Implementing water-energy loss management in water supply systems through a collaborative project: the Portuguese national initiative

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Abstract: The aim of this paper is to present the collaborative project iPERDAS, on water losses and energy efficiency management, and provide examples of the main results achieved by the participants during 2014. iPERDAS, led by LNEC (National Civil Engineering Laboratory, Portugal), was a project through which 17 water utilities developed their own water-energy losses programmes, following a joint training and capacitation approach (www.iPERDAS.org). The group of participating water utilities was distributed across the country and supplies water to nearly 16% of the Portuguese population along 11633 km of pipes. The group was quite heterogeneous in terms of dimension, corporate structure and level of maturity in water losses management which enabled rich discussions and sharing of best practices. Utilities have received collective as well as one-on-one support, specific training, and benefited from networking with each other in a common and simultaneous process, with similar difficulties and challenges, leading to an effective sharing of solutions. The most significant results of this project include the utilities' Water and Energy Losses Management Plans, the establishment of solid procedures to carry out water and energy audits, the improvement of inter-departmental communication and the development of an integrated and sound organisational process for water-energy management.

Keywords: water losses, energy efficiency, integrated approach, collaborative project

Introduction

Improving efficiency in water supply systems, through a more rational use of energy and control of non-revenue water, is one of the main goals of water utilities. Despite important advances in the service levels provided, the values of non-revenue water – unbilled authorised consumption and water losses – are still unacceptable in many utilities worldwide. This issue has gained additional importance in countries where water demand and consequently revenue water is decreasing or where water scarcity problems exist. In Portugal, non-revenue water averages 31% of the total water produced (ERSAR, 2014). Concurrently, energy consumption by public drinking water utilities, which are primarily owned and operated by local governments, can represent 30-40% of operational costs (WWAP, 2014). Water supply systems consume energy through the operation of individual assets (treatment and pumping equipment) and dissipate it in the conveyance process. Reducing water losses has direct implications on energy consumption since less water is needed for treatment, pumping and conveyance. The integrated management of water and energy can, therefore, lead to expressive economic, socio and environmental benefits (Wilkinson, 2007). Water utilities are becoming aware of this, even though important challenges still need to be overcome:

- Utilities are still focusing only on the operational water loss management (real and apparent losses), taking into consideration only the economic dimension and disregarding in most cases the impact on the quality of service, communication with the customers, social awareness and water quality.
- Water loss management tends to be carried out without exploring the impact on energy consumption (*e.g.*, effect of pressure management on pumping, the effect of

water loss reduction on head loss reduction and on energy consumption, etc.) and without establishing integrated actions.

- There is the need to combine the approaches that enable identifying the most critical areas taking into consideration water and energy aspects in combination with other management drivers related, for instance, with quality of service, social awareness, water quality).
- The need to manage water-energy losses taking into consideration short-, medium- and long-term time horizons taking into consideration performance, risk and cost remains poorly addressed.

To answer these challenges, LNEC has launched in 2014 a collaborative project – iPERDAS – where, during one year, 17 water utilities developed their own water-energy losses management plans following a training and capacitation programme (www.iPERDAS.org). The project also aimed to contribute to more reliable and organized processes for water-energy management inside water utilities. Technical assistance to the participating utilities was ensured by LNEC, IST (Technical University of Lisbon), ITA (Polytechnic University of Valencia) and Addition (a software development company). The participating utilities have received collective as well as one-on-one support, specific training, and benefit from networking with each other in a common and simultaneous process, with similar difficulties and challenges, leading to an effective sharing of solutions. In addition, the project offers a set of IT tools to support water-energy losses control.

This paper presents the approach followed during the project, a brief characterisation of the participants and their context as far as water and energy losses are concerned and the main results achieved.

An integrated and long-term approach to water-energy loss management

The water-energy loss management process is more than just a set of interventions to deploy in order to increase water and energy usage efficiency in supply systems. It should be fully interconnected with the organization’s strategic goals regarding the sustainability of the water service and the conservation of resources. These goals should be defined on a broader context, namely, they can support an infrastructure asset management system (Cardoso et al., 2012).

