Implementing tactical plans to improve water-energy loss management
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ABSTRACT

Water utilities are aware of the water-energy loss relevance in supply systems. However, they still mainly focus on daily water loss control (real and apparent losses), without considering the impact on embedded energy. Moreover, they are mostly concerned with the economic dimension and, in most cases, tend to disregard the impact that water-energy loss may have on the quality of service, communication with the consumers, social awareness, water quality and environment. This paper focuses on the application of the developed and tested AWARE-P infrastructure asset management (IAM) methodology to improve water-energy loss management in water supply systems, while demonstrating the main benefits from implementing an integrated approach for water losses and related energy assessment. Results show that indeed the participating iPerdas utilities were able to define tactical measures leading to a more efficient and sustainable service.

Key words | energy efficiency, infrastructure asset management, tactical planning, water loss, water utilities

INTRODUCTION

Improving efficiency in water supply systems through a more rational use of energy and control of non-revenue water is one of the water utilities’ main goals. This issue has gained additional importance in countries like Portugal, where water demand, and consequently revenue water, is decreasing or where water scarcity problems may exist. Conversely, energy costs associated with the overall system’s operation tend to be very significant and, therefore, every measure to increase energy efficiency may have significant economic impacts. Furthermore, due to the water-energy nexus, integrated management of both resources in water supply systems will lead to more significant economic, social and environmental benefits.

Although water utilities are aware of the water-energy loss relevance in supply systems, they are still mainly focusing on daily water loss control (real and apparent losses), without considering the impact on embedded energy. Moreover, they are mostly concerned with the economic dimension and in most cases tend to disregard the impact that water-energy loss may have on the quality of service, communication with the consumers, social awareness, water quality and environment. To ensure the sustainability of water supply systems, these problems should be addressed from a strategic to an operational point of view, including the tactical decisional level.

Aiming at integrated water-energy loss management, the first edition of iPerdas – the Portuguese Initiative for the Management of Water & Energy Losses – was promoted by the National Civil Engineering Laboratory (LNEC). The iPerdas project started in November 2013 and ended in April 2015. In this collaborative project, 17 utilities developed their own water-energy loss management plans, following a joint training and capacitation approach (www.ipertas.org). The project also contributed to more reliable and organized processes for water-energy management within the utilities. Participating utilities received collective, as well as one-on-one, support, specific training and software (AWARE-P, aware-p.org) to develop their tactical plans to improve water-energy loss management,

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while using the infrastructure asset management (IAM) approach – to which the AWARE-P IAM methodology was set.

The IAM approach (Alegre & Covas 2010; Cardoso et al. 2012, 2015; Alegre et al. 2015) consists of an integrated methodology that approaches IAM as a management process, based on Plan-Do-Check-Act (PDCA) principles and requiring full alignment between the strategic objectives and targets and the actual priorities and actions implemented, embedding the ISO 55000/55001/55002 standards on asset management. The approach expressly takes into account that an infrastructure cannot be dealt with in the same way as other collections of physical assets and as a whole it has an indefinite lifespan. IAM must be addressed at different planning decisional levels: a strategic level, driven by corporate and long-term views and aimed at establishing and communicating strategic priorities to staff and citizens; a tactical level, where the intermediate managers in charge of the infrastructures need to select what the best medium-term intervention solutions are; and an operational level, where the short-term actions are planned and implemented.

Following the IAM approach, iPerdas involves three main stages: (1) the establishment of a comprehensive assessment system and a complete water-energy loss diagnosis, (2) the prioritization of the analysis areas for intervention and (3) the prioritization of intervention alternatives for the areas with higher priority. Typically, the decisions taken over water loss reduction are more focused on the real loss component, rather than on apparent loss, without assessing the impact on medium- or long-term horizons (Farley & Trow 2003; Lambert & Taylor 2010). Additionally, decisions usually take into consideration the economic sustainability solely, disregarding other important objectives, namely the quality of service, efficiency of water resources and sustainability of infrastructures (GIZ & VAG 2011).

