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Model calibration and leakage assessment applied to a real Water Distribution Network

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Abstract

The use of water distribution network models depends highly on the confidence that the operators have on them. Models generated automatically from the Geographical Information System using the hydraulic equations integrated in a simulation model [7] are available in most of the water utilities. Once the first simulation results are compared with the available measurements, calibration is required [6]. This paper presents the process of adjusting the original network model of a village called Sant Joan de Vilatorrada network to fit the simulation results with the measurements. The adjustments in the model range from the macrocalibration level to the microcalibration level [3]. The macrocalibration process is based on the analysis done by the engineers, and the conclusions are formalised for future use in other networks. Microcalibration is centred in setting the emitter coefficients using Genetic Algorithm optimisation. The results of the work include an adjusted model for decision taking, an assessment of the background leakage and a methodology to be applied in other parts of the network.

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1. Introduction and Problem Statement

The ability to model larger water distribution systems has improved considerably over the past decades [1]. The cost to set up and execute a mathematical representation or network simulation model has fallen with the advent of widespread usage of microcomputers. However, the cost for calibration of the simulation model and for data collection required to estimate parameters has not decreased. In many cases, due to the high costs and perceived lack of benefits, a thorough calibration effort is not performed. Without good parameter estimates, a simulation model may not be modelling reality, and therefore, the planning or operation decisions made based on simulation analysis, may be in serious error.

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Data in a water company are managed normally by more than one technician. The infrastructure information is updated regularly in a Geographical Information System (GIS) that can generate automatically a mathematical model for simulation. Most of the data involved are very stable in time (e.g. length, diameter, materials). Nevertheless, some modifications in the network are eventually not recorded. Demand data are managed by the billing department. Frequency in data obtaining and recording can vary from the data coming from the third main information supplier: the SCADA. The modeller has to merge all this information in order to have an updated model. The set-up of the model is what is described in this work. It is a very applied experience that allow us to enlighten the easy, but tedious, handicaps that the model use still have. The adjustments in the model range from the macrocalibration level to the microcalibration level [3][4].

1.1. Problem statement

Big networks have their inputs monitored (flows, pressures and tank levels). These measurements are used to automatically set the boundary conditions. It is not always the case, as often the information comes from different sources and has to be harmonized. Once the boundary conditions are fixed, the discrepancies between measurements and prediction can be caused both by events in the management of the network that have not been included into the model and/or parameters that can be tuned. Both these processes are mandatory if we want to rely on the model. The questions that this work aims to answer are:

1. How can we harmonize the different data sources?
2. How the network has evolved since the last model updating?
3. Which is the background leakage in the network?

This work presents how the calibration process is applied to a network presented in section 2. Section 3.4 presents the macrocalibration process and its results. In section 4 the parameter tuning for the background leakage is described. Finally in the conclusions section 5 the results and how the process can be standardised are discussed.

2. Case study

The network used is located in Sant Joan de Vilatorrada, a 11,000 inhabitants village near Barcelona (Catalunya). The hydraulic model and all the data were provided by the water supply company, *Aigües de Manresa*. Figure 1 presents the EPANET model and location of the network.

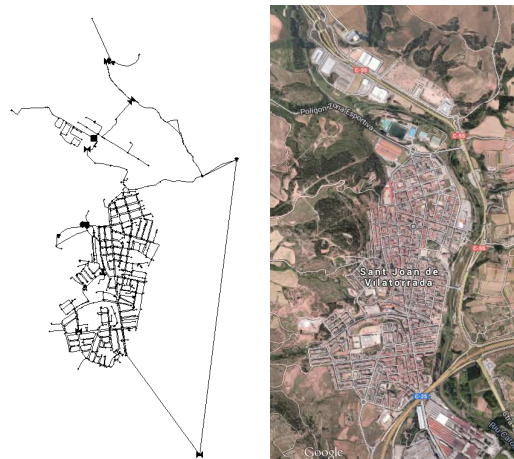


Fig. 1. Model and location of the network of study, Sant Joan de Vilatorrada in Catalunya

