Using practical predictions of Economic Intervention Frequency to calculate Short-run Economic Leakage Level, with or without Pressure Management

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Rate of Rise, Economic Intervention, ELL

Abstract

The development of quick and practical methods for calculating economic leakage levels is a stated objective of the Water Losses Task Force. A barrier to this objective has now been removed, following publication of a simple methodology to assess the economic annual volume of real losses from unreported bursts, for a policy of regular survey, using only three system-specific parameters. The paper explains this rapid and practical approach, in the hope that Utilities currently undertaking insufficient active leakage control (or none at all), will be encouraged to adopt an ongoing basic intervention policy which is demonstrably economic for their system.

       With the economic intervention concept, the three components of short-run economic leakage level (SRELL) can be quickly calculated, for a policy of regular survey, at current operating pressure. Real losses from reported bursts are calculated from number of reported burst repairs, with a pressure-dependent 'per burst' volume allowance. Background (undetectable) leakage is calculated as a multiple of Unavoidable Background Leakage. Economic annual volume of unreported real losses is calculated using Economic Intervention theory. This approach can be used to investigate how the SRELL is influenced by the interaction between cost and efficiency of different intervention methods, and the undetected and unrepaired leakage that remains after an intervention.

       A further development of the methodology allows for the influence of pressure management on SRELL, through changed in leak flow rates, new burst frequencies and repair costs. This permits rapid identification of situations where investment in pressure management should accompany or precede initiatives in active leakage control.

Introduction

Achieving an Economic Level of Real Losses

Figure 1 is now widely used internationally to demonstrate the essential principles for effective management of Real Losses. For all but a very few Utility systems, the Current Annual Real Losses (CARL, represented by the largest box) exceed the Unavoidable Annual Real Losses (UARL, the smallest box), and there is an Economic Level of Leakage (ELL) somewhere between the two. The ratio of the CARL to the UARL is known as the Infrastructure Leakage Index (ILI). Studies from the UK and Australia suggest that the ELL corresponds to an Economic ILI generally less than 2.5 in developed countries

     An economic level of real losses (ELL) for a particular system cannot be achieved, or calculated, unless the Utility commits to effectively applying all four methods of real losses management shown in Figure 1. The ELL can be broadly defined (CIWEM, 2003) as:
.
> *'the level of leakage at which any further reduction would incur costs in excess of the benefits derived from the savings'*
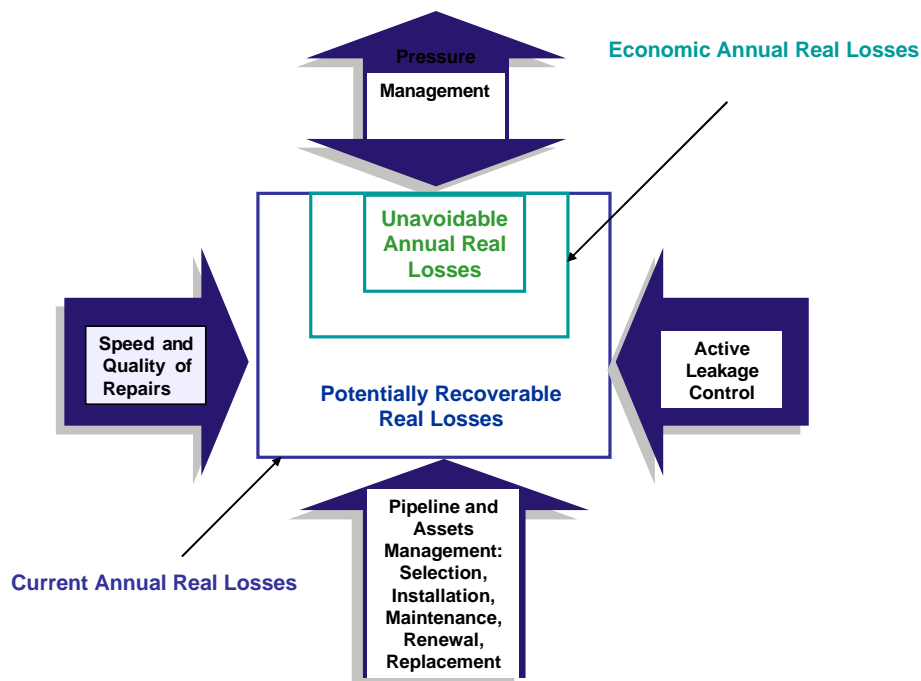
Figure 1: The Four Components Approach to Management of Real Losses

