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# Leak detection and localization using models: field results

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**Abstract**

This paper presents the practical results obtained on the field from two different methods for identifying and locating leaks in water distribution systems using network modeling based algorithms. Both methods are based on the sensitivity analysis of pressure measurements to the demand variation in any node in the distribution system. This work is mainly focused on the obtained results using both methodologies in two different leak episodes, both in Icaria pilot DMA sector in Barcelona. The first episode is a non-calibrated real multi-leak scenario. The second episode was a calibrated artificial leak. Results are similar for both methods, and the identification of location of leaks is found within 150 meter from the actual leaks.



*Keywords*: Inverse Problem; Network analysis; Leak detection; Leak location; sensors

## 1. Introduction

The water sector is facing a continuous increase of the challenge in sustainability. Efficient leak management is one of the key issues, due to the dual effect on production costs and resource depletion. The development of Automated Meter Reading (AMR) technologies paves the way for a massive deployment of pressure sensor at low lifecycle costs, which allows innovative technologies to improve the time to detect, locate and repair leaks.

This paper presents the practical results obtained on the field from two different methods for identifying and locating leaks in water distribution systems using network modeling based algorithms. Both methods have been

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tested in one District Meter Area (DMA) of Barcelona. The water network which contains this DMA supplies both Barcelona and its metropolitan area covering around 3 million of inhabitants and is managed by the water company Sociedad General De Aguas De Barcelona (SGAB). The whole water network is composed by 4.574 km of pipes, 117 pressure levels, and 214 District Metered Areas (DMAs). In this pilot implementation, the Barcelona's DMA of Nova Icària has been used which is included in pressure level 55 within the city network. This DMA has two inlets, 1996 nodes and 3442 pipes with a total length of 38 km. Regarding the instrumentation, the Nova Icaria DMA is equipped by flow and pressure sensors at every inlet and by 6 inner pressure sensors. The sample time is 10 minutes and the sample accuracy is 0,1 meter.

This paper is mainly focused on the obtained results using both methodologies in two different leak episodes, both in Icaria pilot sector in Barcelona. The first episode is a non-calibrated real multi-leak scenario. In October 2011, the Nova Icaria DMA was affected by several leakages which caused successive small increases of the DMA minimum night flow up to 10 l/s. The main leak was successfully located, and the secondary leaks were then found in the same area. The second episode was a calibrated artificial leak generated during December 20th, 2012, in order to check the goodness of the proposed leakage localization methodologies; the calibrated leak started at 00h30 on December 20th, 2012, and finished approximately at 9h00 on December 21st.

## 2. Description of methods

The two methods are based on the sensitivity analysis of pressure measurements to the demand variation in any node in the distribution system. Method I presented in Quevedo et al. (2011) is based on the idea that every possible leakage in the studied DMA provokes an identifiable pattern, so it works by identifying the best match of current situation with theoretical patterns. Current situation at a given time $k$ is expressed through a signature vector computed as the difference between the real pressures on installed sensors at time $k$ and the pressures at sensors location in a simulated calibrated no leakage scenario. This signature vector is then matched, via correlation measures, to simulated leakage patterns. Method II described in Jarrige et al. (2011) computes the sensitivity information on line and makes use of its spatial structure for locating the demand anomaly.

Both methods have similar requirements: both require a significant density of sensors and a detailed and well calibrated hydraulic model of the area.

After a validation of the proof of concept using simulated data, Jarrige et al. (2011) and Pérez et al. (2011), both methods have been tested using live data. For Method I an on-line software prototype was developed which received sensor data from the SGAB Scada system and automatically processed it to check for possible leakages in the studied DMA; more details about this prototype implementation are provided in Meseguer et al. (2013). Method II has been implemented by hand, using procedures to automatically build 24-hours scenarios from the measurement data.

