# Analysis method for apparent losses estimation and identification of technical solutions

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## Summary

This paper aims to demonstrate that through the practical application of advanced methodologies, a significant improvement in the efficiency of distribution systems is not only feasible, but can also provide an example to encourage other utilities to improve their performance. This paper suggests a procedure in which the IWA terminology, the results of field and lab tests, and statistical analysis of meter performance data can be considered jointly with the analysis of demand profiles and numerical models in order to investigate possible mitigation measures for the reduction of apparent losses. The analysis starts from the assessment of potential impact of apparent losses and then, by means of a numerical model, the priorities in the substitution of water meters are suggested. The methodology has been successfully applied to an Italian case study. In addition, the UFR (unmeasured flow reducer) - a device that causes water to go through the meter in batches at flows below the minimum accurately measured flow – has been comprehensively tested in the field. Unrecorded consumption at low flow rates can be evaluated and financial benefits of UFR installation calculated, as part of meter replacement investment strategy.

## Introduction

Water utilities install and maintain domestic water meters but so far in most utilities customer meters are replaced on a run-to-fail basis, as there is not yet a mandatory requirement to replace the water meters. As a consequence residential water meters' park is quite old and inaccurate (Arregui et al., 2005; Arregui, 2007). The international and national literature review demonstrated that there has been limited research to determine optimal replacement for water meters (Davidesko, 2007; Omundsen, 2008; Ferréol, 2005). However, available literature did influence the methodology of the project, including the selected test-flows, and the way in which the data was analysed (Davis, 2005; Feldman, 2007). There are several possible reasons leading customer water meters losing their efficiency, some of which are: meter wear and tear, demand profile or demand type problems. Ageing or an excessive abrasion of meter moving parts often lead to under-register; private roof tank interposed between the customer meter and the points of use modify the standard demand profile of domestic users laminating the instantaneous water demand, reducing the flow rates passing through the meter and so increasing metering errors. In short, while water thefts, meter reading and billing errors are directly related to water utility management and may be removed by improving company procedures, water meter inaccuracies are considered to be the most significant cause of apparent losses and the hardest to quantify and reduce (Rizzo and Cilia, 2005). Moreover, the presence of local tanks may affect apparent losses to the point that the simple meter substitution cannot solve the problem.

This paper initially investigates the financial implications to late replacement which adversely affects capital investment, compromising economic viability of proactive replacement programmes, and raising the cost of water service provision. Then, by means of a mathematical network model and an experimental network, the paper suggests the priorities in the implementation of the replacement strategy and the installation of UFR.

## The case study

The study was carried out on a small district metering area which is part of the distribution network of Palermo (Italy) (Figure 1).

