Understanding the components of your Infrastructure Leakage Index (ILI) is necessary to develop a successful strategy to reduce the overall ILI value – especially in systems with a low ILI

S. J. Preston*, R. Sturm**

* Water Systems Optimisation (WSO), 25 Saxon Road, Worth Crawley, West Sussex, RH 10 7SA, UK, e-mail: steve.preston@wsoglobal.com

** Water Systems Optimization (WSO), 255 King Street, Suite 437, San Francisco, CA 94107, USA; phone: 415 538 8641, 786 877 5752, e-mail: reinhard.sturm@wso.us

Keywords: Infrastructure Leakage Index (ILI); Component Analysis; Target Setting

Abstract

The Infrastructure Leakage Index (ILI) is gaining widespread acceptance as a benchmarking indicator for leakage management initiatives and is being used in many countries around the world. The calculation of the ILI requires a robust water audit, using standard definitions as set out by the International Water Association. However, once the ILI was calculated the next step for a water utility is to ask “how low can we go”. This paper discusses the various components of the UARL/ILI and their impact on the overall ILI.

The Concept of the ILI

The ILI is a dimensionless performance indicator, calculated by dividing the volume of Current Annual of Real Losses (CARL) by the volume of Unavoidable Annual Real Losses (UARL). The volume of CARL is obtained through the results of a standardized water balance using IWA terminology and the volume of UARL is determined by applying individual parameter values for three components of losses on three components of the water supply system (see Table 4).

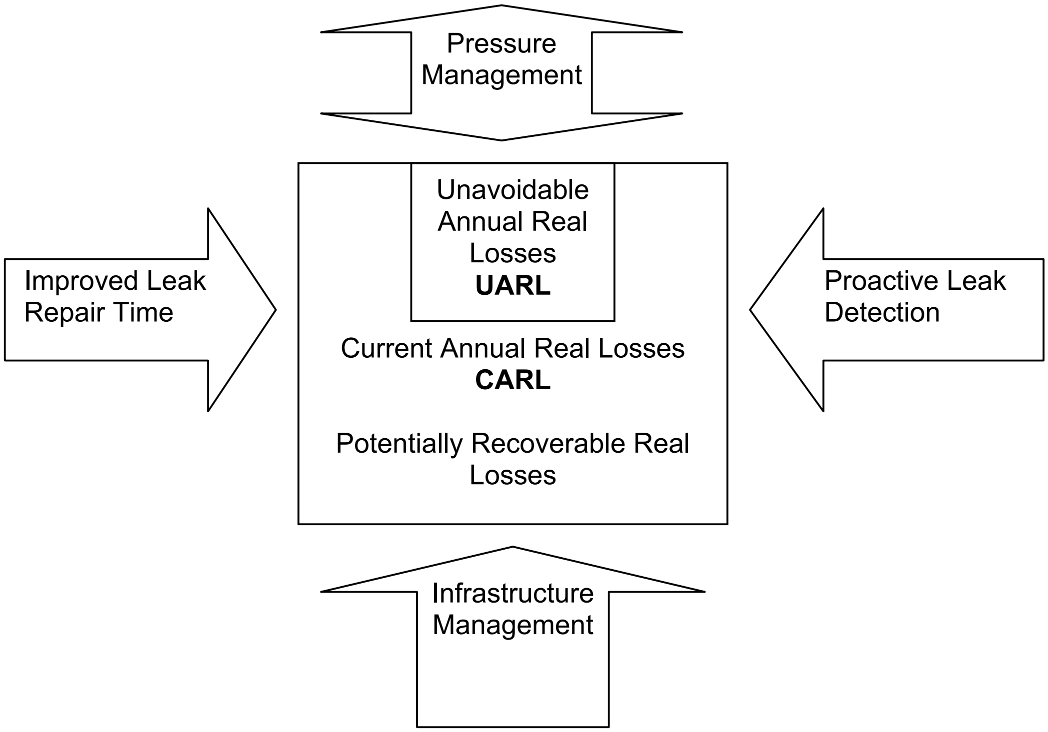
ILI = CARL / UARL

It is a well known fact among leakage practitioners that real losses cannot be eliminated completely, and even in newly commissioned distribution networks, there is a minimum level of leakage. The volume of UARL - the lowest technically achievable annual volume of real losses for a well-maintained and well-managed system at the current pressure – is represented by the smaller inner rectangle in Figure 9. The larger rectangle represents the volume of CARL and the ratio between the large rectangle and the small rectangle represents the ILI.