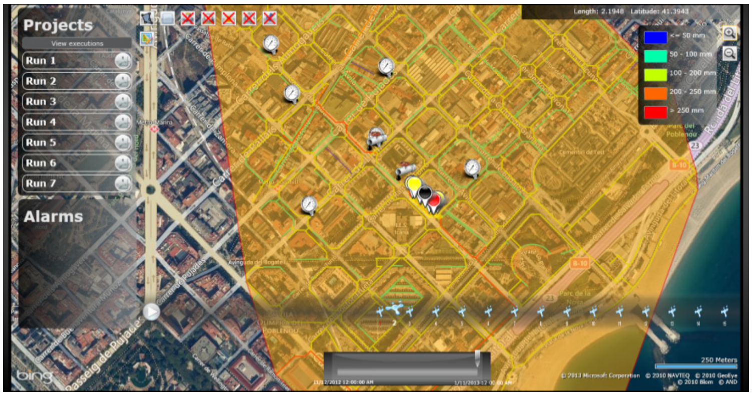


Fig. 1. Web based leakage detection and localization software tool.

### 2.1. Method I

The theoretical basis of this method was developed by a team of researchers from the Polytechnic University of Catalonia, later completed by researchers from Cetaqua and finally included in an integrated web-based tool developed by the AGBAR owned company *Aqualogy-Aquambiente Ingeniería de Sistemas*. Fig. 1 shows a snapshot of this software tool being available as an Internet service. Details about the software or the method can be found in Meseguer et al. (2013) and Quevedo et al. (2011). Section 3.1.1 is devoted to the results obtained in the two mentioned leak episodes.

### 2.2. Method II

It is a two-layer method based on inverse problem solving and explicit calculation of the sensitivity matrices as described in Jarrige et al. (2011). The lower layer implements a general purpose inverse problem solver over an extended period simulation, with respect to pipe roughness, node elevations, demand profiles, and equipment settings, taking into consideration flow rate, pressure and water level measurements. The upper layer implements a spatial refinement process taking into consideration the spatial contribution of each node to the sensitivity matrix.

The method has been implemented into the commercial software 'Piccolo'; it makes use of the software modelling environment and scripting capabilities for handling the field data and running the investigations.

## 3. Field results

### 3.1. Episode I: Real Multi-leak scenario

#### 3.1.1. Method I

In these analyses, the time step used to compute a leakage localization result (so called scenario analysis time step, $T_a$) parameter was set to 1 hour while the sensor sample time ($T_s$) parameter was set to 10 minutes. This means that a whole daily analysis was structured in 24 iterations (one for each hour) where in every iteration the hydraulic model was calibrated using the average value of the sensor measurements corresponding to the last hour. Additionally, the leakage localization result is computed using a sliding window of past time data ($T_w$) which was set to 5 hours and consequently, the scenario analyses were set up to provide an hourly leakage localization result from the 5$^{th}$ iteration. The leak localization model was affected by some anomalies that produced some instability in the pre-location of the leak until the beginning of the week of October 17$^{th}$. Once solved these anomalies, the model response stabilized. According to the simulation of October 15$^{th}$, Fig. 2 shows the area (green) pre-located by the model, the main leak in the sector (red cross), and the area where the remaining real leaks were located (red).

Despite the main leak on the sector was fixed, the minimum flow still had abnormally high values, so the water company management team continued in the identification of new leaks and new simulations were performed with the model. Simulations for October 19$^{th}$ provide a stable output within an area close to the first pre-localization corresponding to October 15$^{th}$. Some leaks were found and repaired within this zone, and model simulations for November 7$^{th}$ provided no leak pre-localization.