Pending the development of a simplified method for calculating economic leakage levels, Utilities such as Malta Water Services Corporation, and Halifax Regional Water Council (Canada) have adopted a practical approach. A series of 'best practice' initiatives within the 4 components that individually have high benefit: cost ratios, or short payback periods, have been identified and implemented. With this type of practical approach, when no further economically viable initiatives can be identified, it can be reasonably assumed that an economic leakage level - based on the above definition of ELL - has probably been achieved, whilst recognising that the economic leakage level will change with time.

Predicting and Calculating Economic Level of Real Losses

Component Analysis software models can be used for predicting and calculating Economic Leakage levels. For each relevant part of the infrastructure (e.g. mains, service connections) the following components of annual real losses volume need to be assessed, using appropriate average flow rates and average run-times:

- **'Background'** leakage (small non-visible, inaudible leaks, running continuously)
- **'Reported'** leaks and bursts (typically with high flow rates, but short run times)
- **'Unreported'** leaks (moderate flow rates, run times depend on Utility policies)

Component analysis calculations are significantly influenced by the effects of pressure on average leak flow rates, and on annual numbers of new leaks and bursts. It is normal practice to do the ELL calculations at current system pressure, and then consider the effects of changing system pressure.

ELL models developed for large systems in the UK assume that continuous night flows are available for highly sectorised networks. They usually also require data on the average number and types of reported and unreported leaks and bursts that occur, on average, each year, under 'steady state' conditions, when the number of new bursts occurring equals the number of bursts repaired. As most Utilities internationally undertake little or no active leakage control, this information is rarely available.

A simpler approach was therefore developed by Water Losses Task Force members (Lambert & Fantozzi, 2005) to encourage more Utilities to commence an active leakage control policy. This method uses a definition of economic intervention as follows:

'the frequency of intervention at which the marginal cost of active leakage control equals, on average, the variable cost of the leaking water'

If unreported leakage is rising at a rate RR, and the variable cost of the lost water is CV, then the minimum total cost of lost water and intervention costs occurs when the accumulated value of the lost water equals the cost of an intervention (CI).

Assuming a basic active leakage control policy of regular survey, the three parameters RR, CI and CV can be used to quickly assess, for any size of system or sub-system:
- the economic frequency of intervention to find unreported leaks
- the economic % of the system that should be inspected each year
- an appropriate annual budget for intervention costs (excluding repair costs)
- an economic annual volume of unreported real losses, corresponding to the economic intervention frequency.

It is hoped this relatively simple analysis option will encourage Utilities currently not doing active leakage control to commence (and gradually refine) an ongoing basic active leakage control policy, that is demonstrably economic for each particular local situation.

The remainder of this paper addresses:
- using the Economic Intervention approach
- incorporating the Economic Intervention approach into a simplified calculation of Short Run Economic Leakage Level (assuming current operating pressures)
- interactions between the cost and effectiveness of different intervention methods, and the background and undetected/unrepaired leaks remaining after intervention
- how pressure management can influence SRELL calculations

Using the Economic Intervention Approach

System Information Required

Examples shown use Canadian dollars ($C), but currency units cancel out in all Economic Intervention predictions except the annual budget. The basic information required is:
- Cost of an Intervention (CI): in $, or $/service connection, or $/km of mains (Note: this does not include the cost of repairing the unreported leaks found)
- Variable Cost of lost water CV : $/m^3
- Rate of Rise of unreported leakage RR (m^3/day, per year)

One of these parameters that may be unfamiliar to readers of this paper is the Rate of Rise. There are several methods of assessing RR, described in Appendix A; some (but not all) are based on night flow measurements. If night flows are used to assess RR, they should be taken at times of year when influences of irrigation and industrial use at night are minimal. Measured night flows should also be adjusted if operating pressures have changed, as some of the change in leakage rate may be due to changes in operating pressure. The following example is from an Italian system with no permanent flow metering facilities serving 900 service connections through 16 km of mains. Night flow measurements were made by insertion meter in Spring of 2002 and 2004.

