Smart Water Fund

Final Report

Understanding apparent water losses through non-registration of domestic meters

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UNIVERSITY OF TECHNOLOGY SYDNEY

Smart Water Fund

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Understanding apparent water losses through non-registration of domestic meters

The relevance for non-revenue water and meter replacement policies

PREPARED FOR: THE SMART WATER FUND

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DISCLAIMER

The results of this research were based on a specific and small sample of tests and should not be considered as representative of all meters.

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Executive summary

Research to date has shown that a fleet of meters becomes less accurate with age and usage. This is commonly understood to be related to the *under-registration*, which is the inaccuracy in the actual meter once activated by a flow. What is less understood is the relevance of the *non-registration* by the meter of the low flows that pass through the meter undetected. The combination of the two can be regarded as the *unregistered* volume and can be expressed as:

unregistered volume = non-registered volume + under-registered volume

The findings from this study indicate that the non-registration is more significant than under-registration, and that both get progressively worse with usage, which has specific relevance for the assumptions used in accounting for non-revenue water and for specifying the replacement schedule for a fleet of meters.

In summary the outcomes of the study indicate that:

1. **non-registration is more significant than under-registration in understanding non-revenue water**, since it could account for a larger percentage of the non-revenue water passing through a meter (illustrated in Table A). The additional volume associated with the percentage of non-registration can help further explain the *apparent losses* (*customer metering inaccuracies*) when calculating the water balance and the overall water loss.
2. **consideration of both the non-registration and under-registration** components of the unregistered volume should be made **when preparing a meter replacement policy**. The percentage of non-registered volume increased more significantly with higher total registered volumes as compared with under-registration (see Table A). The consideration of non-registration therefore has the effect of bringing forward the timing for meter replacements.
3. **the unregistered volume increases with the usage of the meter.** Therefore using an average for a fleet of meters is not reliable enough, and improved estimates can be achieved by **assessing the losses per registration group**. This is especially relevant when calculating the water loss due to meter error and/or specifying the replacement schedule.

Table A: Comparison of the percentage of unregistered volumes

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+
Non-registered %	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%
Under/over - registered %	0.4%	0.3%	0.2%	0.1%	-0.3%	-0.4%	-0.4%
Unregistered % (Combined)	**-0.6%**	**-1.1%**	**-1.6%**	**-2.2%**	**-3.0%**	**-3.5%**	**-4.0%**

For comparison purposes the data obtained for this report (Table A) revealed that the range of non-registration was in the range of 1% to 3.5% of average total daily consumption, while for under-registration it was 0.4% to -0.4%, depending on the total registered flow through the meter. The combination of the two should be used to determine the estimated customer meter inaccuracies.

The results produced in Table A were been derived through the synthesis of the three separate sets of data, viz.:

1. An Unmeasured-Flow Reducer (UFR) was used to reduce the amount of water that flows undetected below the flow meter measurement threshold by changing the flow regime at low flow rates. The results produced the average percentage error in meter non-registration below 5L/hr shown in Figure A.

