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# Influence of future water demand patterns on the district metered areas design and benefits yielded by pressure management

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## Abstract

This paper addresses the influence of different daily patterns of nodal water demands on the District Metered Areas (DMA) design and benefits yielded by pressure management. The objective is to compare the total cost investment and the maximum benefits from leakage reduction for given nodal demands, by implementing the pressure management at the district metered areas entry points. The methodology used (Gomes, 2011; Gomes et al., 2012a) follows the water losses management international best practices and uses a pressure driven simulation model to predict the network hydraulic behaviour under different patterns of nodal demands and pressure conditions.

*Keywords:* District Metered Areas design; Water demand patterns; Pressure management; Water loss

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## 1. Introduction

Rising population and economic growth around the world is driving up water demand, especially in developing countries (UN, 2005). On the other hand, due to the inherent variability of water consumption (daily and seasonal),

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water demand remains a great source of uncertainty (Jowitt and Xu, 1992). For that reason, several researchers are now focused on developing accurate water demand and future water demand forecasts to help in the planning and operation of water supply systems (Qi and Chang, 2011).

Demand forecasts are needed to plan and optimize the management of water resources, and to improve design and management of water infrastructures (WRDMAP, 2010). A water distribution network consists of a complex network of pipes with pumps, valves, and storage tanks, subjected to different loads (water demand and demand pattern) and operating rules, ensuring good levels of service over a given planning period. Some studies have shown that residential water demand makes up the majority of water use in urban water distribution networks (Filion et al., 2007) but the flow varies over time (day, month or year) depending on the number of customers, the water uses, level of water losses, season of the year, the level of economic development and the efficiency in the use of water. In this context, the appropriate water infrastructure planning and management requires reasonable water demand forecasts for the future years, as well as the knowledge of hydraulic behavior, degradation of infrastructures and the need of network expansion. As regards the water demand forecasting, the information available is associated with the historical of water users which have been used to identify trends and peak demands to be used in the water distribution network planning (Alvisi et al., 2007; Hof and Schmitt, 2011). The degradation of water infrastructures depends on the pipe material and accessories, soil aggressiveness, water quality and the service pressures, and the network expansion needs are usually related to the water consumption and/or the population increase.

In this paper, a methodology recently developed by the authors was used to evaluate the impacts of different patterns of nodal demands on District Metered Areas (DMAs) design and benefits yielded by pressure management (Gomes et al., 2012a). It is based on the analysis of the Minimum Night Flow and the BABE and FAVAD concepts, and uses a simulation model to predict the network hydraulic behaviour. Recent studies were conducted to assess the net present value of DMAs design (Gomes et al., 2012b) and the influence of pressure/leakage relationships from existing leaks in the benefits yielded by pressure management (Gomes et al., 2011; Gomes et al., 2013). Knowing that water loss has a great influence in the performance of water companies, the aim of the present study is to assess how far the uncertainty of the daily water demand pattern may influence the reduction of water losses and the cost of DMAs implementation.

## 2. Methodology

In this section the methodology developed by authors is described (for more details please consult Gomes (2011) and Gomes et al. (2012a)). The objective function NPV(X) of the optimization model maximizes the net present value of the differences between the economic benefits from pressure management (reduction of water production minus the reduction of billed water) and the total implementation costs (flow meters and chambers, pressure reduction valves and pipes reinforcement/replacement) along the duration of the project plan, equation (1):

$$maximum: \quad NPV(X) = \sum_{i=1}^{n} \frac{B(X)_i - C(X)_i}{(1+intR)^{t_i}} \tag{1}$$

where NPV(X) is the objective function or net present value of the project (€), n is the number of investment periods along the duration of the project plan, $B(X)_i$ is the total economic benefits during the investment period i and updated to the beginning of this investment period, $C(X)_i$ is the total investment costs at the beginning of the investment period i (€), $t_i$ is the time from the beginning of the project to the beginning of the investment period i (years), and intR is the annual interest rate (%).