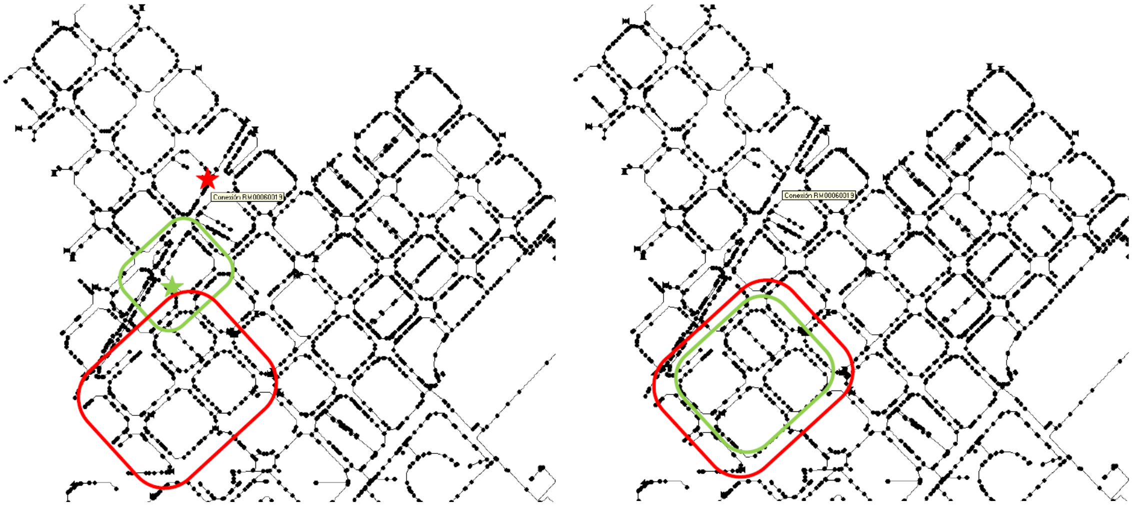

Fig. 2. On the left, main leak on October 2011 in Icaria sector (red cross), pre-localization suggested by the models using data from October 15th in green, and remaining leaks zone in read. On the right, once the main leak was fixed, the output of the models using data from October 19th in green, and the zone containing several smaller real leaks in red.

An interesting question for us was: which would the model output be if data of previous month were used? Some simulations were performed by using data from September 9th, and the model clearly showed the existence of a leak in the sector. Even a simulation performed using data from June 23rd revealed a leak existed in the DMA with quite good localization resolution – within 100 m radius – as shown in Fig. 3. The models, if run continuously, may provide to water company managers an early localization warning for leaks within a DMA.

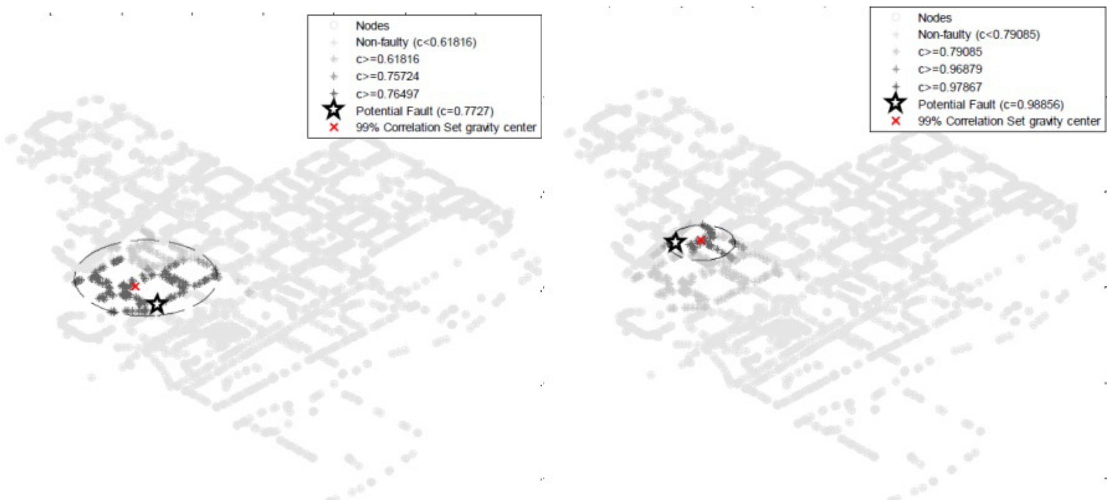


Fig. 3. On the left, pre-localization provided by the models using data from September 9th 2011. On the right, pre-localization proposed by the models using data from June 23rd 2011.

### *3.1.2. Method II*

Calibration step

The subset of data from early August to late October 2011 has been investigated. Starting with the raw model build from the geographical information system (pipes and nodes) and billing system (annual average demand), a preliminary calibration step was required. The analysis of demand patterns showed that the peak demand was reached on September 17th 2011, as well as a high daily average and minimum night flow. The calibration parameters were: friction factors of two valves at each entry point, elevation at 7 pressure sensor nodes, and 6 classes of pipe roughness related to distinct pipe materials. The calibration was carried out using the inverse problem solver for those parameters, with respect to the 7 pressure measurement points × 24 hours × 6 samples an hour, and verified on measurements from September 10th and October 25th.