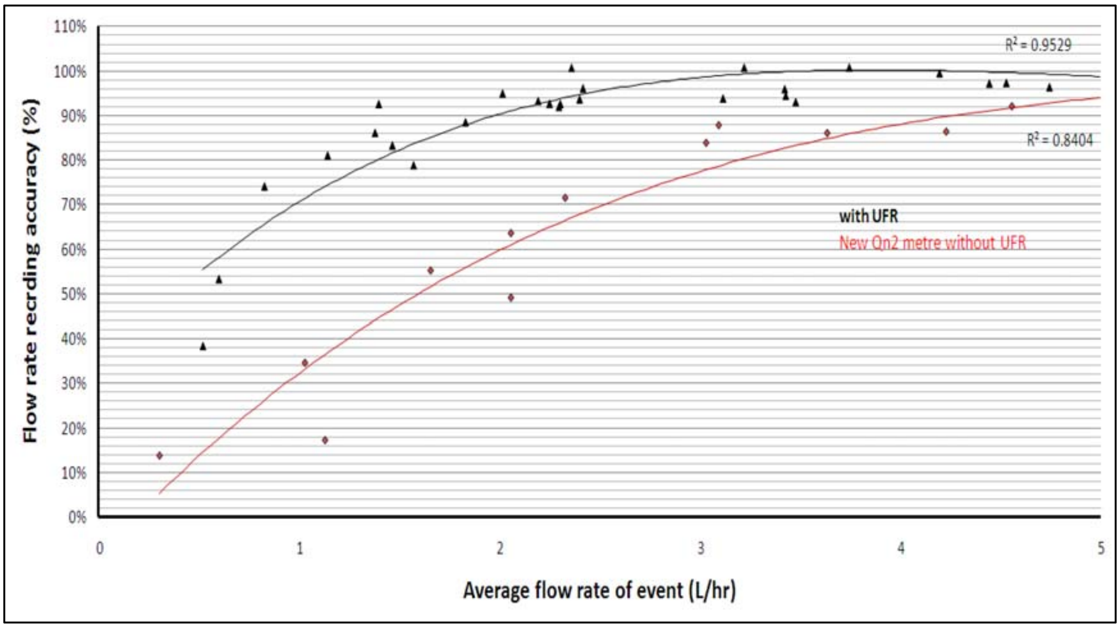


Figure A: Flow rate registration accuracy for a new meter with and without UFR

2. Data was analysed from a sample of domestic customer flow profiles to determine the proportion of average low flow volumes in a day. The average flow below 5L/hh/day was calculated to be 1.31% of the total average household daily consumption.

3. A sample of meters, consisting of new and those with an excess of 3000kL of total registration, were tested to determine their starting registration flow rate. The starting registration was found to be in the order of 2.2 times greater for a meter with a total registration of 3000+kL.

The unregistered volume is made up of both *under-registration* and *non-registration*, as explained previously, and will therefore have implications for both non-revenue water accounting and for setting guidelines and policies for the replacement of domestic meters. The percentages for each registration group will vary for each utility however, based on meter type, network and operating conditions and annual volumes passing through the meter.

The research in this report is based on a limited sample size, range of meters and operating conditions. Further work is needed to undertake to improve the confidence associated with the non-registration percentage losses by undertaking further testing and analysis on a larger sample and range of meters.

In addition, in it important that utilities continue to update the replacement policies and non-revenue water calculations, based on new meter test data undertaken by the utilities, to ensure that more robust and reliable policies are developed.

Table of Contents

Table of tables

Table of figures

1 Introduction

Most Australian utilities have meter replacement programs, but the criteria for replacement vary from utility to utility. It is argued that different operating conditions and pipe materials, the condition of the network and water quality affect the meters differently. However there is still limited understanding of meter accuracy performance with in-situ age, particularly when considering its starting or minimum registration level (Qs). Theoretically, water with a flow rate less than the Qs flow rate of a meter (between 1-15 L/hr) cannot be measured.

In the past, much work has been done on meter accuracy with utilities testing batches of meters in accordance with the NMI R49-2 (2009b). However, the low flows at which the meters are tested at are usually not low enough to measure the actual minimum registration level for each meter. So traditionally under-registration (or over registration) at the various standard flow rates has been assumed to be the primary indicator of the proportion of non-revenue water due to meter inaccuracy, when considering the water balance. The research reported here, will show that **non-registration is more significant than under-registration** and should be considered together with under-registration when estimating the non-revenue water and for determining the replacement intervals for a fleet of meters.

Research has also shown that a fleet of water meters can become less accurate with age and usage (i.e. under-registration of flow) and, as will be shown in this report, the non-registration of the meter can also increase with usage, thereby resulting in higher volumes of unaccounted for water (Arregui et al 2005, 2006).

As part of this project, two pieces of work were conducted by the Centre for Infrastructure Engineering and Management (Griffith University) which serve to inform this report, viz.:

- *Experimental study on meter registration accuracy at low flow rates and benefits of UFR implementation* (CIEM 2011a)
- *Determining average volumes of residential water consumption in flow rate interval categories* (CIEM 2011b)

Work on meter testing was undertaken by Wide Bay Water in the initial stages of this project and have been reported on in their reports:

- *Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters*, (WBW 2009)
- *Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters, Stage 2 Refining the Predictions from Stage 1* (WBW 2011)

The following sub-sections provide a summary of the CIEM reports, results of the analysis considering the impact of usage on the starting registration flow of meters, and a proposed methodology based on the available research for calculating the non-registration volume of a suite of meters and for scheduling the replacement of a meter based on non- and under-registration calculations.

2 Understanding non-registration of domestic water meters

2.1 Meter testing at low flows

In the first study, an Unmeasured-Flow Reducer[1] (UFR) was used to show that non-registration below 5L/hr was apparent (CIEM 2011a). For a standard new Actaris CTS-5 (DN20), the Qs (i.e., minimum flow rate) is specified as 2L/hour (or 0.033 L/min). Theoretically, water with a flow rate less than the Qs flow rate of a meter cannot be measured.

