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Sustainable economic level of leakage in Norway and Sweden – manual of practice

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Abstract

Awareness of water's value, high water losses, occasional water shortages and increased costs arising from new treatment requirements has increased focus on reducing water losses. For water loss management, SELL (sustainable economic level of leakage), can be used. SELL includes not only the long-term utility costs and benefits, but also external social and environmental leakage costs, including traffic disruption during pipe repair and replacement work, carbon footprints and health risk effects from leaking pipes with inadequate pressure. The aim of the project was to adapt SELL to Norwegian and Swedish conditions and prepare a calculation model for SELL for use by water utilities. A spreadsheet was developed to calculate water balances and leakage. Another was developed for calculating SELL for the utility. The latter spreadsheet includes research-based default values if no local data are available. An uncertainty analysis was used to show how much input data uncertainty affects the result. The conclusions are that, when all externalities are included and new leak reduction techniques are developed, SELL is lower than expected. The authors believe that the manual will help significantly in fighting water losses, especially for small- and medium- scale water utilities.

Key words: digitalization, economic valuation, SELL, sustainability, water losses

INTRODUCTION

Historically, countries like Norway and Sweden have had enough water, and it has been cheap to treat and transport. Both countries have high rates of water loss compared to the EU average, (Eureau 2017). Basic conditions, such as generous access to water and long pipe length per inhabitant explain some of the differences between these countries and many others in Europe. However, awareness about the value of water, high water losses, occasional water shortages and increased costs due to new treatment requirements has increased focus on reducing losses.

SELL (sustainable economic level of leakage) includes not only long-term costs and benefits internal to the utility, but also external social and environmental costs, such as traffic disruption during pipe repair and replacement work, carbon footprints and health risk effects from leaking pipes with inadequate pressure. IWA's manual 'Performance Indicators for Water Supply Services. IWA Manual of Best Practice' (Alegre *et al.* 2000) incorporates a definition of 'water balance', a concept that is fundamental to determining a correct value for SELL.

Water losses can also be considered using the infrastructure leakage index (ILI), the ratio of current annual real losses (CARL) and unavoidable annual real losses (UARL) (Lambert *et al.* 1999). CARL is an empirical value for the lowest real losses achievable technically and depends on service

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connection density, system pressure and average service connection pipe length between the water mains and consumers' water meters. According to the World Bank Institute Banding system (Seago *et al.* 2005) an ILI below 1.5 is 'excellent', 1.5–2.0 is 'good' and 2.0–2.5 'reasonable'. In Sweden only 20% of the municipalities have an ILI <2.5.

Many countries are struggling with water loss management. Denmark's water losses are much lower than Sweden's and Norway's. Experience from the LEAKman project (LEAKman 2017) indicates five reasons why Denmark has been so successful in reducing water loss: (1) strategic rehabilitation, (2) good construction, (3) accurate measurement, (4) political incentives and (5) culture change. The claim is made for the project that the approach has worked, but in order to further improve it, new technology, products and services will be used. Denmark also has good, natural basic conditions for keeping pressure relatively even and low in each pressure zone due to its flat terrain. Norwegian and Swedish municipalities are working with water loss management, but there is still a lot to do. Many utilities are small, and neither the time nor the skilled staff are found easily. Most utilities struggle with water losses that are perceived as too high – but with no clue of how much they should be reduced to become sustainable.

The aim of the project was to adapt SELL to Norwegian and Swedish conditions and prepare a calculation model for SELL that can be used by individual water utilities.

METHOD

The model was developed in two spreadsheets, the first for the water balance and the second for SELL calculation. The model was supported by a guideline (Malm *et al.* 2018; Malm *et al.* 2019).

Water balance calculation

The structure and definitions of the IWA water balance (Alegre *et al.* 2000) were used for the water balance spreadsheet, Figure 1. This is an essential prerequisite to enable control of the water losses. Internally, within a municipality when comparing different periods, and externally when comparing municipalities, it is crucial to use the same definitions.