- Night flow measured 14 Feb 2002 after intervention and leak repairs = 10.8 m^3/hr
- Night flow re-measured 10 April 2004 = 18.0 m^3/hr , at same pressure

- Increase in night flow = 18.0 – 10.8 = 7.2m^3/hr = 173 m^3/day approx.
- Average rate of rise RR = 173 m^3/day in 2.15 years = 80 m^3/day per year
  (or 89 litres/service conn./day/year, 5 m^3/km of mains /day/year)

Experience to date in several countries (UK, Italy, USA, and Australia) indicates a wide range of system-specific rates of rise of unreported leakage for different systems and sub-systems, ranging from:
- 0 to 200 litres/service connection/day per year
- 0 to 12 m^3/km of mains/day, per year

Equations used for calculations

If Intervention Cost CI is in \$, Variable Cost CV is in \$/m^3, and RR is in m^3/day, per year:

Economic Intervention Frequency EIF (months) = $\sqrt{(0.789 \times CI/(CV \times RR))}$ ....(1)
Economic Percentage of system to be surveyed annually EP (%) = 100 x 12/EIF ..(2)
Annual Budget for Intervention (excluding repair costs) ABI (\$) = EP% x CI ....(3)
Economic Unreported Real Losses EURL (m^3) = ABI/CV.. (4)

If RR is expressed 'per service connection' or 'per length of mains', any of these equations can be presented in user-friendly tabular or graphical format in any required units (e.g. Figures 2, 3, 4). The ratio CI/CV has an important influence on the calculation of EIF, EP and EAVURL, and CI x CV influences the Annual Intervention Budget (ABI).

Predicted economic intervention frequencies from Figure 2 - anywhere from 4 months up to six years or more - compared well with the following general experiences:
- Companies in England & Wales that are considered to be achieving economic leakage levels intervene from 3 times per year to every 3 years in individual districts
- German DVGW recommends intervention from once/year to once/6 years, depending upon leakage level
- AWWA M36 Manual implies that on average it is economic to intervene every 4 years

An example shown as a broken line in Figures 2, 3 and 4 is for an East Coast North American Utility with 300 km of mains and 18,000 service connections. The RR (assessed from leak detection in 50% of the system each year) is high, at 195 litres/connection/day/year, or 11.7 m3/km mains/day/year. If Intervention Cost CI for a basic sonic leak detection survey is \$C130/km mains, and water is valued at CV = 0.05 \$C/m3, the CI/CV ratio is 2600 m3/km, and CI x CV = 6.5 \$\$/m3/km. The conclusions from the graphs are:

- Figure 2: the economic intervention frequency is approximately every 13 months, or close to 100% of the system each year (not 50% as with the current policy)
- Figure 3: the economic unreported Real Losses will be around 2400 m^3/km/year, or 720,000 m^3/yr, 1970 m^3/day, 6.6 m^3/km mains/day, 109 litres/service connection/day .
- Figure 4: the Economic Intervention budget is around 120 \$/km/year, or \$36,000, or 1.2 \$ per service connection/year

