Decision support system to divide a large network into suitable District Metered Areas
Ricardo Gomes, Alfeu Sá Marques and Joaquim Sousa

ABSTRACT
This paper presents a new approach to divide large Water Distribution Networks (WDN) into suitable District Metered Areas (DMAs). It uses a hydraulic simulator and two operational models to identify the optimal number of DMAs, their entry points and boundary valves, and the network reinforcement/replacement needs throughout the project plan. The first model divides the WDN into suitable DMAs based on graph theory concepts and some user-defined criteria. The second model uses a simulated annealing algorithm to identify the optimal number and location of entry points and boundary valves, and the pipes reinforcement/replacement, necessary to meet the velocity and pressure requirements. The objective function is the difference between the economic benefits in terms of water loss reduction (arising from the average pressure reduction) and the cost of implementing the DMAs. To illustrate the proposed methodology, the results from a hypothetical case study are presented and discussed.

Key words | District Metered Areas (DMAs), network reinforcement/replacement, simulated annealing, water loss management

INTRODUCTION
District Metered Areas (DMAs) are a relatively recent concept in the field of Water Distribution Networks (WDN) management, and is usually a part of a water loss reduction strategy (Farley & Trow 2003; Marques et al. 2005). The size of each DMA varies from system to system, depending on the state of the infrastructure, water quality problems and the financial resources of the water company. DMA design normally depends on the number of service connections (usually between 500 and 3,000 properties), or the length of the network. DMA design based on length is more appropriate in rural systems and the number of service connections should be used in urban areas. Worldwide, there are several successful examples of DMA implementation (WRc 1994; Morrison et al. 2007; Thornton et al. 2008). Although various models have been developed to evaluate the benefits of implementing DMAs (Gomes et al. 2011), the specialized literature contains little information about DMAs design. Sempewo et al. (2008) proposed a method to define zoning schemes for WDN based on an analogy of the graph theoretic and graph partitioning principles used in distributed computing to distribute workloads among processors. Awad et al. (2008, 2009) presented a method that can be used to design DMAs and install Pressure Reducing Valves (PRVs) to reduce excessive outlet hydraulic pressure at certain times of the day. More recently, Di Nardo & Di Natale (2011) proposed a design support methodology to help in identifying the flow meters’ locations and the boundary valves needed to define permanent DMAs. Other authors presented similar studies: use of PRVs to define pressure zones (Nicolini & Zovatto 2009) or to identify the segments and optimal isolation valve system design in WDN (Giustolisi & Savic 2010).

This paper presents an innovative method which helps to define permanent DMAs: it identifies the most appropriate number of metering stations (entry points) and their location, the boundary valves and the pipes to reinforce/replace in order to ensure the maximum velocity and meet the minimum service pressure requirements. This method can also be used to plan the investment needed at different times during the project plan and the total investment can thus be adjusted according to the actual needs and the financial resources of the water company. The economic analysis has been used by other authors in the design/rehabilitation of WDN (Jung et al. 2009; Saldarriaga et al. 2010).

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METHOD

The method proposed here is based on several leakage-assessment approaches from the literature and on WDN modelling. It comprises two operational modules: the first model divides the WDN into suitable DMAs, based on graph theory concepts (Floyd–Warshall algorithm) and some user-defined criteria (network length, number of service connections, ...); the second model uses a Simulated Annealing (SA) algorithm to identify the most appropriate number and location of metering stations, boundary valves and network reinforcement/replacement needs in the project plan. It was implemented as a computational tool written in FORTRAN language and its flowchart can be seen in Figure 1.

DMAs boundaries (1st Model)

For any WDN, the first model enables the identification of DMAs boundaries through the following seven steps: (1) Construction and calibration of the hydraulic simulation model (here it is supposed that it already exists and is calibrated). (2) Definition of the design criteria for the DMAs (maximum size allowed, maximum elevation difference within the DMA, and implicit/explicit constraints). In this context, the implicit and explicit constraints are user-defined conditions that stop the expansion of a DMA in a given direction. The implicit constraints are related to reservoirs, tanks, PRVs, pumps, and so forth. The explicit constraints concern the natural hydraulic/geographic boundaries, the flow paths between the sources and the consumers, pipe flow capacities and municipal boundaries. (3) Identification of the path between each source of water supply and any node of the network, based on the flow direction during the daily peak flow and using graph theory concepts – Floyd–Warshall algorithm (Borgwardt & Kriegel 2005). The ‘path length’ corresponds to the accumulated value of a weight associated with each pipe \( (\eta_w) \), Equation (1) – relationship between the flow \( (Q_w) \) and the pipe diameter \( (D_w) \), as indicated by the resistance law used in the hydraulic simulation (\( \delta \) and \( \varphi \) are coefficients of the resistance law (Giustolisi & Todini 2009)):

\[
\eta_w = \frac{Q_w^\delta}{D_w^{\varphi}} \quad (1)
\]