Calculation of SELL

For calculating, SELL, the costs of reducing water losses are summed with those arising from the losses. When the sum is at a minimum, the cost level is at its optimum:

$$\textit{Optimum cost level} = \min \sum (\text{Cost of water losses} + \text{Cost of reducing water losses})$$

The costs were identified, and quantification examples carried out. SELL depends on factors throughout the urban water system, both within the supply system itself and in wastewater treatment. By looking at the total annual costs, partly for existing water losses and for measures to reduce them, it is possible to estimate the economically optimal level of water loss for each water utility. External costs – for example, the social and environmental costs – were also included, see Figure 2.

Utility costs for water losses

Water losses mean that water is produced and distributed unnecessarily, leading to higher operating costs because of increased pumping and chemical consumption in the waterworks. Water that has leaked from a water pipe can also find its way into sewers at lower levels, both contributing to higher pumping costs and increasing the load on the sewage treatment plant.

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System Input Volume	Authorised Consumption	Billed authorised consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		unbilled authorised consumption	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorised consumption	
			Customer meter inaccuracies	
		Real losses	Leakage from transmission and distribution mains	
			Leakage from service connections up to the customer meter	
			Leakage and overflows from storage tanks	

Figure 1 | IWA water balance (Alegre *et al.* 2000). The columns, from left to right, show the distributed water volume, and the sources/causes of consumption or loss in increasing detail. The column furthest to the right shows the portion of the distributed water that generates revenue.