As these parameters are calculated using 'square root' functions, they are not very sensitive to random errors in CI, CV and RR. This can be shown by using confidence limits in the ALCcalc software. Errors of +/-10% in CV, 5% in CI and 20% in RR in this example calculation produce confidence limits of +/- 15% in predicted Economic Intervention Frequency EIF, Economic Unreported Real Losses (EURL) and Annual Budget for Intervention (ABI).
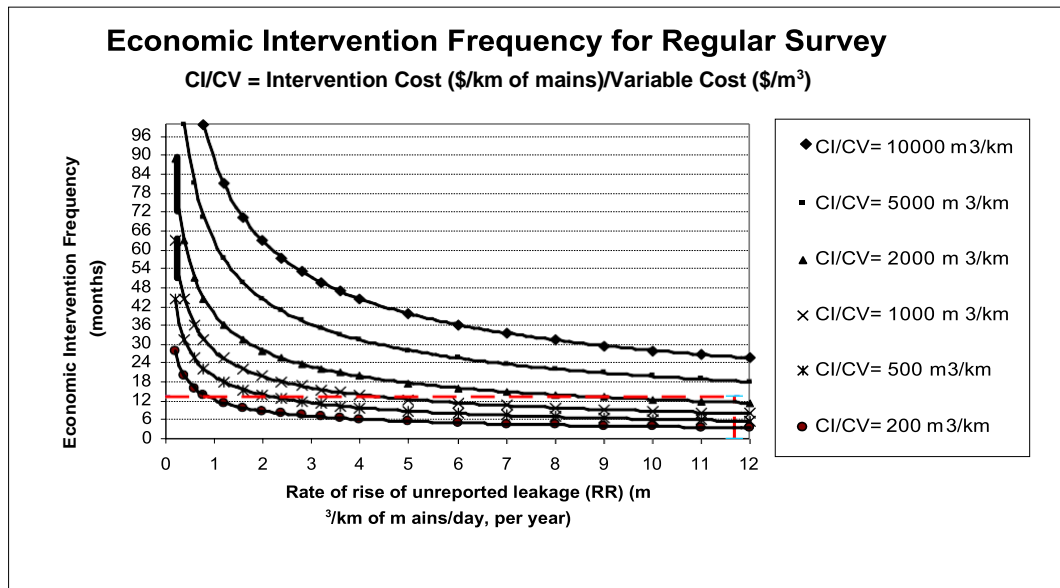
Economic Intervention Frequency for Regular Survey

CI/CV = Intervention Cost ($/km of mains)/Variable Cost ($/m³)

Figure 2: Predicting Economic Intervention Frequency for Regular Survey. Source: ALCcalc software

Economic Unreported Leakage, for Regular Survey

CI/CV = Intervention cost ($/km of mains)/ Variable cost of water ($/m³)

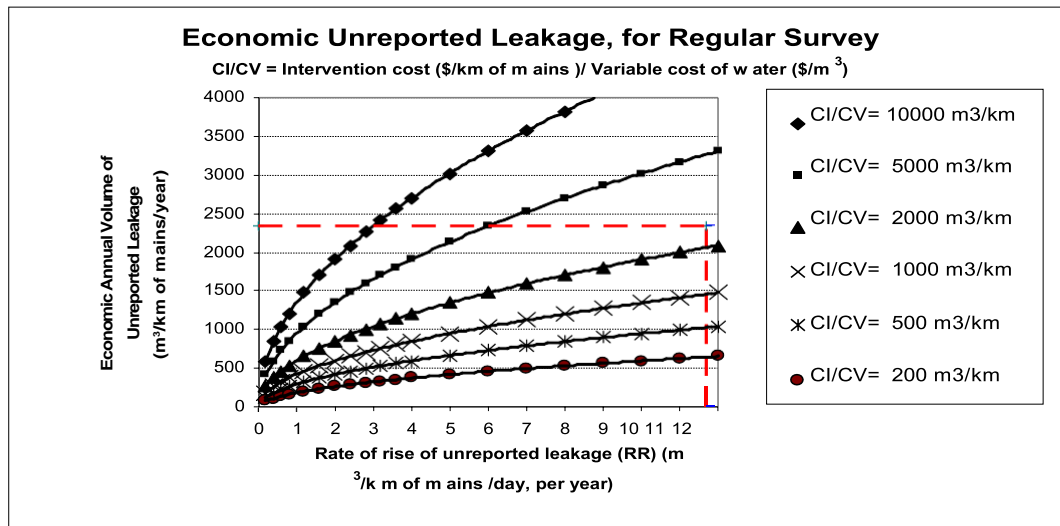Figure 3: Predicting Economic Annual Unreported Real Losses, for Regular Survey. Source: ALCcalc

