Cost and Energy Implication of Leakage in Water Supply Schemes in Ireland

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Short Abstract

Leakage in Water Supply Schemes (WSS) is a growing problem worldwide as well as in Ireland. Cost and energy associated with leakage is becoming more important as progressively poorer quality raw water is treated to increasingly higher standards. Although researches have addressed the growing leakage problem in large water supply schemes around the world, small & medium size schemes as commonly found in Ireland have received little consideration.
This research aims to develop an innovative method to determine cost and energy associated with leakage in WSS. The method is illustrated using collated data for year 2009 from three WSS in Ireland. The results show that significant energy and cost savings were possible if leakage was reduced to an acceptable level. The potential for carbon reduction led to the conclusion that the water sector could contribute in achieving Ireland's carbon emission target to below the Kyoto agreement level.

Keywords: Water Supply, Energy Conservation, Leakage, Pipes and Pipelines

Introduction

'Unaccounted for Water' (UFW) or Non Revenue Water (NRW) is a growing concern worldwide as it is in Ireland. UFW/NRW includes leakage from water supply system, under reading of water meters, water loss through overflow at service reservoirs, theft, etc. UFW figures vary from as low as 6% to as high as 62% of the net water production in countries around the world (Water and Wastewater Utilities, 1996) and in Ireland this figure is estimated to vary from 16.8% to 58.6% in different regions of the country (DOEHLG, 2010a).
It is widely recognised that water is a precious commodity that needs to be managed in an integrated manner. We use water to drink and to keep us clean although

we do not always have enough of it; and the water environment is a source of pleasure as well as a necessary support for the whole of our ecology (DEFRA, 2002). Water has also been described as the new oil or the 'petroleum for the next century' (Cooper, 2008) and it is believed that carbon will be its currency (Caffoor, 2010). As far as possible water needs to be conserved by making sensible use of it. Conservation of water does not only help to preserve our natural water resources but also helps us to use less energy and chemicals; hence reduces the cost associated with treating a large volume of water; a large proportion of which is often lost through leakage in distribution networks and through wasteful use of it.

Water is generally obtained by the natural water cycle. Raw water which becomes available either as surface water or ground water needs several energy intensive processes such as collection, treatment and distribution to ensure a safe supply that complies with all legislative requirements. Enough of good quality water is important in ensuring health. As our understanding of water and its effect to health is increasing, organisations such as the European Council and the World Health Organisation are continuously revising the drinking water quality standard to higher levels. Against a backdrop of increasing water demand, deteriorating raw water quality and more stringent drinking water standards, it is evident that energy and cost of producing a cubic metre of water is on the rise (Sturm and Thornton, 2007; Ragot and Maquin, 2006).

Earlier works in the field (Morais and Almeida, 2007, Ulanicki et al., 2000, Burrows et al., 2000) have acknowledged that water lost from water supply schemes (WSS) is one of the key issues faced by both developing and developed countries throughout the world. It is also recognised that water loss through leakage represents a significant proportion of the total losses (Morais and Almeida, 2007) and this could be either in the distribution side or in the consumer side (Sturm and Thornton, 2007).

Water, Energy and Green House Gas

The fundamental relationship between water and energy is based on the reality that treating water for human consumption and moving treated water to households is extremely energy intensive. The relative energy importance in each stage starting from abstraction to final delivery of water depends on factors such as the topography between the water source and its destination, distance from the bulk water supply, and the integrity of the primary mains (supply pipes) and secondary mains (distribution pipes). It is acknowledged that energy is among the top three cost items to water service providers, often coming second after labour costs (Watergy, 2007). In India, for example, it is found that water works consume more than 12,000 Million Units of electricity as compared to Public lighting which consumes 5,000 Million Units. Energy audits in India have also found that energy costs account for 40% to 60% of the operating expense of supplying water (IFC et al., 2008). In developing countries, energy is thought to be the highest cost associated with water supply (Watergy, 2007) but data to substantiate this thought is not always available. For example, in Ireland energy and costs associated with the water supply sector are still unknown.