Equations for calculating UARL for individual systems were developed and tested by the IWA Water Losses Task Force (Lambert et al. 1999), allowing for:

- **Background leakage** – small leaks with flow rates too low for sonic detection if non-visible. They comprise of small pinholes, leaking joints, etc. As they are “undetectable”, their presence, it can be argued, is not as a result of the lack of leak detection activity. They are a function of the type of infrastructure, ground conditions and age of system.

- **Reported leaks and breaks** – based on frequencies, typical flow rates, target average durations. Reported breaks and leaks are those events reported by customers and the general public because they have a nuisance value. They are typically catastrophic failures that have high flow rates but short durations. These events will arise whether leak detection is carried out or not.
- **Unreported leaks and breaks** – based on frequencies, typical flow rates, target average durations. They are those leaks that can be detected but are too small or in a location that does not cause nuisance to the customers and general public. They can run undetected for long periods of time and their duration is a function of the method and intensity of leak detection activities. Increasing leak detection activity will reduce the overall duration of unreported bursts and so reduce the annual volume of water that is lost through these types of leaks.
- **Leakage-pressure** relationships (a linear relationship being assumed for most large systems).



Source: Adapted from IWA Water Loss task Force

Figure 9 The UARL and the four basic methods of managing real losses

UARL is determined by applying individual parameter values for three components of losses on three components of the water supply system. The nine component values, as published by IWA are as presented in Table 4.

Table 4 Standard Unit Values Used for the Calculation of Unavoidable Annual Real Losses, UARL

Infrastructure Component	Background Leakage	Reported Bursts	Unreported Bursts	UARL total	Units
Mains	9.6	5.8	2.6	18	litres/km of mains/day/metre of pressure
Service connections main to curb stop	0.6	0.04	0.016	0.80	litres/service connection/day/metre of pressure
Service connections curb stop to meter	16	1.9	7.1	25	litres/km of service connection/day/metre of pressure

Source: Adapted from IWA/Aqua 48

It should be noted that no allowance is made for any losses from service reservoirs, break-pressure tanks or other forms of water storage within the water supply system. ILI is strictly limited to pipes only.

The equation used for calculating UARL is based on clearly stated auditable assumptions for background losses, for frequencies and durations of the different types of leaks, and their typical flow rates related to pressure. The UARL equation requires data on four key system-specific factors:

- Length of mains (Lm)
- Number of service connections (Nc)
- Location of customer meter on service connection (relative to property line, or curb-stop in North America) (Lp)
- Average operating pressure when system is pressurized (P)

The UARL equation as shown below assumes a linear leakage-pressure relationship and this assumption works best for large systems with mixed metal and non-metal pipe work.

$$\mathbf{UARL = (18xLm + 0.8xNc + 25xLp) \times P}$$

Use of ILI for Target Setting

The conventional approach to using ILI is to consider ILI as a single value for a system and to compare this against the ILI values for others systems or against a set of guidelines. Well managed systems are expected to have low values of ILI – close to 1.0 – while systems with some deficiencies in infrastructure management will have higher values.

An example of guidelines that are being developed using ILI are those prepared by the American Water Works Association (AWWA) Water Loss Control Committee and presented in their committee report “Applying worldwide BMPs in water loss control” (AWWA Water Loss Control Committee, 2003) (see Table 5).

This approach works well and provides the user with a clearly defined performance indicator that can be used as a general comparator for decision making.