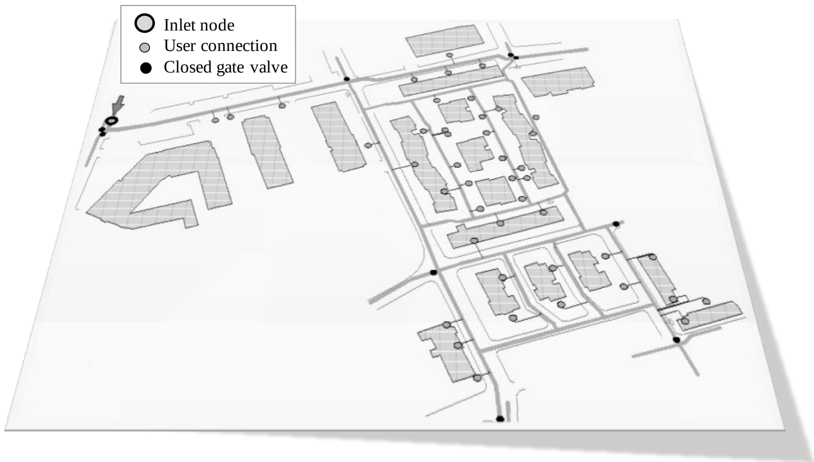


**Figure 1.** The district metering area: a schematic depiction of the network

The monitored network consists of polyethylene pipes with diameters ranging between 110 and 225 mm and of 44 service connections that supply a total of 164 end-users. All end-users have previously installed private tanks downstream of the revenue water meters because the water supply was intermittent in the past. All user flow meters present in the district are multi-jet, all having a diameter of 13 mm. It was globally monitored for about three months (Dec. 2009 – Apr. 2010) by installing an electromagnetic water meter and a pressure gauge in the inlet node to measure the input volume and pressure of the system with a temporal resolution of 30 minutes. Noise loggers and night flow analysis were adopted to check real losses in the district and the results indicated that real losses were practically equal to zero in this system. The user water meter age, obtained by the water utility, is between 1 and 45 years. The 1-10 years old meters are included in class C and the 10-20 years old meters in class B (ISO 4064, 2003). Data about water meters and users demand patterns were used for the initial analysis of the impact of water meters replacement strategies. In order to calibrate the network model, a complete data set about the pressure values on the meters was measured (given by the installed pressure cells every 30 minutes). A continuous data set about the total water volumes passing through each meter with a temporal resolution of 30 minutes was obtained by combining meter readings, the daily pattern of the water flowing into the district and the missing data replacement methods.

## Review of in-service domestic meters

Multiple data types are required for this evaluation, including: meter error tests with low, medium, and high flows for meters; percentage of time residential customers use water at the low, medium, and high flow rates by season; nominal residential meter replacement cost; annual average residential water use per customer; and residential water rates, etc. The database of water meter related to the test area was provided by

Utilities staff for analysis. The database consisted of the 163 meters DN 13 produced by various manufacturers and placed in service from 1965. In order to carry on the research, all the 163 meters in the test area were removed and tested for accuracy. In order to have the calculations with the lowest uncertainty, the selection must take into account the influent criteria affecting the accuracy of a water meter such as: brand and mark of the meter, age, consumption and agressivity of the site where the meter has been installed. The average nominal service life for these meters range between 3 years to 45 years.

The accuracy of a water meter is a function of the circulating flow rate. Therefore users' water consumption in the analysed area was monitored after the substitution of the meters by means of electronic flow meters and data loggers. The figure 2 shows the average consumption pattern for the analysed users.

