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Economic Level of Leakage (ELL) calculation with limited data: an application in Zaragoza

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The Economic Level of Leakage is a systematic way for a water utility to estimate the optimum leakage level below which the costs of reducing leakage further exceed the benefits of saving water.

This is applied in the city of Zaragoza in Spain, with initial estimates of ELL calculated using the Bursts and Background Estimates (BABE) approach with data from water supply records and measurements in a study area, together with empirical relationships from the literature. The analysis shows considerable scope for water loss recovery using active leakage control. The same approach could be used in other cities with limited data, to assess the potential benefits from water loss management.

The concept of Economic Level of Leakage

Leakage control can be expensive, and water utilities need to achieve an economic balance between the costs of leakage control and the benefits there from. The Economic Level of Leakage (ELL) is the leakage level at which the marginal cost of reducing leakage is equal to the benefit gained from further leakage reductions, that is the leakage level which minimises the total of the present value cost of leakage management and the present value cost of the water lost through leakage (OFWAT 2008).

The graph in Figure 1 shows present value costs of leakage management and water lost through leakage, varying with the leakage level (Ml/day). The cost of lost water refers to the costs of actually producing and distributing water of an acceptable quality. The costs of leakage management are those associated with detecting and repairing the leaks. The leakage detection and repair cost increases when the leakage level decreases since is easier to detect bigger leaks, and the effect of detection and repair is greater for bigger leaks. The graph also shows background leakage as an asymptote – this is the sum of all the leakages in all fittings in the network which are too small to be detected. The background leakage is a function of the leakage detection methods employed by the utility.

The slope of the water cost line is the marginal cost of water. If the marginal cost of water is constant, the line will be a single straight line. If not, the line will be made up of a number of straight lines; usually increasing in slope with higher leakage as more expensive water is used. This cost can be (and now usually is) more widely defined than simply costs of production and distribution - it could include bulk supply charges, or deferred capital investment or even be the sale price of water (where water saved from leakage could be sold to other customers) (Personal communication with Allan Lambert, 2010).

The reason that the cost of looking for unreported leaks increases as the volume of unreported leakage reduces, is that the frequency of active leakage control increases, and the average run time of unreported leaks and bursts decreases. It is not usual to include the cost of repairs in the ELL calculation, as the cost of repairs is normally assumed to be independent of the frequency of intervention (as all leaks have to be repaired to achieve ELL).

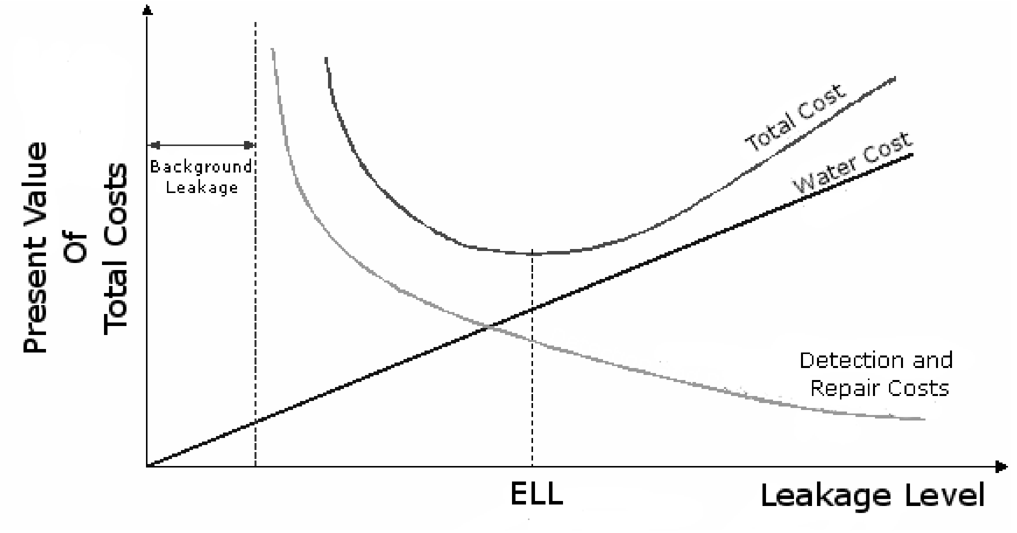

Figure 1. Economic Level of Leakage Calculation

The ELL may be calculated on the basis of the financial costs to the utility, which demonstrates the value to the utility of reducing the leakage of water that has been treated and pumped incurring the cost of energy and chemical bills etc. Alternatively ELL may be calculated on the basis of economic costs to society, which take account of the financial costs to the utility AND externalities like social and environmental impacts.

Different supply zones have different base levels of leakage (due to differing pressures, infrastructure condition, etc.) and different operating costs; therefore a utility-wide economic level of leakage can only be evaluated as an aggregate of economic levels of leakage for individual supply zones.