There is no direct Green House Gas (GHG) emission during water abstraction, treatment and distribution, but there is indirect emission of equivalent carbon dioxide (CO_{2eq}) mainly from the production of electricity and chemicals which are used during these processes (Frijns, 2009). As part of the overall carbon reduction targets, it is believed that the water sector also has a role to play. For example, the UK water industry emitted five million tonnes of GHGs in 2007/2008 (Howard, 2010). In Ireland, CO_{2eq} is estimated for sectors such as electricity generation; industry; transport; residential; and commercial and public services only, (Howley et al., 2010).

Aims and Objectives

The aim of this paper is to demonstrate a simple but innovative method to determine cost and energy associated with leakage in Water Supply Schemes (WSS).

It also aimed to determine the emission of Green House Gas (GHG) associated with energy use during water abstraction, treatment and distribution in the WSS.

Methods

The following steps were involved.

- Selection of the Study Areas
- Data Collection
- Determine energy and costs associated with water abstraction, treatment and distribution.
- Carry out top down water audit to estimate UFW, NRW, infrastructure leakage index (ILI), etc.
- Estimate the total leakage and its potential reduction.
- Determine cost and energy associated with leakage and the CO_{2eq} emission due to energy use.

The following paragraphs provide a justification of study area selected and outline the data collected and the method used to collect the data.

A brief description of the water balance methods used during the study and parameters used to determine leakage are provided.

Selection of Study Areas

WSS in County Galway was selected for the study for the following reasons:-

- County Galway has the highest number of GWS in Ireland. 177 out of a total of 729 GWS are found in County Galway (DOEHLG, 2007).
- UFW in County Galway is at an alarmingly high level. Nearly 50% of water is unaccounted for in County Galway (DOEHLG, 2010b). The figure is very high as compared to the AWWA Leak detection and Accountability Committee (1996) recommendation of 10% as a benchmark for UFW (Sharma, 2008).

While selecting the study areas in County Galway other factors were considered which include:-

- Access and availability of data
- Size and distribution of population
- Size of the networks

After having discussed with staff from the National Federation of Group Water Schemes and Galway City Council, three WSS were selected for the study as listed below.

Study Area	WSS No.
Galway City WSS	1
Ardrahan GWS	2
Caherlistrane/Kilcoona GWS	3

Data Collection

Data required for the study were identified at the outset and these are listed below. A number of methods including interviews, meetings, site visits, consultations of published and unpublished reports and publications were used to collect the quantitative data for a period of one year (January to December 2009). Sources of data included water service providers, operators of water treatment plants (WTP), websites, journals and the internet.

- System input volume (m^3)
- No. of Domestic Customers
- No. of Non Domestic Customers (Metered only)
- Non Domestic Water Consumption (m^3)
- Domestic Water Consumption (m^3)
- Billed consumption (m^3)
- Unbilled authorised consumption (m^3)
- Unauthorised consumption (m^3)
- Customer metering inaccuracies (m^3)
- Systematic Data Handling Inaccuracies (m^3)
- Length of transmission mains, distribution mains and service connections (km)
- Number of registered connections
- Estimated number of illegal connections
- Average pressure (bar)
- Historic burst data
- Level of supply service (24-hour, intermittent, etc)
- Total electricity units (kW)
- Total ESB Cost in 2009 (€)
- Chemical Cost in 2009 (€)
- Exports to Neighbouring district metered areas (DMAs)
- Population Supplied
- Per capita consumption (l/p/d)
- Total length of mains in DMA (km)

The following data were derived using the above data collected from each WSS.

- Cost and energy required to abstract, treat and distribute water
- Leakage level and its potential reduction
- Energy and cost associated with leakage and their potential reduction if leakage is reduced to an acceptable level.
- CO_{2eq} associated with leakage was also estimated.

Leakage was estimated using the following two top down water balance methods

1. The International Water Association (IWA) method; and
2. The UFW Integrated Flow method.

Two water audits methods were used so that the results from both methods could be compared while ensuring their consistency. A brief description of the water balance methods and associated key performance indicators used in this research are provided below.

