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Water distribution network's modeling and calibration. A case study based on scarce inventory data

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Abstract

This paper focuses on modeling and calibration of a small and poorly documented (portion of the) water distribution network (WDN) that shows pressure problems. Field campaigns are conducted to reduce the inaccuracies found in the inventory's drawings and to aid building a first WDN model. A trial and error procedure was then used to produce successive refinements for the desirable WDN's model fit. The paper describes the path followed through the first model to the final calibrated model, including WDN's instrumentation, the definition of network zones and the measures taken to deal with the pressure problems.

Keywords: EPANET, Model Calibration, Water Distribution System.

1. Introduction

Studies on Water Distribution Network' (WDN) performance are a core issue as a tool for water management

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entities decision-making. In order to achieve this goal it is necessary to know both the WDN's infrastructure registration and the hydraulic operating conditions (flows and pressures) for simulation computation. According to Walski et al. (2003) simulation is an emulating process where system's performance is computed using a mathematical representation of the real WDN in order to reproduce the responses of real systems for the same input conditions. This, so called model, must be calibrated. Cesario (1995) defines calibration as "the process of fine-tuning a model until it is able to simulate the conditions prevailing in the system for a particular time horizon (e.g., the scenario peak time consumption), with a degree of accuracy pre-established. Walski et al. (2003) defines calibration as "the process of comparing the results of a model with field observations to, if necessary, adjust the data describing the system until the predicted behaviour agrees reasonably with the behaviour observed in reality for a wide range of operating conditions. In a straightforward definition it is possible to say that calibration is the comparison between simulated data vs. measured data and the higher matching among them benefit the calibration process. Several techniques have been used to calibrate the WDN (e.g., Walski, 1983; Bhave, 1988; Ormsbee and Wood, 1986a, b; Boulos and Wood, 1990).

From the point of view of the model's hydraulic calibration it is important to ensure that both flow values (concerning to systems' inflows and outflows as well as network's flow) and pressure values (or level in the reservoirs) are accurately simulated as it is not acceptable if the calibrated model just reproduce one these variables. Key points for flow measurement are the inputs and outputs of the network sectors. The consumption points represent the network's requests introducing the higher uncertainty associated with its operation, and thus a very particular type of flow.

Enable the hydraulic operation of a sub-WDN in the city of Castelo Branco, which is poorly documented and showing misrepresentations in its registration is the core issue of this research aiming a WDN's model construction using EPANET signalizing its weaknesses and proposing mitigating solutions and thus contribute to a more feasible management without burdening significantly the responsible entities budget. A detailed discussion of the theory behind EPANET (Rossman, 1999, 2000 and Coelho et al., 2006) goes beyond the scope of this paper, but its application in the present case is rather straightforward.

Nomenclature

CAD	Computer-Aided Design
CP	Critical Point
DMA	District Metering Area
PRV	Pressure Reduction Valve
PVC	Polyvinyl Chloride
PZT	Pressure Zero Test
TCV	Throttle Control Valve
WDN	Water Distribution Network

2. Case Study

2.1. Water distribution network characterization

The case study concerns to three suburban residential neighborhoods in the municipality of Castelo Branco characterized by irrelevant commercial activities and no industry. The dwellings are essentially houses with two or three floors where a sports complex can be considered as an outlier as it is a large consumer.

The WDN is a 34 km long pipeline in polyvinyl chloride (PVC) with diameters between 63 and 160 mm and a section in cast iron with a diameter of 150 mm. The closing of five throttle control valve (TCV) on the network set up two district metering area (DMA) based on the existence of two points of measurement and control (entry points) (Fig.1) .

