A DMA DESIGN FOR "NAPOLI EST" WATER DISTRIBUTION SYSTEM

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ABSTRACT

The District Meter Areas (DMA) design is an innovative methodology of water networks management, based on the pressure patterns control and on the water flows monitoring, in order to reduce water losses and to optimize the water systems management. A District Meter Area is an area supplied from few water inputs, into which discharges can be easily measured to determine leaks. So, the DMA design represent an alternative to the traditional approach based on heavy looped distribution network.

In the present paper the DMA design of the "Napoli Est" water distribution system (approximately 70.000 customers), performed with the support of the Water Agency ARIN S.p.A. (Azienda Risorse Idriche Napoli), is discussed.

After analysis of authorized consumption, by means of a monitoring campaign of water fluxes over the area, the system water balance was performed, showing significant water losses, as a consequence of high pressure patterns. This situation was confirmed by the high number of maintenance operations performed in the area during the last years. In order to characterize the piezometric head on the network, ARIN S.p.A. supplied to the installation of six pressure transducers in the most vulnerable areas. The water level in the reservoir was also measured in order to estimate its influence on the network pressure head.

Hydraulic simulations were carried out with the EPANET software version 2.0 (Rossman, 2000) applied to a network layout resulted from the system "skeletonization" (Hamberg e Shamir, 1988), achieved by eliminating out of order pipes, integrating pipelines of same diameter and roughness, replacing dead-end branches and small networks supplied by a single junction with an equivalent flow.

After the skeletonizated network was calibrated, several hypothesis of designing and implementing DMA to reduce physical losses were performed, providing adequate operating pressure of the system and performing many numerical simulations to guarantee adequate head pressure especially for peak hours demand, break of transmission mains and fire hydrant service. A chlorine residuals analysis was also effected, by simulating the transport and decay of chlorine through the network.

Six District Meter Areas, therefore, were designed, and the corresponding hydraulic and water quality investigations and simulations were carried out. A remarkable water saving was achieved, approximately equal to 34% of the physical losses, corresponding to 16% of system input volume.

Actually ARIN S.p.A. is implementing and monitoring the six District Meter Areas planned. A preliminary comparison of numerical simulations with experimental measures showed satisfactory results.

1 INTRODUCTION

From a recent report of the Committee for the Vigilance on the Use of Water Resources (2004), with reference to approximately 61% of Optimal Territorial Ambits (ATO), in Italy the total water losses (physical and administrative) range between 20÷65%, with an average value around 40%.

As well known, the greater share of physical leaks is localized in distribution networks: an active leakage control in order to reduce water losses would concur, therefore, a significant water saving with economic and environmental benefits.

Beside the advances in leak detection practices and techniques (leak localising, leak location, repair of leaks), in the 90ies the District Meter Areas (DMA) design was introduced in the management of the water distribution systems (Cheong, 1993). A District Meter Area is an area supplied from few water inputs, into which discharges can be easily measured to determine leaks. It is well known the pressure-leakage relationship, so in the DMA an effective control of the head patterns is performed, by means of pressure reducing valves to prevent the downstream hydraulic grade from exceeding a set value. Such technique is, therefore, an effective instrument to optimize the management of a water distribution system, with beneficial effects on the water losses reduction and probably also on the pipe failure rates and rupture frequencies.

The DMA design can be chosen in alternative to the traditional approach of heavy looped distribution networks. These systems on the one hand offer a remarkable level of reliability (ready emergency response with little impact on the customers, for example in the case of a main break; simple territorial expansion of the distribution system; etc.) but on the other hand they involve a less effective control of the water network and greater difficulties in the leakage management activities (Artina et al., 2005; Giugni et al., 2007).

D.M. 99/1997 introduced in Italy the DMA design, but until now only few examples of application are known (Modena, Reggio Emilia, Bologna). This in consequence of economic factors and technical difficulties, due to the complexity of the DMA design operations and sometimes to the lack of an accurate acquaintance of the water networks topology.

