Tools for improving decision making in water meter Management

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Abstract
Too often, data regarding water consumption patterns of the users and the results from the meters metrological tests are stored in databases designed for other purposes. This way, calculations about the real performance of the meters are not easy or even possible. Furthermore, engineers have many different methods to obtain the real performance of the meters, being some of them not adequate. A software tool, Woltmann, specially designed to improve water meter management has been developed at the ITA in Valencia. One of the main features of the software is the standardization in the weighted error calculation that it provides. A free Lite version of it will be soon available for download which will help in making unbiased comparisons regarding apparent losses between different water companies.

Keywords: apparent losses, water meter management, weighted error

Introduction
Water meter management requires the knowledge of the real, in field, metrological performance of installed meters. This parameter can only be determined knowing the consumption characteristics of the users and the error curves of the meters in use. Managerial decisions adequacy will strongly depend on how accurate the estimations of the real metrological performance of the meters are.

A good estimation of the real accuracy of the meters will always require a vast amount of data collected on a continuous basis. These data should characterize both, the consumption patterns of the users and the error curves of the meters. In practice, the problem comes from the number of different types of customers and meters that can be found in a water supply. For example, customers can be stratified according to the consumption sector – domestic, commercial, industrial and institutional -, the activity within the sector, the hydraulic characteristics of the facilities and the water use. Moreover, domestic customers can be further classified according to their expected annual income, the number of people that live in a house, the use of the house (main house, vacation, weekend), the type of house, etc.

It is easily understood, because of the number of stratums, that to obtain reliable information about all the different types of water consumption patterns a huge amount of field work has to be carried out. Large customers have to be measured individually, on a periodic basis, while domestic customers have to be studied using a statistical approach. In any case, a considerable number of measurement files have to be stored along with any additional information that may be useful for the analysis in the future (customer ID, characteristics of the water facility, type of measurement equipment used, etc.).

If this work, to determine water consumption patterns is to be extended in time, which is the only way for obtaining reliable information about the water consumption patterns, a specific database that can store all data and allows for its analysis is needed. If such a database is not available, every new additional analysis will consume an unacceptable amount of resources and results will depend on how the files are processed. Even worse, it is likely that after some time most of these files, and the information related, are lost in some folder of an old computer and cannot be used anymore.

A similar situation occurs with the results of the metrological tests carried out to the meters. After several years of work there maybe thousands of accuracy curves of different meters brands and sizes which were tested under different conditions. Some of them are new meters, tested within the quality control procedures, some others are tested because of a customer's complain, some others come from random samples taken from the field, etc.

The laboratory needs a properly designed database that can store all the data that is required for the analysis of these tests. Specific data about the testing procedure, the technician that carries out the test, the reason why the meter is tested, where it comes from and so on, must be stored. Additionally, in case of failure of the meter, pictures can be of great help to identify the different factors that can affect the metrology of the meters.

Organising meter tests results

Recognising the importance, from a managerial and economical point of view, of determining the metrological performance of the meters procured or installed by a water company, it comes as a surprise that not many of them own a suitable test bench where carrying out the tests. Even worse, many of the companies that have a test bench mostly use it to resolve customers' complaints and not to study the average metrological performance of their meters.

Some companies test all new meters before installation. This practice results in thousands of tests which are frequently stored in massive but simple databases. In these cases, the tests procedures followed are those defined by the standards to check the metrology. Seldom these water companies use specific test procedures designed to determine the real (in field) metrological performance of their meters.

In any case, it is important to take into account that a proper water meter management not only require a test bench for testing the meters. A software tool capable of storing, processing and analysing the results is also essential. Its importance is easily understood considering the limitations of an old paper support database and the human resources and time needed for any type of analysis of such a database. The effort required is enormous and the results will not be reliable. Obviously, this is an extreme example, but it illustrates the day to day reality of many water supplies and the importance of an adequate database.

Summarizing, the problems related to traditional databases to store the metrological tests results come from three sources: 1) limitations on the amount of data that is possible to store in the database regarding the meter, its tests conditions and other parameters that may affect the metrology; 2) the type of queries that can be generated on the data stored, 3) consistency of the data introduced in the database

Too often, the structure of the database in which the tests results are collected is not adequate and is not prepared to save all the data that will be essential in the future to analyse the performance of the meters. Clearly, the information required from a meter that is being tested in a standard quality control test is different from the one that characterizes a meter taken from the field. The first case will only require information about the meter, its technical characteristics and how it is selected for testing. While in the second case, additional information about the place where it is installed and the user is needed to establish the effect of those variables that can modify its metrology. The database should have the flexibility to store the data required in both cases.

