Evaluating domestic water meter accuracy. A case study.

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Abstract
This paper describes the methodology used to evaluate water meters performance in a Spanish water supply system. During the study 238 meters of two brands were tested in the laboratory at four different flow rates. A detailed analysis of the starting flows was also carried out. For determining the typical water consumption pattern in the city 58 households of different characteristics were monitored. This two parameters were used to calculate meters weighted accuracy and the optimal renewal frequency and average annual costs for both type of meters. Finally a sensitivity analysis established the influence of water and water meter price on the optimal replacement frequency.

Keywords: Water meters management, Unmetered water.

Introduction

To determine, with a minimum degree of accuracy, the water consumption of a user requires to install in each service connection a water meter as well as reading it periodically. One can say, without place to doubt, that they are basic instruments in the management of any water supply. Therefore, in order to maximise revenues, it is essential to maintain from an economic point of view the utility's water meters under the best possible conditions.

As any measuring instrument, water meters are not able to exactly register the total amount of water consumed since they have a limited range of operation. Its performance mainly diminishes at low flow rates, which are in most cases due to leaks in the user's facilities and the presence of private storage tanks. This problem increases with water meters ageing since the accuracy curve decays over time. In some cases the water meter replacement frequency is too low, which leads to highly degraded accuracy curves and considerable revenue losses for the utility as a result of the unmetered water. On the other hand, renewing the meters too often or selecting unnecessary expensive devices will also produce economical losses caused by the fixed costs of the investment.

This paper describes the methodology used to evaluate, in a Spanish water supply system, the performance of the domestic water meters installed in the system. The interest of the study stands on the special characteristics of this water supply with numerous private storage tanks, inappropriate water meter installation, degraded accuracy curves and frequent leaks in the private user's facilities.

The study has been based firstly on the determination of the domestic water patterns, to estimate the percentage of total consumption at different flow rates, and secondly on laboratory test carried out to establish the average water meters accuracy curve.

Combining these two parameters, the water consumption patterns and the average accuracy at different flow rates, it is possible to calculate the weighted accuracy of the water meters used in the utility and therefore the total unmetered water. When information about the weighted accuracy of meters of several ages is also available, an accuracy rate of decay can be estimated which will be used later to assess the optimum replacement frequency of water meters.

Finally an economic decision model was designed to select the appropriate water meter and to establish the optimum replacement frequency based on the specific parameters of the utility studied. The variables considered were the water and water meter price, the water consumption patterns measured in the town, the accuracy rate of decay for the tested models, etc.

Water meters accuracy curve analysis

Sample description

As it is well known, testing every single water meter in the system is the only way to exactly determine the average performance at different flow rates. Obviously, in practice, implementing this task is not feasible for economic reasons and only a limited number of water meters are effectively tested. For this reason, statistically representative samples of each type are selected and conclusions about the population average performance will be extracted.

A randomly selected sample of 238 water meters, installed in diverse municipality zones and household types, was tested in the laboratory. For statistical purposes this sample was divided into two categories, which correspond to the most common model brands used in the system. At the end of the study 191 meters of *model A* and 47 of *model B* were taken to the test bench. Both meter models were single jet and rated as ISO-4064 Class B with a nominal flow rate of 1.5m^3/h. A more detailed description of the sample is shown in table 1, where the meters tested are categorised by model, age and accumulated volume.

Table 1. Sample description by age and meter reading

Model A		***Model B***	
Year of installation	*Number*	*Year of installation*	*Number*
1992	178	1987	16
1993	2	1988	19
1995	4	1989	9
1996	7	1996	2
		1997	1
Total Number	**191**	**Total Number**	**47**

Model A		***Model B***	
Meter reading (m^3)	*Number*	*Meter reading (m^3)*	*Number*
0-300	37	0-300	2
300-600	42	300-600	1
600-1000	49	600-1000	4
1000-1500	41	1000-1500	4
1500-3000	21	1500-3000	31
>3000	1	>3000	45
Total Number	**191**	**Total Number**	**47**

The average age for *model A* meters is close to 10 years while *model B* meters are older with an average age 14 years. On the other hand, when the accumulated volume is analysed, water meters of *model B*, which were installed for a longer period of time, had also higher meter reading.

