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# **Incorporating energy use into the economic level of Leakage Model**

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## **Abstract**

The Economic Level of Leakage (ELL) 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. Reducing the leakage below the ELL would cost a water utility more than the benefits of the leak reduction. This paper describes research which aims to contribute to the reduction of carbon emissions associated with management of water leakages in water distribution networks. It adapts an IWA methodology for the determination of an Economic Level of Leakage for a water distribution zone with no history of active leakage management, the city of Zaragoza in Spain, considering the energy externalities associated with the components of water loss management.

## **Keywords**

Economic Level Of Leakage; ELL; Energy Externalities; Water Leakage; Sustainable Development

## **INTRODUCTION**

The water lost in leakages costs money, energy and time. For efficient management a water utility must know what is the leakage level that it can recover using the technology and workforce available. However not all water utilities are able to calculate this leakage level. This paper presents a methodology to calculate this figure and complements it with the inclusion of energy externalities in the calculation of the Short Run Economic Level of Leakage.

Water loss management is currently one of the research priorities for the International Water Association (IWA). In 2002 was created a Task Force on water loss management. This task force developed a model for control of the physical losses in a distribution system, shown in the Figure 1.

It's important to stress that there are two components of physical losses in any water distribution network: The first one are Unavoidable Annual Real Losses (UARL) composed of small but numerous background leakages from pipe joints and fittings that are difficult to detect using current technology. The second one are the potentially recoverable real losses with higher leakage flows and pipe bursts, which require significant effort and investment on the part of the organisation to locate and repair them. The four arrows in Figure 1 represent the four strategies that could be adopted to reduce water losses to a minimum.



**Figure 1: Components of water loss management strategy, as developed by IWA (Source: Liemberger and Farley, 2004)**

In order to minimise overall leakage rates in a distribution network, a water utility needs to carry out active leakage management, which is simply described as detection of leakages before they appear on the surface, using various technical equipment. Effective active leakage management requires high levels of technical and organisational capacities on the part of the water utility. So when the water utility mobilizes resources for detection, location and repair of reported leaks only, we are talking about passive leakage control.

The second strategy for minimising leakages in pipes and other assets in the distribution network is maintaining and replacing them as and when their economic life is reached. Good asset management may be accomplished only when life cycles costs are well planned for in the financial model, and when the technical team keeps an asset maintenance management information system.

The volume of water lost in a leakage is a function of the leak flow rate and the duration of the same until is completely repaired. This duration involves a detection time, a localization time and a repair time. The longer the time, the bigger the volume of lost water. Therefore another strategy for leakage minimization shown in Figure 1 is to repair identified leakages and bursts in the shortest time possible, and to ensure that the quality of the repair work is beyond doubt.

Pressure management may be the most cost effective approach to manage real losses, depending on the system pressures and topography of the service area. In general terms, the higher the system pressure, the higher the leakage flow rate (Lambert, 2001). Furthermore, pressure fluctuations play an important role in generating fatigue failures, hence the need to have a water supply system with minimised pressure fluctuations.

## ECONOMIC LEVEL OF LEAKAGE

The Economic Level of Leakage (ELL) is when the marginal cost of leakage control equals the marginal cost of water (from the next resource). At levels below the economic level of leakage further reductions in leakage will be more expensive than developing the resource, and so at this stage the resource should be developed. There are 2 kinds of ELL: In the case of the Short Run ELL, the quantity of at least one input is fixed and the quantities of the other inputs can be varied. The ELL for Long Run is for a period of time in which the quantities of all inputs can be varied, and other new inputs can be introduced. (Pearson and Trow, 2007). This means that approaches like active leakage control and speed and quality of repairs can be affected by changes in labour and shall be considered in the short term while pressure management and asset management would require an investment decision, and be considered in the long term. The approach presented in this paper deals with the Short Run ELL.

The calculation of the ELL requires information about leakage volumes and costs, as Figure 2 shows.