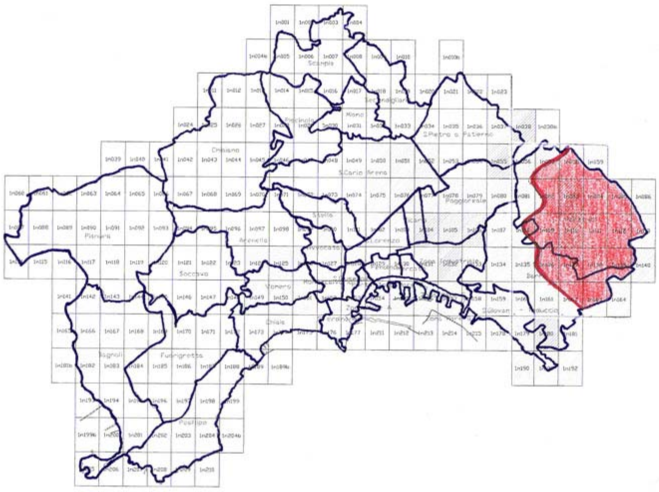


Figure 1. Location of “East Naples” area in the Naples Municipality.

2 THE CASE STUDY: THE “NAPOLI EST” WATER DISTRIBUTION SYSTEM

In the present work are reported the noteworthy points of a research aimed to the DMA design of “Napoli Est” network, pertaining to the system of Water Agency ARIN S.p.A. (Neapolitan Water Resources Agency).

In greater detail, the East Naples area has a surface approximately equal to 920 hectares (nearly 8% of the Municipality of Naples) and covers most of the eastern zone of the city

(East Naples; Fig. 1). Resident number is approximately 65.000÷70.000 and the area elevation varies in the range 11÷78 m above sea-level. The network is supplied by “San Sebastiano” reservoir, with 6 tanks (of which only 5 are currently working) for a total storage volume of 30.000 m^3. The reservoir maximum water depth is 5.40 m and the overflow elevation is 112.50 m above sea-level.

The distribution network is heavy looped (Fig. 2) and pipes are in reinforced concrete (going back to 60ies, with diameter DN 1000), grey cast iron, steel and ductile cast iron, with diameters ranging from DN 40 to DN 1000.