For the iPerdas approach to be successful, it requires the commitment of the organization chief executive officer (CEO) for its implementation. In the plans, this is shown by the alignment between the strategic objectives of the organization and those for water-energy loss management. The development of the water-energy loss management plans requires the assignment of a team inside the water utility responsible for its progress and application, including approval, implementation, revision and full alignment with other existing plans.

The iPerdas methodology uses a systematic and novel approach for water-energy auditing and performance assessment (Alegre et al. 2005, 2006; Mamade et al. 2014, 2015). First, a well-defined water audit (Alegre et al. 2005, 2006) is carried out for the whole system and its analysis areas or functional areas (e.g., district meter areas, subsystems). Second, an energy audit that uses the estimates of system input volume, authorized consumption and water losses is carried out. Main components of this energy audit include: energy associated with authorized consumption, energy associated with water losses, energy delivered to consumers, dissipated energy (in pipes, pumps, valves), recovered energy. This novel approach identifies not only inefficiencies due to equipment, but also inefficiencies associated with system configuration and water losses (Mamade et al. 2014, 2015). This fact encourages utilities to carry out the joint management of water losses and energy efficiency.

Innovation is central to the iPerdas concept: utilities benefit from the collaborative layout for the exchange of experiences; improve awareness about water-energy losses, internally and externally to the organization; contribute to improving existing technological solutions; and benefit from the results obtained from a large set of utilities within the project (e.g., reference values, laboratory tests for estimating metering errors). In summary, four pillars support the iPerdas project methodology, as shown in Figure 1.

This paper focuses on the application of the AWARE-P IAM methodology to improve water-energy loss management
in water supply systems, by demonstrating the main benefits from implementing an integrated approach for water losses and energy assessment. Results show that indeed, participating iPerdas utilities were able to define tactical measures leading to a more efficient and sustainable service. The project also allowed the validation of the methodology while bringing benefits to the utilities in their water losses and energy management. Besides the contribution to the specification of procedures and the identification of the best practices to improve the accuracy of the different water audit components, the iPerdas approach also provided new methods for metering error estimation (Balaguer Garrigós 2013) and for night flow analysis and anomalous event detection (Loureiro et al. 2015).

The paper is organized as follows: in Section 2, the approach to develop tactical plans and support decisions in terms of water-energy loss management is described; in Section 3, the set of iPerdas 2013–2014 participating utilities is characterized in terms of dimension, non-revenue water, real and apparent losses and energy performance indicators; in Section 4, results of the assessment system, selection of critical areas, prioritization of intervention alternatives and selection of tactics are presented; finally, Section 5 shows main conclusions and further developments.

**METHODOLOGY**

The participating utilities’ main goal in the iPerdas project was to develop a water-energy loss management plan integrated in the IAM tactical level of planning. The plan was developed following the AWARE-P IAM approach (Cardoso et al. 2012), which may be addressed for the different planning decisional levels (strategic, tactical and operational). The strategic level is driven by the organization's objectives. This includes the identification of the strategic objectives and assessment system of the IAM plan, and overlooks a long-term planning (at least 15 to 20 years). This is used to define where the utility would like to be at the end of the defined long-term horizon. The tactical level is used to identify the tactical objectives and assessment system of the water-energy loss management plan integrated in the IAM tactical level of planning. This considers the medium-term planning (up to 3 to 5 years), and aims to define the path that the utility needs to follow through the definition of tactics. And the operational level (typically of 1 year) identifies and programs all the actions to be implemented in the short term, based on the alignment with the tactical and strategic plans (Alegre et al. 2013; Cardoso et al. 2015).

