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

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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 / Apparent losses and the Infrastructure Leakage Index (ILI) for international comparisons are indicated using best practice and agreed terminology by the IWA WLTF. 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:

- explain the basic terminology used to develop a standard water balance
- explain the concept of unavoidable annual real losses (UARL) and how it can be used in practice
- identify appropriate Performance Indicators’ (PI’s) and show how they are calculated
- explain how the Infrastructure Leakage Index (ILI) can be used to identify areas of high losses;
- provide examples showing how to the various PI’s are calculated and used

FACTORS INFLUENCING REAL LOSSES

Real or Physical Losses are influenced by many factors including soil conditions, quality of pipe materials, proximity to electrical currents, pressure regime etc. The soil conditions for example can have a great effect on the real losses as well as to the ability for them to be identified and located at the ground surface. Correct selection of pipe materials and proper specifications for the laying of the pipes to suit the different ground conditions as well as the implementation of modern leakage control and detection methods can all help to reduce the overall losses

There are several other key factors which can influence system performance and result in excessive real losses, including; - continuity of supply, length of mains, number of service connections, location of customer meters on service connections, and average operating pressure. It should be noted that careful consideration of these factors will help to reduce the effect and amount of real losses.

Since operating pressures are often constrained by local topography and the specified minimum standards of service (to customers or for fire-fighting) they can vary significantly between systems - from 30 metres to over 120 metres and for this reason it is difficult to recommend an appropriate pressure that should be maintained. This said, however, from a leakage viewpoint it is fair to say that the minimum permissible pressure should be used in all cases for as much of the time as possible.

Many countries already recognise that pressure control is one of the most important aspects of proper leakage management. Pressure reduction not only reduces the water lost through existing leaks but also reduces the frequency with which new leaks occur. In addition, effective pressure management can greatly extend the life of the water reticulation system – an important and often overlooked benefit.

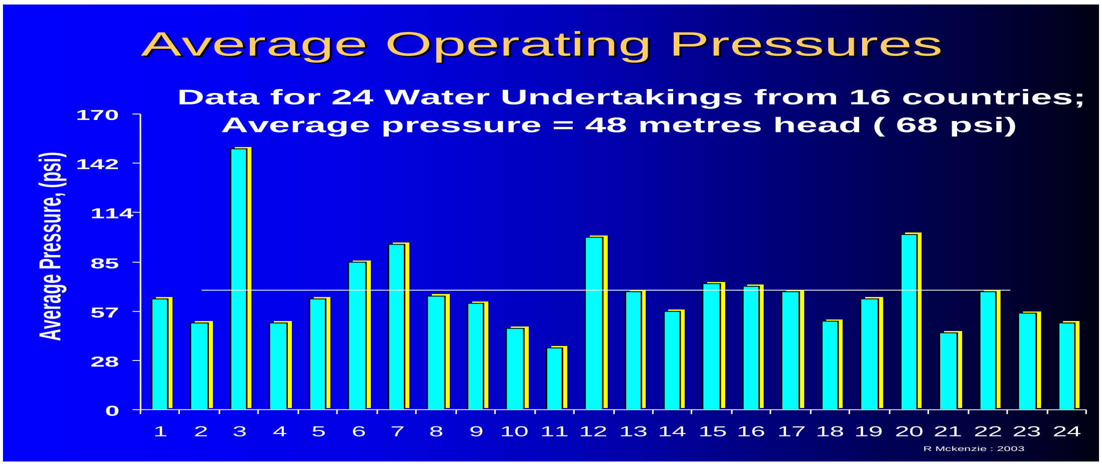

Fig 1

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. This is not classed as a problem but it is advisable that PI's are reported as more than 1 basic indicator.

Table 1: 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

From Table 1 it can be seen that the most commonly used PI namely real losses expressed as a % of system input does not take account of any of the key local factors. In effect, the most commonly used PI is also at best, the least appropriate PI from the list and at worst, completely inappropriate.

Although the IWA no longer recommends using the % of system input as an indicator of real losses, it can be seen in table 2 that it is still used as one of the key PI's in the UK.