<u>Water Audits</u>

Leakage detections and controls are usually referred as the 'bottom up' approach that is used to reduce leakage in water distribution networks. These activities require investment in specialised models and equipment, but their projected costs can objectively be weighed against the inherent costs of water losses as determined by a top-down water audit method (Mathis et al., 2008). The water audit, also referred to as water balance, is used to systematically determine where losses occur in a water supply scheme and evaluates such losses. An internal top-down water audit approach is largely a desktop exercise gathering data and information from water consumption and loss reports already compiled by local authorities. Hence the method can be used to produce sufficient data which can help to determine the best leakage management strategy involving bottom-up activities. These are usually longer in nature and can be implemented incrementally over periods of months or years. Water auditing measures efficiency, encourages water accountability, quantifies water losses, and standardizes water loss reporting.

Works by Morais and Almeida (2007), Farley et al. (2008), Sturm and Thornton (2007) and Mathis et al. (2008) illustrate the application of the water audit method to define different kinds of losses associated with water delivery. Farley et al (2008) has explained the structure and terminology of the standard international water balance method developed by the IWA and which has been adopted by national associations in many countries across the world. Other water audit methods such as the 'UFW: integrated flow method' developed by the Department of Environment, Heritage and Local Government (DOEHLG) in Ireland may also be used in other countries.

Study carried out by Halifax Regional Water Commission (HRWC - Water service provider representing 4 municipalities in Canada) shows that the use of IWA methodology has reduced leakage in the distribution system by 27 million litres/day which represented an annual savings of $500,000 (Yates, 2005). Reduction in leakage also helped to reduce the plant output considerably and hence the cost of treating water. This was considered a major achievement by HRWC.

NRW and UFW

NRW and UFW are two terms widely used to describe water losses in water distribution networks. UFW includes mainly leakage from WSS as well as under reading of water meters, water loss through overflow at service reservoirs, theft, etc.

NRW is water that has been produced and is "lost" before it reaches the customer. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses (for example through theft or metering inaccuracies). High levels of NRW are detrimental to the financial viability of water utilities and to the quality of water itself. NRW is typically measured as the volume of water lost as a share of net water produced.

Definition of UFW and NRW and their interrelationship as commonly used is summarised below (Sharma, 2008).

UFW is the difference between the volume of water delivered into a network and the volume of water that can be accounted for by legitimate consumption'

UFW = "net production" – "legitimate consumption"

NRW is the difference between the volumes of water delivered into a network and billed consumption.

NRW = "Net production" – "Revenue water"
= UFW + water which is accounted for, but no revenue is collected (i.e. unbilled authorized consumption)

Acceptable level of UFW

Acceptable level of water loss is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved. As stated by Sharma (2008), the American Water Works Association (AWWA) leak detection and accountability committee (1996) recommended 10% as a benchmark for UFW. Actions required against corresponding levels of UFW are also provided.

Acceptable level of NRW

The following Index and bands have been set up by international organisations (Sharma, 2008) which are used as benchmarks for the IWA water balance method.

Infrastructure leakage index (ILI)
The ILI is an indicator which describes the quality of infrastructure management. It is the ratio of current annual real losses to unavoidable annual real losses (equation 1).

$$ILI = \frac{CARL}{UARL} \quad (1)$$

Where UARL is the unavoidable annual real losses and CARL is the current annual real losses. UARL can be estimated using equation 2 as provided in Winarni (2009) and CARL can be determined using the IWA water balance method.

$$UARL\ (litres/day) = (18 \times L_m + 0.8 \times N_c + 25 \times L_p) \times P \quad (2)$$

Where L_m is the total length of main in km, N_c is the total number of connections, L_p is the total length of underground pipe between the edge of the street and customer meters in km, and P is average operating pressure in meter.
McKenzie and Seago (2005) reports median ILI results for water distribution systems in England, Wales, USA, Canada, Australia and South Africa to vary from 2.33 to 4.97 and mean ILI to vary from 2.58 to 6.26.
Recent study by Winarni (2009) concludes that ILI results are ideal indicator for making international comparison and provides an improved basis for technical comparisons of leakage management performance.

World Bank Institute Banding System
The World Bank institute (WBI) banding system classifies ILI into Bands A to D and set different limits for developed & developing countries. Each Band has a general description of performance and suggests a range of recommended activities as described in Sharma (2008). The WBI suggests that further loss reductions may be uneconomical in a developed country with an ILI value of below 2 unless there are shortages of water. Ireland is a developed country with fair amount of rainfall and a target ILI value of 2 has been used in this research.

