Reducing Apparent Losses Caused By Meters Inaccuracies

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Abstract Apparent losses caused by meters inaccuracies can be reduced by analysing meters performance in the water supply and identifying the main causes of inaccuracies. These can have its origin on the meters design and accuracy curves, users' consumption patterns, or specific characteristics of the water supply system.

Keywords Apparent losses, water meters, water meters performance.

1 INTRODUCTION

Every volume of water delivered to a customer, that is consumed and not registered, is supplied by the water company free of charge. In such cases, the utility receives no economic compensation for the service provided. This unaccounted volume of water may have an important impact in the company water and economic balance.

Water meters inaccuracies are considered to be a significant component of the apparent losses in a water supply system (Rizzo and Cilia, 2005). However, there may be several sources that contribute to the total apparent losses. The IWA/AWWA water balance divides this concept into three components: theft water, billing anomalies and data handling errors, and metering errors. While the first two components are directly related to the utility customer management, the last component depends on the right choice of the meters technology (displacement meters or velocity meters), the correct sizing and installation of the instruments and the replacement frequency policy followed by the water supply company.

In order to reduce the magnitude of this component an initial analysis of the performance of installed meters should be carried out. This analysis will cover both users' water demand flow rates and meters accuracy curves. Later, once the utility knows those circumstances that affect the most metering efficiency for the particular conditions of the water supply, a correct choice of a water meter technology and replacement frequency can be made.

2 ANALYSIS OF THE ACTUAL METERING PERFORMANCE IN THE UTILITY

The measuring error of a water meter is not constant and independent of the flow rate. For that reason, in order to know which the percentage of the consumed water is registered two parameters are needed (Male et al., 1985; Arregui F.J., 1999; Ferreol E., 2005). The first one is the water consumption pattern of the user which describes the actual flow rates passing through it. The second one is the necessary information about the metrological performance of the meter at different flow rates. The knowledge of these metering errors at key flow rates will allow to reconstruct the accuracy curve in an adequate manner at the minimum cost.

Later these two parameters will be combined to obtain a weighted meter error, i.e. the amount of water that is not registered for every 100 litres of water consumed according to the water consumption pattern of the user. Some authors, instead, prefer to work with the metering efficiency, which is calculated as the amount of water registered for every 100 litres consumed.

When taking to practice this theoretical procedure, domestic and non-domestic users have to be studied in different ways. For domestic meters, the preferred approach is to use statistical tools and to extrapolate results obtained from a representative sample to the rest of the meters and users. On the other hand, industrial users and meters, for their importance, should be studied individually. In any case, independently of how the information about the error curve of the meter and the consumption pattern is obtained, the methodology to follow to calculate the weighted error in both situations is basically the same. For that reason, this paper will mainly focus on domestic meters, knowing that the methodology to obtain the same results for large meters and users is the same with the only difference that in this case the values will not come from a sample but from the specific user/meter under study.

As said before, the large number of domestic users in a utility makes essential to confront the problem from a statistical point of view. Consequently appropriate sampling techniques need to be applied and it is always important to keep in mind that the parameters that are used for the study come from samples. Therefore the results are subject to an uncertainty which be greater or smaller depending on the characteristics of the population and the sample size.

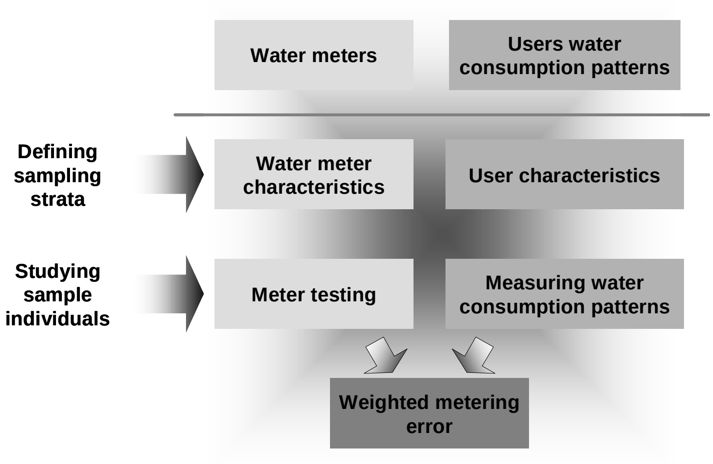

Figure 1. Diagram of the methodology to follow for determining domestic meters performance