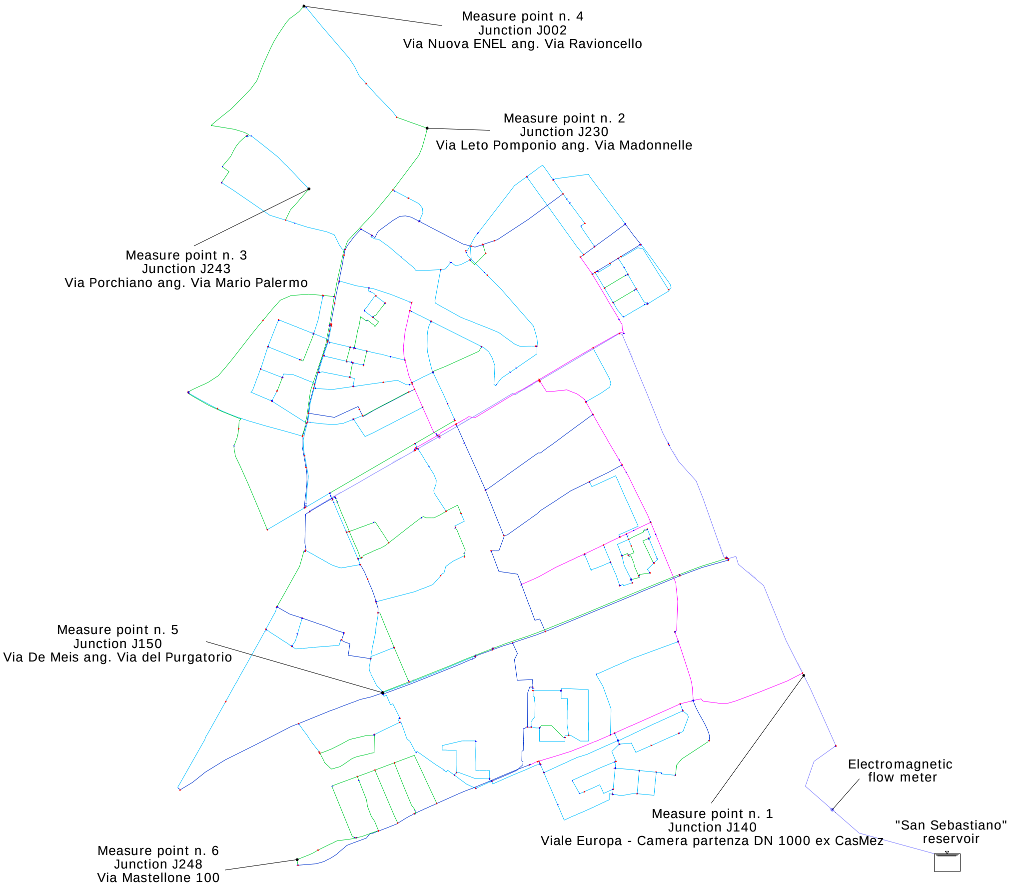


Figure 2. Layout of “Napoli Est” water distribution system (with pressure transducers).

By means of a preliminary field survey, the water system operational conditions were characterized and a database for the calibration of the hydraulic simulation model was implemented. Along the reservoir exit pipe an electromagnetic flow meter was installed (Fig. 2): in Figure 3 the network daily discharge (24÷27/05/2006) was showed as an example.

Collected data showed that:

- the network daily discharge has low week and seasonal variation. The peak hour demand is around 440÷450 l/s, the minimum around 220÷230 l/s. The average-day demand is practically constant and equal to approximately 340 l/s;
- the minimum night flow practically is never smaller than 220 l/s and the peaking factor is approximately equal to 1.3. It follows that “Napoli Est” network has a high percentage of physical losses, since the area is characterized by small night activities (do not exist noteworthy industrial systems or business activities carried out in night hours).

On the basis of collected data, the mass balance (IWA, 2000) of the network (showed in Table 1) was performed, comparing the average daily water volume supplied by "San Sebastiano" reservoir (System Input Volume) with the average daily volume billed to the customers (Billed Authorized Metered Consumption).

	Daily average volume [m³/d]	Daily average flow [l/s]
SYSTEM INPUT VOLUME	29.422	340
BILLED AUTHORIZED METERED CONSUMPTION	9.790	113
Water losses	**19.632**	**227**

Table 1. Water balance of "Napoli Est" distribution system.

The billing data were collected by ARIN S.p.A. by means of a management software integrated with a Geographic Information System (GIS). The billed consumption is equal to 9.790 m^3/d, corresponding to an average-day demand of 113 l/s.

