Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply

A. Criminisi, C. M. Fontanazza, G. Freni and G. La Loggia

ABSTRACT

Apparent losses are usually caused by water theft, billing errors, or revenue meter under-registration. While the first two causes are directly related to water utility management and may be reduced by improving company procedures, water meter inaccuracies are considered to be the most significant and hardest to quantify. Water meter errors are amplified in networks subjected to water scarcity, where users adopt private storage tanks to cope with the intermittent water supply. The aim of this paper is to analyse the role of two variables influencing the apparent losses: water meter age and the private storage tank effect on meter performance. The study was carried out in Palermo (Italy). The impact of water meter ageing was evaluated in laboratory by testing 180 revenue meters, ranging from 0 to 45 years in age. The effects of the private water tanks were determined via field monitoring of real users and a mathematical model. This study demonstrates that the impact on apparent losses from the meter starting flow rapidly increases with meter age. Private water tanks, usually fed by a float valve, overstate meter under-registration, producing additional apparent losses between 15% and 40% for the users analysed in this study.

Key words | apparent losses, private storage tanks, water meter error curve, water meter under-registration, water scarcity

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INTRODUCTION

In a water supply system, water losses can be computed as the difference between system input volume and authorised consumption, as reported in the IWA Standard International Water Balance (Lambert & Hirner 2000; Lambert 2002). Water losses are further segregated into real and apparent losses in the IWA method. Real losses are physical losses consisting of background losses, reported bursts, and unreported bursts (Lambert & Morrison 1996; Lambert *et al.* 1999). Real losses incur direct costs, as the water utility has to augment supply and sometimes tap into additional water resources to meet user demand.

Apparent losses are not physical but rather financial losses. They are caused by unauthorised consumption and metering inaccuracies (Lambert 2002). As a consequence of these accounting errors on the water volumes taken from the network and consumed by users, the water utility does not attain the corresponding compensation for the service provided. This unaccounted volume may have an important impact on the utility's water and economic balances, providing the incentive to recover these unpaid water volumes.

Metering errors are the main cause of apparent losses in a water distribution system (Rizzo & Cilia 2005). There are several possible reasons that cause water meters to lose their efficiency, which include: meter wear and tear, incorrect installation practice, lack of maintenance or calibration, incorrect meter type and class for the application, incorrect meter sizing, demand profile or demand type problems. Assuming that the meter choice, sizing, installation, and calibration have been performed correctly,

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apparent losses caused by water meter age and demand profile still persist. Various types of water meters exist, such as volumetric, electromagnetic, and ultrasonic. The most common residential revenue meters are volumetric, single-jet, and multi-jet models. For this type of meter, ageing or an excessive abrasion of their moving parts often cause meters to under-register. Wear and tear are usually caused by poor water physical and chemical properties, environmental problems and entrapped air bubbles causing high velocities (Thornton & Rizzo 2002). Independent from its age, a water meter is affected by intrinsic errors changing with flow rate and with temporal user demand patterns. Hence, two parameters are needed in order to assess the share of water consumption that is recorded by the meter: the metrological performance of the meter at different flow rates and the user demand temporal pattern (Male *et al.* 1985; Ferreol 2005; Arregui *et al.* 2006*a*,*b*). The latter determines the actual flow rates passing through the meter, which modifies its performance.

The metrological requirements for any type of water meter are given by the mean of four flow rates (ISO 4064-1 2005; EN 14154-1 + A1 2007) identifying different operational fields on the meter error curve (Figure 1): the minimum flow rate, Q_1, the transitional flow rate, Q_2, the permanent flow rate, Q_3, and the overload flow rate, Q_4.