A diagram of the procedure for analysing the metering performance of domestic users it is shown in figure 1. First of all, the population of both meters and users should be stratified according to a certain characteristics that can affect metering performance. The objective is to build more homogeneous groups in order to reduce variability and, consequently, the uncertainty associated to the sampling procedure. Afterwards, random samples of each group are selected and studied. In the case of water meters the study of the sample consists of a series of laboratory or field accuracy tests. On the other hand, the study of the users consists of a continue measurement of its water consumption to determine the actual flow rates passing through the meter.

Determining domestic water consumption patterns

Several studies have been published to date on the determination of domestic consumption patterns. One of the most significant (Bowen et al., 1993) was published by the AWWA Research Foundation. The project carried out continuous measurements of consumption in 706 households located in five US cities. However, even for this sample size, no significant conclusions were extracted from this study about variables, others than household characteristics, which may affect consumption flow rates like occupancy or climate characteristics.

The authors (Arregui et al., 2006) have also carried out water consumption measurements in different cities in Spain and South America. Measurements were made for different types of households in order to identify the consumption behaviour of the users and the flow rates passing through the meters. The results of these measurements have been classified as follows depending on the characteristics of the household:

- *Household Type I*: Apartment blocks with direct injection from the network or a pump. 389 households were monitored for an approximate time period of a week.
- *Household Type II*: Apartment blocks fed from an elevated tank (at the top of the building). Water meter is installed upstream the tank. 58 households were monitored for a week.
- *Household type III*: Independent houses with garden. The summer consumption was monitored for over 4 weeks in 34 households.

Table 1. Typical consumption patterns for different household types

Flow rate	Type I	Type II	Type III
0-12 l/h	4,7%	10,0%	2,7%
12-24 l/h	2,8%	3,1%	1,9%
24-36 l/h	1,9%	1,8%	1,6%
36-72 l/h	4,3%	4,2%	4,5%
72-180 l/h	8,5%	11,6%	5,7%
180-1500 l/h	75,7%	69,3%	63,6%
1500-3000 l/h	1,9%	0,0%	17,3%
>3000 l/h	0,2%	0,0%	2,7%
Average consumption	Aprox: 500 l/day	Aprox: 500 l/day	Aprox: 1.200 l/day

Although the above values (Table 1) can be used as a reference it is strongly advisable to determine for the specific characteristics of the households in the water supply system its associated consumption patterns. For this task, and depending on the funding available, households can be stratified according to the characteristics previously described. Another parameter that can be used for the stratification of the households is the monthly volume of water consumed. It easy to realize that it has a strong influence in the consumption flow rates distribution (Arregui, 1999).

In any case, the most important value to look at in a water consumption pattern is the volume consumed in the lower range which frequently establishes the accuracy in the measure as well as the total amount of water consumed in a reference period of time. Any external element that changes the flow rate distribution in the lower range will influence the capability of the meter to accurately register water consumption.

Amongst the elements affecting the volume of water consumed at low flow rates, two of them stand out: private domestic storage tanks (Figure 2) and leaks inside the households, usually in faucets and toilets (Figure 3). Frequently, as seen in figure 2, the filling of the tank is produced through a proportional ball valve which laminates the instantaneous water demand and reduces the circulating flow rates through the meter.

Figure 2. Private storage tanks on the roof of the buildings.

