

Application of water consumption smart metering for water loss assessment: a case study

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ABSTRACT

Thanks to the advancement of ICT technology, water consumption smart metering is nowadays becoming more popular. Indeed, smart meters can provide several advantages to a water utility such as an easier definition of the bill cost, detection of losses within the buildings and evaluation of leakage rates at DMA level. This paper focuses on this latter aspect, and an application to a real case study is described. It refers to Gorino Ferrarese (FE, Italy), where no tanks are present and where the water balance for leakage assessment between smart metered users water consumption time series and net DMA inflow time series is performed. Sensitivity of the procedure to the lack of different numbers of user water consumption time series is also evaluated. The results highlighted that, for the case study considered and with proper selection of the users, just monitoring 60% of the users would lead to an error in the estimation of the daily total water consumption, and thus in the closing of the water balance, lower than 2%. Thus, even without a complete coverage of all the DMA users, water consumption smart metering can represent a valuable tool for water loss assessment.

Keywords: smart metering, losses, water balance

1 Introduction

In recent years, the issue of sustainable water resource management has taken a leading role worldwide because of several concomitant factors, including climate change and population growth, which significantly reduce water availability [1]. Despite this, most of the water distribution networks (WDNs) are excessively aged and affected by very high level of water leakages. Monitoring and control systems are sometimes scarce, and the water saving issue is often disregarded by users leading to unnecessary squandering [2-3]. Evaluation and control of real water losses thus represent an absolute priority in the context of the sustainable management of water resources. In the last decades, different approaches for water loss estimation were proposed in the scientific literature, which can be divided into two main classes, respectively named bottom-up and top-down [4-5]. In particular, within the framework of the bottom-up approaches, it is worth recalling the Minimum Night Flow (MNF) approach [6]. This approach is based on the measurement of the water discharge entering a District Metered Area (DMA), during the night hours, typically between 02:00 and 04:00, when the users' water demand is minimal, the pressure in the system is high and therefore the rate of discharge due to real losses is dominant. This rate is determined as the difference between the measured night-time discharge entering the district and the evaluation of the admissible night-time consumption. Therefore, the accuracy of the estimate of water losses depends directly on the accuracy with which the users' admissible night-time consumption is evaluated. On the other end, within the framework of the top-down approach it is

worth recalling the Water Balance (WB) method which typically allows evaluation of water losses on longer time horizons. Indeed, with the WB method, (physical) water losses are defined as the difference between the inlet, consisting of the discharge entering the DMA, and the outlet, evaluated as the sum of apparent losses and authorized consumption [7]. Clearly the knowledge of the authorized consumption depends on the planning of the water meter readings, usually performed by Water Utilities (WUs) mainly to fulfill, four-monthly or six-monthly, the billing of consumption [8]. Consequently, under these conditions, it's possible to achieve an estimate of the water losses level on a long term scale, and not in real time. However, thanks to the advancement of the ICT (Information Communication Technology) sector, water consumption smart metering nowadays is becoming more popular in the integrated water services field. Indeed, these systems can provide various operational benefits to the Water Utility managers, including the real-time monitoring of water losses, both at the DMA level and at the individual user level. In fact, first of all, smart meters allow for an easier definition of the bill of each user, being the information regarding the total amount of water consumed by each user collectable via GSM or wireless technology, without requiring a technician to periodically read the meters. Secondly, a continuous monitoring of the water consumptions of the users can be used to make the user itself more aware of the amount of water she/he is consuming, leading to a potential water saving [9]. The user water consumption time series provided by smart meters can also be used to detect the presence of losses within the buildings (i.e. downstream the meter itself) [10]. Finally, if all the users of a WDN or a DMA are monitored, the corresponding time series can be used to evaluate the leakage level within the WDN or DMA, being the net inlet to the WDN or DMA monitored too. In fact, by comparing the WDN or DMA inlet time series with the time series obtained by summing up the time series of all the users obtained in real time by the smart metering system, leakage level can be assessed in continuous, being the water storage within the WDN or DMA known. Given its very nature, the water balance approach done considering that all the users within the DMA are monitored lead to a very good/exact water loss estimation. However, it's also worth noting that situations can occur in which, operationally, the WB cannot be closed exactly due to the shortage of information about some users due, for example, to a failure of some smart meters or of the system used to transfer and collect the data. In this case, there is the need to evaluate the entire water consumption on the basis of the water consumption calculated by monitoring only a fraction of the users belonging to a DMA. It is also significant to note that although smart metering systems for water consumption are developing and becoming increasingly popular, to set up such systems Water Utility managers have to face the problem of replacing thousands of old volumetric meters, which involves field operations, long times and high costs. Therefore, a Water Utility managing a large water distribution system featuring thousands of users and tens or hundreds of DMAs, likely cannot replace simultaneously all the meters but has the to plan campaigns for their replacement. In this circumstance, it could be interesting for the Water Utility manager to understand whether, for the same investment and number of meters to be replaced, it would be more convenient, for example, to replace all the meters of a DMA or replace half of the meters in two distinct DMAs. Indeed, in the first case, the Water Utility manager could exactly close the WB in a single DMA, whereas in the second case he/she could close the WB in two DMAs, event though with some (minor) error degree.