Like all performance indicators, however, the ILI does have some limitations. The most notable limitation is in relation to one of the most effective leakage management strategies, namely pressure management. The linear leakage-pressure relationship used in this equation is an important feature that is often overlooked. The inclusion of the leakage-pressure factor is designed to take into account the fact that systems operated at higher pressure will intrinsically have higher leakage rates than those operated at lower leakage levels. Without the inclusion of pressure as a factor, systems with higher pressure would tend to have higher ILI than those with lower pressure. However, the corollary of this is that changing the operating pressure in any given supply system will affect both the UARL and CARL equally, and therefore the ILI, being the ratio of UARL to CARL, will remain unaffected. In other words, the assumption is that pressure management will not impact on ILI. If ILI is used exclusively as the target indicator for leakage management, then there is little point to look towards pressure management as a tool for achieving a lower ILI.

Table 5 AWWA Guidelines for setting a target ILI

Target ILI Range	Water Resources Considerations	Operational Considerations	Financial Considerations
1.0 – 3.0	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop.	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Water Resources are costly to develop or purchase; ability to increase revenues via water rates is greatly limited because of regulation or low ratepayer affordability.
3.0 – 5.0	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management, water conservation) are included in the long-term planning.	Existing water supply infrastructure capability is sufficient to meet long-demand as long as reasonable leakage management controls are in place.	Water resources can be developed or purchased at reasonable expense; periodic water rate increases can be feasibly imposed and are tolerated by the customer population.
5.0 – 8.0	Water resources are plentiful, reliable and easily extracted.	Superior reliability, capacity and integrity of the water supply infrastructure make it relatively immune to supply shortages.	Cost to purchase or obtain/treat water is low, as are rates charged to customers.
Greater than 8.0	Although operational and financial considerations may allow a long-term ILI greater than 8.0, such a level of leakage is not an effective utilization of water as a resource. Setting a target level greater than 8.0 – other than as an incremental goal to a smaller long-term target – is discouraged.		

Source: Adapted from AWWA Water Loss Control Committee

Component-based approach to using ILI

Having calculated the ILI, most utilities will ask the questions “how low can I go?” or “what steps should I take to reach the guideline target ILI ?”.

In answering these questions, it is important to step back and look at the various components that comprise both the UARL and CARL values. From Table 4 we saw that there are essentially nine components to the UARL value comprising three types of leakage (background leakage, reported bursts and unreported bursts) on three classes of infrastructure (mains, service connections from main to curb-stop and service connections from curb-stop to customer meter). The next step is then to consider what factors will affect each of these components and what actions can be taken to reduce the level of losses from each component. For the purposes of this paper, we have ignored pressure management as an option for reducing ILI on the basis of the reasons explained in the earlier section.

What Influences the ILI?

Background losses comprise the “undetectable” leaks; small pinholes, leaking joints etc. As they are “undetectable”, their presence, it can be argued, is not as a result of the lack of leak detection activity. They are a function of the type of infrastructure, ground conditions and age of the system. The primary tool for reducing background leakage, other than pressure management (which has already been shown to be of no assistance in reducing ILI), is infrastructure replacement.

Reported bursts are those leaks that are reported by customers and the general public because they have a high nuisance value. They are typically catastrophic failures that have high flow rates but short duration, such as a circumferential break on an iron main or total failure of a service connection. They may also be caused by third party damage such as contractors excavating for other utility companies. In most cases, reported bursts cause a loss of supply to one or more customers and can be characterised as ‘sudden and short-lived’ events. It can also be argued that many of these events also arise whether leak detection is carried out or not. For example, the amount of leak detection carried out by the water utility will have no affect on the amount of third-party damage caused by other utility companies and their contractors. Likewise, the number of catastrophic failures caused by pressure surge events will not be affected by the amount of leak detection that takes place.

Unreported bursts are those leaks that can be detected but are too small or in a location that does not cause nuisance to the customers and general public. They can run undetected for long periods of time and their duration is a function of the method and intensity of leak detection activities. Increasing leak detection activity will reduce the overall duration of unreported bursts and so reduce the annual volume of water that is lost through these types of leaks.

The frequency with which leaks occur on water mains and service connections is affected by many factors. These may include pipe material, pipe specifications, installation workmanship, operating pressures, ground conditions, soil types and so on.

