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 customers, social awareness, water quality and environment. This paper focuses on the application of the AWARE-P 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 prone to a more efficient and sustainable service.

Keywords
Infrastructure asset management, water utilities, tactical planning, water loss, energy efficiency

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 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 expressive economic, socio 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 customers, 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, also taking into account the tactical decisional level.

Therefore, aiming at integrated water-energy loss management, the iPerdas project was promoted by LNEC. iPerdas – the Portuguese Initiative for the Management of Water & Energy Losses is a collaborative project, through which 17 water utilities developed their own water-energy losses management plans, following a joint training and capacitation approach (www.iperdas.org). The project also aimed to contribute to more reliable and organized processes for water-energy management within the water utilities. iPerdas started in November 2013 and ended in April 2015. The participating utilities received collective, as well as one-on-one support, specific training and software (AWARE-P, aware-p.org) to develop tactical plans to improve water-energy loss management using the Infrastructure Asset Management (IAM) approach proposed by Alegre and Covas (2010).

According to the IAM approach (Alegre and Covas, 2010; Cardoso *et al.*, 2012; Helena *et al.*, 2013), iPerdas follows three main stages: 1) establishment of a comprehensive assessment system and a complete water-energy loss diagnosis, 2) prioritization of the areas of analysis for intervention and, 3) prioritization of intervention alternatives. Typically, the decisions over water loss reduction are more focused on the real loss component, rather than on apparent loss component, without the assessment of the impact on medium or long term horizons (Farley and Trow, 2003; Lambert and Taylor, 2010). Additionally, decisions usually take into consideration the economic sustainability only, disregarding other important objectives, namely the quality of service, efficiency of water resources and sustainability of infrastructures, which may bias the results (GIZ and VAG, 2011).

The iPerdas approach requires the commitment of the organization CEO – chief executive officer, for its implementation. This commitment is necessary for the alignment between the strategic objectives of the organization and those for water-energy loss management, the assignment of a team inside the water utility responsible for the development of the water-energy loss management plans, including approval, implementation, revision and full-alignment with other existing plans.

The methodology uses a systematic and novel approach for water-energy auditing and performance assessment (Alegre *et al.*, 2006; Alegre *et al.*, 2005; Mamade *et al.*, 2014; Mamade *et al.*, 2015). In the first instance, the well-defined water audit (Alegre *et al.*, 2006; Alegre *et al.*, 2005) is carried out for the system and for all the areas of analysis. Besides the contribution to the specification of procedures and the identification of best practices to improve the accuracy of the different water audit components, the iPerdas approach provided new methods for metering error estimation (Balaguer Garrigós, 2013) and for night flow analysis and anomalous event detection (Loureiro *et al.*, 2015). Once the water audit is complete, the energy audit uses the estimates relatively to system input, authorized consumption and water losses to obtain the energy delivered to consumers, the energy dissipated (in pipes, pumps, valves), the energy recovered and the energy associated to water losses. Therefore, besides the identification of inefficiencies due to equipment, this new approach identifies inefficiencies due to system layout and water losses (Mamade *et al.*, 2014; Mamade *et al.*, 2015), which encourages water utilities to carry out the joint management of water losses and energy efficiency.

The iPerdas projet is also unique since the utilities can benefit from the collaborative work to exchange experiences, to improve awareness about water-energy losses, internally and externally to the organization; to contribute for improvement of 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).

Likewise, the iPerdas project is supported by four pillars according with **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 define tactical measures prone to a more efficient and sustainable service. The project also allowed the validation of the methodology followed while bringing benefits to the utilities in their water losses and energy management.

