Nine steps towards a better water meter management

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ABSTRACT

The paper provides a comprehensive perspective of the critical aspects to be taken into account when planning the long-term management of water meters in a utility. In order to facilitate their quick understanding and practical implementation, they have been structured into nine steps. Ranging from an initial audit up to the final periodic meter replacement planning, these steps cover three aspects of the problem – field work, laboratory work and management tasks; and each one is developed in detail paying attention to the particular data needed and noting the practical outcome it will yield.

Key words | cost–benefit analysis, meter error, water meter management and replacement

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INTRODUCTION

The International Water Association (IWA) water audit classifies water losses into Real (physical) and Apparent (nonphysical) losses. Until now, intensive research has been carried out to develop techniques aimed to reduce real losses. However, although smaller in volume, apparent losses may have a greater economic impact for water utilities.

According to IWA water balance apparent losses are constituted by three components: meter inaccuracies, data handling errors and water theft or illegal use. The first two components can be approached from a technical perspective, while the last one also needs a cultural and/or social perspective.

Just like real losses, apparent losses need to be faced with an integrated strategy (Rizzo *et al.* 2007) that will achieve sustainable and economically viable results (Vermesch & Carteado 2010). This paper will present the benefits of an integrated water meter management approach and a series of actions that will lead into this beneficial circle (Figure 1). Although focused on the first component of apparent losses (i.e. water losses caused by meter inaccuracies) some of the proposed actions will clearly reduce the other two components: data handling errors and water theft.

GETTING READY

Step 1. Audit meters and customers – What do I know about the meters currently installed and the customers I am serving?

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Utility managers often underrate apparent losses and misjudge their importance. However, the importance of apparent losses should be enough to take them into account. As a matter of fact, if the economic consequences of losses are considered, the relative importance of the apparent component increases significantly.

Prior to any other analysis, a detailed evaluation of the system needs to be conducted to prevent any unnecessary estimations that may distort the final results and to obtain an overview of the current water-metering situation.

Such an audit should allow the following questions to be answered:

- What percentage of customers is being metered?
- How many meters are registering a null monthly consumption?
- How likely is water theft in the utility?/Are there any procedures to prevent customers from tampering with meters or establishing illegal connections?
- How many customers are not being billed?/How many customers do not pay their bills?
- What is the tariff structure for the different types of user?
- How many meters are registering monthly volumes too high or too low considering their connection size?
- What is the estimated optimum replacement period of installed meters?/How are meters selected for replacement?
- How are water meters procured and selected?/How is the quality of the meters controlled?