The transitional flow rate occurs between the permanent and minimum flow rates, and divides the flow rate range into two zones, the "upper zone" and the "lower zone", each characterised by its own maximum permissible error. The minimum flow rate is the lowest at which the water meter is required to operate within the maximum permissible error of the lower zone. The maximum permissible error, positive or negative, on volumes delivered at flow rates between the minimum and the transitional flow rates (excluded) is 5%. The permanent flow rate is the highest at which the water meter is required to operate in a satisfactory manner within the maximum permissible error of the upper zone. Finally, the overload flow rate is the highest at which the water meter is required to operate for short periods within the same maximum permissible error. The maximum permissible error, positive or negative, on volumes delivered at flow rates between the transitional (included) and the overload flow rates is 2%. Another very important flow rate is the starting flow Q_s, at which the meter starts measuring the passing water volume, even if the accuracy is quite poor. This flow is not discussed in the ISO standard, but it is relevant when considering under-registration of ageing water meters.

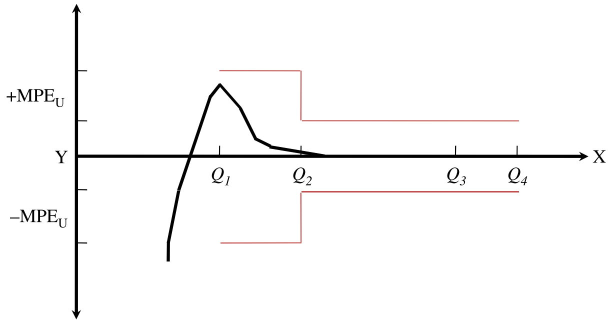

Figure 1 | Sample water meter error curve (ISO 4064-1 2005).

Water meter under-registration due to meter ageing will increase if there is a private roof tank between the revenue meter and the user (Thornton & Rizzo 2002; Arregui *et al.* 2005, 2006*a*,*b*; Rizzo & Cilia 2005; Cobacho *et al.* 2008). This supply scheme is frequent in the Mediterranean, where water shortages are common (Cubillo 2004, 2005). During water shortages, network operating conditions are very far from design conditions; discontinuous water distribution and water resources rationing are often used as the main measure to cope with water scarcity. Users try to compensate for the intermittent water service by building private tanks (Figure 2), which are used for collecting water during serviced periods, and distributing it when public water service is not available (Fontanazza *et al.* 2008). Private tanks modify the demand profile of normal domestic users. The tank is often filled using a proportional float valve, which dampens the instantaneous water demand, and reduces the flow rates passing through the meter. The slow closure of the float valve induces flows that are lower than the starting flow of the revenue meter and are not registered. The larger the surface area of the roof tank or the higher the meter starting flow, the larger the meter under-registration (Rizzo & Cilia 2005; Arregui *et al.* 2006*a*,*b*; Cobacho *et al.* 2008).

The aim of this paper is to assess the apparent losses caused by the combination of meter under-registration and the dampening effect caused by private water tanks. First, metering error curves of several revenue meters were evaluated using a test bench. This experimental part was

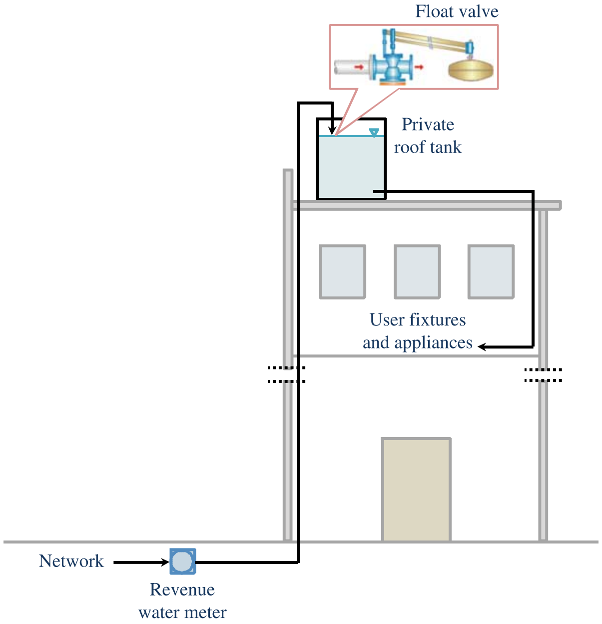

Figure 2 | A schematic of a typical plumbing connection to a private roof tank.

carried out in the Palermo water utility (AMAP S.p.A.) laboratory. The impact of private water tanks on the apparent losses was then evaluated by monitoring the water consumption in five households of the city of Palermo (Italy), which obtained water from roof tanks. In order to generalise the results, a mathematical model was implemented to simulate the system composed of a water tank, float valve, water meter, and user demand. The model was calibrated and validated using contemporary flow data from upstream and downstream of the tank, network pressure data, and tank water level data.

