Adapting the Economic Level of Leakage concept to include Carbon Emissions, and Application with Limited Data

I K Smout*, S M Kayaga*, C Muñoz-Trochez*

*WEDC, Loughborough University, Leicestershire LE11 3TU, UK

Abstract

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. The concept can be adapted to include the economic costs of social and environmental externalities. The paper presents an approach for estimating the economic costs of greenhouse gas emissions and incorporating these in the ELL calculation. This is applied in the city of Zaragoza in Spain, with initial estimates of ELL and externality costs calculated using data from water supply records and measurements in a study area, together with empirical relationships from the literature.

Keywords: Water supply; Leakage; Carbon emissions

Introduction

Climate change is now widely recognised as caused by increased concentrations of greenhouse gases in the earth's atmosphere that absorb infrared radiation. In particular, concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased over the last century as the result of emissions from fossil fuels and industrial processes (IPCC 2007). Climate change has an impact on water resources and water supply systems, through changes in the magnitude and variability of temperature and rainfall, and the frequency and severity of extreme weather events. In addition, water supply systems themselves contribute to climate change through greenhouse gas emissions from the use of energy.

One of the costs of producing water is the amount of energy used during the pumping, treatment and distribution process, and these costs apply to water lost in leakage in the same way as they do to water delivered to consumers. This energy demand is growing as it becomes necessary to develop more energy-intensive water sources for expanding cities and/or to meet higher service quality levels. Desalination is an example of a high energy water source which is becoming more widely used.

The growth in energy use has a number of important implications, including an increase in energy costs for business and government, the increased emissions of greenhouse gases from electricity generation and the additional strain on the existing power grid to meet the higher electricity demand.

After staff costs, energy consumption is generally the second most important operating expense in water utilities, and this might be more critical in developing countries. Increasing attention is being paid to the potential savings through increasing efficiency. For example, the Alliance to Save Energy (2005) estimated that water leakage in Brazil resulted in energy consumption of 3.5 billion kWh per year, costing the water sector US$ 230 million per year.

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). As shown in Figure 1, reducing leakage below the ELL would cost more than the benefits of the leak reduction.

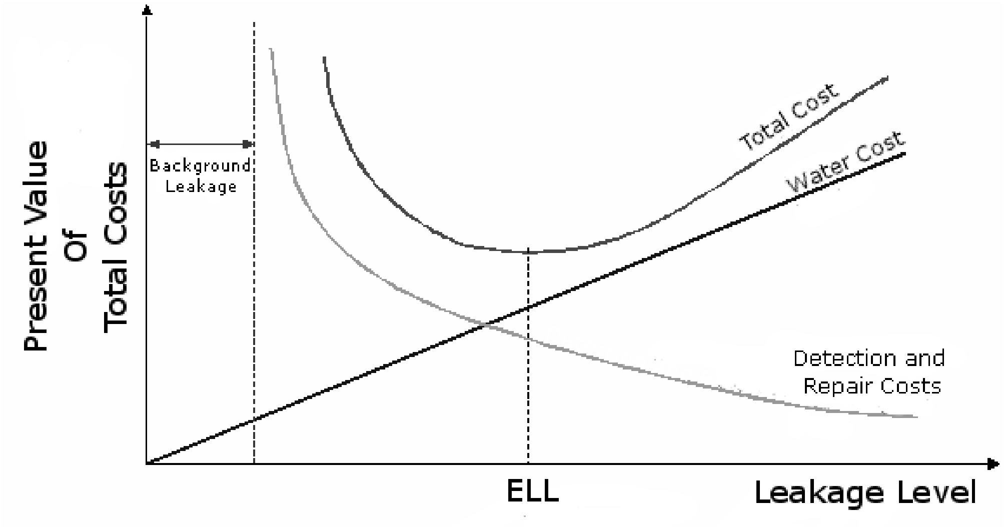

Figure 1:Economic Level of Leakage Calculation

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 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.

OFWAT (2008) has produced guidance for the UK water industry on the process of including externalities in this model of ELL. It defines an externality as "any positive or negative impact arising from an activity that is not normally considered in the decision of the agent (in this case the Water Service Provider) undertaking the activity".

These externalities arise because the positive impacts or the avoidance of negative impacts have a value but there is no obvious market price (or cost) which reflects third parties' willingness to pay. These externalities include social and ecological variables. However the inclusion of carbon valuation in this field is recent, to take account of the cost of climate change and emissions of greenhouse gases.