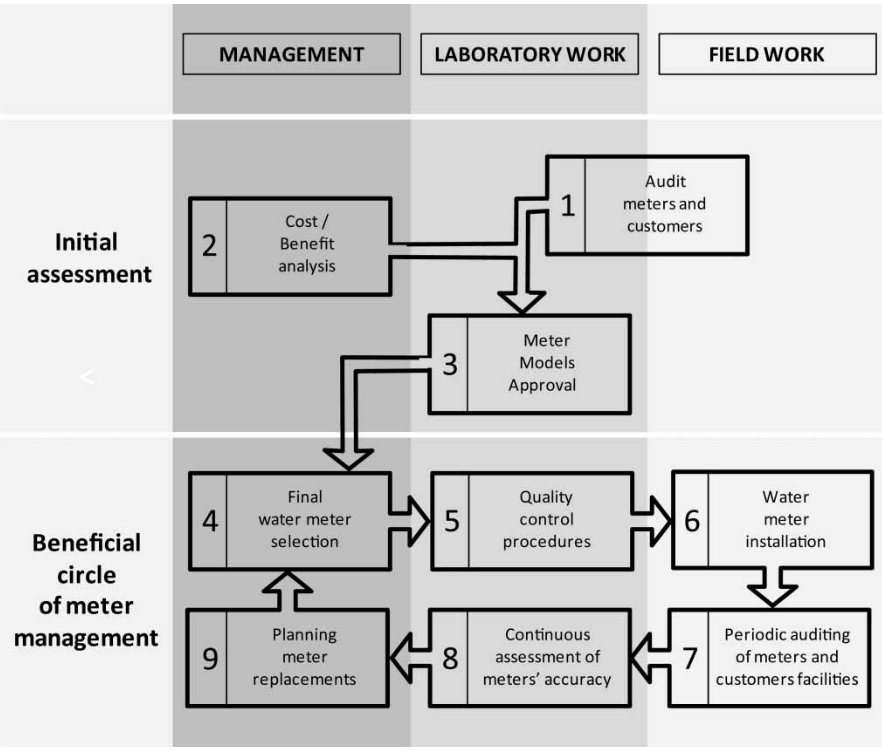

Figure 1 | The nine steps.

- How is the metrological performance of the installed meters controlled?
- Who is conducting the installation of the meters? Is there any control over the installation conditions?

The information gathered during this initial audit will serve as a starting point to all other steps described in the integrated water meter management cycle.

Step 2. Cost–benefit analysis – Should I install high or medium quality new meters?

A straightforward cost–benefit analysis at this initial stage will allow any option that is clearly unsuitable for the utility to be discarded. It will provide an initial guess of the theoretical replacement period depending on the cost of the water meter, the selling price of water and an estimation of the degradation rate of the weighted error of the meters (Arregui *et al*. 2011). However, as this study is conducted before any real data are available, results should only be taken as what they really are: estimates.

This initial study will also allow determination of the maximum price that can be paid for a water meter depending on the water tariff. This sensitivity analysis is explained in detail in Arregui *et al*. (2006). Obviously, a low price of water will complicate the recovery of the additional money invested in a high-end water meter. In these cases the most expensive water meters should not only have a better initial metrology but should also maintain it with greater stability over time.

At this initial stage the water company should also consider the desirable (required) technical characteristics of the meters to be selected. These requirements can be derived from the initial audit (Step 1) and can be fine tuned in the future with additional data and a wider experience. The following issues should be considered:

- *Meter design* to assure a proper performance in adverse installation sites: high temperatures, direct sun light exposure, high humidity, tight spaces (reading), installation at an angle, etc …
- *Frequency of meter tampering*. Generally speaking, when meters are manipulated, buying cheaper meters and replacing them more frequently becomes a better option than choosing expensive meters and maintaining them for a longer period of time.
- Also, anti-tampering devices and seals should be incorporated in the design of the meters to prevent customers from dismounting or disassembling the meters.
- *Water storage tanks* at the customers' facilities. This will affect the sizing of the meters and the metrological class and starting flow required for accurate measurements.

- *Service interruptions* and the discharge of air flows through the meters once the service is restored.
- *Water quality*. Systems with a high number of pipe repairs are not suitable for positive displacement meters or wet totalizers. Also, water hardness may play an important role in the long-term performance of water meters.
- *Legal restrictions*. In most places water meters are under the supervision of national metrological agencies. In Europe, for instance, all water meters used for custody transfer should comply with the European Measuring Instruments Directive 2004/22/EC (MID). In other parts of the world meters are only required to meet ISO 4064:2005 standard or OIML R49:2006 Recommendation.

This list of minimum technical requirements will be more or less comprehensive depending on the previous in-house experience.

THE BENEFICIAL CYCLE OF AN INTEGRATED WATER METER MANAGEMENT

Step 3. Meter models approval – Will all meters in the market match my water supply requirements?

A clear distinction should be made between a legal approval of a meter model and the utility's selection and approval of certain models and technologies. The legal metrological approval will depend on local regulations. However, a utility may only select meters for internal use once they have been satisfactorily tested both in the laboratory and in the field.

This way of proceeding will prevent the use and acquisition of water meters that have not been comprehensively tested (avoiding significant technical problems in the future). It is not uncommon that a manufacturer finds out about a design problem in a model once they have been installed in the field.

