Application of performance indicators to control losses – results from the Portuguese water sector

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Abstract More and more the problem of water losses and leakages in water supply systems is becoming important in the management of water utilities. No matter how developed a country is, there is a growing and general awareness of this subject. Among the several motivations that contribute to this growing concern are, without doubt, the shortage of resources availability in several water supply systems on the one hand and, on the other hand, the economic value of the volume of water lost. Portugal is no exception. In recent years, there has been some dynamism in the sector in the accounting, control, leakages and loss detection, mainly in the biggest systems. This paper presents an approach to the control of water leakages and losses through the setting of performance indicators that allow the evaluation and characterization of the management entity for this aspect. Some results of those indicators will also be described here, as well as their application to several Portuguese water utilities and the assessment methodology of the results obtained. This paper also puts into evidence expressions and correlation curves between the different indicators and factors that directly or indirectly interfere in the result of the water utilities' performance with relation to the water losses and leakages presented.

Keywords Losses; non-revenue water; performance indicators; utilities

Introduction

More and more the problem of water losses and leakages in water supply systems is becoming important in the management of water utilities. No matter how developed a country is, there is a growing and general awareness of this subject. Among the several motivations that contribute to this growing concern are, without doubt, the shortage of resources availability in several water supply systems on one hand and, on the other hand, the economic value of the volume of water lost.

Portugal is no exception. In recent years, there has been some dynamism in the sector in the accounting, control, leakages and losses detection, mainly in the biggest systems. However, there are still entities that have very high values of water losses and leakages, sometimes more than 50%, while there are others that can't even estimate values of the losses and leakages owing to lack of measurement.

Nowadays, the Portuguese water sector is changing. Several public companies were created and these are responsible for the bulk water supply to the municipalities that then have the duty of supplying customers. Because of this fact, most of the management entities of water supply, which buy bulk water, consider the problem of losses and leakages as the greatest challenge they have to face in the near future.

Unless the water tariff greatly increases, which doesn't seem politically acceptable, the economic sustainability of most of the management entities of water supply systems will be seriously compromised.

This paper presents an approach to the control of water leakages and losses through the setting of performance indicators that allow the evaluation and characterization of the management entity for this aspect. Some results of those indicators will also be described here,

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as well as its application to the main Portuguese water utilities and the assessment methodology of the results obtained.

This paper also puts into evidence expressions and correlation curves between the different indicators and factors that directly or indirectly interfere in the result of the water utilities' performance with relation to the water losses and leakages presented.

Characterization of water losses in Portugal

The IWA Standard Terminology (Lambert and Hirner, 2000) water losses, despite being a reference and a terminology to adopt, is difficult to use, in the short term, for the most water utilities in Portugal. One of the reasons for this is the lack of information available relating the system input volume characterization. As such, in this paper, when mentioning water losses or leakages what is meant is non-revenue water.

In Portugal, the water volume produced was about 900 hm^3 in 1999 and about half of this was consumed in 3 districts (Portugal is divided into 18 districts): Lisbon, Porto and Setubal.

The revenue water volume stands near 585 hm^3, corresponding to a level of non-revenue water or losses of about 34.9%. This level is probably under-evaluated because 110 utilities do not account for the revenue water and the water produced simultaneously, or, at least, they did not provide that information to the inquiry made by the Portuguese Association of Water Utilities (APDA, 1999). This leads to some distrust of that value though unavailable information corresponds mostly to small utilities (less than 15,000 inhabitants).

From the 300 water utilities in the country (not considering the bulk water companies), 32 present non-revenue water values greater than 50%, while 33 show values between 40 and 50%. Only 35 water utilities have non-revenue water values less than 20%.

The larger water utilities started specific programs during the last decade to control and minimize water losses. The techniques they use most are the district meter areas associated to night flows, leakage detection through correlation and acoustic methods, pressure management, asset rehabilitation programmes (mains and service connections), meter replacement and preventive maintenance activities.

Only a few utilities use the performance indicators calculation explicitly in water loss management (Covas, 1998). The most common are the indicators of water leakages per kilometre and hour, and water leakages per customer and day. They implement leakage detection campaigns where unexpected rising is detected or take into account reference basis values for urban or rural systems.

Other entities, to define asset rehabilitation and replace strategies, evaluate and determine the number of failures per pipe kilometre, in a non-systematic way (Monteiro and Marques, 2001).

