Calculating SRELL with Pressure Management, Active Leakage Control and Leak Run-Time Options, with confidence limits

P. Fanner, Veritec USA, 980 9th Street, Suite 1600, Sacramento, CA 95814, USA. paul@veritec-us.com. A.O. Lambert, ILMSS Ltd, 3 Hillview Close, Hillview Road, Llanrhos, Llandudno, LL30 1SL United Kingdom. Allan.Lambert@Leakssuite.com

Keywords: Real Losses; Economic Leakage Level; Pressure Management

Abstract
Development of quick and practical methods for calculating economic leakage levels in international situations has been a stated objective of the IWA Water Losses Task Force since 2001.

Data-intensive UK methods for economic intervention frequency based on night flow measurements cannot be applied where District Metered Areas do not exist, or in systems with large seasonal variations in night use. A simpler methodology for assessing economic intervention frequency for a ‘regular survey’ policy (Lambert & Lalonde, 2005) showed that the economic annual volume of real losses from unreported bursts can be calculated from 3 readily identified parameters - Rate of Rise of unreported leakage, Variable Cost of Water and Intervention Cost..

Pressure influences leak flow rates, frequency and costs of repairs, and economic intervention frequency, and therefore Short Run ELL. Using recent outputs of the Water Loss Task Force Pressure Management Group, Fantozzi & Lambert (2007) showed that attempts to calculate SRELL without taking basic pressure management options into account cannot be considered as meaningful.

Calculations and predictions of Real Losses are always subject to some degree of error. This paper describes how predictions of SRELL, with pressure management options, can be calculated using a specially designed software (ELLCalcs V2a, 2008).

Introduction
This paper is one of a series (by Water Loss Task Force members) which have sought to develop and refine practical international methods for predicting Short Run Economic Leakage Levels (SRELLs) for water distribution systems.

The calculation of Economic Leakage Levels can be said to have commenced in earnest in the United Kingdom, during 1994 to 1999. However, various methods used there were in practice mostly concerned with evaluating economic frequencies of active leakage control intervention, and required large amounts of company specific night flow data from District Metered Areas. The methods took no account of any possible additional benefits from pressure management, which was already widespread in the UK, and so implicitly assumed to have been implemented already.

The development of quick and practical methods for calculating economic leakage levels in international situations has been a stated objective of the Water Loss Task Force since 2001. But there have been several barriers to achieving this objective.

The first barrier was that the data-intensive methods developed in the UK for economic intervention frequency could not readily be applied where DMA’s did not exist, or where there was major seasonal variations in night use. So it was necessary to develop a simpler methodology to assess the economic intervention frequency for active leakage control, and the corresponding annual volume of real losses from unreported bursts. This was achieved, for a policy of regular survey, using similar basic economic principles as in the UK, but with only three system-specific parameters: Cost of Intervention (CI), Variable Cost of Lost Water (CV), and Rate of Rise of Unreported Leakage (RR). The methodology was first presented by Fantozzi & Lambert (2005), then in a more user-friendly format at the Leakage 2005 Conference (Lambert & Lalonde, 2005).

The second barrier was the absence of a methodology allowing for the influences of pressure management on Short Run ELL. Changes in leak flow rates could be modelled using FAVAD concepts, but no method existed for predicting changes in burst frequencies on mains and services, and associated cost savings. This deficiency has been remedied through recent developments by the Pressure Management Group (Thornton & Lambert, 2006; Thornton & Lambert 2007).

Using the prediction methods developed by the Pressure Management Group, Fantozzi & Lambert (2007) presented to the WaterLoss 2007 Conference a worked example, in which the predictions of SRELL (starting from a known baseline in 2001) compared well with the actual achievements of an Australian Utility in which both active leakage control and pressure management had been implemented. This example demonstrated that attempts to calculate SRELL without taking a basic pressure management option into account cannot be considered as being meaningful – the many influences of pressure on all components of leakage, and on costs of repairs and economic active leakage control, are simply too substantial to be ignored.