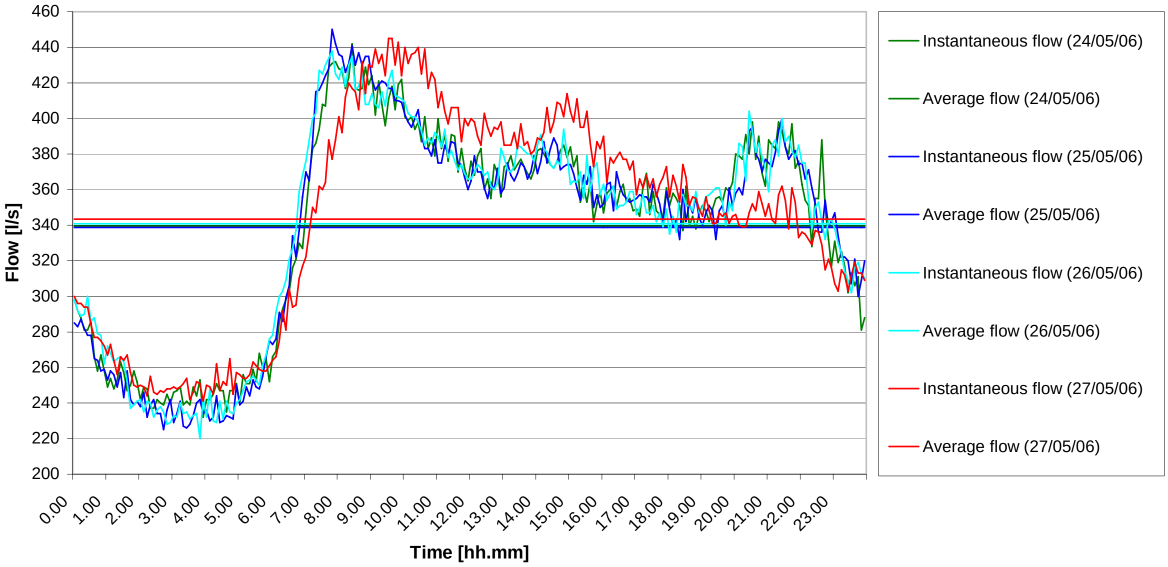


Figure 3. Network daily discharge (24÷27/05/2006).

Therefore, from the water balance of "Napoli Est" distribution system (Table 1) it results -even with inevitable approximations due to measurement errors and uncertainties in the area delimitation- that the network global losses are about 67%.

The heavy losses are confirmed by the high number of maintenance operations performed in the area in 2005 (Table 2). It is probably due to the high number of steel pipelines (with consequential corrosion phenomena) and above all, as it is shortly going to illustrate, to high pressure heads, that surely have a strong impact on water leaks and on pipe failure rates.

Maintenance operations typology	**n.**
Pipelines repairing	129
Horizontal repairing	42
Repairing and replacement of valves, junctions, etc.	32
Other	7
TOTAL	210

Table 2. Maintenance operations in "Napoli Est" network in 2005 (ARIN's Archives, 2005).

In order to characterize the piezometric head on the network, ARIN S.p.A. supplied to the installation of six pressure transducers in the most vulnerable areas (Fig. 2). The water level in the reservoir was also measured in order to estimate its influence on the network pressure head.

Measurements allowed to detect small head losses in the network, due to pipes large diameters. Consequently, the network peripheral areas, characterized by low elevations, are subjected to elevated pressure heads largely superior than the minimum one for efficient distribution (Fig. 4).

The following relationship exists between pressure in network P and physical losses Q^l (Khadam et al., 1991; Khaled et al., 1992; Lambert, 2000; Milano, 2006):

$$Q^l = C \cdot P^{\alpha} \tag{1}$$

being C and α coefficients varying according to pipe characteristics and type of loss. This correlation is confirmed and emphasized by the experimental results on the “Napoli Est” distribution system, so the DMA design appeared a suitable solution to achieve a water losses reduction and for future benefits in monitoring the system water balance.