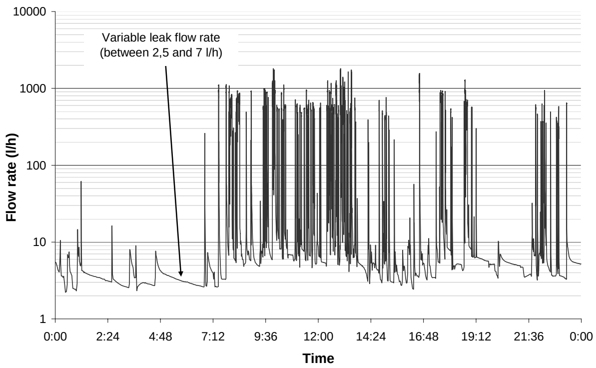

Figure 3. Leak flow rates in a household during a day.

For an accurate determination of water consumption patterns for domestic users many delicate elements need to be considered. Following, some of them are highlighted:

- The stratification of the population of users should be done carefully. Variables that may influence water consumption at low and high flow should be identified and strata should be created consequently. When selecting the samples, households should be selected randomly in each stratum.

  Usually (not always) a sample size of 50 for each category, as long as they have sufficient homogeneity, will provide results with an acceptable uncertainty. Obviously the larger the sample the smaller the uncertainty associated to each consumption pattern. In an ideal situation, a utility would constantly measure water consumption patterns of their users, adding new registers to a data base. That way, in a few years, with a relatively small investment the company would have available reliable data about its domestic users. However, frequently most utilities try to determine this parameter at once, in just one study, which obviously have severe implications in its reliability.
- During the study an adequate instrumentation for measuring water consumption patterns of domestic users should be employed:

- o Displacement meters, with a low start-up flow of 1 l/h. Velocity meters are not suitable for this type of study. For large non-domestic users a water meter with a good sensitivity at low flow is also required.
- o Electronic meters or water meters equipped with pulse emitters with sufficient resolution and robustness. For domestic users the minimum resolution is 0.1 l/pulse.
- o Data loggers with enough memory capacity to store water consumption during a week.

- The measuring equipment should remain installed for sufficient time, especially in the presence of leaks. The minimum recommended time is a week.

Determining domestic water meters error curve

The other parameter that can affect the percentage of registered volume besides the consumption pattern is the error curve of the meter. Its shape and degradation rate defines the capacity of the instrument to measure water volumes throughout its life. Not all metering technologies (not even all meters with the same technology) have the same rate of decay of the accuracy with time. Additionally, external parameters such as the quality of water may influence each model in different ways. The error curve, and the way it evolves, must consequently be obtained for every meter type and utility specifically.

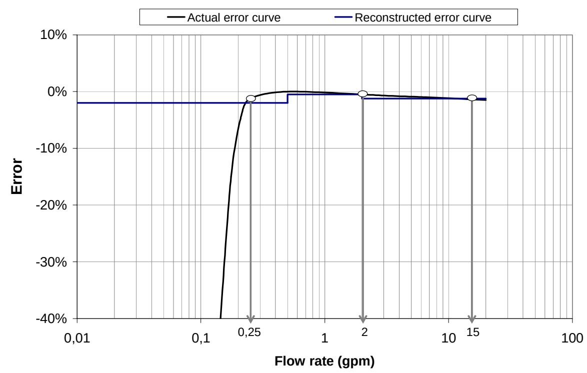

Figure 5. Reconstructed curve following AWWA recommendations

However, obtaining the error curve is not easy. The number of tests needed to obtain a highly defined curve is too large and the process too costly. For that reason meters should be tested only for a few selected flow rates which will allow reconstructing the rest of the curve. The selection of these flow rates is often overlooked despite its importance (Allender H., 1996; Yee M.D., 1999; Davis S.E, 2005). Figure 5 shows the original and the reconstructed curve of a meter following the AWWA-M6 *Water meters selection, installation, testing and maintenance* recommendations. As it can be seen, for low flows, the reconstructed curve is quite different to the actual error curve for that meter.