Results and Discussions
The total cost, energy loss and CO_{2eq} related to leakage in the three WSS were determined using the collected data. The associated potential reductions if water loss was reduced to an acceptable level were also determined.

Energy and costs
Table 1 and 2 provide a summary of energy and cost associated with water abstraction, treatment and distribution in the investigated WSS. It is to be noted that water in Galway city is mainly supplied by Terryland Water Treatment Plant, although a small percentage was supplied by Luimnagh Water Treatment Plant in 2009. Energy and cost figures illustrated in this study are based on data available from Terryland Water Treatment Plant only.

WSS No.	Annual energy use (kWh)	Annual cost of energy (€)	Annual cost of chemical (€)	Total cost (€)
1	6,166,196	673,634	575,120	1,248,753
2	46,581	6,426	574	7,000
3	130,255	29,381	4,128	33508

Table 1 Total cost per m^3 of water in 2009

WSS No.	Cost of energy per unit (€/m^3)	Cost of chemical per unit (€/m^3)	Variable cost per unit (€/m^3)
1	0.0548	0.0469	0.1017
2	0.0977	0.0087	0.1064
3	0.0688	0.0097	0.0785

Table 2 Unit cost per m^3 of water

It is noted that the annual energy use is much higher in Galway City WSS as the volume of water abstracted, treated and distributed is relatively higher than the two smaller WSS. Interestingly it is observed that although the volume of water is higher, the energy use per unit of water abstracted, treated and distributed is not the lowest in the City. Energy use per m^3 of water in Ardrahan WSS is highest while it is the lowest in Caherlistrane/ Kilcoona WSS.

In Galway City, energy cost is only slightly higher than chemical cost while in the other two schemes, the cost of energy is much higher than chemical cost. Again the total cost in Galway City WSS is higher as the water involved is relatively higher.

Variable cost per m^3 of water abstracted, treated and distributed is highest in Ardrahan WSS and lowest in Caherlistrane/Kilcoona WSS. It is also noted that the cost per m^3 of water produced in Galway City is not the lowest although the volume of water involved is highest.

<u>Water Audits</u>

NRW and UFW were determined by carrying out two water audits, i.e. the IWA Water Balance and the UFW: integrated flow methods. The AWWA water loss control committee free water audit software v4.1 (AWWA, 2010) and the Microsoft Excel spreadsheet developed by the DOEHLG (UFW: integrated flow method) were used to undertake the water audits.

A summary of results using the free water audit software v4.1 is provided in Table 3.

WSS No.	NRW (m^3/year)	NRW as a % of System Input	CARL (m^3/year)	UARL (m^3/year)	ILI
1	12,872,997	82.40	7,288,401	677,500	10.76
2	23,971	36.40	8,076	Not Valid	Not Valid
3	123,931	29.00	17,413	46,190	0.38

Table 3 Water balance result based on the IWA method

NRW is significantly high in Galway City as compared to the two smaller WSS. NRW as a percentage of system input is also significantly high in Galway City (82.40%) as compared to Ardrahan and Caherlistrane/Kilcoona WSS (36.40% and 29.00% respectively). Obviously, the high level of NRW in Galway City is associated with the fact that only non domestic customers are charged for water supply. Domestic customers are exempt from any water charge.

ILI in Galway City is above 10 while it is below 2 in Caherlistrane/Kilcoona WSS. ILI in Ardrahan WSS cannot be determined as UARL is not valid for small water distribution systems such as Ardrahan where (L_m x 20) + N_c< 3000, (AWWA 2010). Lm is the total length of main and N_c is the total number of connections. For Ardrahan WSS, L_m and N_c are respectively 11.2 km and 222 connections. Hence, (L_m x 20) + N_c = 446 which is lower than 3000.

The standard excel spreadsheet was used to determine the UFW in the three schemes. A summary of the results is provided in Table 4.

WSS No.	UFW, m^3/year	UFW as a % of total inflow	UFW as rate per connection, m^3/conn/year	UFW as rate per km main per hour, m^3/km/hr
1	7,546,201	48.30	235.96	2.02
2	13,506	20.50	60.84	0.14
3	30,714	7.20	26.71	0.02

Table 4 Water balance result based on the UFW: integrated flow method

The results confirm that water loss in Galway City WSS is relatively high as compared to Ardrahan and Caherlistrane/Kilcoona WSS. UFW as a percentage of total inflow in Caherlistrane/Kilcoona is below 10% and about 20% in Ardrahan WSS while in Galway City WSS it is slightly below 50%.

