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Authors: Arregui F., Cobacho R., Soriano J., García-Serra J.
Affiliation: ITA. Universidad Politecnica de Valencia. Spain
Contact person:
Francisco Arregui
Tel: +34 96 3879898
farregui@ita.upv.es
ITA. Edificio 5C
Universidad Politecnica de Valencia
Camino de Vera s/n
46022 Valencia
Spain

Calculating the optimum level of apparent losses due to water meter inaccuracies

Introduction

Up to date several works have dealt with the optimum replacement frequency of installed water meters. These works concluded that water meters should be replaced based on the meter acquisition and installation costs, the selling price of water, the interest rate of money and the degradation rate of the weighted error. This last parameter it is calculated from the evolution with time of the error curve of the meters and the consumption characteristics of the customers. Arregui et al. 2006 presented an economical model and a simple graphical method to determine the optimum replacement period based on these parameters.
This paper presents the continuation of this work, showing a graphical method that will allow for the determination of the optimum level of apparent losses caused by meter inaccuracies. For this calculation other components of apparent losses, like illegal consumptions or data handling errors, are not considered. Finally it should also be highlighted that this calculation is conducted from a solely economic perspective, other factors that may affect the optimum replacement period of the meters and therefore the optimum level of water meter inaccuracies are not included in the model - for example legal restrictions, sociological issues, etc…
As expected, the optimum level of meter inaccuracies will depend on the same parameters as the optimum replacement period calculation of installed water meters. For simplicity and easiness of use, the solution to the problem is condensed in a single chart which has been prepared running thousands of simulations on the economic model presented by Arregui et. al (2006) for the calculation of the optimum replacement period of water meters. In each case, the average error of installed meters, when conducting a replacement program within the optimum period, has been calculated.

The methodology

The optimum level of water meter inaccuracies is closely related to the optimum replacement frequency of installed water meters. In fact, the optimum level of water meter inaccuracies will correspond to the average error of the meters when they are replaced just at the end of their useful life. For example, water meters installed in systems with a low water selling price will have a long replacement period and, consequently, a higher acceptable inaccuracy than meters installed in cities with higher prices for water.

Factors involved in the optimum replacement policies of water meters

Before presenting the calculation procedure of the optimum level of water meter inaccuracies it is necessary to review and understand all factors involved in the economic model used to find the optimum replacement period of a meter. It should not be forgotten that there is a close relation between the length of time a meter is used and the average error of that meter throughout its live.

- *Initial costs* covering the acquisition price of a new meter, and the installation and administrative costs related to water meter replacement. Unlike the costs caused by unregistered water (which are distributed in time), initial costs are paid when meters are bought and installed. Typically, at the end of the working life of the meter its salvage value is zero (although in cases with meters having electronic components and a replaceable measuring device this assumption can be no longer valid).
- *Distributed costs* due to unregistered water must be considered a real cost for the water company. The monetary losses suffered by the utility are proportional to the unregistered volume and the selling price of water. One of the main causes of unregistered water is water meters inaccuracy. These measuring errors, of different magnitude depending on the meter technology, are present from the moment meters are installed. Consequently, the costs of unregistered water volumes should be considered throughout the meter's working life.
- *Error curve of the meter*. Measuring errors depend on the operating flow rate and are defined by the error curve of a meter. The shape of this curve will vary for different working principles and design characteristics of the meters. As shown in Figure 1, the shape of the error curve of a typical oscillating piston meter has a much different shape than the curve of a typical single jet velocity meter.

  Since errors vary throughout the measuring range, the amount of water not registered by a water meter depends not only on the shape of the curve but also on the consumption flow rates of the users. In order to estimate how much consumed water is not measured, both parameters need to be combined to calculate the weighted error of a meter. This calculation can be easily done using the free software provided by the ITA (Woltmann software).