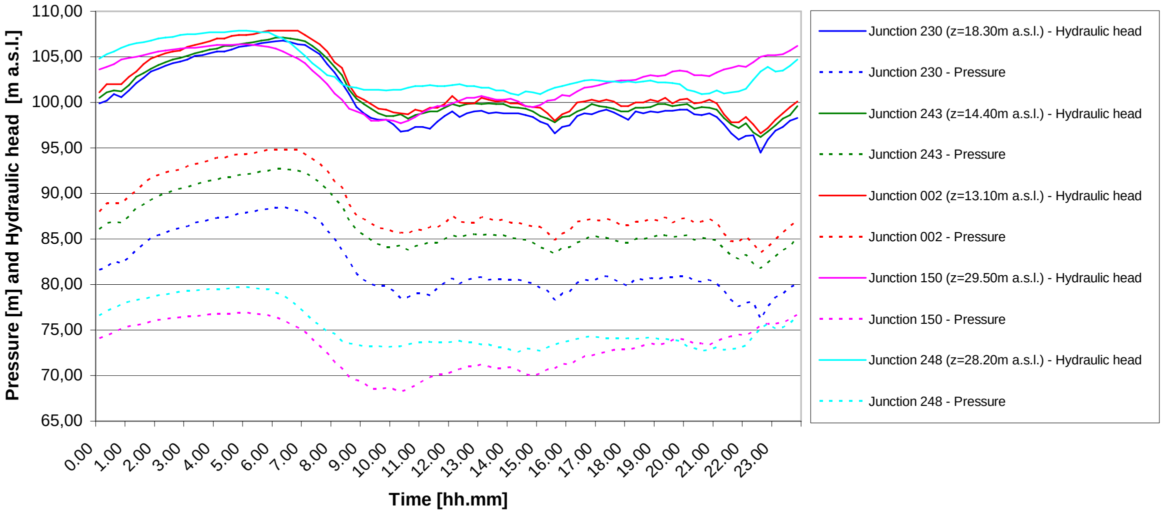


Figure 4. Daily pressures in network.

3 HYDRAULIC SIMULATIONS

Hydraulic simulations were carried out with the EPANET software version 2.0 (Rossman, 2000). Hydraulic layout resulted from the network “skeletonization” (Hamberg e Shamir, 1988), achieved by eliminating out of order pipes, integrating pipelines of same diameter and roughness, replacing dead-end branches and small networks supplied by a single junction with an equivalent flow.

To support the skeletonizated layout, the following input data were used:

- **Planimetric and topographic layout of the system and hydraulic parameters of pipelines and junctions**. The system is constituted by 100 meshes, 259 junctions and 358 pipes. Every pipeline was defined by length, diameter and roughness coefficient (the Hazen-Williams equation was adopted in simulations, defining each pipe coefficient according to material and age); each junction was defined by elevation and by distributed and billed flow.
- **Daily pattern of water levels in the tank**. The daily water level in the reservoir was assigned from measured levels during the field measurement campaign (Fig. 5).

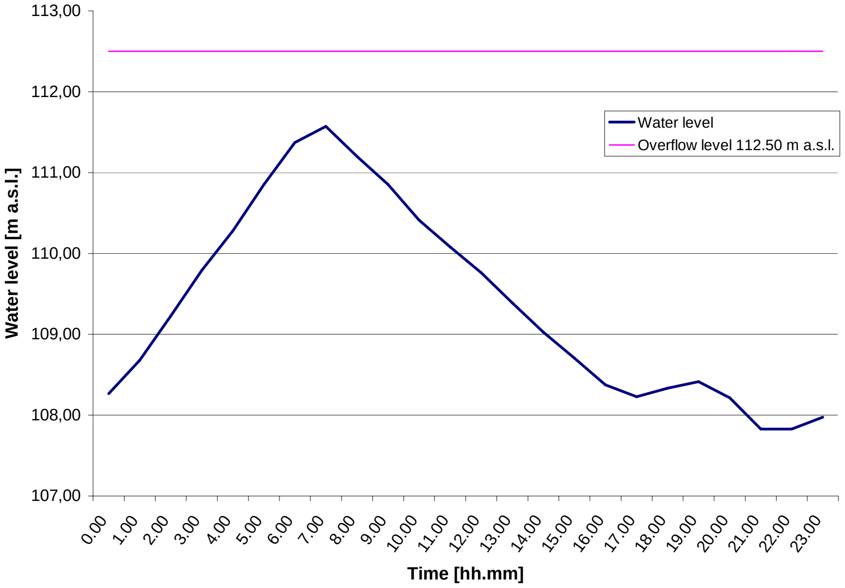


Figure 5. Daily pattern of "San Sebastiano" reservoir water level.

- **Daily consumption**. It represents hourly variation of flow supplied from the junctions (Fig. 6). The consumption pattern was deduced by making the following hypothesis:
  - ✓ the average input flow was 340 l/s (corresponding to a daily input volume of 29.422 m^3);
  - ✓ the total water load supplied by the junctions, according to the billed data, was 113 l/s, corresponding to 9.790 m^3/d. The network demand was divided among the supplying junctions according to authorized and billed consumption collected by ARIN S.p.A.;
  - ✓ the total losses were 227 l/s. The 30% (more or less equal to 68 l/s) was considered apparent losses, assuming a specific per-capita consumption of 240 liters/day. This flow was equally divided among the supplying junctions. Consequently, physical losses were assumed to be 70% (159 l/s).