In the iPerdas approach, before defining the tactical objectives and assessment system, including assessment criteria, metrics and targets, the utilities should have: (1) identified relations between the water-energy loss management plan and other plans within the organization (e.g., investments, strategic, other tactical and operational plans); (2) set the planning and the analysis horizons (3–5 years and 5–15, years respectively); and (3) done a preliminary characterization of the system in terms of water and energy audit and analysis of the water meters. The preliminary characterization of the system is set in terms of water audit (Alegre et al. 2005, 2006), energy audit (Mamade et al. 2014, 2015) and water meter analysis (Balaguer Garrigós 2013). This characterization aims at helping the definition of objectives and the assessment system, by identifying the main water-energy inefficiencies and data gaps. This initial characterization benefits from novel and simplified approaches for energy auditing and the analysis of water meters, and is used for setting up the tactical objectives and assessment system (assessment criteria and metrics). For each metric (e.g., real losses, apparent losses, mains failures) the respective ranges of quality of service (poor, acceptable, and good) should be established as well as the target values for the planning and analysis horizons.

The assessment system is tailor-made for each utility. A utility with a low level of maturity in terms of data (e.g., network data), process and technology (e.g., network sectorization, flow monitoring) will end up defining a more simplified assessment system and less ambitious targets than a more mature utility. Following the methodology, the diagnosis of the whole water system and its functional areas/sectors is conducted, for assessing the priority areas for intervention requiring a more detailed analysis. The diagnosis aims at identifying the main problems in terms of water losses and energy inefficiencies using the previously defined assessment system.

The functional analysis areas correspond to the network areas where it is possible to carry out water and energy audits. Priority areas may be identified using the AWARE-P tool (Alegre et al. 2013), taking into consideration diagnosis both for the reference situation and for the future.
situation. This prioritization can suffer by the action of external factors not considered in the diagnosis but that may affect the decision process (e.g., differences in layout, sensitive areas). After identification of the priority area, a set of alternatives (e.g., infrastructural interventions, or infrastructural and non-infrastructure interventions combined) is identified for that area. These possible alternatives need to address risk, cost and performance dimensions. Finally, the overall diagnosis and the best alternative analyses provide a set of tactics that need to be implemented at the operational level.

CHARACTERIZATION OF THE CASE UTILITIES

In the iPERDAS project, 17 utilities benefited from continuous technical support from the project team. The participating utilities were different in size, organizational framework, system characteristics, complexity, geographic location and context. Their level of maturity in terms of data, network sectorization and flow monitoring was also different. The number of households served ranged from approximately 1,300 to 165,000.

Figure 2 presents the financial performance indicator (PI) of non-revenue water and targets defined by the utilities in the short-term period (3–5 years). Missing values refer to the utilities that did not report their targets. In total, non-revenue water represents 25.6% of the total water input. This global value was calculated as the ratio between the total volume of non-revenue water and the total water input, in the overall 17 utilities. Despite being lower than the national value – 31% (ERSAR 2014) – this global non-revenue water level may suggest important financial inefficiencies in the water utilities. As depicted below, only two utilities showed a ‘good’ service level (below 20%) and five an ‘unsatisfactory’ level (above 30%). The reference values adopted have been defined by ERSAR & LNEC (2015).

On the other hand, the global value of real losses per connection (IWA Op27) is 148 L/(connection-day), thus corresponding to an acceptable service level (ERSAR 2014). Yet, seven utilities reported an unsatisfactory service level (above 150 L/(connection-day)) and only three reported a good service level (below 100 L/(connection-day)).

Regarding the apparent losses (IWA Op25), the global average value was 6%, and reached a maximum of 10.6%. The levels of unmeted consumption (IWA Op39) were globally around 25%, with a maximum of 35%.