TABLE 2: Leakage as a proportion of water supplied

2004-05	Total Leakage (Ml/d)[1]	Distribution Input (Ml/d)	Leakage in litres per property per day	Leakage (to nearest percent)
Water Service Companies				
Anglian & HPL	214	1163	110	18
Dŵr Cymru	226	869	170	26
Essex & Suffolk	67	464	87	14
Northumbrian	155	719	134	22
United Utilities	500	1953	159	26
Severn Trent	502	1925	151	26
South West	83	456	112	18
Southern	92	586	89	16
Thames	915	2809	261	33
Wessex	73	372	132	20
Yorkshire & York	293	1287	137	23
Water Supply Companies				
Bournemouth & West Hampshire	22	164	116	13
Bristol	53	287	109	18
Cambridge	14	75	115	19
Dee Valley	11	68	90	16
Folkestone	8	46	114	17
Mid Kent	29	163	116	18
Portsmouth	30	180	102	17
South East Water	69	391	116	18
South Staffs	74	332	134	22
Sutton & East Surrey	24	161	90	15
Tendring Hundred	5	30	71	17
Three Valleys/North Surrey	149	877	120	17
INDUSTRY TOTAL	3608	15378	2835	23

1 Total leakage includes water leakage on the companies' distribution network and on customers' underground supply pipes.

It should be noted that Ofwat's concern around the use of %'s is due to the fact that it can be very misleading since the value of the real losses will decrease in cases where the overall water use increases. In effect, percentage losses will tend to appear low in countries with high unit water use and appear higher in countries that use small quantities of water per customer. However, it is an unfortunate fact that percentage leakage is often the only indicator that is accepted and understood by the general public. By contrast, Ofwat's preferred measure—litres per property per day—are meaningless for most people except as a means of comparing the relative performance of the water companies.

Of the remaining basic traditional PIs in Table 1, number of service connections' is logically preferable to 'number of properties'. 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 Water Loss 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 that the basic traditional PI with the greatest range of applicability for real losses are:-

litres/service connection /day (if service connections density is < 20) and
litres/km/day (if service connections density is > 20)

However, the Task Force recommended further interpretation of the calculated Current Annual Real Losses (CARL) 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 CARL to UARL becomes a non-dimensional Infrastructure Leakage Index (ILI) this being that as a ratio the ILI has no units and thus is only a comparison between countries that use different measurements (US, imperial or metric), which allows overall infrastructure management performance to be assessed independently of the influence of current operating pressure.

UNAVOIDABLE ANNUAL REAL LOSSES

Leakage management practitioners recognise that it is impossible to eliminate real losses from a water distribution system. There will always be some leakage and therefore some level of 'Unavoidable Annual Real Losses' (UARL) which will still occur at the current operating pressures if there were no financial or economic constraints.

Table 3: 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 after Edge of Street	Length Pressure Min loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration

* as specified at standard pressure of 50m

It can of course be argued that not all systems with good infrastructure condition will experience the same burst frequencies and average flow rates for the leaks. The 'background' loss components of UARL dominate the calculated values, however, and sensitivity testing shows that differences in assumptions for parameters used in the 'bursts' components have relatively little influence on the UARL calculation

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 values 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 provided at the end of the paper.

The values shown in Table 4 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.

BRIEF DESCRIPTION OF THE ILI

ILI is effectively an indicator of how well the distribution network is being managed and maintained at the current operating pressure. It is the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL)

ILI = CARL / UARL

The ILI is widely becoming the preferred indictor in many countries and is continuously being promoted by members of the IWA Water Loss Task Force.

It is important to note that the authors do not support the use of the ILI as the sole PI for real losses but rather as one of several PI's which should be used collectively. While it is accepted that real losses expressed as a percentage is possibly one of the least reliable PI's, it is also a reality that this indicator will always remain in contention for a "top 3" spot. The following PI's are therefore suggested

- **litres/service connection day or l/km/day (if service connections density is > 20)**
- **% of losses**
- **and ILI**

Before "% of system input" can be discarded as a key PI, the water managers must first start to use the other two suggested PI's. The key problem to be overcome is therefore to convince water managers worldwide to adopt the ILI as well as expressing the real losses in "litres/conn/day". A key strategy of the WLTF is to introduce the ILI to all the water loss managers throughout the world

Many problems and myths still surround the calculation of the ILI with the result that it has not been widely accepted by many of the world's leading utilities and water regulation authorities. Key reasons most often quoted include:

- The accuracy of the base data on which the general UARL equation is based is questionable
- Data required to calculate the UARL is often not available
- The ILI is too simplistic and has no physical meaning

Many different software models are now available (free and downloadable via the internet) to assist water managers in calculating their ILI for a given system. It is now widely accepted that the problems through lack of knowledge for some of the required data can be overcome by introducing some form of uncertainty in the estimated value. This concept was first introduced in 1998 in the SANFLOW model (SA Water Research Commission, 1999) and later modified to the current 95% confidence limits by Lambert in the New Zealand BENCHLOSS model (New Zealand WSA, 2002). Through the use of these "uncertainty limits" it is possible to derive a range for the resulting ILI value as well as the other PI's.

