Reduction of customer meters under-registration by optimal economic replacement based on meter accuracy testing programme and Unmeasured Flow Reducers

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Abstract: This paper aims to demonstrate that through the practical application of advanced methodologies, a significant improvement in the efficiency of distribution systems is not only feasible, but can also provide an example to encourage other utilities to improve their performance.

This paper will introduce the research methodologies used and the benefits realised from incorporating whole of life cost, customer flow profiling and actual water use into a scientifically based domestic meter replacement programme.

The methodology has been successfully applied to some Italian case studies and a proposal of optimal replacement period for domestic water meters based on loss/gain calculation has been approved and implemented by the utilities.

In addition the UFR (unmeasured flow reducer) - a device that causes water to go through the meter in batches at flows below the minimum accurately measured flow – has been comprehensively tested in both the field and in the lab. Unrecorded consumption at low flow rates can be evaluated and financial benefits of UFR installation calculated, as part of meter replacement investment strategy.

Results achieved include design of optimal replacement of domestic water meters based on calculation of Net Present Value (NPV) of proposed replacement plan(s), with and without UFR installation.

Introduction

Water utilities install and maintain domestic water meters but so far in most utilities customer meters are replaced on a run-to-fail basis, as in many countries there is not yet a mandatory requirement to replace the water meters. As a consequence residential water meters' park is quite old and inaccurate.

The international and national literature review demonstrated that there has been limited research to determine optimal replacement for water meters. However, available literature did influence the methodology of the project, including the selected test-flows, and the way in which the data was analysed.

A valid methodology for data collection and analysis, which considers actual revenue loss due to inaccurate in-service meters has been developed and applied.

This paper investigates the financial implications to late replacement which adversely affects capital investment, compromising economic viability of proactive replacement programmes, and raising the cost of water service provision.

Methods

The methodology described in this paper, which has been applied in a number of Italian utilities, include the activities described in following chapters.

Review of in-service domestic meters and meter selection

Multiple data types are required for this evaluation, including: meter error tests with low, medium, and high flows for meters; percentage of time residential customers use water at the low, medium, and high flow rates by season; nominal residential meter replacement cost; annual average residential water use per customer; and residential water rates, etc..

In each utility where the methodology has been applied, a large-sized database of water meter was provided by Utilities staff to Marco Fantozzi for analysis in Microsoft Excel format. The large database consisted of typical DN 13 and DN 15 meters manufactured by various manufacturers and placed in service from 1950.

These reports provided the basis for identifying the meters to test within the project.

Meter selection

For each utility a number of meters (defined according to statistical analysis in order to represent the behaviour of the Residential water meters' park) were removed from the utility water system over a three-month period and tested for accuracy. In order to have the calculations with the lowest uncertainty, the selection must take into account the influent criteria affecting the accuracy of a water meter such as: brand and mark of the meter, age, consumption and agressivity of the site where the meter has been installed.

A total of 738 meters (as a statistical sample of around 141.000 meters of 4 water utilities) were removed from the utility water systems over the last year period and tested for accuracy. The average nominal service life for these meters range between 1 year to 20 years.

Meter removal, storage and testing

Meters were removed by Client's existing meter maintenance contractor and stored in a moist environment (drums of water) so that the meter mechanisms did not dry out prior to the meters being flow tested.

The equipment used to test the in-service domestic meters were in accordance to IS04064/3 and completed by an independent meter-testing laboratory officially accredited using certified meter testing bench (according to CEE 75/33).