The optimization problem is solved by a simulated annealing algorithm (Gomes, 2011). Simulated annealing is a probabilistic method proposed initially by Kirkpatrick et al. (1983) and Cerny (1985) for finding the global minimum of a cost function that may possess several local minima. At the initial temperature, the algorithm starts by generating an initial solution, which here corresponds to the maximum cost. At the following temperatures the cost function is minimized to obtain the maximum benefits yielded by pressure management at DMAs entry points and along the project plan. The number of solutions generated at each temperature varies according to the percentage of solutions accepted at the last temperature. Each new solution is generated from the current solution by randomly applying one of the following procedures: 1) select a DMA and reduce/increase its number of entry points; 2) select a DMA and change one of its entry points; or 3) select one of the investment periods and change a pipe diameter. For each solution, a pressure driven simulation model is used to predict the network hydraulic behaviour under different pressure conditions and equation (1) is used to evaluate the NPV for the new solution. The new solution is accepted or not, according to the Metropolis criterion. If it is accepted, this solution becomes the current solution and will be used to produce the next solution. If not, the original current solution will be used. The algorithm ends if the stopping criteria is reached, that is: for two successive temperatures the number of solutions accepted remains lower than 5% and the difference between the averages of the project net present value between two successive temperatures is 1.0% or lower.

### 2.1. Cost of District Metered Areas design

To divide a large water network into a series of DMAs it is essential to close valves to isolate a certain area and install flow meters. After DMAs design, if the service pressure is greater than the minimum pressure required to ensure good service levels, pressure management should be studied at DMAs entry points to reduce water losses. On the other hand, if the service pressure is lower than the minimum pressure required, existing pipes should be replaced by new ones with greater capacities or new pipes should be added in parallel to the existing ones to ensure that the maximum velocity allowed in each pipe of the network is not exceeded and increase the transport capacity of the network to satisfy the minimum pressure requirement. In this module, the cost function C(X), equation (2), describes the total cost of pipe reinforcement/replacement, metering stations (flow meters and chambers), PRVs and the penalties from constraints violations (hydraulic constraints):

$$C(X) = \sum_{p=1}^{NP} CGP(D)_p \times L_p + \sum_{m=1}^{NM} CGM(M)_m + \sum_{PRV=1}^{NPRV} CGR(R)_{PRV} + \sum_{v=1}^{NV} (viol_v \times \beta_v) \tag{2}$$

where NP is the number of pipes in the water distribution network, $CGP(D)_p$ is the unit cost of pipes reinforcement/replacement (€/m), D is the diameter of the pipe (m), $L_p$ is the pipe length (m), NM is the number of DMAs entry points, $CGM(M)_m$ is the cost of DMAs entry points with flow meter (€/un), M is the diameter of the flow meter (m), NPRV is the number of PRVs in the water distribution network, $CGR(R)_{PRV}$ is the cost of DMAs entry points with PRVs (€/un), R is the diameter of the PRV (m), NV is the number of total constraints violations (physical, hydraulic and project constraints), $viol_v$ is the maximum violation for the constraint v, $\beta_v$ is the unit penalty cost for violation v (between 1E+06 and 1E+08).

### 2.2. Benefits yielded by pressure management

As a result of pressure management, the total reduction of water losses volume at each DMA entry point (ΔVL) is given by the difference between the current water losses volume (Phase 1) and the estimated water losses volume after pressure reduction (Phase 2). As pressure is known to influence water consumption, the total billed water will decrease with the pressure reduction (ΔVR), and this decrease can be estimated by the difference between the actual billed water (Phase 1) and the estimated billed water after pressure reduction (Phase 2). Knowing the cost of water production per $m^3$ ($C_p$) and the selling price per $m^3$ ($C_v$), the function B(X), equation (3), estimates the direct benefits that can be achieved with pressure management in DMA (reduction of water production minus the reduction of billed water):

$$B(X) = C_p \times \Delta VL - (C_v - C_p) \times \Delta VR \tag{3}$$

This module can be summarized as follows:

- Phase 1 (Business as Usual - before pressure reduction)

Considering that water losses reduction depends on the nodal pressure, first the total flow entering the water distribution system is divided by all nodes – according to the number of service connections (water consumption) and network length (water losses). Knowing that the minimum water consumption and water losses can be calculated during the MNF period (when most people are not ‘active’ and it is easier to estimate and/or measure water consumption), the total outflow at node j ($QT_{j,MNF}$) is divided into three parts (admitting that the whole water consumption is authorized and billed – revenue water): the pressure-independent consumption, $QRC_{indep}$ (e.g. toilet flushing, roof tanks, washing machines, dishwashers), the pressure-dependent consumption, $QRC_{dep}$ (e.g. shower use, hand washing, watering gardens) and the water losses as pressure-dependent – $QRL_{dep}$ (water losses downstream of the customer meter) and $QNRL_{dep}$ (water losses upstream of the customer meter – non-revenue water). After that, taking the service pressure ($P_{j,MNF}$) and the non-revenue water ($QNRL_{dep,j,MNF}$) as a reference, the amount of non-revenue water ($QNRL_{j,t}$) and total revenue water ($QR_{j,t}$) can be extrapolated for the remaining simulation period, at node j at time t, by Equations (4) and (5), respectively. The exponent N1 expresses the pressure/leakage relationship:

$$QNRL_{dep,j,t}^{Phase1} = QNRL_{dep,j,MNF}^{Phase1} \times \left( \frac{P_{j,t}^{Phase1}}{P_{j,MNF}^{Phase1}} \right)^{N1} \tag{4}$$

$$QR_{j,t}^{Phase1} = QT_{j,t}^{Phase1} - QNRL_{dep,j,t}^{Phase1} \tag{5}$$

- Phase 2 (Pressure management - after pressure reduction)

For each instant of the simulation period, the total outflow in each network node ($QT^{Phase2}$) can be estimated by Equation (6) – adjustment of Phase 1 revenue water ($QRL_{dep}$+$QRC_{dep}$+$QRC_{indep}$) and non-revenue water ($QNRL_{dep}$) to the Phase 2 pressure conditions. The exponent N1 expresses the pressure/leakage relationship and the exponent N2 expresses the pressure/consumption relationship (applied solely to the pressure-dependent consumption). For the optimal solution (the best solution found), to reduce the excess of pressure at DMAs entry points, three types of Pressure Reduction Valves (PRV) are proposed: fixed-outlet PRV; time-modulated PRV and pressure-modulated PRV. The type of PRV can be previously decided or selected by the software according to the maximum pressure variation along the day and the working condition for each type of PRV. For each working period of the PRV and each DMA, the adjustment equals the minimum difference between the service pressure and the minimum pressure required, evaluated at the critical node for all the simulation time steps of that working period:

$$Q \text{ varies with } P^N :$$

$$QT^{Phase2} = \left( QRL_{dep}^{Phase1} + QNRL_{dep}^{Phase1} \right) \times \left( \frac{P^{Phase2}}{P^{Phase1}} \right)^{N1} + QRC_{dep}^{Phase1} \times \left( \frac{P^{Phase2}}{P^{Phase1}} \right)^{N2} + QRC_{indep}^{Phase1} \tag{6}$$

## 3. Case study

To study the influence of different water demand scenarios on the cost of the DMAs design and the benefits yielded by pressure management (water losses reduction), a hypothetical water distribution system was modeled using WaterNetGen (Muranho et al., 2012). The network has three DMAs, as reported in Figure 1, and ensures water supply to a residential area with 27,000 inhabitants (9,000 service connections and per capita water demand 250 l/day/inhabitant). The pipe material is polyvinyl chloride and the peaking factor of water demand is 2.0. The WaterNetGen simulated annealing algorithm option was used to obtain the least cost design for the water distribution network. The network model has 99 pipes and 71 junction nodes and the nodes elevation varies between 484m and 510m, has approximately 45km of pipes and is gravity fed (reservoir elevation is 550m). The maximum and minimum service pressures are 62.32m (node 31) and 25.01m (node 22), respectively, and the maximum daily pressure fluctuation is 25.20m (node 46). The minimum pressure required is 18.37m.