The approach for water-energy loss management process is achieved through the adoption of continuous improvement principles (PDCA: plan-do-check-act), embedding the key requirements of the ISO 50001 and ISO 55000/55001/55002 standards on energy efficiency and asset management, respectively (ISO, 2011, 2013).

The approach implemented by each utility in the water-energy loss management is the following:

Phase 1 - Establishment of the assessment system and water-energy loss diagnosis

This phase started with the identification of the corporate goals to achieve, including but not limited to these related to water-energy loss management. Based on these objectives, an assessment system to specify and monitor them was developed (or adjusted, if pre-existing). This assessment system with objectives, assessment criteria, metrics and reference values for water-energy loss management was used to carry out a diagnosis to decide where and how to act. The diagnosis began with the establishment of procedures describing the calculation of each water balance component followed by the calculation of performance, cost and risk assessment indicators (PI) for the global system (Alegre et al., 2000). On the energy side, an energy auditing scheme based on previous research (Cabrera et al., 2010; Duarte et al., 2009) but never applied before in real cases, was enhanced and implemented by all utilities. In this phase, the global energy supplied and consumed in the system was calculated to quantify the excess of energy in each system (Mamade et al., 2014). Furthermore, a comprehensive characterisation and preliminary analysis of the customer meters has also been carried out to assess apparent losses due to meters inaccuracy.

Phase 2 - Prioritization of the areas of analysis for intervention

Resources are rarely enough to sort out all problems and priorities need to be transparently established. With this in mind, the system was divided into smaller functional units (*e.g.* subsystems or district metering areas). The metrics defined in Phase 1 were assessed for each area, based on better water and energy efficiency information: water balance procedures were reviewed and duly documented; standard procedures to calculate energy balance components have also been established and were customised by each utility. The prioritization takes into consideration relevant scenarios and the analysis horizon, as recommended in AWARE-P methodology (Cardoso et al., 2012). Flow water meters in the system have been characterised and respective times series have been uploaded to the software, in order to determine daily consumption patterns for each area. In terms of apparent losses, a sample of 1300 household water meters was selected to carry out laboratory tests. This allowed improving the accuracy of the metering errors estimation carried out in Phase 1.

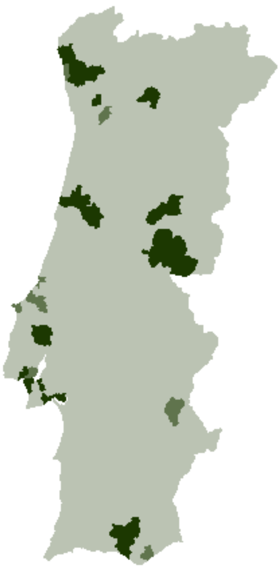
Phase 3 - Prioritization of alternatives

This phase started with the selection of the most adequate alternative solution to manage water-energy losses (*e.g.*, pressure reduction on the network, water meter replacement, pumping and tank operational changes, pipe network replacement). This selection was made after a comparative analysis between different alternatives of intervention, taking into consideration all relevant scenarios. The best alternative solution for each area was also based on simple to understand multi-criteria analysis, carried out using a visual tool of the iPERDAS software (see **Error! Reference source not found.**(d)). The major output of this phase is the Water and Energy Management Plan.

Each phase started with a plenary meeting to share the challenges and results achieved by each utility, a training session to present water and energy loss concepts and demonstrate software updates. Training was complemented with webinars and on-line materials. Two-day workshops took place in the middle of each phase to assist utilities in the development of the work. Commercial sessions dedicated to related topics (*e.g.*, network flow monitoring, leakage detection equipment, information systems, and analysis software) were also organised in each phase. External consultants and technology providers to the project were invited to participate in these sessions. Overall, the project included 97 hours of face-to-face training and 18 hours of e-learning.

Characterization of the participants

Twenty-one Portuguese water supply utilities participated in the iPERDAS project. There were two types of participation models. In type 1 (17 utilities) the participants were involved in the whole process presented above and benefited from a continuous technical support from the team, while in type 2 (4 utilities) the participants were only involved in the training component of the project (classroom training and webinars based training). Participating utilities had diverse size, institutional framework, supply system characteristics, complexity, geographic location and context. The level of maturity in terms of data, information and technology availability was also different. The number of households served ranged from approximately 1,300 to 165,000. **Error! Reference source not found.** shows some characteristics of the participating utilities.



