DISTRICTUALIZATION FOR REDUCING WATER LOSSES IN WDNS

STRATEGIE DI RIDUZIONE DELLE PERDITE NELLE RETI IDRICHE BASATE SULLA DISTRETTUALIZZAZIONE

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Abstract esteso
Il paradigma di gestione delle reti di distribuzione idrica sta evolvendosi sempre di più nella direzione di un controllo della rete volto prioritariamente alla riduzione delle perdite idriche nel rispetto del vincolo di soddisfacimento della richiesta dell'utenza. Nell'ambito di tale approccio risulta fondamentale la Distrettualizzazione della rete, ossia la sua divisione in Distretti di Misura (DMA) nell'ambito dei quali è possibile effettuare il bilancio idrico. Tali Distretti possono essere fisici, se delimitati da valvole, oppure virtuali, se delimitati da misuratori di portata.
Le metodologie più adottate per la stima delle perdite passano attraverso la stima del cosiddetto Consumo Minimo Notturno (Minimum Night Flow – MNF), ossia il minimo consumo che si registra da parte dell'utenza. In genere tale consumo minimo si verifica fra le 2:00 e le 4:00 della notte.
In letteratura si trovano molti contributi mirati alla stima del MNF, tuttavia in generale tali contributi si basano su misure effettuate con elevata frequenza temporale. Nei DMA effettivamente realizzati dai Gestori del Servizio Idrico Integrato, la frequenza di misura è generalmente quella oraria, in particolare per problemi connessi alla trasmissione del dato. Nel presente studio, pertanto, vengono analizzati 14 DMA effettivamente realizzati su reti di distribuzione dell'Ambito Distrettuale Sarnese – Vesuviano della Regione Campania.
Nei DMA analizzati erano contestualmente presenti misure di portata e di pressione, e ciò ha consentito di stimare non solo la perdita media, ma anche la sua variazione temporale.
Il principale risultato ottenuto nell'ambito del presente studio è la proposta di una legge che consente la stima del minimo coefficiente di domanda in funzione del numero di utenti. Tale relazione si scrive come

$$\mu_{CDmin} = 0{,}035\ N_{users}^{0,25}$$

e si può ritenere valida per distretti di misura che vanno da poche centinaia fino a decine di migliaia di utenti, con caratteristiche fondamentalmente residenziali.
Il vantaggio dell'uso della relazione proposta risiede senza dubbio nella sua semplicità, a fronte di altre formulazioni più complesse presenti nella letteratura recente. È stata inoltre messa in evidenza l'importanza di portare in conto la variabilità della perdita durante la giornata, dovuta alle variazioni di pressione, in particolare in distretti nei quali viene effettuato un controllo attivo della pressione con l'uso di Valvole di Riduzione della Pressione (PRV).
In prospettiva si intende estendere lo studio, passando da una formulazione deterministica, come quella qui presentata, a una probabilistica, che consenta anche di valutare gli intervalli di confidenza del MNF stimato.

ABSTRACT
In Italy, in the framework of the PNRR plan of investment, a huge campaign of works has been initiated in order to obtain the target of digitalization of Water Distribution Networks (WDNs) and to reduce the water losses. Distrectualization of complex WDNs is the most used approach in order to obtain such target.
The resulting sectors, called district metering areas (DMAs), are expected to meet some requirements and performance criteria such as minimum number of intervention, pressure uniformity, similarity of demands, water quality and number of districts. DMAs can help in understanding the behaviour of the network, and to program efficient water losses reduction campaigns.
In the present study about 14 DMAs on different WDNs in the Province of Naples (Italy) have been considered. The trade-off between measured flow and pressures have been analyzed highlightening the effect of the Pressure Reducing Valves (PRVs) on the night leakages value estimation. Furthermore a methodology based on the minimum residential night flow consumption for leakages estimation is proposed.

1. Introduction

Water Distribution Networks (WDNs) management is moving nowadays towards leakages estimation and relative control. Several methodologies (e.g. Puust et al., 2010; Mutikanga et al., 2013) are available in the technical literature for supporting WDNs management in leakages quantity estimation. They are mainly based on the water balance, between the inflow water volume and the users required one, and the minimum night flow – MNF (e.g. Farah & Shahrour, 2017; Farley & Trow, 2003; Garcia et al. 2006). The latter, in residential areas, usually occurs between 02:00 and 04:00 hours (Liemberger and Farley, 2004) and by knowing at the same time the legitimate minimum residential water consumption, due to effectively users requests, it is possible to estimate night leakages by subtracting it to the MNF.