Incorporating the economic costs of carbon emissions in the ELL model can be considered in 5 stages:

1. Identification of energy externalities in water supply and leakage management activities.
2. Data collection and assessment of emissions in water supply and leakage management activities.

3. Evaluation of the carbon externalities in the water supply and leakage management activities
4. Inclusion of values of carbon externalities in the economic analysis.
5. Post-analysis monitoring.

Tables 1 and 2 show identified carbon externalities in various activities or interventions for water supply and leakage management, together with data to be collected to enable assessment of emissions per unit of intervention (e.g. per Ml of water supplied or saved).

Table 1: Carbon Externalities in the Cost of Water Supply (adapted from OFWAT, 2008)

Source of Emissions	Intervention and Data Required		
	Abstraction	Treatment	Distribution
Fuel Use	Quantity of each fuel used	Quantity of each fuel used	Quantity of each fuel used
Energy Use (including consumption in offices and data centres)	Quantity of each energy source used	Quantity of each energy source used	Quantity of each energy source used
Water treatment – ozonation		Volume treated by ozone	
Water treatment – disposal of residues		Quantity of waste a) recycled b) land filled	

Table 2: Carbon Externalities in the Cost of Leakage Management (adapted from OFWAT, 2008)

Source of Emissions	Intervention and Data Required				
	Asset Replacement	Active Leakage Control - Detection	Active Leakage Control - Repair	Repair Reported Leaks	Pressure Management
Fuel /energy use - transportation	Quantity of each fuel used	Quantity of each fuel used	Quantity of each fuel used	Quantity of each fuel used	Quantity used for pumping optimisation
Fuel / energy use - worksites	Quantity of each energy source used	negligible	Quantity of each energy source used	Quantity of each energy source used	negligible
Traffic diversion / disruption	Measure of diversion / disruption	negligible	Measure of diversion / disruption	Measure of diversion / disruption	negligible
Materials consumption	Quantity of materials used	negligible	Quantity of materials used	Quantity of materials used	Quantity of materials used

Pressure management is particularly interesting, as a reduction in pressure reduces the leakage rates and the frequency of bursts as a leakage management measure, but in addition it reduces energy consumption and leakage/consumption in users' premises, all of which have both direct financial costs and externalities.

Energy and pressure management has gained a lot of research attention, from optimizing the pumping schemes to developing new control technologies. Table 3 shows an example of payback periods for different approaches to pressure management.

Table 3: Typical payback periods for pressure management technologies and practices (Alliance to Save Energy, 2005)

Function	**Typical Payback Period (years)**
Avoid the unnecessary operation of pumping equipment	0 – 1
To optimize the electromechanical efficiencies of the pumping systems	0.5 – 1.5
Control of pressure and output in the networks	1.5 – 3
Use of highly efficient motors	2 – 3

Valuation of the emissions requires converting volumes of emissions of various greenhouse gases into CO_2 equivalent, and then the application of a shadow price or externality value to convert the quantity of CO_2 emissions to a monetary equivalent. The appropriate value for this shadow price has been a matter of debate in recent years. Current UK guidance is to use a non-traded price of carbon of £51 per tonne CO_2 equivalent for 2009 (DECC 2009). At 2009 exchange rates, this is equivalent to €57 per tonne CO_2 equivalent, which is the figure adopted in this paper.

Research on 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 schemes 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. Data collection has proved more difficult than expected due to the spread of responsibilities across departments of the Municipality. Preliminary estimates are presented in this paper, based on the limited information collected to date. The analysis relates to the situation in 2009.

Estimation of ELL in the City of Zaragoza

The volume of Non Revenue Water in Zaragoza is estimated as approximately 21 million m^3 per year (34%), as shown in Table 4. About half the estimated losses occur in the distribution network.

Table 4: Estimated Water Supply Volumes in Zaragoza, 2008 (Zaragoza Municipality 2009)

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 to 2
Metering errors	4 to 5
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 to 4
Losses in distribution network	9 to 12

To develop an estimated Economic Level of Leakage, physical losses can be analysed in the following categories using the Bursts and Background Estimates (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 bursts
3. Background leakage
4. Unreported real losses

These are considered in turn below.

