Investigations into under-registration of customer meters in Palermo (Italy) and the effect of introducing Unmeasured Flow Reducers

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Abstract: During the last two years, Palermo Water Utility and Palermo University have been investigating the under-registration of customer meters installed upstream of private storage tanks and the effect of introducing Unmeasured Flow Reducers (UFRs). The first series of tests consisted of measurements (inlet pressure, tank inflow, tank outflow) for two individual users located in different situations (a family villa and a separate condominium). The meter under-registration was monitored and calculated over a period of approximately a week. UFRs were then installed, and the test repeated, to allow the benefit of UFR installation to be quantified in each case. A second and different type of comparison, based on introduction of UFRs to a small District Metered Area (DMA) was carried out in late 2008, and the analysis (using a software specially developed for such test) has been carried out. The experimental campaign showed that UFR can effectively reduce water meter under-registration even if it can have a limited impact in those cases in which water meters age is excessively high.

Introduction

Water supply system management has to be based on a deep knowledge of its cost, of the network water and energy consumption and of the level of water losses. Every leakage control program has a water system balance as a common starting point (Ismail and Puad, 2006). As reported in the IWA Standard International Water Balance (IWA, 2000), water losses can be computed as the difference between System Input Volume and Authorized Consumption and consists of Real Losses and Apparent Losses. Real losses are the volume lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering while Apparent losses consist of Unauthorised Consumption and all types of metering inaccuracies (Lambert, 2002).

In the last few years, a great effort has been carried out to better understand the processes on which real losses are based and to reduce them to an economic value. Recently water utility interest included not only real losses but also apparent losses investigation. While real losses are physical losses and a cost for the water utility, apparent losses are not physical but financial losses which represent a lack of revenue for the water utility being due to water volumes taken by the network, consumed by users but not paid for.

This volume may have a great impact on the company water balance and economic balance and water utilities have great interest to recover it.

Apparent losses are caused by water thefts, meter reading and billing errors, meter under-registration (Rizzo et al., 2007). Water thefts arise from illegal behaviour of users being connected to the network without authorization, bypassing or damaging customer meter. Meter reading and billing errors are due to human errors: meter can be misread and volume data can be wrongly charged in the water utility billing system. Meter under-registration is brought about by intrinsic errors affecting water meter and changing with flow rate passed through it.

There are several possible reasons leading customer water meters losing their efficiency, some of which are: meter wear and tear, demand profile or demand type problems. Ageing or an excessive abrasion of meter moving parts often lead to under-register; private roof tank interposed between the customer meter and the points of use modify the standard demand profile of domestic users laminating the instantaneous water demand, reducing the flow rates passing through the meter and so increasing metering errors. In short, while water thefts, meter reading and billing errors are directly related to water utility management and may be removed by improving company procedures, water meter inaccuracies are considered to be the most significant cause of apparent losses and the hardest to quantify and reduce (Rizzo and Cilia, 2005).

In order to assess the share of water consumption that is registered by the meter and so the percentage of customer meter under registration, two parameters are needed: the metrological performance of the meter at different flow rates and the standard domestic consumption profile which is modified due to private tank lamination effect in case of presence of customer storage tanks.

The performance of any type of meter can be described by the mean of key flow values (see figure 1.1) identifying different operational fields on the meter performance curve (European Committee for Standardization, 2005).