(4) Selection of the reference node to increase each DMA (if there are several sources of water supply, for each one select the ‘path’ with the greatest ‘path length’, and, from these, choose the downstream node of the shortest ‘path’). (5) Based on the reference node and considering all its adjacent pipes, the increase of each DMA occurs from downstream to upstream, in all possible directions – guided by the peak flow direction and the design criteria for the DMA. Steps 4 and 5 are repeated until the whole network is divided into DMAs. (6) At this stage an analysis is performed to consider the possible grouping of some DMAs to reduce the number of entry points and boundary valves. For example, if the size of a DMA is too low, it should be added to one of its neighbours. Anyway, the size of the grouped DMA should not exceed the maximum size required – unless some tolerance is allowed. (7) If necessary, the user can adjust the DMA boundaries slightly before proceeding to the 2nd Model.

DMAs design and network reinforcement/replacement (2nd Model)

Economic benefits function

The method reported employs a procedure previously proposed by the authors (Gomes et al. 2011) to estimate the economic benefits from pressure reduction at DMAs entry points – reduction of water loss minus the reduction of billed water. However, other benefits, including fewer bursts in pipes, increased efficiency of the efforts in active leakage control, energy consumption and customer contacts, can also be used, as proposed by Awad et al. (2009). The total reduction of water loss for the network \( (\Delta VL) \) resulting from implementing the DMAs is given by the difference between the current water loss volume \( (VL_{Phase1}) \) and the estimated water loss volume after the DMAs implementation \( (VL_{Phase2}) \):

\[
\Delta VL = \left( VL_{Phase1} - VL_{Phase2} \right) \quad (2)
\]

As pressure is known to influence consumption, the amount of total billed water will decrease with the pressure reduction \( (\Delta VR) \), and this decrease can be estimated by the difference between the actual billed water \( (VR_{Phase1}) \) and the estimated billed water after the DMA implementation \( (VR_{Phase2}) \):

\[
\Delta VR = \left( VR_{Phase1} - VR_{Phase2} \right) \quad (3)
\]
Knowing the duration of each investment period (ny), the annual interest rate (intR), the cost of water production per m³ ($C_p$) and the selling price per m³ ($C_v$), Equation (4) estimates the direct economic benefits $B(X)$ that can be achieved by implementing DMAs. If the computed value is negative, which may happen if the average pressure increases, it represents a cost rather than a benefit.

$$B(X) = \left[ C_p \times \Delta VL - (C_v - C_p) \times \Delta VR \right] \times \left[ 365 \times \frac{(1 + intR)^{ny} - 1}{intR \times (1 + intR)^{ny}} \right]$$

(4)
For this computational application, it is assumed that the customers’ water consumption (revenue water) can be divided into three parts: the pressure-independent consumption, $\text{QRC}_{\text{indep}}$ (toilet flushing, roof tanks, washing machines, dishwashers); the pressure-dependent consumption, $\text{QRC}_{\text{dep}}$ (shower use, hand washing, watering gardens) and the real losses downstream of the customer’s meter as pressure-dependent, $\text{QRL}_{\text{dep}}$. Moreover, real losses upstream of the customer’s meter are not billed and they are regarded as pressure-dependent, $\text{QNRL}_{\text{dep}}$.