Moreover, water meter management is a long term activity and as such should be planned. Hence, one important criterion when designing the database in which the test results will be stored is that it has to be prepared to be used in the future by personnel that did not design it nor have introduced the data in it. For this reason, it has to be capable of storing more information than initially expected. This additional information will allow future users to properly design the queries to identify the variables that affect the metrology of the meters. The meter that best fits the water supply needs will only be found if this complementary information is available.

A final aspect to be considered has to do with the consistency of the database. Very often the names of the manufacturers and meters models are misspelled making more difficult future queries. Some other times, all meters from a manufacturer are stored under the same name, making it impossible to distinguish between models or metrological classes. Other times meters errors are stored in the database without completely meeting the requirements set by the testing procedures. This is especially important at low flows for which a difference of 10% in the tested flow rates can notably modify the error results. Reading mistakes while testing can also alter the final results on the average error for a given meter. It is obvious that there are so many parameters involved in the testing that is essential to check their accuracy before introducing them in the database to obtain reliable results.

To solve the above mentioned problems, a proposal of the minimum fields that is advisable to include in a database where to store the tests results is given:

- *About the testing procedure*
    - Theoretical flow rates for testing
    - Theoretical volume/weight to be circulated during the test
    - Order in which the tests should be performed
    - Flow rate tolerance to accept the test
    - Number of repetitions at each flow rate.
- *Person in charge* of the tests and time and date in which they were carried out.
- *About the tests results*
    - Real volume/weight used as a reference. Water density
    - Duration of the test
    - Meter readings with enough resolution
    - Starting flow rate of the meter
- *Meter information*
    - Serial number
    - Meter model and manufacturer
    - Length, nominal diameter and nominal flow rate
    - Reason for testing. Where the meter comes from:
        - Has it been taken randomly from the field or from a procured lot?
        - Was it selected from a specific user?
        - Was it suspicious of having under or over registration?
        - Does it come from a customer complain?
        - Etc.
    - User ID when the meters is taken from the field, city and installation date
    - Short characterization of the user:
        - Type of user: domestic, commercial, industrial, services,... Considering subgroups of each type it is also advisable
        - Type of user facility: direct connection, private tank, ...
    - Installation position when it was in the field and installation position when it is tested
    - A text field that allow for any comments on the meter or its tests result
    - Pictures of the meter that allow in the future the identification of any problem in the meter design or behaviour.

Although it may be argued that gathering the above information can become impracticable, the truth is that it does not take so much time and the benefits from storing such data are recovered right away. With no doubt, it is much better to have a smaller database with reliable data than having a large database with incomplete data of doubtful precedence. Furthermore, a comprehensive characterization of tested water meters will help in the identification of the parameters which affect their metrology.

Organizing the water consumption patterns

The error curve of a meter is not sufficient to calculate the percentage of water that is registered with respect the amount of water consumed. The weighted accuracy of the meter is the parameter used by engineers and managers to define the performance of a meter when it measures the water consumption of a specific user. It represents the percentage of water that is not registered or is registered in excess for every 100 litres consumed (Arregui et al (2006), Yee (1999), Bowen et al (1993), Male et al (1985)).

The weighted accuracy is calculated by combining the error curve of a meter and the consumption pattern of the user. The consumption pattern of a user defines how much water is consumed at different flow rates. In other words, it gives the probability of a water consumption occurring at a given flow rate.

Typically a water consumption pattern is measured using a reference meter, with an excellent metrology, and a data logger that continuously records the readings from the meter. This generates a considerable amount of data each time a measure is taken.

Water consumption patterns have a great impact on the weighted error of the meters and their degradation rate. In particular, low flow consumptions are extremely important in the calculation and should be measured as accurately as possible. As a result, for the optimization of water meter management, a real need for determining water consumption patterns of every type of user exists. As described in Arregui et al. (2006) water consumption patterns of domestic users have to be established using a statistical approach while more important users have to be worked out one by one.