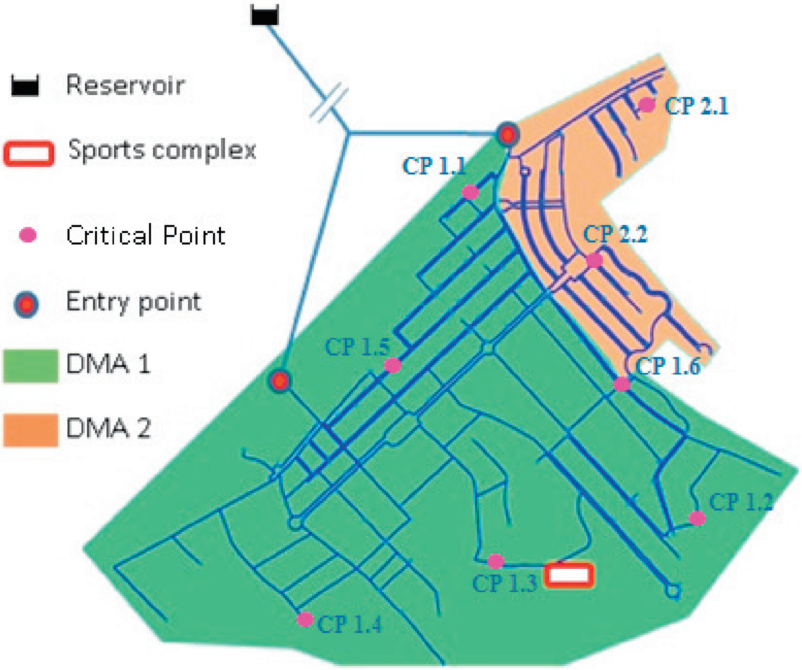


Fig. 1. Water distribution network under analysis.

The DMA1 covers a total of 572 branches, which supply 822 contract customers to whom was billed a total of 82,319 m^3 of water in 2011. DMA2 has 236 branches, 240 customers and 44,766 m^3 of water billed to costumers in 2011. Telemetry was installed in the sports complex and in each entry of the DMAs (entry point).

2.2. Water distribution network model - first step

The first step to the WDN's model construction concerned to the analysis of historical data records (Municipal Water Services of Castelo Branco). The existing documentation, especially drawings, showed to contain inaccuracies and therefore fieldwork validation was needed. All visible network's accessories, including valves, mouths watering, landmarks and fire hydrants for firefighting were recognized and registered.

To confirm the pipes' diameters and taking into consideration that they are buried, the operation of the valves was performed, to count the number of revolutions of the spindle, and thus determine its diameter. The lack of inventory made also necessary to survey the WDN's extensions as well as the identification of the consumption points. These data were then crossed with the consumers list.

To ensure the network's tightness an out zero-pressure test (PZT) was carried out. Pressure data loggers have been installed at critical points in each DMA. The flow was closed in DMA1 and the pressure checked in the data logger until it reaches zero. The same procedure was used for DMA2.

The distribution network was represented in Computer-Aided Design (CAD) and exported to EPANET, and then edited to complete the first phase of construction of the model which consisted in the addition of two reservoirs to simulate water entry in the main inputs (one at each entry point) (Fig.1). The water supplier entity ensured irrelevant water's level variation over 24 hours and so reservoirs were chosen (Fig.1).

Completed the construction phase of the topological model, began the characterization phase of the nodes and links. In the fixed piezometric level nodes was introduced the load. To the junction nodes were calculated and entered in the demand, elevation and consumption's patterns. For the demand were identified the branches within the DMAs and manually calculated the consumption using the available billing dataset. For pipes was adopted the

Hazen-Williams formula for the calculation of unit load losses with a roughness coefficient k = 140 (the lengths were assigned automatically from the CAD, the diameters were manually assigned using literature information and the survey described previously).

The definition of demand patterns was based in telemetry installed in the two monitoring points (entry points) of the DMAs, monitoring pressure and correspondent flow through a data logger at intervals of 15 minutes (Fig. 2 for a week day and Fig. 3 for the week-end).

