Testing Applicability and Cost Effectiveness of Permanent Acoustic Leakage Monitoring for Loss Management in Madrid Distribution Network

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Abstract

Leakage detection by means of acoustic loggers permanently installed in the water distribution network has been reported as an effective technique for losses reduction and control. Permanent monitoring of leaks in the network also provides valuable information on leakage evolution, history, frequency of occurrence, etc., which can be profitably applied to designing leakage management policies.

However, this technique requires significant investment, and decisions on its implementation, scope and field of applicability must be thoroughly assessed. Estimating the cost effectiveness of the method is not a simple task, and investment return must be carefully analysed.

This paper presents a discussion of the most relevant information obtained and conclusions reached from a pilot experience developed at different locations of diverse characteristics and behaviour, all of which form part of the distribution network of the drinking water supply system of Madrid (Spain).

Introduction: Canal de Isabel II leakage management strategy.

Canal de Isabel II is the company that manages the water supply in the Autonomous Region of Madrid, in Spain.

The company currently manages a network with 14,000 km of pipes that supply water to population of five and half million through 535,000 service connections located in 170 cities. About 2,200,000 properties and two million of dwellings are supplied.

Canal de Isabel II is responsible for the abstraction, transport, treatment, distribution and waste treatment of the water in this area. Consumption is controlled for billing purposes by bimonthly readings taken from the individual meters that are installed in 100% of the clients' service connections. Only a small percentage of the connections for outdoor municipal uses are not equipped with meters.

Canal de Isabel II has developed a leakage management strategy that involves preparing an annual water audit for the entire network managed, and for each one of the district metered areas that form part of it.

The results yielded by the loss indicators for the whole network in the year 2004 were as follows:

- Non revenue water: 23.9 %
- Non metered water: 22.9 %
- Authorised water: 84.5 %

With respect to the actual volumes of real losses, according to IWA terminology (Lambert et al., 2000), in mains and service connections, out of the hydraulic balance for the whole system:

- 353 litres / connection / day
- 13.329 litres / km of water mains / day
- 3.01 litres / property / hour

With respect to the minimum net night flow

- 1.65 litres / metre of water mains / hour
- 43.72 litres / connection / hour

The work undertaken at Canal de Isabel II aimed at improving the efficiency of the system is carried out in different areas of action:

Oriented systematic detection of leakage

Systematic leakage detection is based upon an analysis of the zonal performance of the distribution networks.

An analysis of zonal loss indicators will enable specialists to establish where it is advisable to carry out geoacoustic leakage detection. The real losses yielded by the hydraulic balance in the zone are identified to be significant indicators, together with the indicators for the general state of the network, such as the number of bursts[1] per kilometre of mains, and per service connection (Cubillo, 2002).

Every year, an average of 1,000 km of pipes are revised, which amounts to approximately 7% of the whole network. If one takes into account only the networks that are really in a poor state of repair, this percentage is actually greater, because the selection is oriented to areas where it will be more efficient. Checks are also made with respect to the cost / benefit ratio for each campaign, validating and adjusting the values for the selection indicators.

Applying more efficient techniques for active leakage control.

- Increasing the number of sectors that are monitored on line: a project has been undertaken to split the distribution network into sectors, and it is due to be completed in 2007, by which time there will be about 400 controlled sectors, each with approximately 50 km of mains.
- Pilot pressure management test that is beeing conducted in 2005, which is based upon a pilot study carried out in 2004. The aim of this test is to evaluate its feasibility, the implementation conditions and profitability.
- Permanent acoustic leakage monitoring pilot study, which is deal with in this document.

[1] Only spontaneous bursts are considered, i. e., bursts due to the state of the network, and not provoked by third parties, such as works on the street.

Permanent acoustic leakage monitoring: Aim of the study

The purpose of the work is to find out in which environments and under which conditions it is profitable to implement a permanent acoustic leakage monitoring system, in comparison with the traditional extensive geoacoustic search system. Other comparisons could be made done with other different techniques, but they are not analysed in this document.

The evaluated technique consists of installing the instruments of night time noise listening for leak-detection and to keep them permanently in those same positions, patrolling at regular pre-established intervals to read the leakage and non-leakage states. In this study, patrols were made every three weeks. Furthermore, the records collected by the apparatus during the operating period were analysed, with a view to obtaining additional information about the way the leakage situations evolved, the frequency with which they occurred, background, etc.