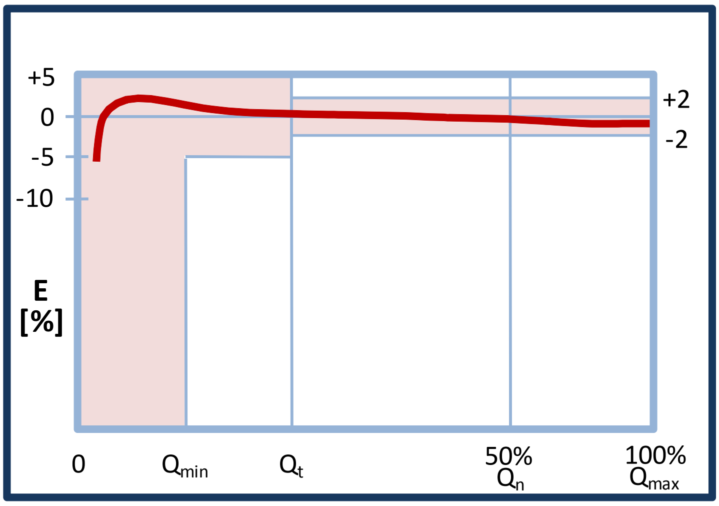

Figure 1.1 Performance curve of a new water meter

The first value is the start-up flow rate (Qa), a flow below which the water meter registers no consumption at all. When the flow is equal to the Minimum flow rate (Q1) or Qmin the meter error should be within ±5%. When the flow is equal to the transition flow (Q2) or Qt, the meter reaches its maximum accuracy and its error is about ±2%. Then we have the nominal flow (Q3) or Qn, being half of the maximum flow (Qmax).

When flowrate through the meter is lower than Q1, meter error increases very rapidly. When an old customer meter is coupled with a private water tank, it may not register even more than the 50% of volume passed through it.

The effect of private tank on customer meter under registration can be evaluated analysing its emptying – filling cycles produced by a float valve inducing flows lower than meter start-up flow rate.

Several hydraulic devices appeared on the market in the last few years, trying to control and reduce apparent water losses connecting with meter inability to measure low flow rates. A possible solution to cope with private water tank lamination effect is the introduction of pulsing valves modifying the tank filling process. The UFR (Unmeasured Flow Reducer) installed upstream or downstream the customer meter changes the way the water flows through it: at low flows the UFR causes water to pulse through the meter at values above the start-up flow rate, at higher flows it allows water to pass undisturbed.

In the last two years, Palermo Utility and Palermo University have been investigating the under-registration of revenue meters installed upstream of private storage tanks and the effect of introducing Unmeasured Flow Reducers (UFRs). The first series of tests consisted of measurements (inlet pressure, tank inflow, tank outflow) for two individual users located in different situations (a family villa and a separate condominium). The meter under-registration was monitored and calculated over a period of approximately a week. UFRs were then installed, and the test repeated, to allow the benefit of UFR installation to be quantified in each case.

The results of these tests, which were quite diverse, are described, and suggestions given relating to additional information needed to fully interpret further tests of this type.

A second and different type of comparison, based on introduction of UFRs to a small District Metered Area (DMA) was carried out in late 2008. Results are presented and analysed.

Experimental analysis of single households

In order to evaluate the capability of the UFR to reduce apparent losses connected with the effect of private tank on meter under-registration, a field monitoring campaign on 2 households of the city of Palermo (Italy) has been carried out.

The selected households (A and B) have suffered intermittent distribution in the past and, for this reason, the users adapted to the unreliable water distribution service by building local reservoirs. In the last 5 years, higher water resources availability and improved system performance greatly reduced the areas of the city where intermittent distribution is still an issue; nevertheless, many users still maintain local reservoir for increasing their resilience to water scarcity.

The campaign has been composed of two periods: in the first period, water volumes, recorded upstream and downstream of the tank, network pressure and tank water level (at only one household) have been measured before installing UFR device, in the second after its installation. In both the households the customer meters (also named revenue meters) are between 5 and 10 years old.

Instrument packs set up have been made up of: a pressure sensor, a level meter based on a pressure cell and two new and calibrated class C volumetric water meter (Figure 1). The pressure sensor has been installed upstream the customer meter to measure and record network pressure data every 15 minutes at different flow rates. Each class C flow meter (diameter 15 mm) coupled to a data logger storing volume data every minute have been installed upstream and downstream the private tank.

The installation has been made according to the specifications of European Committee for Standardization (2005). Finally, at only one household, tank water level has been measured by the pressure cell level meter coupled to a data logger storing data every 15 minutes.

