Taking water efficiency to the next level: digital tools to reduce non-revenue water

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ABSTRACT

Efficiency optimization of urban water systems is a growing concern for water utilities worldwide. This case study aimed at evaluating the impact of using cloud-based tools on the reduction of both real (real-time network monitoring) and apparent water losses (integrated customer meters management) in two water utilities. The incorporation of smart water solutions with a methodology for the management and operation of the systems allowed us to diagnose, prioritize areas and define actions to improve efficiency. Using a real-time monitoring tool allowed us to categorize bursts and to evaluate their impact on water loss volumes and to identify operational inefficiencies regarding detection and repair times, particularly in small and medium bursts. Additionally, the implementation of an integrated customer meters management tool allowed for an optimized meter management reducing apparent losses by estimating metering errors more accurately, enabling the water utilities to replace meters based on specific lifespan. Digitalization, through the implementation of optimized algorithms and early warning systems, allowed the analysis of data in a methodical and prompt manner resulting in non-revenue water reduction up to 8% in 3 years while improving the digital organization of data and its quality (reliability and accuracy), interdepartmental organization and communication, capacity building and utilities’ image among stakeholders.

Key words | apparent losses, cloud-based solutions, digital water, efficiency projects, non-revenue water, real losses

HIGHLIGHTS

- Two water utilities implemented web-based tools to promote the sustainable reduction of non-revenue water.
- Implementing a real-time monitoring tool, utility A and B decreased 13 million m³/year in real losses.
- Using an integrated customer meters management web-tool, both utilities decreased apparent losses by 3.1 million m³/year.
- Non-revenue water reduced by 8% overall, resulting in savings of 5.8 million € in 3 years.
INTRODUCTION

During the last century, the global demand for water has been rapidly increasing due to population growth, food and energy security policies, macro-economic processes such as trade globalization, changing consumption patterns and urbanization. Specifically, increasing urbanization causes highly localized pressures on freshwater resource availability (WWAP 2015). Water losses from urban water distribution systems can amount to one-third of the water abstracted which may imply significant revenue loss (Ananda 2019). With such water distribution losses, water utilities play a key role in guaranteeing an optimized management of the urban water cycle whilst ensuring economic and environmental sustainability. The activities needed to manage water losses can be categorized in three stages: (1) assessment and monitoring of water losses, (2) planification of cost-effective measures and (3) implementation of reactive and proactive actions to detect leakage and illegal use (Farley 2001; AL-Washali et al. 2016).

As such, to tackle water losses, one must first calculate the water balance which quantifies the total water volume entering the system and divides it into revenue water and non-revenue water (NRW). NRW is further divided into unbilled authorized consumption and water losses which are typically divided into real losses (leakage in mains, service connections and storage tanks) and apparent losses (customer meter inaccuracies and unauthorized consumption) (IWA 2000; Alegre et al. 2016).

The complex configuration of water distribution systems must be considered when selecting the real losses identification methodology to be applied. As such, dividing the system into district metered areas (DMA) to analyse the mass balance is commonly used as it results in better leakage detection, location isolation and thus, reduce the detection time (Farley 2001 and references therein; Eliades & Polycarpou 2012). The identification and localization of bursts/leaks can be performed using hardware methods or software-based methods (Li et al. 2015). Hardware methods include acoustic detection methods (e.g., leak correlators and leak noise loggers) and non-acoustic methods (e.g., gas injection, ground penetrating radar technology or infrared photography). These methods are increasingly more accurate but often incur high costs given the expensive equipment and the large number of human resources needed. With the increased innovation in the internet-of-things (IoT) and decrease of cost observed in such devices (e.g., online water flow and pressure meters), practitioners are more and more looking into the deployment of software-based solutions. These are less expensive to implement and provide crucial information on a more limited area where a possible leak/burst may be occurring (Li et al. 2015; Wu & Liu 2017). Furthermore, real-time monitoring and statistical analysis of parameters such as flow allows us to determine the minimum night flow analysis of each DMA and to close the water balance on a daily or even hourly basis and subsequently estimate the level of real loss (Thornton et al. 2008; Loureiro et al. 2016).

