Assessment of real losses in potable water distribution systems: some recent developments

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Abstract Considerable progress has been made over the past 10 years in the assessment and benchmarking of real losses in potable water distribution systems. Most of the advances have been based on the burst and background estimate (BABE) methodology, which was first developed in the mid-1990s by the UK water industry and has since been widely accepted and used in many parts of the world. Since the original BABE methodology was developed, several other key concepts have been added to the ever-growing list of water demand management tools. In particular, the infrastructure leakage index (ILI) and unavoidable annual real losses (UARL) introduced by A. Lambert, and the fixed area variable area discharge (FAVAD) theory by J. May, are now recognised as key "tools of the trade" in any water demand management assessment.

One of the first main developments where the above-mentioned concepts were applied in practice to benchmark leakage was in South Africa, where the local Water Research Commission supported the production of the BENCHLEAK Model. This was basically the first comprehensive model to assess real losses in potable water distribution systems using the UARL and ILI concepts. The model was developed by one of the authors together with A. Lambert, and was soon followed by similar developments in Australia (BENCHLOSS) and New Zealand (BENCHLOSSNZ). Both models incorporated additions and enhancements to the original South African model, and were tailored to suit the local conditions in line with the clients' requirements.

Similar developments took place in parallel by various leakage specialists, most notably in Brazil, Malaysia and Cyprus, to mention just a few of the similar initiatives. Each time a new model was developed, certain improvements were made and the "science" of leakage management and benchmarking was enhanced.

Through the use of the different models and from discussions with various researchers from around the world, it has become clear that there is a genuine need for such models, and they are being readily accepted by clients in most areas. The discussions have also raised many questions concerning the derivation of the terms used to calculate the UARL and the ILI, and, to address these concerns a specialist group was created through the IWA to investigate the various issues.

This paper will highlight the progress that has been made to date with regard to the key issues that have been raised by the task-team members, and recommendations based on the feedback that has been received from around the world. The paper will also present some of the results that have been obtained from different parts of the world to highlight both the progress and the problems associated with the assessment of real losses. The paper will conclude with a short description of several new models that have been developed and are in use, which demonstrate the latest improvements to an ongoing process to assess and benchmark real losses in water distribution systems.

Keywords BABE (burst and background estimate) methodology; benchmarking; distribution systems; leakage reduction; potable water; water audit

Introduction

There is an increasing awareness around the world that water is becoming the critical issue of the twenty-first century. In many countries, surface water resources are being depleted as more new dams are constructed, while groundwater in some areas is effectively being extracted to such an extent that problems are already being experienced with both quantity and quality. In some countries, the problems have been identified and measures are already being undertaken to foster an approach of effective water utilisation and reduction of wastage. Water lost from potable water distribution systems remains one of the key

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problem issues facing not only developing countries but also developed countries throughout the world.

The first real step forward in addressing leakage in water reticulation systems was taken in the 1990s when the burst and background estimate (BABE) procedures were developed by a task team comprising specialists from many of the newly privatised water companies in England and Wales. The BABE techniques are well documented (see UK Water Industry: *Managing Leakage Reports*, 1994) and have been widely accepted as best practice for assessing and managing leakage in potable water distribution systems in most parts of the world. The key issues covered in the BABE methodology (which will not be discussed any further in this paper, since they are already well documented) include:

- the breakdown of total losses into real and apparent losses;
- the influence of pressure on leakage and the N1 exponent;
- the use of component analysis to determine unexplained leakage from a minimum night flow.

Since the introduction of the BABE methodology, many other key developments have taken place, all of which help to explain the leakage process and how it can be analysed and lowered. Some of the most significant developments include:

- standardised water balance;
- the use of key performance indicators to measure real losses (see McKenzie and Lambert, 2004);
- the fixed area variable area discharge (FAVAD) theory (May, 1997);
- the concept of unavoidable annual real losses (UARL): (Lambert).

The remainder of this paper will discuss some of the key issues mentioned above and developments that have taken place to assist water distribution managers to assess and manage the leakage in their water distribution systems.