It was decided to develop a pilot study so that conclusions could be drawn with respect to the following:

- Checking the effectiveness of the applicability of the technology.
- Parameterisation of the network behaviour, by establishing the leakage occurrence rate and indicators of the state of the network.
- Establishing the economic efficiency for the technology in relation to some performance indicators registered in the implementation locations.

Description of the test and results

With a view to evaluating the possibility of widespread implementation of the equipment, three heterogeneous sectors of similar size were selected, in which there are major differences in the network and environmental conditions (circumstances such as the traffic noise and others could be significant for the performance of the technique). The total network controlled contained approximately 75 km of mains, and the study lasted for 6 months. A total of 460 items of listening equipment were installed.

The sectors chosen were:

- Prosperidad Sur: a neighbourhood in the City of Madrid.
- Loeches: a city with 4.300 inhabitants
- Moraleja de Enmedio: a city with 3.900 inhabitants

The basic characteristics of the sectors where the test was conducted can be seen in tables 3.1 and 3.2.

The pilot test consisted of:

- Installing the listening equipments.
- Conducting a first campaign for locating and repairing the leaks detected, until all the detectors are in an idle state (no leakage)
- Periodically patrolling, every three weeks to check the alarm state of the loggers.

Another way of using this technique consists in placing the noise loggers in one sector and, after the first of second patrol, when considered that all leaks have been repaired, to move them to another place. In this pilot study, it was preferred to keep the loggers in the same place for a period of 6 months, in order to get better information on leakage evolution and ratio of appearance.

Table 3.1 Basic characteristics of the network in the study sectors.

	Network length (km)	% Length of cast iron	Less than 5 years old	Bursts in mains / km / year	Total bursts / km / year
Loeches	25.5	86%	21%	0.53	1.80
Moraleja de Enmedio	23.4	44%	90%	0.13	1.73
Prosperidad Sur	25.2	77%	12%	0.56	4.96
Total for sectors	74.1	69%	40%	0.43	2.64

Table 3.2 Bursts per type and per year in the study sectors (data of 2003)

		Loeches	Prosperidad Sur	Moraleja de Enmedio	Total for sectors
	Length of network km	43.4	25.2	23.7	92.3
Bursts in service connection	Number of bursts	55	105	38	198
	Bursts /km / year	1.27	4.17	1.60	2.15
	Est. losses m3/h	2.55	4.31	1.99	3.38
Bursts in elements	Number of bursts	0	6	0	6
	Bursts /Km / year		0.24		0.07
	Est. losses m3/h		16.35		16.35
Bursts in mains	Number of bursts	23	14	3	40
	Bursts /km / year	0.53	0.56	0.13	0.433
	Est. losses m3/h	10.485	49.012	25.443	25.092
Total bursts	Total bursts	78	125	41	244
	Total bursts / km / year	1.797	4.960	1.730	2.644
	Est. losses m3/h	4.887	9.898	3.710	7.256

During the course of the pilot test, 49 leaks were detected by the permanent acoustic loggers, and their exact position located with geophones and correlators. There were no cases for which it was not possible to locate the leak detected by the equipment (i.e., there were no false alarms).

The number of leaks detected for the three sectors in the first extensive operation and subsequent patrols are represented on the next chart. The leakage occurrence rate per kilometre and per year was calculated on the basis of the detections made throughout the time of duration of the study, without including the cases of leakage located during the first campaign, resulting in a rate of 1.06 new leaks per km and year as an average.