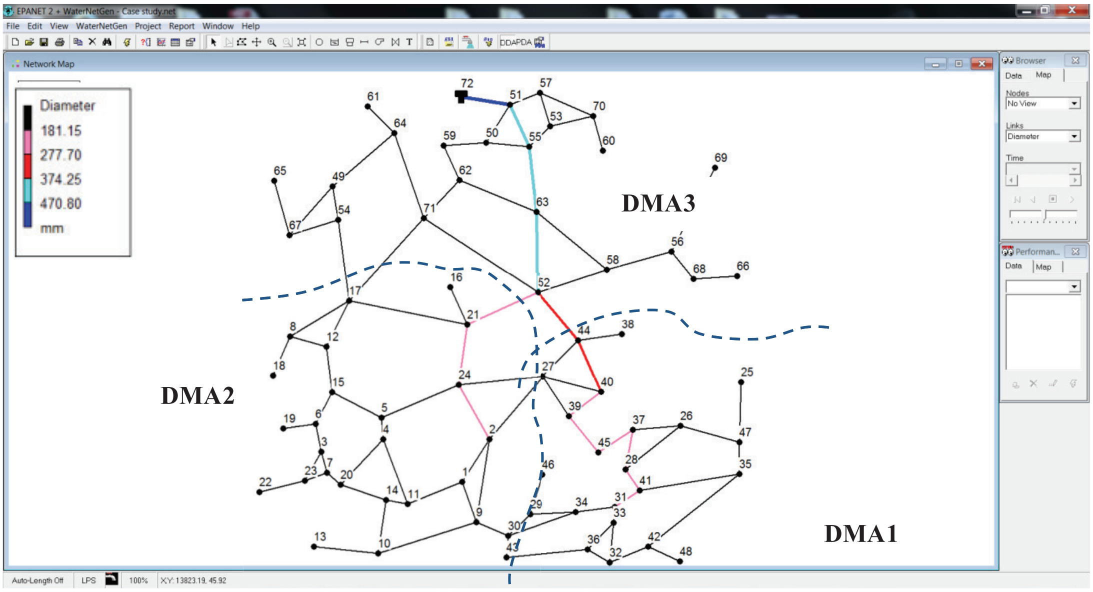

Fig. 1. scheme of the water network (pipe diameter) and DMAs boundaries.

In this case study, a single entry point should be required in each DMA and if service pressure is greater than the minimum pressure required, a fixed-outlet PRV is proposed at the DMAs entry points to adjust the service pressure. To ensure good performance the PRVs head loss should not be lower than 3 m. The unit costs of the pipes to reinforce/replace, metering stations and PRVs were those already used in Gomes et al. (2012a). The pressure/leakage relationship (N1) should be taken as 1.0 (combination of fixed and variable area leaks) and the pressure/consumption relationship (N2) should be taken as 0.5.