The standardised water balance

A clearly defined water balance is the first essential step in the assessment of volumes of non-revenue water and the management of water losses in potable water distribution systems. In July 2000, the IWA Task Forces on Performance Indicators and Water Losses published (Alegre *et al*., 2000) a standard international "best practice" water balance, as shown in Figure 1. This water balance has since been recognised and adopted as international "best practice" by a steadily increasing number of countries and water utilities throughout the world. In a series of articles on various issues concerning leakage in water distribution systems published recently (in 2004) by the IWA, no fewer than five of the eight articles presented the IWA water balance as part of the introduction – testament to the importance placed on the use of a standardised water balance by many internationally recognised leakage specialists.

Leakage performance indicators

In addition to the standardised water balance, the IWA also commissioned a task team to investigate and recommend suitable performance indicators which could and should be used to measure and compare various components of non-revenue water. Of particular significance is the use of the term "non-revenue water" in place of the widely used "unaccounted-for water", due to the scope for misinterpretation and manipulation associated with the latter term. The key elements where performance indicators have been investigated and appropriate recommendations have been made with regard to water losses, include:

- non-revenue water;
- total water losses;

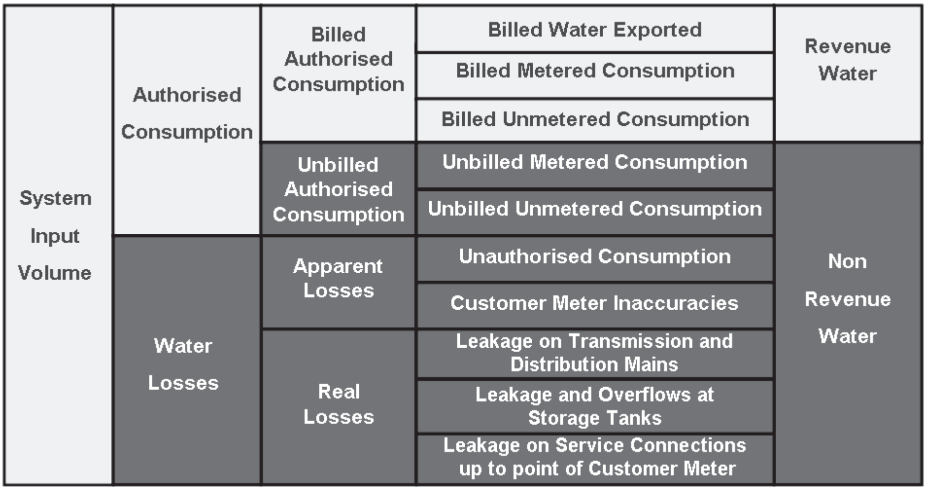

Figure 1 The IWA "best practice" standard water balance

- apparent losses;
- real losses.

While some healthy debate still continues around the world, the IWA approach of selecting different PIs for different purposes (financial, operational, and water resources); is a clear step forward. In each case, PIs have been recommended for both basic and detailed levels within each category. Intermediate PIs have also been proposed in some cases; however, this article will concentrate on only a few of the key and most useful PIs relating to water losses, as shown in Table 1 from the recent paper by McKenzie and Lambert (2004).

Non-revenue water: financial PI

While "percentage by volume" is still recommended as a basic financial PI for non-revenue water, and a basic PI for real losses from a water resources viewpoint, it should definitely not be used for assessing any aspect of operational performance management of water losses (other components of the water balance and, where possible, the recommended PIs given in Table 1 should be used).

The detailed financial PI for non-revenue water is based on the percentage by value of the water, rather than the percentage by volume.

Table 1 Details of selected key PIs

Component	Type	Basic PI	Detailed PI
Non-revenue water	Financial	Volume of NRW as % of system input volume	Value of NRW as % of cost of running system
Real losses	Water resources	Volume of real losses as % of system input volume	
Real losses (In each case, this PI is calculated per day when the system is pressurised to allow for the effect of intermittent supply.) = CARL/UARL	System operational	Litres/service connection/day For systems with 20 or more services/km, mains (32 per mile) Use m^3/km mains/day for systems with fewer than 20 services/km of mains	The infrastructure leakage index: defined as the ratio of the current annual real losses to the unavoidable annual real losses
Apparent losses	Operational		m^3/service connection/year
Water losses	Operational	m^3/service connection/year	

Real losses: water resources PI

The basic water resources PI recommended by Lambert (2003) is "real losses by volume" = volume of real losses as a percentage of system input volume.