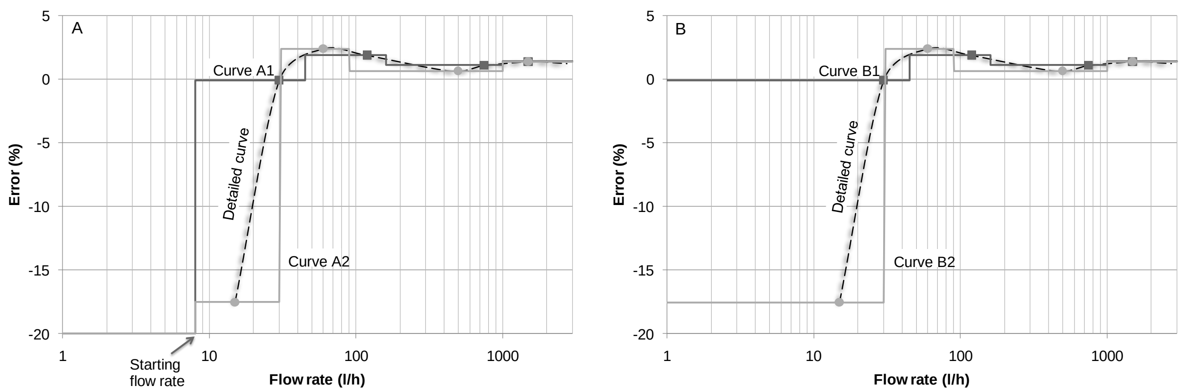
Obviously, good knowledge of water consumption patterns in a water supply requires long time (years) and effort. A huge amount of data will be collected and many people in the company will be involved in the task. It is then necessary that all data is correctly organized and stored in a properly designed database. Moreover, for small users it will be required to combine consumption patterns of different users to obtain an average value. However, most of the software supplied with the data-loggers, used to store the measurements, only allow for simple queries and basic analysis. Frequently these software packages are not even designed to obtain consumption patterns or to combine different measurements to calculate an average value.

Additionally, consumption patterns will have to be combined with the error curves of the meters. Clearly, it seems interesting that consumption information is stored in the same database as the error curves of the tested meters. By doing this, it will be much faster to weight consumption patterns with different error curves.

Again, as with the meter test results, the database in which consumption patterns are stored needs to be capable of recording not only the original measured data, but also additional information regarding the user. Furthermore, it needs to have the enough flexibility to import consumption measures from different commercial data-loggers, and to organize measured data in such a way that it can be easily found and combined with other users' consumption patterns. Finally, information on how measured consumption patterns are obtained should also be stored.

Calculating the weighted accuracy of a meter

The combination of the error curves and the water consumption patterns of the users may appear to be a simple process. However, it can become a complex computation which too often is overlooked and can lead to erroneous results.



Tested Flow rate	Curve A1	Curve B1
Starting flow	8 l/h	-
30 l/h	-0.10%	-0.10%
120 l/h	1.87%	1.87%
750 l/h	1.08%	1.08%
1500 l/h	1.38%	1.38%

Tested Flow rate	Curve A2	Curve B2
Starting flow	8 l/h	-
15 l/h	-17.54%	-17.54%
60 l/h	2.38%	2.38%
500 l/h	0.65%	0.65%
1500 l/h	1.38%	1.38%

Figure 1. Two methods of reconstructing the error curve of a meter

In first place, it should be considered that for practical reasons the complete error curve of a meter will never be obtained (for example the detailed curve in Fig. (1)). Instead, meters are error tested at specific flow rates, which are defined in the testing procedures developed by water companies. Thereafter, the unknown detailed error curve of the meter is reconstructed from that information. Fig. (1) shows two different methods of reconstructing the error curve, considering a starting flow rate for the meter (Fig 1.A) or not (Fig 1.B), and two different set of tested flow rates (curves A1 and A2).

The quality of the reconstructed error curve will depend on:

- The adequate selection of the testing flow rates. As depictured in Fig. (1), the reconstruction of the original curve is unequivocally different depending on the flow rates that are tested form the original (detailed) curve - for example, curve A1 versus curve A2.
- The shape of the error curve. Flatter curves are much easier to reconstruct.
- The consideration or not of the starting flow rate of the meter. Often, many testing procedures do not include the determination of the starting flow rate of the meter. In these cases a method to estimate its value should be developed to reach an accurate value for the weighted error - for example, curve A1 versus curve B1.
- The reconstruction method from the known errors at limited flow rates. In the cases presented in Fig. (1) a reconstruction procedure similar to the one recommended by the AWWA (1999) is followed.

