Leakage Control Policy within Operating Management Tools

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Abstract
Despite the growing concern of water companies throughout the world to have available water resources, which is strongly related to leakage control is not always properly considered within water management companies. Nowadays, the continuous monitoring of water distribution systems is a prerequisite towards the rapid and efficient detection of any abnormal situation.
Within European Union priorities, the problematic of available water sources have paid attention through the development of an integrated policy to reduce and control leakage, as well as to encourage water companies to implement it.
A briefly overview of international water framework conciliating water losses and users needs is presented, as well as the main management plans for a better leakage control in water systems. Since leaks are conceptually orifices, the importance of water losses and costs quantification and the benefit of a monitoring system installation are enhanced. Finally, it is presented a practical implementation by a water company in a controlled zone where is showed the type of developed analysis, the need of having an up-to-date database, which operating system and rules must be implemented in order to avoid damages.

Keywords:
Leakage control policy, water management tools, monitoring systems, water saving.

1 INTRODUCTION

Many water utilities still do not have an integrated policy towards leakage reduction and control, typically taking a passive attitude of waiting for the trouble to come and repairing it only when leaks become self-evident, with inevitable several problems associated for customers.

Leaks or ruptures causes are normally related to high operating pressures, an inadequate design, improper construction, maintenance and exploitation, the infrastructure ageing process and any unforeseen accidents. Leakage has significant costs associated, such as direct cost of the wasted treated water, the supply interruption for pipe repair, the decrease of the level of service, the clean-up of affected zones, the local erosion that can lead to major bursts and, finally, the social damage caused to the affected consumers.

The main principles based on Economically advantageous, Ecologically efficient and Ethically correct policy (Three-E policy) presuppose the implementation of a set of rules to guide water companies operating directly in the water intake, transport and distribution, and enabling a better control of hazard situations. The investment in procedures to reduce and control leakage might be the most efficient way to respond to the consumption needs, as well as to assure a future sustainable development.

2 WATER PLANNING TOOLS

2.1 Briefly International Overview

Firstly, it is important to emphasise that the environmental plans are directly related to urban planning, since this depends strongly on the existence of natural resources, thus the constant reference to international and European reports and treaties.

The growing concern of European countries with the problematic of natural resources and uses, started when the Water European Letter was proclaimed, in 1968, by the Europe Council. By then, an enormous concern with their sustainability was shown, as summarily presented: "[…] there is no life without water since the water is indispensable for all human activities; water resources are not inexhaustible; it is necessary to preserve, control and, if possible, to increase them; an efficient water management might be an integrated part of plans defined by competent authorities; the water protection presupposes the scientific research effort, the training technique and the public information; the water is a common heritage which its value might be recognise by all. Each one has the responsibility of saving and using it carefully."

Water saving policies have gradually been recognised as a priority to every government. Furthermore, both the government and private entities ought to be encouraged to implement ***monitoring*** and ***water control*** systems.

From this document, other remarks have been arisen with identical objectives, but the progressively demanding regards to the ecosystem conservation and the water uses.

In 1972, in the Conference of Stockholm, the subject of the environmental constraints in respect to the economic growth and to the use of the natural water sources was discussed. Later, in the Brundtland Report (1987), the behaviour of the international economy seemed to foresee that “the future generations would not have access to the necessary water sources for their survival". The conference of the UN in 1992, held at Rio de Janeiro, launched a huge political discussion between the official delegations, the representatives of some water sectors of world and of the civil society and several independent scientists. Once more, the question of environmental risk was focused. In this conference, it was approved the so-called Agenda 21 with recommendations for the improvement of the environment in century XXI.

After this event, the sustainable development assumed a greater importance and it has remained as the most significant component in the development of each country. The main priorities, according to this document, were the *modification of consumption standards of the populations, the strong need to control the fast population growth in the under-developed countries, as well as of the industrialisation which may restrict the water sources for human and industrial activities.* Another premise refers to the fact that it should be the government to persuade (through adequate legislation and policy) the investment in the water supply systems.