Spatial distribution of the network maintenance operations in 2005 shows a quite homogeneous distribution. Therefore it was assumed to divide physical losses among all the system junctions (supplying junctions and leaking junctions). Consequently, the following relationships were adopted to evaluate the supplied flows q_{tj} in the generic junction j, in the instant t:

- supplying junctions: $$q_{tj} = c_t \cdot \overline{q_{jSUP}} + C \cdot p_{tj}^{\alpha} \qquad (2)$$
- leaking junctions (emitters): $$q_{tj} = C \cdot p_{tj}^{\alpha} \qquad (3)$$

where:

- q_{SUP}: total billed flow and apparent losses;
- c_t: hourly coefficient;
- C, α: "emitter coefficient" and "emitter exponent" (see eq. (1)).

According to recent literature (Khaled et al., 1992; May, 1994), it was estimate $\alpha = 0.80$. Coefficient C was assumed to be constant for all the system junctions, and when calibration was completed, a value C = 0.02 was returned. This value allowed a reliable simulation of the average daily pattern (Fig. 6). Calibration returned, moreover, reliable values of the pipe roughness coefficients.

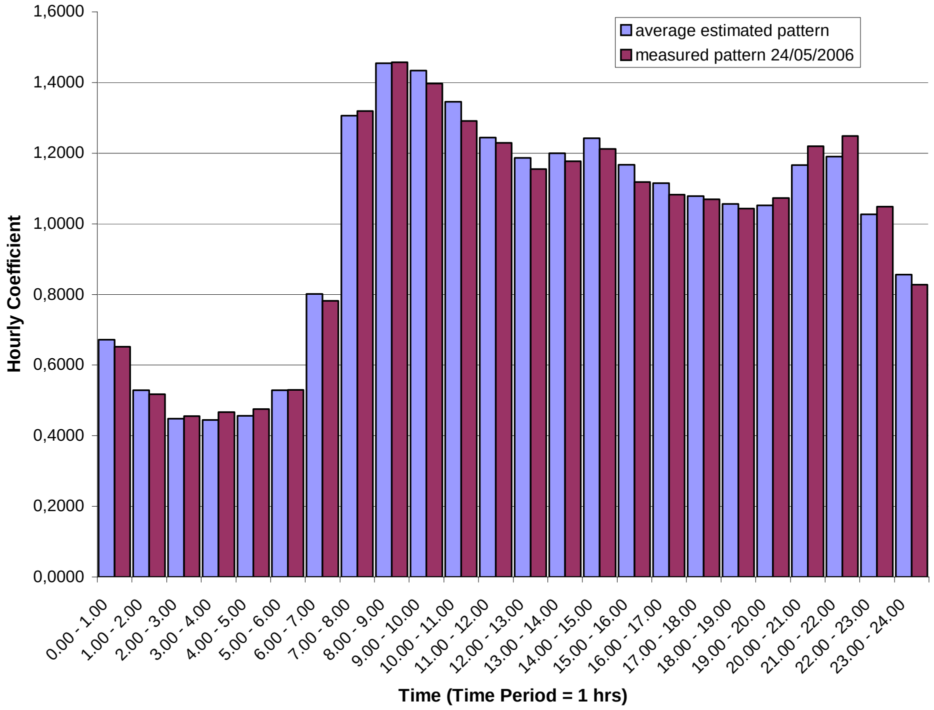


Figure 6. Consumption daily pattern.