This study is within this context and aims to assess the accuracy of a WB obtained by monitoring only a fraction of users belonging to the generic DMA, with the goal of establishing, with reference to a specific case study, some rule of thumbs which could be useful to the Water Utility manager for

the planning the water meters replacement. The subsequent sections of the paper refer to the real case study of Gorino Ferrarese (FE), a DMA monitored in the research project, funded by the European Community, Green-Smart Technology for the sustainable use of water resources in buildings and in urban area (GST4Water).

2 The case study

The case study considered refers to the WDN of Gorino Ferrarese (FE), managed by CADF S.p.A.. This network serves a small town placed in northern Italy and specifically in the easternmost part of the province of Ferrara. It has an extension of about 3 km² and supplies about 650 inhabitants, corresponding to a total of 293 users, of which 276 are residential and 17 belong to public, commercial and touristic activities. The entire WDN is over 9 Km long and from the hydraulic point of view, consists in a DMA (Figure 1) that is supplied at a single point where discharge and pressure are monitored. Within the DMA there are no tanks.



Figure 1. Layout of the WDN of Gorino Ferrarese (FE). The red triangle indicates the point where the DMA's inlet discharge and pressure are monitored

In spring 2016, CADF S.p.A. carried out the replacement of traditional volumetric meter devices with electromagnetic smart meters. The installation of these smart meters allowed to undertake a data collection campaign, making use of a Remote Meter Reading (RMR) system in walk-by mode and of the ability of the smart meters to perform an internal data logging. Therefore, from July 2016, the 1-hour time step time series of the totalized volume of water required by each user were acquired. In particular, in this study the times series recorded from 7 August 2016 to 7 January 2017 were employed. The time series of the water discharge entering the entire DMA was monitored too at hourly time step for the same period.

The consumption of all users during the considered period was around 20,000 m³, and about the 90% of this volume was due to the residential users. Besides, for the same DMA, the annual water consumption of each user in the year previous the observation period (i.e. in year 2015) were available. Usually, this latter information is collected by the operator throughout the WDN, regardless of the presence of smart metering systems, for billing consumption. In particular, also in

2015, public, commercial and touristic activities have contributed to the entire consumption of the DMA with a quite low component (9.3%), of which the 82% is essentially attributable to 3 users (a soccer field, a restaurant and a hostel).

3 Methodology

Different methods were considered in order to evaluate the possibility for the WDN operator to carry out the monitoring of the water consumption of a fraction of the users belonging to a DMA, and at the same time obtaining an accurate evaluation of the consumption of all users (thus closing the WB with sufficient accuracy). Each method was obtained by combining two consecutive operational procedures. The first one concerns the selection of the users to be monitored, the second one the evaluation of the total consumption of all the users of the DMA starting from the knowledge of the consumption of only the selected users measured in real time.

The evaluation of the error, committed by evaluating the consumption of all the users with each of the developed methodologies, was carried out varying the number of users selected. In particular, the average absolute percentage error (MAPE) was calculated, both for the evaluated trend of the hourly discharge of all users and for the evaluated trend of the daily consumption.

Specifically, as regards the selection procedure, fixed the percentage of users to be monitored P (that is assuming to monitor a certain number n_p of users), three different methods were considered to decide where the smart meters should be installed. The first selection method, indicated below with SM1, involves a random selection within the entire pool. The second selection method, indicated below with SM2, involves the choice of users who, regardless of type, presented the highest consumption in the previous year, considering them the more representative of the total consumption of the DMA. Finally, the third selection method, indicated below with SM3, considers the selection of all commercial and public users, considering them as similar from the consumption behavior point of view, and completes the percentage of users to be monitored by selecting, in the residential pool, the users with the highest consumption. It's significant to highlight that the methods for selecting the users to be monitored were defined taking into account only the information available to the operator of the WU before the replacement of traditional meters with smart meters (i.e. the user typology and the respective annual consumption billed in the previous year/years).