Laboratory tests results

To precisely assess water meters performance it is necessary to determine the metering accuracy in the whole range of flows. In practice, because of the time require for such a work, it is not possible to test meters at many different flow rates. Hence sampled meters were only tested at very specific flow rates (Arregui, 1999): 30, 120, 750, 1500l/h. Additionally the starting flow rate of each meter was also determined in the laboratory. The flows at which meters are tested are chosen so that its weighted accuracy could be correctly calculated.

Starting flow rate results

Apart from the accuracy at the flows previously mentioned, another essential parameter to evaluate the overall performance of a water meter is the starting flow rate. An in-depth analysis of this parameter was carried out. The tests results, table 2, show a high percentage of blocked water meters at low flow rates, below 30 l/h, mainly from *model A*.

Table 2. Results from the starting flow rate tests

Model	*Completely blocked*	*Blocked at 120 l/h*	*Blocked at 30 l/h*
A	4	7	68
(191 tested)	**2,1%**	**3,7%**	**35,6%**
B	2	2	7
(47 tested)	**4,2%**	**4,2%**	**14,9%**

Table 3. Starting flow rate excluding completely blocked meters.

Model	***Average starting flow rate (l/h)***	***Median starting flow rate (l/h)***
A	30,8	21
B	15,2	10

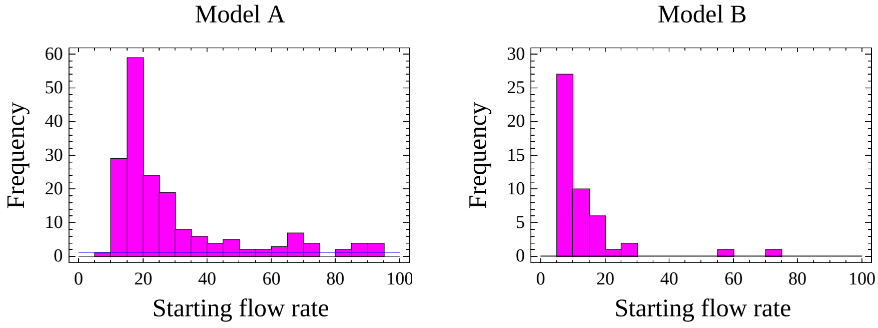

Figure 1. Starting flow (l/h) frequency histogram.

The frequency distribution found for the starting flow is not symmetrical (figure 1) and, in theses cases, the median value is considered to be more representative than the average starting flow rate.

Accuracy tests results

The results of the accuracy tests carried out in the laboratory are shown in table 3. These values have been calculated neglecting those meters that did not start to move at a flow rate of 120l/h which are considered to be blocked. The statistical reliability of the sample was determined using traditional methods of statistical inference (Terriel and Daniel, 1994).

Table 4. Accuracy tests results

Model	*Average accumulated volume*	*A (1500 l/h)*	*A (750 l/h)*	*A (120 l/h)*	*A (30 l/h)*
A	804	**-0,8%**	**-1,6%**	**-4,6%**	**-45,8%**
	Uncertainty (90%)	±0,22%	±0,23%	±1,20%	±4,81%
B	1836	**1,7%**	**0,8%**	**-0,2%**	**-9,3%**
	Uncertainty (90%)	±0,51%	±0,40%	±1,29%	±8,13%

As seen in table 4 the meter accuracy curve of *model A* is much more degraded than the one obtained for model B, even though these meters were installed in the system for a shorter period of time and had a lower accumulated volume. It can be affirmed that *model A* performance is too poor for its age and a better accuracy curve would be expected for this meter. A factor that may have had influence in this high deterioration rate is the installation angle of the device (Arregui, 1999).