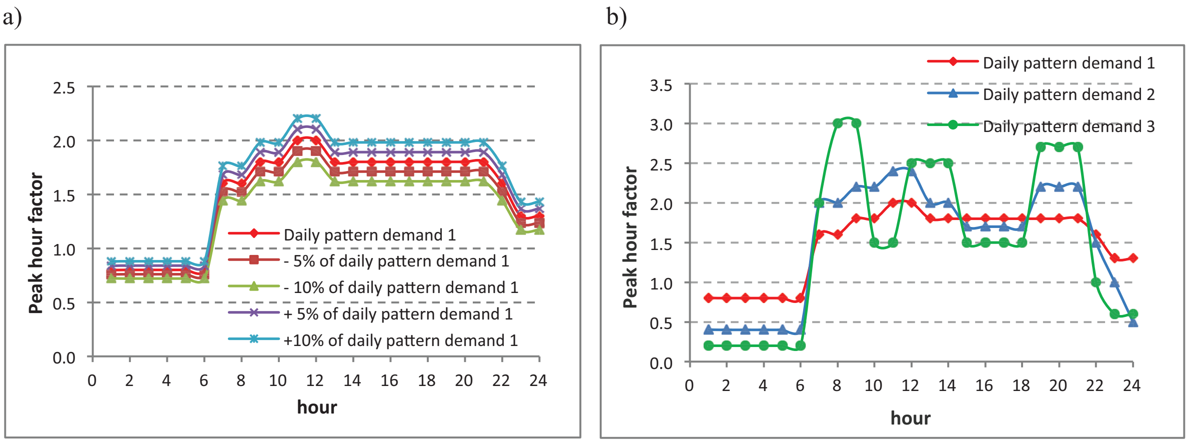

Fig. 2. (a) baseline scenario (including degrees of uncertainty); (b) additional daily water demand patterns (different types of users).

With respect to future water demand, in real world situations forecasts must be investigated based on different variables including population, technological change rate and the efficiency rate for each studied region (Qi and

Chang, 2011). Once the aim of this study is to evaluate the influence of different daily demand patterns on the cost of DMAs design and the benefits yielded by pressure management (water losses reduction), three daily water demand scenarios for the next 10 years were considered as reported in Figure 2a and 2b. Figure 2a presents a baseline scenario, previously used for the network design (see Figure 1) and four alternatives corresponding to different degrees of uncertainty. Figure 2b presents three different daily water demand patterns to consider the influence of different types of users and/or future water demand forecasts for the next 10 years. For any of the scenarios, it is assumed that the consumption increases 1.25% per year and the infrastructure decay rate is 1.0% per year (reduction of the Hazen-Williams coefficients). To estimate the benefits yielded by pressure management, the production cost and selling price of water were taken as 0.75 and 1.50 €/m$^3$, respectively.

### *3.1. Results*

Table 1 shows the results for the DMAs design and the benefits yielded by pressure management for the baseline scenario (scenario 3), previously used for the network design. In this scenario, a single investment period was considered and the net present value demonstrates that the project appears to be sustainable for the next 10 years from an initial investment of the 113 147 € (total cost of pipe reinforcement/replacement, metering stations and PRVs). The total water losses reduction is 4.69%. For each DMA a single entry point was chosen and corresponds to the pipe with greatest diameter (see Figure 1 and Table 3): DMA1 (pipe 52-44); DMA2 (pipe 52-21); and DMA3 (pipe 72-51). After the DMAs design, as the service pressure still exceeded the minimum pressure required, a fixed-outlet PRV was selected for DMA3 entry point – Table 3 shows the hydraulic performance of the network for scenario 3. In DMA1 the minimum service pressure is assured by a fixed-outlet PRV at DMA3 entry point. In DMA2, as the head loss at the entry point is lower than 3 m (minimum head loss to ensure a good performance for the PRV), no PRV was implemented here.

Several researchers use in their models future water demand patterns based on historical water users behaviour along the day, but this is no more than an approximation of the real situation, because the future water demand can change according to types of users, water use efficiency, birth/death rates, immigration/emigration, economic development, etc. In Table 1 four scenarios were developed from scenario 3 (scenarios 1, 2, 4 and 5) to study the influence of little variations in the daily patterns demand on the DMAs design and benefits yield by pressure management (see Figure 2a). Scenarios 1 and 2 represent a little reduction of the peak flow and scenarios 4 and 5 an increase of the peak flow. The results presented in Table 1, for a single investment period, show that the total water production and the water billed reduces after DMAs design, but the great reduction is observed for total water production (due to the reduction of water losses). The total water losses reduction is related to nodal pressure and for all scenarios the major water losses reduction is observed in scenario 1 (7.54%) and the minor reduction in scenario 5 (3.38%). The DMAs entry point, for all scenarios (1, 2, 4 and 5), corresponds to the pipe with greatest diameter and at DMA2 and DMA3 entry points there are fixed-outlet PRVs. The number of pipes to reinforce/replace is related to the implementation of boundary valves (scenario 3) and consumption increase (scenarios 4 and 5). Scenarios 1 and 2 did not imply any pipe reinforcement/replacement because the total consumption along the network is lower that the one used for the network design and the implementation of boundary valves did not affect seriously the hydraulic behaviour. Analyzing the net present value of the project, in all scenarios the sustainability of the project appears to be guaranteed for the initial assumptions. The net present value reduces from scenario 1 (2 448 484 €) to scenario 5 (1 013 471 €) and is related to the increase of the total cost of the DMAs design (pipe reinforcement/replacement, metering stations and PRVs) and the reduction of benefits yielded by pressure management (DMAs design and adjustment of the PRVs) – NPV for scenario 5 is almost 59% lower than for scenario 1.