Furthermore, meter approval procedures will avoid one of the most commons pitfalls in water meter management: the purchase of a large number of meters of a single model at once (typically the cheapest one).

The tests for meter approval to be conducted by a water utility should complement and verify those tests already carried out by the manufacturers and National Metrological Institutions.

Testing procedures for water meter approval should comprise two phases. The first one to be conducted in the laboratory and a second phase in the field, at the facilities of selected customers.

The laboratory tests should be designed to verify the real metrology of the meters and other functioning characteristics that are not considered in the standards, for example:

- Strength of the *magnetic coupling*.
- The real value of the *starting flow* of the meters (Richards *et al*. 2010). This parameter is not defined in any standard and therefore is not officially tested by any manufacturer or metrological institution.
- The *shape of the error curve*. The weighted error of a meter is calculated combining the error of the meter at each flow rate with the amount of water that is consumed at every flow rate, given by the consumption pattern of the user (Bowen *et al*. 1993; Fantozzi *et al*. 2011).
- *Mechanical strength* of the totalizer, pipe connections, or any other component that can be tampere with.

Contrary to laboratory tests, field tests require that the meters remain installed in the field for at least a year or two before they can really provide any useful information. These tests should be carefully planned and tested meters should always be installed at premises with adverse conditions.

Although some conclusions about the degradation rate of the weighted error may be obtained from these field tests, it is important to keep in mind that the main objective is not determining how fast meters degrade but identifying design defects or other factors that may cause meter failures.

Only meter models that successfully pass laboratory and field tests should obtain the approval certificate of the water company.

Obviously, this methodology will only be useful if new meter models are continuously tested and the water company has a sufficient stock of meters approved for each diameter.

Step 4. Final water meter selection – Am I choosing the right meter for each customer?

The final meter selection should be conducted by means of an extended cost–benefit analysis restricted to preselected meters, but including in the analysis other parameters that may be of importance for the water utility. One of the issues to be considered is the ability of the meter manufacturer to supply enough quality instruments in a given time. Some manufacturers are not prepared to supply large batches of meters while maintaining the desired quality levels. Quite often the average quality of large batches is significantly lower than the quality of smaller lots. Previous experience with a manufacturer or with the same or similar water meter model, should be taken into consideration for meter selection.

In order to reduce the risk involved in the use of a single meter model, several manufacturers and meters should be selected; enough to reduce the risk of a generalized meter failure, but not too many so the benefits of procuring large quantities of meters are maintained. In our experience, the ideal number of meter models to be selected would be between two and four depending on the number of customers and meters to purchase. The selection for domestic customers should range between three and four different models, while large customers would only require two or three at the most.

The final selection of a meter model will be associated with a customer and depend on its specific characteristics. One meter can get the approval from the utility but only be suitable for users that meet certain conditions. There are meters that can only be installed in a fully horizontal position, others which cannot stand high pressures, low temperatures, high or low flows, suspended solids, or cannot be exposed to direct sunlight.

Step 5. Quality control procedures – Do newly procured meters perform according to my expectations/requirements?

Just like any other good, procured meters should be checked for compliance with the theoretical technical specifications. This is particularly important for metrological requirements which can influence economic losses. ISO 4064:1993 standard (and European Directives EEC 75/33 or 2004/22/EC) define a set of initial verification tests for meters. These tests are usually conducted at the manufacturer's facilities prior to the shipment of the meters.

Considering that most water meters are built from high precision mechanical or electronic components that can be easily damaged during transportation, it is highly advisable to re-check a sample of the procured meters (Neilsen *et al*. 2011). These re-checks are also advisable in situations in which manufacturers are under great pressure to produce a large number of water meters in a short period of time at very low price.

Finally, it should be taken into account that water meter components are under continuous manufacturing changes and so is their performance. These changes are not usually notified to customers.

As manufacturer tests cannot possibly reproduce the actual working conditions (including consumption values) quality control procedures should be designed to complement the initial verification tests as defined by international standards.

