Theme: A. Technologies for Water Management and Monitoring
Subtheme: A5. Optimization techniques and their application
Special session: S6. Model predictive control for water management

Definição de estilo: HIC18-Abstract

Locating unreported leaks with modelling tools and pressure monitoring: a case study

Ribeiro, L.[1,4], Sousa, J.[1,4], Muranho, J.[2,4], Sá Marques, A.[3,4]

[1] Polytechnic Institute of Coimbra, Department of Civil Engineering, 3030-199 Coimbra, Portugal
[2] University of Beira Interior, Department of Computer Science, 6201-001 Covilhã, Portugal
[3] University of Coimbra, Department of Civil Engineering, 3030-788 Coimbra, Portugal
[4] MARE – Marine and Environmental Sciences Centre, University of Coimbra, 3004-517 Coimbra, Portugal

Corresponding author: luirenco@isec.pt

Abstract. Water losses are a major concern for water companies, mostly due to their economical, technical, social and environmental negative impacts.

Unreported leaks are a major cause of water losses in water distribution networks (WDNs) and they are difficult to locate, particularly in plastic pipes, large diameters and low pressure conditions. The location of these leaks is very time consuming and requires specialized human resources, using sophisticated and costly acoustic equipment.

The use of modelling and optimization tools, supported by flow and pressure measurements, is showing to be a challenging alternative to the traditional procedure. This paper presents the application of the proposed methodology proposed in [1–3] to a real WDN, highlighting the major difficulties faced when dealing with real world conditions, namely gathering and checking data, and building and calibrating the water distribution model.

The results obtained in this case study show that this approach is very promising, encouraging future applications and developments.

Keywords: Leak location, minimum night flow, sensor placement, simulated annealing, water distribution network, water losses

1 Introduction

Water losses exist in all WDNs and are a major concern for water companies worried about their negative impacts: economic losses, technical and social problems, environmental damages and difficulties in guaranteeing the water quality safety.
Water losses include apparent losses and real losses. Real losses correspond to the volume lost through all types of leaks, bursts and overflows on mains, service tanks and service connections, up to the point of customer metering [4]. Unreported leaks (mains and service connections) are a major cause of real losses as they correspond to the water lost during 24 hours of every day.
In the literature, numerous papers have contributed to the location of unreported leaks [5]; some considering pressure-driven analysis [6,7], or demand-driven analysis [8,2]. and others considering the leakage modelling as a pressure-dependent demand [9].
Unreported leaks are difficult to locate, particularly in plastic pipes, large diameters and low pressure conditions. Traditionally, the exact location of unreported leaks is very time consuming

and requires specialized human resources, using sophisticated and costly acoustic equipment. Monitor of the Minimum Night Flow (MNF) is a quick way to estimate the unreported leaks flow because customer demand tends to be minimal at night. Simultaneously, the pressure in the WDN tends to stabilize near its maximum value due to the small flow, mostly caused by unreported leaks.
The use of modelling and optimization tools, supported by flow and pressure measurements, is showing to be a challenging alternative to the traditional procedure. Following previous works [1-3], this paper presents the application of the proposed methodology to a real WDN. The methodology requires monitoring the tank (level and flow) and some specific locations in the WDN (pressure) during the night period. A WDN calibrated model (based on the steady state equations) relates pressure and flow for different scenarios, and an optimization tool (Simulated Annealing algorithm) is used to identify the most probable leaky pipes.
In the next section the methodology is described. Details of the case study are shown in section 3. Finally, in section 4 some conclusions are outlined, the capability of the methodology is illustrated and emphasis is given to the major difficulties faced when dealing with real world conditions, namely gathering and checking data, and building and calibrating the water distribution model.

2 Methodology to identify the most probable leaky pipes

In this section the methodology to identify the most probable leaky pipes in a WDN is presented. The proposed methodology uses two tools: a modelling tool to simulate the WDN behaviour under different leak scenarios and an optimization tool to identify the locations and estimate the flows of the leaks in the WDN.
The modelling tool needs the WDN data (demand, topology, nodes, pipes, valves, …). The calibration of the WDN model (pipe roughness and node demand) is a critical stage independently of the final purpose for the model. It also needs monitoring the permanent flow and water level in the tank to produce an accurate WDN model.
The optimization tool requires the results of the modelling tool and pressure measurements in some strategic nodes in the WDN. Due to local limitation, few locations can be equipped with pressure sensors.
The continuous monitoring of the tank flow allows the identification of the MNF and associate the pressure at the monitored nodes in that period. During the MNF period consumption is minimal, the pressure along the WDN is close to its maximum value and leakage flows are also near its maximum. During the MNF period it is assumed that the flow is totally due to unreported leaks. This flow is divided in a certain number of possible leaks which are assigned to some pipes. The methodology uses a hydraulic steady state model that relates node pressure and pipe flows using the resistance laws in pipes to simulate the WDN behaviour.
Modern heuristics, like Simulated Annealing, are very useful tools to solve difficult problems. In the present case, the problem is to find the location of the leaks with a minimal predetermined flow. To estimate the position of the leaks at MNF period, an objective function is used to minimise the differences between calculated pressures and measured ones.
After the modelling and optimization analysis, the results highlight the most probable leaky pipes with their leakage flows. Previous experience applying this methodology shows that usually the pipes identified (or adjacent pipes) have a leak.
After analysing the results of the methodology, the human intervention in the field with specialized equipment and trained staff can then be planned. The field intervention effort will be focused towards specific pipes, and this can be a great contribution to increasing the efficiency of active leakage control.
This paper presents the application of the proposed methodology to a real WDN, highlighting the major difficulties faced when dealing with real world conditions, namely gathering and checking data, and building and calibrating the water distribution.