Table 1. Net present value of the project using a baseline scenario, previously used for the network design.

| Project plan (10 years) | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|
| | -10% of DDP1 | -5% of DDP1 | Daily demand pattern 1 (DDP1) | +5% of DDP1 | +10% of DDP1 |
| Total daily water production before DMAs design ($m^3$) | 10 317 | 10 891 | 11 464 | 12 037 | 12 610 |
| Total daily water production after DMAs design ($m^3$) | 9 053 | 9 778 | 10 555 | 11 126 | 11 881 |
| Total daily water billed before DMAs design ($m^3$) | 5 799 | 6 153 | 6 517 | 6 891 | 7 277 |
| Total daily water billed after DMAs design ($m^3$) | 5 762 | 6 122 | 6 494 | 6 868 | 7 259 |
| Total daily water losses before DMAs design (%) | 43.79 | 43.50 | 43.15 | 42.75 | 42.29 |
| Total daily water losses after DMAs design (%) | 36.25 | 37.39 | 38.46 | 38.26 | 38.91 |
| Number of pipes reinforcement/replacement | 0 | 0 | 2 | 15 | 20 |
| Number of boundary valves | 5 | 5 | 5 | 5 | 5 |
| Number of metering stations | 3 | 3 | 3 | 3 | 3 |
| Total cost of reinforcement/replacement (€) | 0 | 0 | -45 650 | -314 994 | -370 032 |
| Total cost of PRVs and metering stations (€) | -65 157 | -65 157 | -67 497 | -76 419 | -80 711 |
| Total economic benefits (€) | 2 513 641 | 2 220 950 | 1 822 275 | 1 826 954 | 1 464 213 |
| Net present value of the project (€) | 2 448 484 | 2 155 793 | 1 709 128 | 1 435 541 | 1 013 471 |

Scenario 3: Baseline scenario used for the network design; DDP: daily demand patterns

Table 2. Net present value of the project for different water users.

| Project plan (10 years) | Scenario 3 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 |
|---|---|---|---|---|---|---|---|
| | DDP1 | DDP2 | DDP3 | DMA1 (DDP1)<br>DMA2 (DDP2)<br>DMA3 (DDP3) | DMA1 (DDP2)<br>DMA2 (DDP1)<br>DMA3 (DDP2) | DMA1 (DDP1)<br>DMA2 (DDP1)<br>DMA3 (DDP3) | DMA1 (DDP2)<br>DMA2 (DDP3)<br>DMA3 (DDP2) |
| Total daily water production before DMAs design ($m^3$) | 11 464 | 11 464 | 11 464 | 11 464 | 11 464 | 11 464 | 11 464 |
| Total daily water production after DMAs design ($m^3$) | 10 555 | 11 277 | 11 433 | 11 098 | 11 092 | 10 900 | 11 301 |
| Total daily water billed before DMAs design ($m^3$) | 6 517 | 9 340 | 10 643 | 8 727 | 8 558 | 7 920 | 9 708 |
| Total daily water billed after DMAs design ($m^3$) | 6 494 | 9 329 | 10 636 | 8 711 | 8 542 | 7 900 | 9 697 |
| Total daily water losses before DMAs design (%) | 43.15 | 18.52 | 7.16 | 23.87 | 25.35 | 30.91 | 15.32 |
| Total daily water losses after DMAs design (%) | 38.46 | 17.28 | 6.97 | 21.51 | 22.98 | 27.50 | 14.20 |
| Number of pipes reinforcement/replacement | 2 | 23 | 35 | 19 | 10 | 10 | 26 |
| Number of boundary valves | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Number of metering stations | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Total cost of reinforcement/replacement (€) | -45 650 | -433 728 | -835 408 | -403 402 | -203 836 | -137 777 | -703 711 |
| Total cost of PRVs and metering stations (€) | -67 497 | -92 723 | -102 264 | -88 432 | -92 723 | -70 717 | -97 015 |
| Total economic benefits (€) | 1 822 275 | 345 967 | 35 757 | 702 820 | 720 808 | 1 109 072 | 296 954 |
| Net present value of the project (€) | 1 709 128 | -180 484 | -901 915 | 210 986 | 424 249 | 900 578 | -503 771 |