4 THE DISTRICT METERING PROCEDURE

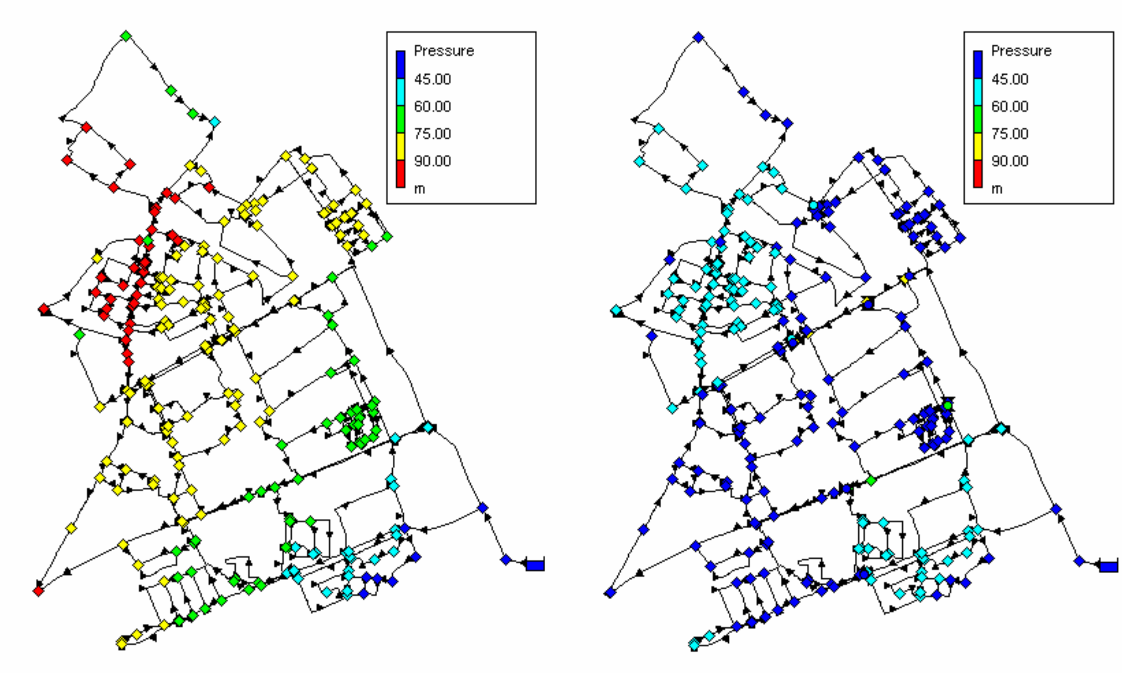
After the network was calibrated, several hypothesis of designing and implementing DMA to reduce physical losses were performed, according the following procedure:

1. **District Meter Areas and the transmission mains connecting them to the network were identified**. Each District Meter Area had similar elevation, few connections with the remaining part of the network, and served a population of 10.000÷15.000.
2. **Implementing each zone with intercepting valves and/or pressure reducing valves**.
3. **Preliminary analysis of the district metered network was performed to provide adequate operating pressure of the system**. A minimum head pressure of 25 m was guaranteed with peak demands, as 5-6 stories buildings were present. The network served as well 8 insulated tower buildings, which were supposed to be served with their own on site pumps.
4. **Many numerical simulations** were performed to guarantee adequate head pressure for:
   - daily demand, especially for peak hours demand;
   - break of transmission mains;
   - fire hydrant service. Peak demands due to fires were estimated by assuming a concentrated flow of 30 l/s, requiring a minimum head pressure of 5 m.

chlorine residuals analysis, by simulating the transport and decay of chlorine through the network (Fang et al., 1999; Rossman et al., 1999).

Table 3 summarizes minimum head pressures and water losses reduction after the numerical simulations for each district metering implementation were performed. Six different scenarios were analyzed, in which the number of District Meter Areas was progressively increased. For each scenario Table 3 shows the number of intercepting and pressure reducing valves and the physical losses reduction.