2.1 Optimization tool and modelling tool

The methodology developed is implemented in a computational application. The goal of the methodology is to identify the most probable leaky pipes and this is achieved by exchanging information between the modelling tool and the optimization tool.

The flow and water level in the tank during the MNF period is the starting data. The process starts at a certain initial temperature (a control parameter). For the initial solution the number of possible leaks is defined and the MNF is divided into equal parts, which are assigned to different pipes. The WDN modelling is performed and the results are passed to the optimization tool to assess the value of the objective function. The procedure continues by randomly generating new candidate solutions (different leak locations and flows), which can be accepted or rejected by applying the Metropolis criteria. After a few attempts, the temperature is decreased and the process continues until the stopping criterion is reached.

The final results of the methodology highlight the leaky pipes and estimate their leakage flows.

3 Case study

The real WDN has one tank (65.3m). The network has 150 junction nodes and 160 pipes. The total length of the network is near 20 km, with topographic elevations of nodes between 3.9 m and 45.5 m. Four pressure transducers were installed in the network; the tank flow was monitored as well as the tank water level.

This WDN supplies water to about 3,100 inhabitants, the MNF was 2.2 L/s and the peak flow was 13.65 L/s.

The actual number of leaks is unknown. So it was assumed that the total leak flow could be allocated to ten different locations. With this high number of possible locations the methodology is free to search for the correct number of leaks and respective flows.

For different nights, with slightly different MNFs, the methodology identified repeatedly some pipes as having leaks with considerable flows. Other pipes were identified occasionally, with reduced leak flows.

It is important to notice that the pipes with higher leak flows were easier to identify than the pipes with lower leak flows. This fact is important because increases the benefits associated with the leak repair and the leakage control.

The final version of the paper will contain a figure representing the problematic area of the WDN and the pipes identified as having leaks.

3.1 Field intervention

With the locations of the probable leaky pipes, the water company planned a field intervention. A preliminary inspection of the problematic area was executed. The results from the methodology were confirmed in the field with the use of a geophone to identify the exact leaks positions.

In general, the leaks were along the pipes identified or along pipes that shared a junction node with the pipes identified (adjacent pipes).

4 Conclusions

The case study highlighted the benefits of using a computational application to locate leaky pipes. Firstly the MNF monitoring was very useful to estimate the unreported leaks flow. The MNF proved to be mostly caused by unreported leaks.

The methodology was able to overcome the technical limitations imposed by data and measurements uncertainties and the stochastic nature of the optimization method. The methodology also surpassed typical real world problems, like gathering and checking data and building and calibrating the WDN model.

Looking at the final results, the main conclusion is that the methodology produced accurate solutions, identifying correctly the most probable leaky pipes in the WDN, giving a significate contribution to increase the efficiency of active leakage control activities.

5 References

[1] Ribeiro L, Sousa J, Sá Marques A. Improving the efficiency of leak location via optimal pressure sensor placement in water distribution networks. Water Util J 4 (2012) 3–12.

[2] Ribeiro L, Sousa, J.; Sá Marques A, Simões N. Locating leaks with TrustRank algorithm support. Water 7 (2015) 1378–1401. doi:10.3390/w7041378.

[3] Sousa J, Ribeiro L, Muranho J, Sá Marques A. Locating leaks in water distribution networks with simulated annealing and graph theory. Procedia Eng 119 (2015) 63–71. doi:10.1016/j.proeng.2015.08.854.

[4] Lambert AO, Brown, T., Takizawa M, Weimer D. A review of performance indicators for real losses from water supply systems. J Water Supply Res Technol - AQUA 48 (1999) 227–237.

[5] Pudar R, Liggett J. Leaks in pipe networks. J Hydraul Eng 118 (1992) 1031–1046.

[6] Giustolisi O, Savic D, Kapelan Z. Pressure-driven demand and leakage simulation for water distribution networks. J Hydraul Eng 134 (2008) 626–635.

[7] Wu Z, Sage P, Turtle D. Pressure-dependent leak detection model and its application to a district water system. J Water Resour Plan Manag 136 (2010) 116–128.

[8] Wu Z, Sage P. Water loss detection via genetic algorithm optimization-based model calibration. ASCE 8th Annu. Int. Synposium Water Distrib. Syst. Anal., Ohio, Agosto 27-30: 2006.

[9] Almandoz J, Cabrera, E., Arregui, F. CEJ, Cobacho R. Leakage Assessment through Water Distribution Network Simulation. J Water Resour Plan Manag 131 (2005) 458–466.