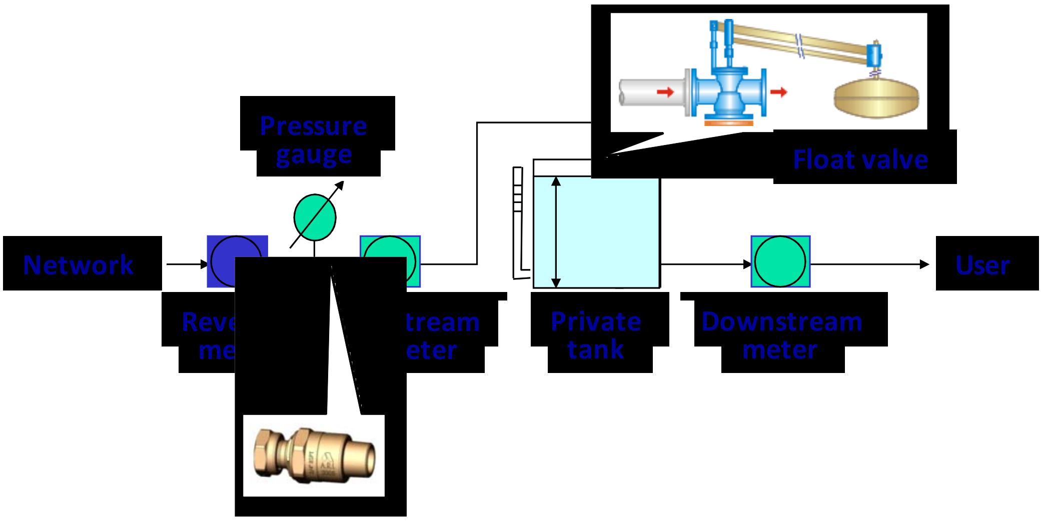

Figure 1.2 Installation scheme at monitored households

The first and the second monitoring periods of household A lasted 6 days, respectively from 14th to 20th December 2007 and from 7th to 12th February 2008. Network pressure data showed the household A has always been supplied by the public network during the two monitoring periods. Therefore, before UFR installation, the roof tank was always full, the float valve was partially open and flow through the meter into the tank was at very low flowrates.

The difference between volume data recorded by upstream and downstream calibrated meters was very high, about -45% at the end of the first monitoring period (see Table 1). In the second period an UFR was installed upstream the first new meter and the private tank creating short pulses at a flowrate higher than meter Start-up Flowrate. The UFR led the meter to measure most of the volume passed through it. Table 1.1 shows that the difference between volume data recorded by upstream and downstream new meters changed from -45% to about -7%.

Household B monitoring periods took place from 25th October to 6th November 2007 and from 20th to 26th March 2008. At the end of the first period (before UFR installation), the difference between volume data recorded by the two new water meters installed upstream and downstream the private tank was about -12%.

This result was due to pressure network values, equal to zero during day time and sufficient to take water from the network from about 6 pm to 10 am. Therefore the tank is partially emptied by the user during the period of low pressure and no service and then it is rapidly refilled during the late afternoon when pressure increases.

At the end of the second period, characterized by the presence of an UFR device, cumulated volumes recorded by the new water meter upstream the private tank have been higher (about 8%) than downstream ones (see Table 1.1). This occurrence depends on the effect of UFR on allowing water passes at values higher than meter starting flow, on the downstream meter inability to measure flow lower than start-up flow rate (Qa) and on the phase displacement between tank emptying – filling up.

Table 1.1 Measured volume upstream and downstream of the private reservoir

Household		Upstream meter [l]	Downstream meter [l]	Error [%]
A	Cumulated volume without UFR	806	1464	-45
	Cumulated volume with UFR	1088	1176	-7
B	Cumulated volume without UFR	11460	13020	-12
	Cumulated volume with UFR	7349	7411	-1

Experimental analysis of a small district metered area

In order to test the efficacy and reliability of UFR, a small district metered area (SDMA) within the Palermo water distribution network has been identified. The SDMA is included into a bigger district called “Noce-Uditore”, one of the 46 districts of the water distribution network of the city.