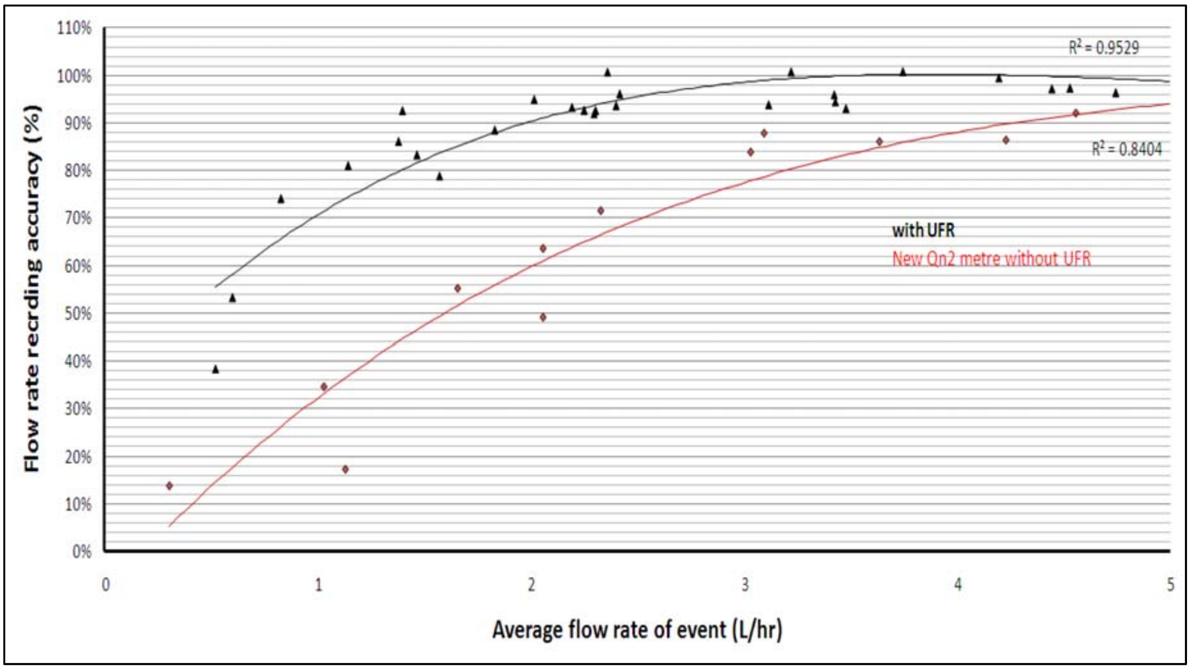


Figure 1: Flow rate registration accuracy for new CTS-5 DN20 meter with and without UFR

A summary of key findings from the study (CIEM 2011a) are detailed below and are shown in column C of Table 1:

- A new Actaris CTS-5 water meter (DN20) has poor water recording accuracy less than 3 L/hr.
- A new Actaris CTS-5 water meter displays accurate measurement after 6 L/hr with or without installation of UFR.
- For flow rates from 0–2 L/hr, there are significant under registration of flows without the UFR, with only 13.87% and 36.24% recorded from flow rates of 0–1 L/hr and 1–2 L/hr, respectively. Whereas, with the UFR, the measured flows have been improved to individually 55.21% and 85.06%, indicating that measurement in these lower flow rate intervals improved with the UFR by 41.35% and 48.82%.
- From 2–3 L/hr, with the UFR, there is almost 95% (i.e., 94.49%) flow recording accuracy, compared to 61.48% without the UFR (i.e. 33.01% more accurate than without UFR);
- From 3–6 L/hr (potentially 2L/hr), the meter with UFR is considered accurate. The UFR contributes to 5.30-10.51% improvements in the measurement recording accuracy of the new Actaris meter.

[1] The UFR is designed to reduce the amount of water that flows below the flow meter measurement threshold by changing the flow regime through the water meter at low flow rates.