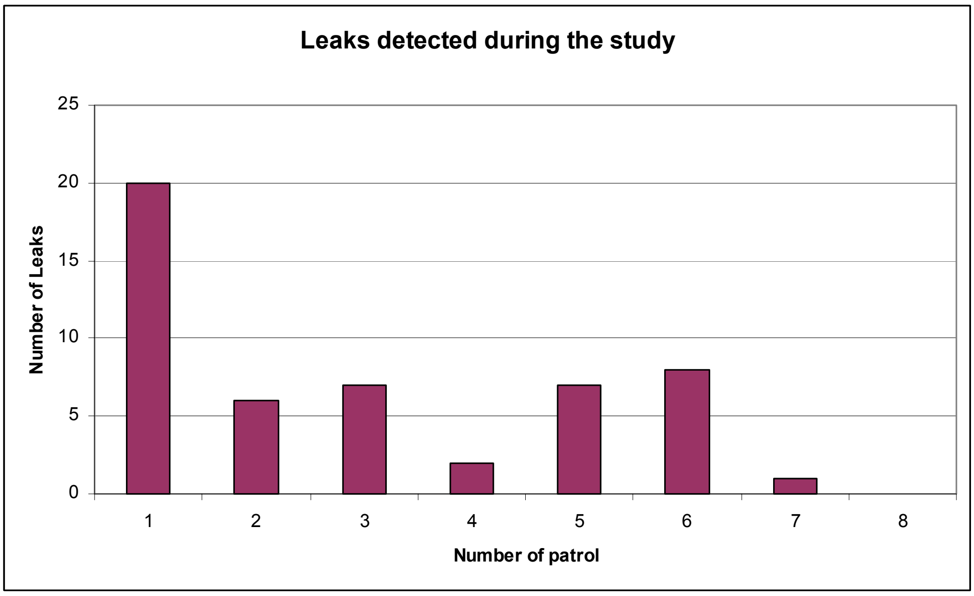

Figure 3.1 Number of leaks detected through the study

The next table shows the leakages detected in the different sectors, classified into types. The leakages that were located during the first campaign were not taken into account when calculating the leakage occurrence rate, i.e. the leaks that already existed before the work started were not included. However, the leakage that was detected in the initial campaign was counted when establishing the average flows for the different types of leakage, because it increased the sample without distorting it.

Table 3.3 Leaks detected and located during the study period

		Loeches	Prosperidad Sur	Moraleja de Enmedio	Total for sectors
	Length of network km	25.5	25.2	23.4	74.1
Leak in service connections	Number of leaks	13	4	2	19
	Leaks / km / year	0.57	0.28	0.25	0.37
	Flow m3/h	1.33	6.27	0.79	2.31
Leak in elements	Number of leaks	0	10	1	11
	Leaks / km / year	0.00	0.83	0.00	0.28
	Flow m3/h	0.00	0.25	0.10	0.24
Leak in private networks	Number of leaks	3	2	4	9
	Leaks / km / year	0.11	0.14	0.12	0.13
	Flow m3/h	1.13	5.09	0.31	1.65
Leak in mains	Number of leaks	2	5	3	10
	Leaks / km / year	0.23	0.28	0.37	0.29
	Flow m3/h	10.85	9.78	8.04	9.48
Total leaks	Number of leaks	18	21	10	49
	Total leaks / km / year	0.91	1.51	0.74	1.06
	Flow m3/h	2.35	4.13	2.71	3.19

At the end of the work a search was made using conventional methods (geoacoustics) checking the entire network of the sectors, to check the efficiency of the system. The results obtained were considered satisfactory because only one additional leak was detected, which is congruent with the calculated rate of leak occurrence. Furthermore, the records of noise occurrence over the last eleven days were retrieved from the memories of the installed loggers, and after their analysis, one burst was found, that had happened over the last week and that had been repaired by the services responsible whenever the water reached public thoroughfares.

Profitability analysis in the study sectors

The two technologies: conventional geoacoustic detection and permanent acoustic monitoring were compared.

The analysis curves are constructed from the gauging of the leakages detected and repaired and from the comparative-cost study for both techniques. The curves show the annual loss volumes (abscissa axes) and what would cost for each technology not to exceed that situation. The annual cost is made up of the cost of the depreciation of the equipment, plus cost of operating the technology, and the cost of producing the water that is lost in the sector.

The cost of the water lost is indicated by a straight line with a slope equivalent to the unit cost of water production in the supply system. The cost of reducing leakage by means of extensive geoacoustic campaigns grows exponentially, as the amount of water loss decreases. At the other end, the cost is reduced to zero if the network is not maintained. The analysis curve is constructed by addition of the two figures.

The permanent acoustic monitoring curve was plotted in the same way. For scenarios where there is major water loss, only the cost of the equipment is relevant, because it is assumed that this situation is close to a non-intervention state. That is to say, the loggers are installed but they are not "read", thereby saving the patrolling and detection expenses.