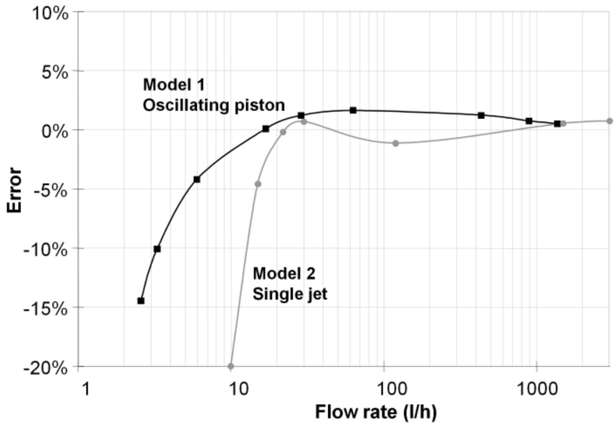

Figure 1. Initial error curves of two residential meters

- *Consumption profile of the user*. Water consumption of a user, expressed as a percentage of the total volume, is usually plotted against the flow rate at which it is consumed. In statistical terms it can be defined as the density function of water consumption with respect the consumption flow rate.
- *Weighted error*. The importance of the meter error at a given flow rate –as defined by the error curve of the meter– will depend on how much water is consumed at that specific flow rate. If small volumes of water are consumed at a certain flow rate, its importance will be less than if larger volumes are consumed. To account for this, the weighted error of a meter is defined as the combined error at different flows considering the percentage of water that it is consumed at each flow rate. This parameter provides, for a specific consumption profile, the amount of water, in percentage, that is not measured (or measured in excess) for every liter consumed.
  In the economic model used (Eq 2.) the weighted error of the meters is assumed to evolve linearly with time. However other evolution patterns of the weighted error can be easily used in the model.
- *Water tariff* structure is needed in order to transform unregistered water volumes into distributed costs. Multiplying by the appropriate water-selling price will convert unregistered water volumes into monetary figures. In case of a tier-structured tariff, the profit loss caused by meter inaccuracies will be the cost of the last cubic meter consumed and not billed.
- *Discount rate*. To properly evaluate the total cost of unregistered water, future economic losses must be converted to their present value. For that conversion, the nominal discount rate, r, is used. Its value is directly linked to the applicable interest rates and the risk of the investment (Bierman and Smidt, 1993). In this paper, to correct the effect of inflation, s, the real discount rate, r', will be considered instead of the nominal discount rate (Eq. 1).

$$r' = \frac{(1+r)}{(1+s)} - 1 \quad (1)$$

As a conclusion, and considering all factors, it can be said that large volumes of water consumed at low flow rates and high prices of water will increase the need for accurate and expensive meters, especially with low discount rates. In this case, meters will have a short scheduled lifespan. Conversely, in a utility billing cheap water and supplying consumers with no leaks in their facilities (less consumption at low flow rates) the chosen meter would not need to be so accurate or expensive, and could be replaced after a longer period of use.

Economic model to calculate the optimum replacement period

It is relatively common that the opportunity value of money it is not considered in the economic model used to obtain the optimum replacement period of installed water meters (Male et al., 1985; Allender, 1996; Yee, 1999; Johnson, 2001; Ferreol, 2005). Using this simplistic approach, the optimum replacement period is typically found by calculating the minimum of the average annual costs of the meters.

Nonetheless, when considering that money has a different value today than it will have in the years to come, such approach is no longer valid (Seitz et al., 1999). In these cases, a method based on the NPV approach (Arregui et al., 2006) can be used to compare options with different lifespan. The proposed approach calculates the NPV of the costs of infinite replacements conducted at fixed intervals of time. The present value of the cost of those infinite replacements is typically called NPVC (net present value of the replacement chain):

$$NPVC_n = \left[C_{acq} + C_{inst} + C_{adm} + \sum_{i=1}^{n} \forall_i \cdot \varepsilon_i \frac{C_W}{(1+r')^{(i-1)}} \right] \cdot \frac{(1+r')^n}{(1+r')^n - 1} \qquad (2)$$

where C_{acq}, C_{inst} and C_{adm} are the acquisition, installation and administrative initial costs, C_W is the selling price of water (considered constant throughout the calculation period), $\forall_i$ is the average volume consumed by a user on the year i, ε_i is the weighted error of the meter for year i, r' is the real discount rate and n is the number of years of the replacement period.