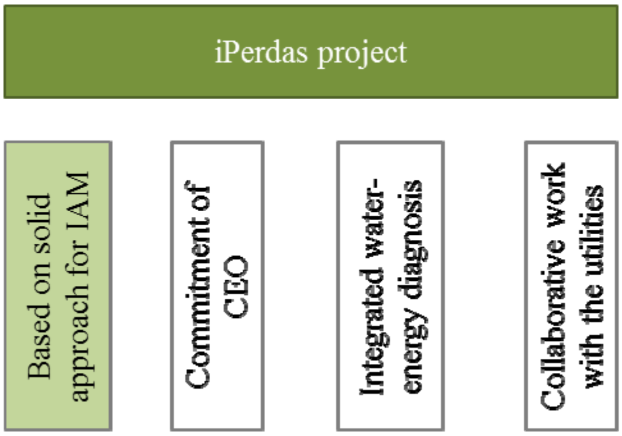

Figure 1. Pilars of the iPerdas project.

This paper is organized as follows: in Section 2, the approach adopted in the iPerdas project to develop tactical plans to support decisions in terms of water-energy loss management is described; in Section 3, the set of participating utilities is characterized in terms of dimension, non-revenue water, real and apparent losses and energy performance indicators; in Section 4, the results focus on i) the objectives and the assessment system, ii) the selection of priority areas, iii) the prioritization of intervention alternatives and selection of tactics; finally, in Section 5, conclusions and further developments are presented.

METHODOLOGY

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

In the iPerdas approach, before defining tactical objectives, assessment criteria, metrics and targets, the utilities should have: 1) identified the relations between the plan for water-energy loss management and other existing plans in the organization (e.g., investments, strategic, other tactical and operational plans); 2) set the planning and the analysis horizons and; 3) done a preliminary characterization of the system in terms of water and energy audit and analysis of water meters. The preliminary characterization of the system is set in terms of water audit (Alegre *et al.*, 2006; Alegre *et al.*, 2005), energy audit (Mamade *et al.*, 2014; Mamade *et al.*, 2015) and water meters' 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 main 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, which is composed by the tactical criteria and metrics.

The assessment system must be tailor-made by 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) and people may define a more simplified assessment system and targets that are less ambitious than in the case of a more mature utility. 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.

Following the methodology, the diagnosis of the whole water system and its' functional areas/sectors is conducted, for assessing the priority areas for intervention that require 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 areas of analysis correspond to network areas where it is possible to carry out water and energy audits. Priority areas may be identified using the AWARE-P tool (Helena *et al.*, 2013), taking into consideration both diagnosis for the reference situation and for the future situation. This prioritization can be adjusted by the action of external factors that have not been taken into account and that may affect the decision process. After identification of the priority area, a set of alternatives (e.g., only infrastructural interventions, combined infra-structural and non-infrastructural interventions) are identified for that area. These possible alternatives need to combine 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.

CASE STUDIES

In the iPERDAS project, 17 utilities have benefited from a continuous technical support from the team. Participating utilities were different in size, organisational 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 PI-performance indicator of non-revenue water and targets defined by the utilities in the short-term period (3-5 years). Some utilities did not express 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 17 utilities. Despite being lower than the national value – 31% (ERSAR, 2014) – this global value still suggests a lack of financial efficiency from 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 and LNEC (2013).