MNF can provide important information about district water losses (Wrc/WSA/WCA 1994). Moreover MNF measurement can be used for prioritisation of districts for leak detection and location activity. District MNF is monitored by calculating the difference between the inflow and outflow in each district during hours of low consumption.

It is widely recognized that WDNs management can be substantially improved by permanent Water District Metering (WDM) which is one of the most efficient techniques for water loss detection and pressure management (AWWA 1999, 2003, Lambert and Hirner 2000).

WDM consists of partitioning a water system into subsystems (called 'districts') delimited by control valves (physical district) or by flow meters (virtual district). This methodology, originally developed in the UK (Wrc/WSA/WCA 1994) and already implemented in many countries, aims at:

(a) simplifying network water balance calculation by monitoring night flows in each district in order to detect unreported bursts and to enable leakage identification and location (using acoustic methods, step tests, etc.);
(b) carrying out pressure management in order to reduce hydraulic head and water leakage;
(c) improving water system management with district hydraulic data continuous monitoring in order to prevent water shortage and to plan better maintenance operations.

In order to perform a water balance it is required the installation of flow meters at strategic points throughout the WDN. In this way MNF monitoring is simplified.

Water district metering can be carried out in different ways and with various partitioning levels: in particular, WDM can be 'permanent' or 'temporary', with reference to time duration, and can have different sizes as a function of its specific objective (network management, water balance, pressure regulation, etc.).The best results in leakage monitoring can be achieved by defining a small permanent district, called District Meter Area (DMA). Depending on the characteristics of the network, DMAs maybe supplied by single or multiple feeds, may flow into adjacent DMAs or be self-contained. The fewer the flow meters the easier and cheaper the calculation of DMA water balance is; this can be obtained by using boundary valves to reduce the number of pipe connections according to hydraulic constraints and performance. Indeed, for each district, there is a cost to purchase, install and maintain the equipment and, with an equal number of DMAs, it is better to have the lowest possible number of flow meters. The best condition would be to have one single inflow meter for each district so as to make it easy for the operator to calculate the synchronous water balance. DMA planning is simpler for branched networks and is much more complicated with looped networks that are typical of residential areas. Permanent WDM changes the original topological layout of water systems and reduces network water pressure, especially during peak demands.

In the present work a number of permanent DMAs realized on real WDNs in the Ambito Distrettuale Sarnese-Vesuviano of the Campania Region are analysed in order to investigate the relationship between the MNF and the DMA characteristics (first of all the number of users). The generalization of obtained relationships can improve our capability of estimating water losses in a DMA and then to perform strategies for water losses reduction.

2. Case studies data: analysis and results

The DMAs considered in this study are characterized by a number of users ranging about 600 to 23000. Demands and pressures data considered are referring to the winter period, from September to February, and to solely weekly days. Data are recorded continuously with a mean interval time of 1 hour.

Water demand has been represented dimensionless (Eq.1) by means of the demand coefficient CD (t):

$$\mathrm{CD(t)} = \frac{\mathrm{Q(t)}}{\mu_{\mathrm{Q}}} \quad (1)$$

where μ_Q is the mean water demand of the examined period and Q(t) - the value of water demand at time - t.

The study of the water demand of aggregate users, as in the case herein proposed, requires a trade-off between the need of characterize the water requirement as close as possible to the real consumption by considering a shortest interval time and the necessity of recording and collecting a big amount of data. Several contributions (i.e. Alvisi et al. 2014; Gargano et al., 2017; Moughton et al., 2007; Vertommen et al., 2005) are reporting the incidence of the interval time of discretization on the water demand estimation. Tricarico et al. (2018) and Gargano et al. (2016), showed the importance of considering a short interval time, ranging among 1-10 min, for studying the probability of null water demand (F0) in reference to a number of users ranging in between 500-1250, being for greater intervals the F0 almost null.

Despite of this, Water Companies, have the need to manage a big amount of data and then the assumed sampling interval time is usually of the order of 1 hour. In order of modelling the water demand for practical application, thus, it is necessary to estimate and characterize the water demand at hourly time step. In this case it will be almost impossible, even for the lower number of users of the examined range, to detect an hour of the day in which there is the probability that a user is not requiring water, even more when the number of users increases. Under this consideration, it is of interest to model the hourly minimum consumption at varying the users number.