For each instant of the simulation period, the total outflow in each network node ($Q_i$), after the DMAs implementation, can be estimated by Equation (5) – adjustment of the Phase 1 values ($\text{flow} - Q_0$, and pressure – $P_0$) to the Phase 2 pressure conditions ($P_t$). In Equation (5), the exponent $N1$ expresses the pressure/leakage relationship, whereas exponent $N2$ expresses the pressure/consumption relationship (applied solely to the pressure-dependent consumption):

$$Q \text{ varies with } P^N : \left\{ \begin{array}{l}
Q_1 = \left( \frac{\text{QRI}_{\text{dep},0} + \text{QNRL}_{\text{dep},0}} {P_0} \right) N1 \times \frac{P_1} {P_0} + \frac{\text{QRC}_{\text{dep},0}} {P_0} \times \frac{P_1} {P_0} N2 \quad \text{if } P_1 > 0 \\
0 \quad \text{if } P_1 \leq 0 
\end{array} \right. \quad (5)$$

**Cost function**

The cost function $C(X)$, Equation (6), describes the total cost of pipe reinforcement/replacement, metering stations and the penalties for constraint violations. The pipe reinforcement/replacement is related to the installation of new pipes parallel to the existing ones or the substitution of existing pipes by new ones with greater capacities, and has two objectives: 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. These costs are computed by multiplying the pipe length ($L_p$) by the unit cost for the pipe reinforcement/replacement ($C_{\text{pipe},p}$ ($D_p$)), which depends on the diameter of the new pipe ($D_p$). The cost of the metering stations depends on the diameter of the flow meter ($C_{\text{inlet},m}$ ($\text{DF}_m$)), which in turn was set assuming a maximum velocity of 1.0 m/s. For the maximum violation for the constraint $v$ ($\text{viol}_i$), the unit cost of penalty ($\beta_0$) varies between $1 \times 10^6$ and $1 \times 10^8$. The cost of the boundary valves is not considered, because it is supposed that they already exist:

$$C(X) = \sum_{p=1}^{NP} \left[ C_{\text{pipe},p}(D_p) \times L_p \right] + \sum_{m=1}^{NM} C_{\text{inlet},m}(\text{DF}_m) + \sum_{p=1}^{NV} (\text{viol}_p \times \beta_0) \quad (6)$$

where $NP$ – number of pipes; $NM$ – number of DMA entry points; $NV$ – number of constraint violations.

The constraints considered in this optimization model are those usually used in the design of WDN (Cunha & Sousa 2010):

$$\sum_{p=1}^{NP} I_i \times Q_{p,t} = QC_{i,t} \quad \forall i \in \text{NN and } \forall t \in T \quad (7)$$

$$\Delta H_{p,t} = K_p \times Q^2_{p,t} \quad \forall p \in \text{NP and } \forall t \in T \quad (8)$$

$$H_{\text{max}} \geq H_{i,t} \geq H_{\text{min}} \quad \forall i \in \text{NN and } \forall t \in T \quad (9)$$

$$V_{p,t} \leq V_{\text{max}} \quad \forall p \in \text{NP and } \forall t \in T \quad (10)$$

$$D_p \geq D_{p,\text{min}} \quad \forall p \in \text{NP} \quad (11)$$

$$D_p = \sum_{j=1}^{\text{ND}_p} YD_{pj} \times DC_{p,j} \quad \text{with} \quad \sum_{j=1}^{\text{ND}_p} YD_{pj} = 1 \quad \forall p \in \text{NP} \quad (12)$$

$$\text{DMA entry points}_{\text{max}} \geq \text{DMA entry points}_{\text{min}} \quad (13)$$

$$\text{DF}_m = \sum_{j=1}^{\text{NDF}_m} YDF_{mj} \times \text{DCF}_{m,j} \quad \text{with} \quad \sum_{j=1}^{\text{NDF}_m} YDF_{mj} = 1 \quad \forall m \in \text{NM} \quad (14)$$