No further work has been done on this PI by the Water Losses Task Force since 2000. As previously mentioned, percentages by volume are strongly influenced by differences and changes in consumption, and if improvements to this PI are to be considered, it would be useful to assess whether or not the "real losses" become available for re-use.

Real losses: operational PI

The *IWA Best Practice Report (2)* clearly states that "percentages by volume" are unsuitable for assessing the efficiency of operational management of real losses. This conclusion has been endorsed by many organisations throughout the world, including: Ofwat in England and Wales, the national regulator in Malta, AWWA in North America, WSAA in Australia, NZWWA in New Zealand, and DWAF in South Africa.

As comparatively few systems have less than 20 service connections/km, "litres/service connection/day" is the preferred basic operational PI for most distribution systems. This basic PI is the best of the "traditional" PIs but has certain limitations, as it does not allow for the following:

- density of connections (per km of mains);
- length of service pipe between the main and the customer meter, and;
- average pressure (leakage rates vary approximately linearly with pressure for systems with mixed pipe materials).

UARL and ILI

To address these deficiencies, a detailed operational PI for real losses was developed, and is referred to as the infrastructure leakage index (ILI). This relatively new PI is the ratio of the current annual real losses (CARL) to the unavoidable (technical minimum) annual real losses (UARL), and is discussed in detail by Lambert *et al*. (1999), and calculated as follows:

$$\text{UARL} = [(18 \times L_m) + (0.8 \times N_s) + (25 \times L_p)] \times P$$

where UARL = unavoidable annual real losses (L/connection/day)
L_m = length of mains (km)
N_s = number of service connections
L_p = length of unmetered underground pipe from street edge to customer meter (km)
P = Average operating pressure at average zone point (m).

The ILI measures how effectively a utility is managing real losses under the current operating pressure regime, and is simply the ratio of the actual estimated real losses, divided by the UARL.

It is important to note that the ILI calculation does not imply that the pressure management in the system being considered is optimal, and it is usually possible to reduce the volume of real losses (but not the ILI) by improved active pressure management. This "twin track" approach to leakage management directly addresses comments that the ILI somehow favours water utilities that operate at high pressures and discriminates against those that implement strict pressure management measures. Once again, this is the subject of considerable debate; however, the speed at which water utilities throughout the world have adopted the ILI as their preferred PI for real losses is clear testament to its value in the water industry. The ILI has in fact been the subject of many workshops and is included in many water-balance models, including: BENCHLEAK, BENCHLOSS, BENCHLOSSNZ, AQUALIBRE, AQUAFAST, FASTCALC, etc. Some details of the various models can be found in the references.

Apparent losses: operational PI

The operational PI for water losses (i.e. the sum of real and apparent losses) and apparent losses in the 2000 PIs Report (2) was m^3/service connection/year (to provide consistency with the basic PI for real losses). However, numerous international applications of the water balance since 2000 have identified a need for more specifically focused practical operational PIs for unbilled authorised consumption (UAC), and the components of apparent losses (AL). When auditing and comparing volumes attributed to UAC and AL, it is necessary to check that these components are not excessive.

Considerable effort is being spent investigating the various components of the apparent losses, and some initial results were presented by Thornton and Rizzo (2002).

Standard water audit software

The first water audit "software" accompanying the UARL/ILI methodology was a basic Microsoft Word file in which the user simply followed a given template in a standard manner to derive the UARL and finally calculate the ILI. This was followed in 2000 by the development of a standardised software package (BENCHLEAK) in Microsoft Excel, which was developed for the South Africa Water Research Commission (McKenzie and Lambert, 2002). The South African model was quickly followed by an Australian model (BENCHLOSS), as well as a similar model for use in New Zealand (BENCHLOSSNZ). Each new model incorporated new features, and numerous other models were also developed by many other individuals and organisations for use in other parts of the world, including Brazil, Malaysia, Canada, etc.