A specialist software developed to include pressure management options (ELLCalcs V1a, 2006), was used in North America as part of a recent AWWARF study (Fanner et al, 2007); this was recognised as being the most advanced software for international SRELL calculations, but it did not include confidence limits.

Confidence limits are important, because calculations and predictions of Real Losses are always subject to error, to a greater or lesser degree. Software programs for calculations of Current Annual Real Losses from annual water balances now usually include confidence limits. For systems where the Infrastructure Leakage Index is close to 1.0, calculated volumes of Current Annual Real Losses are rarely reliable to better than +/- 25%, even if Water Supplied and Metered Consumption during the Water Year are each measured to within +/- 2% with no systematic errors.

Predictions and calculations of Short-Run Economic Leakage Levels are also subject to uncertainty. Accordingly, an update of the specialist software ELLCalcs Version 2A (2008) now also incorporates confidence limits in the SRELL calculations, together with the facility to interactively modify key parameters (run times of reported leaks and bursts, Infrastructure Condition Factor etc) and observe the effect on each particular component of the SRELL. The software has been designed so that, once the 'current situation' and several key parameters have been defined, and the SRELL at current pressure for a reference year calculated, the SRELL at alternative pressures can be calculated simply by entering new average and maximum pressures. The paper will explain how the SRELL can be calculated using the software, on a step-by-step basis.

The methodology and current software has recently been used to predict the SRELL for Saskatoon (Canada) as part of a NRW reduction program and is also being used in a similar project in another large Canadian City.

Economic Intervention and the Influence of Pressure on SRELL

Before showing the ELLCalcs V2a software calculations, a brief reminder is provided of the principle of Economic Intervention, and the Influences of Pressure Management on Components of Real Losses

Economic Intervention

If unreported leakage is rising at a rate RR, then the minimum total cost of lost water and intervention costs occurs when the accumulated value of the lost water (the volume in the red triangle in Figure 1, multiplied by the variable cost of water CV) equals the cost of an intervention (CI).

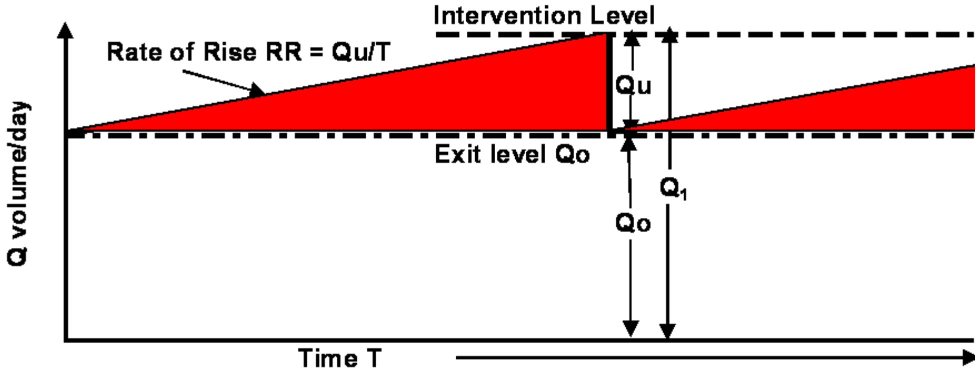


Figure 1 Economic Intervention for an Active Leakage Control Policy of Regular Survey

If the Intervention Cost CI is in \$, the Variable Cost CV is in \$/m^3, and Rate of Rise RR is in m^3/day, per year, it can be shown that:

Economic Intervention Frequency EIF (months) = √(0.789 x CI/(CV x RR))
Economic % of system to be surveyed annually EP = 100 x 12/EIF
Annual Intervention Budget (excluding repair costs) ABI (\$) = EP% x CI
Economic Annual Unreported Real Losses EURL (m^3/yr) = ABI/CV

As these equations include square root functions, confidence limits for calculating each of the above parameters are relatively insensitive to errors in RR, CI and CV.