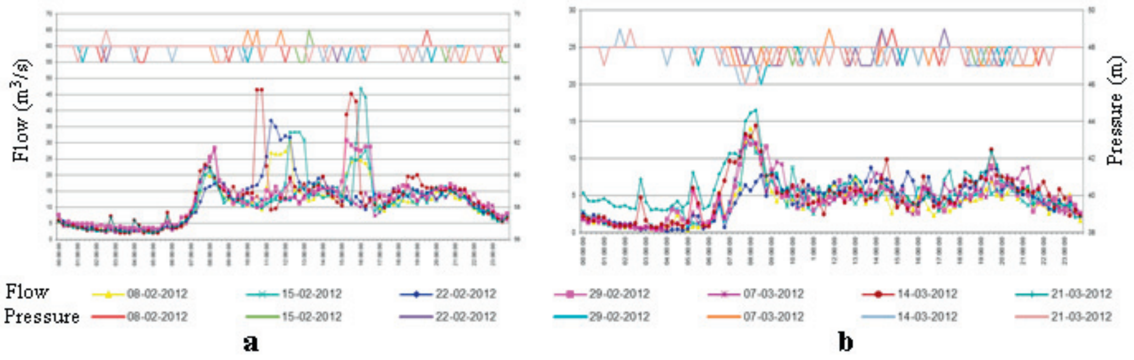


Fig. 2. Demand and pressure profiles for a week day: (a) DMA1; (b) DMA2.

For week days of the reporting period DMA1 showed higher consumption between 10h and 11h and between 15h and 16h (Fig. 2a), explained by the existence of the large consumer (sports complex).

For the week days in the reported period DMA2 shows a regular profile for household consumption (Fig. 2b). A consumption peak is observed at 8 a.m. and slightly increased at lunch and dinner, being higher for the evening meal. The nocturnal flow is very close to zero which indicates the absence of ruptures in the DMA. Pressure oscillates 1 m in average.

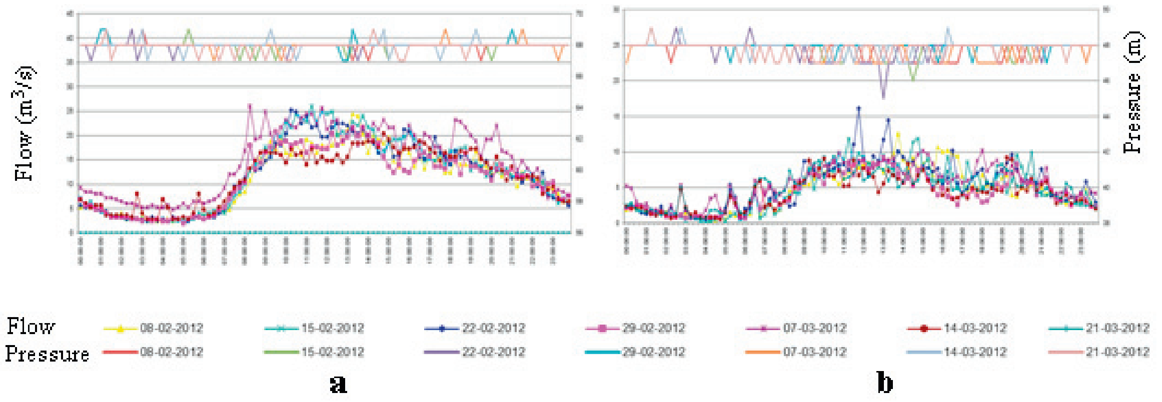
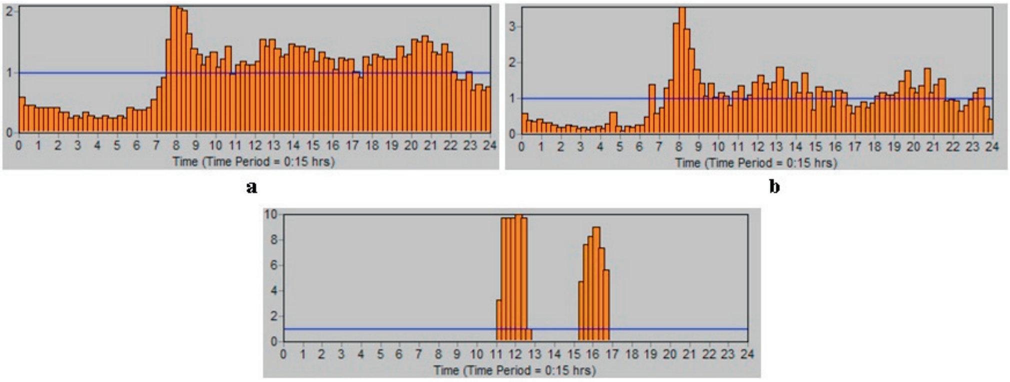


Fig. 3. Demand and pressure profiles for a week-end: (a) DMA1; (b) DMA2.