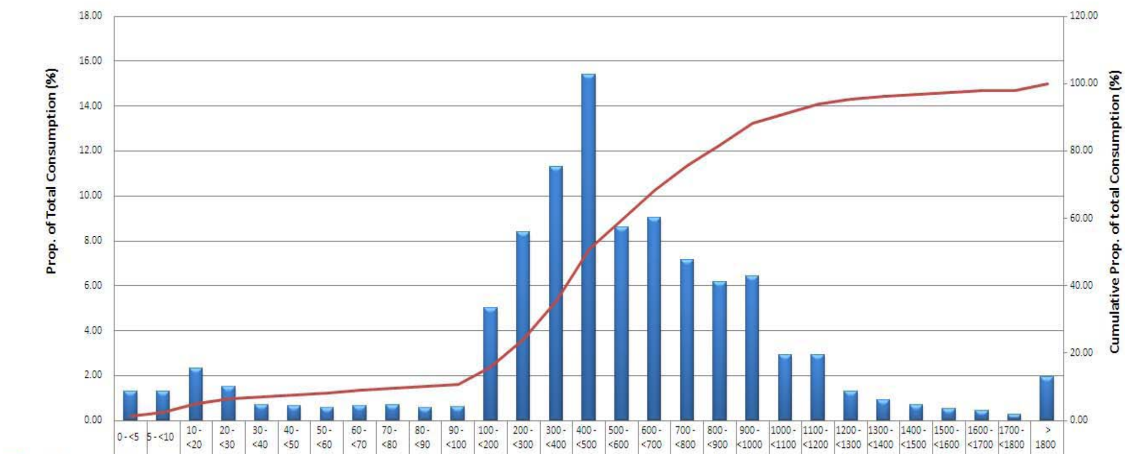
- The reason for some degree of non- or under-registration at these very low flow rate levels when using the UFR could not be established.
- Based on the recorded accuracy with and without UFR, the average accuracy for flows recorded below 5L/hr is 57.3%. This inaccuracy is attributed to non-registration.

This report gave an estimation of the magnitude of non-registration. The next section explores how prevalent low flow rates are, which could give rise to significant non-registered volumes.

2.2 Consumption flow rate profile: prevalence of low flow events

To determine how often low flow events occur in a day, data was analysed from a sample drawn from the South East Queensland and Melbourne regions. The results are summarised as follows (CIEM 2011b):

- The first 11 flow rate categories shown in **Figure 2** (i.e., from ≤ 5 L/hr up to the 91-100 L/hr category) generally showed low flow events. Sources include leaks, internal taps, toilets, dishwashers, and some part of shower and clothes washer events. Data collection does not include volumes of consumption in flow rates less than 2L/hr (i.e. minimum registration of new meter is 2L/hr in specification and potentially higher in practice) (See previous section);
- The middle flow rate range made up the majority of total water use (i.e., from 100L/hr to 1200L/hr), especially the 300-600L/hr interval. Sources include showers, clothes washers, irrigation and external taps; and
- The rest of the range (i.e., from 1200L/hr to over 1800L/hr) can be attributed to showers, clothes washers, irrigation, external taps and uncommon water usage (e.g., service break leaks).



	0 - <5	5 - <10	10 - <20	20 - <30	30 - <40	40 - <50	50 - <60	60 - <70	70 - <80	80 - <90	90 - <100	100 - <200	200 - <300	300 - <400	400 - <500	500 - <600	600 - <700	700 - <800	800 - <900	900 - <1000	1000 - <1100	1100 - <1200	1200 - <1300	1300 - <1400	1400 - <1500	1500 - <1600	1600 - <1700	1700 - <1800	> 1800
Prop of Tl Con(%)	1.31	1.29	2.32	1.49	0.70	0.64	0.57	0.66	0.67	0.55	0.60	4.99	8.39	11.28	15.38	8.60	9.01	7.14	6.17	6.43	2.89	2.90	1.30	0.92	0.67	0.51	0.43	0.26	1.92
Cum Pro of Tl Con(%)	1.31	2.60	4.91	6.40	7.10	7.73	8.30	8.96	9.63	10.18	10.79	15.78	24.17	35.44	50.82	59.43	68.44	75.57	81.75	88.18	91.08	93.97	95.27	96.20	96.87	97.37	97.80	98.07	100.00

Figure 2: Proportion and cumulative proportion of total water consumption (%) in each flow rate category (SEQ and Melbourne region combined sample, *n* = 406)