Model B presents a lower wear and for medium and high flow rates the metering errors become positive. This effect can be attributed to the system used by the manufacturer to adjust the water meter the accuracy curve, which consists of a by-pass passage that is easily obstructed after a few years of working life. For a given flow, a reduction of the effective section of this passage increases the impact velocity of the water upon the turbine generating a higher rotating speed and consequently positive metering errors.

Accuracy degradation over time

Once the accuracy curve of the sample have been calculated, the next step in the methodology is to estimate the degradation profile at different flow rates, which in this case have been considered to be linear (Figure 4 and 5). This is a common assumption (Allender, 1996; Male et al., 1985) that have been checked to be close to reality in previous studies (Arregui, 2000).

In this case there are no new meters available in the utility so the initial accuracy had to be estimated (figures 2 and 3). The impact of this assumption in the final conclusions is negligible since the accuracy of new meters had to comply with ISO4064 standard and therefore the estimated accuracy at a given flow would not differ much from the real initial accuracy.

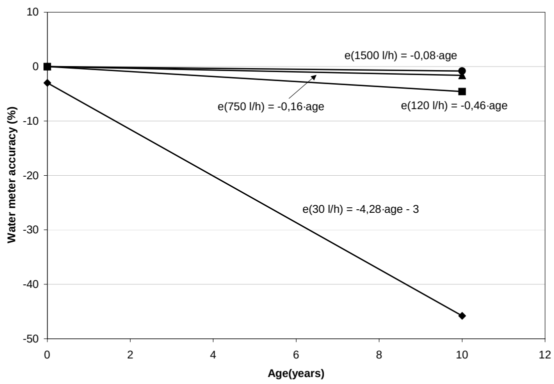

Figure 2. Model A. Accuracy degradation profile at different flows

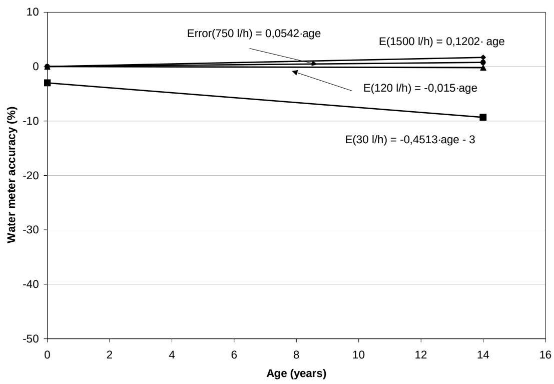

Figure 3. Model B. Accuracy degradation profile at different flows

Water consumption pattern determination

Sample description

Since meters have different accuracies at different flows another parameter required for determining water meter weighted accuracy is the water consumption pattern, which gives information about how much water is used at different flow ranges.

For determining the average water consumption pattern of a typical residential household in this town, a sample of 58 users were monitored. The sample was chosen so that the building and the users characteristics were representative of the city and included detached households with small garden and apartments in buildings with private storage tanks. The users studied were distributed in diverse areas of the system with different pressure levels.

The equipment used for the field work included portable data loggers and ISO-4064 Class C precision volumetric water meters. These devices were able to accurately detect very low flow rates, down to 1 l/h, which are the most important for estimating the unmetered water. Field work started in March 2001 and finished May 2002, generating approximately 900 measurement days.

Water consumption pattern

The domestic water consumption pattern (Figure 4) indicates a high percentage of volume used at low flow rates, 14.9% below 36 l/h. This high value is caused by the frequent leaks that have been detected in private user’s facilities or in the proportional valves installed in private storage tanks. After the field work was finished it was concluded that 42% of the dwellings measured had some kind of leak.