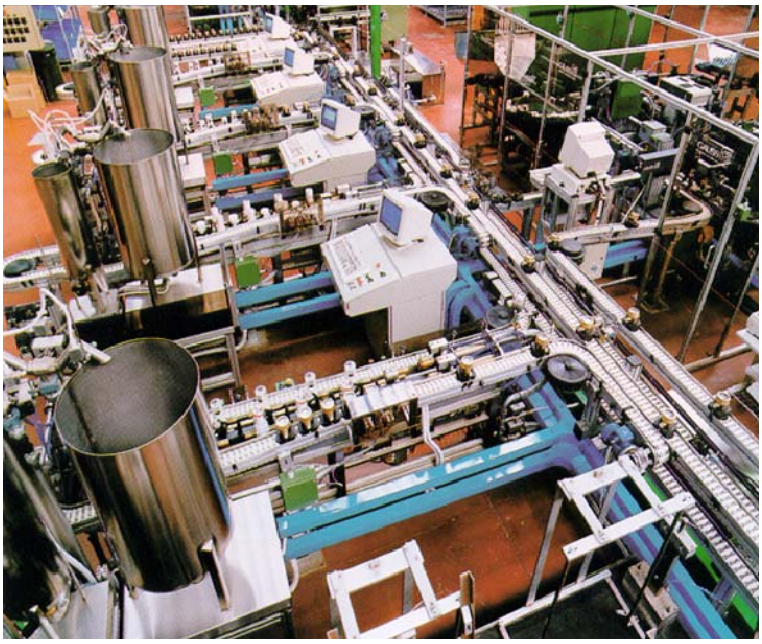

Figure 1.1 Meter-testing laboratory (source: Maddalena, Italy)

Definition of water consumption patterns

The accuracy of a water meter is a function of the circulating flowrate. Therefore the ability of that instrument to accurately measure water consumption strongly depends on the flowrates at which consumers use water. In particular, a water meter registers no consumption at all when the flowrate is below its start-up flow rate (Qa), and registers with more than 5% error when the flow rate is between its start-up flow rate and its Minimum flow rate (Q1).

In order to define water consumption pattern for the typical customer, two following methods have been used and results compared:

- Use standard domestic consumption profiles available in technical literature. The problem with this method is that the actual consumption pattern may differ from the predicted one. It is possible that a customer uses a large amount of water at constant low flows.
- Replace a number of user’s meter by a reference one, previously calibrated in laboratory. As this method is by far much more expensive than the others, the method has been applied to 50 selected customers. Water demand pattern has been determined by installing data loggers on the 1 l/h pulse emitter of water meters. This procedure allows estimating consumption at both, low and high flows.

Results achieved using the two methods above were very similar and brought to adopt the consumption profile shown in following figure.

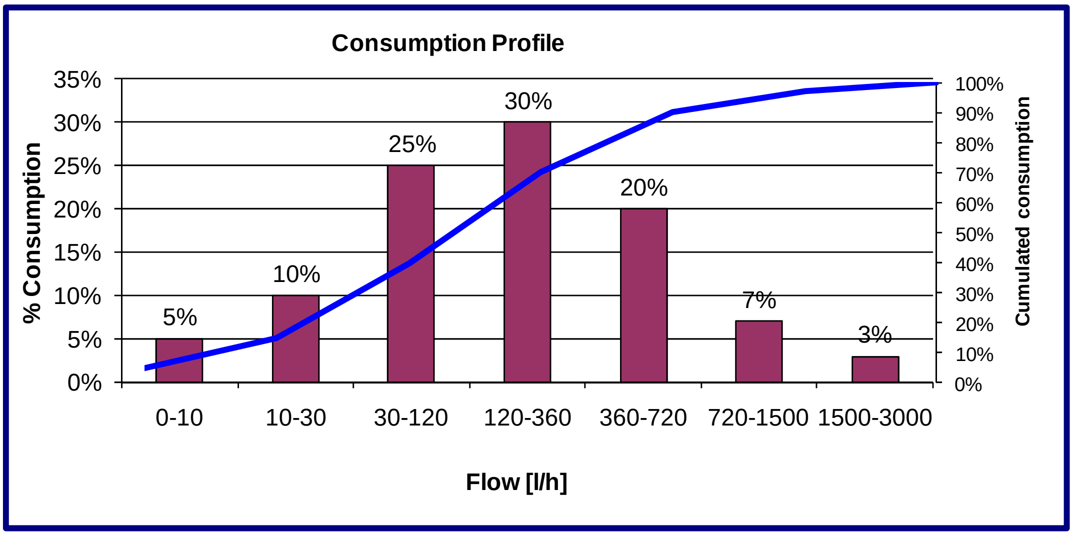

Figure 1.2 Consumption profile according to flow rate category for a residential consumer

This chart is called the pattern of consumption. According to the tested flow rates, the meter gives its answer in term of which percentage of the volume it can measure. Therefore the error of the meters at different flow rates can be calculated.

Therefore we need to calculate the efficiency which corresponds to what the meter can measure when it sees a certain pattern of consumption. It is the "multiplication" of the error curve by the pattern of consumption.

Meter testing in lab

Accuracy tests were conducted at low, medium, and high flows as established by Water Meter testing standards for this size meter according to EN 14154-3 (2005). Test flows are defined as shown in Table 1 below.