Influences of Pressure Management on Components of Real Losses

Figure 2 shows how pressure management can influence the components of SRELL (calculated using BABE Component Analysis).

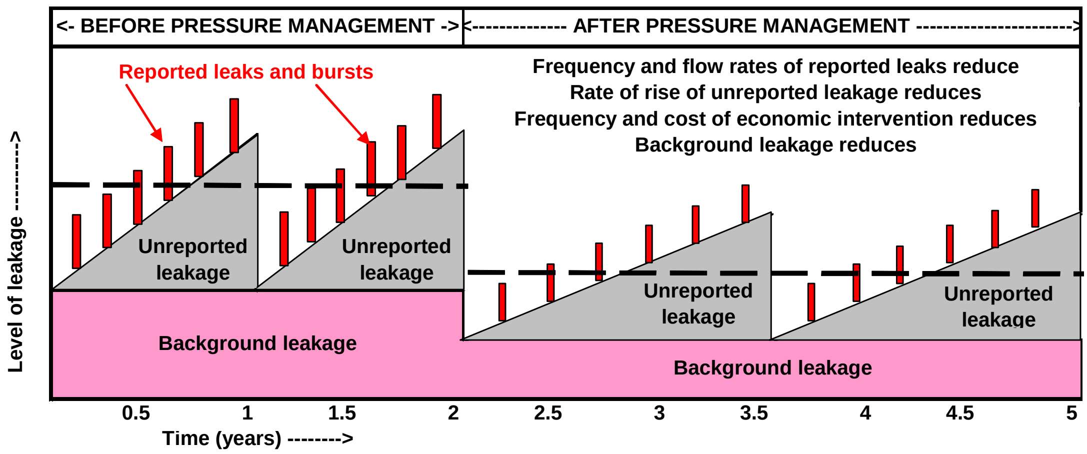


Figure 2: Influence of pressure management on simplified BABE components of SRELL

Background (undetectable) leakage from small hidden leaks runs continuously. Unreported leakage gradually accumulates, at an average rate of rise RR, and economic intervention occurs when the accumulated value of the ‘triangle’ of unreported leakage equals the cost of the intervention. The process then repeats itself. Reported leaks and bursts (generally high flow rates but short duration) are superimposed on the other two components. The SRELL (shown as a dashed line) is the annual average of all three components. The situation before pressure management is shown on the left hand side of Figure 2.

After pressure management, if excess pressures and surges are reduced:

- the background leakage (which is very sensitive to pressure, N1 = 1.5) reduces
- the rate of rise of unreported leakage also reduces
- the frequency and flow rates of reported leaks and bursts may be reduced
- the SRELL reduces to the lower dashed line

SRELL Calculations using ELLCalcsV2a

The ELLCalcs V2a Professional software is an Excel Workbook with 19 Worksheets. Because of limitations of space, only the two principal calculation Worksheets will be briefly described in this paper:

- ***‘CARL at Current Pressure***’ is used to calculate components of SRELL at current average pressure, for comparison with Current Annual Real Losses for a Reference Year (from an annual water balance), with confidence limits.
- ***‘Summary of Options***’ is used to calculate components of SRELL at alternative average and maximum pressures, with confidence limits

Colour Coding of Cells are as follows

Essential data entry	Data entry	Variable Defaults	Fixed Defaults	Key Calculated Values	Calculated values	Data from another Worksheet

‘CARL at Current Pressure’ Worksheet

In Part 1 of this Worksheet, the System Data for the Reference Year are entered. Guideline Favad N1 exponents for pressure:leak flow calculations are presented, based on % of rigid pipes, but the user can select alternative values. Components of Variable Cost CV (or a total CV) are entered, with confidence limits.