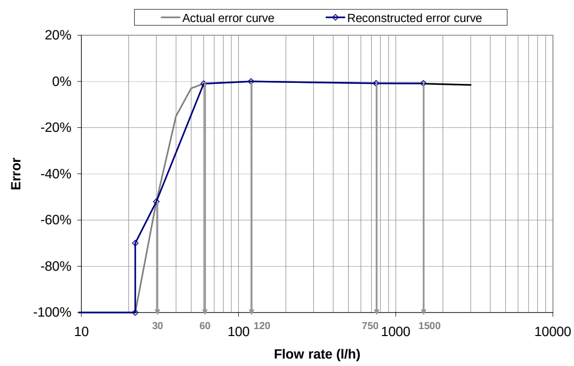

Figure 6. Reconstructed curve of a 1.5 m^3/h, class B meter

In order to correctly reconstruct the error curve in this range it is important to know or closely estimate the start up flow. It is also recommended to test the meter at the minimum flow rate (ISO-4064:1993) and at another flow rate between the minimum and the transitional values. Finally and taking into account that the consumption flow rates for domestic users (except for those with outdoor use) rarely go above 1500 l/h, and that the error at medium and high flow rates is almost the same, tests at 750 and 1500 l/h would be enough. It can be considered that the error from that flow rate onwards remains reasonably constant up to the maximum flow. The errors at all other flow rates may be obtained by a linear interpolation between the available points. Figure 6 shows the reconstruction of the error curve of a meter using the described methodology, which reproduces the real curve, at low flows, much more accurately than the previous procedure.

Once the test flow rates have been selected, the sampling must be planned in order to limit the uncertainty to a desired level while covering the different models and ages groups of the tested meters. It is important to always bear in mind that the results obtained for the error curve of domestic meters will always originate from a sample of meters, and the conclusions are always estimates with associated uncertainties that should not be forgotten. The details to calculate these uncertainties can be found in any book of statistical inference (Terriel and Daniel, 1994). As a general rule it can be said that: 1) the larger the sample the lower the uncertainty and 2) the lower the variability of results the lower uncertainty.

From the accuracy tests carried out by the authors it has been checked that variability at low flows is much greater than at medium and high flows. Consequently the uncertainty about the real performance of meters at low flows will always be greater than at higher flows.

Calculating how accurate the meters are

Once the users' consumption patterns are known and the error curve of the meters has been reconstructed for each stratum, it is possible to determine the percentage of the actual water consumption that these meters are registering. This calculation is as simple as multiplying the percentage of water consumed in a flow range by a user and the average error of a type of meter at the medium flow rate of the flow interval. Calculating the weighted error for the meter of Figure 6 and a *Type I household*, the figures in table 2 are obtained.

Table 2. Calculating the weighted error of a meter

Flow rates	Household type I	Meter error (Figure 6)	Registered volume
0-12 l/h	4,7%	-100%	**0,00%**
12-22 l/h	2,3%	-100%	**0,00%**
22-24 l/h	0,5%	-68%	**0,16%**
24-36 l/h	1,9%	-52%	**0,91%**
36-72 l/h	4,3%	-11%	**3,83%**
72-180 l/h	8,5%	0%	**8,50%**
180-1500 l/h	75,7%	-0.8%	**75,09%**
1500-3000 l/h	1,9%	-0.8%	**1,88%**
>3000 l/h	0,2%	-0.8%	**0,20%**
		Total	**90,6%**
		Weighted Error	**-9,4%**

Since there will be multiple combinations (subgroups) of water consumption patterns and water meter classes they should be weighted appropriately to obtain the final average error of the installed meters. This procedure requires determining the importance –weight- of each group in the total consumption of water. The weighting coefficients could be calculated in a first approach as: 1) percentage of meters in the group over the total number of meters and 2) percentage of volume registered by meters in the group over total registered volume

However, the most accurate method, which considers the different meters sizes, consist of calculating the weighting coefficient for each subgroup, i, based on the percentage of the actual volume consumed by the users of that subgroup, with respect the total volume consumed (adding together all the subgroups).