The associated weighted error for each reconstructed error curve is calculated by combining it with a water consumption pattern, for example the one presented in Fig. (2). In this case a wide variety of results are obtained. As seen in table 1, the differences found in the weighted errors are significant. These differences are of great magnitude, especially when considering that all weighted errors come from the same original data: the detailed error curve in Fig. (1) and the water consumption pattern of Fig. (2). In fact, an absolute difference of 5.13% is found between the weighted error associated to the detailed curve (-4.33%) and the curve B1 (+0.80%).

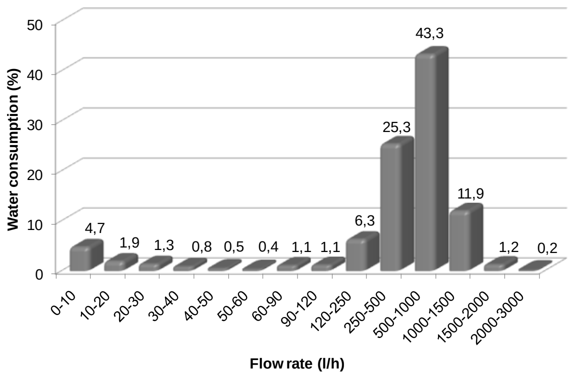


Figure 2. Typical consumption pattern of a domestic user

Table 1. Weighted errors associated to the different reconstructed curves and the water consumption pattern in Fig. 2

Curve	Weighted Error
Detailed	-4.33%
A1	-2.72%
B1	0.80%
A2	-3.75%
B2	-0.66%

From these results an important conclusion arises: **a standardization of the methods used to calculate the weighted accuracy is needed**. This standardization should comprise the selection of the testing flow rates and the reconstruction and weighting methods. Otherwise, it will not be possible to compare data, referred to the apparent losses, from different water supplies.

To help towards this standardization a specific software package, Woltmann, has been developed. Among the capabilities of the application it incorporates a module designed to weight the error curve of a meter and an associated water consumption pattern.

For the example presented, Woltmann has been used to calculate the weighted error of the meter in Fig. (1). Woltmann linearizes the error curve from the available data (tested errors at different flow rates), allowing for a more reliable reconstruction of the curve. The software also includes an algorithm that estimates the starting flow rate of the meter, in case it has not been tested, depending on the error value at low flow rates.

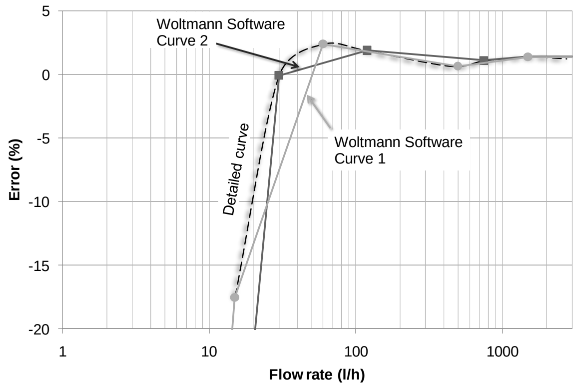


Figure 3. Detailed curve reconstructed by Woltmann software for two different sets of tested flow rates

Table 2. Errors of the meter at different flow rates

Tested Flow rate	Woltmann Curve 1	Tested Flow rate	Woltmann Curve 2
Starting flow*	6.7 l/h	**Starting flow***	8 l/h
30 l/h	-0.10%	**15 l/h**	-17.54%
120 l/h	1.87%	**60 l/h**	2.38%
750 l/h	1.08%	**500 l/h**	0.65%
1500 l/h	1.38%	**1500 l/h**	1.38%
Weighted error	**-4.28%**		**-3.81%**

*Automatically calculated by Woltmann software

Once, a linearized curve is calculated by the software, it combines the curve with the specified consumption pattern of the user. For the two different sets of tested flows, obtained from the same initial detailed curve, the weighted error of the meter becomes -4.28% for the reconstructed curve 1, and -3.81% for the reconstructed curve 2. These results are much closer to the weighted error obtained for the detailed curve than the previous ones presented in Table (1).