Five years later (in 1997), from the so-called “Rio +5”, in the Conference of Kyoto, a synthesis was made of that was really achieved. From this conference, maximum values for the emission pollutants (gases, liquids and solids) were established. These values intended to reduce their emissions and to reach a global minimum goal. However, different minimum values were specified based on the economic development of each country.

Based on these documents, several procedures related to the environment and the future planning of the water sources have culminated in the Proposal of a Directive that establishes the Actions for the Politics of the Water of the European Union (Water Framework Directive). In this Proposal, the Water Framework Directive presents the following global objectives: (i) the analysis and monitoring of impacts due to the human activities on the water; (ii) the economic analysis of the water uses and the gradual application of a financial regime aiming at, in a first stage, the payback of the costs of the infrastructures and, afterwards, the internalisation of other ambient costs, including the cost of scarcity. The first objective stands for questions related to the environmental impact assessment and to the control of activities that can be harmful to the quality of the water and its uses. The problematic of water losses in supply and distribution systems, is a question that is directly related to the economy of the water uses.

2.2 Management Plans

From a practical point of view, the objective of water supply to satisfy the consumption and the needs of both human beings and socio-economic activities is faced of the adjusted environmental protection. However, the water supply is not only derived from the environment protection, but also from the uses (namely when lost through leakage). In the management plans that this directive aims to apply, the necessary analysis related to the problem of leakage, for each river basin region, are the following: (i) the prediction of the several users consumptions (volumes supplied, seasonal variations, efficiency of water uses); (ii) the economic analysis of the drinking water uses (i.e. water intakes and distribution systems, predictions of long stated period of water offer/demand, estimative of the infrastructures investments for the public and private sector, trends of water uses, including seasonal variations and different prices and investments scenarios), as well as the implementation of monitoring systems.

The first point focuses on the question of the water supply volumes, and it is based on these values that conclusions should be drawn about the difference between the taken and the effectively consumed water volumes. The economic analysis is much more related to the costs associated to the type of management, as for example the estimation of investments in infrastructures.

Hence, the measures to foresee the necessary fulfilment of the considered objectives are among others the following: ***legislative*** and ***regulatory instruments***, appropriate measures for the ***water recycling***, the ***infrastructures refurbishment*** (directly related to leaks occurrences and ageing of the system), ***information*** and ***education***. The use of ***environmental taxes*** to integrate the environmental costs of the water, due to its ***scarcity*** and ***restriction*** to the consumption, should be balanced as an important means of minimising water shortage. In the Portuguese case, the Hydrographical Basin Plans (HBP) contemplate the essential requirements of Water Framework Directive which is in accordance to the Management Plans of the water uses regarding the management, control and supervision.

3 LEAKAGE CONTROL

3.1 Introduction

The normal operating pressure is one of the main causes of leakage in water supply systems, particularly in water distribution networks, being any anomaly reflected in a pressure change. Normally, the occurrence of a rupture is noticed by a pressure drop in the certain sites of the system, eventually detectable by the reduction of the available water to the consumers.

Within European Union priorities, joint efforts have been carried out focusing on the leakage control, as well as to encourage water companies to implement a new strategy. The fact is that water losses represent a significant amount of the total water volume distributed that may vary between 10% and 60 %, depending on each country [13].

There is a new trend pointing out to the system liability and hydraulic performance as the key elements to achieve a better control and management of water-drinking systems.

3.2 Pressure variation in water systems

The control of pressure assumes increasingly greater importance, since it assures an adequate hydraulic and economic performance of the system, as well as the satisfaction of the consumers. Hence, the occurrence of a significant leak or a rupture creates a sudden reduction of the pressure in a certain area of the system, leading consumers complaints. Furthermore, an adequate pressure management not only assures a higher level of service but also enables the use of standard pipes and fittings, which means a lower cost of the infrastructures, as well as reduces the frequency of the leaks occurrence in the network.

The operating pressure in a distribution network does not have to be neither too low nor too high. Indeed, to assure a good hydraulic performance of the system, there is a recommendable range of operating pressures which depends on system topology, elevation, number of consumers, type of material, among others.