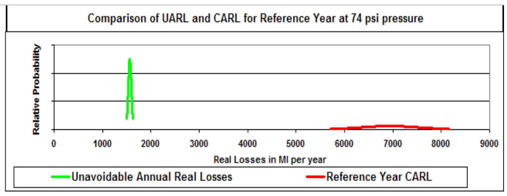
PART 1: SYSTEM DATA FOR REFERENCE YEAR AT CURRENT PRESSURES							
System	Saskatoon		95% Conf. Limits +/-	% of Rigid Pipes	FAVAD N1 for detectable leaks		95% Conf. Limits +/-
Connection density	58.6	per km of mains			Guideline N1	Selected N1	
Hydrants	Number	5875	1.0%	100%	0.50	0.50	17%
Mains	km	1041	1.0%	75%	0.75	0.75	25%
Services, main to curb stop	Number	60988	1.0%	65%	0.85	0.85	28%
Services, curb stop to meter	km	549	15.0%	65%	0.85	0.85	28%
Average System Pressure in Reference Year in					psi =	74.0	10.0%
Maximum Pressure at AZP in Reference Year in					psi =	80.0	10.0%
Components of Variable Cost of Real Losses in					$C/m3	Total Variable Cost	95% conf limits +/-%
Bulk Imports	Power	Chemicals	Other:	From 2006 Audit			
0.000	0.000	0.000	0.123			0.123	1.0%

In Part 2, the annual numbers of breaks and leaks in the Reference Year (reported and unreported), the typical cost of repairs, and the assumed typical flow rates at 71 psi (50 metres) pressure are entered.

PART 2: ANNUAL NUMBERS OF BREAKS & LEAKS REPAIRED, AND REPAIR COSTS, IN REFERENCE YEAR, at 74 psi PRESSURE; and TYPICAL AVERAGE FLOW RATES at 71 psi pressure							
Annual numbers of Breaks and Leaks				Cost of repairs		Assumed typical flow rate at 71 psi	
Infrastructure Component	Reported	Unreported	Total	$C/repair	k$C/yr	Reported m3/hr	Unreported m3/hr
Valves & Hydrants	44	0	44	1000	44	1.6	0.8
Mains	228	0	228	3000	684	40.0	10.0
Services, main to curb stop	177	0	177	1500	266	1.6	1.6
Services, curb stop to meter	0	0	0	100	0	1.6	1.6
TOTALS --->	449	0	449		994		

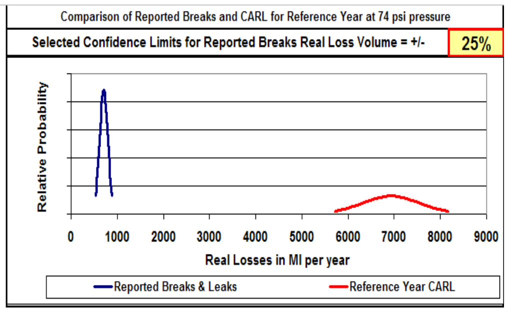
In Part 3, the Current Annual Real Losses (CARL) for the Reference Year, calculated from an annual water balance (with confidence limits), are entered. The Unavoidable Annual Real Losses (UARL) is calculated and confidence limits entered. The Infrastructure Leakage Index (ILI) is calculated, with confidence limits. The adjacent graph compares the UARL with the CARL for the Reference Year

PART 3: CARL and UARL for REFERENCE YEAR at 74 psi pressure					
Yellow data entry cells E33, E34, H33 and H34 should use data transferred from a PIFastCalcs Water Balance	Litres/ conn/ day	Ml/ yr	Variable Cost $C/m3	k$C/yr	95% Conf. Limits +/-
Current Annual Real Losses CARL	312	6937	0.123	853	17.6%
Unavoidable Annual Real Losses UARL	70	1563	0.123	192	4.0%
Infrastructure Leakage Index ILI =				4.4	18.0%



In Part 4, average run times for each type of reported break and leak are entered. The adjacent graph compares the resulting real losses from reported bursts with the Current Annual Real Losses. This method of presentation of data and adjacent graph allows the sensitivity of changing average run times for reported leaks and bursts to be calculated and demonstrated immediately in a user-friendly manner.