LABORATORY STUDIES

Laboratory experiments were performed to obtain the metering error curves for different flow meter classes and ages that are in service in the Palermo water distribution network. A total of 180 water meters were collected from the distribution network to be representative of those still in service. The flow meters have a diameter of 15 mm, and all were taken from residential users, which comprise 85% of the city total. Their service life ranged between 0 and 45 years; water meters installed before 1997 are included in class B, those installed after 1997 (thus being less than 10 years old) are in class C, as formerly defined by the first issue of ISO 4064:1993 and currently adopted in Europe by Directive 75/33/EEC (1974). The selected flow meters were divided into nine age classes, with each class holding 20 meters (Table 1).

Flow meters tests were performed using a volumetric calibration bench (Figure 3), following ISO 4064-3 (2005) and EN 14154-3:2005 + A1 (2007). The test bench consists of a water supply tank, pipeworks, a calibrated transparent tank for precision volume estimation, a pressure gauge, and a reference electromagnetic water meter. The pipeworks are comprised of a test section in which the meter is placed, valves for establishing the desired flow rate, one or more air bleeds, a non-return device. The reference flow meter is used only for setting valves in order to obtain a specific test flow, but was not used for error curve assessment. The meter placement in the test section is consistent with ISO 4064-2 (2005) and EN 14154-2:2005 + A1 (2007), to avoid

Table 1 | Key results from the laboratory experiments

Flow meter age (*) (years)	No. meter tested	Average starting flow (l/h)	Average error at 35 l/h (%)	Average error at (120 l/h)
0–5	20	5.69	−2.60	0.78
5–10	20	6.69	−8.80	1.18
10–15	20	12.31	−8.90	2.67
15–20	20	11.48	−7.90	1.44
20–25	20	16.43	−19.50	−1.57
25–30	20	9.92	−7.90	−2.59
30–35	20	16.48	−36.80	−6.10
35–40	20	18.74	−45.10	−8.47
40–45	20	33.40	−83.10	−17.92

*Flow meters installed more than 10 years ago are in class B according to ISO 4064:1993 and Directive 75/33/EEC; others are in class C.

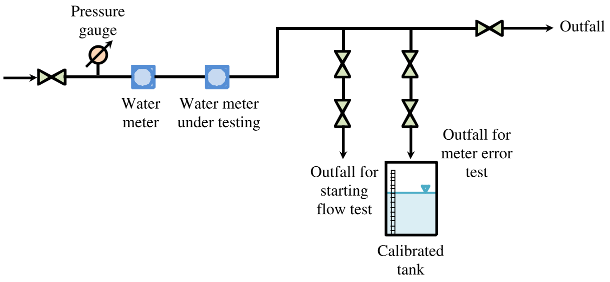

Figure 3 | A schematic of the test bench.

vibrations, shocks, and disturbances capable of altering velocity profile. All tests were carried out at constant hydraulic head provided by a variable velocity pump fed by a fixed level tank positioned on the laboratory rooftop. This ensures an undisturbed flow, and that the pressure at the inlet to the meter never exceeds the maximum admissible working pressure of the meter.

The test method applied to determine measurement errors is the so-called "collection" method (ISO 4064-3 2005). The quantity of water passed through the water meter was collected in a calibrated tank, and the quantity determined volumetrically. The flow rate was kept constant throughout the test, and the measurement was taken after the flow conditions stabilised. A switch diverted the flow into the calibrated tank at the beginning of the measurement, and diverted it away at the end. The meter was read during operation. The meter reading was synchronised to the flow switch. The volume collected in the tank is the volume passed. The measurement error was checked by comparing the the meter during the test against the calibrated tank. The error ε, expressed as a percentage, is defined by the equation:

$$\varepsilon = \frac{V_\mathrm{i} - V_\mathrm{a}}{V_\mathrm{a}} 100 \tag{1}$$

where V_i is the indicated volume and V_a is the actual volume.