A mean leakages value can be estimated, for any DMA, by subtracting the averaged billed flow to the mean input flow. Nevertheless, the considered DMAs were characterized by an high leakage level due also to the high pressures present in the systems. Because of this, in some districts a Pressure Reduction Valve (PRV) has been introduced and a deep study on the flow-pressure Water Utility data has been done in order to estimate the leaks value in the analysed period and their daily patterns, which varies with the pressure regulation value (Figure 1). The PRV is regulating the pressures over the 24 hours of the day, by reducing them during the night time. The result of this is evident in the plots of Figure 1 in which the losses flow is lower during the night time than the daily one.

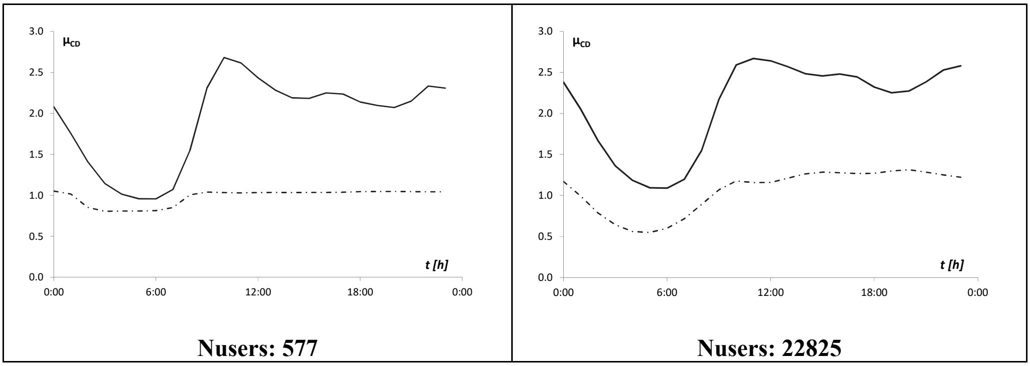

Figure 1 - Example of mean measured daily CD pattern (-) and leakage flow pattern (-·-) for two DMAs with PRV for a different number of users

Fig. 1 - *Patter del coefficiente di domanda (-) e di perdita (-·-) per due DMA con PRV in funzione e per un differente numero di utenze*

The same proceed has been undertaken also for DMAs in which the PRV is not present but a measure of pressures at each t interval time [h] is available (Figure 2). In these cases, as expected, the losses flow during the night is higher than during the day time, not being the pressures regulated by a PRV.

The consideration of leakages variation in function of the pressures has been demonstrated, in these specific case studies examined, of particular relevance in order to detect the water losses accurately. In fact, it is not possible to consider the water losses constant and equal to the mean leakages value in case of PRV regulation being the night water loss reduced and in case of DMAs without regulation, as shown in Figure 2, it could lead to an underestimation of the leakages during the night and an overestimation of leakages during the day.

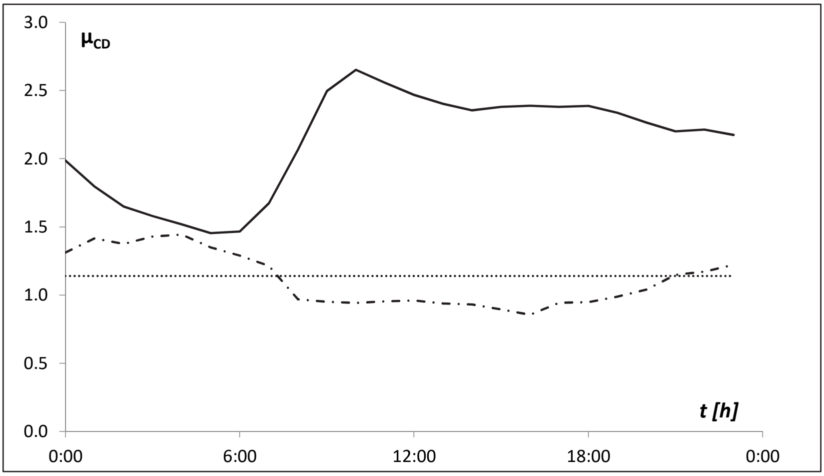

Figure 2 - Example of mean measured daily CD pattern (-) and leakage flow pattern (-·-) for a DMA without PRV (702 users). Comparison of the leakage flow pattern (-·-) with the constant leakages estimation (····)
Fig. 2 - *Patter del coefficiente di domanda (-) e di perdita (-·-) per un DMA senza PRV per un numero di utenze pari a 702. Confronto tra il pattern di perdita variabile con la pressione (-·-) e il valore costante di perdita (····)*

Once leakages for all DMAs have been estimated, data recorded have been cleaned from the water losses in order to estimate effectively the users water requirements. The cumulative density function (CDF) of the mean demand coefficient CD in the analysed period for the three different DMA has been analysed in Figure 3, by comparing the behaviour of the CDF when leakages are present and when they have been cleaned from the data, i.e. No Leakages (NL).