	Households served(*)	Municipal service	Municipal company	Multi-municipal company	Concession	Participation model in iPERDAS
AGERE Braga	69,459		x			1
AGS Paços de Ferreira	12,730				x	1
Águas de Alenquer	19,388				x	1
Águas de Barcelos	31,433				x	1
Águas de Coimbra	74,198		x			1
Águas da Covilhã	25,147		x			1
Águas do Sado	56,545				x	1
CM Barreiro	38,281	x				1
CM Óbidos	7,168	x				2
CM Peniche	18,143	x				2
CM Reguengos de Monsaraz	5,851	x				2
EMAR Vila Real	24,514		x			1
Infralobo	1,822		x			1
Inframoura	12,874		x			1
Infraquinta	1,342		x			1
INOVA Cantanhede	17,942		x			1
SIMAS Oeiras Amadora	164,232	x				1
SM Castelo Branco	33,681	x				1
SM Nazaré	11,008	x				2
SMAS Almada	94,824	x				1
SMSB Viana do Castelo	36,352	x				1

(*) Data refers to 2012 (source: ERSAR (2014))

Figure 1 Water utilities participating in iPERDAS collaborative project (dark green – participation model type 1; light green – participating model type 2)

Figure 2 presents the financial PI of non-revenue water (Alegre et al., 2006) and the water input volume for the Type 1 utilities. Globally, 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, only two utilities have a good service level (below 20%) and five have an unsatisfactory level (above 30%). All the reference values adopted have been defined by ERSAR and LNEC (2013).

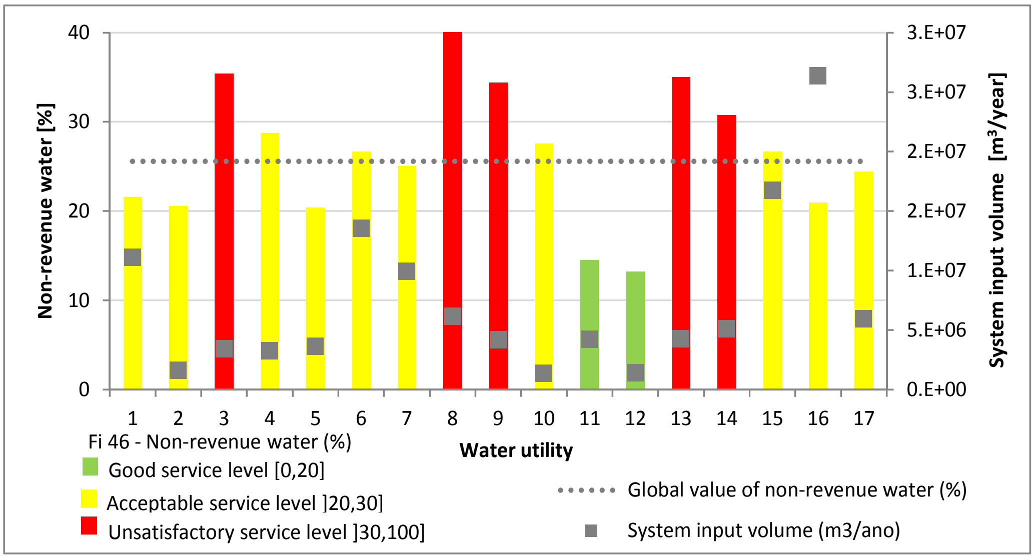


Figure 2 Non-revenue water and system input volume for the 17 water utilities

Moreover, the global value of real losses per connection (IWA Op27) is 148 l/(connection·day), which corresponds to an acceptable service level (ERSAR & LNEC, 2013). Nevertheless, seven utilities report an unsatisfactory service level (above 150 l/(connection·day)) and only three report 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) are globally around 25%, with a maximum of 35%.

On the energy side, the average standardized energy consumption (IWA Ph5) is 0.47 kWh/m^3·year, which corresponds to an acceptable service level (ERSAR & LNEC, 2013). This PI expresses the average amount of energy consumed per m^3 at a pump head of 100 m. ~PIThe 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 energy supplied and minimum energy required the has been calculated. Globally, the iPERDAS utilities supply 2.3 times the minimum energy required by consumers.