Table 1.1: Test flows

Test Flow					
DN (mm)	**N° meters**	**Qnominal (Q3) (l/h)**	**0,3 Qnominal (0,3 Q3) (l/h)**	**Qtrans (Q2) (l/h)**	**Qmin (Q1) (l/h)**
15	**738**	**1.541**	**473**	**124**	**32**

In addition for each tested meter the Start-up Flowrate has been measured in order to quantify the volume of water delivered to client, which is not measured at all.

As a meter has an error depending on flow rate, it is important to look at the consumption of a user by representing it according to ranges of flow rates and indicating for each range the proportion of water which is passing. By doing this, it gives a weight for each flow rate interval. The following table shows how consumption volumes at different flow rates are grouped in flow bands.

Table 1.2 Pattern of consumption of a residential consumer in flow bands

Flow Range (l/h)	% of Customer Consumption	Flow Band	Weight for flow band
0-10	5%	Qmin (Q1)	15%
10-30	10%	Qmin (Q1)	
30-120	25%	Qt (Q2)	55%
120-360	30%	Qt (Q2)	
360-720	20%	0,3 Qn (0,3 Q3)	20%
720-1500	7%	Qn (Q3)	10%
1500-3000	3%	Qn (Q3)	

Data analysis and calculation of weighted error and water lost

The Average Weighted Error (AWE) of each in-service meter was calculated. AWE combines the four flow rate errors that are measured for each in-service meter and combines these into one, weighting the relevance of each flow by taking into account the Domestic Water Usage profile in Table 1.2.

Most water meters do not register any flow below 15 L/hour (DN 15mm meters).

In regards to leaks and low flow rates that are not measured, this quality can be defined mainly through the Start-up Flowrate (Qa) that is the leftmost point of the error curve. This metrological parameter is quite difficult to define.. It can be defined as the value of the flowrate that generates motion in the meter when the mechanism is at rest. The same concept could be expressed as the stoppage flow rate meaning the minimum flow rate necessary to maintain the meter in motion. This definition (Arregui et al. 2007) assesses more accurately the capacity of a meter to measure a small leak.

The start-up flow rate of existing installed meters is a function of the volume registered since they have been installed (that is directly related to age), type and class of the meter.

But it is also important to take into account the error at the low flow rate and particularly when the flow rate is between Qa and Q1. Then the error curve is generally stable in time at medium and high flow rates.

Different curves have been used for different turbine meters (single jet and multi jet meters) and for different size (DN 15 and DN 20). By combining the Patterns of consumption with the Ageing laws, we can calculate the evolution in time of the water meters park efficiency according the influent criteria.

Meter testing in lab with the UFR

The UFR (Unmeasured Flow Reducer produced by A.R.I.) is a smart and simple product, installed on the water main (In-Line), adjacent to the water meter, which regulates the water flow so that there is no water flow at all through the UFR part of the time, while the rest of the time, the flow is high enough to be measured by the water meter.

The operating range of the UFR were between 0 and 25 l/h in order to impact both the flow rates below Qa but also a significant part of the flow rate between Qa and Q1. When the flow rate increases over the maximum value of the operative range of the UFR, the UFR remains permanently open, so that it does not interfere with measurements.

A sample of 33 meters of Acegas APS utility has also been tested with the UFR (Unmeasured Flow Reducer produced by A.R.I.) in Maddalena Meter-testing laboratory in Udine (Italy). Aim of the test has been to measure the contribution of the UFR at low flows which would not be measured by the water meters with high Start-up Flowrate. The variable flow control valve in the test rig has been adjusted to a flow rate of 5 l/h and then to a flow of 10 l/h.

In tests on 33 meters DN 20 MM Class C Turbine meters, Q1 = 25 l/h, with meters age between 1 to 7 years, with and without UFR, the following results have been achieved in terms of average benefits (water recovered) at different flow rates:

+ 94% recovered water for flows below Start-up Flowrate,

+ 31,8 % recovered water at Start-up Flowrate.

+ 14,4 % recovered water at Q1.

The following figure describe the volume of water recovered (measured by the meter below Start-up Flowrate) for each of the tested meters.