On the energy side, the average standardized energy consumption (IWA Ph5, ERSAR AA15ab) was 0.47 kWh/m³·year, which corresponds to an acceptable service level (ERSAR 2014). This PI expressed the average amount of energy consumed per m³ at a pump head of 100 m. The use of this PI to assess the system’s global efficiency is not recommended, as it only considers the efficiency associated with the pumping stations (equipment). Additionally, it does not allow comparing systems, or alternatives. Hence, a new
PI that establishes the ratio between supplied energy and the minimum required energy was defined and calculated (Duarte et al. 2009; Mamade et al. 2014). Supplied energy refers to the sum of natural and shaft input energy. Minimum required energy refers to theoretical minimum energy required to supply the consumers, considering average elevation, minimum pressure requirements and authorized consumption.

Globally, this PI showed that the iPERDAS utilities were supplied with 2.3 times the minimum energy required for the consumers. This excessive energy in the global system (1.3 times the minimum energy) can be associated with inefficiencies due to: pumping stations, water losses (real and apparent), excessive pressure, valve headlosses, and pipe friction, among others.

**UTILITIES RESULTS**

**Objectives and assessment system**

Following the proposed methodology, the establishment of the tactical plan objectives and the corresponding assessment system is one of the most important milestones for the utilities, as these will be the main drivers to assess their system’s current performance, as well as predict future performance. Likewise, the Portuguese urban water utilities are obliged by the Water and Waste Regulator (ERSAR) to respond yearly to an assessment system, intended to address the quality of service provided (ERSAR & LNEC 2013). This system is also organized in an objectives-criteria-metrics framework. As a result, most of the identified objectives are derived either from this system or from their IAM strategic plans – when available. Table 1 shows an example of the objectives and corresponding assessment system as defined by an iPerdas utility. It can be seen that, besides the economic and financial sustainability of the service, water-energy loss management is important to ensure infrastructural and environmental sustainability. This allows the approach to be a more comprehensive framework than the existing approaches (GIZ & VAG 2011). This assessment system also integrates the two components of water losses – real and apparent losses. Besides, it aims at promoting environmental sustainability through water-energy efficient management. Relatively to the energy efficient management criterion, the selected metrics allow the assessment of the impact of water loss reduction (e.g., energy in excess per unit of the revenue water), pump improved efficiency (e.g., standardized energy consumption) and other efficiency improvements (e.g., ratio of the maximum energy in excess), which covers new perspectives related to energy efficiencies.

**Prioritization of the analysis areas for intervention**

By dividing their systems into functional areas – analysis areas – and based on their objectives and assessment system, the utilities were able to rank their areas in terms of priority needs. Table 2 describes the priority areas

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Criteria</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To secure economic and financial sustainability</td>
<td>1.1 Non-revenue water reduction</td>
<td>Non-revenue water (%)</td>
</tr>
<tr>
<td></td>
<td>1.2 Apparent losses reduction</td>
<td>Non-revenue water in terms of costs (%)</td>
</tr>
<tr>
<td></td>
<td>2.1 Infrastructural sustainability adequacy</td>
<td>Apparent losses (%)</td>
</tr>
<tr>
<td></td>
<td>2.2 Infrastructure operability sustainability</td>
<td>Infrastructural leakage index (→)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water losses per connection (L/connection/day)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mains failures (No./100 km/ year)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Service connection failures (No./ 1000 connections/ year)</td>
</tr>
<tr>
<td>2. To attain infrastructural sustainability</td>
<td>3.1 Environmental resources management</td>
<td>Inefficiency in use of water resources (%)</td>
</tr>
<tr>
<td>3. To promote environmental sustainability</td>
<td>3.2 Energy efficiency management</td>
<td>Energy in excess per unit of input volume (kWh/m³)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy in excess per unit of the revenue water (kWh/m³)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ratio of the maximum energy in excess (→)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standardized energy consumption (kWh/m³/ 100 m)</td>
</tr>
</tbody>
</table>
identified by the utilities #4, #13 and #14. The problems are listed in terms of the metrics with an unsatisfactory service level. As shown, most of the selected priority areas were revealed not to have real water losses problems only, but also energy, infrastructural and installed water meter inefficiency issues. Such problems may have been disregarded when applying more traditional methodologies, namely the ones concerning only water losses control (Farley & Trow 2003; Lambert & Taylor 2010), in comparison with the AWARE-P IAM methodology.