where $I_i$ – incidence matrix of the network at instant $t$; $Q_{p,t}$ – flow in pipe $p$ at instant $t$ (m$^3$/s); $QC_{i,t}$ – demand in the node $i$ at instant $t$ (m$^3$/s); $\text{NN}$ – number of nodes; $T$ – simulation period (usually 24 h, with time step of 1 h); $\Delta H_{p,t}$ – head loss in pipe $p$ at instant $t$ (m); $K_p$ and $n$ – resistance law coefficients; $H_{\text{max}}$ and $H_{\text{min}}$ – maximum and minimum
pressure requirements (m); \(H_{i,t}\) – head in node \(i\) at instant \(t\) (m); \(V_{p,t}\) – velocity in pipe \(p\) at instant \(t\) (m/s); \(V_{\text{max}}\) – maximum velocity allowed (m/s); \(D_p\) – pipe diameter (mm); \(D_{p,\text{min}}\) – minimum diameter requirement (mm); \(N_{D_p}\) – number of commercial diameters assigned to pipe \(p\); \(YD_{p,j}\) – binary variables representing the use of a given diameter in pipe \(p\); \(DC_{p,1}\), \(DC_{p,2}\), \ldots , \(DC_{p,N_{D_p}}\) – set of commercial diameter for pipe \(p\) (mm); \(DF_{m}\) – flow meter diameter (mm); \(N_{DF_m}\) – number of commercial flow meter diameters assigned to entry point \(m\); \(YDF_{m,j}\) – binary variables representing the use of a given flow meter diameter in entry point \(m\); \(DCF_{m,1}\), \(DCF_{m,2}\), \ldots , \(DCF_{m,N_{DF_m}}\) – set of commercial flow meter diameters for entry point \(m\) (mm).

**Objective function**

The objective function \(\text{NPV}(X)\), Equation (15), maximizes the net present value of the differences between the economic benefits (water loss reduction arising from the average pressure reduction) and the total costs of the DMA implementation (chambers and pressure reduction) and the total costs of the project plan:

\[
\text{max } \text{NPV}(X) = \sum_{i=1}^{n} \frac{B(X)_i - C(X)_i}{(1 + \text{intR})^{t_i}} \quad (15)
\]

where \(\text{NPV}(X)\) – net present value of the project (€), \(n\) – number of investment periods for the duration of the project plan, \(B(X)_i\) – total economic benefits during the investment period \(i\) updated to the beginning of that investment period, \(C(X)_i\) – total investment costs at the beginning of the investment period \(i\) (€), \(t_i\) – time between the start of the project and the beginning of the investment period \(i\) (years), and \(\text{intR}\) – annual interest rate (%).

**Simulated annealing algorithm**

The implementation of a SA algorithm can be described as follows (Metropolis et al. 1953; Cunha & Sousa 1999). At the initial temperature \((T_0)\), the algorithm starts by generating an initial solution \((X_0)\) – all the pipes of the DMA boundaries are replaced and all the other pipes in the network are reinforced at the beginning of the project plan (the biggest diameter is assigned to every new pipe in the network). Moreover, every pipe entering a DMA is an entry point (there are no boundary valves closed). At temperature \(T_{k+1}\), the number of solutions generated is \(L_{k+1}\), which varies according to the percentage of solutions accepted at the last temperature \((P_{ak})\). Each new solution \((X_k)\) is generated from the current solution \((X_{k-1})\) 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 (in 60% of the cases the diameter is reduced). The hydraulic simulator evaluates the hydraulic performance, Equations (4) and (6) estimate the total economic benefits and costs for each investment period, and Equation (15) evaluates the net present value of the project (NPV) for the new solution. The new solution is accepted or not, according to the Metropolis criterion. If it is accepted, this solution will be used as the starting point for the next step. If not, the original current solution will be used. After five temperatures without accepting any modification between DMA entry points, the search is focused only on applying procedure (3) for the last accepted solution. The algorithm ends if the stopping temperature is reached, that is: for two successive temperatures the number of solutions accepted \((P_{ak})\) remains lower than 5% and the difference between the averages of the project net present value between two successive temperatures is 1.0% (\(\varepsilon\)) or lower. Table 1 shows the cooling scheme adopted for the SA algorithm. To test the robustness of this cooling scheme two procedures were used for several case studies: (1) using different initial solutions; (2) define part of the final solution, from the results obtained in procedure (1). Although the results have been satisfactory, it is not possible to ensure that the best solution corresponds to the global optimal solution for each problem (this problem belongs to the class NP-hard).

**CASE STUDY**

The adaptation of the WDN described by Arulraj & Rao (1995) was used to evaluate the performance of the proposed methodology (see Figure 2). The system can be described as follows: (1) the average flow at the network entry point is 383.40 m³/h; (2) the network is approximately 26.5 km long and is gravity-fed from one reservoir (node 81); (3) the minimum and maximum service pressures are 26.23 m (node 79) and 52.69 m (node 1), respectively; and (4) the minimum and maximum service pressure required are 25.74 and 60.00 m, respectively. The purpose of this study is to divide the
network in three DMAs, based on the number of service connections. This study considered a 20-year project plan (two investment periods of 10 years each). Moreover, it was 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 net present value of the project for different solutions, an annual interest rate of 5% was used.