Leak investigation

The investigation of potential leakage was carried out on the September 9th to October 26th period. As mentioned previously, it consists in solving the inverse problem with 10 min time step demand patterns as parameters. Those parameters are time dependant but spatial information is expected. It is obtained by an iterative hierarchical approach: an additional small demand is allocated to a specific demand type over a subset of nodes, the inverse problem is solved, and those nodes which sensitivity is positive are removed from the set. Then the method iterates 6 to 8 times until a very small number (1 – 3) of nodes is left in the set.

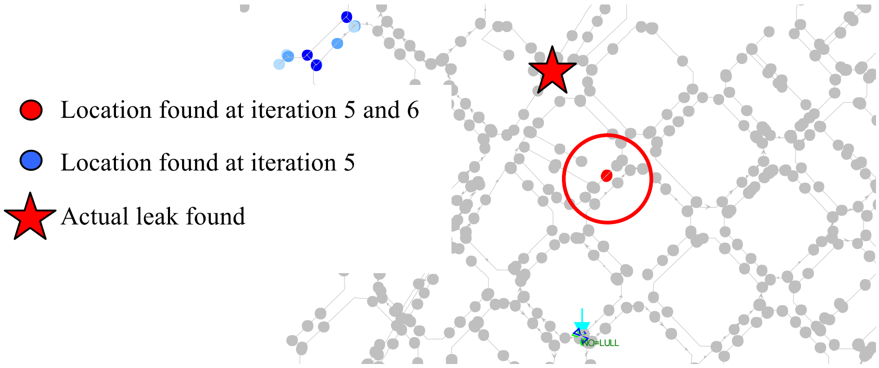


Fig. 4. Location of actual leak using method II - field data October 14th

The 24 hours periods for which missing data has been found have not been investigated. After analysis of remaining data between September 13th and October 25th, the same anomaly location shown in Fig. 4 points out 19 times with increasing intensity, up to October 17th inclusive, when the leak was fixed. The daily volume estimation of the anomaly is shown at Fig. 5. The anomaly location is 150 meters away from the actual leak.

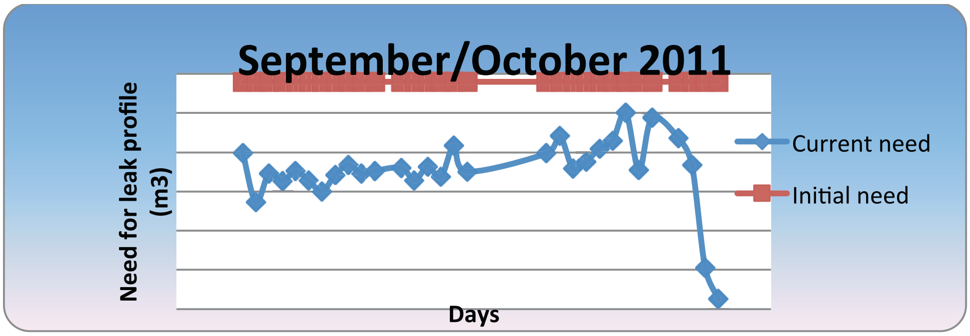


Fig. 5. Estimation of the leak volume per day - Icaria DMA

### 3.2. Episode II: Calibrated leak

#### 3.2.1. Method I

During the study of this leak, some inconsistencies in the sensor (pressure) data were detected, those could have different reasons:

- Sensor elevation erroneously estimated.
- Non-calibrated internal pressure sensors resulting in the existence of an offset between measured and simulated internal pressure: different offsets in each pressure sensor.
- Pressure sensors clock with 1h shift with respect pressure and flow data from control points in the DMA; data used as boundary conditions for model calibration.
- One of the six internal pressure sensors was affected by a fault and consequently, was not considered in the leak analysis scenario.

Fig. 6 below shows the consistency of data before and after corrections have been made.