In the week-end the DMA exhibit similar behaviour (Fig. 3). Consumption made throughout the day does not show significant variations (possibly because most people stay at home). The consumption of night approaches zero and pressures have low oscillation, approximately 1 m.

Taking into account the mentioned profiles three dimensionless specific consumption patterns were created in EPANET: one for each DMA, and another one to the large consumer (Fig. 4).



a

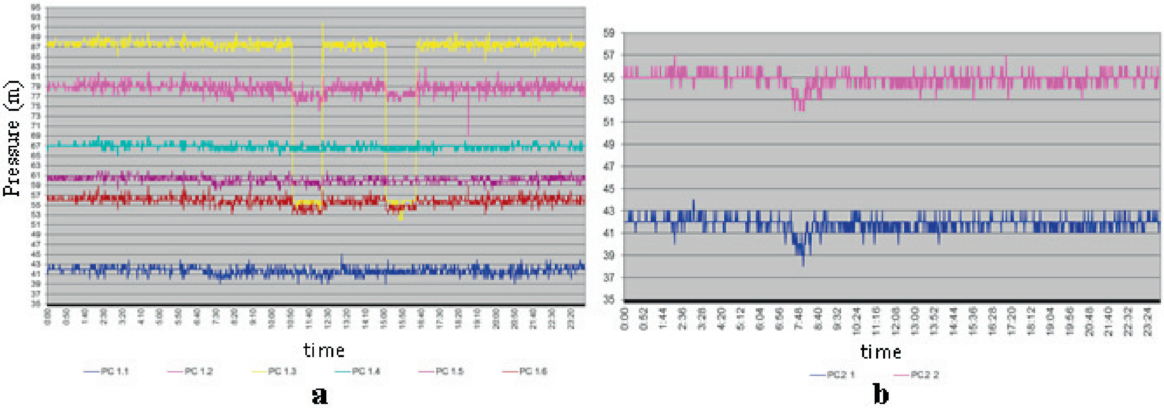
b

c

Fig. 4. Demand patterns: (a) DMA1; (b) DMA2; (c) Large consumer (Sport complex).

2.3. Model calibration and model refinement

After the hydraulic model construction proceeded its calibration. For calibration different consumption patterns were used and pressure data measured along the network and defined as critical points. The criteria underlying the choice of critical points were the size of the DMA and land topography. Eight critical points (CP) were set up, six in DMA1 and two in DMA2 (Fig. 1). One of critical points is near to the large consumer (CP 1.3). In the CPs were installed monitoring devices for pressure control. Pressure data in network's CPs is shown in Fig. 5.



a

b

Fig. 5. Pressure profiles measures in the critical points: (a) DMA1; (b) DMA2.

Two incongruent situations were detected when comparing the real and simulated results. The first is due to the existence of a pipe that was not registered (Fig. 6).

The suspicion of the existence of this unknown connection came up with the search for an explanation to the absence of change in pressures recorded in CP 1.4, when the large consumer had high intakes. The observed discrepancy is shown when pressure real values and the simulated ones (in the absence of the connection) are compared (Fig.7).

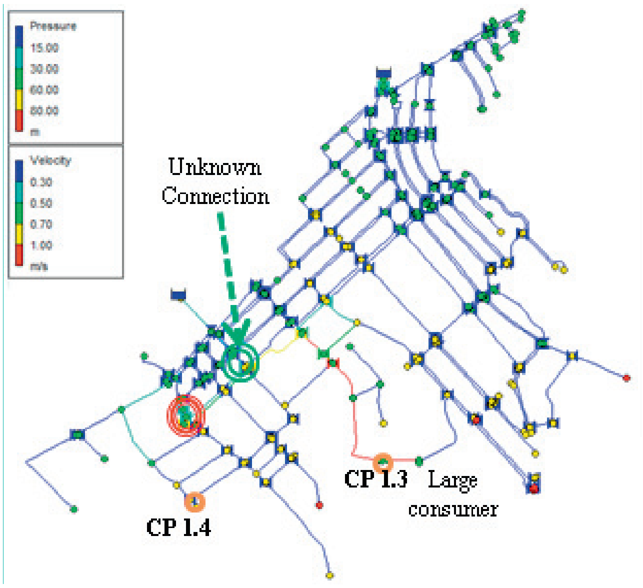


Fig. 6. Demand patterns: (a) DMA1; (b) DMA2; (c) Large consumer (Sports complex).