While real losses refer to the physically lost water, apparent losses refer to the sum of water that has been used but has not been paid for (AL-Washali et al. 2016). In well-managed utilities, metering errors account for a high percentage of the apparent losses (Arregui et al. 2018). To reduce metering errors, water utilities traditionally replace customer meters based on their age. However, the error associated with each meter can be due to meter wear and tear, incorrect installation practice, lack of maintenance or calibration, incorrect meter type and class for the application, incorrect meter sizing, demand profile or demand type problems (Criminisi et al. 2009). These metering errors can be minimized by implementing a continuous programme which includes field work (e.g., water meter installation and periodic auditing), laboratory work (e.g., audit meters and assessment of meter’s accuracy) and management tasks (e.g., cost-benefit analysis, meter selection and meter replacement plan) (Arregui et al. 2012). There are several water meter types which are classified on the flow measuring mechanism (mechanic, electromagnetic and ultrasonic) which affects the measurement accuracy. In addition, the model and brand of the meters can also have an effect of such measurement even when using the same measurement technology (Karadirek 2020). As such, an optimized and utility-specific replacement plan which takes into consideration all these steps is crucial to maintain apparent losses to a minimum.

In summary, NRW reduction projects typically require high amounts of data generated from the daily operations of
Finding water utilities which need to be analysed in a quick and effective manner. As such, for utilities aiming to improve its efficiency, the development and implementation of cloud-based solutions to assist such projects in reducing real and apparent losses is a must have. Having cloud-based solutions is particularly important since having a third-party provider exempts the water utilities from having specialized hardware or IT personnel to maintain the solutions. Additionally, cloud-based solutions offer faster implementation and updates allowing its use in a short time.

On one hand, real-time monitoring tools may perform a comparison between normalized water consumption patterns and real online flows, triggering alerts for anomalous or extraordinary events such as leaks, pipe bursts, meter or transmission malfunctions or anomalous consumptions. On the other hand, the integrated customer meters management tool may compute metering errors based on diameter, consumption, age, brand and model. Subsequently, it generates a list with all the meters to be replaced, potentially stopped, with anomalous consumptions and wrongly sized. The case study presented herein aimed at evaluating the impact of using two online tools on the reduction of both real (flowise for network monitoring) and apparent water losses (meterwise for integrated management of meters).

METHODS

Main objectives

The work herein presented aimed to evaluate operational improvements and its impact on NRW reduction programmes promoted by AGS, a Portuguese water company, owned by Marubeni, and responsible for the management of 13 water utilities in Portugal and Brazil under concession agreements and public–private partnerships and for the provision of engineering services to water utilities in Europe, South America and Asia.

Specifically, the work presented focuses on two Chilean water utilities through the analysis and management of anomalous events detected by the real-time monitoring software and the reduction of apparent losses by using a cloud-based software which selects critical customer meters to be replaced. The NRW reduction programmes in each water utility are assessed in this study from 2015 (year 0) to 2018.

Detection of bursts and anomalous consumption (flowise)

For the reduction of real losses, AGS developed flowise, a real-time network monitoring system which integrates information from historic flow measurements and other hydraulic variables such as pressure, water levels, chlorine concentration or conductivity. The data are updated and continuously analysed by algorithms which have been published and validated by the scientific community (Loureiro et al. 2016). Data are automatically validated and normalised by detecting and correcting anomalies due to metering problems, like faulty transmission or inadequate acquisition. This normalization aims at obtaining data with a regular time step, preferentially of 15 min, where the mean flow value (or other variables) is obtained through numerical integration.

Additionally, flowise is structured based on existing DMA of each distribution system. DMA are first identified by an engineering team and singled out in flowise. These DMA correspond to geographical areas described in the existing cadastre with the specific flow being defined by a single or a set of meters. Subsequently, consumption patterns are determined and regularly updated for each specific DMA reflecting daily (weekdays, Saturday, Sunday and holidays), weekly and seasonal human behaviours. Subsequently, a comparison between the normalized consumption patterns and online flow measurements is performed. Alarms are triggered when significant differences (considered when three or eight consecutive flow measurements are above the 95th percentile, for large and medium bursts, respectively) are detected (Figure 1). These differences are due to abnormal uses and can be categorized into events such as leaks, pipe bursts, meter or transmission malfunctions and anomalous consumption. The categorization of events is done by the operational team in the field. These alarms are automatically sent to selected users, so that action can be taken to minimize or prevent the consequences of such events.

