Accuracy Limitations of the ILI - Is it an Appropriate Indicator for Developing Countries?

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Keywords: ILI; accuracy limitations; developing countries

Introduction

Since the level of water losses from potable water distribution systems is one of the key efficiency issues, it would be expected that reliable performance indicators are used for benchmarking, international performance comparison or target setting. Unfortunately this is not the case in most parts of the world and utility managers and consultants around the world as well as the International Financing Institutions still continue to express water losses as % of System Input Volume.

The serious problems of using % of system input as a key PI have been highlighted in many conferences around the world, (e.g.Liemberger, 2002) and there is general consensus that this indicator should not be used for comparison or target setting purposes.

Experienced practitioners consider the Infrastructure Leakage Index (ILI, recommended by IWA and AWWA) as the most appropriate performance indicator for real losses (physical losses). In many cases, however, poor data quality as well as low operating pressures; particularly in developing countries, are often cited as motivation for not using the ILI in which cases the % of system input tends to re-appear.

Brief description of the ILI

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

$$ILI = CARL / UARL$$

Being a ratio, the ILI has no units and thus facilitates comparisons between countries that use different measurement units (U.S., metric or imperial). But what are unavoidable losses and how are they calculated? Leakage management practitioners around the world are well aware that Real Losses will always exist - even in new and well managed systems. It is simply a question of how high these unavoidable losses will be.

The complex initial components of the UARL formula were converted to a 'user friendly' pressure-dependent format for practical use:

$$UARL\ (liters/day) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P$$

where Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, property boundary to customer meter (km); P = average pressure (m).

Is the ILI well known and widely used?

The answer unfortunately is NO. The authors are most certain that a minority of utility managers and consultants (presumably a single digit percentage) around the world have heard of the ILI or using it regularly. However, significant promotional efforts have been made:

- in Australia (the WSAA is publishing the ILI of their members on an annual basis)
- in New Zealand it was introduced in 2001 and is currently being used by many water utilities throughout the country.
- in South Africa the ILI is well accepted and used by many utilities. It is soon to be implemented as the key PI for assessing water losses by the regulator throughout the country
- in Italy (by the "water loss user group")
- in North America (by the AWWA water loss control committee)
- by members of the IWA water loss task force (WLTF) in their working environment

One of the key challenges to the WLTF is to develop a strategy of how best to introduce the ILI to utility managers and consultants around the world.

Part of the problem is that people are simply not aware of the ILI - and the other part of the problem is the limited understanding and acceptance of the ILI. In this regard, many practitioners prefer not to use the ILI for one or other of the following reasons:

- the accuracy of the UARL formula is questionable;
- data required to calculate UARL are not available;
- nobody uses and understands the ILI - it is basically not accepted in the industry;
- the ILI is not needed - the classical performance indicators (like real losses per km mains per day) are sufficient;

In addition to the above there are another two reasons why the ILI is sometimes not used:

- 10% water losses always sounds acceptable and low - while the ILI in many cases highlights that the true leakage performance is far from satisfactory
- *Warnings from the Water Losses Task Force that the ILI must not be used for systems with less than 25 m average pressure or less than 5 000 connections.*

Initial applicability limitations for the ILI

The equation used for calculating Unavoidable Annual Real Losses (UARL) (Lambert et al 1999), is based on components of Real Losses originally calculated at 50 metres pressure, then corrected for pressure, assuming a linear pressure: leakage rate relationship for large systems with mixed pipe materials.

Practical limitations placed on applying the UARL formula were, originally, that systems should not have less than 5000 service connections, not less than 20 connections/km of mains, and not less than 25 metres of pressure. Following recent research, the lower limits for number of service connections is now 3000 and the lower limit on density of connections has been removed.

The lower limit of 25 metres for pressure was introduced to avoid significant errors from extrapolating the assumption of a linear pressure: leakage relationship to systems with 100% flexible pipes at low pressures, where the N1 exponent would be close to 1.5 (note: Leakage varies with $Pressure^{N1}$).

Advanced pressure reduction is becoming an increasingly popular technique to reduce both leakage and burst frequencies and in some cases utility managers try to maintain system pressures to avoid the average pressures exceeding 25 meters. To compound the problem, most of water distribution networks in the developing world do not even enjoy continuous supply - and pressures of more than 10 or 15 meters tend to be the exception and not the rule. Should such utilities be discouraged from using the ILI ?

General ILI accuracy considerations

The accuracy of the ILI depends less on the accuracy of the (empirical) UARL formula but on the accuracy of:

- annual volume of real losses
- average pressure
- distribution network data

The following example demonstrates the accuracy problem of a system with a low level of leakage:

- System input volume: 45 million m^3/year (+/- 1%, this is already considered a very good accuracy).
- Real Losses: 4.1 million m^3/year (but since the amount is small the accuracy is only +/- 11%, using the statistical 95% confidence limits methodology).
- Length of mains: 2,000 km, number of connections: 200,000 (both +/- 1%)
- Average length of private supply pipe 5 m (+/- 20%)
- Average pressure 40 m (+/- 5%)

The ILI was calculated to be 1.27 - but the 95% confidence limits are 1.12 and 1.43. This means that with 95% confidence it can be assumed that the ILI of this system is between 1.12 and 1.43 - although the assumed data quality of this example is truly excellent.