Moreover, the new connection lack would cause a pressure drop in the CPs of DMA1 whenever thigh intakes were observed, situation that was not observed in the pressure recordings. To confirm and locate the new section, tests of opening and closing of valves were conducted and thus validating its existence. Model updating showed consistency between measured and simulated data.

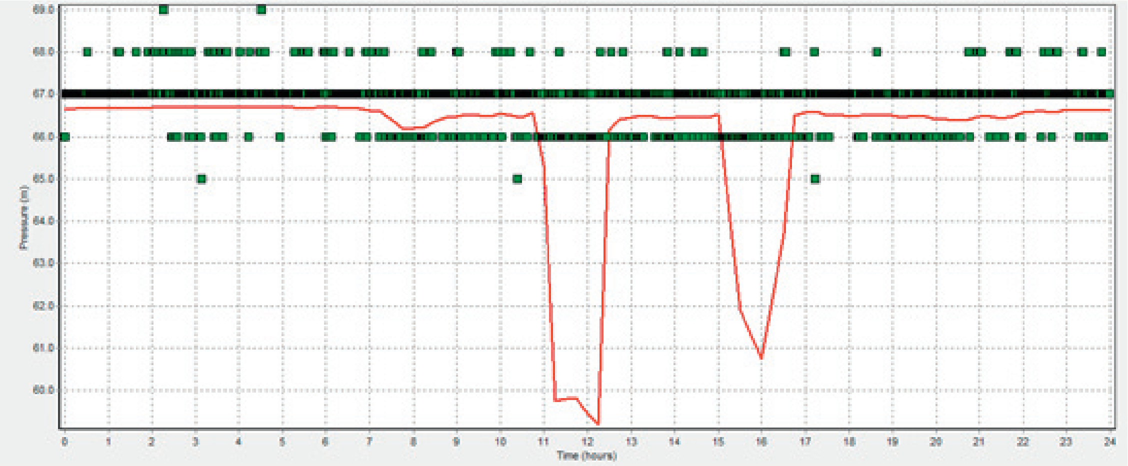


Fig. 7. Pressure plot for control point CP 1.4, showing the discrepancies between real system pressures (dot points) and simulated ones (red line)–"Scenario without the "new" pipe".

The second inconsistency concerns to control point CP1.3 which shows a sharp pressure drop when the sports complex consumption is high (Fig. 8).

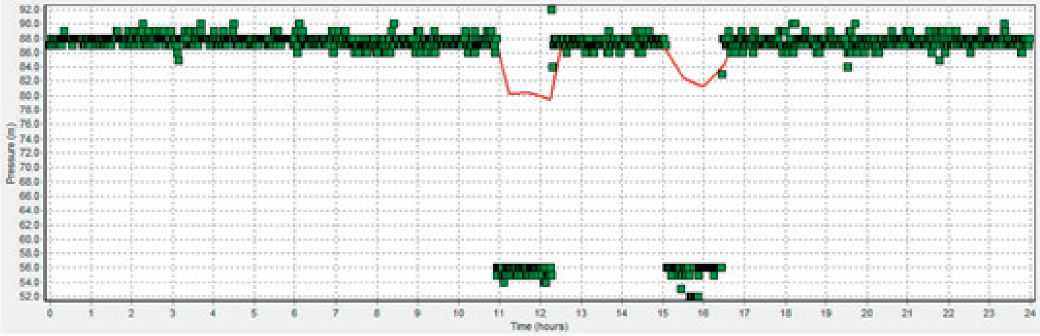


Fig. 8. Pressure plot for control point CP 1.3, showing the discrepancies between real system pressures (dot points) and simulated ones (red line)–"Scenario with control valve in open state".