In order to obtain the optimum replacement period of a meter type, the $NPVC_n$ for several values of n should be calculated. For a given meter, the value of n that gives the minimum $NPVC_n$ will be the replacement option that generates the minimum cost for the water utility. In other words, n will be the optimum replacement period of the meter. This procedure provides the best theoretical solution in terms of economic optimization. Nonetheless, apparent losses caused by, for example, data handling errors, stolen water and tampering of water meters are not incorporated in the model (although they could be estimated and easily included).

If Eq.2 is solved for different (thousands) values of the parameters involved, a general graphical solution for the replacement period can be obtained (Figure 2). This graph makes it much easier to obtain the optimum replacement period of a meter in a given water supply.

For a proper use the chart the following steps should be applied:

- Calculate the V parameter for the meter type according to the formula provided in the chart. This parameter gives indication of how much the water meter costs (including all initial costs) compared to the estimated amount of money that it will be billing every year. In other words, it tells how many years are needed to payback the meter with the billed water.
- Calculate the real discount rate r' of money. Only discount rates up to 4% are plotted.
- Draw a vertical line until it intersects the region corresponding to the estimated degradation rate of the weighted error and the line of the r' parameter.

- From the intersection, draw a horizontal line to obtain the optimum replacement period for that meter type.

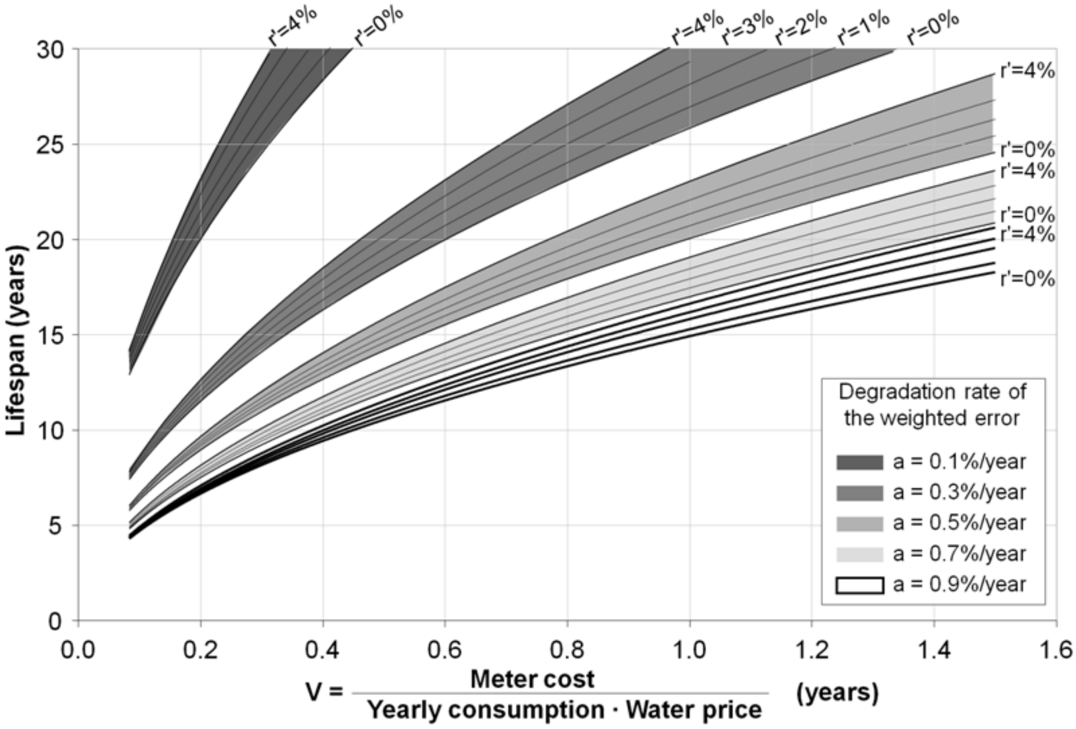

Figure 2. Chart for calculating the optimal replacement period of meter

Obtaining the average error when a meter is optimally replaced

As seen in Figure 2, the degradation rate of the weighted error has a major influence in the optimal replacement period of the meters. Unfortunately, this parameter is not known when meters are first installed in a water supply. However, it can be obtained for each meter type by testing meters in the laboratory and measuring water consumption profiles of the users. Faster degradation rates will lead to shorter replacement periods while slower degradation rates of the meters will advise to maintain the meters installed longer periods of time. This can be easily seen in Figure 2 by drawing a vertical line (representing a meter type installed in a specific type of user). Higher values of the weighted error degradation rates (a) will lead to longer replacement periods.