If the system input of this example is changed to 75 million m^3 (leaving everything else unchanged) and therefore the real losses increase by 30 million m^3/year to 34.1 million m^3, the ILI would be between 9.9 and 11.2 (best estimate: 10.6).

The first example would mean an ILI accuracy of +/- 12%, the second one +/- 6%. Adding this to the accuracy limitation of the UARL formula (at 40 m pressure up to +/- 10%) it is obvious that the ILI's overall accuracy will not be less than 15% but could be considerably more.

Another problem is the accuracy of the average pressure since this is normally not calculated by water utilities and is often estimated based on a few pressure measurements (if any). It is certainly unusual for the accuracy of the system wide average pressure to be better than +/- 10%. Furthermore, increasing average pressure is a simple way in which utility managers can "improve" their ILI.

Taking the previous examples and increasing average pressure by 10% (from 40 to 44 m), the corresponding ILI’s would be reduced to between 1.0 and 1.3 or 9.0 and 10.2 respectively.

Showing too many decimal places sends a misleading signal of the ILI's accuracy and the authors therefore recommend the following:

- don't show decimal places for ILIs > 10
- use only one decimal place for ILI's below 10
- in a more comprehensive analysis, always calculate and report the potential ILI bandwidth

The accuracy issue must be taken into account if the ILI is used for regulatory purposes.

Data availability and quality in developing countries

When introducing the ILI in the developing world, most utilities initially face the following problems:

- no reliable information on the true network length. Maps (if any!) often show only a fraction of the existing network (result: UARL underestimated → ILI overestimated)
- number of service connections is not known - number of customers is used instead (number of customers will in most cases be higher than the number of connections, result: UARL overestimated → ILI underestimated)
- neither pressure data nor pressure loggers available. Estimated average pressure usually too high ("wishful thinking"!) (result: UARL overestimated → ILI underestimated)
- high level of apparent losses (difficult to estimate) and therefore unreliable and inaccurate volume of real losses

The following three examples are from cities in Vietnam, Indonesia and Sri Lanka. In all three cases substantial field work (flow and pressure measurements) and comprehensive data collection and analysis were undertaken. Water balances and performance indicators, including accuracy estimations, were undertaken using the Aqualibre™ Water Balance Software.

Table 1: Annual volumes and system characteristics of three cities in developing countries

	Vietnam		**Indonesia**		**Sri Lanka**	
		+/-		+/-		+/-
System Input Volume [m^3/a]	365,440,000	2%	20,415,203	1%	10,263,867	2%
Authorised Consumption	214,830,000	0.3%	12,247,970	0.0%	5,626,176	0.3%
Billed Consumption	213,730,000	0.0%	12,235,450	0.0%	5,589,676	0.0%
NRW	151,710,000	4.9%	8,179,753	3.5%	4,674,191	4.4%
Water Losses	150,610,000	4.9%	8,167,233	3.5%	4,637,691	4.4%
Apparent Losses	17,040,000	9.9%	1,397,676	13.5%	547,573	4.8%
Real Losses	133,570,000	5.7%	6,769,557	5.1%	4,090,118	5.0%
Length of Mains [km]	2,647	5.0%	756	2.8%	421	1.7%
Number of Connections	426,000	0.7%	45,280	1.7%	25,229	1.9%
Average length of private pipe [m]	0		5	20.0%	5	25.0%
Total length of private pipe[km]	0		226		126	
Supply Time [%/day]	99%	10.0%	95%	3.0%	86%	10.0%
Pressure [m]	12	10.0%	11	10.0%	11	15.0%

Table 2: Real loss performance indicators

	Vietnam	Indonesia	Sri Lanka
l/conn./day	**866**	**430**	**519**
min	766	403	460
max	966	457	577
l/conn./d/m pressure	**72**	**38**	**48**
min	60	34	39
max	84	43	57
ILI	**79**	**31**	**39**
min	67	24	32
max	91	37	47

Simulating the scenario of an overestimated number of service connections (by using the number of customers) the number of connections was reduced by 20% and the changed real loss performance indicators can be seen in Table 2.

Table 2: Real loss performance indicators after number of connections has been reduced by 20%

	Vietnam	Indonesia	Sri Lanka
l/conn./day	**1,083**	**538**	**648**
min	958	504	575
max	1,208	572	722
l/conn./d/m pressure	**90**	**48**	**60**
min	60	42	49
max	84	53	72
ILI	**96**	**36**	**46**
min	81	32	38
max	111	41	55

Going a step further and assuming that the drawings were incomplete and increasing the length of mains by 20%, the ILI would of course change (see Table 3):

Table 3: Real loss performance indicators after increasing length of mains by 20%

	Vietnam	Indonesia	Sri Lanka
ILI	**93**	**34**	**44**
min	79	30	36
max	108	39	52

Average pressure in all three systems is well below 15 m (11 - 12 m) and therefore the question: how wrong are the calculated ILI values?