Apparent losses reduction (meterwise)

The methodology used to develop the web-based solution to assist in apparent loss reduction (meterwise) followed the principles presented by Arregui et al. (2006). The methodology determines the optimal lifespan of a meter considering the balance between the cost of meter
replacement and the gains obtained from the reduction of sub measurements. Briefly, the time (year) when replacing a meter is economically favourable is determined taking into consideration the Net Present Value (NPV) of the replacement Chain (NPVC) (Equation (1)) which is calculated over a period of 30 years. The optimized lifespan corresponds to the year when \( \text{NPVC}_t < \text{NPVC}_{t-1} \).

\[
\text{NPVC}_t = \left[ \frac{(1+r)^t}{(1+r)^t - 1} \right] \times \text{NPV}_t
\]

where \( \text{NPV}_t \) is the net present value for year \( t \) and is determined by the sum of the initial cost of the meter with the generated cash-flows since the beginning of the project until year \( t \); \( r' \) is the real discount rate which is the discount rate taking in consideration the inflation rate; and \( i \) is the years since installation. The annual cash-flow represents the revenue based on the customer meter's billing and is determined according to the following equation:

\[
\text{Cash - flow} = \frac{V_R + C}{(1 + r)^{t-1}}
\]

where \( C \) is the average tariff and \( V_R \) is the registered volume and is calculated using Equation (3).

\[
\text{Registered volume} = \text{AYC} + \text{AYC} \times \epsilon_i + \text{AYC} \times (i - 1) \times a
\]

where \( \text{AYC} \) is the average yearly consumption; \( \epsilon_i \) is the initial error; and \( a \) is the degradation rate.

In order to determine the degradation rate, which is the rate of decay in metering accuracy over time (increase of metering error), and the initial error which is the customer meter's error at the time of installation, a group of customer meters from each utility was selected for laboratory bench tests which allowed us to build the error curve.

In the case study presented, the number of meters selected for testing in each utility was also dependent on the available budget of each utility. As such, in order to reduce possible inaccuracies, a compromise was obtained by selecting a range of different meters to comply with the budget. To have a representative sample, the group of meters selected for testing was selected from clusters with the highest volume consumption and was defined with the analysis of the areas, ages and models. The representative clusters were also divided by different water sources to account for different water quality. The number of meters selected for testing is shown in the Results and Discussion section.

For each meter, an error curve was obtained in order to determine its evolution in time as well as each meter global error. The weighted global error for each meter was obtained by crossing its error curve with the histogram of the average water consumption. Based on the global error of each meter and its age, the degradation rate was obtained using a linear regression.

Based on the results obtained and applying the lifespan methodology, the two utilities presented replaced customer meters with critical errors in an optimized way to reduce apparent losses.
**System’s design architecture and implementation**

Producing data is now the easiest step towards the real-time analysis of integrated information. The management and analysis of this data are the bottleneck of organization implementing smart system. When developing such a system, it is essential to understand which data are needed to support the tools and understand the wide range of databases needed to collect all the data. As such, AGS designed the system in order to securely collect vast amounts of information from multiple sources and formats providing insight and helping decision-making (Figure 2). For network monitoring purposes, it is important to ensure that all relevant variables are being properly metered using adequate equipment and are integrated in a systematized and automatic manner. This means that flow, pressure, chlorine, pH or other data from each individual meter are sent to a database for storage. In many cases, the different metering equipment installed in the utility from different suppliers can result in data being stored in different formats and in multiple databases such as SCADA or telemetry systems which will disperse and hamper the analysis of data. This issue can be overcome by gathering all data from all platforms to a single platform as explained in this section.