Commonly, for simplification purposes, most of the calculations performed by several authors to obtain the optimal replacement period of the meters assume a linear evolution of their weighted error. This work (and also Figure 2) makes such assumption. This way, if a meter type has an initial weighted error of -6%, and its weighted error increases linearly 0.5% per year and the optimal replacement period for this meter type is 10 years, the average error for these meters throughout their life, under these conditions, will be -8.5%.

The explained procedure will allow for the calculation of the average error of the meters when they are optimally replaced. This procedure has been significantly improved making it much faster by means of a specific chart.

A Graphical method to obtain the optimum water meter inaccuracy

A new chart has been prepared putting together the results shown in Figure 2 and the assumption of linear evolution for the weighted error. This chart, shown in Figure 3, will provide the increment of water meter errors when meters are replaced within a time period equal to the optimum replacement period. Then, a figure for the optimum level of water meter inaccuracy will be attained adding this value to the initial error of the meter. The procedure will be as follows:

- Calculate the V parameter for the meter type according to the formula provided in Figure 2.
- Calculate the real discount rate r' for the investment. The new chart only considers values for r' up to 3%.
- Draw a vertical line until it intersects the region corresponding to the estimated degradation rate of the weighted error and the line of the r' parameter
- From the intersection draw an horizontal line to obtain the increment of water meter inaccuracy when replaced at the optimum replacement period
- The optimal level of error for the water meter type analyzed will be the previous figure plus its initial error which can be easily obtained by testing new meters (combining this information with the appropriate consumption patterns).