ISO and EN standards set the guidelines for testing new meters, but the present study aims to test used and aged water meters and, for this reason, some modifications were put in place to address the specific needs of the study. In particular, two aspects were considered: first, the possible effect of network pressure on water meter error curves and the starting flow; second, the influence of the flow velocity on the starting flow. Regarding the first aspect, preliminary tests demonstrated no relevant impact of the system pressure on the error in pressure ranges found in the network revenue water meters (between 0.5 and 2 atm). For this reason, all tests were performed at 0.8 atm, which represents the average pressure on the revenue meters of the analysed network. For the second issue, the starting flow test was done by progressively increasing the flow in the system until the analysed water meter started to register the passing water volumes. This test was repeated seven times for each meter, and the average value was considered to characterise the water meter error curves.

Instead of running tests simply according to ISO standards, several discharges were adopted in order to evaluate the measuring error throughout the flow meter operating range. Approximately 6–7 points were obtained to characterise errors at different discharges between the starting flow and the overload flow rate. Table 1 shows the average starting flow and percentage errors at two relevant discharges used as references: 35 and 120 l/h. The former is the rounded starting flow of the last age class (40–45 years); the latter is the transitional flow rate of new class B meters. The selected flows are included in the range minimum-transitional flow for class B water meters and in the range transitional–permanent flow for class C. Therefore, class B meters should provide errors in the range ±5% for both flow values; class C should provide errors in the range ±2%.

The following trends can be taken from the laboratory studies:

- starting flow increases with the flow meter age, except for the age class between 25 and 30 years, which were characterised by highly reliable meters;
- the average error demonstrates a general under-registration of transited volumes, and the reported values are generally higher than limits prescribed by ISO and EN standards;
- meters under-registration is more evident for low flows confirming that the presence of local tanks may have an increased effect on water meter errors;
- considering that the average age of the flow meters in the network is between 5–10 years, laboratory results show that a significant water volume may be delivered to the users without being registered;

- 8% of the tested flow meters reported starting flows higher than 65 l/h.

Laboratory results can be used to characterised flow meter errors, but field studies are needed to evaluate the impact of such errors on real users, to account for their demand patterns and the presence of private tanks.

FIELD STUDIES

Water meter inefficiencies are caused by the combined effect of the meter error curve and water use pattern. In order to evaluate the effect of the presence of private tanks on meter under-registration, a field monitoring campaign of four households (A, B, C, D) and 1 residential building (E) in the city of Palermo was performed. All selected households have suffered intermittent distribution in the past, and for this reason, the users adapted to the unreliable water distribution service by building local tanks. In the last five years, higher water resource availability and improved system performance reduced the parts of the city where intermittent distribution is still an issue; nevertheless, many users still maintain private tanks to maintain their resilience to water scarcity. Some of the selected households are in this category while others are still connected to intra-day intermittent distribution systems. The selected users are depicted in Figure 4.

Figure 4 | Monitored residential users.

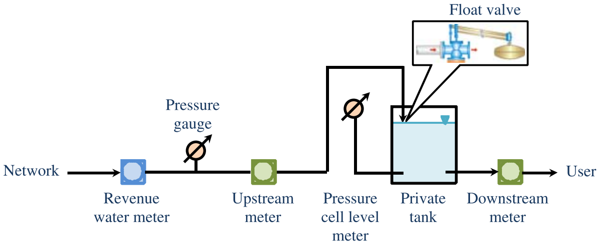

Figure 5 | A schematic of the monitoring installation.

Installed instrument packs consist of: a pressure sensor, a level meter based on a pressure cell, and two new and calibrated class C volumetric water meters. The pressure sensor was installed upstream of the revenue meter to measure and record network pressure data every 15 minutes. Each class C flow meter of diameter of 15 mm ($Q_{\min} = 15$ l/h, $Q_t = 22.5$ l/h, $Q_n = 1.5\,\text{m}^3$/h, $Q_{\max} = 5\,\text{m}^3$/h) was coupled to a data logger storing volume data every minute, and was installed both upstream and downstream of the private tank (Figure 5). The installation was done according to ISO 4064-2 (2005) and EN 14154-2:2005 + A1 (2007) specifications. Finally, tank water level was measured by the pressure cell level meter coupled to a data logger storing data every 15 minutes.