The Water Distribution Network (WDN) is divided in three District Metered Areas (DMA): *Sant Joan* (typically urban sector), *Aigua Elevada* (domestic consumers with detached houses) and *Pla de Vinyats* (industrial sector). Figure 2 shows a schematic representation of the network. It will be very useful for further understanding of the calculations and modifications introduced in the model. The main elements of the network are:

1. 5 tanks: *Costa Rodona*, two in *Sant Joan*, one in *Mollet* and one in *Aigua Elevada*
2. 6 flow transducers, two of them manually read.
3. 3 pumps : two in parallel at the output of *Costa Rodona* tank and the third at the output of *Mollet* tank. They are on-off pumps.
4. 5 throttle valves
5. 1 pressure reduction valves (PRV)

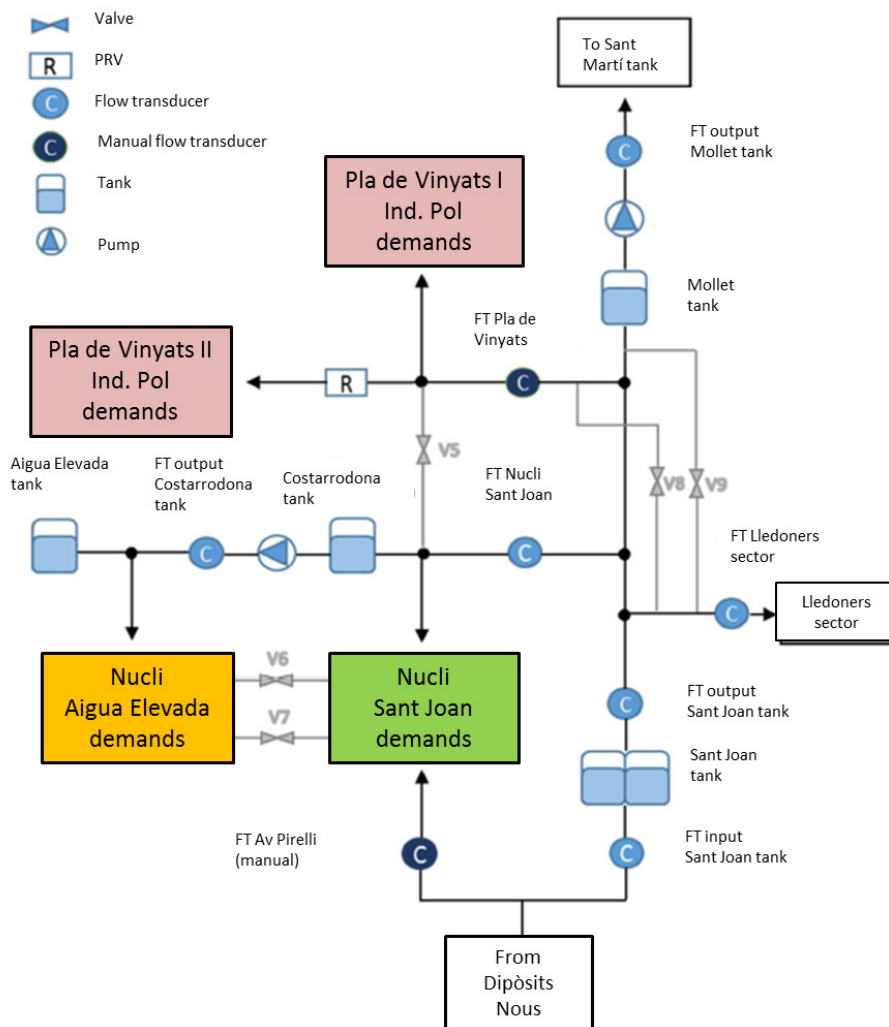


Fig. 2. Schematic representation of the network

The software used for this work is the EPANET hydraulic simulator connected with its TOOLKID to Matlab. The DLL library of functions was adapted and is available in the CS2AC web site with a graphical interface and benchmarks [5].

