Figure 2 shows the range of ILIs for the reference data set, which vary from around 0.7 to just over 10.

The effect on real losses of managing operating pressures – increasing pressures to meet minimum standards of service, or decreasing them to reduce excess pressures in parts of the system, or at specific times of day – can and should be assessed separately from the ILI calculation. A simple initial assumption for such calculations is that real losses in large systems will increase and decrease linearly with average pressure, over small ranges of pressure.

DISCUSSION OF RESULTS FROM REFERENCE DATA SET

Operators of all of the systems which have ILIs between 1.0 and the median value of 2.9 in the reference data set (Fig 2) make substantial efforts to manage and maintain their infrastructure, ensure that all detected leaks and bursts are promptly repaired, and undertake active leakage control on a continuous or semi-continuous basis. Those which have ILIs in the range 1.0 to 2.0 also have good reputations in technical leakage management. The lowest ILI reading of 0.7 is from a country (Netherlands) where the ground conditions favour leaks showing rapidly at the surface and little active leakage control is required (so assumptions for calculating UARL are likely to produce over-estimates to some extent).

Almost all systems which have ILIs significantly greater that the median value of 2.9 have problems associated with old or poor infrastructure, or a relatively relaxed active leakage control policy. In some cases, because of relatively low pressures and high consumption per connection, the previous use of %s as a traditional performance indicator appears to have masked opportunities for further reductions in real losses.

Comparison of Figures 1 and 2 shows that the omission of some of the key local factors from the basic recommended TIRL may, in certain situations, compromise the assessment of true performance in managing real losses - for example in systems 4,5, 11, 13 to 16, 22 to 24, 26 and 27. Although the more diagnostic approach based on UARL and ILI requires assessment of estimates of density of service connections, meter location, and average operating pressure, the extra effort is likely to be justified.

CONCLUSIONS

The main messages of this paper are:

- Key local factors which constrain achievable Annual Volume of Real Losses have been identified
- Traditional PIs have been checked against these key factors – continuity of supply, mains length, number of service connections, location of customer meters, and average operating pressure
- The common practice of expressing Real Losses as a % of volume input has to be rejected as a technical PI; it takes none of these factors into account, and is unduly influenced by consumption
- In most well-run systems, the greatest proportion of real losses volume occurs on service connections.
- The recommended basic Technical Indicator for Real Losses (TIRL) is therefore the annual volume of real losses in litres per service connection per day, when the system is pressurised (w.s.p) rather than real losses per km of mains per day (w.s.p)
- The TIRL does not take account of the local key factors of Density of Connections, location of customer meters and average operating pressure. In the international reference data set, these factors varied widely.
- An approach which takes these local factors into account has been developed and tested, to assist in interpreting the calculated TIRL values
- The improved approach is based on predicting components of Unavoidable Annual Real Losses (UARL) for each individual system, taking into account these local factors.
- The ratio TIRL/UARL becomes a non-dimensional Infrastructure Leakage Index (ILI)
- The Infrastructure Leakage Index approach provides an improved basis for technical comparisons, which separates aspects of infrastructure management performance (pipe selection/ installation/ maintenance/renewal/replacement, speed and quality of repairs, and effectiveness of active leakage control policy) from aspects of pressure management.

ACKNOWLEDGEMENTS

To Laurent Hecquet (France) who was an initial member of the Task Force. To all water suppliers who contributed data to the study, and to Dr Wolfram Hirner and the many practitioners world-wide who assisted with their comments and constructive criticisms

EXAMPLE CALCULATIONS

Example : A distribution system has 1500 km mains and 60,000 service connections with customer meters located (on average) 6 metres from the edge of the street. The system is pressurised for 90% of the time, and the average pressure (when pressurised) is 30 metres. The current Annual Real Losses in the above system, calculated from Annual Water Balance, are 4000 x 10^3 m^3/ yr. Calculate the Technical Indicator for Real Losses (TIRL), Unavoidable Annual Real Losses (UARL) (using Table 4) and the Infrastructure Leakage Index (ILI).

Technical Indicator for Real Losses (TIRL)

$= 4000 \times 10^3 \times 10^3 / (60{,}000 \times 0.9 \times 365) =$ **<u>202</u>** **<u>litres/service connection/day w.s.p</u>**

Unavoidable Annual Real Losses (UARL) Components:		10^3 m^3/ yr.
Mains	$= 18$ l/km/d/m x 1500 km x (0.9 x 365) days x 30 m/10^6	= 266
Connections to edge of street	$= 0.8$ l/conn/d/m x 60,000 x (0.9 x 365) days x 30 m/10^6	= 473
Edge of street to customer meter	$= 25$ l/km/d/m x (60,000 x 6/1000) x (0.9 x 365) days x 30 m/10^6	= <u>87</u>
Total Unavoidable Annual Real Losses UARL		**= <u>826</u>**

$= 826 \times 10^3 \times 10^3 / (60{,}000 \times 0.9 \times 365)$ **= <u>42 litres/service connection /day w.s.p</u>**

Infrastructure Leakage Index (ILI) = TIRL / UARL = 202/42 = **<u>4.8</u>**

References

1 Losses from Water Supply Systems: Standard Terminology and Performance Measures. Lambert A & Hirner W.H. IWSA Blue Pages (in preparation, 1999)

2 Ogura, Japan Water Works Association Journal June 1979

3 Leakage Control Policy and Practice, DoE/NWC Standing Technical Committee Report 26 (1980) ISBN 0 904561 95 X

4 May, J. Pressure Dependent Leakage. World Water and Environmental Engineering, Oct 1994

5 International Report: Unaccounted-for Water and the Economics of Leak Detection. IWSA World Congress, Copenhagen, 1991

6 'Consulting Services within the Project Water Distribution Network Rehabilitation in Sarajevo, Bosnia Herzegovina. NRW Draft Report October 1996. Seba Messtechnik GmbH & Co KG

7 Managing Leakage Report B 'Reporting Comparative Leakage Performance'. ISBN 1 898920 07 9, 1994

8 Deutscher Verein des Gas- und Wasserfaches (DVGW) e.V Technische Mitteilungen W391, Wasserverluste in Wasserverteilungen, S.8.(DVGW Standard Regulations, Note-Paper W391: Water Losses in Water Distribution Systems: Identification and Assessment) October 1986

9 Code of Practice for the Management of Potable Water Distribution Systems (in preparation), South African Bureau of Standards, Private Bag X191, Pretoria 0001, S Africa, 1998

10 1997-98 Report on leakage and water efficiency. Office of Water Services ISBN 1 874234 42 6

11 Managing Water Leakage: Economic and Technical Issues. Financial Times Energy. ISBN 1 84083 011 5 (1998)

12 Lambert, A.O. Accounting for Losses – the Bursts and Background Estimates Concepts. Journal of the Institution of Water and Environmental Management, 1994, Volume 8 (2), pp 205-214

13 Managing Leakage Report E 'Interpreting Measured Night Flows'. ISBN: 1 898920 10 9, 1994

14 Heide, G. Private communication of data attributed to Dr Hoch of Germany

15 Sattler, R: Einfuhrung der bundesweiten DVGW-Schadensstatistik Wasser-verteilung, gwf Wasser Special 138 (1997) Nr. 13, S27-S31

16 Minutes of American WaterWorks Association Leak Detection and Water Accountability Committee, 21st September 1998

17 Agence de l/Eau Rhone Mediterranee Corse: Le Diagnostic des reseaux d'eau potable (1990)

18 England & Wales Environment Agency Demand Management Bulletin, Issue 33, February 1999