The maximum value of operating pressure is usually established in order to assure a certain level of service and, simultaneously, it should be compatible with the nominal pressure of the conduits and other devices. The minimum limit is established in order to prevent the occurrence of sub-pressures in the system that may lead to the contamination of the drinking water. Moreover, the minimum or maximum pressures during transient events may induce the occurrence of more leaks or/and ruptures.

Thus, in a water distribution system, the leak discharge varies according to the pressure oscillation. In fact, a leak has a typical behaviour of an orifice, whose outflow is a pressure-dependent function. For complex and large systems, the simplification of a linear relationship between the average operating pressure and total leakage losses can be considered acceptable [10]. However, a better pressure control as well as a more uniform pressure distribution in the network can be attained through the following procedures: (i) division of the network in pressure levels; (ii) location of intermediate elevated reservoirs; (iii) optimisation of pump schemes and adjustment to new operating conditions; (iv) installation of pressure reducing valves or equipment for energy recovery in network areas with excess of available pressure.

3.3 Monitoring systems

The monitoring of the water supplying systems allows the control of the occurrence of any type of anomaly through the continuous analysis of the pressure/flow measurements. This methodology is of the utmost importance for an adequate management of any water system. The analysis of pressure/flow measurements during the occurrence of abnormal situations, such as ruptures, allows a better understanding of the implication of these anomalies in the normal operation of the system. The occurrence of instabilities generated during these situations can induce the occurrence of even more severe pressures and, consequently, more leaks and damages in the infrastructures. Disturbances in the system, such as the ones induced by a pump trip-off or a valve sudden closure, generate hydro-transitory regimes that are rapidly attenuated by the network configuration as well as by the presence of leakage (Figure 1). By means of the dynamic response of the system, it may be possible, in the near future, to implement a computer supported advanced method that, based on computational modelling and monitoring systems, may be able to detect any abnormal situation [6].

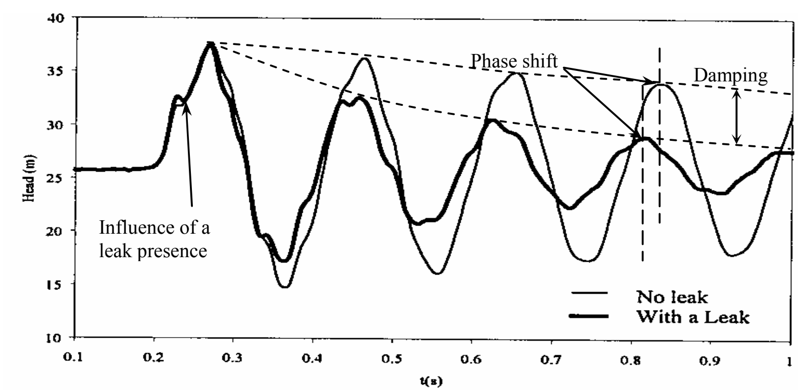

Fig. 1 Typical example of a transient event in a system network

3.4 Leakage quantification

Apart from the direct costs, the occurrence of rupture has always other social consequences associated, since it involves the interruption of water supply during the infrastructure repair, as well as the reduction of the available water in the system.

Assuming that the influence of viscosity, the friction and the jet contraction are represented by the discharge coefficient, μ, the theoretical leak discharge, Q_L(m^3/s), can be estimated by the following equation:

$$Q_L = \mu\, S \sqrt{2gh} \quad (1)$$

Being S the leak area (m^2), g the gravity acceleration (ms^{-2}) and h the pressure difference between inside and outside the pipe (m). For the discharge coefficient, the value of 0.6 is currently adopted. Considering a water supply system under a constant piezometric head of 30 m, where a leak appears with a circular orifice of cross section S, the leak discharge, Q_L, will be, given by:

$$Q_L = 14.5\, S \quad (2)$$

For different diameters of leak orifices, the leak discharge is according to [11]:

$\varnothing = 1$ mm $\Rightarrow$ $Q_L = 0.0114$ l/s = 0.985 m^3/day
$\varnothing = 10$ mm $\Rightarrow$ $Q_L = 1.14$ l/s = 98.5 m^3/day
$\varnothing = 100$ mm $\Rightarrow$ $Q_L = 114$ l/s = 9850 m^3/day

Considering an average water consumption of 125 l/user.day and a pressure in the network of 30 m, Table 1 shows the number of consumers who could be supplied with the lost volume through a leak with different sizes, during one day:

Table 1- Number of persons who could daily be supplied with the leak water

Leak diameter [mm]	Number of people who could be supplied with this volume, during one day, for a consumption of 125 l/user.day [consumer]
1	8
10	788
100	78 800

For instances, in a domestic pipe network, assuming that the corrosion could damage the pipe system and create an orifice with 1 mm of diameter, the average annual cost for the consumed water would suffer a significant increasing (e.g. on average, four persons per family):

- average annual cost of the measured consumed water:
  4 users × 0.125 m^3/user.day × 365 days × 0.05€ = 9.125€
- additional cost by the existence of an orifice in the in-house pipe system:
  0.985m^3/day × 365 days x 0.05€ = 17.98€
- perceptual increase of water cost due to the leak (to the family):
  17.98€/ 9.125€ = 197% ≈ 200%

This simple analysis leads to the conclusion that the total water costs to a family would triple only due to a small orifice of 1 mm of diameter (in case the property has a flow meter). The situation would be even worse if the consumption level increased simultaneously.

This case emphasises the fact that it is not the water supply company who pays the wasted water, but the consumers themselves, either directly and more severely in the measured water if the leak occurs inside their properties, or in the average price of the water.

4 A PRACTICAL IMPLEMENTATION

4.1 Brief description of the system

The Compagnie Generale des Eaux Portugal (CGE), a private water company that manages the water supply and distribution system in Mafra since 1995, is one of the few entities in Portugal to have a monitoring system for leakage and detection control. In this zone, with an area of 290 km^2, the number of water consumers is around 26,000, corresponding approximately to 45,000 inhabitants, and being estimated an increase of more 20 000 seasonal inhabitants during summer [3]. This company has been responsible to manage approximately 800 km of water distribution network system, with pipe diameters varying between 60 mm and 400 mm, and 44 reservoirs (Figure 2). The main objective is to supply water to the local population, buying water to EPAL (Lisbon Water Company) and supplying two main reservoirs, as well as buying to some private water intakes. The former (EPAL) represents 91,6% of the distributed water while the latter only 8.4 % [3].

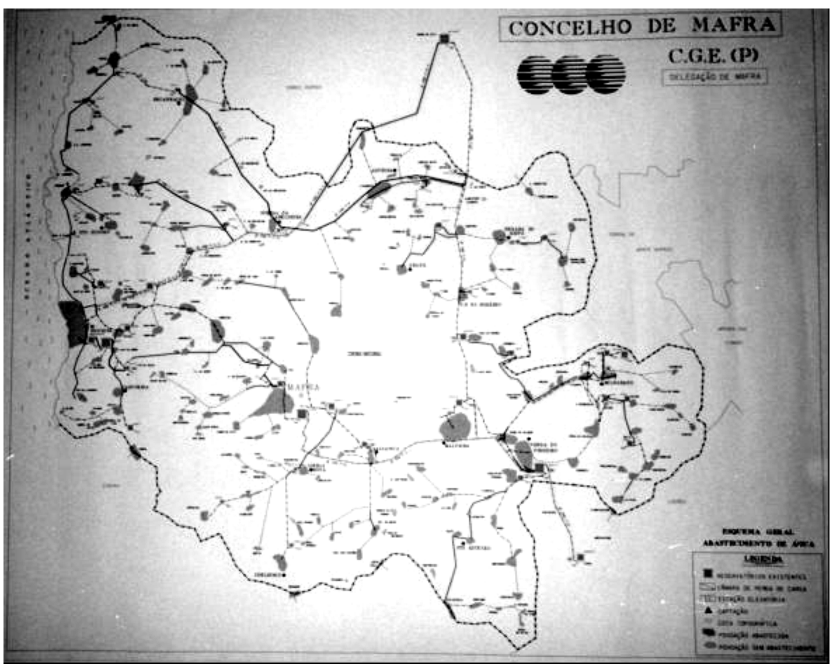

Fig. 2 Mafra water supply and distribution system (in Portugal)