Operationally, data from multiple origins (e.g., SCADA, Telemetry and other) are imported using Representational State Transfer (REST) APIs into the real-time network monitoring module (flowise) where it is aggregated and normalised to generate processed data and warning events (alarms). More specifically, all metered data are converted into a normalized time step and stored in a centralized database using a standard format. Subsequently, data can be analysed to perform water balances in DMA considering data from the water network input and output meters in an easy and expeditious manner, even if meters are initially associated to different systems. The monitoring system was designed to collect data from original databases with the highest frequency possible (real-time); however, some water utilities do not have data with such frequency and adopt a time step that balances the need for information and the cost of communication (e.g., a 15 min or hourly frequency).

To understand the behaviour of water distribution networks, it is also important to have information about each DMA or distribution system characteristic in terms of number of customers, pipe length, diameter and materials, number of service connections or area, to name a few. Most of these variables are discrete and stored in the geographic information system (GIS). This alphanumeric and spatial data (pipes presented as lines/polylines and DMA presented as polygons) can be directly uploaded to flowise as shape files.

Other data such as customer data, meter data and meter readings from a customer relationship management (CRM) database are processed using specialized algorithms by the integrated customer meter management tool (meterwise). meterwise can connect with any CRM used for commercial management. This is done either through a direct

![Figure 2 | System’s design and architecture.](http://iwaponline.com/jh/article-pdf/23/3/453/892596/jh0230453.pdf)
connection to the CRM or with a copy or extraction of the original database. Thus, to collect the indispensable data regarding customer meters, two REST webservice were developed to obtain: (1) customer meter’s features (diameter, installation date, equipment type, brand, model or precision class) and (2) meter readings (reading date and volume). Data regarding the meter’s cadastre and readings are stored in different tables and are automatically associated by using each meter’s ID. Update frequency is customizable depending on the utility’s practices for customer meter readings. For water utilities that do not have smart metering technology, a monthly update is generally enough.

The resulting analyses from both modules are integrated in a business intelligence solution for in-depth analysis and reporting which will assist in the definition of action plans. Such action plans might include the replacement of customer meters or the repair or replacement of a water pipe. The data resulting from these actions will be uploaded to the system and updated.

In summary, the software tools’ infrastructure is secure (all integrations are IP restricted and all tenants are logically separated from each other), reliable (all data are backed up into cloud servers and have a guaranteed 99.999% service level agreement (SLA) uptime), flexible (hardware resources are available on demand with no need to install new physical components) and directly accessible by a virtual private network (VPN). In order to access the utility’s databases and infrastructure, data are remotely transferred without further local interventions. The end users can access the tools using any device through their browser which allows remote assistance as shown in this study.

RESULTS AND DISCUSSION

Characterization of the water utilities

The main characteristics of the water system of each utility are presented in Table 1. The two Chilean water utilities are responsible for supplying 1.3 million inhabitants and managing 400,000 customer meters which measure an average volume of 9.8 million m³/month. In 2015 (year 0), utility A and utility B presented NRW levels of 35.8 and 42.8%.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Variable</th>
<th>Units</th>
<th>Utility A</th>
<th>Utility B</th>
</tr>
</thead>
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<td>Customers</td>
<td>No.</td>
<td>161,896</td>
<td>240,444</td>
</tr>
<tr>
<td></td>
<td>Network length</td>
<td>km</td>
<td>1,117</td>
<td>2,032</td>
</tr>
<tr>
<td></td>
<td>District meter areas</td>
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<td>115</td>
<td>116</td>
</tr>
<tr>
<td>Infrastructural</td>
<td>Mains bursts</td>
<td>No.</td>
<td>781</td>
<td>188</td>
</tr>
<tr>
<td>condition</td>
<td>Service connection bursts</td>
<td>No.</td>
<td>5,077</td>
<td>5,231</td>
</tr>
<tr>
<td>Operational control</td>
<td>Flow meters</td>
<td>No.</td>
<td>146</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>Pressure meters</td>
<td>No.</td>
<td>230</td>
<td>170</td>
</tr>
</tbody>
</table>

To assist in managing water loss reduction, both utilities have several IoT flow and pressure meters strategically placed in the network which communicate with flowise in real-time. In addition to differences in flow data, flowise detects differences in pressure data from pressure reduction valves (PRV) or pressure critical points (PCP). These differences can indicate and pinpoint the occurrence of bursts when a significant pressure reduction is detected.