Another important indicator of the assets preservation state is the excessive number of failures occurring in water supply networks. This is particularly serious in the service connections where a relation of five times the number of failures was detected for a group of water utilities analysed (Figueiredo *et al*., 2000).

Water sector activity for water losses

The water sector in Portugal is suffering deep transformations. The possibility to use European Union funding enabled the Portuguese government, together with the municipalities, to develop an integration and optimization strategy of the existing systems (1st phase occurred from 1995 to 2000; the 2nd phase is taking place from 2000 to 2006).

This development policy, similar to the one that took place in other countries (e.g. Galli Law in Italy), allows the growth of water supply reliability and reduces the operation and maintenance costs, while at the same time it improves the quality of service delivered to a large extent.

As a consequence of the strategy followed, there was the creation of regional water companies that sell bulk water to the municipalities, which then supply it to the customers.

The municipalities buy water from the regional companies at a medium cost which stands between US$0.30 and 0.4 per cubic metre but if a medium value of losses of 35% is added to that, the real cost of the volume of water provided will stand between US$0.46 and US$0.54. This cost, and the costs associated with the distribution, lead to a significant increase in the present tariff.

When management realize this they start to put water losses as their main concern. Hence, there is considerable growth in the development of activities related to loss reduction and control.

It is predictable that common strategies to solve this problem will be developed not only at the national level but also by the water utilities' management. The performance indicators' application (in progress for 15 water utilities in the scope of IWA field test, (Alegre, 2001)) and the possibility of using the benchmarking tools will be strategic initiatives to improve the water utilities' management.

Performance indicators to water losses control and management

The application of performance indicators is a powerful tool for the management of water supply systems. It has several advantages for the water utilities and also for other intervenients in the sector (Alegre *et al.*, 2000). In what concerns the control and management of water losses, the setting of performance indicators has the following advantages:

- reinforcement of institutional power of managers, making easier the justification of reforms, the adoption of measures and the setting up of its priority in relation to others inside the organization (i.e. investment in assets rehabilitation);
- detection of fragilities and "weak points" in the system, becoming a stimulus to this resolution or reduction (i.e. priorities in preventive maintenance) and at the same time giving emphasis to the strong points;
- enable the water utilities to implement the management through objectives while establishing indicator targets, causing a series of proceedings and routines so that they can reach the intended values (i.e. the application of benchmarking);
- finally, make the internal and external auditing easier and at the same time make the characteristics and results of productive and management activities more transparent.

There are many works and proposals of performance indicators' application through the world. As far as water losses are concerned the publications of Yeppes and Dianderas (1997) and of Lambert *et al.* (1999) can be pointed out. In a broader scope, there are two reference works with a table of indicators proposal for the water industry. These are the works from IWA (Alegre *et al.*, 2000) and from the World Bank (World Bank, 1999). The former, including the application of 133 indicators broken down into three levels, is extremely complete and needs many resources to be put into practice. The World Bank work is not so ambitious and it is devoted to developing countries.

Bearing in mind the publications mentioned above, a group of performance indicators, presented in the following table, was set not only to characterize and justify the inefficiency existing in Portugal, related to water losses, but also to act as a tool and serve as a guide to the future performance.

The indicators adopted consider the information available and the development level of the Portuguese water utilities. As stated earlier, there is some lack of precision in the use of the most appropriate terminology, namely in relation to the water balance components. There are also other indicators of particular importance, which are not included in this paper because there are not data available and which are fundamental for a detailed analysis

Table 1 Water losses control and management indicators

Indicator	Unit	Importance	Notes
Non-revenue water	(%)	High	
Non-revenue water per pipe length	$m^3\,km^{-1}\,year^{-1}$	High	Excludes length of service connection
Non-revenue water per S. connection	$m^3\,con^{-1}\,year^{-1}$	High	
Operations and maintenance staff	no. $10^{-2}\,km^{-1}$,	Medium	Only transm. and distribution O/M staff
Operations and maintenance staff	no. $10^{-3}\,con.^{-1}$	Medium	Only transm. and distribution O/M staff
Mains rehabilitation	% $year^{-1}$	Medium	Include replacement too. 3 years mean
Service connection rehabilitation	% $year^{-1}$	Medium	Include replacement too
Failures	no. $10^{-2}\,km^{-1}\,year^{-1}$	High	Excludes include length of service connection
Meter replacement	% $year^{-1}$	High	3 years mean

of water losses. The indicators mentioned are, among others, the ones related to pressure, network age, its material, network inspection and maintenance.