3. Macrocalibration

Demands are not physically in the network like nodes or pipes. They are inputs because they are the driving force behind the hydraulic dynamics occurring in water distribution systems [7]. Thus the first step in the calibration of a model is to generate the demands. The demand model uses the inflow measurements in each DMA (*Aigua Elevada*, *Sant Joan* and *Pla de Vinyats*), calculated using the flow and tank level data, and the percentage of consumption of each demand that comes from billing. Equation 1 expresses the demand $d_i(t)$ of node i at time t .

$$d_i(t) = \frac{bd_i}{\sum bd_i} q_t(t) \quad (1)$$

where bd_i is the so-called base demand of the node i and $q_t(t)$ is the total demand of the DMA calculated at time t .

3.1. Demand Calculation

The water consumed in *Aigua Elevada* DMA ($d_{AE}(t)$) is the difference between the pumped flow ($q_{cCR}(t)$) and the mass balance of *Aigua Elevada* tank ($d_{AET}(t)$) (eq. 2).

$$d_{AE}(t) = q_{cCR}(t) - d_{AET}(t) \quad (2)$$

The water consumed in *Sant Joan* DMA (d_{SJ}) is obtained from the flow transducers of *Sant Joan* (q_{cSJ}), the constant flow of *Pirelli* ($q_{Pirelli}$), the mass balance of *Costa Rodona* tank (d_{CRT}) and its output flow transducers (q_{cCR}) (eq. 3).

$$d_{SJ}(t) = q_{Pirelli}(t) + q_{cSJ}(t) - d_{CRT}(t) - q_{cCR}(t) \quad (3)$$

The water consumed in *Pla de Vinyats* DMA (d_{PV}) is obtained from the output flow transducer of *Sant Joan* tank (q_{cSJ}), the flow transducer of *Sant Joan* (q_{cSJ}) and *Lledoners* (q_{cLI}), the mass balance of *Mollet* tank (d_{MT}) and its output flow transducer (q_{cM}) (eq. 4).

$$d_{PV}(t) = q_{cSJ}(t) - q_{cSJ}(t) - q_{cLI}(t) - d_{MT}(t) - q_{cM}(t) \quad (4)$$

Figure 3 presents the calculated demands for one day. *Sant Joan* DMA water consumption presents the typical profile of a urban area. *Pla de Vinyats* DMA has a more constant water consumption as it corresponds to an industrial area. Finally anomalies are present in *Aigua Elevada* DMA and *Pla de Vinyats* DMA where negative consumptions appear.

The simulation of the model is validated comparing the level of the tanks. In figure 4 these levels show major discrepancies. Only *Aigua Elevada* tank presents good predicted levels due to the independence of hydraulic elements further than the demand calculated using its own data.

3.2. Pump curves

The anomalous demand pattern of *Aigua Elevada* DMA with negative values during long periods of time was the first suspicious source of the mismatch between predictions and measurements. Looking at figure 2 and equation 1 it is clear that only data coming from *Aigua Elevada* tank and *Costa Rodona* flow transducers can produce this bad demand calculation. The negative demands coincide with the periods of pumping, when the pumps are switched on. Furthermore, the shape of these changes is sharper than the changes present in a DMA consumption. All this suggest that the flow coming from the pump is underestimated. By correcting the pumping flows, the demand in *Aigua Elevada* is improved, avoiding negative values, figure 5.