Household A was monitored for six days, from 14th to 20th December 2007. Figure 6 shows the temporal trend of the measured variables. Network water head data show that household A received water from the public network throughout the monitoring period. Therefore, the roof tank was always full, the float valve is partially open, and flows going through the meter into the tank are very low. The difference between the volume data recorded by the

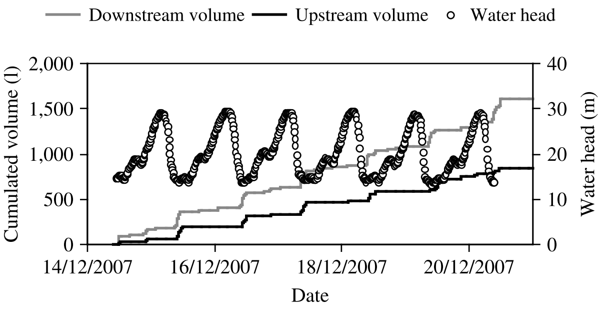

Figure 6 | Temporal trend of measured network water head and volume, downstream and upstream of the tank (household A).

upstream and downstream calibrated meters was very high (greater than 49%, at the end of monitoring period). This value must be increased by the error from the age of the revenue meter (11 years). The value used was 6%, and it was assessed as the difference between the volume recorded by the revenue meter and the new calibrated meter installed upstream of the tank.

Household B was monitored from 25th October to 5th November 2007. Figure 7 shows the temporal trend of the measured variables. The difference between volume data recorded by the two new water meters installed was 8%. This difference is due to the intermittent distribution during the day, with a service period of about 16 hours (6 PM to 10 AM). The tank is partially emptied by the user during the central part of the day, and then it is rapidly refilled during the late afternoon when pressure is sufficient to supply the tank. The additional error caused by the age of the revenue meter (22 years) was 3.2%.

Households C and D were each monitored for six days. Both of the roof tanks are about 30 meters above the roadway, and are completely emptied during day because network pressure is too low to feed them, and they are refilled during the evening. In these conditions, apparent losses caused by roof tank effect are negligible, since the flows circulating are always greater than the starting flows of both the revenue and the new calibrated meters. The only apparent losses are due to revenue meter age, equal to 4.3% and 6.1% for households C and D, respectively.

Residential building E was monitored from 13th to 21st February 2008, and is made up of 38 apartments. Figure 8 shows the temporal trend of the measured variables.

The private water tank was in the basement level of the building and was fed by a float valve. Water resources supplied by the network go into the tank, and then are delivered to the users via pumps. The continuous feeding of the tank, which has a water level always close to the maximum, should result in high apparent losses. Instead, the tank dampening effect caused meter under-registration of about only 4%, as flows circulating in the system are greater than the meter starting flow. In this case, the low level of apparent losses may be due to the characteristics of the float valve made by inhibited opening, thus allowing higher pulsing flows to enter the tank even when it is almost full. The effect of meter age yielded an error of 7.2%. Table 2 summarized the field study results.

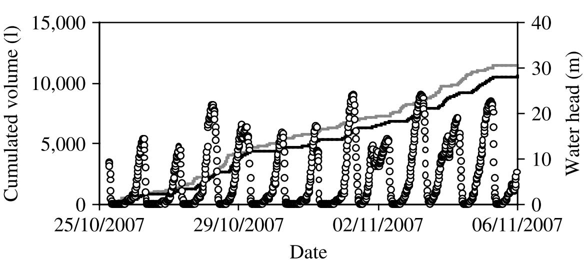

Figure 7 | Temporal trend of measured network water head and volume, downstream and upstream of the tank (household B).