Potential reduction in UFW and CARL

Table 5 provides the potential reduction in UFW in the three schemes. The potential reduction in UARL in the two schemes (Galway City and Caherlistrane/Kilcoona) using the targeted ILI of 2 is provided in Table 6. ILI for Ardrahan WSS has been omitted in Table 6 as the UARL for this scheme is not valid.

WSS No.	Actual level of UFW (%)	Targeted level of UFW (%)	Potential Reduction of UFW (%)	Potential Reduction in UFW (m^3/year)
1	48.30	10	38.30	5,981,164
2	20.50	10	10.50	6,918
3	7.20	Current level below 10	Nil	Nil

Table 5 Potential reduction in UFW

WSS No.	Actual ILI	Targeted ILI	UARL (m^3/year)	Targeted CARL (m^3/year)	Potential Reduction in CARL (m^3/year)
1	10.76	2	677,500	1,355,000	5,933,401 (7,288,401 - 1,355,000)
2	0.38	Level <2	46,190	Nil	Nil
3					

Table 6 Potential reduction in CARL

The potential reduction in UFW and CARL in Galway City is remarkably close (5,981,164 as compared to 5,933,401). The 1% operational use of water as assumed in the UFW: integrated flow method does seem to be a good estimate in this particular case. The potential reduction in NRW or UFW for Galway City WSS is relatively high. In Caherlistrane further reduction in leakage is not economical as confirmed by the low UFW percentage (<10%) and ILI (<2). In Ardrahan WSS, there is some scope to reduce the current UFW level to below 10%.

Energy Loss and Associated CO_{2eq}

Energy loss in a water distribution network is the product of variable energy used per m^3 of water abstracted, treated and distributed; and the total water leakage in the WSS. Water loss (or CARL) and the energy use per m^3 of water produced were used to estimate the energy loss due to leakage. Table 7 shows the total energy loss and the potential energy savings that can accrue if leakage level in the three WSS was reduced to an acceptable level. For Ardrahan WSS, the potential reduction in UFW has been used rather than CARL.

WSS No.	Energy use per m^3 of water (kWh/m^3)	CARL / UFW (m^3/year)	Total Energy Loss (kWh)	Potential Reduction in CARL / UFW (m^3/year)	Potential Energy Saving (kWh)
1	0.5039	7,288,401	3,672,625	5,981,164	2,989,841
2	0.7080	13,506	9,562	6,918	4,898
3	0.3052	17,413	5,314	Nil	Nil

Table 7 Energy loss due to leakage and potential reduction in 2009

Table 8 shows CO_{2eq} associated with energy loss and potential energy saving in the three schemes. Electricity is the only energy used in the three schemes and the corresponding CO_{2eq} is obtained using 533g of CO_{2eq} for every 'kWh of electricity consumed in aggregate' (Howley et al., 2010).

WSS No.	CO_{2eq} associated to total energy loss (Kg)	CO_{2eq}associated to potential energy saving (Kg)
1	1,957,509	1,593,585
2	5,097	2,611
3	2,833	Nil

Table 8 CO_{2eq} Associated to energy loss and potential reduction in 2009

The total energy associated with water loss in Galway City is over 3.5 million kWh with potential savings of nearly 3.0 million kWh if water loss was reduced to an acceptable level. CO_{2eq} associated with projected savings in energy in Galway City is over 2,000 tons. Considering that an average dwelling uses approximately 5,067 kWh of electricity and emits approximately 7.3 tons of CO_{2eq} annually (energy related emission including electricity), (Howley et al., 2010), the potential energy saving in Galway City is equivalent to the electricity usage by approximately 590 dwellings and its associated CO_{2eq} is equivalent to emissions from 218 dwellings.

The total real loss in Ardrahan in 2009 is over 8,000 m^3 with potential water loss reduction of about 7,000 m^3 achievable if leakage was reduced to an acceptable level. The potential water loss reduction in Ardrahan represents approximately 5,000 kWh of energy and over 2.6 tons of CO_{2eq}.