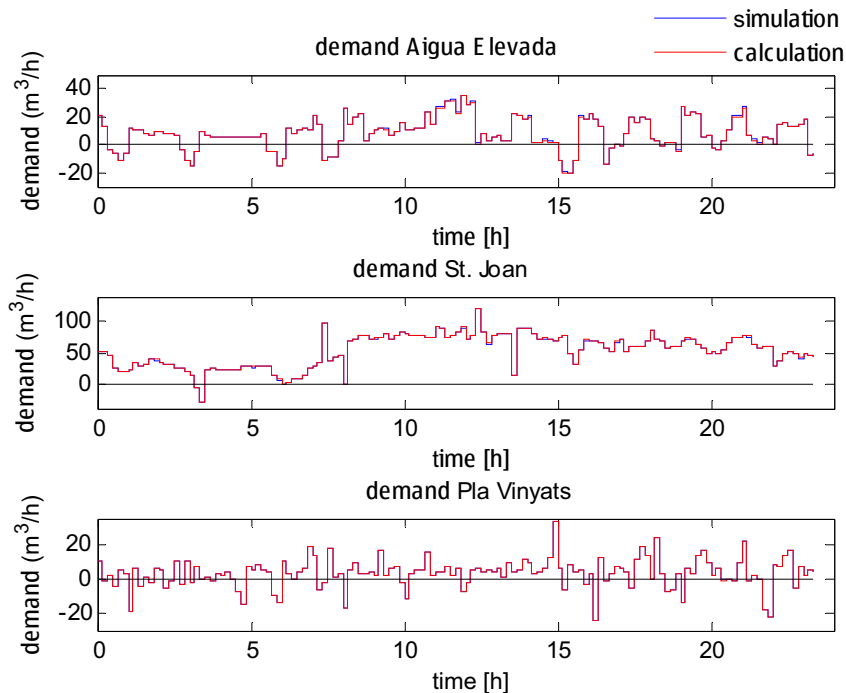


Fig. 3. Demands calculated for the three DMA for 1 day

3.3. Re-sampling and filtering

The different sources of data imposes a re-sampling task of the measurements in order to have a coherent set of inputs for the model. A straightforward re-sampling (sample-and-hold) induced a mismatch in the demand pattern of *Sant Joan*. In figure 6 it is obvious that the sharp changes in demands in *Sant Joan* DMA are due to a false relationship to the pumping.

The measurements used for the mass-balance of *Costa Rodona* tank had a random sampling with long periods with no data. The re-sampling of the information produced a wrong estimation of the water entering the tank. When the pumps were switched on in the output, in absence of measurements in the tank, the water was assumed to come from *Sant Joan* DMA. By changing the model using a constant inflow in the tank, the demand pattern in *Sant Joan* improves its shape.

Finally, the demands are filtered using a local polynomial regression in order to smooth the pattern and avoid the spurious data. Figure 7 presents the total demand (very similar to that of *Sant Joan*) with a typical urban pattern. Demand of *Aigua Elevada* DMA has a residential pattern. Finally, the lowest demand corresponds to the industrial area *Pla de Vinyats* DMA.

3.4. Valves

The behaviour presented by *Mollet* tank could not be explained unless the flow coming form *Sant Joan* tank were underestimated. The hydraulic constraints are the head loss in the main pipe thus a first attempt was to tune these parameters. The unsuccessful results suggested that maybe one of the valves (*V8* or *V9*) were actually open. Results with such correction improved. In figure 8 the comparison between the prediction in levels and measurements shows an improvement respect to figure 4.