PART 4: Estimate REAL LOSSES from REPORTED BREAKS and LEAKS at 74 psi pressure							
	Average run time					Volume lost/year, valued at Variable Cost of 0.123 $C/m3	
Infrastructure Component	UARL Guideline	Selected for SRELL	Number per year	Typical flow rate m3/hr	Volume per event		
	Days	Days		at 74 psi	Ml	Ml/ yr	k$C/yr
Valves & Hydrants		104.0	44	1.63	4.08	179	22
Mains	3.0	1.3	228	41.3	1.29	294	36
Services, main to curb stop	8.0	33.4	177	1.66	1.33	235	29
Services, curb stop to meter	9.0	52.0	0	1.66	2.07	0	0
Note: Typical flow rate uses 'reported' flow rates (Part 2) & N1s (Part 1)						708	87



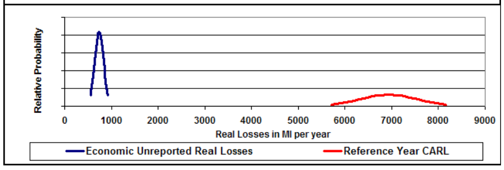
In Part 5, the economic volume of unreported real losses, for an active leakage control policy of regular survey, are calculated. Rate of Rise is entered in Part 5B. If there is already a 'steady state' policy for active leakage control, a guideline rate of rise calculated from the unreported bursts data in Part 2 is calculated. Or, the Rate of Rise can be assessed from 3 other Worksheets (ERR1, ERR2, ERR3) in the software. Or a Rate of Rise appropriate to one of the Categories shown (Very Low, to Very High) can be entered.

The cost of an Active Leakage Control Intervention is then entered in Part 5C, and the Economic Intervention parameters calculated in Part 5D. The adjacent upper graph compares the resulting real losses for unreported bursts (with economic intervention) with the CARL for the Reference Year. The lower graph compares the sum of reported and economic unreported real losses with the Reference Year

CARL. This method of presentation of data and adjacent graphs allows the sensitivity of Rate of Rise and Cost of Intervention to be both calculated and demonstrated immediately in a user-friendly manner.

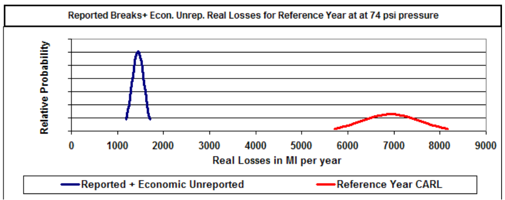
PART 5: Estimate ECONOMIC VOLUME OF UNREPORTED LEAKAGE at 74 psi pressure							
5A: Variable Cost of Real Losses =		0.123	$C/m3	95% Conf Limits = +/-			1.0%
5B: Specify Rate of Rise of Unreported Leakage in Reference Year at 74 psi pressure							
Category		Very Low	Low	Moderate	High	Very High	95% conf limits +/-%
litres/conn/day/yr		< 20	20 to 40	40 to 80	80 to 160	> 160	
Guideline RR using actual unrep. breaks =	0	litres/conn/day/yr	Selected Rate of Rise =	40	litres/conn/day/yr		50.0%
				2440	m3/day/year		
Note: Guideline Rate of Rise is calculated using numbers of unreported breaks and typical flow rates for unreported bursts in Part 2, together with FAVAD N1 values selected in Part 1.							

Economic Unreported Real Losses & CARL for Ref. Year at at 74 psi pressure



5C: Cost of an Active Leakage Control intervention in $C	151007	$C/service conn =	2.48	5.0%	
		$C/km of mains =	145		
5D: ECONOMIC INTERVENTION PARAMETERS, REGULAR SURVEY				95% conf limits +/-	95% conf limits +/-%
Economic Intervention Frequency is every	19.9	months		5	25%
Economic % of system to be checked annually	60%			15%	25%
Economic Volume of Unreported Real Losses	739	Ml/ yr		186	25%
Annual budget for ALC Interventions	91	k$C/yr		23	25%
Value of Annual Unreported Real Losses =	91	k$C/yr		23	25%