Annual Budget for Economic Intervention, for Regular Survey

CI x CV = Intervention cost ($/km of mains) x Variable cost of water ($/m³)
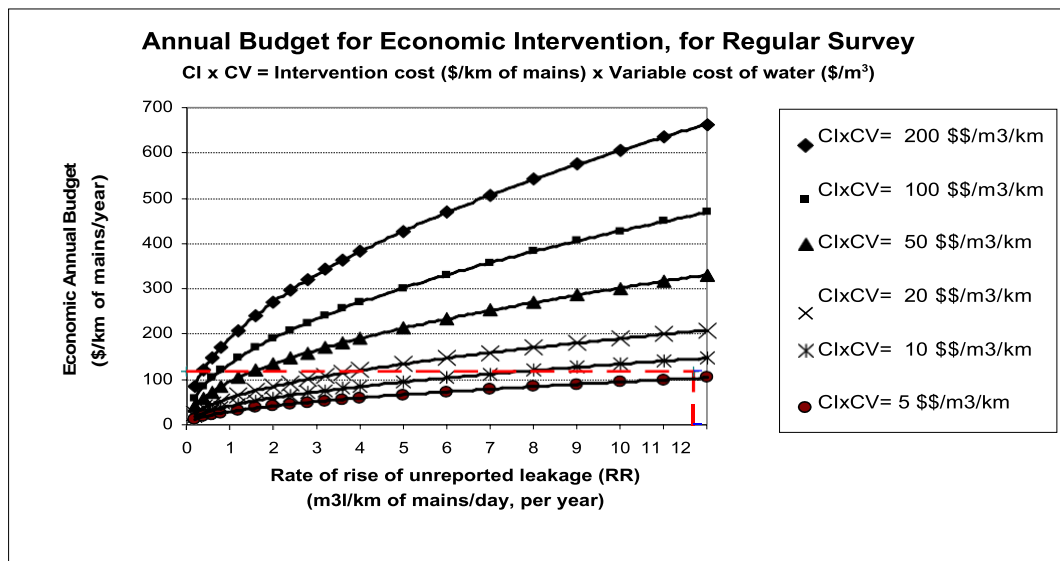

Figure 4: Predicting Annual Budget for Economic Intervention, Regular Survey. Source: ALCcalc

The authors hope that the simple approach outlined above will encourage readers from Utilities that do not currently practice active leakage control to carry out their own calculations, and implement an economic intervention policy appropriate to their circumstances. Utilities that are already intervening in some specified % of their system each year can now easily check if their frequencies and budgets are at an economic level.

Once an economic frequency of intervention and a budget has been set for a whole system, and interventions have commenced, data on the numbers and types of unreported leaks will become available for sub-systems (either districts or city blocks), allowing their individual RR to be assessed. Economic intervention frequency for each sub-system can then be separately defined, and the annual budget used more effectively.

A lot of additional useful information can be obtained from a more detailed analysis of detected unreported leaks. For example, if there is a high proportion of unreported mains bursts, the advantages of introducing sectorisation, with continuous or frequent night flow measurements can be assessed.

Economic Leakage Level Calculations using Economic Intervention

Concept

Economic Leakage Level (ELL) is usually assessed on a 'whole system' basis, but within a very large Utility, it should be assessed for each major sector (particularly where these are different pressure zones) and the results added to give the Utility total ELL.

The short-run economic leakage level (SRELL) is usually defined as the economic leakage level which should be attained at the current operating pressure, assuming:
- all reported leaks and bursts are repaired quickly and reliably
- an economic frequency of intervention to locate unreported leaks
- an appropriate assumption is made for background (undetectable) small leaks

The formula to calculate Unavoidable Annual Real Losses UARL (see Fig 1), the technical minimum, assumes that a well-managed system with infrastructure in good condition will have a specified frequency of mains bursts (13 /100 km/year, 95% reported) and service pipe bursts (3 per Utility side connection/year, 75% reported) and background leakage equal to Unavoidable Background Leakage (UBL), for infrastructure in good condition, assuming all unreported leaks are detected and repaired

In contrast, the calculated SRELL for current operating pressure is the sum of:
- actual numbers of reported bursts/year, with appropriate volume allowances/burst
- annual volume lost from unreported bursts with an economic intervention policy
- actual background leakage plus undetected/unrepaired leaks after interventions