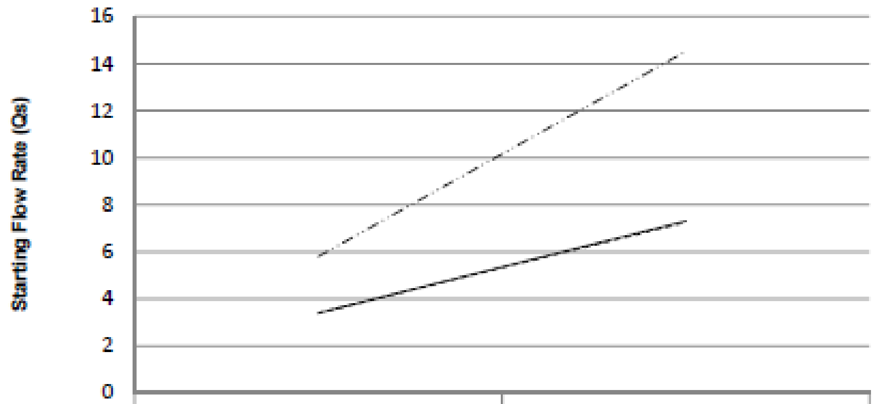
The first three categories in **Figure 2** are most important for non-registered volumes and the following values are therefore for estimating the volume of non-registered flow recommended in conjunction with the information in Section 2.1:

- **0 ≤ 5 flow rate interval category**: 4.42 L/hh/d or 1.31% of total residential consumption
- **5 ≤ 10 flow rate interval category**: 4.35 L/hh/d or 1.29% of total residential consumption
- **10 ≤ 20 flow rate interval category**: 7.83 L/hh/d or 2.32% of total residential consumption

2.3 Impact of usage on non-registration

It is well known that meter aging, or more correctly meter usage, affects meter accuracy (Arregui et al 2005), the older the meter the less accurate. The decreasing accuracy of the meter not only results in under-registration of usage volume but also results in higher non-registration thresholds (as was shown previously). As such any estimation of non-registered water must take account of meter age and type. Very little information about the relationship of non-registration of meters and age is available.

To address this knowledge gap, a sample of 90 meters from across the Melbourne utilities with differing registration volumes were tested to determine their Qs (WBW 2011). The meters were assembled in sets of three meters with similar usage registration. The worst case for each set was recorded, i.e. the flow at which the last meter began to register a flow. The results are illustrated in Figure 3, where it can be seen the older meters (3000+ kL) exhibit a Qs which is more than double the Qs of a newly installed meter. The test results for the ELSTER V100 and the ACTARIS CT5 produced very similar characteristics (the two lines virtually overlap).



	New	3000kL+
ELSTER V100	3.4	7.31
ACTARIS CT5	3.4	7.26
RMC WM204	5.8	14.52

Figure 3: Starting flow rate (Qs) of tested meters

As can be seen, the Elster and Actaris meters exhibited the same characteristics under low flows. In order to simplify the analysis in this report, the calculations in the subsequent sections have been based on the results of these two meters.

2.4 Calculation of meter non-registration

This section combines the findings from 2.1, 2.2 and 2.3 to develop an estimate of the potential non-registered volume.

The recording accuracy of the meter in column C of **Table 1** is based on the non-registration determined by using the UFR in Section 1.1. The allocation of average volume per flow rate interval below 5L/hr is not known, therefore a distribution for this range has been estimated based on the practical likelihood and is shown in column A. For the other ranges, the proportion of flow per range has been assumed to be equal. Using a illustrative example based on an average daily volume of 207 litres, the non registered water can be calculated to be 1%, which in this case is 2.067 L/day.

Table 1: Non-registered water for a new Actaris meter based on an average flow of 207 L/day

Flow rate interval (L/hr)	Proportion of volume in category	Measured Volume (L/hh/d)	Recording accuracy (%)	Adjusted volume (L/hh/d)	Non-registered water (L/hh/d)
	A	B=A*daily volume	C	D=B/C	E=D-B
0 to 1	0.05	0.136	0.15	0.904	0.768
1 to 2	0.13	0.339	0.35	0.968	0.630
2 to 3	0.23	0.610	0.60	1.017	0.407
3 to 4	0.30	0.814	0.85	0.957	0.144
4 to 5	0.30	0.814	0.90	0.904	0.090
5 to 6	0.20	0.534	0.95	0.562	0.028
6 to 7	0.20	0.534	1.00	0.534	0.000
7 to 8	0.20	0.534	1.00	0.534	0.000
8 to 9	0.20	0.534	1.00	0.534	0.000
9 to 10	0.20	0.534	1.00	0.534	0.000
10 to 11	0.10	0.480	1.00	0.480	0.000
11 to 12	0.10	0.480	1.00	0.480	0.000
12 to 13	0.10	0.480	1.00	0.480	0.000
13 to 14	0.10	0.480	1.00	0.480	0.000
14 to 15[2]	0.10	0.480	1.00	0.480	0.000
					2.067 (1%)