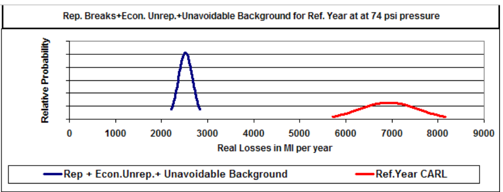
Reported Breaks+ Econ. Unrep. Real Losses for Reference Year at at 74 psi pressure



In Part 6, the Unavoidable Background Leakage UBL is calculated from data previously entered, and compared with the Reference Year CARL.

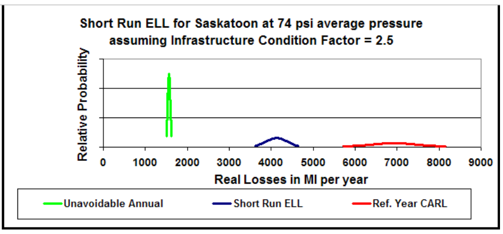
PART 6: UNAVOIDABLE BACKGROUND LEAKAGE UBL AT at 74 psi AVERAGE PRESSURE							
FAVAD N1 FOR BACKGROUND LEAKAGE =				1.5	Ml/ yr	k$C/yr	95% conf limits +/-%
Mains and hydrant leads	1041	kms at	20	lit/km/hr	194	24	15.0%
Services, main to curb stop	60988	service conns at	1.25	l/conn/hr	711	87	15.0%
Services, curb stop to meter	549	kms at	33	lit/km/hr	169	21	21.2%
				TOTALS->	1074	132	15.2%

Rep. Breaks+Econ. Unrep.+Unavoidable Background for Ref. Year at at 74 psi pressure



In Part 7, the Infrastructure Condition Factor ICF – the multiplier for UBL- is entered, and in the adjacent graph, the SRELL, being the sum of all the SRELL components now calculated, is compared with the Reference Year CARL and UARL. It will generally be found that SRELL calculations are particularly sensitive to the ICF parameter. The authors, working with Water Loss Task Force colleagues (Thornton et al, 2009) have developed several methods for assessing ICF, which will appear in the 3rd Edition of the M36 Manual 'Water Audits and Loss Control Programs' (AWWA, 2009).

PART 7: SELECT AN APPROPRIATE INFRASTRUCTURE CONDITION FACTOR (ICF)						
Background leakage may be higher than the Unavoidable Background Leakage (UBL) if the infrastructure is not in good condition, or not all detectable leaks are found and repaired.						
This can be allowed for by multiplying the UBL by an Infrastructure Condition Factor (ICF) Methods of estimating ICF are outlined on the 'Infrastructure Condition Factor' Worksheet.						
Selected ICF =	2.5	95% conf limits +/- %	25%	Ml/ yr	k$C/yr	95% conf limits +/-%
Unavoidable Background Leakage UBL =				1074	132	15%
Additional background leakage if Selected ICF =			2.5	1610	198	25%
Total of Unavoidable and Additional Background Leakage =				2684	330	16%



In Parts 8A and 8B, the Current Annual Real Losses and Costs are summarised and compared for the Reference Year, and for the SRELL using the same average and maximum pressures as in the Reference Year. This shows the SRELL if no pressure management is included in the SRELL calculations.