Economic volume for reported leaks and bursts

This can be assessed by allocating a nominal volume allowance, per reported burst repaired, using an appropriately short run time multiplied by an appropriate average flow rate, adjusted for actual pressure. Calculations can include many different categories of reported bursts, but a simplified example using the volume allowances per reported burst from the UARL calculation (Lambert et al, 1999) is shown below. At 50 m pressure, these volume allowances are:
- Mains: 864 m^3 per event (36 m^3/hr for 1 day, or 12 m^3/hour for 3 days, etc)
- Services (Utility side): 307m^3 per event (1.6m^3/hr for 8 days, 0.8m^3/hr for 16 days, etc)

Table 1 shows the calculation of the volume lost through reported bursts in an Australian system. The UARL volume allowances per burst at 50m pressure have been adjusted to actual pressure assuming a linear relationship between leakage and pressure.

Table 1: Example calculation of annual volume lost through reported bursts

Key to cells >	Data entry			Calculated value	
System	Wide Bay Water, Australia	Average pressure (m.) =			65
Infrastructure Component	Length or number	Reported bursts	Volume per burst @ 50m	Volume per burst @ 65m	Loss/year from reported bursts
		Number	m³	m³	Thousand m³
Mains (km)	603	82	864	1123	92.1
Services	16000	333	307	399	132.9
Total		415			225.0
Loss/yr from reported bursts =		38.5	lit./conn/day	1.02	m³/km mains/day

Economic volume for unreported leaks and bursts

All parameters for Economic Intervention are quickly calculated from equations (1) to (4). For this system, RR = 0.020 m^3/conn/day/year or 320 m^3//day/year, CI = \$5.0/service connection or \$80,000, CV = \$0.12/m^3, so CI/CV = 5.0/0.12 = 41.7 m^3/service connection.

EIF (months) = $\sqrt{(0.789 \times CI/ (CV \times RR))}$ = $\sqrt{(0.789 \times 80000/(0.12 \times 320))}$ = **40.5 months**
Economic % of system to be surveyed annually EP (%) = 100 x 12/EIF = **29.6%**
Annual Budget for Intervention (excluding repair costs) ABI (\$) = EP% x CI = **\$23,680**
Economic Unreported Real Losses EURL (m^3) = ABI/CV = **197,300 m³/year**

EURL can also be directly assessed using an alternative form of equation (4)
EURL (m^3/service conn./year) = $(182.5 \times RR \times CI/CV)^{0.5}$ = $(182.5 \times 0.02 \times 41.7)^{0.5}$ = 12.33
EURL =12.33 m^3/service conn/yr = **197,300 m³/yr = 34 litres/conn/day, 0.90 m³/km/day**

Economic volume for background leakage

The first step is to calculate the Unavoidable Background Leakage, using the relevant UARL parameters in Lambert et al, 1999 – 20 litres/km mains/day and 1.25 litres/service connection/day at 50m pressure. These are then adjusted for actual average pressure using a FAVAD N1 exponent of 1.5. See Table 2 below

Table 2: Calculation of Unavoidable Background Leakage at current pressure

System	Wide Bay Water, Australia		Average pressure (m.) =			65
Infrastructure Component	Length or number	Unavoidable background leakage UBL				
		@ 50m pressure			@ 65 m	
		lit/km/hr	lit/conn/hr	m³/day	m³/day	Thousand m³/yr
Mains (km)	603	20.00		289	429	157
Services	16000		1.25	480	711	260
Total				769	1140	416
Unavoidable background leakage		71.3	lit./conn/day	1.89	m³/km mains/day	

An Unavoidable Background Leakage Multiplier (UBLM) is then used to adjust the calculated UBL to a value consistent with the leakage remaining immediately after a leak detection intervention & repairs/shutoffs. A UBLM higher than 1.0 can represent either:

- infrastructure which is not in as good condition as the IWA assumptions for unavoidable background leakage; or

- undetectable background leakage, together with some potentially detectable leaks which were not identified by the active leakage control method used (or not repaired for whatever reason).