Using a similar approach for a well used meter that had registered in excess of 3000 kL, the estimated total non-registered volume is 7.362 L/hh/d, i.e. 3.5% (See **Table 2**). In Section 1.3 of this report, it was shown that a meter registering in excess of 3000 kL, the worst case Qs can be expected to be 7.4 L/hr. Given that for a new meter the worst case for the Qs was 3.4 L/hr and this equated to 85% average non-registration, the same logic was applied to the well used meter. 85% average non-registration for the well used meter was associated with 7.3 L/hr, and similar linear curve was applied back to the flows of less than 1 L/hr to assign the percentage of recording accuracy in column C of **Table 2**.

[2] Flow rates between 15-20 L/hr have not been included in this table since the finding in Section 2.1 indicate that non-registration at these flows in negligible.

Table 2: Non-registered water for a used Actaris meter which has registered more than 3000 kL, based on an average flow of 207 L/day

Flow rate interval (L/hr)	Proportion of volume in category	Measured Volume (L/hh/d)	Recording accuracy (%)	Adjusted volume (L/hh/d)	Non-registered water (L/hh/d)
	A	B=A*daily volume	C	D=B/C	E=D-B
0 to 1	0.05	0.136	0.08	1.808	1.672
1 to 2	0.13	0.339	0.18	1.868	1.529
2 to 3	0.23	0.610	0.29	2.083	1.473
3 to 4	0.30	0.814	0.40	2.012	1.199
4 to 5	0.30	0.814	0.52	1.577	0.764
5 to 6	0.20	0.534	0.63	0.852	0.318
6 to 7	0.20	0.534	0.74	0.723	0.189
7 to 8	0.20	0.534	0.85	0.628	0.094
8 to 9	0.20	0.534	0.90	0.593	0.059
9 to 10	0.20	0.534	0.95	0.562	0.028
10 to 11	0.10	0.480	1.00	0.480	0.000
11 to 12	0.10	0.480	1.00	0.480	0.000
12 to 13	0.10	0.480	1.00	0.480	0.000
13 to 14	0.10	0.480	1.00	0.480	0.000
14 to 15	0.10	0.480	1.00	0.480	0.000
					7.362 (3.5%)

Based on the percentage of non-registration for the two ends of the usage spectrum, the percentage of non-registration for the range of registered volumes can be linearly interpolated (this is shown in **Table 3**). These calculations have been based on the Actaris meter testing results.

Table 3: Percentage of non-registration associated with each range of total registered volume

Range of total registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+
% non-registration	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%

3 Under-registration of domestic meters

All meters have specified ranges of accuracy and must comply with the NMI R 49 specifications for maximum permissible error for domestic flow meters, as shown in **Table 4** (NMI 2009a). The under-registration of a fleet of meters is best established by annual sample testing to take into account the specific network and operating conditions, and the registered usage of the meter.

Table 4: Permissible meter registration error (NMI 2009a)

	Permanent flow rate	Flow rate zone	Accuracy
Class 1	>100kL/hr	Lower zone (<32 L/hr)	± 3%
		Upper zone (>32 L/hr)	± 1%
Class 2	<100kL/hr	Lower zone (<32 L/hr)	± 5%
		Upper zone (>32 L/hr)	± 2%

To obtain the average error for a meter across a range of flows, the meters are tested against the flow rates shown in **Table 5**, and the errors weighted according to the flow profile (similar to the one shown in **Figure 2**) of an average domestic consumer.

Table 5: Meter testing flow rates and weightings

Flow Rates L/Hr	Weighting %
300	**27.0%**
600	**42.0%**
1200	**23.0%**
2400	**8.0%**
	100.0%

Table 6 provides the average error in the meter registration for a batch of 60 Actaris 20mm meters, based on the total registration of the meters. As can be observed, the results fall well within the NMI specifications. Also, the error in the registration begins as an over-registration when the meter is relatively new and under-registers when the meter has registered greater than 2000 kL.

Table 6: Percentage of under-registration associated with each range of total registered volume for a batch sample (South East Water)

Total meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+
Under/over - registered %	0.4%	0.3%	0.2%	0.1%	-0.3%	-0.4%	-0.4%

When compared with the non-registration shown in **Table 3**, it is clearly demonstrated that for the Actaris 20mm flow meter the under-registration is much less, and hence both sources of error should be taken into account when considering the effectiveness of the meter – as is shown in the next two sections.