Major outputs of the collaborative project

This project has brought up substantial progress for the participants. The major outputs are the following:

- *An integrated and consolidated methodology*: the approach is driven by quality of service objectives in the short-, medium- and long-term horizons; it involves the whole organisation, not just a water losses team, enabling synergetic solutions that respond to multiple criteria; it addresses all the causes of non-revenue water in a balanced and systematic way.
- *A novel energy efficiency assessment*: energy audits are carried out following a two-step procedure: (i) simplified energy auditing and calculation of efficiency metrics for the global system or for any subdivision of it and (ii) detailed energy auditing for critical sectors.
- *A complete portfolio*: several training materials, procedures to calculate water and energy balance components and templates for the Water and Energy Losses Management Plan have been developed to support the utilities.

- *A software platform*: a web-based tool suite that is also available to the participants after the projects ‘conclusion. More details are presented below.
- *Water and Energy Loss Management Plan*: developed by each utility, the plan comprises the diagnosis, the prioritization and the selection of alternatives of intervention. More details are presented below.
- *Common results*: analyses carried out with data from the whole set of utilities, which would not be possible without the scale and chain effect characteristic of the collaborative projects. More details are presented below.

Software platform tools: one tool is dedicated to input the water balance components and assess key water loss performance indicators (**Error! Reference source not found.**(a)). Flow data time-series can be uploaded and combined with others to calculate daily consumption patterns for analysis areas and outliers in flow series can be detected and removed (**Error! Reference source not found.**(b)).

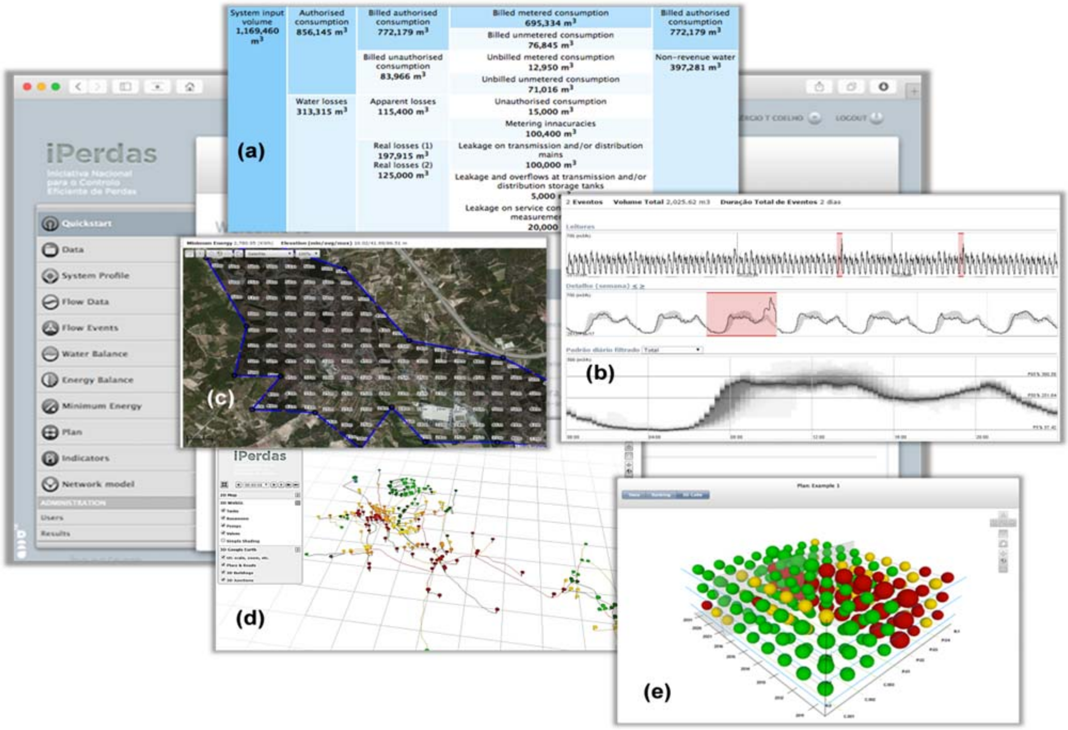


Figure 3 Screenshots with different modules from the iPERDAS software: (a) Water balance; (b) Flow events; (c) Minimum energy; (d) Network model; (e) Plan