The UBLM associated with the Australian system, which is sectorised with continuous night flow measurements, and leak detection using noise loggers, is 1.1. The SRELL calculations for this system, for a policy of regular survey, are summarised in Table 3 and Figure 5). The SRELL for this system corresponds to an Economic ILI of around 1.6.

Because Wide Bay Water has a sectorised system with continuous night flow measurements, it can identify, locate and repair unreported mains and larger service pipe bursts as soon as they occur, and thus achieve a lower SRELL (around 730 thousand m3/year, or ILI of 1.3) than would be the case for a more basic policy of regular survey.

Table 3: Summary of ELL calculations for Wide Bay Water, assuming regular survey

| System	Wide Bay Water, Australia			Average pressure (m.) =	65
Unavoidable background leakage multiplier UBLM =			1.1		
Infrastructure Component	Length or number	Real Losses from Reported	Background leakage		Economic Unreported	Short -run Economic
			Unavoidable	Additional		
		m^3/year	m^3/year	m^3/year	m^3/year	m^3/year
Mains (km)	603	92,100	157,000	15,700	197,300	881,000
Services	16000	132,900	260,000	26,000		
Total		225,000	417,000	41,700	197,300	881000
SRELL =	150.9	litres/service connection /day		4.00	m^3/km mains/day	
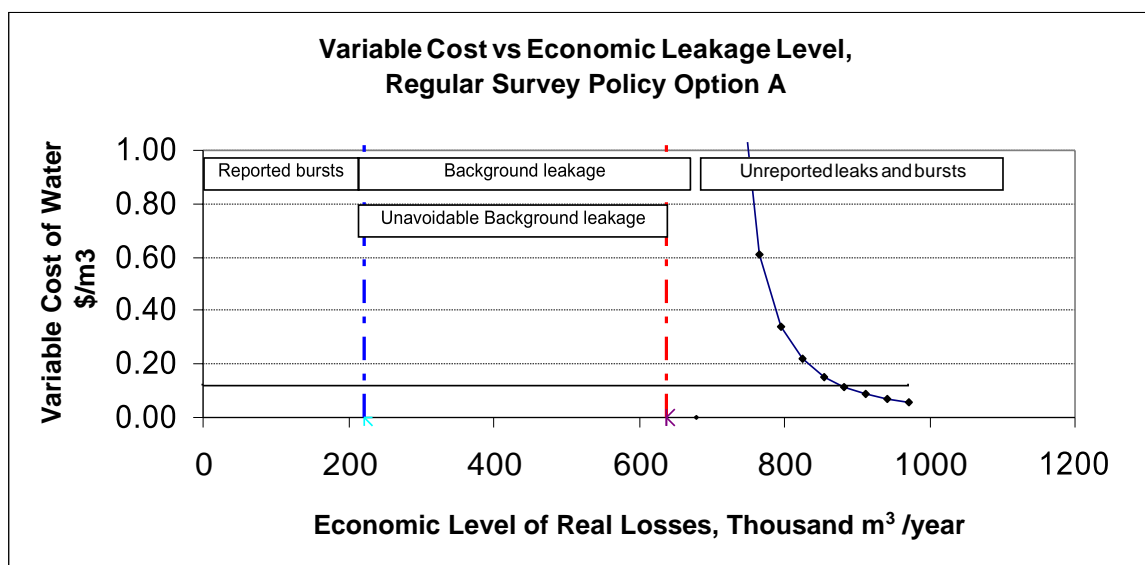
Figure 5: Components of SRELL for an Australian System, regular survey. Source: ELLcalc software

Interactions between the cost and efficiency of different intervention methods, and background and undetected/ unrepaired leaks remaining after intervention

Methods of intervention range from simple (listening on hydrants) to complex (noise loggers and night flow measurements), and have different costs. In general, the more expensive the method
- the higher the CI and CI/CV ratio, leading to less frequent intervention and higher Economic Unreported Real Losses

- the higher the efficiency of detection, and the lower the UBLM (if all detected unreported leaks are repaired)

In practice, Utilities and their contractors often try to estimate the balance point between the cost and efficiency of the method of intervention, and the potentially detectable leaks that remain unlocated or unrepaired after the intervention. Different options (A, B, C etc) can be quite easily modelled and assessed using specialist software such as ELLcalc, with confidence limits, to assess the optimal strategy, and presented in user-friendly formats such as Figure 5.