Prioritization of alternatives (in short and medium term)

Once the most critical area of intervention was selected, the best alternative of intervention was selected based on the objectives and the assessment system established before. Each alternative's consequences on the system’s behaviour and performance were studied in a short and medium term horizon. By doing this, the utilities were able to foresee and assess their performance properly, justifying promptly the best-chosen alternative. The example chosen in Figure 3 illustrates the evaluation of three different alternatives of intervention: A.01 ‘Status Quo’; A.02 ‘Water tank and pumping station deactivation combined with a water meters renovation program’; A.03 ‘Resize the water pumping station combined with water meters renovation program’. Assessing all three alternatives, with the metrics systems previously established, and its impact throughout the medium and long-term horizon, it was possible to see that alternative 2 was the best alternative of intervention to be chosen, addressing the three risk, cost and performance dimensions. In this example, the Status Quo alternative (option to not carry

Table 2 | Example of priority areas selected for utilities #4, #13 and #14: general characteristics and problems

<table>
<thead>
<tr>
<th>Utility ID</th>
<th>Characteristics</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>#4</td>
<td>It shows problems related to incrustations, due to hard water, throughout the entire network. Major pipes are asbestos cement. The network has multiple tanks (13) and pumping stations (13) due to strong variations in the slope topography.</td>
<td>Water losses (service connection)</td>
</tr>
<tr>
<td>#13</td>
<td>Gravity supplied system with the network mainly consisting of PVC pipes installed in the 80s, with a total length of 23 km. Service connections (677) are in plastic materials (PVC) and were installed at the same time as the network. This system works simultaneously as a conveyance and a distribution network.</td>
<td>Energy in excess per unit of input volume</td>
</tr>
<tr>
<td>#14</td>
<td>Gravity supplied system, with a booster to ensure the water supply in some nodes with higher elevation. Systems’ network is mainly PVC, with a total length of 7.8 km having been built in the 1990s.</td>
<td>Non-revenue water</td>
</tr>
</tbody>
</table>

Figure 3 | Utility example on the selection of the best alternative intervention.
out structural interventions and keep the operating practices and maintenance of infrastructure) was comparatively the worst solution.

The selection of alternatives of intervention ends with the definition of tactical measures to be further implemented by the utilities during their plan’s horizon. Table 3 illustrates an example. Alternatives of intervention may combine several actions of different nature to be implemented, which actions are later organized as tactics to be implemented. Each tactic is characterized according to its nature: infrastructural, operation and maintenance, and other non-infrastructure tactic, and respective relevant information is provided in terms of the investment to be made and the schedule for their implementation.

## CONCLUSIONS

iPerdas (the Portuguese Initiative for the Management of Water & Energy Losses) is a collaborative project led by LNEC, through which water utilities developed their own water-energy losses management plans, following a joint training and capacitation approach. This paper focused on the application of the AWARE-P IAM methodology in the iPerdas project to improve water-energy loss management in water supply systems, along with the main benefits of implementing an integrated approach for water losses and related energy assessment. This approach was and has been applied successfully in 17 water utilities, with different dimensions and maturity levels, during the iPerdas project. It is also flexible to distinct water utilities and is different from typical approaches that are more focused on the daily real water loss control or on the efficiency of pumping systems while disregarding the impact of water loss or network layout on energy consumption. In this case, it was possible to assess the economic, technical, social and environmental impact of water-energy loss and respective intervention alternatives, in short- and more long-term horizons. For each priority area and for the selected intervention alternative, a comprehensive and well-justified set of tactics was obtained and prepared to implement at the operational level. The proposed approach will be applied in a second edition of this collaborative project to take place in 2016. The incorporation of this approach by the utilities remarkably contributed to improving the quality of service and the sustainability of water supply systems and water-energy resources.

## ACKNOWLEDGEMENTS

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