PART 8A: CURRENT ANNUAL REAL LOSSES AND COSTS FOR REFERENCE YEAR at current average pressure of 74 psi and maximum pressure of 80 psi							
Real Losses Performance Indicators and Volumes					Variable Cost	Sub-total	Total
Current Annual Real Losses	Litres/ conn/ day	ILI	Ml/ year	95% CLs +/-%	$C/m3	k$C/yr	k$C/yr
	312	4.4	6937	17.6%	0.123	853	853
Current Annual Budget for Active Leakage Control Interventions, excluding repair costs =						0	0
Annual Cost of Repairs actually carried out in Reference Year			Reported k$C /yr	Unreported k$C /yr	Sub-total k$C/yr		
Note: number of unreported breaks repaired may not be typical of average number for SRELL	Valves and Hydrants		44	0	44		994
	Mains		684	0	684		
	Services, Main to Curb Stop		266	0	266		
	Services, Curb Stop to meter		0	0	0		
Summary: Real Losses Ml /yr =			6937		Sum of Costs k$C/yr =		1847

PART 8B: INITIAL PREDICTION OF SRELL AND COSTS FOR REFERENCE YEAR at current average pressure of 74 psi and maximum pressure of 80 psi							
Real Losses Performance Indicators and Volumes					Variable Cost	Sub-total	Total
Volume and value of annual SRELL	Litres/ conn/ day	ILI	Ml/ year	95% CLs	$C/m3	k$C/yr	k$C/yr
	186	2.6	4131	12.2%	0.123	508	508
Annual Budget for Economic ALC Interventions, excluding repair costs =						91	91
Annual Cost of Repairs actually carried out in Reference Year			Rep k$C/yr	Unrep k$C/yr	Sub-total k$C/yr		
Note: number of unreported breaks repaired may not be typical of average number for SRELL	Valves and Hydrants		44	0	44		994
	Mains		684	0	684		
	Services, Main to Curb Stop		266	0	266		
	Services, Curb Stop to meter		0	0	0		
Summary: Real Losses Ml /yr =			4131		Sum of Costs k$C/yr =		1593

In Part 9, the final step in this Worksheet, the frequencies of breaks and leaks entered in Part 2 (Fbo) is compared with the reference values in the UARL formula (Fbu), and the ratio Fbo/Fbu calculated. This ratio can be used to predict if the burst frequency of each of the components of infrastructure will be sensitive to pressure reduction, or not. Guidance is given on another Worksheet (Pr&BEstimates)

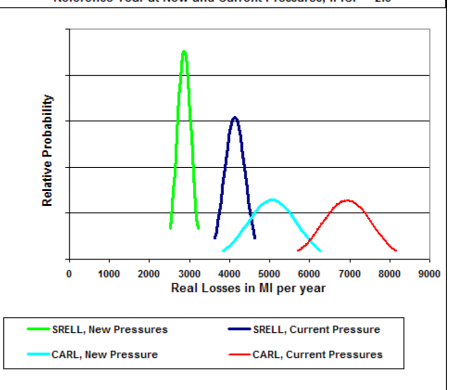
PART 9: COMPARE REFERENCE YEAR BREAK FREQUENCIES (Fbo, adjusted for numbers of unreported breaks) with those used in UNAVOIDABLE ANNUAL REAL LOSSES (UARL) CALCULATION for well maintained infrastructure in good condition. THEN ASSIGN APPROXIMATE CATEGORIES FOR RATIO Fbo/Fbu.					
Infrastructure Component	Frequency of Breaks and Leaks				Assign an approximate Category for Fbo/Fbu based on Repairs in Ref. Year
	Units	Ref. Year Fbo	UARL formula Fbu	Fbo/ Fbu	Options: Very Low, Low, Average, High or Very High
Mains	/100 km/yr	22.1	13.0	1.7	Average
Services, main to curb stop	/1000/year	3.3	3.0	1.1	Low
Services, curb stop to meter	/100 km/yr	3.2	13.0	0.2	Very Low

‘Summary of Options’ Worksheet

On this Worksheet, all that is required is to enter new average and maximum pressures in Part A of this Worksheet, and the predictions of CARL and SRELL for the Reference Year at current pressure can be immediately compared with the predictions of CARL and SRELL for the Reference Year at the new pressure.