To figure out what was happening field work campaigns were conducted. It was possible to check that one valve located near the large consumer was closed and this way forcing all the flow through the pipe where the CP 1.3 was located (Fig. 9).

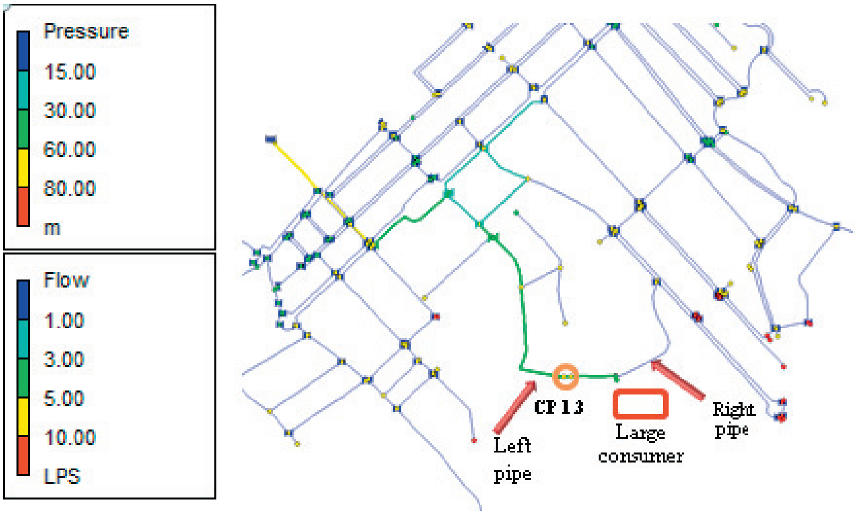


Fig. 9. All water supplying the large consumer comes from the left pipe.

Fig. 10 shows the plot of pressures collected at control point CP 1.3 after the adjustment of the valve state in the model.

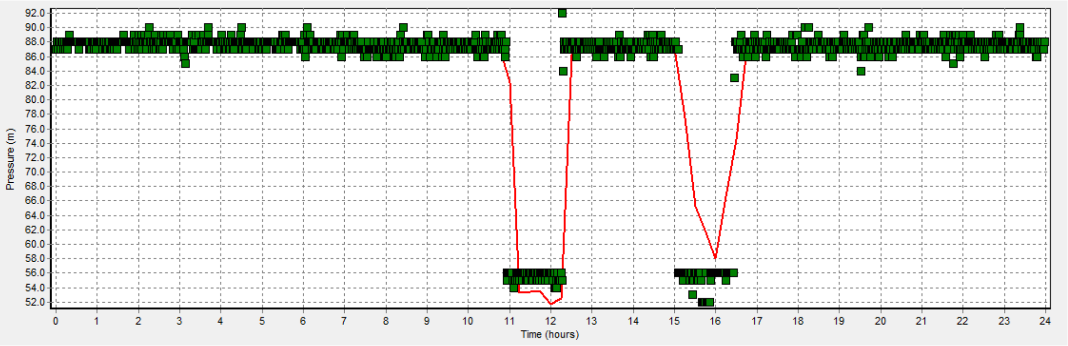
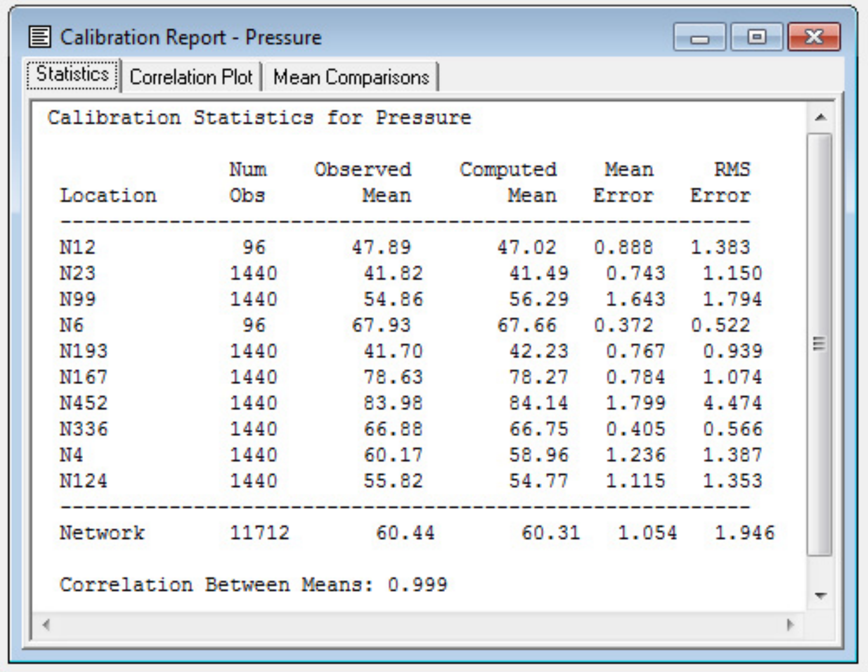