Furthermore, polygons representing areas from the distribution system can be drawn to automatically calculate the minimum energy required by the consumers (**Error! Reference source not found.**(c)). The energy balance tool guides data input and assesses energy efficiency metrics. For utilities with more resources, there is a Java-implemented Epanet simulation engine for full-range hydraulic and water quality network simulation (**Error! Reference source not found.**(d)). To complete the software tools, there is a decision-support environment where alternatives can be measured up, compared and prioritized according to the utility assessment system (**Error! Reference source not found.**(e)). A single-user deployment of the iPERDAS tool suite was produced for the participants after the project’s conclusion.

Water and Energy Management Plans: 17 plans were produced by the respective utiliy team (Figure 4). Each plan includes the corporate objectives, the assessment system, the diagnosis, the areas for intervention prioritization and the selection of alternatives in each priority area. The plan also establishes the resources needed, as well as responsibilities, procedures and frequency for the plan monitoring and review.

Figure 4 Covers of the Water and Energy Loss Management Plans developed by the utilities

Common results: quality controled data, colected according to common standard procedures, are rarely available and extremely valuable for further analysis and research. A paradigmatic example of this collaborative work are the laboratory results from 11 utilities, summing 1300 household meters. This allowed improving the estimation of the metering errors. Figure 5 shows the metering errors against the age of the 15 mm diameter meters (993 meters). A trend line has been estimated, as well as the confidence intervals for each age range.

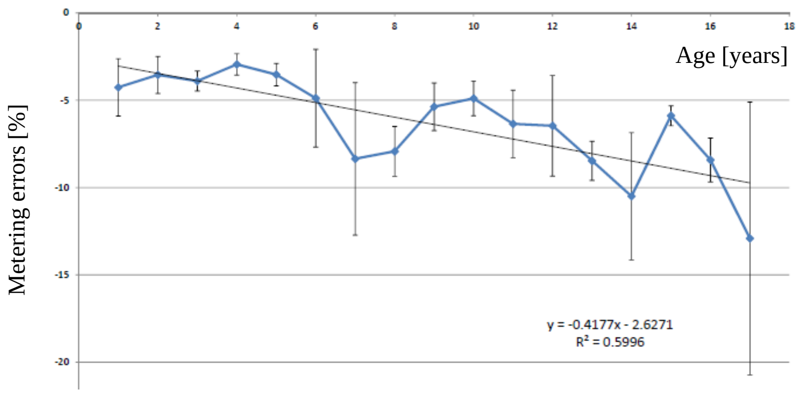


Figure 5 Metering errors by age for meters with diameters of 15 mm collected and tested in laboratory

Conclusions

iPERDAS was a collaborative project with 17 water utilities, that supply water to nearly 16% of the Portuguese population along 11633 km of pipes. This project followed the well tested format of LNEC's collaborative projects, which creates peer competitiveness (Alegre et al., 2015). These projects place significant positive pressure on all utility teams for staying on schedule and avoiding lagging behind with implementation and result reporting. The pressure thus created was crucial for the early adoption of the iPERDAS integrated approach, as making space for novel tools, methods or processes is inevitably an uphill struggle in the intense environment of daily utility management and operation.

Most of the studies related to water losses focus either on tackling real losses or apparent losses, always leaving behind the energy to the equation. iPERDAS successfully implemented an integrated approach that considers water and energy losses comprehensively along with other management drivers (*e.g.*: quality of service), is objective-oriented and accounts for medium and long-term horizons. It has been successively tested with the 17 utilities is now consolidated, ready to be reproduced in the project's second edition scheduled for 2016.

As a result of an intense year of joint work and commitment, the main project achievements is the set of utilities' Water and Energy Losses Management Plans, the establishment of solid procedures to carry out water and energy audits, the improvement of inter-departmental communication and the development of an integrated and sound organisational process for water-energy management.

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