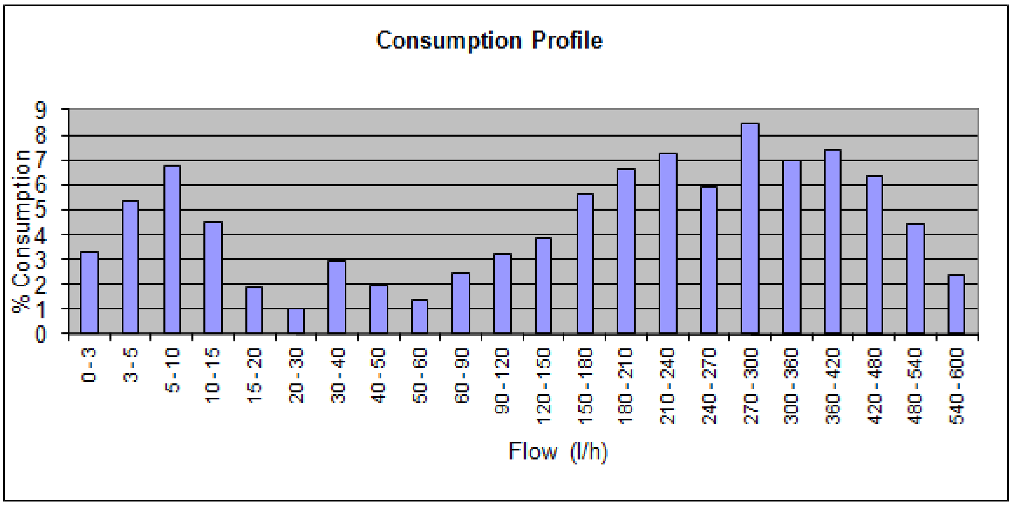


**Figure 2** Consumption profile according to flow rate category for a residential consumer

This chart, called the pattern of consumption, shows a high percentage of consumption at low flows as in Palermo most customers have roof tanks. According to the tested flow rates, the meter gives its answer in term of which percentage of the volume it can measure. Therefore the error of the meters at different flow rates can be calculated. Therefore we need to calculate the efficiency which corresponds to what the meter can measure when it sees a certain pattern of consumption. It is the "multiplication" of the error curve by the pattern of consumption.

Accuracy tests were conducted at low, medium, and high flows as established by Water Meter testing standards for this size meter according to EN 14154-3 (2005).

In addition for each tested meter the Start-up Flow rate has been measured in order to quantify the volume of water delivered to client, which is not measured at all.

As a meter has an error depending on flow rate, it is important to look at the consumption of a user by representing it according to ranges of flow rates and indicating for each range the proportion of water which is passing. By doing this, it gives a weight for each flow rate interval.

The Average Weighted Error (AWE) of each in-service meter was calculated and is reported in Figure 3. AWE combines the different flow rate errors that are measured for each in-service meter and combines these into one, weighting the relevance of each flow by taking into account the Domestic Water Usage profile shown in Figure 2. In regards to leaks and low flow rates that are not measured, this quality can be defined mainly through the Start-up Flow rate (Qa) that is the leftmost point of the error curve. It can be defined as the value of the flow rate that generates motion in the meter when the mechanism is at rest. The start-up flow rate of existing installed meters is a function of the volume registered since they have been installed (that is directly related to age), type and class of the meter (Figure 4).