A United Kingdom Water Industry Research (UKWIR) project (MacKellar and Pearson, 2003) collected mains failure data from water companies in United Kingdom. The data set is comprehensive and is a good source of comparators, especially given the UK Water Industry focus on optimizing leakage levels. The UK Water Industry average mains failure rates for various pipe materials for the periods 1998 to 2001 are presented in Table 6. This clearly shows that different pipe materials have differing failure rates. Table 7 also demonstrates that the failure rate is also affected by pipe size. Since any given network will have a unique combination of pipe materials and pipe sizes, it is understandable that the burst frequency will vary from network to network.

Table 6 UK water industry average mains failure rates for various pipe materials

Material	**Mains Failure Rate per 100 km per year**			
	1998	**1999**	**2000**	**2001**
Asbestos Cement	16.4	17.1	15.1	15.8
PE	3.5	2.9	3.3	3.1
PVC	9.6	9.1	7.2	7.4
Ductile Iron	5.0	5.3	4.8	4.8
Cast Iron	23.7	23.7	19.1	21.7

Source: constructed from data contained in the UKWIR National Database of mains Failures

Table 7 UK water industry average mains failure rates for 2001 for two different pipe materials

Nominal pipe diameter (mm)	**Mains Failure Rate per 100km per year**	
	UK Water Industry Average for 2001 for Asbestos Cement	**UK Water Industry Average for 2001 for Ductile Iron**
200	8.0	3.9
150	16.7	6.8
100	23.8	7.4
80	26.0	26.3

Source: constructed from data contained in the UKWIR National Database of mains Failures

The UARL values for mains bursts is based on an assumption of 13 bursts per 100 kilometres per year with 95% of bursts being reported (12.35 bursts/100km/year) and 5% being unreported (0.65 bursts/100km/year) (Lambert and McKenzie, 2002). If the network being considered is predominantly asbestos cement pipes of nominal diameter of 150mm or less, then it could be expected that the natural burst frequency will be higher than that assumed in the UARL calculation and that the network, all other things being equal, will naturally have an ILI higher than 1.0.

This demonstrates that is essential to look beyond the ILI as a single value when considering what range of ILI can be achieved for any given water utility. As an example we might consider a water utility with an overall ILI of 2.0. Is the amount of water being lost from each of the Real Loss components (background losses, reported bursts and unreported bursts) and on each of the infrastructure components twice the UARL volume for each component? Or is it possible that the CARL volume on the background losses component is equal to the UARL value (ILI=1.0) and some other multiplier on the other components? And what impact will this have on working out how low we can go?

Conversion of UARL values into standardised units

The first step in looking at ILI on a component basis is to convert the UARL into standardised units for all the nine components so that they can be readily compared against one another. It can be seen from Table 4 that the UARL for the three infrastructure components are in different units. To convert the UARL values into standardised units requires the connection density of the network (number of service connections per kilometre of main) and the assumed average length of the service connection from curb-stop to customer meter expressed in km.

The following example is for a water utility with 100 service connections per kilometre of main and an average of 4 metres of service connection length between curb-stop and customer meter. The UARL units for the example water utility are presented in Table 8 and have been converted into litres/service connection/day/metre of pressure using the following methodology:

For mains, UARL (litres/km of main/day/metre of pressure) divided by service connection density (service connections per km of main) equals UARL (litres/service connection/day/metre of pressure);

For service connections, curb-stop to meter, UARL (litres/km of service connection/day/metre of pressure divided by the assumed average length of the service connection from curb-stop to customer meter (km) equals UARL (litres/service connection/day/metre of pressure).