This approach enables countries with unknown or dubious data to complete an ILI calculation which will include an indication of the level of uncertainty within the results.

I.e. system with an average ILI of 12* (range of ILI estimation 9 – 15).

INTERPRETING THE CARL, UARL AND ILI VALUES

The Performance Indicator for Real Losses is Litres per connection/day – this is the traditional basic performance measure with the greatest range of applicability. However, individual values of Real Losses may still be influenced by operating pressure, location of customer meters and low density of connections. Figure 2 shows the values of Real Losses for 24 systems, which vary from 29 to 832 litres/connection/day w.s.p. – a range of 28 to 1.

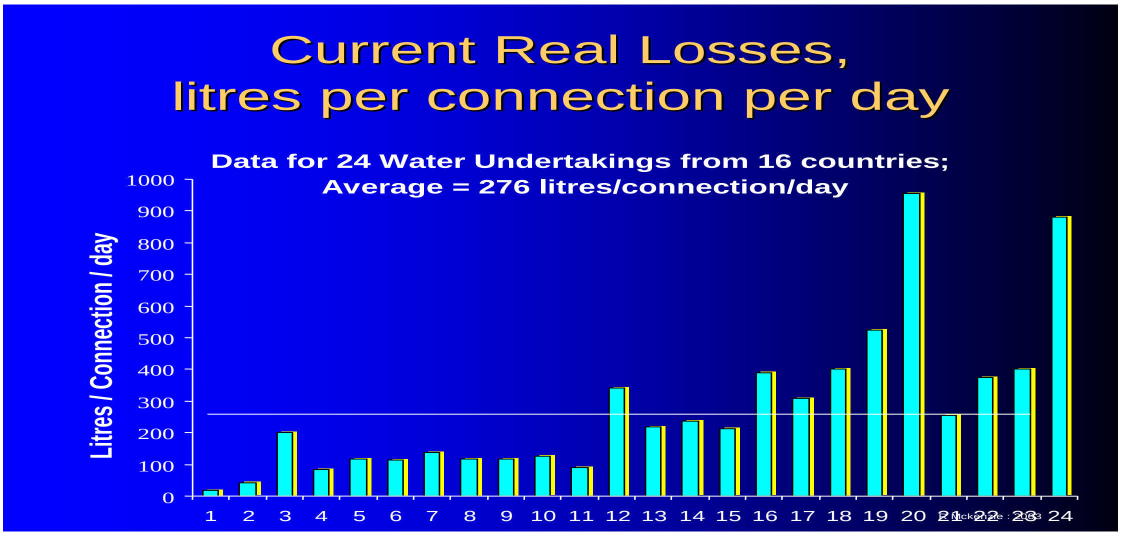

Fig 2

The Unavoidable Annual Real Losses (UARL) 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 and in most cases the economic level of leakage is well above the UARL. The ability to calculate reasonably reliable values of UARL has several applications in leakage management studies, but this paper considers only its link to the various key performance indicators.

The Infrastructure Leakage Index (ILI) is the ratio of the CARL to the value of UARL calculated for current pressures and continuity of supply. As this is a ratio and hence has no units and it can be said that this is a non-dimensional Performance Indicator of the current overall management of the infrastructure for leakage control purposes which can be used as a comparison between countries of different measurement. 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.
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.