In order to obtain the actual consumption, the volume registered by each subgroup of meters (i), corresponding to one category of meter and one type of user, is corrected with its weighted error (ε_i) expressed as per unit fraction. As a consequence, the global error for all the meters will be obtained as the ratio between the non-metered volume (or over registered) and the actual consumed volume:

$$\varepsilon_{global} = \frac{\sum \frac{\text{Registered volume}_i}{1-\varepsilon_i} - \sum \text{Registered volume}_i}{\sum \frac{\text{Registered volume}_i}{1-\varepsilon_i}} = 1 - \frac{\sum \text{Registered volume}_i}{\sum \frac{\text{Registered volume}_i}{1-\varepsilon_i}}$$

Identifying variables that increase apparent losses due to meter under-registration

From a rigorous field study of water consumption patterns of users and actual performance of installed meters, through a meter testing program, it is possible to identify which variables affect more severely water registration efficiency. Only when these variables are known, measures to reduce apparent losses due to meters under-registration can be undertaken.

For such purpose, and in order to improve metering efficiency, it is essential to know the metering technologies available in the market nowadays and to choose the one that suit best the specific characteristics of the utility and its users. Details of different variables that can affect water meters performance can be found in Arregui et al (2005, 2006).

For the utility it is also very important to know, from the accuracy test of the meters, how and why the installed meters in the water supply are failing. That way, it is possible to reduce these specific failures in the future. Among the different variables described in these works which contribute to increase metering error the following can be highlighted:

- Water consumption patterns. As said before, a favourable consumption pattern, with negligible consumption volumes at low flow rates, will allow to maintain in service a water meter for a longer period of time and to improve accuracy. On the contrary, an unfavourable consumption pattern will increase metering error and meters replacement frequency. Additionally a consumption pattern with high flow rates, close and above the maximum flow rate of the meter, will degrade it at a faster rate.
- Water quality. Velocity meters and displacement meters are both affected by water quality, specially in the case of presence of suspended solids and depositions build-up. The actual effect of water quality is difficult to predict in advance and has to be tested for the real conditions of the water supply system.
- Environmental conditions. Meters installed outdoors are subject to extreme weather conditions. High temperatures may deteriorate plastic components and even deform them. On the other hand, low temperatures, below freezing, may increase the pressure inside the meter above the maximum allowable value.

- Mounting position. Some velocity meter may deteriorate more rapidly if they are not installed in the correct position.
- Velocity profile. Velocity meters are influenced, in a higher or lower degree depending on the design, by flow profile distortions upstream the measuring element.
- Seasonal water use. Some water supply systems have a seasonal water use, for example, small towns which are only occupied during summer vacations. In these utilities, meters remain stopped between eight or ten months a year.
- Tampering. Not all meters can be manipulated as easily and some meters are protected against tampering more effectively than others.

Since the combined effect of all these variables is difficult to quantify for a new meter, it is always recommended that the water company carries out field and laboratory tests of the different acceptable options to examine, previous to a universal installation, the actual metering performance. These tests should reproduce, for at least a year or two, the future working conditions of the meters in the utility in order to have a real estimation of which will be the initial and over time performance.

Besides the field and laboratory tests commented, other investigations to determine the water meter performance, based on the customer information systems, can be carried out (Arregui et al. 2003). This tool will allow to extend the sample under study to a large numbers of meters, since it only requires from the customer data base, information that has already been introduced in it, like the monthly registered volume, accumulated volume, installation date, type of user, etc. Making the appropriate queries in the data base a performance comparison between meter models can be obtained without the need of further tests or water consumptions measurements.

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