Whilst some meters were installed before the kick-off of the project, a few more IoT meters were strategically installed throughout the project. While utility A installed 11 and 125 flow and pressure meters, respectively, utility B installed 12 and 147 flow and pressure meters, respectively. The reasoning behind this was to achieve total sectorization of the network (DMA) and monitoring via flowise to reduce NRW and comply with the local regulatory demands.

Technical and operational challenges

When implementing such NRW and digitization projects, several technical and operational challenges may arise. Being responsible for the management of the entire urban water cycle in their regions, the utilities, presented in this study, faced the challenge of decreasing their NRW levels while having to continuously supply over 400,000 customers which are scattered over large areas. At the start of the projects, water operations had a large dependency on manual labour and internal procedures had low levels of sophistication, control and traceability. This made assessing performance either at DMA level or utility level and
auditing results a lengthy and slow process. Records of daily operations were made on paper and were not analysed unless a major problem occurred.

These procedures not only hampered the decrease of NRW but also allowed a continuous degradation of infrastructure. The existing software before year 0 was very poor as it only allowed the support of day to day operations, not allowing a comprehensive monitoring in terms of spatial coverage and data frequency. Additionally, not having the information audited and centralized in a systemic way caused constraints in terms of misrepresented information with different data being presented for the same variable depending on the employee who provided it. This caused interdepartmental communication to be a difficult and time-consuming task.

In such a sense, digitalization of water services was a key topic to be addressed in the utilities. These challenges were overcome during the implementation of the projects presented in this study.

**Detection of anomalous flow events**

The implementation of flowise allowed the generation of 2,544 and 3,592 anomalous events in utility A and utility B, respectively, from 2015 to 2018. The different anomalous events were analysed and categorized by the utility operators as (i) illegal consumption, (ii) bursts, (iii) high demand customers, (iv) maintenance works, (v) PRV adjustment, (vi) zone changes, (vii) pipe flushing and (viii) others (which includes water used for fire services, third-party bursts and tank overflows) (Figure 3).

The majority of flow increase events in utility A are due to high demand customers (32%) and zone changes (25%). Bursts come in fourth place, representing 13% of total events, indicating that the water infrastructure condition can be compromised in some locations. The high percentage of high demand customers in utility A is due to its location close to the coastal area with high consumers in the port and services. Due to seasonal water scarcity, the zone changes, which involve modifying the network sectorization, are crucial in this utility to ensure supply due to quantity and quality issues. In utility B, most events are due to bursts (33%) followed by maintenance works (29%) and pipe flushing (20%). From this analysis, one can conclude that categorizing the events is a crucial step to fully understanding the nature of the increase which in most cases is not due to real losses.

**Categorization of bursts and reduction of leak runtime**

The degradation of water supply infrastructure mainly due to age and operational conditions can cause issues like pipe bursts, loose joints and fittings (Eliades & Polycarpou 2012). This degradation will ultimately result in leakages and bursts which will increase the water loss in the system and consequently cause consumer problems, health risks and financial losses (Farley 2001). Depending on the nature and size of the bursts (slowly developing or abrupt), different approaches must be taken. As such, the identified bursts were categorized in three different categories: (1) small bursts or leaks – corresponding to average flows less than 5 l/s, (2) medium bursts – corresponding to average flows between 5 and 15 l/s and (3) large bursts – corresponding to average flows higher than 15 l/s.

During the period of 2015–2018 (Figure 4), utility A presented 71 small bursts, 88 medium bursts and 80 large bursts. The large bursts’ flow was mostly between 21.7 and 55.7 l/s with the maximum detected flow being 231.5 l/s. On the other hand, utility B presented 323 small bursts, 266 medium bursts and 434 large bursts. In terms of flow, the largest burst reached 291.3 l/s with most large bursts having flows between 22.0 and 44.3 l/s.