**Table 1** | Cooling scheme for the SA algorithm

<table>
<thead>
<tr>
<th>Initial configuration</th>
<th>$X_0 = {D_1, D_2, \ldots, D_{NP}} = D_{max}$; where NP Number of network pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial temperature</td>
<td>$T_0 = \left(\frac{0.10 \times NPV(X_0)}{NPV_{00}}\right)$; where: $P_{00} = 80%$</td>
</tr>
<tr>
<td>Number of transitions at each temperature</td>
<td>if $P_{k} &gt; 80%$ then $T_{k+1} = 0.50 \times T_k$ and $L_{k+1} = 20 \times NP$</td>
</tr>
</tbody>
</table>
| Stop criterion       | $P_{k} < 5\%$  
|                      | $\varepsilon \leq 1.0\%$ |

with $\varepsilon = \frac{|NPV_{\text{average},k} - NPV_{\text{average},k+1}|}{NPV_{\text{average},k+1}}$

**Figure 2** | DMAs boundaries and daily consumption pattern (1st and 2nd investment periods).
DMAs design

Table 2 shows the topology of the DMAs boundaries and the total number of service connections in each DMA, obtained using the prediction of the hydraulic behaviour for the system at the middle of the project plan. Solution 1 was obtained taking pipes 42 and 54 as explicit constraints (based on the pipe flow capacity and on the flow direction) and a reference

Table 2 | Initial DMAs boundaries adopted

<table>
<thead>
<tr>
<th>Network topology</th>
<th>DMAs boundaries</th>
<th>Number of service connections</th>
<th>Network length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution 1</td>
<td>DMA1</td>
<td>77/78–72–89</td>
<td>4,089</td>
</tr>
<tr>
<td></td>
<td>DMA2</td>
<td>4/5–42–54</td>
<td>4,366</td>
</tr>
<tr>
<td></td>
<td>DMA3</td>
<td>77/78–72–89–4/5–42–54</td>
<td>3,046</td>
</tr>
<tr>
<td>Solution 2</td>
<td>DMA1</td>
<td>88–72–79–80</td>
<td>4,832</td>
</tr>
<tr>
<td></td>
<td>DMA2</td>
<td>4/5–42–54</td>
<td>4,366</td>
</tr>
<tr>
<td></td>
<td>DMA3</td>
<td>88–72–79–80–4/5–42–54</td>
<td>2,303</td>
</tr>
</tbody>
</table>

Table 3 | Influence of the number of entry points in the NPV

<table>
<thead>
<tr>
<th></th>
<th>Reinforcement cost (€)</th>
<th>Metering stations cost (€)</th>
<th>Benefit (€)</th>
<th>NPV (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–10</td>
<td>10–20</td>
<td>0–10</td>
<td>10–20</td>
</tr>
<tr>
<td></td>
<td>Cost/benefit analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solution 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II) Solution 1</td>
<td>1–4/5–77/78 42–54–72</td>
<td>–4,463</td>
<td>–4,488</td>
<td>92,156</td>
</tr>
<tr>
<td></td>
<td>Cost/benefit analysis</td>
<td></td>
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<tr>
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<td>Solution 2</td>
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<td>Cost/benefit analysis</td>
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<tr>
<td></td>
<td>Solution 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1–4/5–77/78 42–54–72–89</td>
<td>–103,289</td>
<td>47,244</td>
<td>80,440</td>
</tr>
<tr>
<td>IV) Solution 1</td>
<td>1–4/5–77/78 72</td>
<td>–100,696</td>
<td>6,904</td>
<td>11,685</td>
</tr>
<tr>
<td></td>
<td>Cost/benefit analysis</td>
<td></td>
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<tr>
<td></td>
<td>Solution 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1–4/5–77/78 79–80</td>
<td>–2,028</td>
<td>–2,527</td>
<td>107,272</td>
</tr>
<tr>
<td>V) Solution 1</td>
<td>1–4/5–77/78 77–78–89</td>
<td>–104,915</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cost/benefit analysis</td>
<td></td>
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<tr>
<td></td>
<td>Solution 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1–4/5–77/78 79–80</td>
<td>–107,301</td>
<td>–5,588</td>
<td>21,265</td>
</tr>
<tr>
<td>VI) Solution 2</td>
<td>1–4/5–77/78 79–80–88</td>
<td>–112,918</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost/benefit analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(i) 3 DMAs entry points; (ii) 4 DMAs entry points; (iii) 5 DMAs entry points; (iv) 6 DMAs entry points; (v) 7 DMAs entry points; (vi) 8 DMAs entry points.
limit of 4,500 service connections per DMA, with a tolerance of 500 service connections. Solution 2 was obtained taking the same criteria as for Solution 1, plus a node elevation constraint (minimum elevation difference between the highest node and the lowest node in each DMA – a useful measure for pressure management purposes).