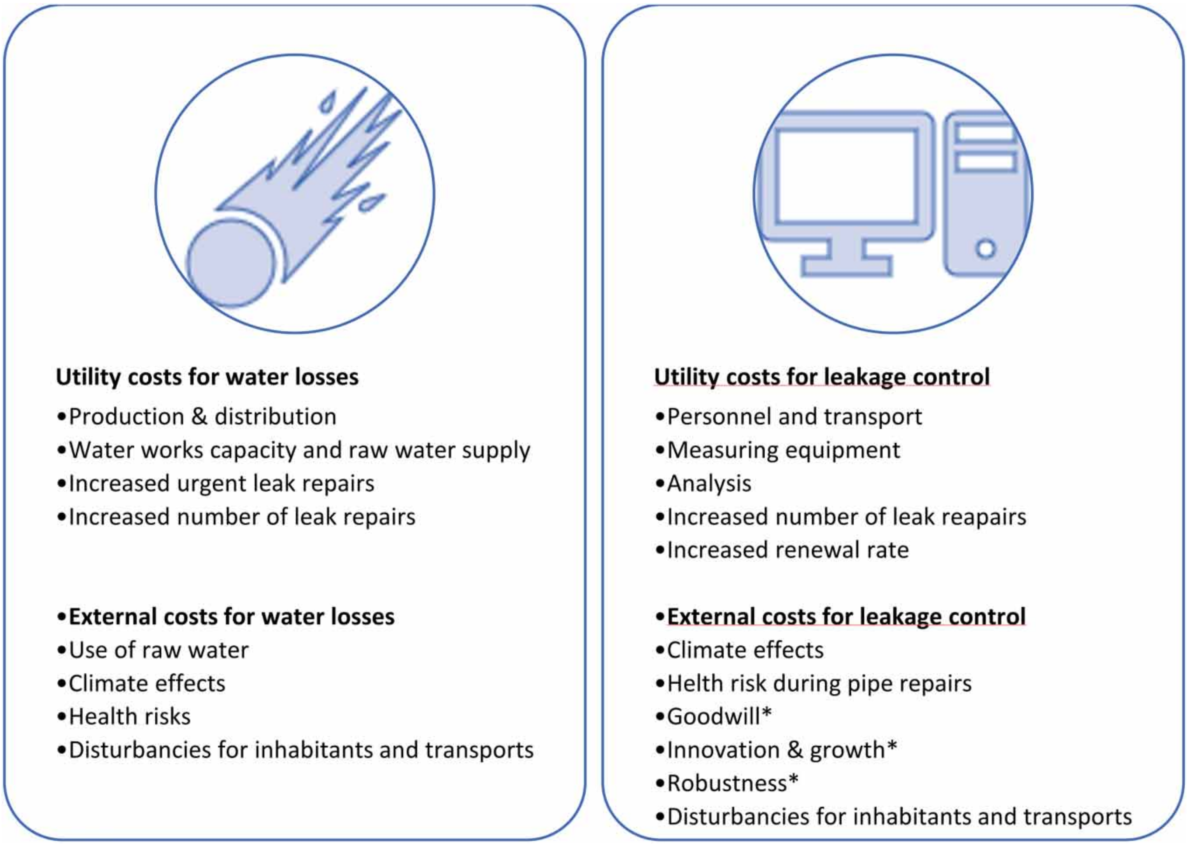

Figure 2 | Costs included in SELL; those marked with an asterisk (*) are negative.

If the water loss is so large that it leads to a need to expand the waterworks, or even to establish new water sources and/or waterworks, this entails considerable costs. High water losses can mean increased service risk as the system may not be able to handle the changes in demand, if the volume produced is close to the operating limit.

Less active leak control increases the probability that more leaks will need urgent repairs, often at higher cost. Further, if no extra renewal effort is made to reduce water losses, more pipe leaks are likely, entailing higher leak repair costs than if a larger proportion of the network had been renewed.

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External costs for water losses

When raw water extraction for supply affects the natural flow in a watercourse significantly, environmental costs will increase due to water loss. Every unit of energy is a cost to both the utility cost and the environment, and must be included in the calculation. Pumping during energy power peaks also incurs environmental costs.

Any leakage in a system poses risks when water pressure is lost. The hole from which the leak occurs can enable groundwater intrusion, as well, possibly, as sewage from nearby leaking sewers. An epidemiological study in Norway showed an increased risk of gastrointestinal diseases, by between 8 and 12%, in areas that had been depressurized as a result of repairs or maintenance (Nygård *et al.* 2007). In Sweden, a study by Säve-Söderbergh *et al.* (2017), conducted in five municipalities in 2014–2015, showed a corresponding increase in risk, although from 1.0 to 1.6%. Malm *et al.* (2013) showed data that do not support a general significant increase in risk related to leak repairs in Gothenburg, although there was an indication that the risk is greatest during total pressure loss and when the inside of the pipe is exposed. The risk is also more likely to increase with repair of more acute and stressed leaks. The better the repair routines, the lower the risk. As most Swedish municipalities do not assess health risk themselves, the results from Säve-Söderbergh *et al.* have been used as the default in the spreadsheet together with society loss data for work leave per occasion.

When there is no active leak detection, fewer leaks are repaired but the repairs that occur cause greater disturbance because they are acute. The disturbances are not usually so extensive, however, that they entail significant social cost (Speers *et al.* 2002). If the repairs take a long time, consumers often receive temporary supplies, making delivery disturbance insignificant. According to Marlow *et al.* (2011) and Ofwat (2008), disturbance for commercial business occurs during pipe break repairs, including noise, impaired access, interference in public transport and effects on aesthetic conditions.

Utility costs for leakage control

Leakage control generates a need for technicians and engineers who work on leak detection and analysis. The biggest costs are for salaries and vehicles. The costs of measuring equipment such as sensors, flow meters and pressure meters must also be included. For example, if the utility uses pressure reduction to decrease water losses, this entails costs for installing and operating the systems. Experience shows that leakage is reduced by 1.4% for a 1% pressure reduction (Thornton & Lambert 2007). The load on the pipe system also decreases if the pressure is reduced.