This requires (a) keeping records of all Active Leak Control activities and costs at supply-zone level, (b) the determination of a base level of leakage for each supply zone, and (c) a calculation of the marginal cost of supply for each zone. (Howarth, 2007)

But what if a water utility wishes to calculate the ELL and doesn't have enough information about those activities and costs? What if the water utility is just *starting* to implement Active Leak Control? Also consider that the current position on the curve represents a static situation of the balance between average leakage over a number of years at a constant resource level. It may take years to reach stability when detection resources are changed.

For this reason another approach has been developed for the calculation of the detection and repair costs curve, an empirical model known as the Burst and Background Estimate (BABE), used in the UK and accepted as best practice for assessing and managing leakage in water distribution systems all over the world. UKWIR/WRc (1994) Managing Leakage Report describes with more detail the issues of the BABE methodology.

To develop an estimated Economic Level of Leakage, physical losses can be analysed in the following categories using the BABE methodology and empirical relationships developed by the IWA Water Loss Task Force:

1. Trunk mains and service reservoir leakage
2. Real losses from reported leaks and bursts of very short duration but with high leak volumes
3. Background leakage at joints with very small leak volume that makes them invisible to detection.
4. Unreported real losses from unreported leaks and bursts with moderate flow rates and average duration that depend on the active leakage control method used by the water utility.

The influence of pressure on leakage is adjusted using the concept of N1 exponent (Lambert, 2001) and the use of component analysis is used to determine unexplained leakage from a minimum night flow.

The N1 exponent is used to calculate leakage: pressure relationships and the most appropriate general equation is (ibid):

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1}$$

Where L is the leakage rate (volume/unit time) and P is pressure.

The higher the N1 value, the more sensitive existing leakage flow rates will be to changes in pressures. Undetectable small 'background' leaks from joints and fittings in distribution systems are quite sensitive to pressure, with N1 values typically close to 1.5 where larger detectable leaks from plastic pipes typically have N1 values of 1.5 or even higher. In the case of larger detectable leaks in metal pipes the N1 value is usually close to 0.50.

Estimation of ELL in the City of Zaragoza

Research on the ELL is being undertaken through the EU-funded SWITCH project whose overall objective is to apply Integrated Urban Water Resource Management concepts for achievement of effective and sustainable urban water systems in the 'city of tomorrow (i.e. projected 30-50 years from now)'.

Zaragoza is one of the partner cities for the SWITCH project, and is a demonstration city for the demand management work package of the project. Zaragoza, situated in the central area of the River Ebro basin, is the capital of Aragón region in North-eastern Spain. Water supply is provided by the Municipality, through its Infrastructure Department (with the involvement of other departments), rather than by a separate utility. Research field work started in Zaragoza in October 2008, since when District Meter Areas have been set up, flow and pressure loggers installed and the DMAs have been calibrated. The volume of Non Revenue Water in Zaragoza is estimated as approximately 21 million m^3 per year (34%), as shown in Table 1. About half the estimated losses occur in the distribution network. This values come from an study by the Zaragoza Water Utility.

Table 1. Estimated water supply volumes in Zaragoza, 2008

Item	Annual Volume (m^3x10^6/yr)
Treated Water delivered to distributions system	61.09
Metered delivery to customers	39.69
Non Metered Consumptions	1.0 to 2.0
Metering errors	4.0 to 5.0
Losses in treatment plant and tanks	0.5 to 1.5
Losses in private installations (e.g. inside the house or the network inside a university...)	3.0 to 4.0
Losses in distribution network	9.0 to 12.0

Trunk mains and service reservoir leakage

As a part of the SWITCH research, leakage from trunk mains and service reservoirs has been estimated from data on the water distribution system infrastructure in Zaragoza, taking account of the age of the pipes using empirical figures from Lambert (2009), as shown in Table 2.

Table 2. Trunk mains and service reservoirs leakage

Infrastructure Component	Length or Volume	Leakage Allowance (m3/km/day)	Leakage Allowance (% of storage/day)	Mains and Service Reservoirs Leakage (m^3x10^3/yr)
Trunk Mains (km)	238.61	3.26		283.92
Service Reservoirs (m^3)	275,510		0.1	100.8
Total				384.72

Real losses from reported bursts

The volume of real losses from reported bursts in distribution mains and service connections is estimated using data on the number of reported bursts in Zaragoza in 2009, and the average system pressure of 36m, together with empirical relationships developed by Lambert et al (1999) as shown in Table 3.