Advantages of using a software tool

Numerous advantages arise from using a software package like Woltmann to calculate the weighted errors of the meters:

- A software package like Woltmann forces the Water Company to develop detailed testing procedures and long term planning of the tests, giving higher reliability to the results.
- The same comment may apply for the water consumption patterns determination.
- Additional information regarding both the error curves and the consumption patterns is collected in a structured manner. This allows for the establishment of influence factors on the metrology of the meters.
- The software allows for queries that otherwise would be impossible to perform or would take a very long time to answer them. For example, the software will allow to obtain the average error curve of selected meters models tested between some given dates by a given person, using a specific testing procedure, having a given diameter, length, comment, tag, age, accumulated volume, or any other variables previously defined (22 of them).
- Similarly, an average water consumption pattern of a specific user or a given type of user that meet specific requirements can be calculated.
- Uniform results for the weighted errors are always reached, since they are obtained using the same calculation procedure. The results will not depend on the technician in charge of doing the calculation.
- Prevents mistakes and inaccuracies in the calculations of the weighted error.
- All data needed to perform the calculation of the weighted error of a meter can be stored in the same software package. This way, this data can be easily found and is always available for a new calculation.

An example of how a software tool can be used for meter selection

Although water meter selection strongly depends on the local conditions of the water supply company, a software tool can be of great help in making the correct decision. This paper presents an example of how Woltmann, or any other software tool, may help in the selection of the most appropriate meter, considering the initial performance of the meters.

For this example, it is assumed that the water company is testing a sample of every lot of new meters that is being bought. Four residential water meter models are being procured by the water company, being model 1 a positive displacement meter and models 2, 3 and 4 single jet meters. In this case, the query is simple, and selects the meters tested within a given period of time, of the four procured models having a precise nominal diameter, using the testing procedure defined for quality control. The software will provide the individual and average results of the meters tested in a tabulated and graphical format (Figure 4 and Table 3).

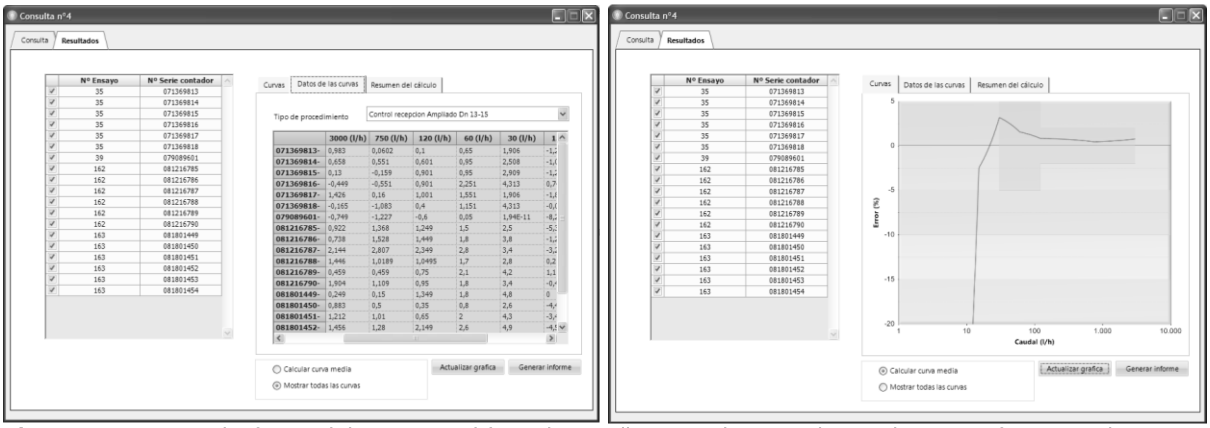


Figure 4. Tests results for Model 2 extracted from the quality control tests using Woltmann software package

Table 3. Average tests results from the quality control tests for the four models under study

	Metro. Class	3000 l/h	1500 l/h	750 l/h	120 l/h	60 l/h	30 l/h	15 l/h	Q_{start}	Acquisition Price
Model 1	C	-0.4%	0.1%	0.6%	1.7%	1.6%	1.7%	1.3%	1 l/h	25€
Model 2	B	0.8%	0.6%	0.5%	0.8%	1.6%	3.2%	-2.7%	5 l/h	18€
Model 3	C	-0.3%	-0.2%	-0.4%	0.3%	0.9%	1.6%	-4.6%	5 l/h	18€
Model 4	B	-0.6%	-0.4%	-0.3%	0.2%	-1.1%	-0.9%	-8.5%	8 l/h	12€