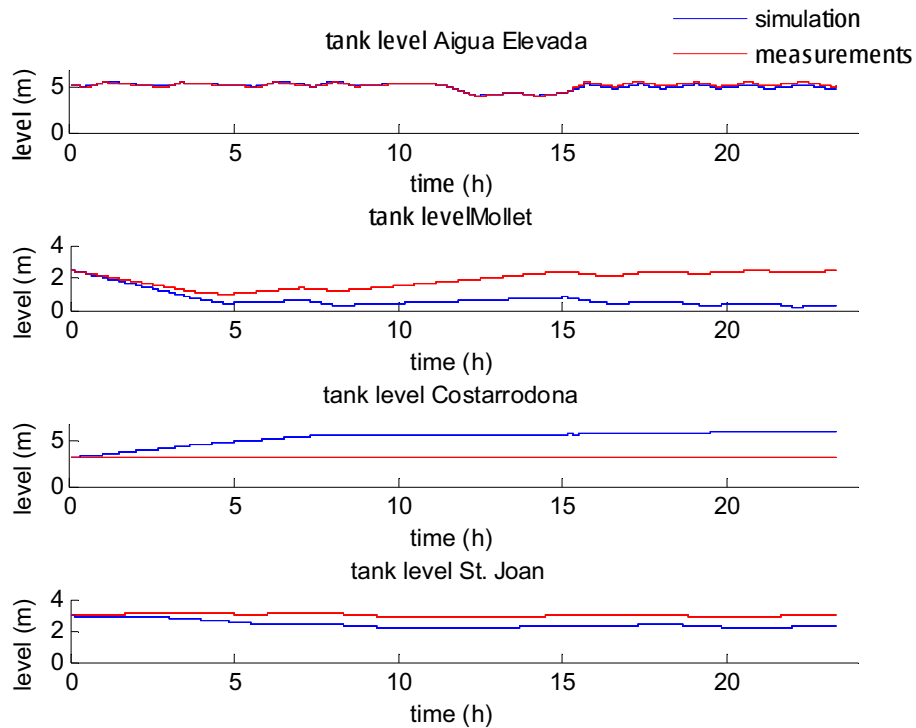


Fig. 4. Tank levels for the simulation of the original model with the calculated demands

4. Microcalibration

Demands in the three DMA have been calculated so far from the boundary conditions without considering background leakage. This leakage is modelled as an extra pressure dependant demand, equation 5.

$$q_l(t) = Cp^\gamma \quad (5)$$

where q_l is the leak flow at a node with pressure p ; the exponent $\gamma = 0.5$ is a constant of the model and the emitter coefficient C depends on the network and node. The tuning of these emitter coefficients is formulated as an optimisation problem that aims to minimise the predicted levels' errors (eq. 6). The optimisation variables are the three different emitter coefficients, one for each DMA.

$$RMSE = \frac{1}{N} \sqrt{\sum_{t=1}^N h_{mea}^2(t) - h_{sim}^2(t)} \quad (6)$$

where $h_{mea}(t)$ and $h_{sim}(t)$ are the measured and simulated level at sample time $t = 1 \dots N$. The optimisation problem is solved using genetic algorithms (GA), namely in this work the GA functions of Matlab [2]. At each iteration for the cost generation the new coefficients are used for the simulation. This simulation is a multi-step process:

1. Simulation with the new emitter coefficients and total inflow.
2. Calculate the loss of each DMA.
3. Extract the total loss to the total inflow.
4. Calculate the new demands with the new total inflow.