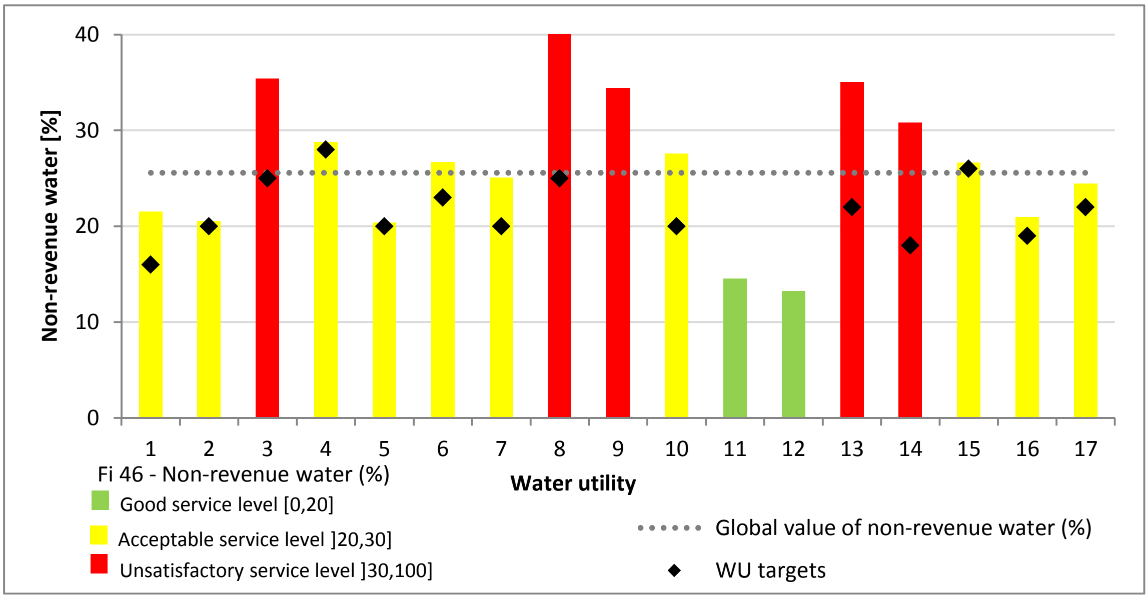

Figure 2. Non-revenue water and system input volume for the 17 water utilities.

Moreover, the global value of real losses per connection (IWA Op27) is 148 l/(connection·day), thus corresponding to an acceptable service level (ERSAR, 2014). Nevertheless, 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 apparent losses (IWA Op25), the global average value is 6%, reaching a maximum of 10.6%. Levels of unmetered consumption (IWA Op39) were globally around 25%, with a maximum of 35%.

On the energy side, the average standardized energy consumption (IWA Ph5) was 0.47 kWh/m^3·year, which corresponded to an acceptable service level (ERSAR, 2014). This PI expressed the average amount of energy consumed per m^3 at a pump head of 100 m. The use of this PI to assess the system´s global efficiency is not recommended as it fails to consider other inefficiencies associated, for instance, to layout design and water losses. Additionally, it does not allow comparing systems, or alternatives. Hence, a new metric that establishes the ratio between the energy which was supplied and the minimum energy required was defined and calculated. Globally, the iPERDAS utilities supplied 2.3 times the minimum energy required by consumers.

RESULTS

Objectives and assessment system

The establishment of the tactical plan objectives and the corresponding assessment system is one of the most important milestones for the utilities following the proposed methodology. These objectives and assessment system will be the main driver to assess their systems current performance, as well as predict future performance. The Portuguese urban water utilities are obliged by the Water and Waste Regulator (ERSAR), to yearly respond to an assessment system, intended to address the quality of service provided (ERSAR and LNEC, 2013). This system is also organised in an objectives-criteria-metrics framework. Being familiar with this assessment system, it was observed that most objectives either derived from this system or from their IAM strategic plans – when existed. Table 1 shows an example of the objectives and corresponding assessment system defined by an iPerdas utility. It can be seen that, besides ensuring economical and financial sustainability of the service, water-energy loss management is important to ensure infrastructural and environmental sustainability, which constitutes a more comprehensive framework comparatively with the existing approaches (GIZ and VAG, 2011). This assessment system also integrates both components of water losses – real and apparent losses. Besides, it aims at promoting environmental sustainability through water-energy efficient management. Relatively to 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., standardised energy consumption) and other efficiency improvements (e.g., ratio of the maximum energy in excess), which cover new perspectives in terms of energy efficiency.

Table 1. Example of the objectives and corresponding assessment system, chosen by an iPerdas utility.