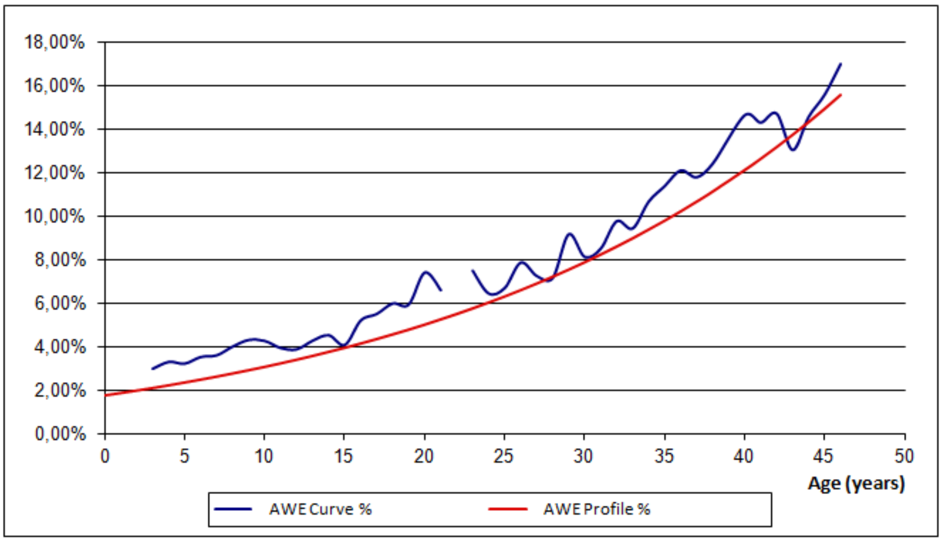


**Figure 3 Average** Error curve for a residential consumer in Palermo case study

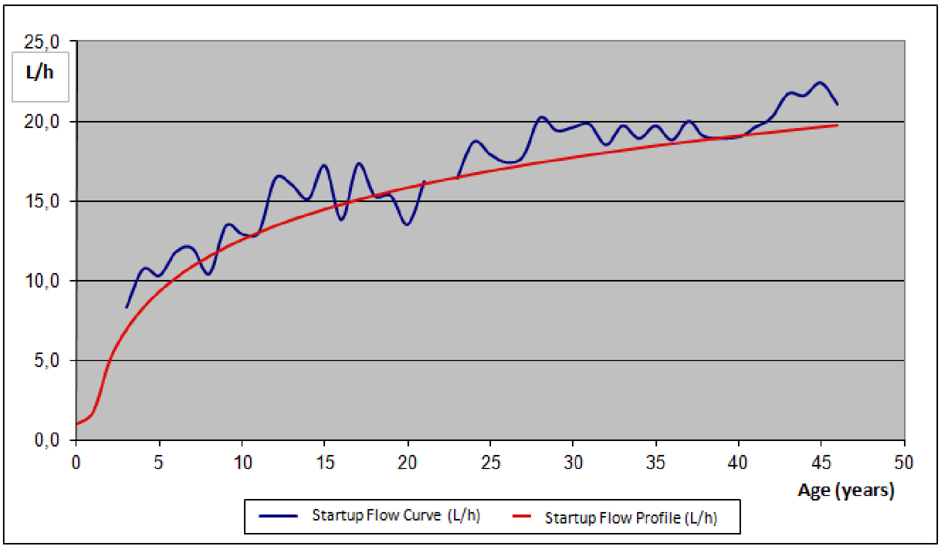


**Figure 4** Start up curve for a residential consumer in Palermo case study

But it is also important to take into account the error at the low flow rate and particularly when the flow rate is between Qa and Q1. Then the error curve is generally stable in time at medium and high flow rates. By combining the Patterns of consumption with the Ageing laws, we can calculate the evolution in time of the water meters park efficiency according the influent criteria. The analysis demonstrates that starting flow increases significantly in the first 10 years of water meter life. This increment can be relevant for the presence of local tanks that increase the percentage of consumption at low flows. For this reason, the replacement of meters only when are clogged or considerably old or used (high volume) is a policy that is admissible only in those utilities with low price of water and metering costs to be kept very low. Anyway, this low profile policy will lead to significant meter errors and, as a general rule, to a mediocre control of consumption. In fact, in many developed countries, due to national or local regulations, meters must be checked and eventually replaced after a certain period of time. However a replacement policy should be based on a revenue loss/gain calculation based on deterioration of meters accuracy, meter replacement costs and economical data such as sale price of water, etc.

## The application of a numerical model

The previous analysis is able to evaluate the effectiveness of meters replacement strategies and the timing for the substitution but a deeper analysis is needed to investigate the effect of local tanks and possible alternative solutions for apparent losses reduction. For the analysis of such complex networks, common network models have to be modified to take into account the presence of the tank and the float valve that progressively reduce inflow volume while the tank is filling. Before entering the tank, the node outflow passes through the water meter being measured. The model has to compute the measured flow depending on the actual transited flow based on meter characteristics mainly dependent on age.

The model is based on the combination of the tank continuity equation, the float valve emitter law and the measuring error equation. Details about the model can be found in Criminisi et al. (2009). The model is also able to simulate the presence of devices, such as the pulsing valves, that are able to reduce apparent losses. The pulsing valve UFR (Unmeasured Flow Reducer produced by A.R.I.) is a smart and simple product, installed on the water main (In-Line), adjacent to the water meter, which regulates the water flow so that there is no water flow at all through the UFR part of the time, while the rest of the time, the flow is high enough to be measured by the water meter. The operating range of the UFR is between 0 and 25 l/h in order to impact both the flow rates below Qa but also a significant part of the flow rate between Qa and Q1. When the flow rate increases over the maximum value of the operative range of the UFR, the UFR remains permanently open, so that it does not interfere with measurements (Cohen, 2007).