All the demand simulations previously described (peak hour demand, break of a transmission main, fire hydrant service) provide a minimum pressure head of 25 m and a minimum chlorine residual of 0.2 mg/l. For example, Figure 7 shows pressure head at the junctions during peak hour demand, both in the current configuration and after six DMA were implemented, with a significant reduction of pressure head in the lowest part of the network. Numerical simulation showed as well head pressure fluctuation due to daily demand variation, so providing a preliminary estimate of physical losses reduction after DMA design. Simulations analysis showed that the best performance can be achieved by scenario 6, which provides for six DMA by placing 14 intercepting valves and 9 pressure reducing valves.



(a) (b)

Figure 7. Pressure head at the junctions during peak hour demand in the current configuration (a) and after DMA design (b).

This configuration should provide a physical losses reduction of 34%, corresponding to 16% of system input volume (i.e. 4665 m^3/d and 1.70 million cubic meters per year).

SCENARIO	DMA DESIGN		DMA	WATER SAVING		
	Number of intercepting valves	Number of pressure reducing valves		Minimum head pressure	System input volume reduction	Physical loss reduction
1	2	2	**A+B**	J230: 25,12 m	6,60%	14,11%
2	6	3	**A, B**	J230: 25,15 m	8,33%	17,81%
3	10	5	**A, B, C**	A5: 25,75 m	11,94%	25,54%
4	10	6	**A, B, C, D**	A6: 25,00 m	13,37%	28,59%
5	11	7	**A, B, C, D, E**	A7: 25,00 m	13,96%	29,85%
6	14	7	**A, B , C, D, E, F**	J119: 25,17 m	16,05%	34,31%

Table 3. Summary of “Napoli Est” DMA design.

For sake of clarity, Figure 8 shows the network map with displayed the DMA, the minimum head pressure junction and the reduction of the system input volume.

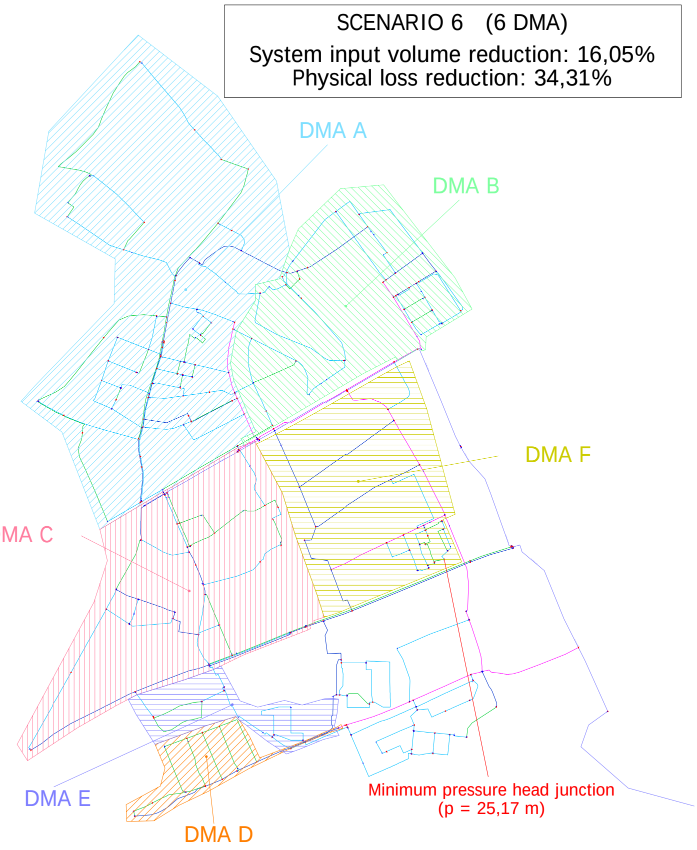


Figure 8. "Napoli Est" DMA design.

5 CONCLUSIONS

Coupling the DMA design with the existing water flow remote measurement system will provide the following benefits:

- remarkably reducing water losses;
- reducing the number of maintenance operations, after reducing the operating pressure of the system;
- easy finding the most vulnerable areas of the network;
- making quick maintenance and repair in the network.

Obviously, results of numerical simulations are only preliminary, and should be confirmed in the future by implementing and monitoring one or more DMA and comparing numerical simulations with in situ measurements.

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