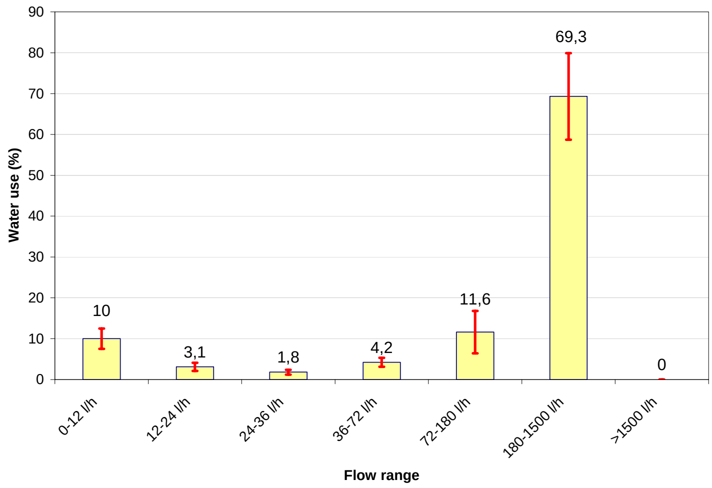

Figure 4. Water consumption pattern (%). Confidence level 90%.

As it can be seen in figure 4 the uncertainty about the average water consumption pattern is low, specially at low flows which are the most important for calculating the weighted accuracy.

Weighted accuracy of water meters

The weighted accuracy of the water meters used in the utility can be calculated combining both parameters (Arregui, 1999), the average water consumption pattern (figure 4) and meter accuracy profiles (figures 2 and 3). The weighted accuracy is the parameter used to estimated the total unmetered water volume over time and the optimal replacement frequency of meters.

Figure 5 shows the estimated weighted accuracy over time for both models. As seen in the graph the wear rate for model A is much higher than for model B. The average weighted accuracy decay rate found for the first model is 0.68% per year. For *model B* this figure decreases up to 0.11% per year.

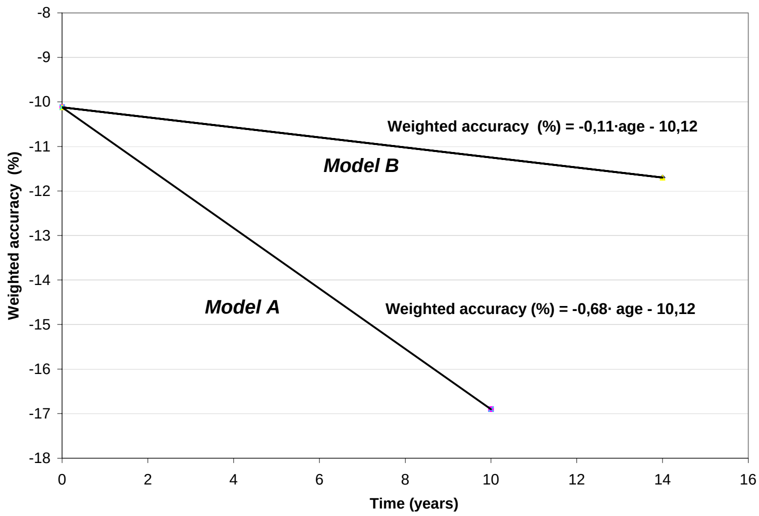

Figure 5. Model A and B weighted accuracy degradation profile for average conditions..

In addition, the confidence limits for meters weighted accuracy will be calculated (Arregui, 2002) using both, the uncertainty for the domestic water consumption pattern and for the accuracy degradation profile. Figure 6 shows the estimated weighted accuracy evolution for different conditions: average, favourable and unfavourable. These degradation profiles have been calculated using the associated uncertainties for water meter accuracy curves and for water consumption patterns.