With regard to the evaluation procedure, the (average) hourly discharge (m^3/s) of the entire DMA Q_h is evaluated starting from the observed time series of the corresponding discharges q_{h_i} of the users with $i = 1 : n_p$ as follow:

$$Q_h = F_a \cdot \sum_{i=1}^{n_p} q_{h_i} \quad (1)$$

where F_a is an amplification correction factor defined as:

$$F_a = \frac{\sum_{j=1}^{n_{tot}} \overline{V}_{y_j}}{\sum_{i=1}^{n_p} \overline{V}_{y_i}} \quad (2)$$

in which $\sum_{j=1}^{n_{tot}} \overline{V}_{y_j}$ represents the average annual water volume of all the n_{tot} users of the DMA,

calculated taking into account the annual consumption billed in the previous year, while $\sum_{i=1}^{n_p} \overline{V}_{y_i}$ represents the average annual water volume of the n_p selected users, similarly calculated taking into account the annual consumptions billed in the previous year.

Finally, as regards the assessment of the goodness of the evaluations, the average absolute percentage error *MAPE* is used. *MAPE* is evaluated both at hourly and daily level as follow:

$$MAPE = \frac{1}{n} \cdot \sum_{k=1}^n \left| \frac{x_k^{obs} - x_k^{eval}}{x_k^{obs}} \right| \cdot 100 \quad (3)$$

where n is the number of observed data (i.e. the number of elapsed hours or the number of elapsed days from 7 August 2016 to 7 January 2017), x_k^{obs} represents the observed variable (the hourly (average) discharge or daily (consumed) volume of all users of the DMA) and x_k^{eval} represents the corresponding variable but evaluated with the methods described above.

4 Analysis and discussion of results

The approaches considered for the selection of users (SM1, SM2 and SM3) were applied to evaluate the total consumption of the DMA with percentages of monitored users ranging from 10% to 90% with a 10% step. Table 1 shows the results obtained in terms of MAPE concerning the evaluation of the hourly consumption for the various selection methods and percentages of monitored users.

Table 1. MAPE values for the evaluation of the hourly consumption (average discharge) of all the users.

Selection Method		% of monitored users									
		10	20	30	40	50	60	70	80	90	100
SM1	mean	30.2	22.2	17.5	14.2	11.6	9.4	7.7	5.6	3.3	0.0
	min.	23.5	18.2	14.5	12.5	10.1	7.3	5.7	3.9	2.2	0.0
	max.	47.9	30.9	22.0	16.8	14.2	12.0	10.8	9.9	7.7	0.0
SM2		24.7	15.9	11.9	8.6	5.6	4.0	2.5	1.5	0.6	0.0
SM3		27.3	14.3	11.4	8.2	6.1	4.0	2.7	1.5	0.7	0.0

In particular, with reference to the SM1 the random selection (and consequently the evaluation procedure) was repeated 100 times and in Table 1 the mean value of the MAPE made in the evaluation of the hourly discharge of the entire pool of users together with the minimum and maximum values are reported. For example, randomly selecting 60% of users, the MAPE concerning the evaluation of the hourly discharge is 9.4% and varies between a minimum value of 7.3% and a maximum value of 12.0%. More generally, regardless of the adopted method for the selection of users, as expected, MAPE value decreases as the number of users monitored increases. Instead, with specific reference to selection methods, SM2 and SM3 approaches give significantly better results than SM1. For example, considering the monitoring of 60% of users for both the SM2 and SM3 the MAPE is around 4%, while considering the SM1 and the same percentage of monitored users the MAPE is on average around 10%. This result emphasizes that the selection of users on the basis of information connected to them is more appropriate in order to obtain a more accurate WB. On the other hand, SM2 and SM3 provide quite similar results being the percentage of monitored users the same. This can be explained considering that the most important commercial users are not only included in the SM3, where all the non residential users are automatically included, but also in the SM2, being their consumption very high. In fact, in 2015 the 3 commercial users with the highest consumption (the 82% of the total consumption of all commercial users) are the same 3 users with the highest consumption of all 293 users.

Similar considerations can also be developed by analyzing the MAPE values on the evaluation of the daily volume by all the users, reported in Table 2.

Table 2. MAPE values for the evaluation of the daily volume of all the users.

Selection method		% of monitored users									
		10	20	30	40	50	60	70	80	90	100
SM1	mean	12.2	9.8	8.1	6.7	5.4	4.4	3.7	2.5	1.3	0.0
	min.	6.3	5.4	5.0	4.6	4.1	2.9	2.0	1.1	0.6	0.0
	max.	33.2	21.2	13.1	10.4	8.4	6.9	7.1	6.4	5.6	0.0
SM2		15.4	10.3	7.6	4.6	2.6	1.7	0.9	0.6	0.4	0.0
SM3		9.0	4.6	5.3	3.6	2.0	1.3	0.8	0.6	0.4	0.0

Specifically, it is worth observing that at daily level, the monitoring of the 60% of users on the basis of the approaches that consider the annual volume in 2015 (SM2 and SM3) allows to obtain a very good estimation of the daily volume/consumption of all the users, being the MAPE lower than 2%. Indeed, Figure 2 shows, for sake of example, a one-month time series of the daily volume entering the DMA (in magenta) and the corresponding times series of the daily volume/consumption of all users obtained by summing up the volume time series of all the users of the DMA (in blue) and the daily volume/consumption of all users evaluated considering 60% of users selected with the SM3 method (in green).