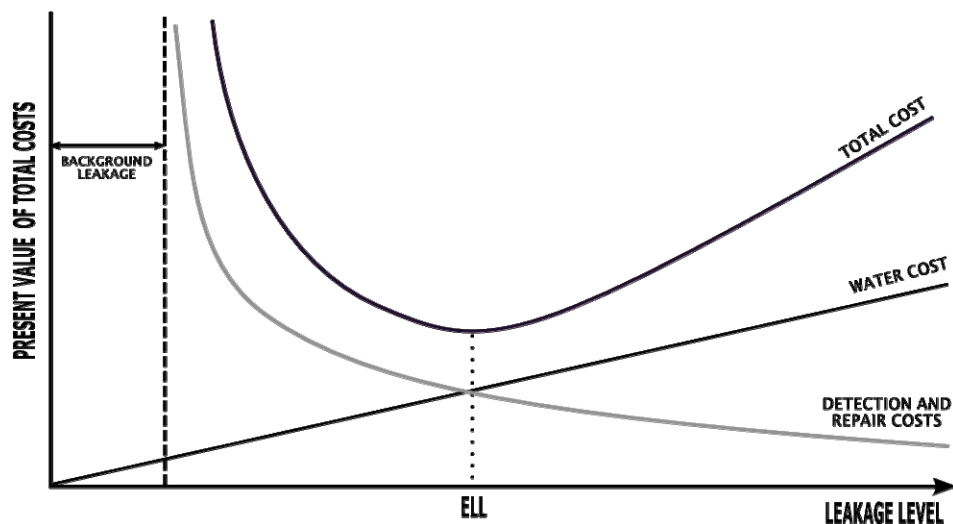


Figure 2: Economic Level of Leakage Calculation

To calculate the ELL, the marginal cost of water approach will be used since it compares the marginal cost of obtaining additional water from leakage control with the marginal cost of obtaining water from developing the next representative resource scheme. If the marginal cost of obtaining additional water from leakage control is less than that for the next resource then it will be cost effective to reduce leakage.

A water utility with enough information about the activities and costs can easily plot the curve. But under a passive leakage control scheme, the common case is to have only one point of the Detection and Repair Cost curve since there is only one value of saved volume and one of cost. And even under that condition, the volume of water that will be saved with a certain investment is unknown.

For that reason, the IWA Water Losses Task Force has developed 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 methodology was first presented by Fantozzi & Lambert (2005), then in a more user-friendly format at the Leakage 2005 Conference (Lambert & Lalonde, 2005). This last paper also presents application examples of this methodology in a Canadian and an Australian water distribution system.

This methodology requires only three system-specific parameters: Cost of Intervention (CI), Variable Cost of Lost Water (CV), and Rate of Rise of Unreported Leakage (RR) can be used to quickly assess the Short Run ELL for any size of system or sub-system.

The CI is obtained from the repair and detection logs using the costs of workforce and materials. It doesn't include the cost of repairing the unreported leaks found since there is no active leak detection. There can be different CI for different strategies. The units are \$, or \$/service connection, or \$/km of mains. The CV is obtained from the water utility costs database and the units are in \$/m<sup>3</sup>. In the case of the RR a water utility might lack the information about night flow measurements but can have water balances for several years where there has been no active leakage control. The Rate of Rise RR will be:

$$RR = \frac{(RL1 - RLN)}{N}$$

Where RL1 is the annual volume of Real Losses in year 1, RLN is the annual volume of Real Losses a number N of years before, obtained from a water balance. If the number of service connections or average pressure has changed, RLN shall be adjusted to number of connections and pressure in Year 1. (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 Fixed And Variable Area Discharges (FAVAD) concepts, that describe water leakage flow rates as proportional and sometimes increase variably with increases in pressure (May, 1994), 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).

## **ENERGY EXTERNALITIES**

One of the costs of producing water is the amount of energy used during the treatment and distribution process. The amount of energy consumed worldwide in water supply is more than 6552 Petacalories (26 Quads; 1 Quad = 10<sup>15</sup> BTU), is roughly equivalent to the amount of energy used by Japan and Taiwan together, about a 7% of the total energy consumption. (Alliance to Save Energy, 2003).

After the staff costs, the energy consumption is the second most important expense in the water utilities. And this might be more critical in developing countries. The consumption of fossil fuels and the CO<sub>2</sub> emissions associated with the energy generation is other very important variable that now is starting to be considered since the energy usage is set to increase in future, as it becomes necessary to develop newer and more energy-intensive water sources for growing cities and/or to meet higher service quality levels. The efficient use of water and energy can help achieve those objectives since the energy consumption, and the associated emissions, can be reduced when treating a lower water volume or improving the distribution conditions. A better

understanding of these relationships will then be reflected in the total cost of system, performance and demand.

The UK regulator OFWAT has been working on the process of including externalities on this model of ELL. An externality "...is 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" (OFWAT, 2008). Such impacts impose a cost or benefit to third parties but not to the water utility. These externalities are a result of the concept that 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. The current trends in economic theory had allowed the development and refinement of methodologies for the evaluation of external costs and benefits. However the inclusion of carbon valuation in this field is recent, as a product of including the cost of climate change and emissions of greenhouse gases.

The case study for this research is the city of Zaragoza, situated in the central area of the River Ebro basin, is the capital of Aragón region in North-eastern Spain. Zaragoza is situated in a semi-arid region with an average annual precipitation of 314 mm. The city has been working on demand management on the consumer side and have been really successful on the education of users.