Table 8 Standardised UARL values for a specific water utility example

Infrastructure Component	Units	Background Leakage	Reported Bursts	Unreported Bursts	UARL total
Mains	litres/service connection/day/metre of pressure	0.096	0.058	0.026	0.180
Service connections main to curb stop	litres/service connection/day/metre of pressure	0.600	0.040	0.016	0.800
Service connections curb stop to meter	litres/service connection/day/metre of pressure	0.064	0.008	0.028	0.100
TOTAL	**litres/service connection/day/metre of pressure**	**0.760**	**0.106**	**0.214**	**1.080**

By standardising the parameter values to the same units for each component in this way, it is now very easy to compare the relative contribution that each component makes to the overall UARL total. In the example given it can be seen that background losses on services connections dominate the UARL value. The UARL for background losses on service connections is 0.664 litres per service connection per day per metre of pressure out of a total UARL value of 1.080 litres per service connection per day per metre of pressure – almost 70% of the UARL value is associated with the single component of background losses on service connections! It should be remembered that standardisation of the UARL components into similar units is system specific and that the example shown is for an urban situation with relatively high service connection density.

Applying the calculated ILI value to the UARL values

The next step is to consider how the single ILI value relates to each component of the UARL total. In our example utility, the CARL value has been calculated from an annual water balance and an ILI of 3.0 has been calculated. How should the ILI value be applied across all of the UARL components and what does this mean for possible leakage management strategies?

In Table 9, the ILI of 3.0 is assumed to be constant across all the UARL components. If a standard leakage management strategy of increasing the amount of active leakage control activity that is carried out is considered, such that the duration of unreported bursts is reduced, then it can be assumed that the losses from background leakage and reported bursts would be unaffected. Figure 10 presents the active leakage control cost curve that would result from the application of the selected leakage management strategy of reducing the duration of unreported bursts by increasing active leakage control activity for an ILI of 3.0 assuming this is uniformly applied across all UARL components. It can be seen from the cost control curve, that it would be necessary to increase the expenditure on active leakage control six-fold to reduce the overall ILI from 3.0 to 2.5.

In Table 10, the ILI of 3.0 is not assumed to be constant across all the UARL components. The utility keeps careful records of the number and type of bursts that take place and the length of time that is taken to locate and repair those bursts and the individual ILI values for each of the reported and unreported burst components have been calculated. The background leakage component is allocated an ILI of 1.0 and is inferred from the difference between the other components and the total overall ILI of 3.0.

Note that both examples have the same overall ILI but with quite markedly different CARL values for each of the nine components.

Table 9 Standardised UARL values for an ILI of 3.0 assuming uniform application (Example 1)

Infrastructure Component	**Units**	**Background Leakage**	**Reported Bursts**	**Unreported Bursts**	**Total**
Mains	UARL litres/service connection/day/metre of pressure	0.096	0.058	0.026	0.180
	Component ILI	**3.0**	**3.0**	**3.0**	**3.0**
	CARL litres/service connection/day/metre of pressure	0.288	0.174	0.078	0.540
Service connections main to curb stop	UARL litres/service connection/day/metre of pressure	0.600	0.040	0.016	0.800
	Component ILI	**3.0**	**3.0**	**3.0**	**3.0**
	CARL litres/service connection/day/metre of pressure	1.800	0.120	0.480	2.400
Service connections curb stop to meter	UARL litres/service connection/day/metre of pressure	0.064	0.008	0.028	0.100
	Component ILI	**3.0**	**3.0**	**3.0**	**3.0**
	CARL litres/service connection/day/metre of pressure	0.192	0.023	0.085	0.300
TOTAL	UARL litres/service connection/day/metre of pressure	0.760	0.106	0.214	1.080
	Component ILI	**3.0**	**3.0**	**3.0**	**3.0**
	CARL litres/service connection/day/metre of pressure	2.280	0.317	0.643	3.240

Table 10 Standardised UARL values for an ILI of 3.0 assuming non-uniform application (Example 2)

Infrastructure Component	**Units**	**Background Leakage**	**Reported Bursts**	**Unreported Bursts**	**Total**
Mains	UARL litres/service connection/day/metre of pressure	0.096	0.058	0.026	0.180
	Component ILI	**1.0**	**3.0**	**11.0**	**3.11**
	CARL litres/service connection/day/metre of pressure	0.096	0.174	0.286	0.559
Service connections main to curb stop	UARL litres/service connection/day/metre of pressure	0.600	0.040	0.016	0.800
	Component ILI	**1.0**	**3.0**	**11.0**	**3.12**
	CARL litres/service connection/day/metre of pressure	0.600	0.120	1.760	2.496
Service connections curb stop to meter	UARL litres/service connection/day/metre of pressure	0.064	0.008	0.028	0.100
	Component ILI	**1.0**	**3.0**	**3.5**	**1.86**