4.2 Water losses

The water distribution company (CGE) working in Mafra, developed a control system to reduce the losses and, consequently, to minimise the costs associated to the non-paid water. Nowadays, this monitoring system covers the entire zone, having already shown positive effects in the losses control, since the efficiency[(1)] (1-percentage of losses) of the system has increased from 73%, before the water system management implementation by CGE, to a present efficiency value of 80% (see Table 2).

Despite the fact that the percentage of losses during these three years did not varied significantly, it is considered satisfactory once it indicates an improvement in the control of the expenses related to water losses.

As well known, a passive control of leaks (e.g. the consumer complaints of low pressure or then the damage is visibly detected - abnormal water existence in some) can lead to a percentage of losses around 40%. According to experts and taking into account the experience of other countries [12], a percentage of 10 to 15% of losses is considered fairly satisfactory and, when an inferior value is verified, it seems not to be economically feasible to invest in leakage control and repair.

Table 2 – Losses of water in Mafra water supply system [3]

	1997	1998	1999
Distributed water	3,872,880	4,221,834	4,329,206
Sold water	3,080,426	3,296,296	3,478,686
Losses	792,454	925,538	850,520
Percentage of losses	20,5%	21,9%	19,6%

4.3 The benefit of monitoring

Mafra monitoring system includes 10 District Metered Areas (DMA) with 44 sub-zones, in order to be able to control the minimum night flows and analyse the Night Losses Indicator (NLI). With the definition of the DMAs, the company has installed flow meters at every single inlet and outlet of each sub-zone, in order to control the minimum nocturnal flows. In the most important DMAs, there are permanent flow meters, while in zones with very low consumption, the flow meters are only installed during the nocturnal period whenever necessary. In the latter case, it is convenient to keep a record with the normal operating conditions (without anomalies), so that, in case of leakage, the repair might be carried out as soon as possible.

An abnormal variation of the total volume of consumption can happen, with a sudden increase of it, what may to point to a possible sudden burst, being, in these

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(1) *Efficiency* is the ratio between the variation of effective distributed water volume and the total volume entered in the system.

cases, initiated the alert system for the verification of the problem. Moreover, losses inside the properties can occur as well, and in these cases, it is very difficult to detect them, except when the monthly consumption rises without apparent reason. In this situation, the affected consumers are contacted immediately, in order to understand the cause of such consumption increase.

The permanent flow meters measurements are analysed at a daily basis in an attempt to detect leaks of large dimensions. However, small leaks are not obvious in the readings of the meters of large zones due to the great fluctuation of the consumption during the day. This type of control not only takes into account the leaks, but also ruptures that occur in the distribution system. In order to better understand this control and the difference between a rupture and a leak, Figures 3 and 4 show a typical supply system, where real flow measurements have been carried out over the night period.

Figure 3 shows the normal situation of night flows in Marvão zone without anomalies, on the 11^{th} to 12^{th} of November of 1999, where the normal situation corresponds to consequent peaks between 22:30 and 2:00 and between 6:00 and 7:30, while between 2:00 and 6:00 presents a continuous discharge of 0.25 m^3/h. In this way, an important database is the Nocturnal Losses Indicator (NLI), which allows the company to have the information of which zones are the most propitious to the occurrence of leaks.

Figure 4 shows an abnormal situation, a rupture, occurred on the 6^{th} to 7^{th} of December of 1999, that has been easily detected by the sudden flow increase from 0.25 m^3/h (the minimum value in the normal situation) to 3.25 m^3/h at 22:00. In this case, after assessing the cause of this flow increase and all the eventual possible reasons, like the filling of a swimming pool, it was verified that it was a rupture and the system was immediately repaired.