Furthermore, the residential minimum consumption data have been deeply analysed and the mean value of the minimum CD recorded in each day of the examined period (μ_{CDmin}) has been plotted at varying the users number (Nusers), i.e. for the different DMAs analyzed, and it is reported in Figure 4.

The minimum demand coefficient is increasing with the number of users, as it was expected. For the analyzed DMAs, the experimental data show the trend proposed in relationship (2) with R^2=0.92:

$$\mu_{CDmin} = 0{,}035\ N_{users}^{0{,}25} \qquad (2)$$

The proposed relationship can allow the estimation of the legitimate users night flow consumption, by knowing only the mean inflow at the DMA and the number of users.

It is worth noting that if the water losses were considered constant during the day and equal to the mean leakages estimation, the minimum CD value for the DMA of 702 users was greater, by moving from about 19% of the mean flow (circled point) to 32% (squared point in Figure 4).

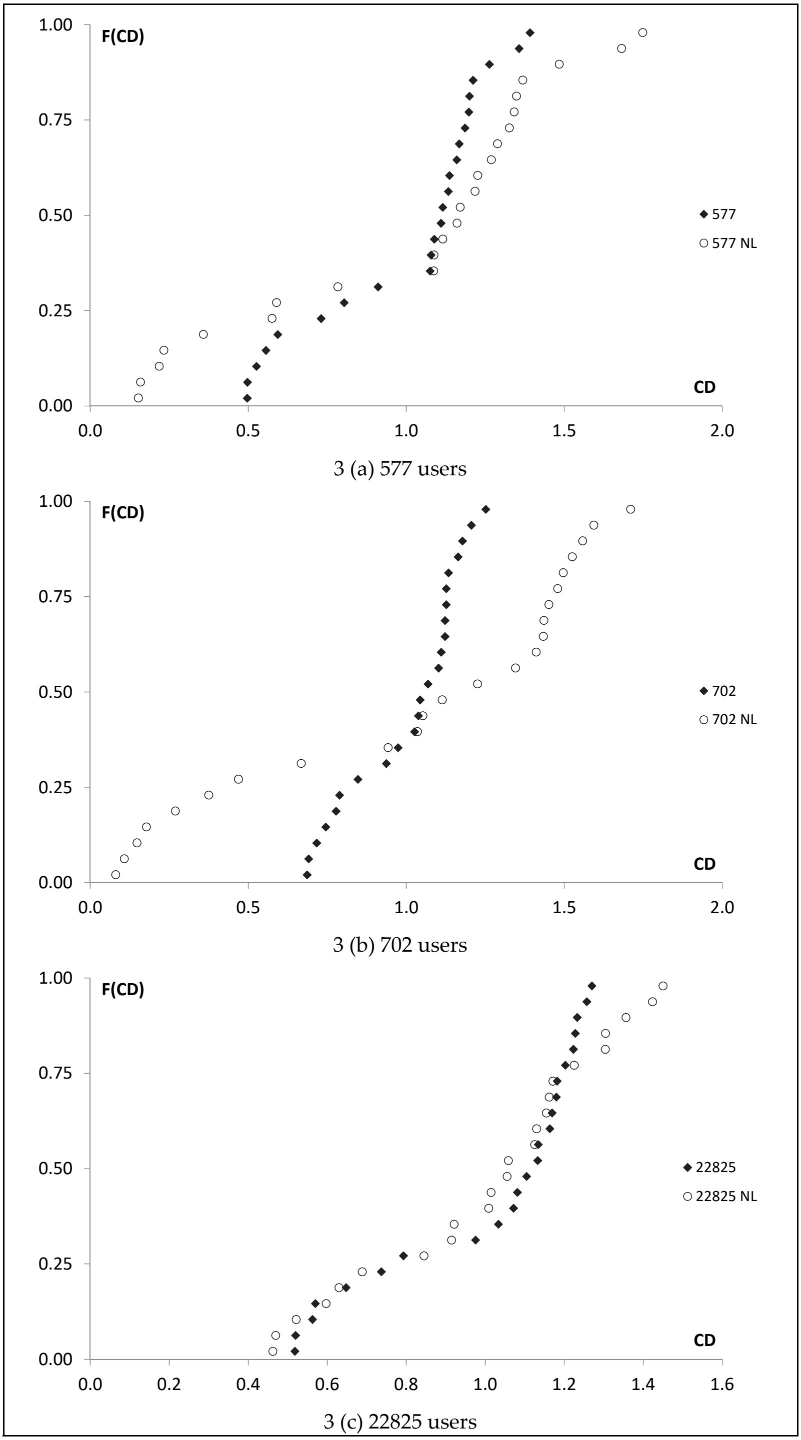

Figure 3 - Comparison of CDF of the mean CD at varying the number of users with and without leakages (NL)
Fig. 3 - *Confronfro delle funzioni di distribuzione cumulata del valore medio del CD al variare del numero degli utenti serviti e in presenza o meno delle perdite (NL)*