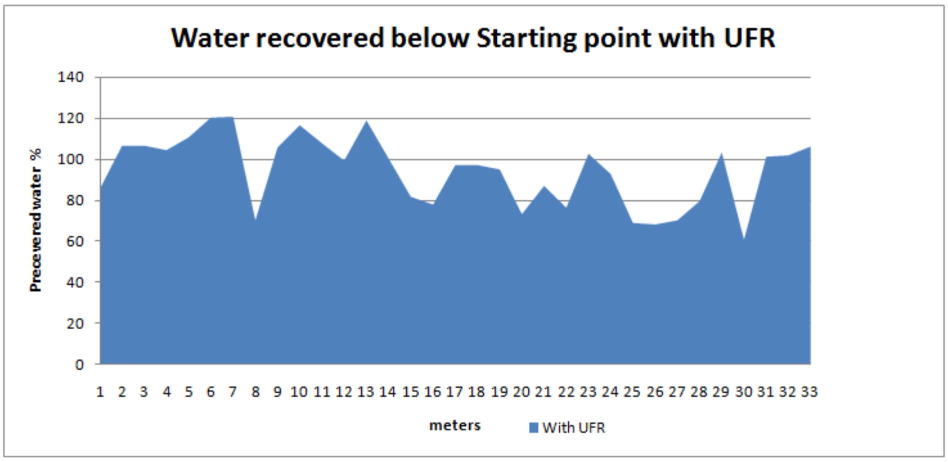

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Figure 1.3 Volume (in %) of water recovered for each of the 33 tested meters.

Meters Renovation Frequency

Replacing the meters only when are clogged or considerably old or used (high volume) is a policy that is admissible only in those utilities with low price of water and metering costs to be kept very low.

Anyway, this low profile policy will lead to significant meter errors and, as a general rule, to a mediocre control of consumption. In fact, in many developed countries, due to national or local regulations, meters must be checked and eventually replaced after a certain period of time. However a replacement policy should be based on a revenue loss/gain calculation based on deterioration of meters accuracy, meter replacement costs and economical data such as sale price of water, etc..

Optimal replacement period for domestic meters

The optimal replacement for an in-service domestic water meter was formally calculated by using the Net Present Value of the Revenue Lost or Gained for all the Italian utilities.

The following figure shows that for the utility under examination, at the eleventh year it is convenient to replace the meter, in case of installation of the UFR.

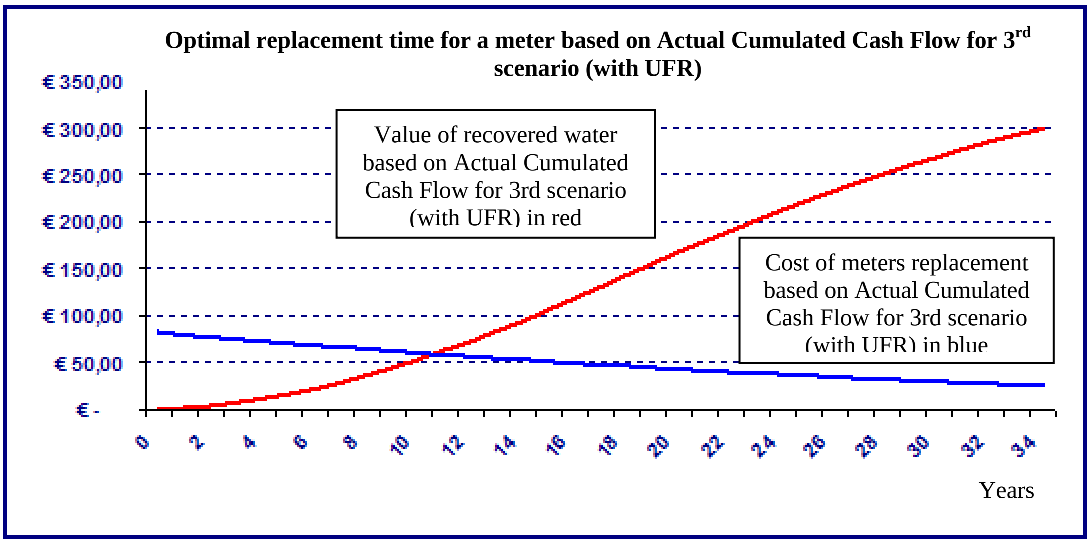


Figure 1.4 Optimal replacement time for a meter based on Actual Cumulated Cash Flow for 3rd scenario.

Revenue loss/gain calculation

With the aim to assess the economic benefits of a meter replacement policy and of the installation of the UFR, three different scenarios have been considered:

- 1st scenario: a policy where meters are replaced only on a run-to-fail basis.
- 2nd scenario: A policy where meters are replaced based on an economic calculation.
- 3rd scenario: A policy where meters are replaced based on an economic calculation and the UFR is also installed. In this case additional measured volume has been considered as well as additional cost due to UFR installation.