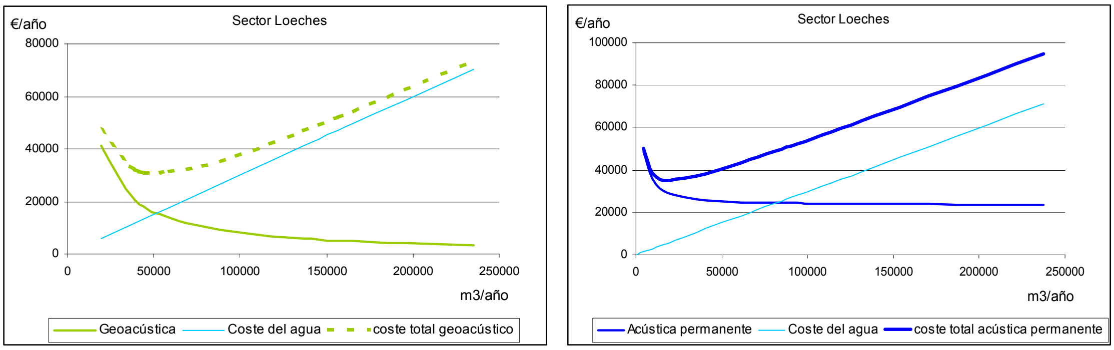

Figure 4.1 Constructing the profitability analysis curves

Graphs were plotted for each sector, and for the sum of the three sectors; these graphs simultaneously depicted the curves generated from leakage detection with the permanent acoustic monitoring system, and from the conventional extensive detection system. The most economical point for reducing the water lost due to leakage was sought for each sector, which corresponds to the point with the lowest ordinate (€ / year). The operating procedures of both technologies that are being compared, are, on the one hand the reiteration of a complete search on the network with traditional geoacustic method at an interval which yields the aimed loss reduction, and, on the other hand, installation of permanent noise loggers and patrolling them with the required recurrence in order to get the same results.

It can be seen in the Loeches Sector that permanent acoustic monitoring is more profitable for scenarios with minimum water loss. However, the minimum cost point belongs to the systematic geoacoustic detection line.

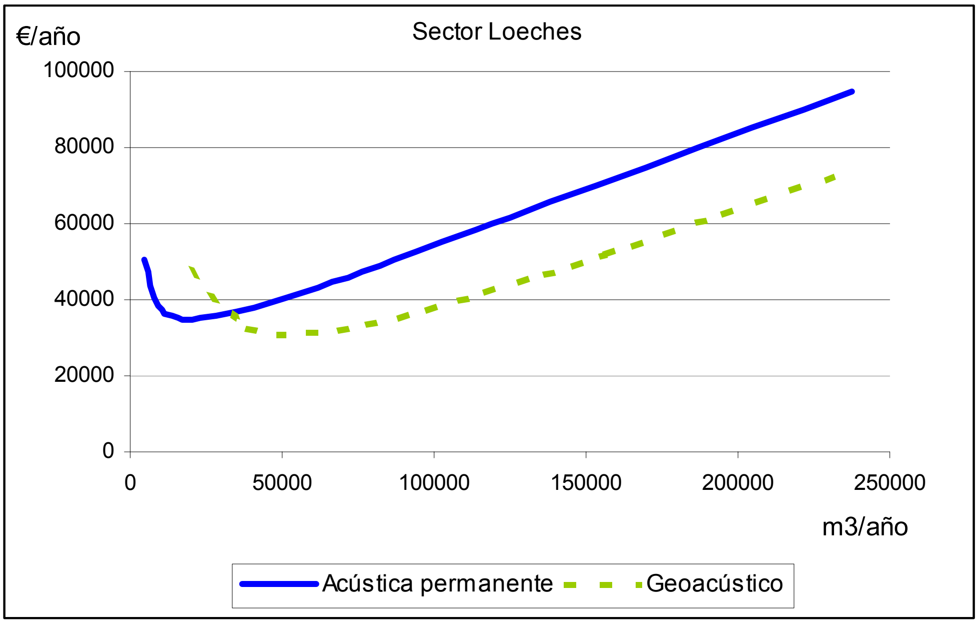

Figure 4.2 Profitability analysis in the Loeches Sector

The same procedure is used for the Moraleja de Enmedio sector. In this sector with less leakage volume, the most economical point still belongs to the geoacoustic campaign curve, the cost being lower than in the Loeches case.