Structured work to reduce water losses brings the cost of personnel to do analyses, as well as computer programs. Hydraulic network models bring advantages when working on leakage control, but the costs of establishing and operating them should not be included because their use brings other advantages, such as the ability to test how new connections and capacity changes affect the system.

There will also be additional costs for repairing the leaks discovered, although some will be so large that they would be found anyway. Increasing the pipe renewal rate to reduce water losses adds to these costs. Pipe renewal is often done to repair leaks, not to reduce leakage levels, and there is usually no correlation between pipe renewal rate and reduced water losses (Venkatesh 2012; Malm *et al.* 2015). For reduction, the renewal must be both targeted and comprehensive to be effective. Since where the leakage location in the pipe network is not always known exactly, many meters must be replaced to reduce water loss. However, renewal is important to maintain general good status in the network.

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External costs for water loss management

Active searching for leaks yields more that need repair and, hence, leads to increased carbon dioxide emissions. Ofwat (2008) suggests using the environmental price based on carbon dioxide emissions from fuel during replacement and repair work.

The size of the health risks depends on how the pipe break/leakage occurs and how the repair is carried out, as described above.

Goodwill is the value that exceeds the physical value of the company's assets, things like 'good reputation', and high trust and confidence – for example, a water company that does not waste water. In the water industry, low water loss can also increase employee pride, which increases the attractiveness of the workplace. Using smart water technology has the highest potential and greatest opportunities for contributing to social benefits (DNV GL AS 2017). Goodwill is a 'negative' cost – that is, it reduces the total cost.

Smart water technology has the potential to contribute to social benefits by increasing economic growth (DNV GL AS 2017) and it is suggested that the innovation potential is about 5–10% of the cost of installation. Innovation and growth both lead to reduced total cost.

Active leak detection provides a good overview of the management system and low leakage levels provide security for employees. Security means that the operators need not worry, and that less working time is used to describe and explain leakage and missing results, which, at later stages, reduces stress levels. Robustness also yields reduced costs.

Active leakage work leads to more repairs, but, as they often become easier, the social impact is reduced and thus the total cost is low. In many cases, traffic is only disrupted temporarily. Equally, most water users can accept short breaks in supply, especially if they are forewarned; that is, planned breaks (Bylund & Lille 1999; Speers *et al.* 2002).

RESULTS AND DISCUSSION

The water balance spreadsheet was developed and used to calculate the water balance and leakage on the basis of the minimum night flow; that is, both top-down and bottom-up perspectives. Performance indicators are generated and some of the input data are accessible from the SCADA system. An uncertainty analysis shows how much input data uncertainty affects the result. ILI results are also shown and can be compared to the World Bank Institute Banding system (Seago *et al.* 2005).

The other spreadsheet enables determination of the utility's SELL and incorporates research-based default values for use where no local data are available. Default values for leak reduction management and installing new technology are included, and the results can be evaluated for different conditions. Research-based default values for health risk are also included. The SELL spreadsheet is linked closely to that for water balance and described in a manual. The results are shown in tables and figures, like Figure 3.

The work was done in co-operation with leading Norwegian and Swedish water utilities. The conclusion in relation to assessing water loss is that its measurement as m^3/km/d is a much better indicator than the use of percentages. The proposed approach is based on and adapted to local conditions.

During model testing, it was found that a need to expand the treatment works, or establish new water sources and/or waterworks, has the greatest effect on the level of SELL. Parameters like goodwill can also affect the results significantly.