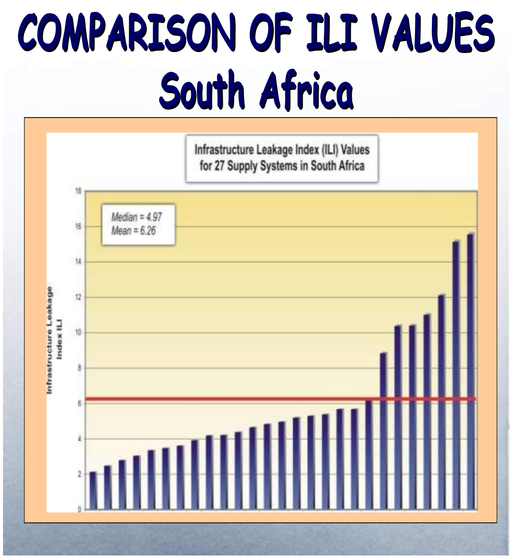

Fig 3

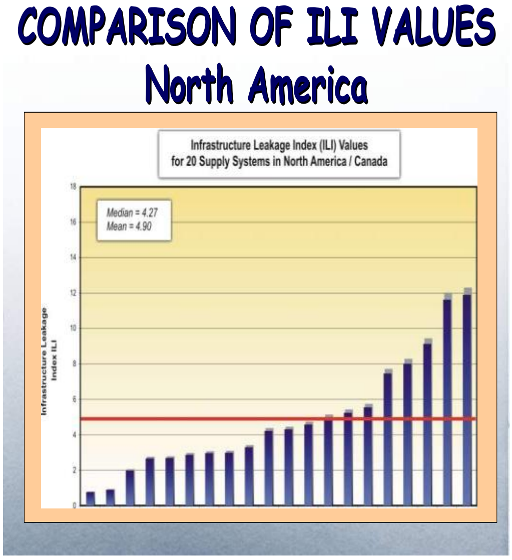

Fig 4

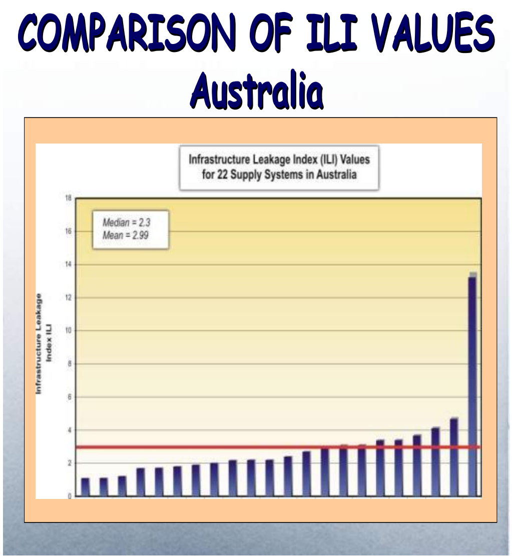

Fig 5

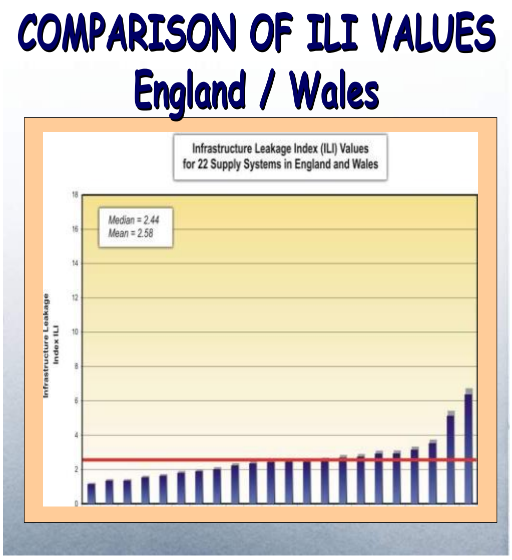

Fig 6

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 (CARL), Unavoidable Annual Real Losses (UARL) (using Table 4) and the Infrastructure Leakage Index (ILI).

Performance Indicator for Real Losses (CARL)

= 4000 x10^3 x10^3 /(60,000 x 0.9 x365) = **202 litres/service connection/day w.s.p**

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	= 87
Total Unavoidable Annual Real Losses UARL		**= 826**

= 826 x 10^3 x 10^3 /(60,000 x 0.9 x 365) **= 42 litres/service connection /day w.s.p**

Infrastructure Leakage Index (ILI) = CARL / UARL = 202/42 = **4.8**

CONCLUSIONS

The key conclusions from this paper are::

- Traditional PIs have been checked against these key factors including 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 should be rejected as a technical PI since it takes none of these factors into account, and is unduly influenced by consumption. From a practical viewpoint, however, many Clients still insist that % of system input be used in which case it should be supplemented by at least two other more meaningful PI's namely"litres/conn/day" and the ILI.
- In most well-run systems, the greatest proportion of real losses volume occurs on service connections.
- The recommended basic Performance Indicator for Current Annual Real Losses is therefore the annual volume of real losses in litres per service connection per day, when the system is pressurised (w.s.p).
- An approach which takes these local factors into account has been developed and tested, to assist in interpreting the calculated CARL 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 CARL/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.

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