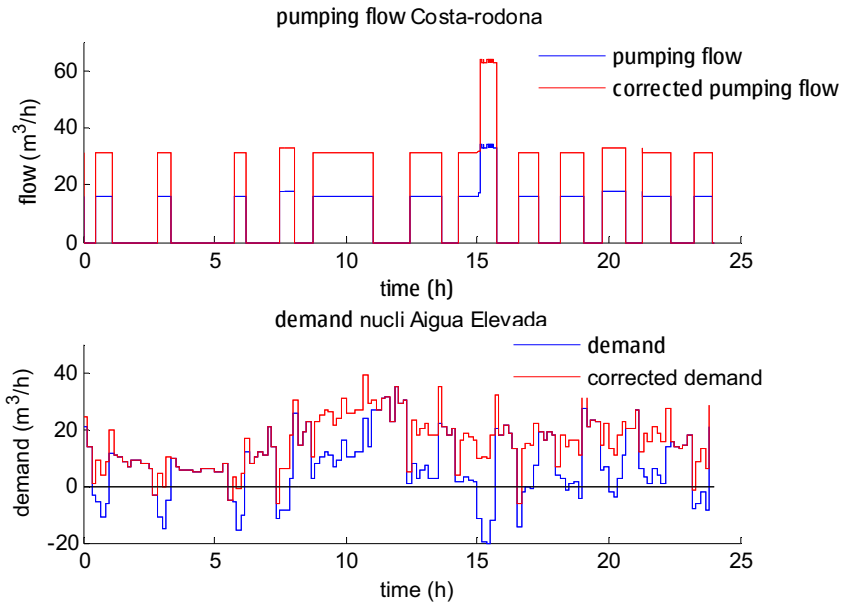


Fig. 5. Pumping flow correction and new demand pattern for *Aigua Elevada*

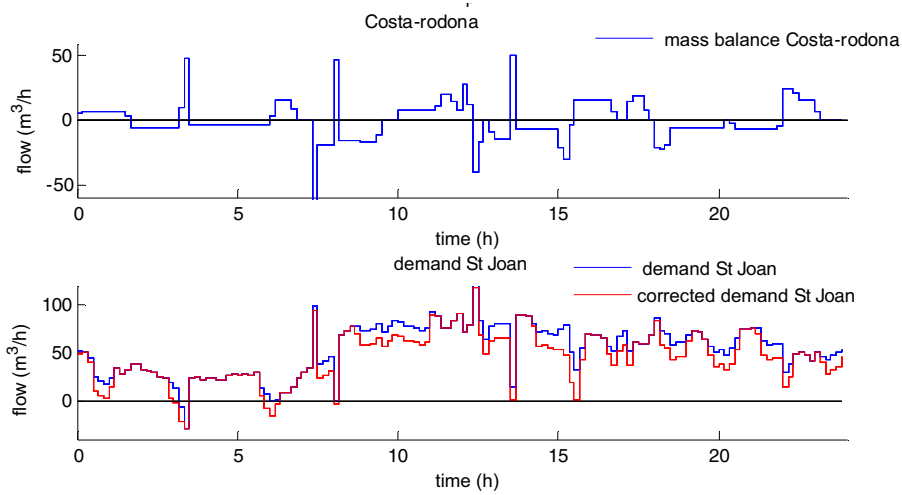


Fig. 6. Mass balance in *Costa Rodona* tank and demand in *Sant Joan* before and after pumping correction of figure 5

5. Simulate.

This process produces a different emitter coefficient for each DMA and thus a new distribution of the total inflow maintaining the distribution for the revenue water. It improves the tank level prediction as seen in figure 9. In table 1 the emitter coefficients obtained by the optimisation are presented. They agree with the expected emitters for the

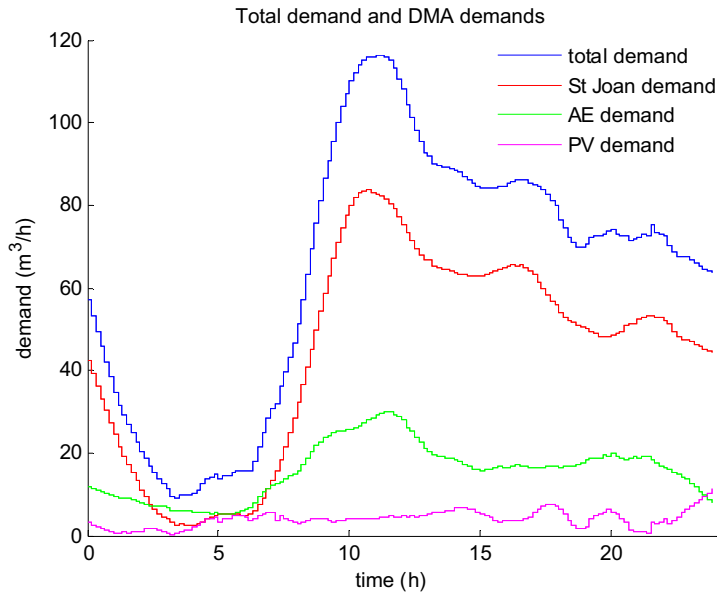


Fig. 7. Total demand and demands for each DMA after the pumping and sampling correction and with the filtering based on local polynomial regression

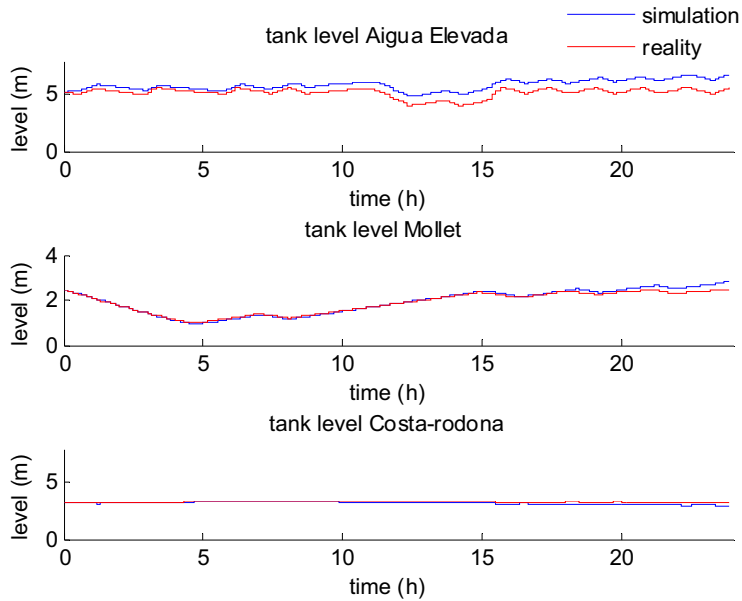


Fig. 8. Tank levels for the simulation of the model with the corrected demands, pumping and valve position