Experience from the project and use of the spreadsheets shows that it is difficult to find true monetary values for the social costs of water losses – the 'S' in SELL. How much does reputation loss cost due to high water losses or the disadvantages arising for individuals due to an increased number of

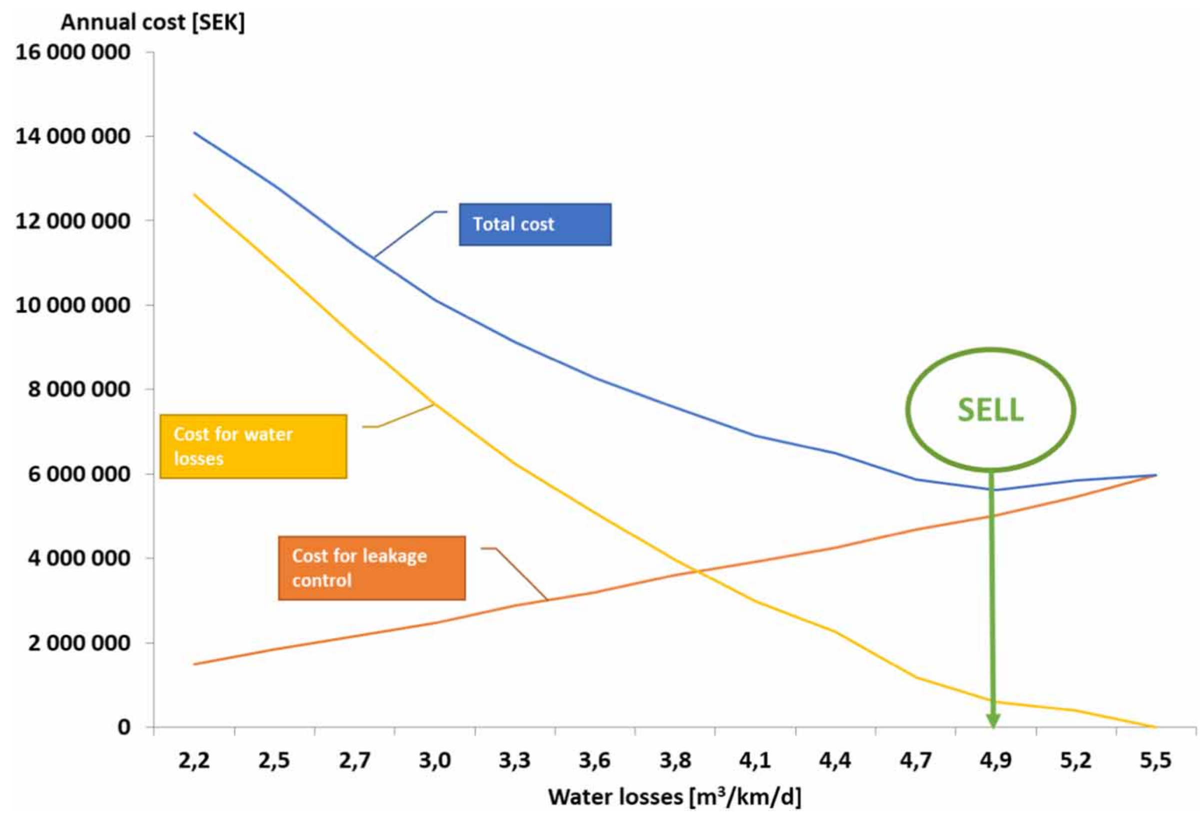

Figure 3 | Typical SELL calculation results.

leak repairs? These are difficult issues for municipalities to quantify, and experience of including social costs in calculations is rather limited in Sweden and Norway.

CONCLUSIONS

The model developed provides an overview of the water balance and shows the water utility how they can best work to reduce water losses. Assessing the desired level of water loss using socio-economic analysis – comparing the utility and social costs of water losses with the same costs of reducing water losses – provides a good basis for water utilities to optimize their work. Each municipality must find its own optimum SELL value as one size does not fit all.

A correct water balance will provide the basis for statistics at national level, as well as for accurate data when communicating with news media, international contacts and authorities, and so on. If the national water loss values are wrong, the wrong measures could be communicated. It is important that this does not happen, especially in communications about water shortage.

Finally, when all externalities are included and new leak reduction techniques are developed, the value of SELL is lower than would have been expected. The authors believe that the manual will be very valuable in fighting water loss, especially for small- and medium- scale water utilities.

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