Zaragoza got involved on a research study that is part of an integrated project funded by the European Union (EU). The five-year SWITCH (Sustainable Water management Improves Tomorrow's City Health) project aims at developing efficient and interactive urban water systems and services in the city's geographical and ecological setting, which are robust, flexible and responsive to a range of global change pressures. Zaragoza is one of the partner cities for the SWITCH project, and is a demonstration city for the research activities under the Demand Management work package of the project. The leakage control in the city has been passive since the budget of the water utility, which is a public utility, does not allow the creation of an active leakage control work crew.

So after the initial analysis of the resulting short run ELL in Zaragoza, the energy associated externalities will be included. The resulting model will calculate the ELL for different leakage management approaches and allow the review of energy related emissions and their impact on the leakage volumes. Also the energy externalities to be studied in this research do not include the asset management approach or the social externalities, only the externalities associated with leakage control in the water distribution system, from the meter at the exit of the water treatment plant to the meter at the service connection. The externalities in the cost of water extraction and treatment will be considered using the values in the literature to give a total economic cost of the water.

The seasonality of the energy consumption is an important variable in this study. Right now we are able to quantify a great part of the energy consumption in the different approaches for leakage management but we need data that covers a longer period of time. That is the most important variable in this study since the energy consumption has a seasonality factor. Also we need to consider the different alternatives in the market for some of the tools used by the water utility in the leak management process to access the change in consumption and the impact in leak management of this new tools.

## **APPLICATION**

The model developed in this research will allow the calculation of the Short Run ELL in water utilities who currently do not use active leakage control, such as in developing countries and will allow the calculation of the energy externalities associated with the leakage control approaches used by the water utilities.

## **MATERIAL & METHODS**

### **ELL Calculation**

The calculation of an ELL requires that for each relevant part of the infrastructure, such as mains and service connections, the background leakage, the reported leaks, the Mains and Reservoirs leaks and the unreported leaks need to be assessed. In the UK, it is assumed that there are continuous night flows for the different sectors in the network. 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 normal 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.

Methods of locating leaks 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 Undetected Background Leakage (if all detected unreported leaks are repaired).

With the economic intervention concept, the three components of Short Run ELL can be quickly calculated, for a policy of regular survey, at current operating pressure. In the case of the Unreported Real Losses, they depend on the leakage control strategy used by the water utility. According to the method of active leakage control, the water utility will calculate a cost for the “whole system” intervention that will exclude the cost of repairs (Lambert, 2005).

Since most of the repair costs are in excavation costs, and it is difficult to know this cost until the repair has taken place, considering that under an active leakage detection policy, all leaks would eventually become reported, then the repair costs are assumed as unimportant (Morisson, 2007).

The RR, calculated using the information of two water balances during two different years, allows the calculation of an Economic Intervention Frequency than will be related with the Assumed Variable Cost of Water (VC) to determine the Economic Unreported Real Losses volume.

The Trunk Mains and Service Reservoir Leakage depend on the age of trunk mains and on the allowances for real losses in trunks and reservoirs set by the water utility. The Reported Burst Volume in Distribution Mains and Service Connections depend on the number of events and the repair times.

To estimate the Background Leakage, we will apply the Burst and Background Estimate (BABE) methodology (Lambert, 1994). This methodology distinguishes between leakage burst events, which exceed some defined threshold flow rate (500 l/h at 50 m pressure in the UK) and can be managed using policy and technology approaches, from the background leakage, which has a

lower flow rate and are a function of the condition of the network infrastructure. It is described with more detail in the Report C of the UKWir “Managing Leakage” series of reports UKWIR/WRc (1994).

The BABE data requires a value for the Infrastructure Condition Factor (ICF). This value can have a value from 0.5, that means the infrastructure is in good condition, to 2.0, that means the water tightness in the pipes is very poor. Considering that the estimation of background losses require data from the average zone night pressure, and that data is currently unavailable just like the ICF value, the recommendation (Farley, 2001) is to assume an average condition for the pipes (ICF = 1.0) to be sure that the background losses are underestimated and consequently the recoverable losses are overestimated. Using a higher ICF can result in overestimation of the background losses which will cause an underestimation of the true excess loss reduction potential.

The obtained data, combined with the use of the BABE methodology will be used initially for the calculation of the ELL in the test sector. This is illustrated in Table 1 .