This district was completely renewed in 2002 by substituting the old distribution cast iron mains ruined by time and by corrosion with a system of new polyethylene PE100 pipes. The SDMA identified is made by 434 m of pipelines DE110 and 14 service connections which supply 52 end users.

Meters installed include 33 Class C turbine meters (age of meters up to 11 years), 17 Class B meters and 2 Class A meters (age of meters higher than 11 years). In addition almost all clients have storage tanks, making consumption at low flows a relevant part of total customer meter consumption.

Figure 1.3 Map and view of the small District Metering Area (14 connections, 52 consumers)

The following test methodology has been applied to test the viability of the Unmeasured Flow Reducer (UFR) in the SDMA. Methodology include a total of 5 sequential steps described below.

Step 1 - Consumer Audit

Test in the field confirmed that the zone is hydraulically encapsulated and that all the consumers are metered and no meter is blocked. A computer database (in excel) was build to allow to keep track of these metered consumers, in parallel with existing billing data.

In order to improve reliability of test a checklist of actions has been prepared and applied to zone as described in following figure.

CHECKLIST OF ACTIONS TO IMPROVE RELIABILITY OF TEST	Yes or No
Is Zone Inflow Meter correctly sized to record minimum and maximum flows during the tests?	Yes
If Zone Meter Under-registration is claimed, has it been confirmed from Zone Inflow Graphs?	Yes
Were all service connections either metered or shut off during the tests?	Yes
Were malfunctioning meters replaced before the tests were started?	Yes
Were customer meters read on site and the readings double checked by two people?	Yes
Was the Zone checked to identify and stop any unauthorised consumption before the tests?	Yes
Were all detectable reported and unreported leaks identified and repaired before and after the tests?	Yes

Figure 1.4 Checklist of actions for field test in trial zone

Step 2 - Pilot Zone Master Meter

A DN 50 mm class C zone meter has been installed onto the inlet water supply into the zone (see arrow in figure 2) to measure zone input.

Step 3 - Eliminate all Real Losses and other Apparent Loss Components Prior to the Test

'Noce Uditore' zone has been selected also because all mains and connections have been recently replaced and there are no existing leaks in the system.

Therefore, except for Unavoidable background leakage (UBL), all following components of zone water balance can be considered equal to zero: Other Authorised Consumption (OAC), Unauthorised Consumption (UC), Detectable Unreported Leaks (DUL), and Detectable Reported Leaks (DRL).

Step 4 – Field test exercise

The Field test is executed in two stages as follows. In the first stage readings of the consumer meters and the zone master meter are taken before and after a two weeks period.

A comparison of the zone meter to the accumulated consumer meters will give the % Customer Meter Under-registration without UFRs. In the second stage the same procedure is repeated with the UFR units in place. The Customer Meter Under-registration value now shows a reduced value due to the UFR functionality.

Step 5 – Zone water balance and comparison of Customer Meter Under-registration CMU with and without UFRs

AMAP Palermo used the software UFRCalcs developed by ILMSS Ltd (Allan Lambert) to implement a methodology to calculate zone balance and compare Customer Meter Under-registration (CMU) with and without UFRs.

Zone balance calculation and Customer Meter Under-registration CMU are shown in figure 1.5 for pilot zone.