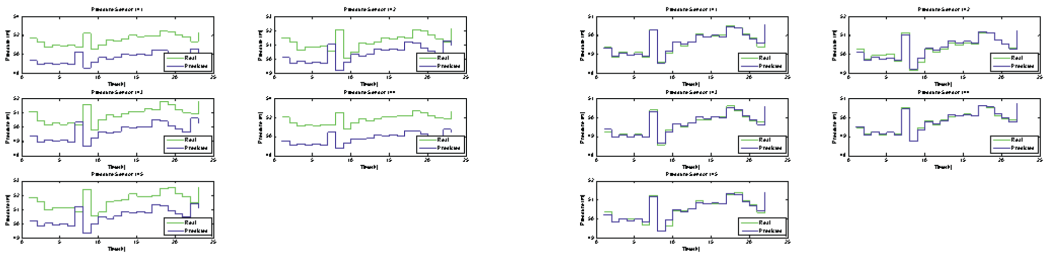

Fig. 6. On the left, inconsistent internal pressure sensor data; on the right, consistent internal pressure data after some treatment.

In this case, we varied the sliding window parameter to 10 hours, being the sensor sample time and the time step used to compute a leakage localization result (Fig. 7) the same as in Episode I. From a simple night flow analysis the estimated leakage size was 5.6 l/s, which turns to be very similar to the one generated for the experiment.

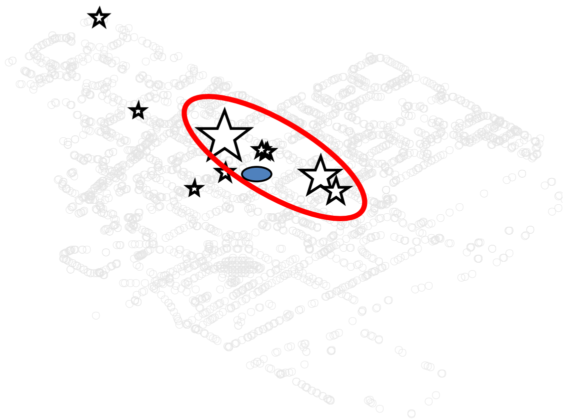

Fig. 7. Leakage detection provided by the models on the calibrated leak episode on December 20th 2012. The stars correspond to the aggregated probability of the given nodes from having a leak. Calibrated leak exact localization is given by the blue coloured circle.

### *3.2.2. Method II*

The model has been updated early 2012. After identifying independently and fixing the same inconsistencies as mentioned above the calibration is made using measurements from December 17, 18 and 19th. Then analysis is carried out using data from December 20th. The results are presented in Fig. 8 below:

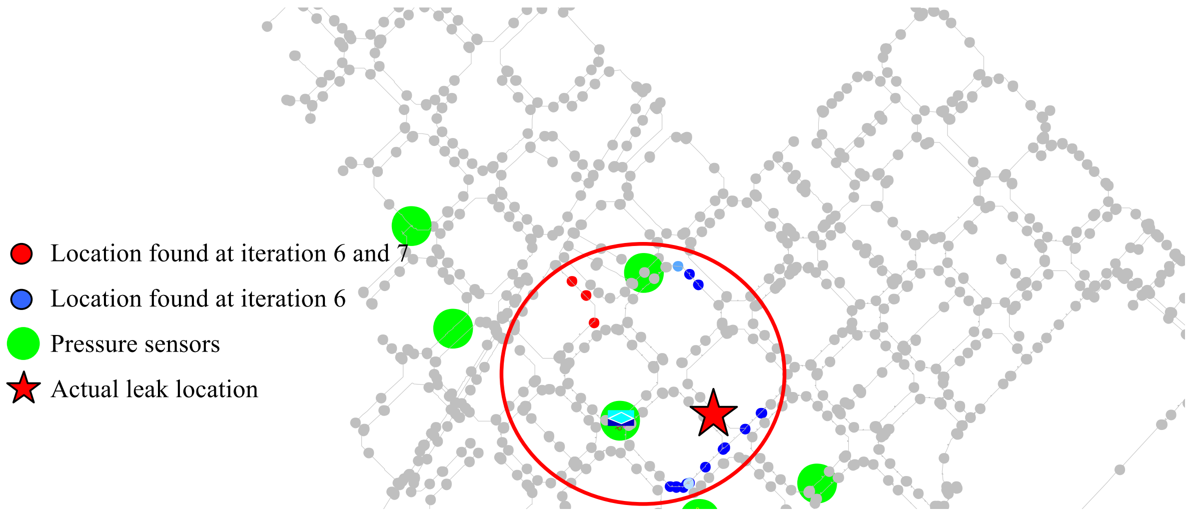


Fig. 8. Spatial location of the calibrated leak on December 20th

The leakage location is determined within a circle of radius of 150 meters.

The average intensity of the leak as identified with method II is 19 l/s, which is over-estimated. The identified pressure patterns are very close to the measurement points, as shown in Fig. 9.

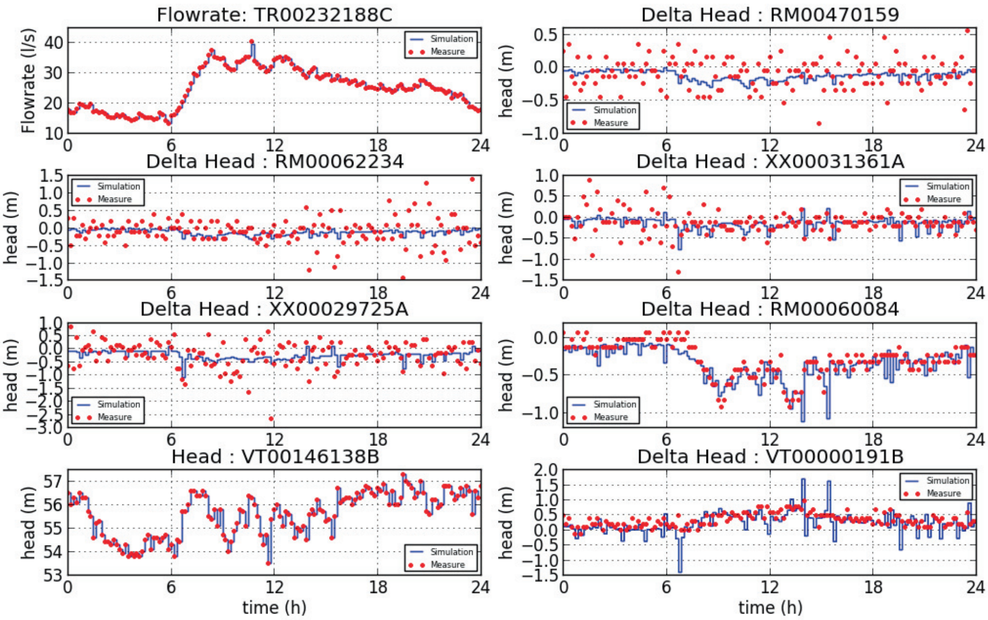


Fig. 9. Hydraulic head time series relative to the main entry node VT00146138B

## 4. Conclusions and future work

This paper describes the results obtained on the field from two different model-based leakage localization methods for water distribution networks considering two leakage scenarios in one DMA of Barcelona: the first scenario is a non-calibrated real multi-leak scenario (October 2011) and the second episode was a calibrated artificial leak generated during December 20th, 2012.

The two methods are based on the sensitivity analysis of pressure measurements to the demand variation in any node in the distribution system: Method I from Quevedo et al. (2011) is based on the idea that every possible leakage in the studied DMA provokes an identifiable pattern, so it works by identifying the best match of current situation with theoretical patterns while Method II from Jarrige et al. (2011) computes the sensitivity information on the fly and makes use of its spatial structure for locating the demand anomaly.

The results obtained using both methods are very similar and show that the leakage detection and localization may be performed efficiently and the detection/localization time for a leak is significantly reduced. The leak is located within a circle of 150 meters radius. Nonetheless, certain limiting factors on the ability of the methodology to detect and locate leaks may exist, namely: the need for a well-calibrated hydraulic model (topological structure and parameters), the accuracy in estimating the spatial demand distribution within the DMA and the precision of the sensors installed in the network.

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