Table 3. Calculation of reported burst volume of leaks

Infrastructure Component	Number of Reported Bursts	Volume per event @ 50m pressure (m^3)	Volume per event @ 36m pressure (m^3)	Reported Burst Volume (m^3x10^3/yr)
Mains	302	1,440	1,190.19	359.44
Service Connections	360	576	476.07	171.39
Total				530.82

Since the relationships developed by Lambert are based on an average system pressure of 50m, a lineal relationship between the volume of leakage and pressure is assumed. This assumption is reliable considering a combination of factors (Lambert and McKenzie, 2002) especially for large systems with mixed metal and non-metal pipework, with average pressure in the range 30 to 70 metres. This is based in an UKWIR study of some 70 mixed-pipework sectors in the UK (Ibid).

Estimated background leakage

The Unavoidable Background Leakage (UBL) is calculated using the equation for Unavoidable Annual Real Losses (Lambert et al 1999):

$$\mathrm{UBL\ (l/h)} = (20 \cdot \mathrm{Lm} + 1.25 \cdot \mathrm{Ns}) \cdot (\frac{\mathrm{AZNP}}{50})^{1.5}$$

$$UBL(m^3x10^3 / yr) = (20 \cdot \mathrm{Lm} + 1.25 \cdot \mathrm{Ns}) \cdot (\frac{\mathrm{AZNP}}{50})^{1.5} \cdot \frac{24 \cdot 365}{10^6}$$

Where AZNP is the Average Zone Night Pressure, Lm is the length of mains and Ns is the number of service connections.

This represents the minimum level of background leakage that could be achieved at this pressure for an average condition of the pipes according with the conditions of the BABE methodology. This means an Infrastructure Condition Factor (ICF) value equal to 1.0. The ICF is the ratio between the actual level of Background Leakage in a zone and the calculated unavoidable Background Leakage of a well maintained System (Liemberger and Farley, 2004) and is used here in the ELL estimate. In practice however the Unavoidable Background Leakage depends on the water loss strategies in use. The values of 20 and 1.25 are the expected leakage for Mains Length (in l/km/hr) and Service connections (in l/conn/hr) for an average pressure of 50m. For an length of 1,235.02 km and 21,530 service connections, the Table 4 shows the results.

Table 4. Calculation of reported burst volume of leaks

Infrastructure component	Length or Number	Unavoidable background leakage (UBL) @ 36m pressure (m^3x10^3/yr)
Mains (km)	1,235.02	132.19
Service Connections	21,530	144.03
Total		276.26

In Zaragoza the residential areas are mainly apartment buildings. The number of connections (21,530) is used in this UBL calculation, rather than the number of customer properties (320,178), following Lambert and McKenzie (2002):

"Where several registered customers or individually occupied premises share a physical connection or tapping off the main, e.g. apartment buildings, this will still be regarded as one connection for the purposes of the applicable PI [Performance Indicator], irrespective of the configuration and number of customers or premises."

Unreported real losses

The introduction of active leakage control methods will reduce the volume of unreported real losses from mains and service connections. The economic limit (where the cost of intervention exceeds the cost of saved water) is estimated using the method and equations presented by Lambert and Lalonde (2005), together with estimates of the cost of intervention and rate of rise in Zaragoza as described below. This gives the Economic Unreported Real Losses (EURL).

The Variable Cost of lost water in 2009 (CV) is taken as €0.734 per m3 after consultation with water supply managers in Zaragoza. It's important to stress again that this cost of lost water is not only the costs of production and distribution.

Research with leak control staff using noise loggers in the Actur area of the city, gave an estimated cost of intervention (CI) of €410 per km of mains. This value was obtained considering the number of pipe repair and replacement incidents, the duration of those events, the cost of the repair crew, transport and materials and the pipe length.

The Rate of Rise (RR) was estimated from two water balances for one DMA. This equated to 49 litres/connection/day/year or 1,057 m3/day/yr for the city as a whole. This estimate was used in the absence of data from the rest of the city, though the pipe system in the test zone is relatively new and in good condition compared with other parts of the city, so this rate of rise may be an underestimate.

The Economic Intervention Frequency EIF is:

$$\mathrm{EIF} = \sqrt{\frac{2 \cdot \mathrm{CI}}{CV \cdot RR}} = \sqrt{\frac{2 \cdot 410 \cdot 1235}{0.734 \cdot 1057 \cdot 365}} = 1.89\ \mathit{years}$$

Where CV is the Variable Cost of lost water, CI the Estimated Cost of Intervention and RR the Rate of Rise.

This EIF allows the definition of an Economic Percentage of the system to be surveyed annually (EP):

$$\mathrm{EP}\,(\%) = \frac{100}{\mathrm{EIF}} = \frac{100}{1.89} = 52.88\%$$

The Economic Unreported Real Losses (EURL) can be expressed as:

$$\mathrm{EURL}\,(\mathrm{m}^3) = \frac{\mathrm{EP} \cdot \mathrm{CI} \cdot \mathrm{Lm}}{\mathrm{CV}} = \frac{0.5288 \cdot 410 \cdot 1{,}235}{0.734} = 364{,}792\,\mathrm{m}^3/\mathrm{yr}$$

This analysis shows that active leakage control survey should be carried out on 52.88% of the system per year, to reduce unreported losses from the distribution mains and service connections to an economic level. This will require an Annual Budget for Intervention (ABI):

$$\mathrm{ABI} = \mathrm{EP} \cdot \mathrm{CI} = 0.5288 \cdot 410 \cdot 1235 = €267{,}764$$

Where EP is the Economic Percentage of the system to be surveyed annually and CI the Estimated Cost of Intervention.