In these tests all materials, equipment and methods should be traceable. Otherwise the results of the tests could easily be contested by the supplier and will not be useful in any potential claim. For this reason it is extremely important that all parties know and agree in advance on the quality control procedures at the reception of the batches.

Parameters that can be checked during these quality control tests are:

- Weighted error of the meter (according to a predefined formula).
- Starting flow rate of the meter.
- Magnetic coupling strength.
- Anti-tampering protection.

For each one of these tests acceptance and rejection criteria should be defined using statistical methods. An example on how to define a quality control test for the weighted error of a meter can be found in Arregui *et al*. (2006). Also standards like the ISO 2859 and ISO 3951 can help in defining the sampling plans and the acceptance/rejection criteria for the tests.

As a general concept, conformance criteria will depend on the minimum acceptable quality level of the batch (defined as the maximal percentage of nonconforming meters), the inspection type (Normal, tightened, reduced) and level (determines the relation between the batch size and sample size).

However, and as only a limited number of meters are tested, all decisions are subject to errors. The probability of acceptance of a defective shipment is called a type I or α error, and may be considered a risk on the buyer's side. The probability of rejection of a correct shipment is known as a type II or β error, and defines the seller's risk. Defining a sampling plan implies selecting a value for type I and II errors. Suppliers will obviously try to minimize type I probabilities while water utilities will try to reduce type II.

Step 6. Water meter installation – Are all meters I use properly installed and protected?

As with any other instrument, water meters may not perform as expected if they are not installed properly.

Designing a standard/reference installation site for each water meter technology or size will greatly improve the quality of the resulting installations. The most significant factors that should be considered are:

- Most water meters that use a velocity/area method to infer the flow rate are sensitive to flow profile distortions (Burke & Hannah 2010). Therefore, the distance of straight pipe between the meter and any distorting element should be long enough to assure a minimum 'quality' of the velocity profile distribution (and hence of the measurement).

- Most water meters are designed to measure a single phase liquid: water. The presence of air will change the metrological performance of the meter and can significantly degrade its mechanical components (Baker 2000). An upstream air-valve will only remove the air that is trapped close to the meter under zero flow conditions but will not prevent the air flowing through the meter under a normal water flow. For a complete removal of air, volumes have to be mostly discharged before they get close to the meter. Unfortunately, in most cases, this is not possible.
- Most meters, at some time, need to be tested in the field. This is especially true for small and medium caliber meters. The installation of a verification tap downstream of the meter will allow such tests. This tap will also provide a fast method to identify clogged meters.
- The measuring errors of mechanical meters under forward and reverse flow conditions are often different (Baker 2000). The installation of good quality non-return valves should be required. They will protect the utility from any intrusion of uncontrolled water in the network and will also assure a proper metrology of the meters.
- Quite often the space left around the meter is not enough to facilitate maintenance or replacement operations. This will greatly increase the replacement costs of meters. Also, the lack of space may condition in the future the type of meter that might be installed. As mentioned in Arregui *et al.* (2006) this will cause a loss of accuracy as well as a faster degradation rate of the metering performance.
- A general modification of the installation sites to fix this problem may not be economical. However, this is a factor to take into account when planning new installation sites or when selecting the meters.
- Measuring errors can also be caused by manipulation of the meters. This is why meters should be installed in such a way that protection against tampering and theft is maximized, while still allowing the instrument to be read. Installation of meters in the interior of households should be avoided as much as possible.
- All meters contain pieces or components that can be altered by unfavorable environmental conditions, such as direct sunlight exposure, high temperature or humidity. Installation sites should be designed to avoid these harmful environments.
- Mechanical meters can be seriously damaged by suspended solids or debris transported by water. The installation and proper maintenance of a strainer upstream from the meter is highly recommended, especially for medium and large meters and in networks with a high bursts frequency. Nonetheless it should be highlighted that an improper maintenance of a strainer installed too close to a meter can cause significant measuring errors.
- Frequent low flows through the meter may cause a severe under-registration that will increase with time (Arregui *et al.* 2006; Grothaus 2007; Richards *et al.* 2010).
- Finally, a frequent cause for mechanical meters failure is the existence of unexpected high flows (above the maximum flow of the meter). Utility staff should avoid under-sizing mechanical meters in excess.