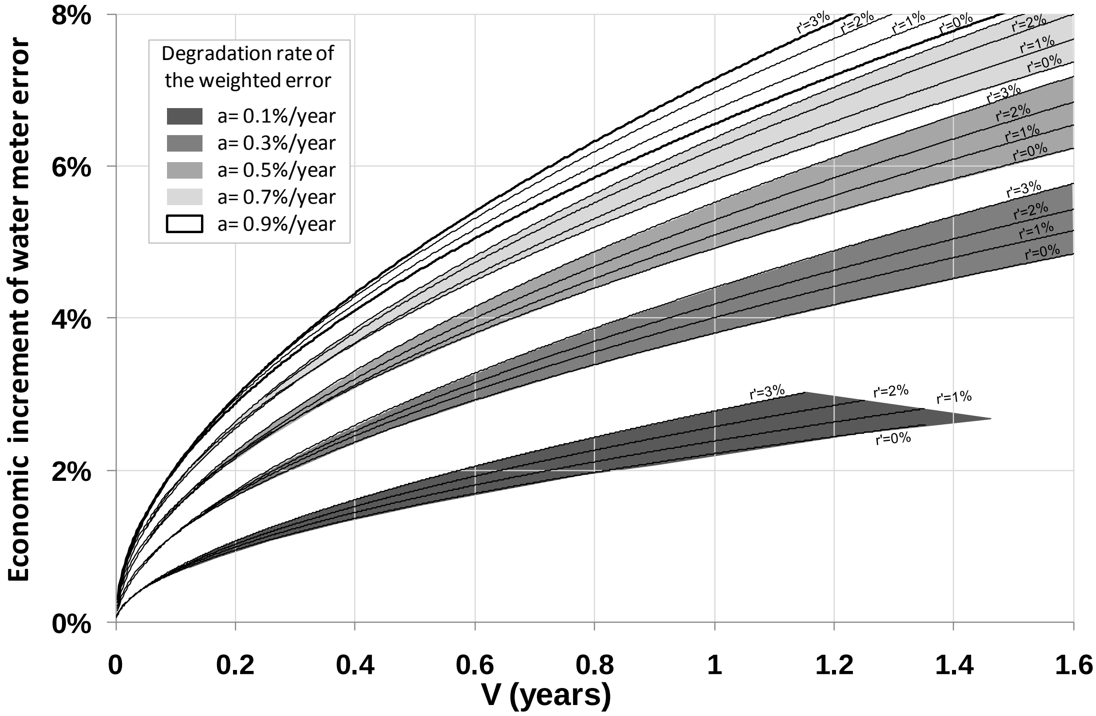

Figure 3. Chart for calculating the optimal increment of water meter error (under-registration)

Example

Domestic customer

Consider a water meter costing (acquisition and installation) 20€, measuring an average consumption of 160 m^3/year, in a water supply selling water at a price of 0.25€/m^3. From this data, the V ratio for this meter is 0.5 years.

Additionally, from laboratory tests and the water consumption profiles of the users the initial error of the meter has been established as -4% (Woltmann software) while the degradation rate of its weighted error has been estimated to be -0.5% per year. The water company uses a real discount rate to analyze the feasibility of its investments of 2%.

Drawing a vertical line in Figure 3 at V equal to 0.5 and intersecting it with the line corresponding to a real discount rate of 2%, in the region of the degradation rate for the weighted error of -0.5%/year a value of 3.75% for the increment of water meter inaccuracy is obtained. Then, the optimum level of water meter inaccuracy is the sum of -3.75% and the initial error, -4%. This operation gives a total figure of -7.75%.

This value can also be obtained using Figure 2. For the V ratio of the considered meter type the optimum replacement period is approximately 15 years. Since the estimated degradation rate of the weighted error is -0.5%/year the error at the end of it useful life will be -11.5% while the initial error for this meter type is -4%. Therefore, the average error of this meters, when replace at their optimum lifespan will be -7.75% which is the same value obtained from Figure 3.

If the same meter is installed under the same conditions but the water selling price is increased from 0.25€/m^3 to 1.00€/m^3 then the V ratio decreases from 0.5 to 0.125 years. The optimum level of water meter inaccuracy decreases from -7.75% to -5.75%. Contrarily, if the water price decreases from 0.25€/m^3 to 0.125€/m^3 then the V ratio increases to 1.00 years and the optimum level of water meter inaccuracy grows up to -9.50%.

Conclusions

From a closer analysis of the chart presented in Figure 3 the following conclusions can be reached (maintaining the rest of the parameters constant):

- the higher the degradation rate of the weighted error the higher the optimum level of water meter error
- the higher the discount rate of money the higher the optimum level of water meter error
- the higher the selling water price of water the lower the V parameter and the lower the optimum level of water meter error
- the higher the consumption volume of the users the lower the V parameter and the lower the optimum level of water meter error
- the higher the acquisition cost of a water meter the higher the V parameter and the higher the optimum level of water meter error
- the higher the installation costs of a water meter the higher the V parameter and the higher the optimum level of water meter error
- the higher the amount of volume used at low flows (which increase the degradation rate of the weighted error since meters degrade in first place at low flows) the higher the optimum level of water meter error

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