Objectives	*Criteria*	*Metrics*
1. Secure economical and financial sustainability	1.1 Non-revenue water reduction	Non-revenue water (%) Non-revenue water in terms of costs (%)
	1.2 Apparent losses reduction	Apparent losses (%)
2. Attain infrastructural sustainability	2.1 Infrastructural sustainability adequacy	Infrastructural leakage index (-) Water losses per connection (l/connection/day)
	2.2 Infrastructure operability sustainability	Mains failures (No. /100 km/year) Service connection failures (No./1000 connections/year)
3 Promote environmental sustainability	3.1 Environmental resources management	Inefficiency use of water resources (%)
	3.2 Energy efficiency management	Energy in excess per unit of input volume (kWh/m^3) Energy in excess per unit of the revenue water (kWh/m^3) Ratio of the maximum energy in excess (-) Standardised energy consumption (kWh/m^3/100m)

Prioritization of the areas of analysis for intervention

By dividing their systems into functional areas – areas of analysis – 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 identified be the utilities 4, 13 and 14. The problems are listed in terms of the metrics with an unsatisfactory service level. Therefore, most priority areas selected revealed to have not only real water losses problems, but also demonstrated energy efficiency issues, infrastructural problems and also problems related with the efficiency of the water meters installed. Such problems may have been disregarded if more traditional methodologies had been used, namely the ones concerning only water losses control (Farley and Trow, 2003; Lambert and Taylor, 2010).

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

Utility ID	Characteristics	Problems
#4	Most extent network, from the entire municipality, 180km. It shows problems related with 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.	Water losses (service connection) Energy in excess per unit of input volume Energy in excess per unit of revenue water Non-revenue water
#13	Gravity supplied system with the network mainly consisting in PVC installed in the 80's, with a total length of 23km. Service connections (677) are in plastic materials and were installed at the same time as the network. This system works simultaneously as a conveyance and a distribution network.	Non-revenue water Non-revenue water in terms of costs Apparent losses Energy in excess per unit of input volume Energy in excess per unit of revenue water Ratio of the maximum energy in excess Mains failures Water losses (service connection)
#14	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 7,8km having been built in the 90's.	Pressure of supply adequacy Non-revenue water Infrastructure value index % of water meters with less than 12 years Standardised energy consumption

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 on Figure 3 illustrates the evaluation of four 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 assess that alternative 2 was the best alternative of intervention to be chosen. In this example the Status Quo alternative (option of not carry out structural interventions and keep the operating practices and maintenance of infrastructure) was comparatively the worst solution.

Figure 3. Utilities example on the selection of the best alternative intervention.

The selection of alternatives of intervention culminates in the definition of tactical measures to be further implemented by the utilities during their plans horizon. Table 3 illustrates an example of the chosen alternatives of intervention and their corresponding tactics. Alternatives of intervention may combine several actions of different nature to be implemented; these actions are later organized as tactics to be implemented.

Table 3. Selected intervention alternatives and corresponding tactics for the priority areas in the utilities 4, 13 and 14.

Utility ID	Selected intervention alternative	Tactics
#4	• Replacement of the network pipes with incrustation issues combined with the installation of variable speed drives	– Variable speed drives installation in water pumping stations A, B and C – CCTV inspections to detect illegal connections – Development of a plan to rank the pipes need for rehabilitation, derived from incrustation issues
#13	• Network pipe rehabilitation and elimination of service connections from the conveyance pipe network	– Water tank rehabilitation – Network pipes rehabilitation
#14	• Shift of the network delivery point to a higher elevation node and deactivation of the tank and booster, combined with a water meters renovation programme	– Construction of a new pipe to reach the principal water main – Network flow meter installation at delivery point – Replacement of water meters with more than 12 years – Leak detection tests

Each tactic is characterized according to their 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

This paper focussed on the application of the AWARE-P IAM methodology in the iPerdas project to improve water-energy loss management in water supply systems as well as on the main benefits of implementing an integrated approach for water losses and related energy assessment. This approach has been applied successfully in 17 water utilities, with different dimensions and maturity levels, during the iPerdas project. 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 approach in 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, disregarding the impact of water loss or network layout on energy consumption. Following the iPerdas approach, it is possible to assess the economic, technical, social and environmental impact of water-energy loss and respective intervention alternatives, in short and more long time horizons. For each priority area and for the selected intervention alternative, a comprehensive and well justified set of tactics were obtained and prepared to be implemented at the operational level. Proposed approach will be applied on a second edition of this collaborative project to be launched in 2016. The incorporation of this approach by the utilities contributed remarkably to improve the quality of service, the sustainability of water supply systems and water-energy resources.

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