A desirable good practice for the water utility is to record the key facts from each installation site to be used in future meter selection processes. This information will not only provide support for decision making in meter acquisition but also valuable data for the analysis of factors that can contribute to the degradation rate of the meters' accuracy.

Step 7. Periodic auditing of meters and customer facilities – Are meters working under the expected conditions?

Water meters should never be left without proper supervision by the water utility. As mentioned above, there are many reasons that can lead to unacceptable accuracy levels. Because of this, both meters and customers' facilities should be inspected periodically. Special attention should be paid to the control of newly installed meters as the failure rate of any instrument is higher at the beginning and end of its life cycle.

There are several advantages associated with the described auditing procedures:

- Any manufacturing or design defect of the procured meters will be detected considerably faster. This will reduce the economic losses associated with the procurement and installation of meters with high failure rates or prone to have problems.
- Some damaged mechanical meters can be easily identified by just looking at the smoothness in the motion of the pointers. When the mechanical pieces of a meter are damaged, pointers are likely to move with a jerky motion.
- Frequent inspections will provide information about tampering and manipulating techniques for the meters and their installation sites.
- Customers will be aware that the utility is looking after the meters and the installation sites.

- Auditing the installation sites will allow identification of improper working conditions of the meters.
- If economic and staff resources allow it, data logging activities can be conducted to obtain water consumption patterns of the customers.

At this point a final warning on prepaid meters should be issued. This type of meter is generally used to reduce the amount of time required to take the readings of the meters and to improve the percentage of paid bills (making them a popular choice in low and medium income countries). However, the utilization of prepaid meters may result in a lack of visits from water utility staff to the customers' premises for years.

Step 8. Continuous assessment of meters' accuracy – How fast do the installed meters degrade with time?

The economic models that are used to assess the optimal replacement period of a meter (Allender 1996; Yee 1999; Johnson 2001; Ferreol 2005; Hill & Davis 2005; Arregui *et al*. 2011; Johnson 2011) need to be fed with reliable data about how fast the weighted error of a meter degrades with time. The only way to obtain such data consists in periodically testing the meters.

However, a significant sample of meters' errors requires testing meters periodically. Otherwise the amount of available data will not be sufficient to obtain definitive conclusions about the degradation rate, and the uncertainty associated with the results will be too large. A snapshot of the meters' errors at one moment in time is not the same as a continuous monitoring of the error evolution as meters age. And this is particularly true if the snapshot is only taken when the meter is new (which is when all standardized tests apply). Tracking the evolution provides a significantly larger amount of useful information.

Meter testing procedures should be defined to provide information about the real behavior of the meter in the field. Quite often these procedures are not properly designed and they distort the metrological behavior of the meters. A clear example is when a positive displacement meter is first tested at a very high flow rate (which has never occurred in the field) and then tested at low flows. In such cases, the errors at low flows obtained in the laboratory will probably be much better than the errors of the meters in the field.

Additionally, testing procedures for used meters should be designed so that the error curve of the meters can be properly reconstructed from the results of the test (Arregui *et al*. 2009). The aim of these tests is completely different from initial verification tests in which meters are checked for legal requirements about errors at different flow rates. However, as the tests for used meters need a larger quantity of data, it is good practice to include in such tests the flow rates of the initial verification procedures as well.

Finally, it is necessary to include the collection of complementary data during field tests. Otherwise, it will be impossible in the future to establish the effect of different parameters in the metrological behavior of the meter. For instance, it is always interesting to gather data about the characteristics (hydraulic, sociological, etc …) of the customer the meter was serving, the installation site and network conditions in the surrounding area, meter characteristics (length, type, model version, year of production, thread size), water quality, etc.