Average leaks and bursts runtime include three components: awareness, location and repair time, known as the ALR concept (Lambert & Morrison 1996). This will
allow us to determine in a more accurate way the effective real losses volume of a burst, considering both the flow rate and duration time.

Most lost volume in both utilities results from small and medium bursts (Figure 5) which is probably a result of the long time needed for ALR. In fact, most physical water losses at yearly scale can be attributed to the background leakages from the presence of leaks from joints, holes and cracks (Covelli et al. 2015).

In both utilities, large bursts present similar behaviour with the lowest runtime when compared to the other type of bursts. Utility A and utility B had an average runtime of 0.3 and 0.2 days, respectively.

Differences can be observed when comparing the runtime in small and medium bursts in the two utilities. In 2015, at the start of the NRW reduction project, utility A took on average 15.2 and 4.7 days to locate and repair small and medium bursts, respectively. Utility B, in the
same year, had longer runtimes for small bursts, 26.3 days and shorter runtimes for medium bursts, taking on average 3.3 days. The differences observed in small bursts can be explained based on the geographical location of each utility. Utility A is located in a desert area, where it is easier to locate small bursts that can only be detected by acoustic equipment. Whereas utility B is located in an area where the groundwater level is very high, making it more difficult to locate bursts. For medium bursts, these differences are less evident since they can be visibly detected in both utilities. In addition, utility A has more human resources available and thus, more effective when developing active leakage detection activities.

These high detection and repair times had a large potential for improvement as they corresponded to operational inefficiencies which could be tackled and upgraded. Based on this analysis, targets for reducing detection time and repair time in medium and small bursts were defined considering each utility’s context. AGS supported local operational teams through weekly follow-up meetings focused on improving active leakage detection planning and reducing repair times. Results were continuously monitored on the real-time monitoring tool enabling a better control of systems’ performance.

Results show a significant reduction of the leak runtime in small and medium bursts for water utilities A and B after implementing flowwise (Figure 5). During the course of the projects, utility A reduced leak runtime of small bursts from 15.2 to 3.4 days while in utility B, the reduction was from 26.3 to 8.3 days. For medium bursts, the reduction of runtime was from 4.7 to 1.2 days and 3.3 to 0.3 days for utilities A and B, respectively. This reduction has also led to a reduction in the percentage of water loss related to small and medium bursts (Figure 5), contributing to a significant decrease of NRW levels, overall. The results obtained demonstrate that by implementing a real-time monitoring tool, the existing and new problems were highlighted in a methodical and systematic manner enabling the utilities to identify the small and medium bursts faster and thus, to implement oriented actions to successfully reduce runtime and consequently water loss. Based on the infrastructure problems evidenced by flowwise, utility A and utility B successfully replaced 36 and 57 km of their network, respectively.

Customer metering inaccuracies determination

In order to determine the customer metering errors, and taking into account the considerations presented in the Methods section, a global sample of 687 meters was selected (304 meters for utility A and 383 meters for utility B) for laboratory analysis through water meters bench testing. Each water utility selected the domestic meters to be tested based on the highest volume consumption and representativity. The selected meters included DN15 and DN20 diameters of different brands, models and ages (Figure 6). Laboratory bench tests were conducted on these meters in certified laboratories.

The metrological tests conducted allowed us to determine the average error curve of the meters per age and the evolution of the weighted global error and subsequently, the degradation rate. For comparison purposes and as an example, the results obtained for one brand and model are presented in Figure 7. The degradation rate is higher in utility A (−0.8585%/year) than in utility B (−0.4174%/year) for the same brand and model. This difference is most likely due to the different water quality and meter installation.

![Figure 6](http://iwaponline.com/jh/article-pdf/23/3/453/892596/jh0230453.pdf)
procedures which are two of the most common causes for meter deterioration (Criminisi et al. 2009).