Since the initial South African BENCHLEAK Model was developed in 2000, many improvements have been made to the methodology, and various key problem issues have been investigated, if not addressed. At the recent IWA Leakage Workshop, held in Cyprus in 2002, it was agreed that one Task Group would look into the whole issue of water auditing, and try to gather results from around the world to highlight the value of the new ILI indicator, as well as to demonstrate how quickly the water utility managers had adopted the new methodology. Some of the initial results from around the world are provided in Figures 2 to 5. It should be noted that the authors of this paper have collected information from various other specialists, and that the figures present the work of others and not specifically the efforts of the authors.

Figure 2 provides some preliminary values from England and Wales, courtesy of the Environment Agency (D. Howarth), while Figure 3 provides similar information for utilities in the USA and Canada. Figure 4 provides the information from various Australian data-sets (courtesy of T. Waldron of Wide Bay Water) and Figure 5 is from South African water utilities.

From the different data-sets, it is interesting to note that developed countries with strict regulation tend to have low ILIs, while developing countries such as South Africa tend to have higher ILIs. The USA and Canada appear to have a full range of ILIs, suggesting that there are some systems with very high leakage. While there are many possible explanations for the different trends in the different countries, the cost of water and the presence of a strict regulator are possibly two of the key factors. In the UK for example, the system leakage is being driven down (often below the economic level of leakage) by the regulator, who is able to impose leakage targets for all water utilities. Australia appears to be operating in the same manner, and the levels of leakage within the Australian utilities are also relatively

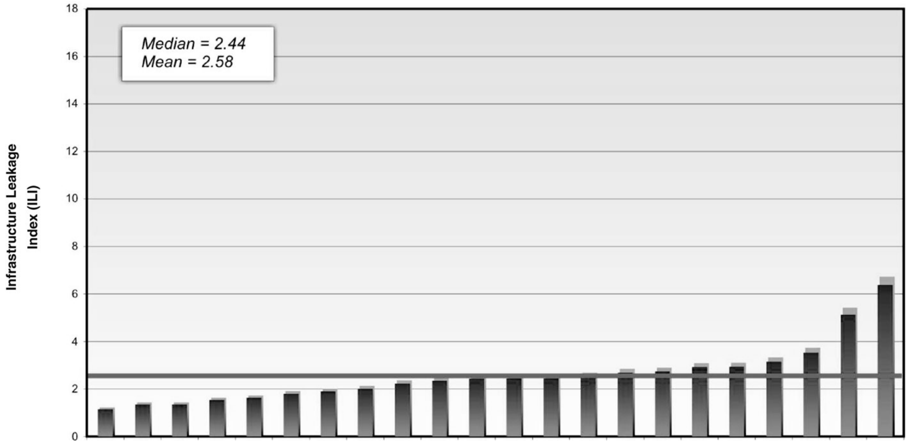

Figure 2 ILI results for 20 systems from England and Wales. (Source: February 2004 paper by David Howarth, Environment Agency)

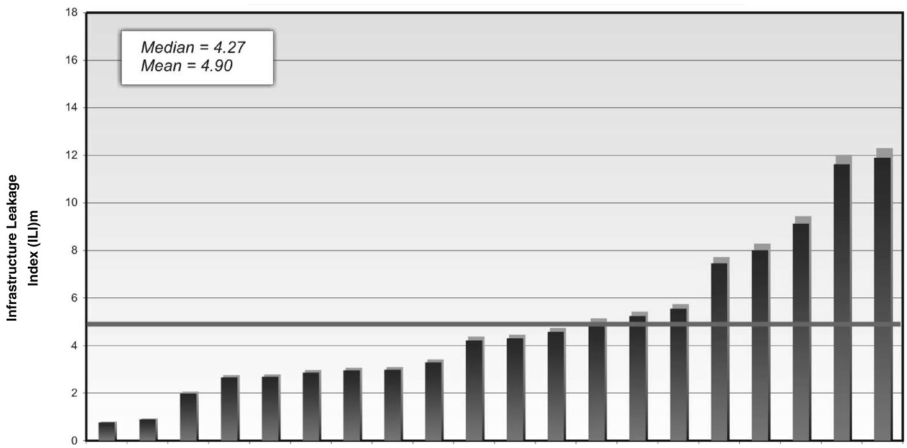

Figure 3 ILI results for 20 systems from the USA and Canada. (Source: June 2004 presentation by T. Waldron and A. Lambert, based on various data sources