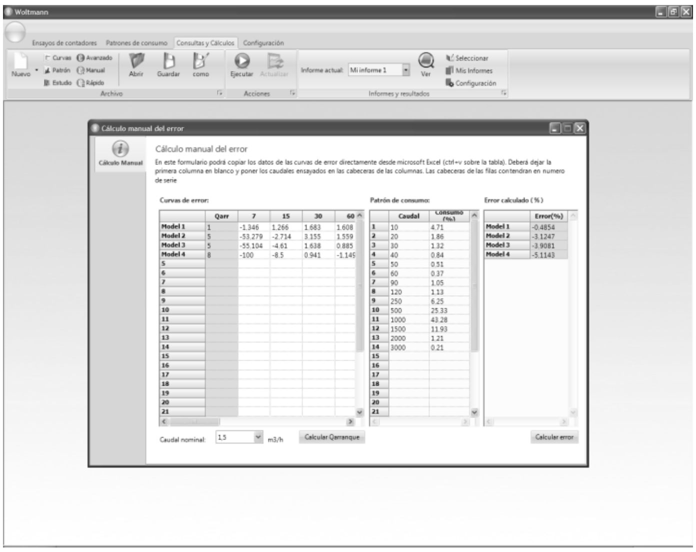


Figure 5. Calculating the weighted error of the four models considered using Woltmann software

The question now is which of the above meters, have the smaller weighted error if the consumption characteristics are those in Figure 2. The software will automatically calculate the weighted error for all of them (Figure 5). Clearly the meter model 1 is the model with smallest error. However it is also more expensive. Will it be worth to buy the meter instead of the cheaper models? The answer to this question is not simple and will only be known with time, after testing meters that have been installed in the field for several years. However, an initial guess can be done assuming the same degradation rate of the weighted error for all meters, 0.7%/year.

For this example, water is being sold at a price of 0.3€/m^3, the installation costs of the meters are 10€, the real discount rate is 3% and the average annual consumption is 120 m^3. Under these conditions the results in table 4 are obtained.

Table 4. Economical analysis of the considered options (0.3€/m^3)

	Optimal replacement	Cost of inf. replac.	Cost after 10 years
Model 1	18.1 years	163.8€	47.0€
Model 2	16.1 years	178.2€	48.1€
Model 3	16.1 years	189.1€	50.6€
Model 4	14.1 years	186.1€	48.3€

Table 5. Economical analysis of the considered options (1.5€/m^3)

	Optimal replacement	Cost of inf. replac.	Cost after 10 years
Model 1	7.7 years	367.4€	94.8€
Model 2	6.9 years	492.4€	128.5€
Model 3	6.9 years	542.1€	141.0€
Model 4	6.1 years	581.8€	153.7€

Although, model 1 seems to be the best option when replaced every 18 years, it should be taken into account that meters using this technology are more likely to get clogged or to stop than velocity meters. Furthermore, the degradation rate for all three meters has been supposed to be the same. It is known that the error of positive displacement meters will always get larger as they get older, while this may not be true for velocity meters (a testing program of used meter is needed to establish the real degradation rate). The risk of choosing model 1 is high and the cost is not significantly lower to assume such a risk. Under this considerations model 2 is a better option, although the real degradation rate of this model should be establish to confirm this selection in the future. Therefore, it seems reasonable to start buying model 2, 3 and 4, do some field testing for two or three years and then, depending on the real performance, proceed with a new economical analysis.

Things would be considerably different if the selling price of water rises to 1.5€/m^3 (table 5). In this case, the cost difference between model 1 and the rest is quite significant and the risk of a greater failure rate can be assumed.

Conclusions

Determination of water meter performance is a task that should be extended in time, continuously testing meters and measuring water consumption patterns. An appropriate database that can store all data and perform the necessary calculations and queries is required to attain the maximum benefit from a very expensive field and laboratory work. These calculations should include at least the weighted error and the optimal replacement period of the meters. The ITA in Valencia has developed a specific software tool that solves most of the abovementioned needs and constitutes a great help in water meter management.

Acknowledgments

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