**TABLE 1: Description of calculation of ELL**

Item	Unreported Annual Real Losses	Reported Losses + Technical Losses	Real Losses	Cost of Water Losses	Survey cost	Total cost
Units	(m3x1000/year)	(m3x1000/year)	(m3x1000/year)	(1000£)	(1000£)	(1000£)
Description	The Unreported Annual Real Losses are calculated using the RR and the length of mains during the amount of time the analysis is done.	Mains and Service Reservoir Leakage + Reported Burst Volume in Distribution Mains and Service Connections + Estimated Background Leakage if ICF = 1	Unreported Annual Real Losses + Reported Losses + Technical Losses	Real Losses x VC	Annual Budget for Interventions X Economic Unreported Real Losses/Unreported Annual Real Losses	Cost of Water Losses + Cost of one 'whole system' intervention (Excluding cost of repairs)

Applying an approach of budget distribution during the time of analysis of the ELL, the Detection and Repair curve illustrated in Figure 2 can be traced using the following criteria:

- Detection and Repair Costs curve is Real Losses Vs Survey Cost
- Water Cost line is Real Losses Vs Cost of Water Losses
- Total Cost curve is Real Losses Vs Total Cost

After obtaining the Detection and Repair curve, relationships between leakage and costs can be inferred. By calculating the average duration of detectable leaks considering Awareness, Location and Repair times for the pressure management, active leak detection and leak repair, these concepts can be used to model any utility policy, increasing or decreasing the detection effort with its consequent effect on the time for leaks to be located and repaired. This model will analyze separately each of the approaches such as the introduction of an active leakage detection crew or the implementation of new detection and repair crews.

The results from the analysis will be processed as relationships between leakage control activities and leakage cost. The establishment of current and future supply demand balance and alternative investments will be defined according with the plans that the government from Zaragoza have.



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.

### **Data Collection Protocol**

The first step in the data collection process is to establish the boundaries of the collection. In this case only the current protocols in use by the water utility for detection, repair and pressure management will be considered. The consideration of alternatives for this protocols will be one of the uses of the ELL model that is going to be developed under this research and will use data and considerations from successful applications in other cases, that will be obtained from the technical literature.

The water utility will provide the data, using a format that will be filled out every time a detection, repair, asset or pressure management action is carried out. The data will include the different aspects that include energy consumption and emissions such as fuel and electricity consumption. The data collection time using the format will be 6 months and it started in December 2009. The historical data available about leakage repair starts at 1995.

The data collected in the format will be compared with the repair and fuel consumption information in the pipe replacement and repair and pressure management logbooks to guarantee an appropriate level of confidence in the data. Also the logbooks will provide information about the working crew used in the different leakage control approaches used.

These data will be used for a first estimate of the ELL, which will be refined by looking at energy cost issues in more detail, including the savings in energy consumption through reducing leakage. This will show how the ELL may vary, depending on the financial cost of energy, and this analysis can be taken further to consider social and environmental externalities, e.g. the economic cost of carbon.

### **Data analysis**

After achieving the ELL, it is necessary to include the energy externalities. In this research we'll focus in the following items :

- Fuel used in active leak detection, leak repair and pressure management.
- Electricity used in active leak detection, leak repair, pressure management

The analysis of the obtained data will be focused on obtaining a relationship between the fuel and electricity consumption and the detection and repair time of the leaks and between the fuel and electricity consumption and the volume of water lost. In this way, we can predict the amount of emissions related to a time and volume.

Later the model will require the input of a combination of leakage control strategies, specified by the user, with the same time frame or with different time frames. For example comparing the effects of having a single standard leakage control crew versus the use of two or more. Considering the historical data provided, it will calculate the volume of water saved by the strategy and the cost of that saved leakage, the cost of the implementation and the amount of emissions associated with each strategy. From the amount of emissions, the model will calculate

a cost of the energy externalities, applying the concept of Shadow Price of carbon, and complement the ELL with that cost.

## RESULTS AND DISCUSSION

The ELL is definitely a really useful tool for a water utility since it allows to justify investments and priorities for leakage control strategies, specially when the financial resources are very low or just can't keep with the grow rate of the cities. This is something that a water utility in a developing country can apply but this research has showed how information intensive is the calculation of the ELL. The use of a simplified model allows a water utility, with a passive approach to leakage control, to obtain an ELL that will need to be improved but is a good starting point.

The externalities impact on the ELL might seem unimportant when compared with variables such water cost. However this opinion needs to be supported by data and the worldwide trend on accounting and controlling emissions shows the need for guidelines on which energy costs and consumptions values have to be included in the ELL calculation.

## CONCLUSIONS

The model developed in this research will allow the calculation of the Short Run ELL in water utilities without active leakage control, such as in developing countries and will allow the calculation of the energy externalities associated with the leakage control approaches used by the water utilities.

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