**DMA design and network reinforcement/replacement**

Each DMA can be supplied from one or multiple entry points, in which the flow must be measured to manage water loss. Single entry point DMAs are often preferred because they are easier to implement and simpler to manage. On the other hand, the flow metering accuracy can be reduced when the number of entry points increases. Table 3 illustrates the influence of the number of DMAs entry points in the NPV (based on the cost/benefit analysis), as well as the location of the DMAs boundary valves when the number of entry points increases. For each solution (50 trials), the maximum difference found was less than 5%, and is related to minor adjustments in terms of the network reinforcement.

As expected, the NPV varies with the number of DMA entry points and is related to the cost of the metering stations and the network reinforcement (see Table 3). It can be seen that a minor reinforcement of the network pipes, to adjust the maximum velocity and the pressure at the critical node, may increase the global benefits and even be sufficient to make the DMA implementation self-sustainable. On the other hand, when the number of entry points increases, the total cost of the metering stations increases and the network reinforcement cost falls. For all solutions, analysing the hydraulic behaviour of the network before and after DMAs implementation, the DMAs entry points correspond to the pipes through which the largest flows were passing or which allowed a closer connection to the central part of the DMA, avoiding excessive network reinforcements. The network reinforcements are a consequence of the maximum velocity allowed and the minimum pressure requirement, and they depend on the location of the DMAs entry points. In this case study, the cost/benefit analysis Solution 2-1 leads to the largest NPV of the DMAs implementation (single entry point DMAs).

Figure 2 represents the final DMAs boundaries and the network reinforcement/replacement for the project plan, considering a single entry point for each DMA (Solution 2). After the DMAs implementation (due to the reduced number of DMAs entry points, network reinforcement/replacement, consumption increase and infrastructure decay), the minimum service pressure is not the same as before, and the critical node can also change. Furthermore, the maximum service pressure during the minimum night flow period may also change. The minimum service pressure varies between 26.19 (node 79, 1st investment period) and 25.74 m (node 60, 2nd investment period), and the maximum service pressure between 52.55 (node 1, 1st investment period) and 52.41 m (node 1, 2nd investment period). For this solution, the DMAs entry points correspond to the pipes through which the largest flows were passing during the peak flow (pipes 1, 4, 5 and 88).

**CONCLUSION**

Water loss management is of fundamental importance to improving the efficiency of many systems worldwide, to ensure long-term environmental and social sustainability. Monitoring the flow in DMAs enables the quantification of water loss and provides information to prioritize active efforts to control leakage, guiding the authorities to the worst parts of the network.

Taking the needs of the water industry into consideration, this paper described a method that can be applied by designers and water companies to help in defining the most appropriate DMAs design for any WDN, considering both the costs and the benefits. In particular from the elaborations carried out it was possible to observe the possible NPV differences from considering a single or multiple entry points in each DMA. Furthermore, it was found that, after the DMAs implementation, a minor reinforcement of the network pipes to adjust the maximum velocity and the minimum pressure at the critical node may increase the global benefits and even be sufficient to make DMAs implementation self-sustainable. The proposed method can also be used to plan the investment needed at different times during the project plan and the total investment can thus be adjusted according to the actual needs and the financial resources of the water company.

To conclude, it should be noted that DMAs implementation can open the way to pressure management in certain parts of the network by installing PRVs inside or at the DMAs entry points, and this can result in considerable additional benefits in terms of water loss reduction, especially at night. The method presented in this paper is now being extended to include the implementation of pressure management in the DMAs, using different types of PRVs.
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