## Results and Discussion

The initial status analysis showed very high apparent losses in each service connection except in those where the water meters were quite new (Figure 5). This result may not be only originated from metering errors, so it highlights the significant effect of the tanks and the low network pressure on the apparent losses.

Initially the UFR installation was modelled without substituting the water meters in order to evaluate the impact of the device on the present condition. In this phase, the model results show some issues that were suggested by the analysis of the field measures: the UFR devices produce a relevant effect only on the water meters that are characterised by low starting flow. Figure 6 shows that, after UFR installation, the apparent losses dramatically decreased (lower than 10%) where water meters were quite new; elsewhere the decreasing was less clear.

Finally, the phase in which all the meters were replaced was analysed. Figure 7 shows that the level of the district apparent losses was physiologic, being globally equal to 5%. Furthermore, two different zones can be identified in the network: the lower zone, where higher pressure turned into higher flow rates passing through the meters, and then into lower apparent losses; and the higher zone, where lower pressure and flow rates caused great metering errors.

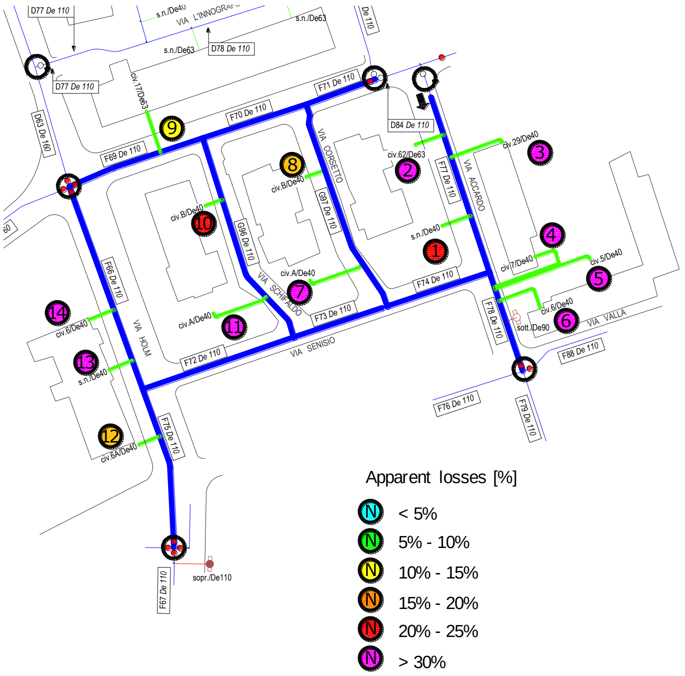


**Figure 5.** Apparent losses in the district service connections: initial status

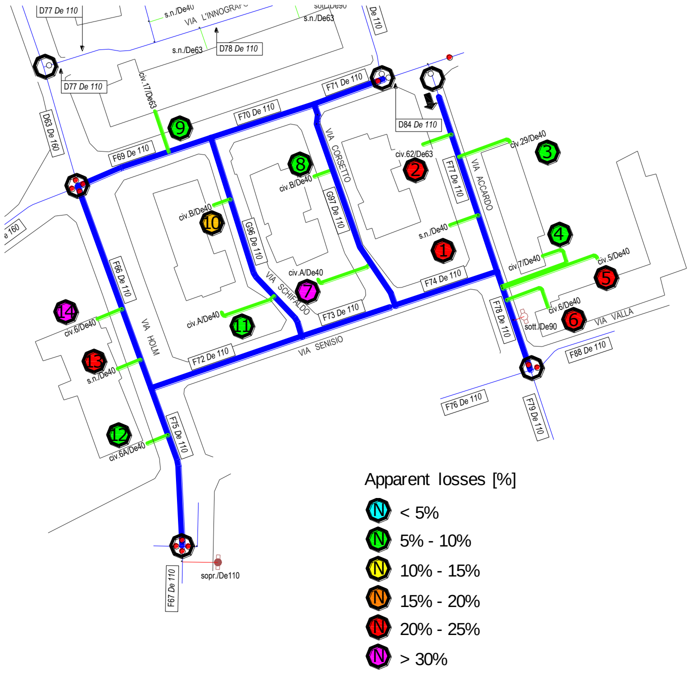


**Figure 6.** Apparent losses in the district service connections after the UFR installation

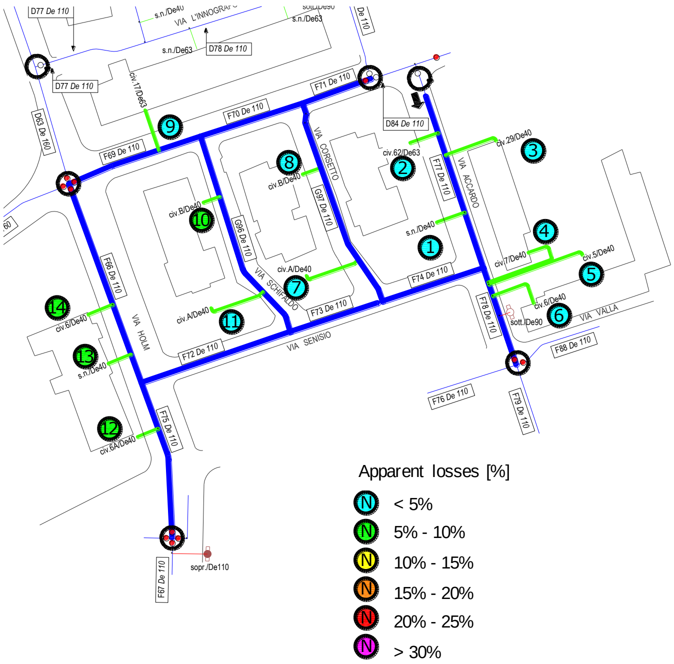


**Figure 7.** Apparent losses in the district service connections after the substitution of all the meters

The modelling approach was efficient enough for analysing the complexity of the real system and was an useful method to examine the networks and to highlight the areas where apparent losses may be high. Furthermore, the model may foresee the effects of meters substitution plan or of the installation of such devices that, as the UFR, reduce the effect of the tanks on the amount of apparent losses due to meter under-registration. A final analysis was performed by simulating