Thornton and Lambert (2005) suggest the use of a pressure correction factor in the UARL formula that would in this case be in the order of 0.6 (since most but not all leaks are on flexible pipes). Consequently the "true" ILI values would be significantly (60%) higher. In the Vietnamese situation, the ILI would increase from between 67 and 111 to between 112 and 160. The issue to be resolved is whether or not it is necessary to introduce a new parameter to the ILI and if the adjusted ILI estimates are more reliable and meaningful that the original values. The answer to this question is highly debatable and the authors tend to favour the original unadjusted values on the grounds that a new parameter may simply confuse a methodology that has yet to be universally accepted and the impact of the adjustment is not particularly important once the ILI's are already so high. It is after all considered to be a relative indicator which is used to highlight whether or not a system has a serious leakage problem. A system with an ILI of 30 will be regarded as having a serious leakage problem as will a system with a value of 130. It is, however, important to understand that ILI values in low pressure situations tend to err on the low side and can often be up to 60 % higher - depending of the material mix of mains and service connections.

How meaningful are ILI values of distribution networks in developing countries?

The present approach of expressing water losses as "Non-Revenue Water" in terms of percentage of system input volume often significantly underestimates the true extent of the leakage problem in developing countries and tends to penalise systems with lower consumption. This can be clearly seen from the previous examples:

- Vietnam: 42 % (ILI = 79)
- Indonesia: 40% (ILI = 31)
- Sri Lanka: 46% (ILI = 39)

As can be seen the % losses do not reflect the huge difference in leakage performance between the Vietnam system and the remaining two systems.

It is therefore the view of the authors that despite the accuracy limitations described above, the ILI is still the best indicator to quickly describe the level of real losses of a system. Many utility managers and consultants, however, remain reluctant to switch from the "prehistoric" % UfW or % NRW to the ILI (both in the developed and developing world). To help address this issue, a simple look-up table based on the ILI was suggested by Liemberger (2005). This allows a first simple assessment using litres per connection per day in combination with the approximate average pressure. This table has meanwhile been included in the new water loss reduction training modules of the World Bank Institute (WBI, the capacity building arm of World Bank Group).

Technical Performance Category		ILI	Litres/connection/day (when the system is pressurised) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 – 4	< 50	< 100	< 150	< 200	< 250
	B	4 – 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Figure 1: Proposed use of ILI as PI in developed and developing countries (Liemberger, 2005)

As can be seen from the figure, different ILI ranges have been provided for developing and developed countries. The proposal attempts to classify the leakage levels within the Water Utilities into four categories based on the ILI value as follows:

Category A: Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost effective improvement

Category B: Potential for marked improvements; consider pressure management; better active leakage control practices, and better network maintenance

Category C: Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyze level and nature of leakage and intensify leakage reduction efforts

Category D: Horrendously inefficient use of resources; leakage reduction programs imperative and high priority

Since the vast majority of water utilities in the developing world will have ILI values exceeding the upper limit of the table (16), reducing real losses to below 16 will be the starting point. As soon as utilities start to introduce active leakage control, carry out flow and pressure measurements, and improve overall data quality the bandwidth of the ILI will dramatically be reduced. Often leakage reduction will also lead to an improved supply situation and pressure increases that will make the calculation of the UARL formula more accurate.

Conclusions

The ILI has, in recent years, proved to be a very useful performance indicator when benchmarking leakage in water distribution systems.

Although various limits on the use of the ILI have been proposed by its original developer to safeguard the soundness of the results, the authors have found that it can still provide a useful indication of high leakage even when used outside the normally accepted limits. It is certainly also a most suitable indicator for water utilities in developing countries and it is now understood that "true" ILI's of low pressure systems will always be higher than the calculated figures. This suggests that the leakage problem in developing countries is even more serious than previously anticipated.

There have been various suggestions on how the ILI can be improved by refining certain coefficients or adding new terms in the underlying equations. While further research should never be discouraged, the authors do not feel that modifications are necessary at this time. There is a danger that modifying the equations before the basic approach has been universally accepted will undermine much of the confidence that has been gradually created over the past 5 years. It took a tremendous effort from the original developers of the ILI together with its numerous proponents around the world to get the ILI officially endorsed by the IWA and it is unlikely that this can be repeated with a modified formula. Changes in the UARL formula will certainly disrupt and even confuse users around the world that are not so familiar with the concept and methodology. The present UARL formula has been published in papers and books around the world and it will take many years to spread new information. It may not be in the interest of the industry to create a new UARL formula as this is likely to lead to at least two versions being in use at the same time – clearly a difficult and contentious issue that will no doubt draw considerable debate.

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