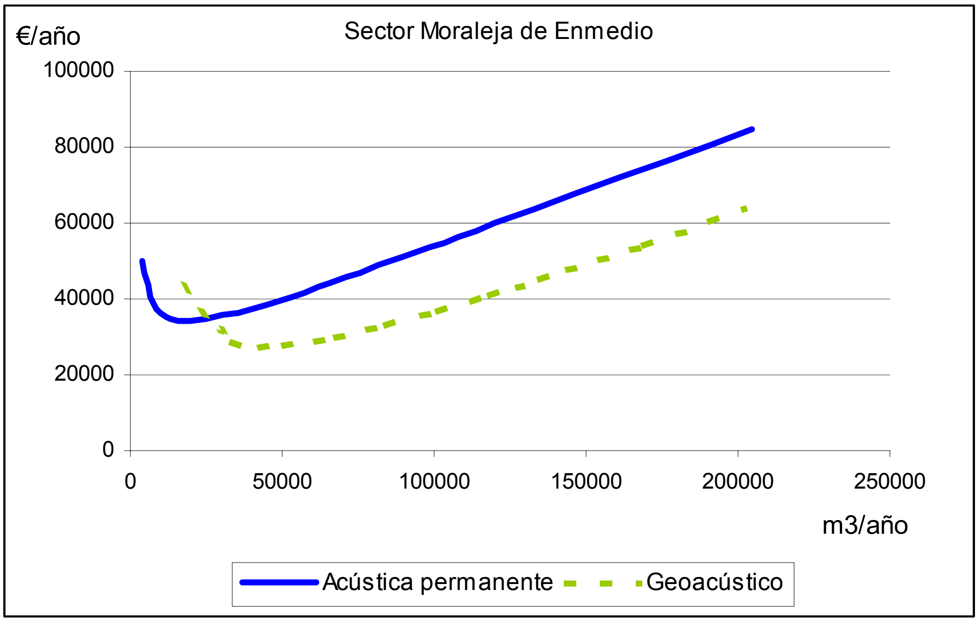

Figure 4.3 Profitability analysis in the Moraleja de Enmedio Sector

Where the Prosperidad Sur Sector is concerned - this sector yielding results of leakage rates that are very high with respect to the two previous ones -, the most economical point lies above the figure of 40,000 € / year, and this is achieved with the permanent acoustic monitoring technique.

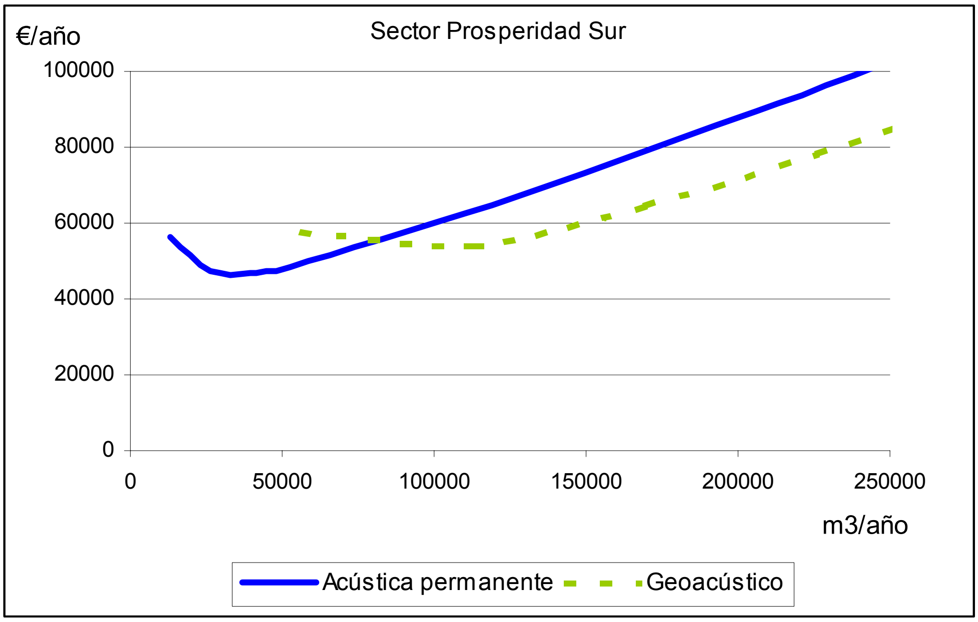

Figure 4.4 Profitability analysis in the Prosperidad Sur Sector

Finally, the curves were plotted for the sector that results from adding together the three above-mentioned ones. In this area, with 75 km of network and a leakage occurrence rate of 1.1 leaks per km per year, once again we find the most economical point in the permanent acoustic monitoring technology.