4 Relevance for Non-Revenue Water

Customer metering inaccuracies account for some of the apparent losses when undertaking a water balance of the system. Since this value cannot be precisely measured or determined, WSAA has provided a default value for the purposes of preparing the water balance.

System Input Volume	Authorised Consumption	Billed authorised Consumption	Billed Metered Consumption	Revenue water
			Billed unmetered consumption	
		Unbilled Authorised Consumption	Unbilled metered Consumption	**Non-Revenue Water (NRW)**
			Unbilled Unmetered Consumption	
	Water Losses	**Apparent Losses**	Unauthorised consumption	
			Customer metering inaccuracies	
		Current Annual Real Losses (CARL)	Leakage on Transmission and distribution mains	
			Leakage and overflows at storage Tanks	
			Leakage on service connections, up to customer meter	

Figure 4: Water Balance

The WSAA (2010) default value for average non-revenue water based on an *under-registration* of residential meters is 2.0% of recorded residential metered volume. In earlier versions of the WSAA Handbook (2006), the default value for residential meters was 1.5% for under-registration, with an additional 0.5% being added to the residential meter error to account for meter non-registration. This change results in a simplification of the sources of meter error and loses the focus on non-registration as key source of non-revenue water, as is demonstrated in this report. The unregistered consumption should be expressed as:

unregistered volume = non-registered volume + under-registered volume

Based on the data obtained for this report, the range of non-registration is in the range of 1% - 3.5% of average total daily consumption, and 0.4 to -0.4 for under-registration, depending on the total registered flow through the meter. The combination of the two should be used to determine the estimated customer meter inaccuracies, as is illustrated in **Table 7**.

Based on a random sample of 71 100 meters from City West Water (Sample A)[3], the average non-registration was calculated to be 1.50% for the range of total meter registrations, which equates to an average annual financial loss of $4.39 per flow meter (based on an average price of $1.77/kL). Whereas, the average under-registration for the same batch of meters was calculated to be a net gain of 0.25%, with a corresponding annual financial gain of $0.73per meter. The non-registration loss in this example is six times the magnitude of the under/over-registration volume. The average for the batch will vary depending on the number of meters that fall in the low registration rage

[3] The data for this example is provided in more detail in Appendix 4 of this report.

versus those that fall in the high registration group. The higher the registration, the higher the non- and under-registration will be. In this example, two thirds of the meters fall in the <500kL group, which accounts for the relatively low average meter error.

Table 7: Unregistered volumes for City West Water meter sample A

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Average for Total	
Non-registered:									
% of non-registered/ measured volume	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%	**-1.50%**	
Average non-registered volume per meter	-1.4	-2.5	-3.4	-5.0	-6.4	-7.7	-12.1	-2.5	KL/year
Average lost revenue per meter per year	-2.54	-4.50	-5.97	-8.88	-11.26	-13.68	-21.46	- 4.39	$ per flow meter
Under-registered:									
% of under-registered/ measured volume	0.40%	0.30%	0.20%	0.10%	-0.30%	-0.40%	-0.40%	**0.25%**	
Average under-registered volume per meter	0.6	0.5	0.4	0.2	-0.7	-1.0	-1.4	0.4	KL/year
Average lost revenue per meter per year	1.02	0.95	0.65	0.39	-1.25	-1.76	-2.43	0.73	$ per flow meter
Combined unregistered:									
% of combined unregistered volume	-0.60%	-1.12%	-1.65%	-2.17%	-2.99%	-3.52%	-3.94%	**-1.25%**	
Average combined unregistered volume per meter	-0.9	-2.0	-3.0	-4.8	-7.1	-8.7	-13.5	-2.1	kL/year
Average lost revenue per meter per year	-1.53	-3.55	-5.33	-8.49	-12.51	-15.44	-23.89	- 3.66	$ per flow meter

When considering another random sample of 49360 meters from City West Water (Sample B)[4], the average non-registration was found to be 3.23% for the range of total meter registrations, which equates to an average annual financial loss of $7.41 per flow meter (based on an average price of $1.77/kL). Whereas, the average under-registration for the same batch of meters was calculated to be 0.33%, with a corresponding annual financial loss of $0.75per meter. The non-registration loss in this example is ten times the magnitude of the under/over-registration volume.

The key reason for the higher unregistered volume is that more than 50% of the meters fall in the >3000+ kL group, which have higher inaccuracies.