The following figure describe for one of the Italian case studies with around 16500 meters, the volume of water lost for each of the 3 scenarios over a 10 years period. The 3rd scenario (with UFR) enables to achieve the best result in terms of volume of water recovered.

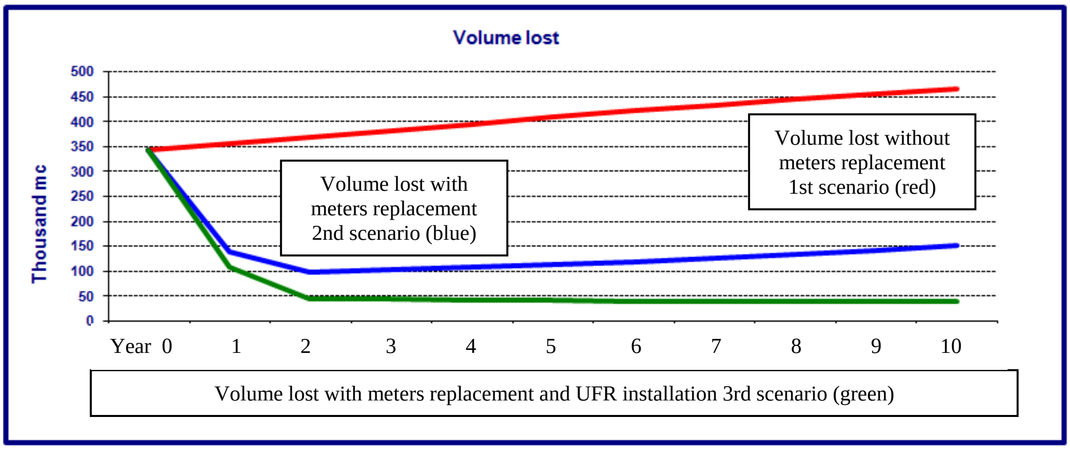


Figure 1.5 Volume of water lost for each of the 3 scenarios over a 10 years period.

The Cash Flows have been calculated as difference between the costs of the first scenario and the costs and benefits of the other two scenarios.

The following figure describe for the same Italian case study, the economic benefit (Net Present Value, NPV) due to recovered water with the implementation of 2nd and 3rd scenario over a 10 years period. The 3rd scenario (with UFR) enables to achieve the best result in terms of cumulated cash flow and NPV.

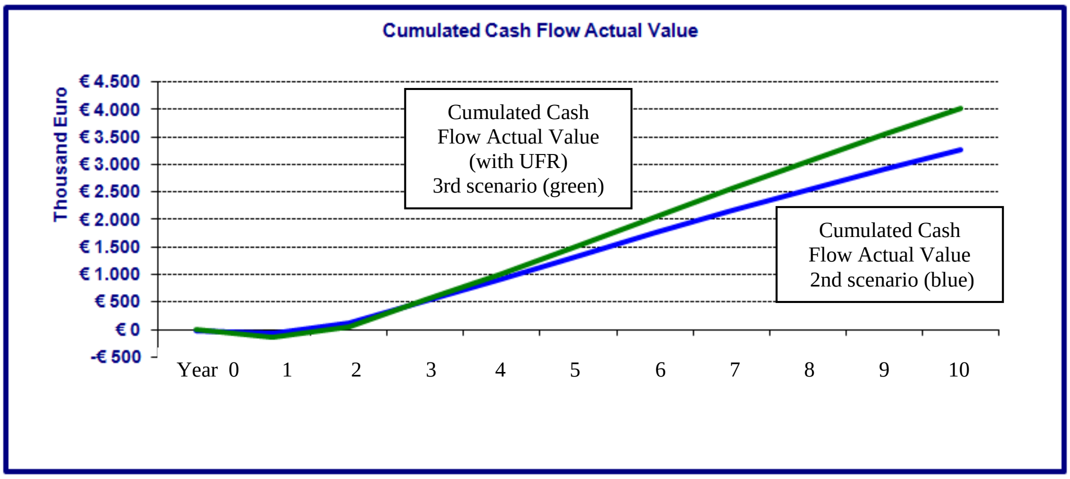
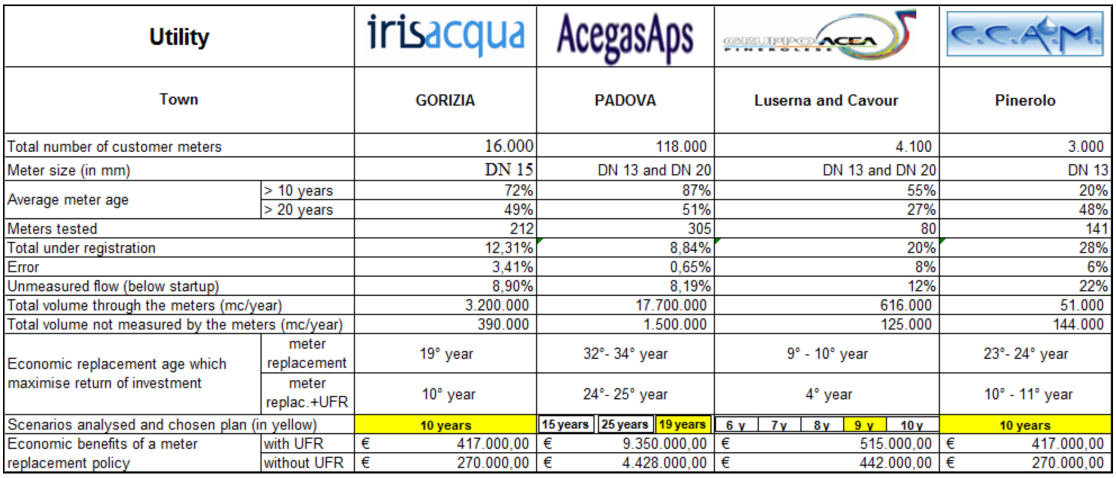