From the above analysis, the Economic Level of Leakage for Zaragoza is estimated as 1,556 m^3x10^3/yr, as shown in Table 5. This is based on only one approach for active leakage detection (using noise loggers) and different approaches or combination of approaches will have different results for this ELL analysis.

Table 5. Estimation of the economic level of leakage for Zaragoza (m^3x10^3/yr)

Infrastructure Component	Trunk mains and service reservoir leakage	Real losses from reported bursts	Estimated background leakage	Economic unreported real losses
Trunk Mains (km)	283.9			
Service Reservoirs (m^3)	100.6			
Distribution Mains (km)		359.4	132.2	
Connections		171.4	144.0	
Total	384.5	530.8	276.2	364.8

ELL for Zaragoza = 384.5 + 530.8 + 276.2 + 364.8 = 1,556.3 m^3x10^3/yr.

If we compare the ELL with the figures in Table 1, which show current losses of 9 to 12 m^3x10^6/yr, i.e. 6 to 8 times the ELL, there is considerable potential for water loss recovery in Zaragoza. Investing in leak detection and control will then be a good idea and would allow tapping this huge potential of water loss recovery.

Conclusions

In cities where ELL is not currently estimated, this research shows how available data can be compiled to improve understanding and management of water losses. This in itself should lead to savings of water and improved performance, and data from water loss management activities can then be used for ELL analysis.

Of course this method requires an advanced knowledge of the network. Key information such as average system pressure is often unknown. However, this is the type of information that can be collected relatively easily and does not require a serious capital investment. The knowledge of the network is thus a prerequisite for the application of this approach.

Since the Cost of Intervention depends on the approach used for active leakage detection, the ELL depends on the choice options of the Water Utility. In this way the company has a very useful tool to maximize their investment being able to compare different active leakage detection options and to choose the most appropriate for their priorities.

This method uses information from different stakeholders within the Water Service Provider / Utility. A constant problem is not being aware of activities and results obtained by the different layers and components of the organisation. The Data collection process might be difficult due to the spread of responsibilities across Departments of the Municipality. For this reason one of the authors’ recommendations is to share and disseminate information within the organisation. Granting read privileges (but not modification privileges) of the data, will result in a “global vision” that will allow an organized flow of information. This also will result in an improvement in the working environment within the organisation, a perception that everyone in the organisation "knows where we are going".

The BABE method is a very good starting point that has the advantage that it can be refined using further information. By obtaining an ELL, the Water Utility knows what information to collect and refine for the next calculation so that the previous calculation can be updated and results improved.

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References

Howarth D. A. (2007) *Arriving at the Economic Level of Leakage: Environmental Aspects*, Water and Environment Journal, Vol 12 Issue 3, P 197-201

Lambert A., Brown T.G. Takizawa M. Weimer D, (1999). *A Review of Performance Indicators for Real Losses from Water Supply Systems*. AQUA, Dec 1999, ISSN 0003-7214

Lambert, A. (2001). *What Do We Know About Pressure / Leakage Relationships in Distribution Systems?*. Proceedings IWA Specialised Conference: System Approach to Leakage Control and Water Distribution Systems Management, Brno, Czech Republic.

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

Lambert, A. and McKenzie, R. (2002) *Practical experience in using the infrastructure leakage index*. Proceedings of IWA Conference 'Leakage Management: A Practical Approach', Lemesos, Cyprus

Liemberger, R. and Farley, M. (2004) *Developing a non-revenue water reduction strategy*, paper presented at the International Water Demand Management Conference, May 30- 3 June 2004, Dead Sea, Jordan, accessed at http://www.wdm2004.org/new_web/technical_session/files/roland_liemberger.pdf

OFWAT (2008) *Providing Best Practice Guidance on the Inclusion of Externalities in the ELL Calculation*. Ref PROC/01/0075. Guidance V08. 1st October 2008

Pearson, D and Trow S.W (2007). *Calculating Economic Levels of Leakage*. Accessed at http://waterloss2007.com/Leakage2005.com/pdf/Calculating%20Economic%20Levels%20of%20Leakage.pdf

UKWIR/WRc (1994) *Managing leakage (Report C): Setting economic leakage targets*. UK Water Industry Research. Water Research. Water Research Centre, Water Services Association, Water Companies Association, ISBN 1 898920 08 7

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