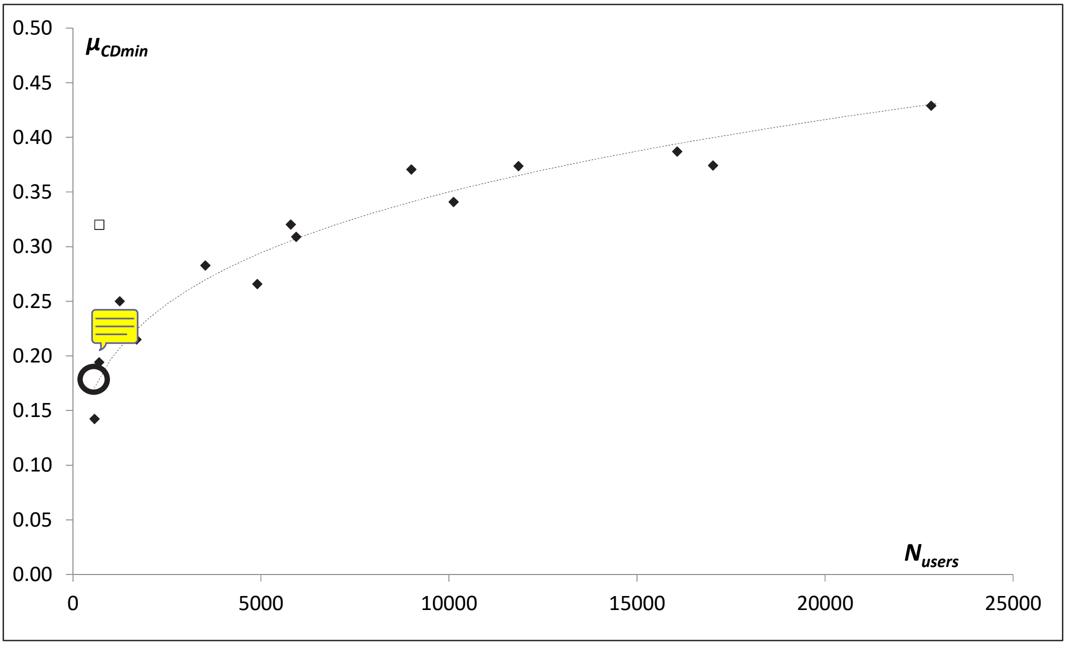

Figure 4 - DMA mean CD minimum (μ_{CDmin}) at varying the number of users
Fig. 4 - *Andamento del valore medio dei minimi coefficienti di domanda (μ_{CDmin}) al variare del numero di utenti per i DMA considerati*

3. Conclusion

Leakages estimation are of particular importance for WDNs management. In the present study a deep analysis of leakages estimation in function of the pressure variation in 14 different DMAs of the Napoli Province, with a number of users ranging in between 600-23000, has been investigated. Winter weekly water demand data at hourly time step have been analyzed and the hourly minimum consumption at varying the users number has been modelled. For the number of users investigated, a relationship for the minimum legitimate consumption in function of the users supplied has been proposed. The knowledge of the legitimate minimum residential consumption is of great interest for the leaks quantification, being usually known from the water companies solely the total flow supplied to the urban area during the different time of the day.

In order to analyse in depth this topic and overcome limitations of deterministic study, a probabilistic approach and a larger number of DMAs should be investigated.

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