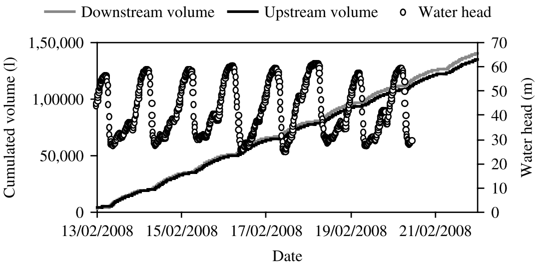

Figure 8 | Temporal trend of measured network water head and volume, downstream and upstream the tank (building E).

MODEL DESCRIPTION

In order to increase the applicability of the experimental study, a mathematical model was used to estimate apparent losses associated with both flow meter errors and dampening caused by private tanks. The model aims to represent the tank filling process, the variation of the tank inflow, depending on the network pressure, float valve characteristics, tank water level, and finally the measuring errors of

Table 2 | Apparent losses caused by private tank dampening and meter age effect

	Apparent losses due to private tank (%)	Apparent losses due to meter age (%)
A	49	6
B	8	3.2
C	–	4.3
D	–	6.1
E	4	7.2

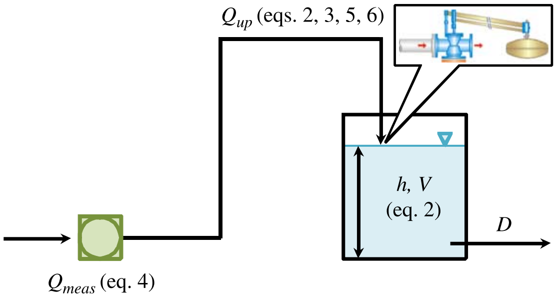

Figure 9 | A schematic of the modelled system.

the revenue water meter. Figure 9 shows a schematic of the modelled elements with the indication of the main variables.

The model is thus based on the combination of the tank continuity Equation (Equation (2)), the float valve emitter law (Equation (3)) and the measuring error Equation (Equation (4)). The main model equations may be summarised as:

$$Q_{\mathrm{up}} - D = \frac{\mathrm{d}V}{\mathrm{d}t} = A\frac{\mathrm{d}h}{\mathrm{d}t} \tag{2}$$

$$Q_{\mathrm{up}} = C_{\mathrm{v}} \cdot a \cdot \sqrt{2gP} \tag{3}$$

$$Q_{\mathrm{meas}} = f(Q_{\mathrm{up}}) = \begin{cases} \text{if } Q_{\mathrm{up}} < Q_{\mathrm{s}} \Rightarrow Q_{\mathrm{meas}} = 0 \\ \text{if } Q_{\mathrm{up}} > Q_{\mathrm{s}} \Rightarrow Q_{\mathrm{meas}} = Q_{\mathrm{up}} \cdot \left[1 - \frac{Q_{\mathrm{s}}}{Q_{\mathrm{up}}} \cos\left(\pi \frac{Q_{\mathrm{up}} - Q_{\mathrm{s}}}{\mathrm{Per}}\right)\right] \end{cases} \tag{4}$$

where D and Q_{up} are the user water demand and the discharge, respectively, from the distribution network to the private tank [m^3/s]; V is the volume of the storage tank [m^3] having area A [m^2] and variable water depth h [m]; C_{v} is the float valve emitter coefficient [–], a is the valve effective discharge area [m^2], P is the hydraulic head over the distribution network [m], and g is the gravity acceleration [m/s^2]; finally, Q_{meas} is the flow measured by the meter [m^3/s], Q_{s} is the flow meter starting flow [m^3/s], and Per is the semi-period of measurement error oscillation near zero, which both negative and positive errors to be accounted for, depending on passing water flows [m^3/s]. Float valve emitter coefficient C_{v} and the effective discharge area a depend on the floater position, and thus on the water level in the tank according to the following empirical laws:

$$C_{\mathrm{v}} = f(h) = \begin{cases} \text{if } h < h_{\min} \Rightarrow C_{\mathrm{v}} = C_{\mathrm{v}}^* \\ \text{if } h > h_{\min} \Rightarrow C_{\mathrm{v}} = C_{\mathrm{v}}^* \cdot \left(\frac{h_{\max} - h}{h_{\max} - h_{\min}}\right)^n \end{cases} \tag{5}$$