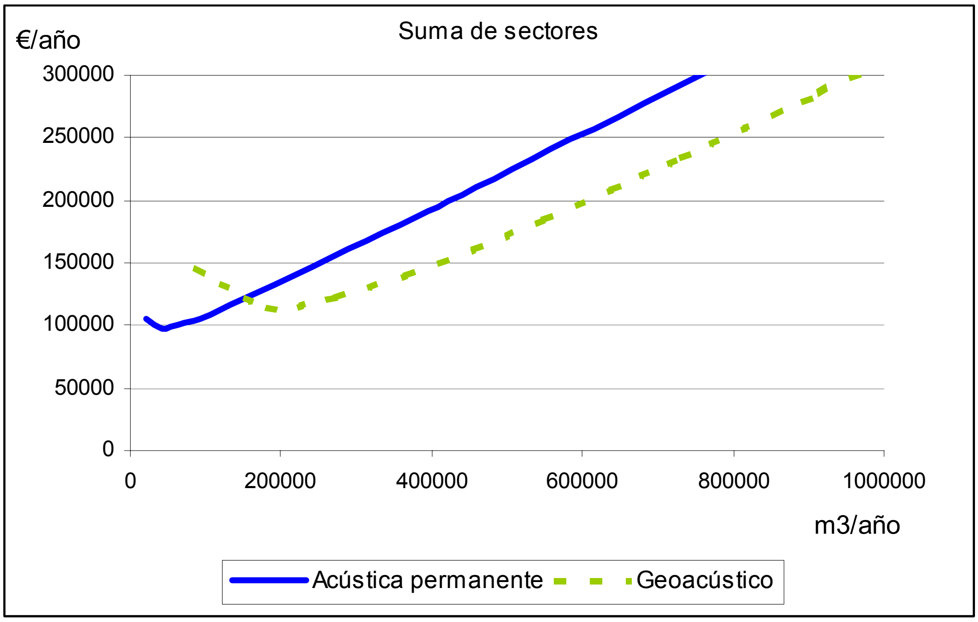

Figure 4.5 Profitability analysis for the sectors as a whole

This collection of curves, which correspond to networks that behave in different ways, was used to study whether or not it is profitable to implement this technology in a generic sector of the networks managed by Canal de Isabel II.

Applicability of the permanent acoustic leakage monitoring technology

It is important to have an indicator that provides sufficient information about the profitability of implementing the technology that is being assessed. The indicator must be objective, be applicable to sectors of different sizes, and there must be a certain amount of historical records readily available. It is needed for it to be an indicator for which the calculations can be made with the data that Canal de Isabel II knows at present with enough accuracy, and that it be based upon information that is both reliable and independent of the state of network operations or the maintenance state of the control elements (flow metres and the state of the valves).

In the context of the supply system for Madrid - and while accurate indicators of actual losses are not available with sufficient length of records for small areas (sectors) -, on the basis of analysis of the data and results obtained, it was concluded that the most suitable indicator for studying the advisability of implementing this technology in a specific sector, would be the number of bursts that take place per kilometre and year in that particular sector.

This indicator is associated with the number of leaks that occur on the network itself, as was verified in the sectors where the study was conducted. The ratio between the number of leaks and bursts per km, year was found to be an average of about 0.4 as an average (0.51 in Loeches, 0.31 in Prosperidad Sur and 0.43 in Moraleja de Enmedio).

This relation is expressed in graphic form in the following chart, and illustrates conclusions to this study.