PART A: COMPARISON OF PREDICTED VOLUMES OF COMPONENTS OF REAL LOSSES									
Real Losses Management Policy >>>>>>>		Current Annual Real Losses CARL at Current Pressures		New Pressures with no change in current ALC policy		SRELL at Current Pressures		SRELL at New Pressures	
Pressures in	psi	Ave	Max	Ave	Max	Ave	Max	Ave	Max
		74.0	80.0	55.0	70.0	74.0	80.0	55.0	70.0
Real Loss Components		Ml /year		Ml /year		Ml /year		Ml /year	
Reported Breaks & Leaks		708		515		708		515	
Unavoidable Background Leakage		1074		688		1074		688	
Additional Background Leakage if ICF =2.5		1610		1032		1610		1032	
Economic Volume of Unreported Real Losses		739		2829		739		628	
Excess Real Losses component of CARL		2806				0		0	
Volume of Real Losses		6937		5064		4131		2863	
95% Confidence Limits +/-%		17.6%		24.0%		12.2%		12.0%	
Performance Indicators	litres/conn/day	312		228		186		129	
	ILI	4.4		4.4		2.6		2.5	

Predicted SRELL at New and Current Pressures, compared to CARL in Reference Year at New and Current Pressures, if ICF = 2.5



Conclusions:

- calculation of economic leakage levels in international situations has been a stated objective of the IWA Water Losses Task Force since 2001
- but data-intensive methods developed in the United Kingdom for District Metered Areas with continuous night flow measurements cannot be applied where DMA's do not exist, or where there are major seasonal variations in night use
- attempts to calculate Short Run Economic Level of Leakage (SRELL) without taking basic pressure management options into account cannot be considered as being meaningful, as pressure influences so many components of SRELL
- research and development by Task Force members into a simple approach to Economic Intervention, and improved understanding of pressure:leak flow and pressure: bursts relationships, has enabled an international methodology for assessing SRELL to be developed
- Version 2a of the ELLCalcs software now allows these calculations to be done in a user-friendly systematic step-by-step approach, with sensitivity testing and confidence limits
- ELLCalcs is also available in US units, with pressure in p.s.i.; and in international versions (Europe, Australia, …) with metric units and pressure in metres

Acknowledgements:

To the many Water Loss Task Force colleagues who have contributed to the progress achieved since 2001; with special mention of Marco Fantozzi, Alain Lalonde, David Pearson, Julian Thornton and Stuart Trow.

References

Fantozzi M and Lambert A (2005) Recent advances in calculating Economic Intervention Frequency for Active Leakage Control, and implications for calculation of Economic Leakage Levels. Proceedings of IWA International Conference on Water Economics, Statistics and Finance, Crete, July 2005; and Wat. Sci. Tech. Water Supply Journal Vol. 5, No 6, 263-271

Lambert A and Lalonde A (2005**).** Using practical predictions of Economic Intervention Frequency to calculate Short-run Economic Leakage Level, with or without Pressure Management. Proceedings of IWA Specialised Conference 'Leakage 2005', Halifax, Nova Scotia, Canada

Thornton J and Lambert A (2006): Managing pressures to reduce new break frequencies, and improve infrastructure management. Water 21, December 2006.

Fantozzi M and Lambert A.(2007). Including the effects of pressure management in calculations of Short-Run Economic Leakage Levels. Proceedings of IWA Specialist Conference 'Water Loss 2007'', Bucharest, Romania, 23-27 September 2007.

Thornton J and Lambert A (2007). Pressure management extends infrastructure life and reduces unnecessary energy costs. Proceedings of IWA Special Conference 'Water Loss 2007', Bucharest, Romania, 23-27 September 2007.

Fanner P., Sturm R., Thornton J, Liemberger R (2007): Leakage Management Technologies, AWWARF project report.

ELLCalcs Version 2a (2008). Software for calculation of Short Run Economic Leakage Level. ILMSS Ltd, UK. www.LeaksSuite.com

Thornton J, Sturm R, Kunkel G: Water Loss Control, 2nd Edition July 2008 McGraw Hill New York ISBN 978-0-07-149918-7.

Water Audits and Loss Control Programs (2009). 3rd Edition of M36 Manual, American Water Works Association (in Press).