Some results

The indicator non-revenue water is defined as the ratio between the non-revenue water volume and the distributed water volume. The distributed water volume results from the difference of the volume that enters the network and the exported volume to other utilities. It comprises the unbilled authorized consumption, the apparent losses and the real losses. Figure 1 shows the result of this indicator to the Portuguese water utilities, being the national average of about 35%.

The non-revenue water volume per pipe length is defined as the ratio between the volume of non-revenue water per year and the total pipe length. This indicator, besides its economic and environmental meaning, is extremely important to decision making about rehabilitation levels, meter replacement, leakage detection campaigns, and preventive maintenance versus corrective maintenance, among others.

The non-revenue water volume per service connection is defined through the relation between the non-revenue water volume per year and the number of service connections. This indicator is similar to the previous one in meaning.

Figures 2 and 3 present the results of these indicators and relate them to the customer density of the Portuguese water utilities.

An example of the kind of information obtained for some water utilities in an enquiry done by the authors is presented in Tables 2 and 3.

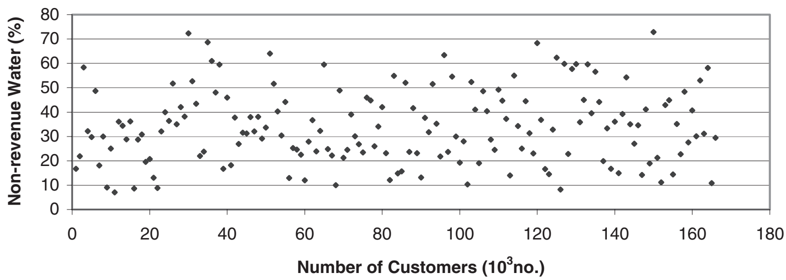

Figure 1 Non-revenue water for the Portuguese water utilities (data: APDA, 1999)

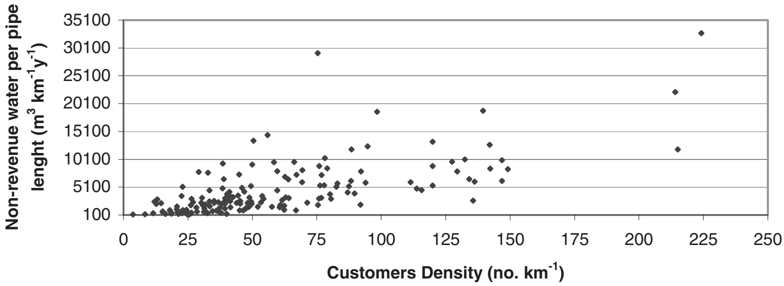

Figure 2 Non-revenue water per pipe length (data: APDA, 1999)

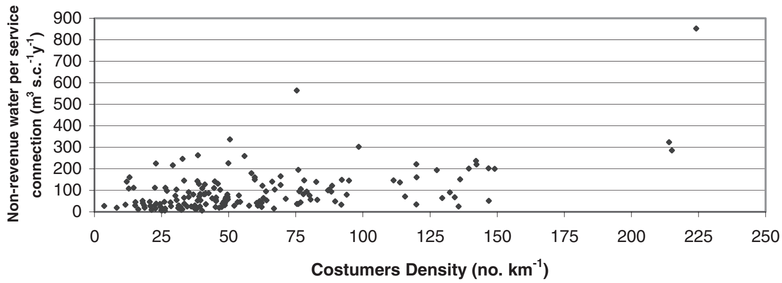

Figure 3 Non-revenue water per service connection (data: APDA, 1999)

Table 2 Results of the proposed indicators to control and management of water losses

Water utility	Clients (no.)	Non-revenue water (%)	Non-revenue water (m^3/h/y)	Non-revenue water (m^3/s.c./y)	Failures (no./100 km)
1	31470	32.2	2491.8	69.2	220.5
2	32645	31.3	5986.6	146.0	111.9
3	71000	33.6	4536.4	150.4	231.7
4	91764	34.4	9928.0	202.8	148.8
5	136508	23.2	4816.0	137.0	156.1
6	147925	36.7	22158.8	324.2	582.2
7	318322	42.1	32764.4	851.9	450.3

Table 3 Results of the proposed indicators to control and management of water losses

Water utility	O/M staff (no./100 km)	O/M staff (no./1000 s.c.)	Mains rehabilitation (%/year)	Service connection rehabilitation (%/year)	Meter replacement (%/year)
1	4.72	0.95	0.79	1.58	8.58
2	10.24	0.92	1.57	0.66	5.55
3	6.72	1.13	0.65	1.28	3.37
4	6.40	0.44	0.96	0.74	7.68
5	6.67	0.59	1.00	1.84	3.55
6	20.26	0.95	1.88	1.27	2.84
7	15.92	0.71	1.77	1.98	3.24

Analysis of the results

The analysis of the information available followed two methods. The first one consisted of obtaining adjustments between the different indicators and parameters that would enable correlation expressions for them. The second method consisted on comparing the results obtained for each indicator with the national and international reference values, considered the most appropriate or the ones that have a better performance.