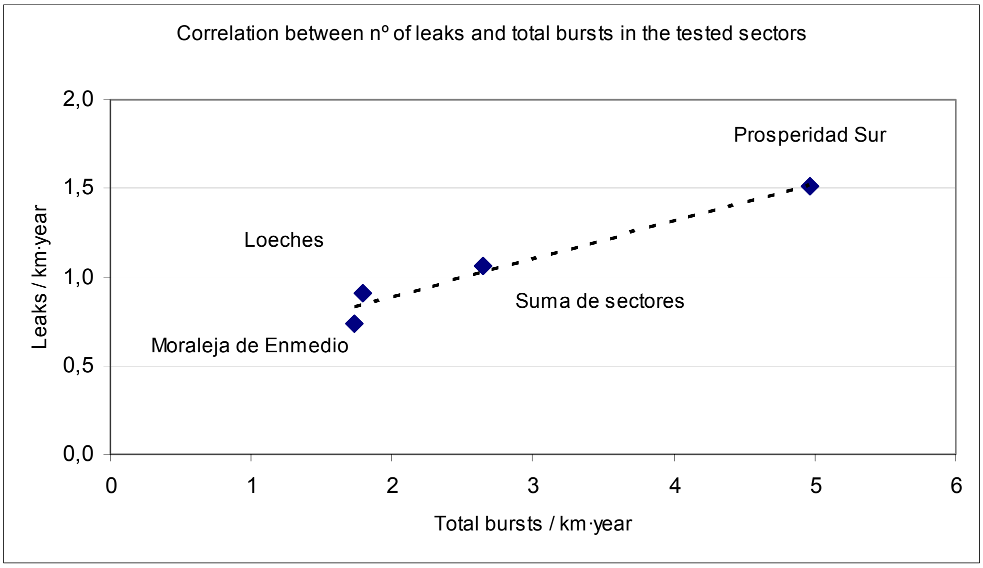

Figure 5.1 Relationship between the total number of Leaks and Bursts in the studied sectors

It can already be stated that it is more profitable to implement permanent acoustic leakage monitoring systems in the sectors where the total burst occurrence rate per kilometre and year is highest.

The lowest cost (most economical point on the curves shown in the preceding chapter) provided by each technology in a sector of reasonable proportions (75 km of network), has been calculated for the leakage conditions associated with certain burst rates that range from 1 to 5 bursts / km / year.

The conclusion reached is that for the conditions of soil and infrastructures of the Madrid system, for those networks whose total burst rates per kilometre and year are greater than 2.0 (bursts / km / year) it is profitable to implement permanent acoustic leakage monitoring equipment. The following graph shows the intersection of the minimum cost curves yielded by the different types of technology, and it can be seen that the permanent acoustic monitoring system is more advantageous as from 2 bursts per kilometre and year on the network.

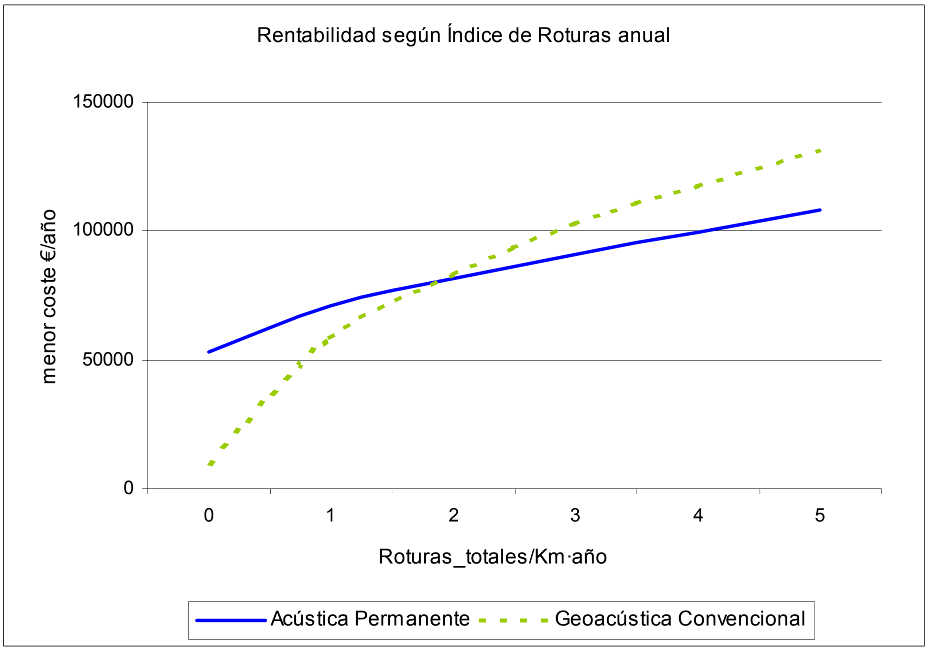

Figure 5.2 Profitability in a 75 km sector de 75 km on the basis of the annual burst occurrence rate