Scenario 3: Baseline scenario used for the network design; DDP: daily demand patterns

To study the influence of different types of users (different daily demand patterns) on the DMAs design and benefits yielded by pressure management, the results for scenarios 3, 6 and 7 were compared (see Tables 2 and 3). The main differences between these three scenarios are related to the peak flow hours along the day (see Figure 2b) and total daily flow. Analyzing the results of scenarios 3, 6 and 7 (for a single investment period), when the water demand along the network increases the net present value decreases. In scenarios 6 and 7, once the daily consumption along the network is greater than in scenario 3 (baseline scenario, used for the network design) the project is no longer sustainable – because the total cost of the DMAs design is greater than the benefits yielded by pressure management. In scenarios 6 and 7 the DMAs entry points correspond to the pipes with the greatest diameter and at DMA3 entry point there is a fixed-outlet PRV, as for scenario 3. The hydraulic performance of the network and the adjustment of the PRVs are presented in Table 3.

Table 3. Simulations results of hydraulic behaviour for different water users (scenarios 3, 6 and 7).

| **Project plan (10 years)** | | **DMA1** | **DMA2** | **DMA3** |
|---|---|---|---|---|
| Scenario 3 | DMA entry point (pipe) | 52-44 (Flow meter) | 52-21 (Flow meter) | 72-51 (Flow meter + PRV) |
| | DMA output point (pipe) | --- | --- | 52-21 : 52-44 |
| | Boundary valve (pipe) | 27-24 : 27-2 : 30-9 | 54-17 : 71-17 : 27-24 : 27-2 : 30-9 | 54-17 : 71-17 |
| | Fixed-outlet PRV (m) | --- | --- | 541.19 |
| | Maximum head loss PRV (m) | --- | --- | 8.796 |
| | Minimum head loss PRV (m) | --- | --- | 8.713 |
| | Maximum peak flow (l/s) | 65.316 | 48.877 | 166.549 |
| | Minimum peak flow (l/s) | 23.974 | 17.479 | 59.972 |
| | Minimum pressure (m) | 18.370 (node 46) | 19.104 (node 22) | 27.593 (node 59) |
| | Maximum pressure (m) | 54.020 (node 31) | 45.164 (node 9) | 42.819 (node 54) |
| Scenario 6 | DMA entry point (pipe) | 52-44 (Flow meter) | 52-21 (Flow meter) | 72-51 (Flow meter + PRV) |
| | DMA output point (pipe) | --- | --- | 52-21 : 52-44 |
| | Boundary valve (pipe) | 27-24 : 27-2 : 30-9 | 54-17 : 71-17 : 27-24 : 27-2 : 30-9 | 54-17 : 71-17 |
| | Fixed-outlet PRV (m) | --- | --- | 543.74 |
| | Maximum head loss PRV (m) | --- | --- | 6.251 |
| | Minimum head loss PRV (m) | --- | --- | 6.104 |
| | Maximum peak flow (l/s) | 82.982 | 62.293 | 211.550 |
| | Minimum peak flow (l/s) | 12.655 | 9.275 | 31.822 |
| | Minimum pressure (m) | 18.370 (node 46) | 19.634 (node 22) | 28.545 (node 59) |
| | Maximum pressure (m) | 59.030 (node 31) | 49.334 (node 9) | 46.429 (node 54) |
| Scenario 7 | DMA entry point (pipe) | 52-44 (Flow meter) | 52-21 (Flow meter) | 72-51 (Flow meter + PRV) |
| | DMA output point (pipe) | --- | --- | 52-21 : 52-44 |
| | Boundary valve (pipe) | 27-24 : 27-2 : 30-9 | 54-17 : 71-17 : 27-24 : 27-2 : 30-9 | 54-17 : 71-17 |
| | Fixed-outlet PRV (m) | --- | --- | 542.96 |
| | Maximum head loss PRV (m) | --- | --- | 7.037 |
| | Minimum head loss PRV (m) | --- | --- | 6.961 |
| | Maximum peak flow (l/s) | 105.161 | 78.379 | 267.392 |
| | Minimum peak flow (l/s) | 6.349 | 4.648 | 15.973 |
| | Minimum pressure (m) | 18.370 (node 46) | 18.621 (node 22) | 25.883 (node 59) |
| | Maximum pressure (m) | 58.848 (node 31) | 48.891 (node 9) | 45.900 (node 54) |