	CARL litres/service connection/day/metre of pressure	0.064	0.023	0.099	0.186
TOTAL	UARL litres/service connection/day/metre of pressure	0.760	0.106	0.214	1.080
	Component ILI	**1.0**	**3.0**	**10.1**	**3.0**
	CARL litres/service connection/day/metre of pressure	0.076	0.317	2.164	3.241

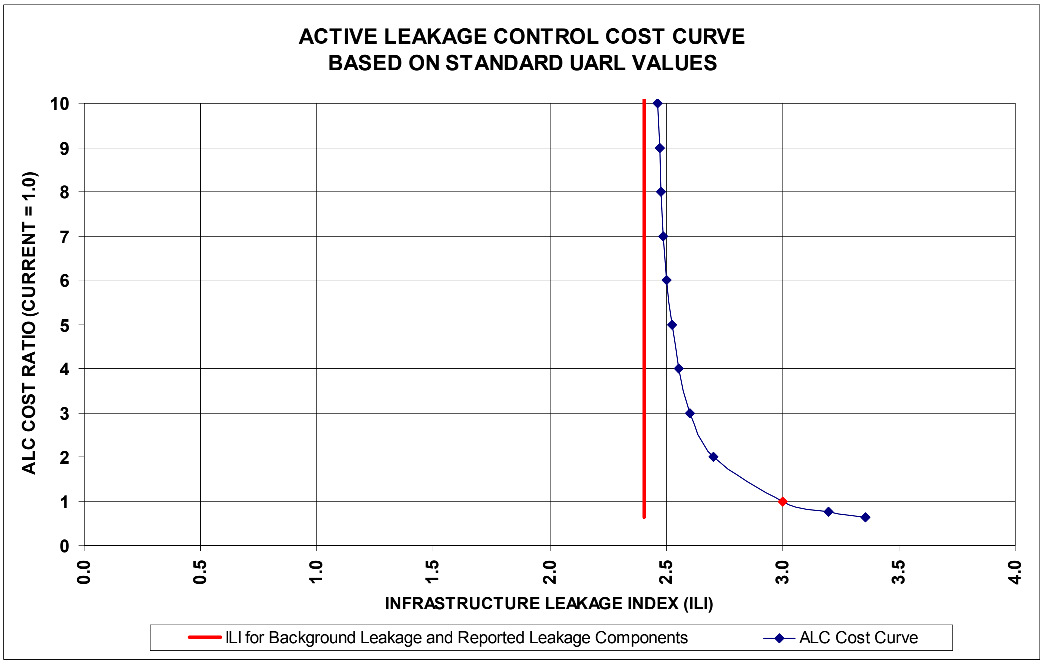


Figure 10 Active leakage control cost curve for example 1 with ILI = 3.0

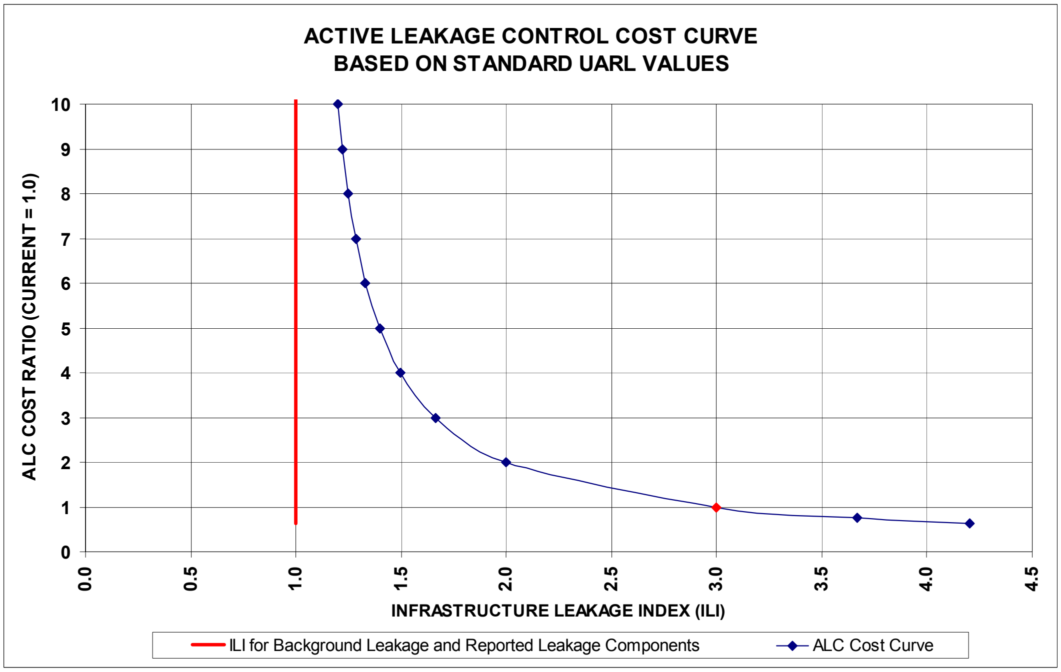


Figure 11 Active leakage control cost curve for example 2 with ILI = 3.0

Figure 3 presents the active leakage control cost curve that is developed for example 2 using the same leakage management strategy as used in example 1. The difference between example 1 and example 2 is immediately obvious. Although both examples have a starting ILI of 3.0, it is clear that in example 2, a much lower ILI can be achieved for any given increase in leakage management activity. For instance, in example 2, a six-fold increase in leakage management activity would result in an overall ILI of 1.3 compared to an overall ILI of 2.5 in example 1.

Alternatively, the utility in example 2 could achieve an ILI of 2.5 for a relatively modest 50% increase in active leakage control compared to the six-fold increase required by the utility in example 1.

Summary and Conclusions

The paper has discussed the various components that comprise the UARL and CARL values and how ILI, the ratio of CARL to UARL, is now being used as a target setting tool for water utilities. It has been shown that the main limitation of ILI as a target setting tool for leakage management is that pressure management, one of the most effective methods of leakage reduction, is known not to reduce ILI.