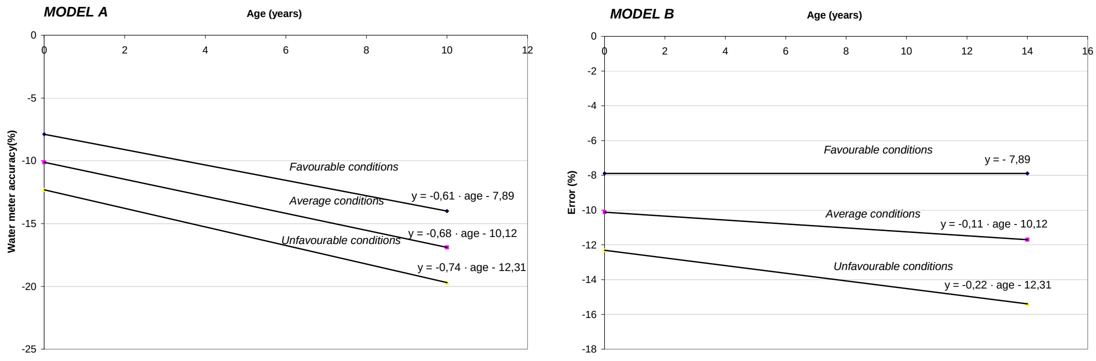

Figure 6 . Weighted accuracy degradation profile of both tested models in different conditions.

Economic analysis of municipality water meter.

The optimal replacement frequency rate has been calculated from the point of view of costs minimisation (Yee M.D., 1999; Arregui, 1999; Allender, 1996; Male et al., 1985) using the assumptions of table 5.

Table 5. Assumptions used for the economic analysis

Water meter cost		
	Model A	27,05 €
	Model B	27,05 €
Installation cost		9,02 €
Average water price		0,44 €/m^3
Discount rate		0
Average annual water consumption volume		132 m^3
Weighted accuracy curve		Figure 5
Consumption pattern		Figure 4

The optimal replacement frequency, from an economic point of view, can be determined by calculating how average annual costs change with time. The replacement age for a given water meter can be found at the minimum point of the costs curve (figure 7).

For *model A*, under average degradation conditions, the lowest cost is found when meters are 13 years old. For favourable and unfavourable conditions optimal replacement frequency is barely the same (figure 7), although the costs significantly change. The accuracy degradation rate for *model B* is significantly lower, which leads to a greater service life (figure 7). Since the optimal replacement age is too high, economic criteria would not be critical for the renewal of this type of meters. In this case water meter renewal would be undertaken individually, that is to say, water meter would be retired due to sudden decreases in water billing, because of company's image or because of legal restrictions.

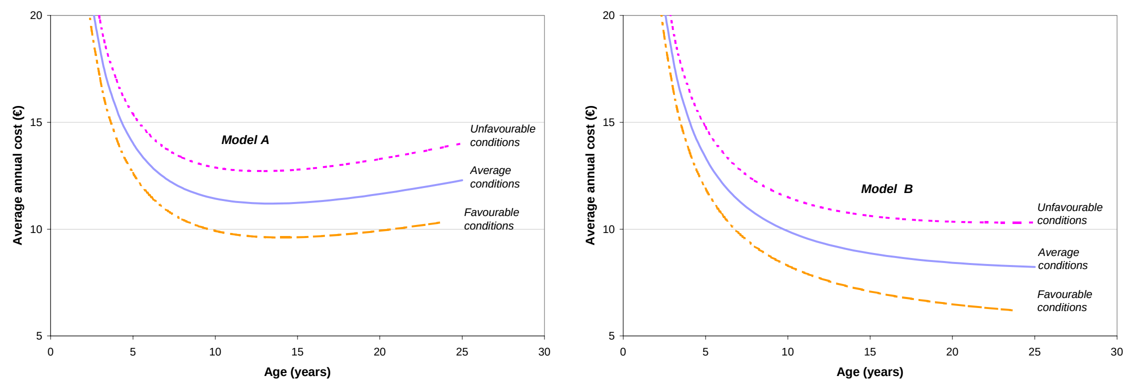

Figure 7. Average annual cost versus age

Sensitivity analysis

To complete the study a sensitivity analysis was carried out to estimate the influence of two parameters on meters annual average cost and optimal replacement frequency. The variables considered were the water meter purchase cost and the water price.