The real loss in Caherlistrane/Kilcoona WSS is over 17,000 m^3 and the leakage level was found to be at an acceptable level. Energy associated with the total real loss was estimated to be over 5,000 kWh which represents over 2.8 tons of CO_{2eq}.

While further reduction of energy loss in Caherlistrane/Kilcoona is uneconomical, the potential reduction in energy loss in Galway City and Ardrahan is important.

Cost associated with leakage

The cost associated with leakage is essentially the variable cost of water abstraction, treatment and distribution. Cost associated with leakage is the product of variable cost of water per m^3 and the estimated volume of water leakage. The total cost associated with leakage and the potential cost reductions in the three schemes if leakage level is reduced to an acceptable level are provided in Table 8. For Ardrahan, UFW has been used rather than CARL. Table 9 also shows the total cost associated with leakage and the potential cost reduction in the three schemes if the CARL/UFW level is reduced to an acceptable level.

WSS No.	Variable Cost of water per m^3 (€/m^3)	CARL / UFW (m^3/year)	Total Cost Associated with CARL/ UFW (€/year)	Potential Reduction in CARL/ UFW (m^3/year)	Potential Reduction in Cost (€/year)
1	0.1017	7,288,401	741,230	5,981,164	603,427
2	0.1064	13,506	1,437	6,918	736
3	0.0785	17,413	1,367	Nil	Nil

Table 9 Total cost associated with leakage

It is evident that the cost implication of leakage is significant and is much higher in Galway City WSS due to its size. Further cost saving is not economical in Caherlistrane/Kilcoona, but savings in Galway City is high enough to warrant further reflection.
The total cost and potential reduction in cost if leakage is reduced to an acceptable level in Galway City are 741,230 and 603,427 respectively.

Conclusions

The method used has successfully exposed the severity of leakage in the three WSS by associating energy and cost with it. The main conclusions are summarised below.
In Galway City WSS UFW is as high as the volume consumed and is far higher than the two other schemes studied.
The two different water audit methods used have proved to be very useful for assessing and comparing leakage in the three WSS. The method developed by IWA has recently received lot of attention and has proved to be very successful in many countries around the world but it has some limitations especially when considering small WSS like the Ardrahan where the UFW: Integrated Flow Method may still be used. More work is however required to standardise the later method.

Based on the ILI results, it is concluded that leakage management in Galway City WSS is not adequate and the following activities based on Sharma (2008) are required urgently.

- Review asset management policy
- Deal with deficiencies in manpower, training and communications
- 5-year plan to achieve next lowest band
- Fundamental peer review of all activities

The level of leakage in Caherlistrane/ Kilcoona is acceptable and the following activities are important.

- Investigate pressure management options
- Investigate speed and quality of repairs
- Check economic intervention frequency

The total energy associated with water loss and potential reduction in energy use if water loss is reduced to an acceptable level is significant, especially in Galway City. Being a large network on its own, Galway City Council can invest in additional resources both in terms of manpower and equipment to reduce the level of water losses. The potential reduction in energy losses is low in Ardrahan WSS, which may not justify the use of full time resources to manage leakage. In similar WSS, there may be scope to build up a centralised team responsible for leakage control activities in a few schemes which are within a common area.
The potential CO_{2eq} reduction due to reduction of leakage to an acceptable level shows that the water sector may help to reduce the overall Ireland GHG emission to some extent. It may help Ireland to maintain its current level of CO_{2eq} to below the Kyoto target level which is set to slightly above 60 Million tons (Howley et al., 2010) for the period 2008 – 2012.

Once energy data is available, the indirect CO_{2eq} associated with it can readily be estimated. Similar exercise in other WSS in Ireland may help to quantify the total indirect CO_{2eq} associated with the drinking water supply in the country although more works are required to determine the CO_{2eq} associated with the use of chemical to help quantify the total indirect CO_{2eq} emitted in this sector. The estimate of CO_{2eq} for the water sector is important as it will help to quantify the contribution of the water sector to the total GHG emission in Ireland.

The unit variable cost of water in Galway City is highest which confirms that unit cost of water does not depend solely on size of a WSS but also on factors such as raw water quality and topography of the area it serves.

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Disclosures

Authors have nothing to disclose.