$$a = f(h) = \begin{cases} \text{if } h < h_{\min} \Rightarrow a = a^* \\ \text{if } h > h_{\min} \Rightarrow a = a^* \cdot \left(\frac{h_{\max} - h}{h_{\max} - h_{\min}}\right)^m \end{cases} \tag{6}$$

where $h_{\min}$ and $h_{\max}$ are the water depths at which the valve is fully open and fully closed [m] (Figure 10), respectively, C_{v}^* and a^* are the emitter coefficient [–] and the effective discharge area of the fully open valve [m^2], respectively, and m and n are shape coefficients [–], usually ranging between 0.5 and 2, and must be calibrated.

The formulation of Equation (4) was based on the above laboratory study, by determining the best fit to the experimental error curves. It is applicable to either the error curves characterised by metered water volume underestimation for the entire analysed range, or the curves that exhibit an oscillating behaviour with alternated positive and negative errors in the analysed flow range.

In summary, apart from system geometric characteristics that can be directly measured, the model is dependent on the following parameters that require calibration:

- Q_{s} and Per, which characterise the measurement error;
- C_{v}^*, m, and n, which describe float ball valve emitter law.

The float ball valve parameters were estimated during the model calibration, and will be discussed in the following paragraph. The evaluation of error curve parameters Q_{s} and Per were obtained by interpolation of the laboratory test results once the water meter age was known. This approach was necessary because the water manager was not legally authorised to dismount and remount the revenue water meter for laboratory testing.

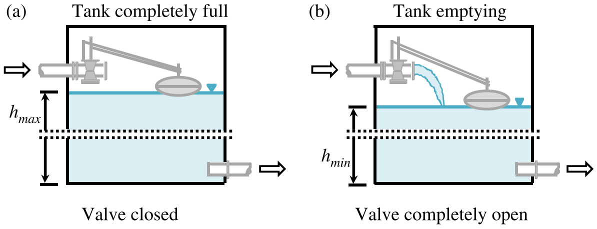

Figure 10 | Extreme positions of the float valve depending on the tank water level.

Table 3 | Model parameters and normalised RSME for measured flow (calibration) and for tank water level (validation)

	Flow meter age (years)	Q_s (10^{-6} m^3/s)	Per (10^{-6} m^3/s)	C_v^* (–)	m (–)	n (–)	Flow RSME (–)	Water level RSME (–)
A	11	3.39	2.37	0.56	1.02	1.08	4.1%	1.2%
B	22	4.42	4.63	0.44	0.95	0.82	3.6%	2.4%
C	14	3.71	6.18	0.66	1.31	1.44	4.2%	6.8%
D	7	2.26	3.64	0.69	1.41	1.48	2.7%	5.5%
E	33	4.70	4.14	0.74	0.67	0.61	1.2%	0.9%

RESULTS AND DISCUSSION

Model sensitivity analysis and calibration were carried out by running 10,000 Monte Carlo simulations. Sensitivity analysis demonstrated that the most sensitive parameters are the starting flow Q_s, which highly affects flow meter measuring errors in such installations, and the exponents m and n, which affect the float valve opening law curvature, thus modifying the flows entering the tank when it is nearly full.

In the present application, water demand D was monitored by the downstream meter, and then transferred to the model as an input time series. The water volumes measured by the upstream meter were used for model calibration, and local tank water levels were used for validation. Calibration and validation were done by evaluating the root square mean error (RSME) between the measured and simulated values (normalised using measured data average). The agreement between model results and measured data was generally good, as indicated in Table 3 and using building E as an example, in Figure 11. Errors in the calibration were always lower than 5%, and validation errors were always lower than 7%; higher validation errors were noted for households C and D, which are characterised by higher tank level oscillations, although they fall within quite an acceptable range.