PART A: ZONE WATER BALANCE WITHOUT UNMEASURED FLOW REDUCERS (UFRs)						
Period of 'Before UFR' Test		21,00	days	24-ott-08	to	14-nov-08
Components of Zone Water Balance without UFRs installed				Volume m3	litres/ connection / day	% of Corrected Zone Inflow
Inflow to Zone	Inlet meter recorded volume ZMRV =			458,09	419,5	100,0%
	Zone meter under-registration ZMU =	0,00%	of ZMRV	0,00	0,0	0,0%
	Corrected Zone Inflow CZI = ZMRV + ZMU =			458,09	419,5	100,0%
Authorised consumption, Apparent losses and Real Losses in Zone	Customer meter recorded consumption CMRC =			323,31	296,1	70,6%
	Other authorised consumption OAC =	0,00%	of CZI =	0,00	0,0	0,0%
	Unauthorised consumption UC =	0,00%	of CZI =	0,00	0,0	0,0%
	Unavoidable background leakage UBL	0,41	m^3/day =	8,70	8,0	1,9%
	Additional background leakage ABL =	0,00	m^3/day =	0,00	0,0	0,0%
	Detectable Unreported Leaks DUL =	0,00	m^3/day =	0,00	0,0	0,0%
	Detectable Reported Leaks DRL =	0,00	m^3/day =	0,00	0,0	0,0%
	Customer meter under-registration without UFRs installed =			126,08	115,5	27,5%
	Customer Meter Under-registration CMU without UFRs =			39,00%	of Customer Meter Recorded Consumption	
	Customer Meter Under-registration CMU without UFRs =			28,06%	of Best Estimate of Metered Consumption	

Part B: ZONE WATER BALANCE WITH UFRs				
28,00	days	12-dic-08	to	09-gen-09
Components of Zone Water Balance with UFRs		Volume m3	lit/conn/day	% of Corrected Zone Inflow
Inflow to Zone	ZMRV =	598,07	410,8	100,0%
	ZMU =	0,00	0,0	0,0%
	CZI =	598,07	410,8	100,0%
Authorised consumption, Apparent losses and Real Losses in Zone	CMRC =	475,59	326,6	79,5%
	OAC =	0,00	0,0	0,0%
	UC =	0,00	0,0	0,0%
	UBL =	11,60	8,0	1,9%
	ABL =	0,00	0,0	0,0%
	DUL =	0,00	0,0	0,0%
	DRL =	0,00	0,0	0,0%
	CMU =	110,89	76,2	18,5%
CMU with UFRs =		23,32%	of Customer Meter Recorded Consumption	
CMU with UFRs =		18,91%	of Best Estimate of Metered Consumption	

Figure 1.5 Zone water balance for 'Noce Uditore' zone (UFRCalcs Software)

Results achieved for Customer Meter Under-registration (CMU) before and after UFR installation are as follows:

- CMU (without UFRs) = 28,06 % of Best Estimate of Metered Consumption
- CMU (with UFRs) = 18,91 % of Best Estimate of Metered Consumption

High values of CMU is due to old inaccurate meters and presence of storage tanks.

During the test period the UFR proved to be effective in reducing Customer Meter Under-registration allowing to get an additional 9,15% revenue. Remaining Customer Meter Under-registration has been reduced almost to zero by replacing all customer meters with new turbine Class C meters DN 15 mm.

Conclusions

This study investigates possible solutions to water meter under-registration in households characterized by the presence of local private reservoir. Apparent losses due to under-registration are relevant in these cases mainly because of the presence of floating valves which make a relevant part of the flow entering the private reservoirs at low flow rates even lower than the start-up flow rate of the water meter.

In both experimental analysis (on single households and on trial small DMA) the application of the UFR proved to be effective in the reduction of customer meters under-registration. Customer Meter Under-registration has been drastically reduced in those cases that are characterized by relatively new water meters, while Customer Meter Under-registration has been greatly reduced, but is still present in cases characterized by older water meters.

The case of the small DMA is emblematic because the introduction of UFR valves produced a relevant reduction of Customer Meter Under-registration allowing to get an additional 9,15% revenue. Customer Meter Under-registration was then reduced to almost zero after the substitution of old water meters in the small DMA.

Following the above tests and results achieved, AMAP Palermo is now aware that Customer Meter Under-registration can be drastically reduced with a combined strategy including economic meter replacement plan and installation of UFRs.

Above management policy, which is actually under development, will include economic evaluation of costs and benefits considering deterioration of meters accuracy, meter replacement costs and economical data such as sale price of water, presence and influence of storage tanks, cost and effectiveness of UFR installation, etc..

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