A meterwise solution was implemented and tailor made for each utility based on the customer meter’s initial errors and degradation rates. Thus, data from each utility’s active meters were imported into meterwise. This covered a 2-year period, 180,000 customer meters for utility A and 275,000 customer meters for utility B as well as meter readings data covering, corresponding to over 4,115,000 registries. Additionally, certain specificities from each utility were considered such as the average water tariff and cost of customer meters purchase and installation.

The previous results show that initial error and degradation rate are clearly different between utilities. Thus, the meters in each utility will have different lifespans and consequently, different renewal needs. Based on the degradation rate obtained, the lifespan was calculated for different monthly consumptions (Figure 8). This estimation was performed assuming an average tariff of 1.62 and 1.29 €/m³ and a meter replacement cost of 30 and 31.22 €/(DN15 meter), for utilities A and B, respectively. Results show that for the same meter model, utility A will need to replace the meters between 2 and 7 years earlier, depending on the consumption, than utility B.

Such a result clearly indicates that the implementation of a customer meters management tool which incorporates the methodology described can translate into a significant reduction of apparent loss volumes and, thus, into significant revenue increases for a water utility.
This study confirms that the same meter type can have different ageing processes when installed in different water utilities, that different types of meters behave differently within the same water utility (Arregui et al. 2018) and that meter selection should be done based on several parameters such as water quality, consumption, cost and ease of installation (Karadirek 2020).

Reduction of apparent losses

Two alternatives for replacing meters were analysed. Alternative 1 considered the replacement policy at the beginning of the project, in which all meters with ages equal to or above 8 years are replaced. On the other hand, in Alternative 2, the meters are to be replaced based on the lifespan estimation presented in the previous sections and which is the outcome of meterwise.

Utility A, due to water scarcity, has a higher water tariff which results in high gains regardless of the approach taken (Table 2). Nevertheless, replacing the customer meters based on the lifespan (Alternative 2) would need lower initial investment and higher gains and result in a lower payback period. This advantage is more notorious in utility B. By investing 2.8 times less, the utility can increase the NPV by 1,079,765 € and the payback period from 4.1 to 1.8 years.

Therefore, in both utilities presented, Alternative 2 represents the most optimized solution for meter replacement management. The theoretical results obtained (Table 2) were in line with what was obtained in both utilities. During the project, utility A replaced close to 52,884 meters having an average payback of 1.39 years. On the other hand, utility B replaced 53,254 meters and had an average payback of 2.16 years. Thus, by implementing meterwise, utilities were able to increase their revenue whilst decreasing the initial investment.

Table 2 | Economic viability study

<table>
<thead>
<tr>
<th>Utility</th>
<th>Alternative</th>
<th>Investment (€)</th>
<th>NPV (€)</th>
<th>Payback period (years)</th>
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<td>A</td>
<td>1</td>
<td>1,382,478</td>
<td>1,431,697</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>988,986</td>
<td>1,971,952</td>
<td>1.0</td>
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<tr>
<td>B</td>
<td>1</td>
<td>3,414,107</td>
<td>4,442</td>
<td>4.1</td>
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<tr>
<td></td>
<td>2</td>
<td>1,236,554</td>
<td>1,084,206</td>
<td>1.8</td>
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</table>

5-year period with a 10% discount rate.

Global reduction of non-revenue water

In order to reduce NRW, AGS assisted the utilities to incorporate a methodology for the management and operation of the systems, allowing us to diagnose, prioritize areas and define actions to improve efficiency. The implemented tools and actions allowed for a significant reduction of NRW throughout the years of the projects (Figure 9).

Utility A decreased real water losses 7.1 million m³/year, and utility B decreased 5.9 million m³/year.

In terms of apparent losses, in 2017, both utilities adopted the methodology incorporated in meterwise to determine which customer meters to replace. This approach, estimating metering errors based on each meter’s lifespan rather than basing decision solely on the meters’ age, assisted in decreasing the apparent losses volume (Figure 9) whilst promoting the increase in utilities’ revenues (Table 2). This approach led to a decrease of apparent losses of 1.0 and 2.1 million m³/year in utility A and utility B, respectively (2015–2018).