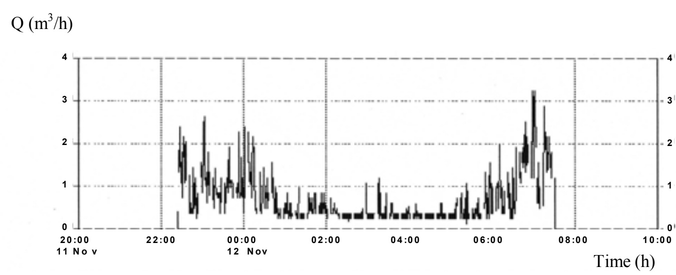

Fig. 3 Night flow measurement at Marvão without damage [3]

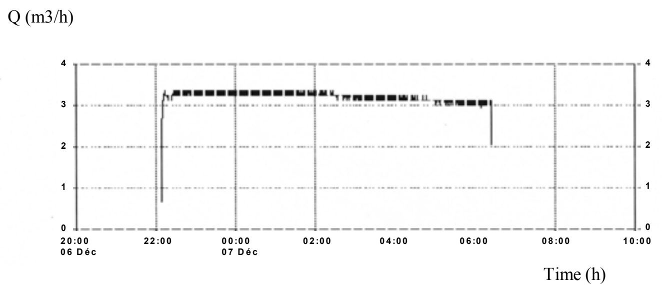

Fig. 4 Night flow measurement at Marvão with a rupture [3]

In companies where a passive control of the leaks is taken, a rupture cannot be detected if it occurs in a small branch, particularly if it is out of use. Similarly, if a rupture occurs close to a pluvial or sewer systems, the same situation will occur; apparently, at the surface nothing abnormal will be visible, since the water would be drained by the gutter. On the other hand, in the countryside zones, leaks can be detected by visual observation, such as the unusual development of vegetation. Moreover, the consumption in these zones has a daily evolution very well defined, thus an anomaly is easily detectable, while in urban areas, the pattern of the daily consumption varies much more during the day.

Hence, it should be emphasized that the occurrence of any anomaly in the readings of minimum nigh flow might immediately induce the implementation of appropriate actions, in order to avoid economic and social damages.

Each water company should create a database with all types of damages, even the induced ones to control and test the accuracy of metering system. According to Figure 5, most damages occur in pipes (54%) followed by problems in other devices and fittings, such as valves and pipe-junctions.

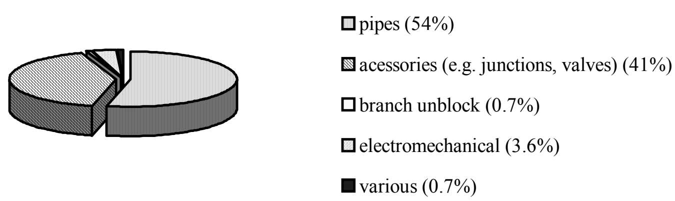

Fig. 5 Percentage of different type of damages [3]

The other damages presented in non-pipe elements do not necessarily imply water losses (e.g. valves damage that will only influence the system operation).

5 CONCLUSIONS

The leakage issue has received particular attention within the European Union in the recent years, owing to the intensity of droughts. Since then, water companies of several countries jointed efforts to develop an integrated policy to reduce and control leakage. There are several direct or indirect causes for leaks and ruptures: i) the high normal operating pressure which can influence leakage by continuous pipe stressing, increasing the frequency of bursts and the rate of water losses; ii) the ageing process of the infrastructure, in which water distribution systems deteriorate resulting in higher leakage levels and burst frequency; iii) an improper design and construction/installation; iv) the soil characteristics by which differential settlements of the pipeline may result in pipe crack; v) frequent traffic loadings. Hence, the implementation of monitoring systems has proven to be a promising methodology to assess the performance of each water system, as well as to predict eventual abnormal situations that may occur, such as sudden bursts or increase of water losses.

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