Fig. 10. Pressure plot for control point CP 1.3 considering the control valve in the closed state (real scenario).

After the needed corrections, calibration data analysis was performed. The average absolute deviation between measured and simulated data is fairly low (average=1.054) and the correlation, for average values is around 1 (r=0.999), showing a fitted model for the network as a whole (Fig.11).



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Calibration Statistics for Pressure

                  Num    Observed     Computed    Mean      RMS
 Location         Obs        Mean         Mean   Error    Error
 ---------------------------------------------------------
 N12               96       47.89        47.02   0.888    1.383
 N23             1440        41.82        41.49   0.743    1.150
 N99             1440        54.86        56.29   1.643    1.794
 N6                96       67.93        67.66   0.372    0.522
 N193            1440        41.70        42.23   0.767    0.939
 N167            1440        78.63        78.27   0.784    1.074
 N452            1440        83.98        84.14   1.799    4.474
 N336            1440        66.88        66.75   0.405    0.566
 N4              1440        60.17        58.96   1.236    1.387
 N124            1440        55.82        54.77   1.115    1.353
 ---------------------------------------------------------
 Network        11712         60.44        60.31   1.054    1.946

 Correlation Between Means: 0.999
```

Fig. 11. Calibration results considering the field measures. The calibration process shows a very good fit (correlation 0.999). The nodes listed under column "Location" are the critical points: CP 1.1 (N193), CP 1.2 (N167), CP 1.3 (N452), CP1.4 (N336), CP 1.5 (N4), CP1.6 (N124), CP 2.1 (N23) and CP 2.2 (N99).

2.4. Model exploration

Several sectors show excessive pressure (according to the Portuguese regulatory standards, the maximum pressure must be below 60 m) at the lowest intake hour (3.30 pm) (Fig.12). In fact, there are a large number of nodes whose maximum pressure ranges from 60 m to 80 m and even a set of nodes whose maximum pressure is above 80 m. This excessive pressure is associated with the loss of water, among others, which must be mitigated. To reduce the high pressures two pressure reducing valves, PRV, were installed in the network model in the DMA's entrance in order to have 60 m maximum pressure (Fig.12).