The implementation of flowwise and meterwise allowed the analysis of data in a methodical and prompt manner resulting in NRW reduction of 8.2 and 6.7% in utility A and B, respectively, corresponding to a total volume of 12.8 million m³/year, in the course of the project (2015–2018) (Figure 9).

Digitalization of the water sector

The urban water sector has been facing complex challenges which can be summarized in being able to supply water to customers, with high quality and quantity, while keeping operations affordable. Thus, it is crucial for a water utility to implement smart water solutions to collect and analyse data in a more efficient and coherent manner. By installing IoT devices and tools to aid in data analytics, such as the tools presented in this study, the water utilities can better understand their system and, thus, optimize the operational work and teams whilst guaranteeing the service. The outputs obtained from implementing operational tools such as flowwise and meterwise can be integrated in a dynamic data analysis platform (waterwise; Figure 2) to calculate key performance indicators to assess performance at operational, commercial and financial levels. This will assist water
utilities in the definition of operational actions and support decisions on if, when and how to invest in equipment and activities such as network metering and sensing, customer meters, pipe rehabilitation, active detection equipment and others. Ultimately, with the use of IoT and software tools, the water utilities can improve asset management, workforce transformation and reduce NRW in a more prompt manner which will improve customer service and reduce financial losses (Ramos et al. 2020).

In the last years, new technologies have emerged exponentially and have slowly been adopted by water utilities worldwide which present different digital maturity levels (Sarni et al. 2018). Unfortunately, digitalization of urban water systems is typically left behind when compared with other infrastructures. This is probably due to the fear of new vulnerabilities in a sector that is essential to human life. In addition, water utilities are extremely complex organizations with different and, frequently, isolated siloes. However, the fact that this is a slow moving sector can be seen as an opportunity since lessons can be learned from other sectors and risks mitigated (Moy De Vitry et al. 2019). Different stakeholders should continue to converge to scale and catalyse the adoption of digital solutions to minimize the risks such as water scarcity and security, increasing demand, old and undermaintained infrastructure and climate change.

**CONCLUSIONS**

Real-time monitoring and data analytics tools allow a more comprehensive, diverse and accurate understanding of systems’ behaviour leading to a more effective control of the distribution network and water supply system. Thus, AGS developed and implemented software tools to support operational management, combining two important features, the ability to intervene in systems through events generation and the ability to explore data in a long-term period (based on historical data). This will ultimately contribute to a considerable increase of the environmental and financial efficiency level in water utilities.

The case study presented has highlighted these advantages. On one hand, the use of flowise for real-time monitoring allowed us to categorize bursts and to evaluate their impact on water loss volumes in order to identify operational inefficiencies regarding detection and repair times, particularly in small and medium bursts. This analysis reinforced the importance of operational work efficiency on the reduction of NRW levels, mainly regarding the increased understanding of network events and the reduction of the response time to those events, with a focus on small and medium bursts, usually responsible for the higher volumes of water loss in utilities.

On the other hand, the implementation of meterwise for optimized customer meter management promoted the review of water utilities’ internal processes to guarantee higher metrological control and customer meters data reliability. By estimating metering errors more accurately, utilities were able to replace meters based on lifespan rather than solely on the meter’s age. This further reduced the apparent losses, reducing costs and increasing revenues.

Overall, during the course of the projects, both utilities replaced 106,138 customer meters and rehabilitated 93 km of their smart water network in an optimized way. The project implemented, with the crucial support of flowise and

![Figure 9](https://iwaponline.com/jh/article-pdf/23/3/453/892596/jh0230453.pdf)

*Figure 9* | Real losses, apparent losses and NRW level evolution from 2015 to 2018 in utilities A and B.
meterwise for data analytics, reduced NRW levels by 8% which resulted in reducing 15 million m$^3$/year of real water loss and savings of 5.8 million Euros in 4 years which can be reallocated in other areas of water loss control. In addition, having a common goal, interdepartmental organization and communication improved, capacity building increased and image among stakeholders improved, both at customer and regulatory level. The improvement of the digitalization process in these utilities has allowed them to take water efficiency to a new dimension.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES


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