When a meter fails, in order to find the reason for failure, it is highly advisable to disassemble the meter. Sometimes, the failure may be the result of external manipulation. Other times a design or manufacturing defect will be found. These kinds of data, together with the results of the tests, need to be recorded and will help in the future in the development of the procurement conditions. Unfortunately test bench manufacturers do not usually provide a database capable of managing both types of data. The authors have developed Woltmann, a commercial software developed at ITA (Arregui *et al*. 2010) designed to store and analyze these data.

Step 9. Planning meter replacements – How many meters do I have to replace next month? And next year?

The replacement frequency of a meter depends on many factors that cannot be easily controlled (even legislation). The final decision relies most of the time on an economic optimization of the problem. A detailed description of the economic model (which is not uncertainty free) that can be used to determine the optimum lifespan of a meter can be found in Arregui *et al*. (2006) and Arregui *et al*. (2010). Solutions may be conditioned by legal restrictions, suitable technologies, etc.

Meters with a higher risk of malfunctioning or assigned to users with a higher consumption potential should always be replaced first. It is obvious that the average bill of a customer is a key priority for meter replacements. Quite often, the best economic option is to leave customers with subsidized tariffs with the oldest and lowest cost meters.

During meter testing activities it is likely that at some point the utility will find it advisable to recalculate the lifespan of a meter. This can happen when the metrological performance in the field of a specific meter model does not meet the expectations, and specific factors are found to negatively affect the degradation rate of the error. In such cases, the replacement period should be recalculated with the latest available information.

The calculation of the replacement frequency of the meters gives as a result a time span depending mostly on the price of water. In those utilities in which the revenue for the utility for each cubic meter is low, the cost curve is usually quite flat. This is the reason why utilities with higher tariffs really need to accurately determine which is the optimum replacement period of the different meters used. On the other hand, water utilities with a low selling price do not need to be so precise in the calculation.

Meter replacement campaigns should be evenly distributed throughout the year. A well-trained team is key to ensure that meters are properly installed and to keep management informed about any irregularity in the installation sites. This team should also uninstall meters in such a way that they are still valid for testing and obtaining reliable conclusions about the influence of different parameters. In other words, they should treat meters as what they really are: precision instruments.

During meter replacement activities any sign of tampering in the meter or the customer facility should be investigated. Meter replacement activities are a good time to identify how meters are manipulated and how illegal connections are made. The experience gained from these findings can always be incorporated in future meter procurement procedures.

Planning a proper replacement campaign implies a sufficient stock of new meters, which implies having completed all previous steps. It is not uncommon to find water companies that cannot install new meters because they have no new stock. The lack of stock can be caused by a combination of factors: there are no approved meters types due to the fact that approval procedures are very slow, laboratory tests have proved that approved meter are actually failing, manufacturers do not have the production capacity to serve the meters on time, procured meter batches have been rejected because of quality problems, etc.

CONCLUSIONS

Traditionally, water meter management has seldom been seen as a discipline on its own. Quite often, utility managers have purchased disregarding the fact that their performance is linked to operating conditions, and that the optimum economic choice may not necessarily come from the cheapest device. Water meters are precision devices that deteriorate, are sensitive to installation conditions, sensitive to operating conditions and may produce significant errors under apparently normal conditions. However, water utilities rely on these imperfect devices to obtain most of their revenue, and even the smallest of aggregated errors in the measurement of consumption has a direct effect on the utility's income.

This direct effect on the economic figures should be enough to pursue an optimization of the cost–benefit ratio related to metering. The recipe to maximize the efficiency of the metering system lies in a continuous programme of: research to find the most appropriate models; field testing to establish their real behavior and their evolution with time; and planning, by looking ahead and preparing different aspects of meter management before they are needed (assessing the optimum replacement period; proper installation procedures to facilitate later replacement, testing and reading; stocking good quality meters ahead of replacement plans; testing new meter models before they are needed in the field; etc.).

This paper summarizes all these procedures and concepts in a comprehensive nine-step methodology which should serve as a guide to achieve an integrated water meter management in a utility.

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