It has also been shown that for any given value of ILI, the CARL value may be made up of many different variations in the component ILI values for the nine stated components of real losses. This demonstrates that although ILI is a useful performance indicator, it is still necessary to develop a thorough understanding of the volume of real losses by component for each specific water utility so that the most appropriate leakage management strategy is selected. A water utility with an overall ILI of 3 and where the CARL values of each of the nine components are assumed to be 3 times the UARL values will have the majority of real losses arising from background leakage. In this case even very large increases in expenditure on active leakage control or repair duration will have very little impact on the overall ILI. By comparison, a water utility with an ILI of 3 and where the CARL values of each component are such that background leakage is 1 times the UARL and unreported bursts on mains and service connections in the street are 11 times the UARL value, will be able to achieve a much lower ILI with the same leakage management strategy and the same increase in expenditure.

It can therefore be concluded that water utilities with similar ILI do not necessarily have similar ratios of real losses across all of the nine identified components used in the UARL calculation. It also follows that water utilities with similar amounts of infrastructure may need to apply quite different leakage management strategies and spend quite differing sums of money to achieve the same overall ILI.

Only by carrying out the detailed component based analysis of real losses is it possible to determine whether any particular leakage management strategy will be effective in achieving a target level of ILI.

References

Alegre, H. et al (2000) Performance Indicators for Water Supply Services - IWA Manual of Best Practice. IWA Publishing, London, United Kingdom.

Lambert, A. et al (1999) Review of Performance Indicators for Real Losses from Water Supply Systems. Journal of Water Supply: Research and Technology-AQUA 48: 227-2237

MacKellar, S. and Pearson, D. (2003) Nationally Agreed Failure Data and analysis Methodology for Water Mains. UK Water Industry Research, London, United Kingdom.