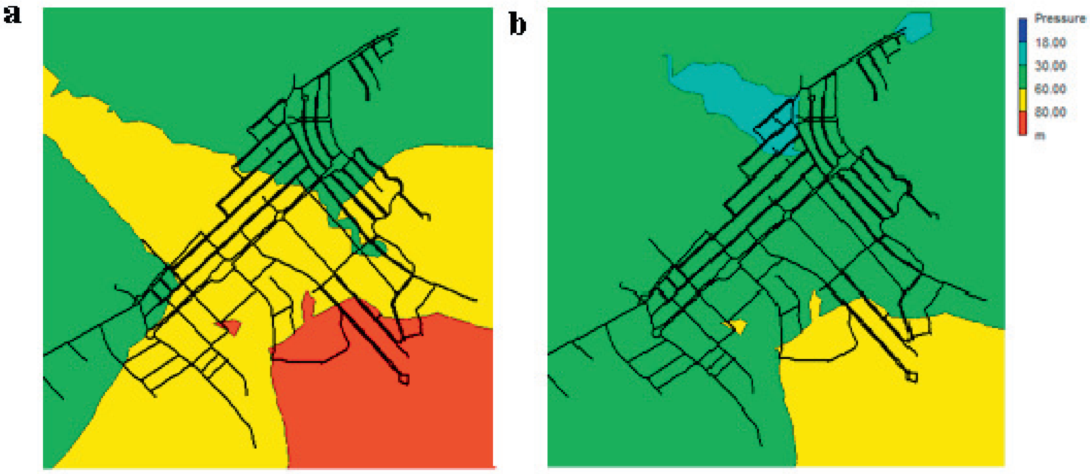

Fig. 12. Contour (isoline) plot for nodal pressure at less demand hour (3:30h). (a) original DMA; (b) with PRV installed at network entry points.

Some network's nodes still show pressures between 60 and 80 m. However, it is not possible to lower the pressure in the PRV, since the minimum pressure observed in the most unfavorable network is close to 18 m (according to the Portuguese regulation the minimum pressure should be above $10 + 4 \cdot N$ m, where N is the number of floors). The overpressure in DMA1 can be further reduced by the inclusion of other PRV to control the area above 60 m. However, an alternative solution can be obtained by resetting the DMA transferring the zone where the pressure was lower for DMA2, and thus lowering the pressure at DMA1 entrance (Fig.13).

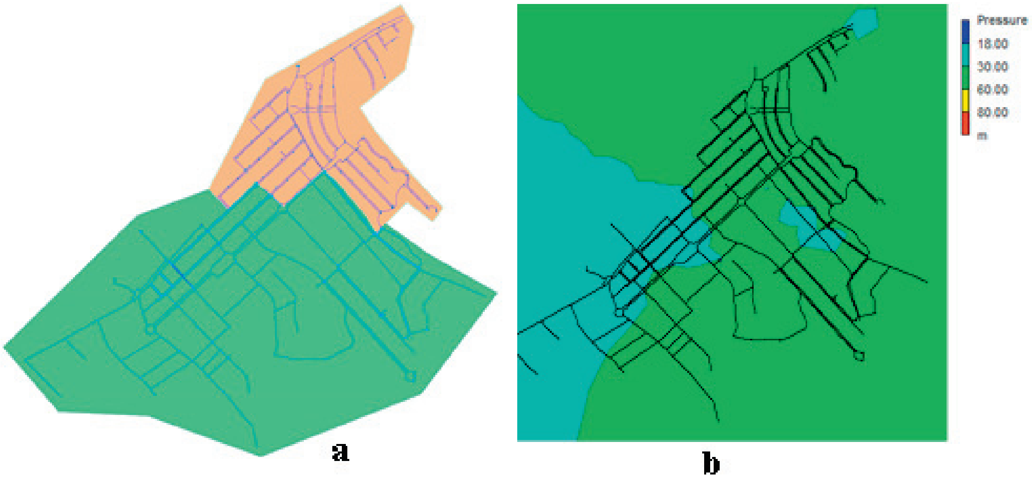

Fig. 13. (a) New definition of DMA; and (b) Contour plot for the new DMA.

This new solution, obtained by the operating network's valves and the reducing of pressure in 35 m in DAM1 and 10 m in DMA2, leads to the shown pressure's map (Fig 13b). This solution with pressure's performance optimization has associated lower water losses.

3. Conclusions

The built and calibrated model showed to be fairly accurate and is key issue in decision-making for water supply management.

The simulation model allowed a better knowledge of the network's physical structure working as a worth tool for inventory updating and anomalies mitigation. New operating configurations have been proposed to achieve excessive pressure reduction and a sustainable distribution of pressure reducing valves on technical points economically more favorable.The control of pressure within the network nodes and the reduction of water losses in the system is noteworthy as it is one of the more complex problems to deal with concerning water supply networks.

Small budgets supported by highly qualified human resources and a well-planned action line allow very important water and energy (and money) savings as well as a better network's exploitation achievement.

Acknowledgements

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