An analysis is added that deals with sensitivity to the estimated cost of water. A water production cost of 0.30 €/m^3 has been taken in the preceding calculations. The next graph shows two sets of curves, one for each of the technologies being compared, with water production costs ranging from 0.10 to 0.50 €/m^3. The curves have been plotted on the basis of the all the sectors being studied.

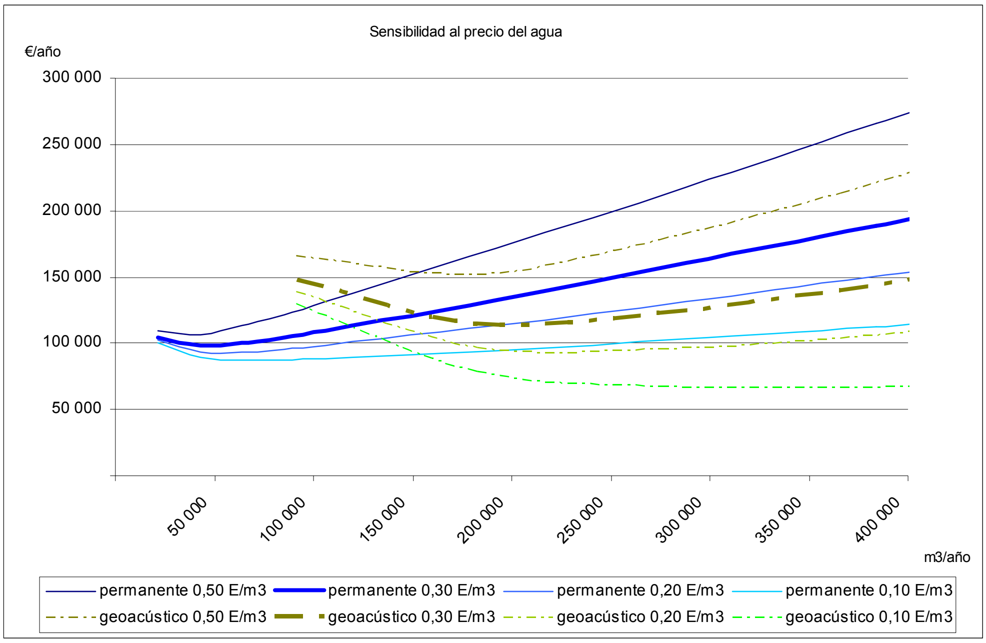

Figure 5.3 Analysis of water cost sensitivity

Higher water production prices raise the most economical point for the two technologies, while at the same time moving them towards scenarios with lower water losses.

Conclusions

Conclusions to the pilot study described are based on the field works developed with permanent noise logging devices installed uninterruptedly during six months, on three significantly different sectors of the Madrid distribution network, and covering 75 km of mains, which were considered representative of the overall distribution network.

From the analysis of the information collected during the study, the following outstanding points may be concluded:

Permanent acoustic leakage detection is an effective technique under all the tested conditions, which represent different characteristic states of the distribution network of the Canal de Isabel II water supply system in the Autonomous Region of Madrid.

From an economic perspective, this technology is more efficient than conventional leakage detection with ground microphones and correlators only in those networks with a certain degree of deterioration. This threshold has been established for the Madrid distribution system in 2.0 total bursts per kilometre and year. This level is only reached in a limited number of network sectors, which account for less than 15% of the total length of the Madrid water distribution network. For those heavily deteriorated networks, having poorer indicators, pipeline renewal is an option to be considered.

When accurate indicators of real losses are not available, the number of bursts per km and year has proved to be an alternative value, closely related to the number of leaks and water losses, where the Madrid system and soil conditions are given.

Additional information acquired from this study is the natural ratio of leaks occurrence, that is, for an average sector in the Madrid network of 1.06 new leaks / km year

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