the presence of new flow meters without the presence of the UFR. The analysis showed that the total apparent losses in the district increased from 5.5% to 9.5% showing that the 4% of apparent losses is strictly due to the presence of the local tanks. Such losses are not avoidable by means of flow meters substitution strategies and require the adoption of additional solutions such as the UFR.

## Conclusions

Universal metering has been in place in most utilities in many countries since the 50'. Nevertheless since now meters were mostly replaced only on a run-to-fail basis.

This paper demonstrates that through the practical application of advanced methodologies, the prediction of system-specific economic meter replacement policies is feasible as well as a significant improvement in the efficiency of distribution systems. The moment when a meter is changed is an ideal one to install the UFR as well, as we know that even new meters do not measure very low flows and as meter Start-up Flow rate increases over meter life. In addition, installation costs are kept to a minimum in case of simultaneous installation.

The study highlights the complexity of the problem studied that may sometimes cause a considerable impact on the utility's economic balances, requiring immediate measure. This complexity reflects on the choice of the solution to adopt:

- The sole meter substitution may produce results lower that expectations depending on the network pressure and the private tanks (the apparent losses were higher than 10% of the system input volume in some service connections);

- The installation of the UFR device shows significant effects when water meters are not very old (from 10 to 15 years old), but provides limited benefits when metering errors are very high, especially at low flow rates;
- The modelling approach, as that presented in this paper, may help to identify the priorities of action during the planning phase and to evaluate the effect of each measure before its implementation.

Following the above it is expected that water utilities become more sensitive to the water metering issue and that meters management policy would be modified to include economic evaluation.

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