It's clearly obvious that the monitoring of the 60% of users allows to evaluate the total consumption of the DMA correctly, and then, through the implementation of the WB method, an accurate evaluation of the water losses can be performed. Actually, in the time period between 7 August and

4 September 2016, a water loss level of $1.55 \text{ m}^3/\text{h}$ was observed in the WDN, and more or less the same value would be obtained by evaluating the consumption of all users with the SM3 method ($1.60 \text{ m}^3/\text{h}$) when 60% of users is considered.

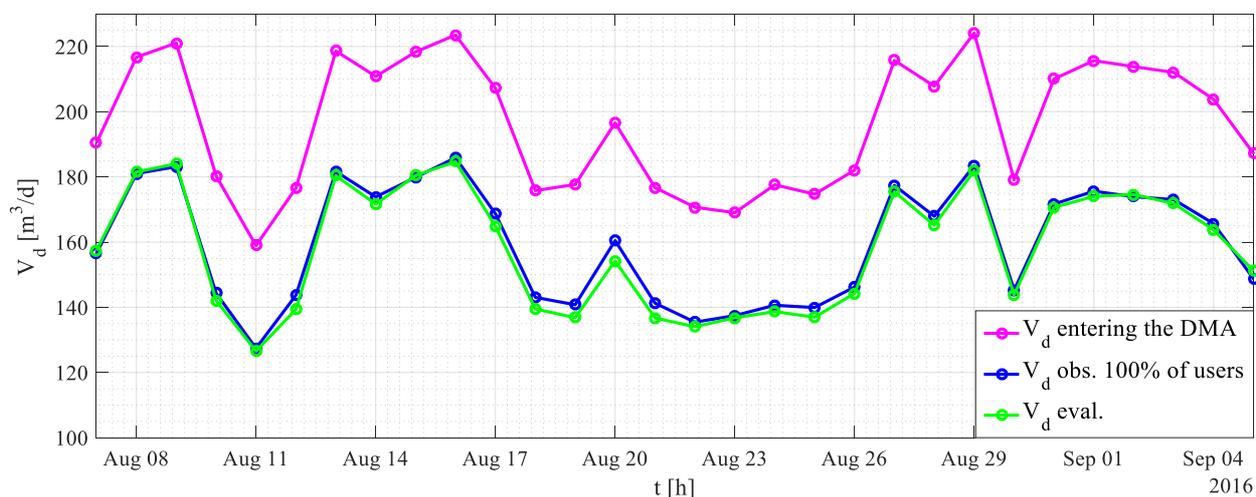


Figure 2. Comparison of the time series of the daily volume V_d entering the DMA (in magenta) and consumed by all the users of the DMA, observed (in blue) and evaluated considering the 60% of users selected with SM3 method (in green).

5 Conclusions

In this paper, with reference to the real case study of Gorino Ferrarese (FE), benefits achievable by the use of smart meters for the DMA water loss assessment are considered. In particular the attention is focused on the error done in the evaluation of the total volume/consumption of the district, and thus in the assessment of the water losses, when the consumptions of only a fraction of all the users belonging to the district are monitored through smart meters. Various methods for evaluating the total volume/consumption were developed, where each method consists of a) a selection procedure of the users to be monitored and b) an evaluation procedure of the volume/consumption of the entire district using only the volume/consumption of the selected users. The selection methods are based on a random approach or on information typically available to Water Utilities such as type of the user and previously billed volumes. The results show that selection of users on the basis of their characteristics (type and annual billed volume), compared to random choice, allows to reduce significantly the error that is committed on the evaluation of the volume/consumption of all the users. In particular, it was observed that being the users properly selected, monitoring of nearly one half of them can lead to quite a good estimation of the total volume consumed by all the users of the DMA. Indeed, by monitoring the 60% of the users, mean percentage error in the evaluation of the (average) hourly discharge and daily volume/consumption, around 4% and 2% are obtained, respectively. Clearly, it follows that, by applying the methods developed, it's possible to obtain a good evaluation of the WB, and therefore of the water losses, in the face of a real-time monitoring of a fraction of users belonging a DMA. These results can

represent a useful support to the Water Utility managers to plan the campaign for the replacement of traditional meters with new smart meters in other DMAs.

6 References

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