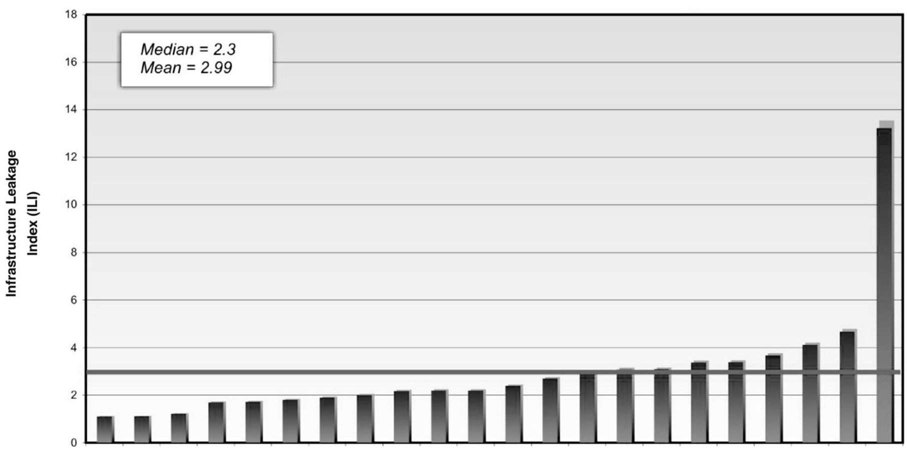

Figure 4 ILI results for 20 systems from Australia. (Source: March 2004, T. Waldron, Wide Bay Water)

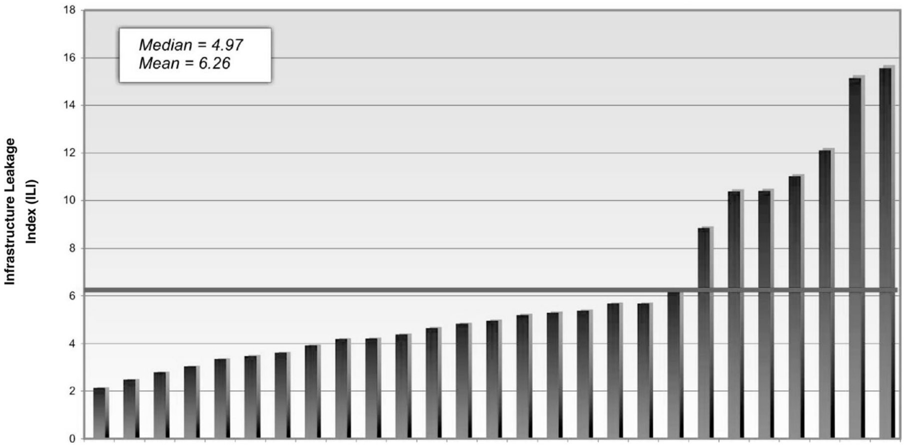

Figure 5 ILI results for 27 systems from South Africa. (Figures courtesy of the South African Water Research Commission)

low. In South Africa, the situation is clearly that of a developing country, and many areas experience very high levels of leakage, which are being reflected by the high ILI values. Water in South Africa is relatively cheap, despite the fact that it is a water-scarce country. Efforts are being taken to address high leakage levels in the country; however, the problems are being exacerbated by a general unwillingness to pay for water in many areas, together with the recent policy to provide free water to everyone up to a level of 7,000 litres per property per month.

Conclusions

The various water audit models currently available are proving very useful for assessing and comparing leakage among water utilities around the world. The value of a standardised approach is only beginning to emerge, and already many countries are using the ILI indicator as a tool to identify water utilities which have a serious leakage problem. It is also very useful in providing an indication of the savings that can be achieved.

There remain a few issues which require further discussion and clarification, but in general the approach of using the standard IWA water balance and a few key performance indicators is proving to be a very powerful tool for assessing and managing losses in potable water distribution systems.

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