Scenario 3: Baseline scenario used for the network design; DMA: district metered area; PRV: pressure reduction valve

The influence of different water users along the network on the DMAs design and the benefits yielded by pressure management was reproduced by scenarios 8 to 11 (see Table 2). In each DMA a specific daily demand pattern was used and the net present value for each scenario was analyzed for a single investment period. Results show that the water demand pattern can affects the sustainability of the project (scenario 11) or not (scenarios 8 to 10). In scenario 11 the net present value does not ensure the sustainability of the project for the next 10 years because the total cost of the DMAs design is related to the water demand increase at downstream DMAs (see Table 2 and Figure 1). In this case, the total cost of the DMAs design depends on the number pipes to reinforce/replace at DMAs upstream to ensure the minimum pressure requirement and the maximum pipe velocity. In scenarios 8 to 11 the DMAs entry points correspond to the pipes with the greatest diameter and at DMA3 entry point there is a fixed-outlet PRV, as for scenario 3.

## 4. Conclusions

This paper addresses the influence of different daily patterns of nodal demands on the DMAs design and benefits yields by pressure management (water loss reduction) using a methodology developed by the authors. A pressure driven simulation model was used to predict the network hydraulic behaviour during the next 10 years for different scenarios, and the simulations showed that the total daily water production reduction is greater than the water billed reduction after DMAs design and pressure management. With respect to DMAs design, a single entry point was proposed in each DMA, and corresponds to the pipe with the greatest diameter. A fixed-outlet PRV is proposed at the DMAs entry points to adjust the service pressure (but other types of PRVs could be used). However, if the PRV head loss at the DMAs entry point is lower than 3 m (minimum head loss to ensure a good performance of the PRV), no PRV was implemented here. The number of pipes to reinforce/replace is related to the implementation of boundary valves (scenario 3) and the consumption increase (scenarios 4 and 5). The total water losses reduction is related to the nodal pressure and for all scenarios the major water losses reduction was observed in scenario 1 (7.54%). The net present value is related to the total cost of DMAs design (pipes reinforcement/replacement, metering stations and PRVs) and benefits yielded by pressure management (DMAs design and adjustment of the PRVs at the entry points). Analyzing the net present value for different scenarios, it possible to observe that the special nodal demand can constrain the sustainability of the project (scenarios 6, 7 and 11) or not (scenarios 1, 2, 3, 4, 5, 8, 9 and 10). For that reason, analyses of different scenarios of demand patterns may be important to support different decision maker's options concerning DMAs design and water loss management.

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