Calibrated parameter variability is generally high, and a few considerations should be taken from the study:

- even if Q_s values are based on previous laboratory studies, and therefore not directly associated with the specific field application, the model calibration results and applications were acceptable, thus demonstrating that the model can be applied without an estimation of the actual revenue water meters;
- the model was shown to be somewhat sensitive to Per, so using a simple default constant from laboratory values did not have a significant impact on the model output;
- C_v^* variability is relatively small, as was its impact on model sensitivity both for its physical scarce variability and its influence on the tank being filled via low flows;
- m and n variability represents the main limitation to model generalisation, as they affect model results, and cannot be estimated without field or laboratory monitoring; a possible solution to this drawback is the laboratory characterisation of the specific parameter of interest widely used commercial valves, so that they can be applied to the study of interest.

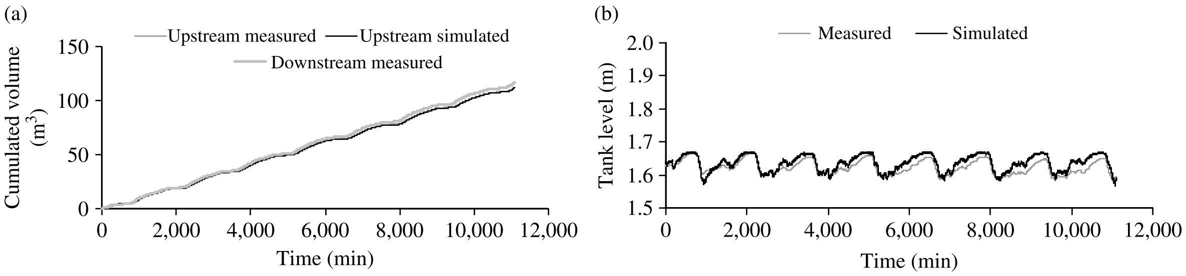

Figure 11 | Model application results for building E: (a) cumulated volumes measured and simulated at the upstream flow meter; (b) water levels in the tank.

Table 4 | Apparent losses simulated by the model varying flow meter age for household B in one week

Flow meter age (years)	Measured volume (m^3)	Water consumption (m^3)	Apparent losses (%)
Class C–new	12.645	13.699	−7.8
0–5	12.702	13.699	−7.3
5–10	12.623	13.699	−7.9
10–15	12.482	13.699	−8.9
15–20	12.207	13.699	−10.9
20–25	12.112	13.699	−11.6
25–30	12.518	13.699	−8.6
30–35	11.645	13.699	−15.0
35–40	11.427	13.699	−16.6
40–45	6.447	13.699	−52.9

According to the presented guidelines, the mathematical model was applied to the monitored households and building, and the characteristics of flow meter measuring error were changed. Table 4 shows the increase in apparent losses, and its dependence on flow meter age for household B.

CONCLUSIONS

There were three major aspects to this study: an initial laboratory study for characterising the measuring error of aged volumetric flow meters; a field study undertaken in order to quantify the effect of private tanks and user demand patterns on measurement error; finally, a mathematical model implemented to generalise the results of the study. Several conclusions can be taken from this work:

- measuring error increases rapidly with the flow meter age and it is significant even for meters installed less than 15 years ago; this is true especially when the starting flow is sufficient for the use of small fixtures (such as small sinks or boilers);
- private storage tanks can play different roles; if the tank is almost full, the flow meter errors are amplified due to the low flows entering the tank. If the tank is periodically emptied and filled, the flow meter errors can be lower, because refilling usually requires much higher flows than those typical of indoor water use;
- the model was shown to be applicable to real systems, providing a reliable tool for evaluating the potential present and future apparent losses for specific users or specific areas in a network.

This study demonstrates that the risk of having high apparent losses connected with private storage tanks is present in the case where tanks are constantly supplied; i.e., in all those networks where intermittent supply strategy is used as a method of coping with water scarcity. In such cases, the poor service reliability requires users to adopt local tanks to enable continuous supply, this behaviour resulting in high apparent losses. Increasing the service reliability and focusing on a communication strategy (information campaigns and population involvement) can greatly improve the situation; moreover, some technical upgrades, such as the introduction of impulse valves, can be adopted to transform low flows that usually fill up the tanks in high flow pulses.

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