How Pressure Management can influence SRELL Calculations

In England and Wales, many thousands of cost-effective pressure management schemes have already been implemented, and all detected leaks and bursts (however small) are promptly repaired. This is because mandatory economic leakage targets are agreed and monitored by the Water Companies' economic regulator, OFWAT. So in England & Wales, it tends to be automatically assumed that active leakage control is the only one of the 4 components (Figure 1) that should be used to assess Short-run ELL. .

However, in most situations outside England and Wales, little or no pro-active pressure management has been done, and not all reported and detected leaks are repaired; failure to repair service connection leaks appears to be a common problem. Utilities reporting high ILIs can often achieve large reductions in real losses by simply repairing, and limiting the run-time, of all reported leaks. Simple pressure management can significantly reduce flow rates from existing leaks, and new burst frequencies, creating spare capacity in repair gangs leading to reduced run-times, etc.

Accordingly, in the International context, the authors consider that SRELL calculations cannot simply be limited to the investigation of alternative active leakage control options. Software models can be used to predict the effect of pressure management on leak flow rates and new burst frequency, and to identify if a Utility contemplating introduction or refinement of active leakage control should implement basic pressure management either before, or in parallel with, an economic intervention policy.

Acknowledgements

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APPENDIX A: Methods of Assessing Rate of Rise of Unreported Leakage

Note: an approximate assessment of Rate of Rise is acceptable to get started on Economic Intervention calculations – predictions can easily be refined once some initial data on numbers and flow rates of unreported leaks and bursts has been obtained.

The following examples outline some of the methods used in the ALCcalc software.

Method 1: Compare Real Losses from Water Balances several years apart

- Method could be used for systems without night flow measurements, where there has been no active leakage control in the period between the Annual Water Balances
- Calculate the annual volume of Real Losses in year 1 (= RL_1)
- Calculate the annual volume of Real Losses 'N' years previously (=RL_N)
- If number of service connections or average pressure has changed , adjust Real Losses in year 'N' to number of connections and pressure in Year 1 (=RL_N')
- Rate of Rise RR = (RL_1 - RL_N')/N

Method 2A: Using data from a single intervention for all or part of the system

- Method could be used for systems without night flow measurements, where there has been a single active leakage control intervention in all or part of the system,
- Classify the leaks detected by typical average flow rate (e.g. Class A, Class B, Class C) and which part of the infrastructure they occurred on (Mains, Hydrants, service connections Utility side, service connection customer side).
- Estimate the aggregate flow of all of the leaks found
- Estimate a number of years over which they may have accumulated
- Divide to get the average annual rate of rise
- Express the annual rate of rise 'per service connection' or 'per km mains' for the part of the system surveyed, and assume this applies to the whole system

Method 2b: Using data for Systems/Sub-Systems with successive 100% Interventions

- Method could be used for systems without night flow measurements, where there have been two or more interventions with a known time interval in between
- Classify the leaks detected by typical average flow rate (e.g. Class A, Class B, Class C) as in Method 2a.
- Estimate the aggregate flow of all of the leaks found, and divide by the time period between the interventions to get Rate of Rise
- When applied to individual City Blocks or Districts within a large system, RR can be used to predict when to intervene next in each particular Block or District

Method 3: Using Measured Night Flows

- Method can be used for small and medium sized systems within a single pressure zone. Night flow measurement facilities need not be continuous or permanent
- Measure the flow over several nights at times of year when exceptional night use (irrigation, industrial) are minimal or absent, or can be identified.
- Adjust the measured flow rates for any changes in pressure, or other influences
- Calculate the Rate of Rise in m^3/hour/year from the difference in adjusted night flows, divided by the time period. Multiply by a suitable Night-Day Factor NDF (to allow for diurnal variation of leak rate with pressure (use NDF = 24 hrs/day as default)