Trunk mains and service reservoir leakage

Leakage form trunk mains and service reservoirs is 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 5.

Table 5: Calculation of Trunk Mains and Service Reservoirs Leakage

Infrastructure Component	Length or Volume	Mains and Service Reservoirs Leakage		
		Leakage Allowance (Lambert 2009)		Mains and Service Reservoirs Leakage
		$m^3/km/day$	% of storage/day	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 6.

Table 6: Calculation of Reported Burst Volume of Leaks

Infrastructure Component	Number of Reported Bursts	Reported Burst Volume		
		Volume per event (m^3) (Lambert et al, 1999)		Reported Burst Volume
		@ 50m pressure	@ 36m pressure	m^3x10^3/yr
Mains	302	1440	1,190.19	359.44
Service Connections	360	576	476.07	171.39
Total				530.82

Estimated Background leakage

The Unavoidable Background Leakage is estimated from data on the water distribution system infrastructure and pressure, using empirical relationships presented by Lambert et al (1999) as shown in Table 7. This represents the minimum level of background leakage that could be achieved at this pressure for an average condition of the pipes (ICF = 1.0) and is used here in the ELL estimate. In practice however the Unavoidable Background Leakage depends on the water loss strategies in use.

Table 7: Calculation of Unavoidable Background Leakage at current pressure

Infrastructure Component	Length or Number	Unavoidable Background Leakage (UBL)				
		@ 50m pressure			@ 36m pressure	
		l/km/hr (Lambert et al 1999)	l/conn/hr (Lambert et al 1999)	m^3/day	m^3/day	m^3x10^3/yr
Mains (km)	1,235.02	20		592.8	362.2	132.19
Service Connections	21,530		1,25	750	458.2	144.03
Total				1342.8	820.4	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 m^3 after consultation with water supply managers in Zaragoza. 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. 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 m^3/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 Actur 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

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

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:

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

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):

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

Table 8 shows that this EURL analysis is relatively insensitive to the estimated parameters derived from the study area.

Table 8: Sensitivity of Estimates of Economic Unreported Real Losses

	Economic Unreported Real Losses (EURL) (m^{3}x10^3/yr)		
Rate of Rise (m^3/day/yr)	CI = €205/km	CI = €410/km	CI = €820/km
1057	258	365	516
1500	307	435	615
2000	355	502	710
2500	397	561	793
3000	435	615	869

Note: changes in the costs of water (CV) have an inverse effect on EURL to changes in the cost of intervention (CI), e.g. halving the cost of water has the same effect as doubling the cost of intervention

Economic Level of Leakage

From the above analysis, the Economic Level of Leakage for Zaragoza is estimated as 1,556 m^{3}x10^3/yr, as shown in Table 9. 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 9: Estimation of the Economic Level of Leakage for Zaragoza

		Losses in $m^3 x 10^3/yr$				
	Length or number	Trunk mains and service reservoir leakage	Real losses from reported bursts	Estimated Backgr'nd leakage	Economic Unreported Real Losses	Total
Trunk mains (km)	238.61	283.9				
Service reserv-oirs (m^3)	275,510	100.6				
Distrib-ution mains (km)	1,235.02		359.4	132.2	See below	
Connect-ions	21,530		171.4	144.0	See below	
Total		384.5	530.8	276.2	364.8	1,556.3

Externality Costs of Emissions

No data have been obtained from Zaragoza on emissions in the abstraction, treatment and distribution of water. For illustrative purposes in this paper, data have been taken from an example given in Ofwat (2008), as shown in Table 10.

Table 10: Example of Carbon Externalities in the Cost of Water (adapted from OFWAT, 2008)

For a system with total water throughput 2000 Ml/yr and leakage 1.5 Ml/d	
	Emissions/yr
Abstraction (t CO_2 /Ml)	0.09
Treatment (t CO_2 /Ml)	0.52
Distribution (t CO_2 /Ml)	0.07
Total (t CO_2 /Ml)	0.68
	Costs
Externality cost (€ /t CO_2)	€57
Externality cost (€/Ml)	€39
Externality cost (€/ m^3)	€0.04

If the externality cost of €0.04 /m^3 in this example also applied in Zaragoza, it would represent about 5% of the financial cost of water.

The externality cost of emissions from leakage control in Zaragoza is estimated considering the work of the leak control crew during 2009, using Zaragoza municipality records.