In what concerns the former method and according to Figure 2, for example, there is relatively clear evidence of a correlation between the non-revenue water per pipe length and the customer density. Thus, the results taken from 195 water utilities led to the following expression:

$$Y = 28.579\, X^{1.171}\ (\rho^2 = 0.5069)$$

where: X represents the customer density (no. km^{-1}); Y represents non-revenue water per pipe length ($m^3\, km^{-1}\, year^{-1}$).

To consider explanatory factors multiple regression analyses were used. A significant increment of the correlation factor was obtained adding the failures per pipe length indicator. The addition of other indicators was tried but they revealed only residual improvement in the correlation factor, thus with no statistical significance. The next expression relates the non-revenue water per pipe length and per service connection with the customer density and the failures per pipe length:

$$Y1 = 5.221\, X1^{1.083}\, X2^{0.402}\ (\rho^2 = 0.836)$$

$$Y2 = 0.167\, X1^{0.880} X2^{0.518}\ (\rho^2 = 0.787)$$

where: X1 represents the customers density (no. km^{-1}); X2 represents the failures per pipe length (no. $10^{-2}\, km^{-1}\, year^{-1}$); Y1 represents non-revenue water per pipe length ($m^3\, km^{-1}\, year^{-1}$); Y2 represents non-revenue water per service connection (m^3 s.c.$^{-1}$ $year^{-1}$).

There are some considerations about the adoption of this methodology. On the one hand, if one applies a least squares method there will be a better adjustment in relation to the whole data available, having the mean as a basis. If there is a bad performance in the sector it will not be a good idea to use this expression as comparison element. On the other hand, the parameter customer density is the one that best suits the non-revenue water per pipe length but this can show that part of the value of this indicator might be related to metering inaccuracies.

With regard to the comparison of the reference values available in the bibliography, for example the indicator network rehabilitation, the average value for the Portuguese water utilities observed was 1.1% with a higher value of 1.9% and a minimum value of 0.5%, which corresponds to an average life span of 93 years for the pipes. Skarda (1997), recommends values of water network rehabilitation for his company between 1.5% and 2.0%. However, the number of failures that exist in his company is about a 1/3 of the average value that exists in Portugal. It is not easy to fix reference values for the water utilities, at least, in most cases. A study in Portugal (Marques, 1999) points out the value of 2% per year as a reference to the Portuguese water utilities although this depends on explanatory factors, such as the age and material network and the number of failures. Nevertheless, the results obtained with this study led to some important conclusions that justify the worse performance of some water utilities, namely:

- asset rehabilitation level far from the ideal (the situation is more critical in reference to service connections, being emphasized by the higher number of failures in these elements);
- insufficient number of meters replaced per year, which makes one believe that a significant part of the water losses are apparent losses;
- corrective maintenance that requires most of the staff, causing the preventive maintenance to be non-existent in many water utilities;
- fewer human resources than necessary in many water utilities.

Conclusions

This paper outlines part of an investigation that is still underway about water losses in Portugal. It includes some comments about the Portuguese situation in this matter, as well as an assessment and characterization methodology of the water losses based on performance indicators.

The main conclusions taken from this study are:

- performance indicators are a powerful tool to assess the performance of a water utility for the water losses;
- although it is not an easy task to define aims to performance indicators, the water utilities should have reference values for their management practices;
- the use of this device should be complemented with a search of the factors that justify a better or worse performance – if possible it should include the process benchmarking;
- the more indicators that exist, the more complex is the analysis, but it is also easier to consider explanatory factors; sometimes, setting only one indicator (or a reduced number of them) has restricted value and can lead to misleading conclusions;
- water loss level in Portugal is quite large, partly because most of the investment of the water utilities has been in new asset building to extend the service coverage instead of giving attention to systems operation and maintenance.

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