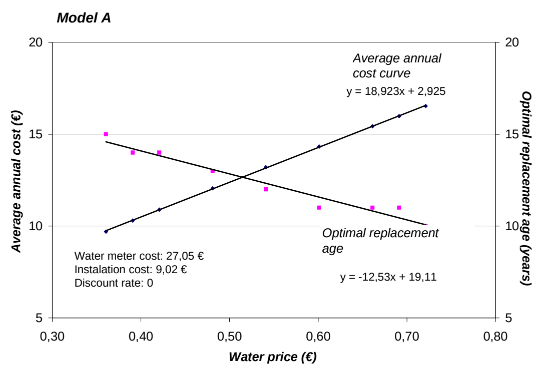

Figure 8. Water price sensitivity analysis. Model A.

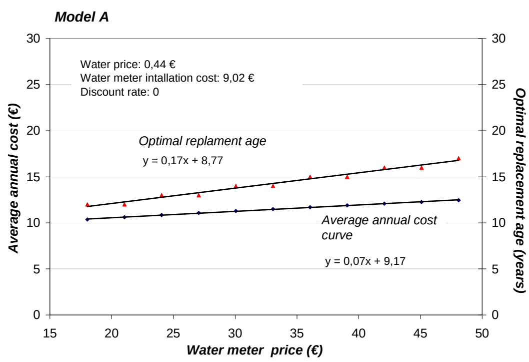

Figure 9. Water meter purchase cost sensitivity analysis. Model A.

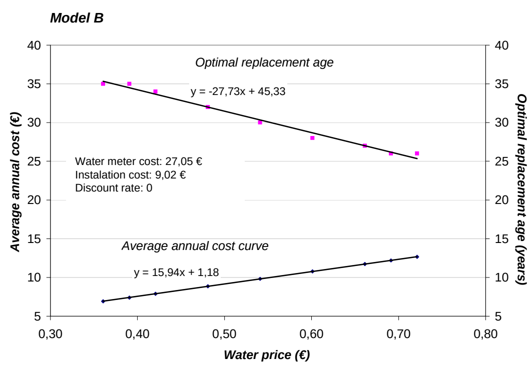

Figure 10. Water price sensitivity analysis. Model B.

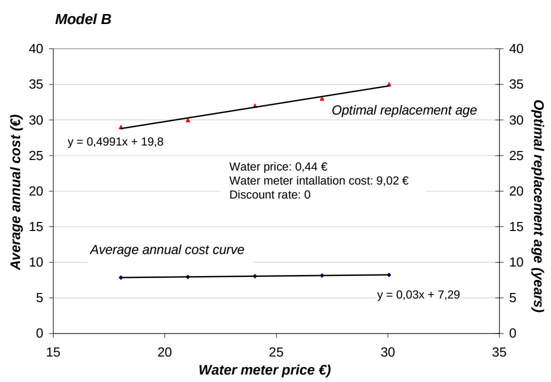

Figure 11. Water meter purchase cost sensitivity analysis. Model B.

A rise on water price increases the optimal renewal frequency in both cases. For example for *model A*, if water price rises to 0.7 € the optimal replacement age would descend from 13 to 10 years.

As seen in the previous figures water price sensitivity for *model B* is greater than for *model A*. The same increment in water price (up to 0.7€) causes a significant reduction in the optimal renewal period, from 33 to 26 years. However, due to the slow meter degradation profile the water price should not be a condition to determine the renewal frequency period because it is, in any case, excessively high.

On the other hand, the water meter purchase cost affects the optimal replacement age in opposite sense. A greater price of the instrument implies a longer time to recover the money invested. This can be seen for both models, figures 10 and 12, where the optimal replacement period increases with the water meter purchase cost.

Conclusions

This paper describes the methodology used to estimate the optimal replacement frequency of two water meters models installed in a Spanish water supply and the influence of two parameters, water price and water meter purchase costs, on this variable.

From figure 7 it is easily concluded that water meters of *model A* have to be replaced much more urgently than those of *model B*. Probably because of meters design and quality, and the special characteristics of the water supply system, *model B* is much more appropriate in this city than *model A*.

Acknowledgment

This study has supported by MINISTERIO DE CIENCIA Y TECNOLOGÍA (DPI2000-0657) under the framework of the project "Propuestas metodológicas para el cálculo de la vida útil de los contadores de agua".

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