The usual setup for leak control work involves one van and 4 persons. The value of emissions from the use of labour are estimated to be approximately 1 kg

CO_2e/person/hour (UKWIR, 2008). This is based on the assumptions: i) that site workers travel an average distance of 25 km each day from their lodgings to site and then back again by car or van (2 persons to a vehicle); and ii) that each labourer makes use of site welfare facilities (large heated portacabins). So the value of emissions for the leak control crew will be 32 kg CO_2e per day or 6944 kg CO_2e per year + the emission related to the distance travelled for repair.

In 2009 a total of 7227 km were driven by various light vehicles for work on leakage control. Considering a value of 0.210 kg CO_2/km (UKWIR 2008) we obtain 1518 kg CO_2e for the vehicle emissions for leakage control activities during 2009 in Zaragoza.

During 2009 a total of 835 events all over Zaragoza involved the leak control crew, of which 501 were repair events. Further data on the diameter and pipe material from 71 of these repair events, enabled the emissions from repair to be estimated as 344 kg CO_2e/m length of pipe. Data on the pipe length per repair is not currently available but based on information from the repair crew we assume a replacement of 2 m per event. This gives an average of 688 kg CO_2e per repair and a total value of 344,265 kg CO_2e for all 501 repair events during 2009 in Zaragoza.

The average of 688 kg CO_2e per repair in Zaragoza is of a similar order to the estimate of 286 kg CO_2e per repair in South Staffordshire, UK (South Staffordshire Water 2009).

Table 11 summarises the externality costs of leakage control activities for one crew. The total is €20,105, which is less than 10% of the financial cost. The data show that the fuel, energy and materials use at worksites is the major source of emissions, not energy use by labour and transport.

Table 11: Estimated Emissions from Leakage Control Activities in Zaragoza, 2009

Source of Emissions	Description	Recorded data	Rate	kg CO_2e	Externality cost (€)
Labour – commuting and welfare	Crew of 4	217 days	32 kgCO_2/day	6944	€396
Fuel /energy use - transportation	Car and vans	7227 km	0.210 kgCO_2/km	1518	€87
Fuel / energy / materials use – worksites		501 repair events	344 kgCO_2/m pipe x 2m	344,265	€19,623
Total					€20,105

Way Forward

This paper has demonstrated how energy externalities can be included in the economic level of leakage concept, and has applied this to active leakage detection in Zaragoza. Initial research estimates suggest that the externalities cost is not likely to have a major impact on the economic level of leakage. These estimates need to be refined and extended to include investigations of other water loss strategies. These will feed into a model which is being developed within the SWITCH project to provide a tool for estimating ELL, taking account of energy externalities.

Although the economic effect of the energy externalities in the ELL may be small, the issue is important and demands the generation of guidelines and recommendations for accounting as a reference for reduction or offset measures.

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 energy and improved performance, and data from water loss management activities can then be used for ELL analysis.

References

Alliance to Save Energy (2005). Financing Municipal Water Infrastructure Efficiency as the Least Cost Alternative, accessed at http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=958274 on 22 May 2010

Colombo, A F and. Karney, B W (2003). Pipe breaks and the role of leaks from an economic perspective, *Water Supply Vol 3 No 1-2 pp 163–169*

DECC (2009) Carbon Valuation in UK Policy Appraisal: A Revised Approach. Department of Energy and Climate Change, UK. July 2009

Hammond, G & and Jones, C. (2007) Inventory of Carbon and Energy (ICE). Sustainable Energy Research Team (SERT). Version 1.5 Beta. University of Bath: Department of Mechanical Engineering.

IPCC, 2007: Summary for Policy Makers. In: *Climate Change 2007: Impacts, Adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK

Kayaga, S M, Sainctavit, L, Smout, I K and Bueno, V. Partnerships for enhancing the water-saving culture in Zaragoza, Spain*. IWA World Water Congress, Vienna, Sept 2008*.

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

Lambert, A. (2009) Personal Communication

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

South Staffordshire Water (2009). Final Water Resources Management Plan. South Staffordshire Water plc. August 2009

UKWIR (2008) Report Ref No 08/CL/01/6 Carbon Accounting In The UK Water Industry: Guidelines For Dealing With ‘Embodied Carbon’ And Wholelife Carbon Accounting, ISBN 1 84057 495 X