Figure 1.6 Actual Cumulated Cash Flow for 2nd and 3rd scenarios over a 10 years period.

Results and Discussion

As meter type, sale price of water, meter error and Start-up Flowrate etc. were different in the four utilities considered in the study, the optimal replacement period was also different, as shown in following table.

Table 1.3 Pattern of consumption of a residential consumer in flow bands



Utility		irisacqua	AcegasAps	GRUPPO ACEA PINEROLESE	C.C.A.M.
Town		**GORIZIA**	**PADOVA**	**Luserna and Cavour**	**Pinerolo**
Total number of customer meters		16.000	118.000	4.100	3.000
Meter size (in mm)		DN 15	DN 13 and DN 20	DN 13 and DN 20	DN 13
Average meter age	> 10 years	72%	87%	55%	20%
	> 20 years	49%	51%	27%	48%
Meters tested		212	305	80	141
Total under registration		12,31%	8,84%	20%	28%
Error		3,41%	0,65%	8%	6%
Unmeasured flow (below startup)		8,90%	8,19%	12%	22%
Total volume through the meters (mc/year)		3.200.000	17.700.000	616.000	51.000
Total volume not measured by the meters (mc/year)		390.000	1.500.000	125.000	144.000
Economic replacement age which maximise return of investment	meter replacement	19° year	32°- 34° year	9° - 10° year	23°- 24° year
	meter replac.+UFR	10° year	24°- 25° year	4° year	10° - 11° year
Scenarios analysed and chosen plan (in yellow)		**10 years**	**15 years** **25 years** **19 years**	**6 y** **7 y** **8 y** **9 y** **10 y**	**10 years**
Economic benefits of a meter replacement policy	with UFR	€ 417.000,00	€ 9.350.000,00	€ 515.000,00	€ 417.000,00
	without UFR	€ 270.000,00	€ 4.428.000,00	€ 442.000,00	€ 270.000,00

In the four case studies analysed, optimal replacement periods calculated by using the Net Present Value range between 9 and 19 years.

In all the four cases UFR installation progressively increases Cash Flow over time, making meter replacement plus UFR installation more beneficial than meter replacement alone.

Conclusions

Universal metering has been in place in most utilities in many countries since the 50'. Nevertheless since now meters were mostly replaced only on a run-to-fail basis.

This paper demonstrates that through the practical application of advanced methodologies, the prediction of system-specific economic meter replacement policies is feasible as well as a significant improvement in the efficiency of distribution systems. The optimal replacement for an in-service domestic water meter was formally calculated by using the Net Present Value.

The moment when a meter is changed is an ideal one to install the UFR as well, as we know that even new meters do not measure very low flows and as meter Start-up Flowrate increases over meter life. In addition, installation costs are kept to a minimum in case of simultaneous installation.

Following the above it is expected that water utilities become more sensitive to the water metering issue and that meters management policy would be modified to include economic evaluation.

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