DMA, higher in the residential and industrial sectors than in the urban sector. Root mean squared error for the tank levels are presented in table 2.

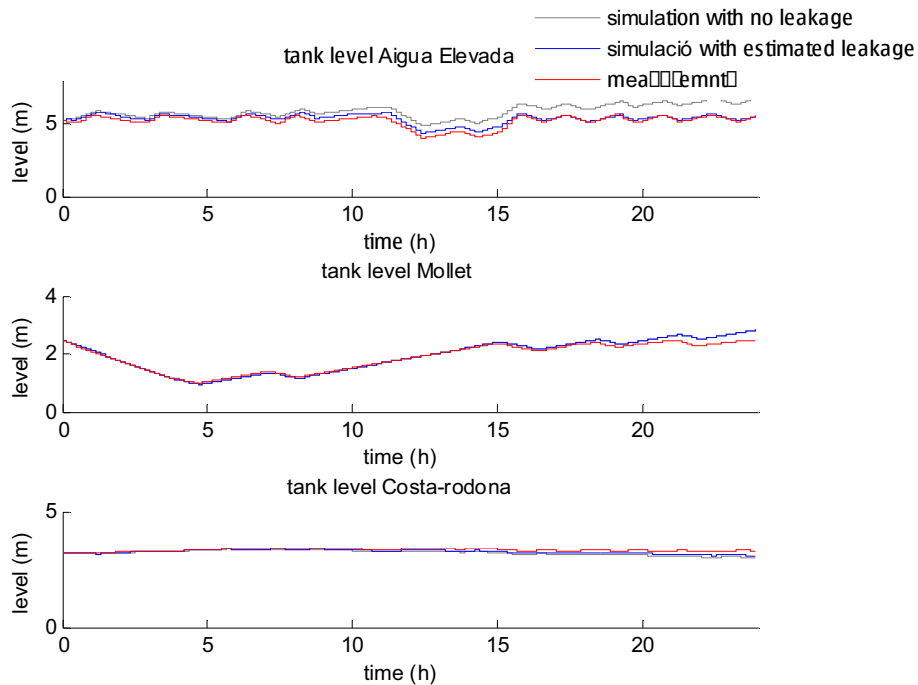


Fig. 9. Tank levels for the simulation of the model with the corrected demands (pumping and valve position) without considering background leakage and with the estimated emitter coefficients

Table 1. Emitter coefficients for the three DMA

	<i>Sant Joan</i>	<i>Aigua Elevada</i>	<i>Pla de Vinyats</i>
Emitter coefficient	$6.2 \cdot 10^{-4}$	$3.4 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$

Table 2. predicted-measured root mean squared error for the three tanks

	without leakage	with emitter coefficients
Aigua Elevada tank	0.0964	$4.2 \cdot 10^{-8}$
Mollet tank	0.0292	0.0295
Costa Rodona tank	0.0271	0.0196
total tank	0.1527	0.0491

5. Conclusions

The work started with the intention of assessing the background leakage existing in the different DMA of a network. This assessment is finally carried out with results that agree with the technician experience. The exciting part of the work is that such assessment had not been done before because the model presented discrepancies that clearly went beyond a mere leakage effect.

The major errors in the modelling of the network have been detected and corrected: a bad calibration of an important flow transducer; a bad re-sampling of data in a tank with low frequency of sampling and a valve status. The valve status correction seems not to be a real situation and we are further investigating. The company's technicians suggest topographic data as the source of the problems in level prediction in Mollet.

The effort in such set-up of models has to be in generating easy tools that can adapt to the varying structure of models and information related that exist in the water sector.

Acknowledgements

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