[4] The data for this example is provided in more detail in Appendix 5 of this report.

Table 8: Unregistered volumes for City West Water meter sample B

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Average for Total	
Non-registered:									
% of non-registered/ measured volume	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%	**-3.23%**	
Average non-registered volume per meter	-0.8	-0.8	-1.3	-2.0	-2.8	-3.7	-5.5	-4.2	KL/year
Average lost revenue per meter per year	-1.47	-1.36	-2.33	-3.51	-4.88	-6.47	-9.81	-$7.41	$ per flow meter
Under-registered:									
% of under-registered/ measured volume	0.40%	0.30%	0.20%	0.10%	-0.30%	-0.40%	-0.40%	**-0.33%**	
Average under-registered volume per meter	0.3	0.2	0.1	0.1	-0.3	-0.5	-0.6	-0.4	KL/year
Average lost revenue per meter per year	0.59	0.29	0.25	0.15	-0.54	-0.83	-1.11	-$0.75	$ per flow meter
Combined unregistered:									
% of combined unregistered volume	-0.60%	-1.12%	-1.65%	-2.17%	-2.99%	-3.52%	-3.94%	**-3.56%**	
Average combined unregistered volume per meter	-0.5	-0.6	-1.2	-1.9	-3.1	-4.1	-6.2	-4.6	kL/year
Average lost revenue per meter per year	-0.88	-1.08	-2.08	-3.36	-5.42	-7.30	-10.92	-$8.16	$ per flow meter

The research presented in this report therefore suggests that:

4. **non-registration is more significant than under-registration in understanding non-revenue water**, i.e. it could account for a larger percentage of the non-revenue water passing through a meter. The additional volume associated with the percentage of non-registration can help further explain the *apparent losses* (*customer metering inaccuracies*) when calculating the water balance and the overall water loss. By increasing the contribution of *apparent losses*, the proportion of *real losses* will decrease, which will have the effect of reducing the percentage of leakage that requires detection and therefore will reduce the associated costs.
5. The **total unregistered volume is significant when estimating apparent losses** for a meter, and the fleet of meters should therefore be disaggregated into the registration groups when calculating the water loss due to meter error.

5 Relevance for Meter Replacement Policies

5.1 Current meter replacement policies

NMI R 49 specifies the maximum permissible error for domestic flow meters and recommends that tested meters that fall outside of this range should be replaced, as shown in **Table 4** (NMI 2009a).

There is a wide range of replacement policies within the water industry, which use a combination of the age and the total registration of the meter (See **Table 9**). The policies and practices, provided by the three Melbourne based utilities are shown in the Appendices.

Table 9: Current replacement policies for a range of water utilities

Utility	Age of meter (years)	Registration (kL)
City West Water	***10***	***4200***
South East Water	***10***	***Depends on type of meter***
Yarra Valley Water	***-***	***3685***
Other utilities for comparative purposes:		
GWM Water (Vic)	8	4000
Hunter Water (NSW)	15	3600
NT Power Water (NT)	10	7000
Wannon Water (Vic)	14	3500

5.2 Relevance of non- and under-registration

The unregistered volume is made up of both *under-registration* and *non-registration*, as explained previously, and therefore both should be considered when determining the optimum replacement interval of a suite of meters.

As can be seen in **Table 10**, the average non-registration increases threefold from 1% to 3.5% with the usage of the meter from being new to having recorded over 3000 kL of flow respectively. The range for average under-registration falls within a range between -0.5% and +0.5%[5] and changes on average from being positive when relative new to being negative for higher registration volumes. Australian pattern approvals permit new meters to over-register (provided they are within the specified upper and lower limits shown in **Table 4**) and this now occurs with popular types of new positive displacement meters.

When combined, the over-registration for the new meter offsets the non-registered volume, whereas for older meters, the two combine to produce a higher unregistered volume. This brings into question the focus on under-registration as the indicator for poor performance of the meter and potential loss of revenue, whereas in this study non-registration has been illustrated to be more significant and becomes progressively worse with usage.

Table 10: Comparison of the percentage of unregistered volumes

[5] These results are based on a batch of 60 meters that were test by SEW.

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+
Non-registered %	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%
Under/over - registered %	0.4%	0.3%	0.2%	0.1%	-0.3%	-0.4%	-0.4%
Unregistered % (Combined)	**-0.6%**	**-1.1%**	**-1.6%**	**-2.2%**	**-3.0%**	**-3.5%**	**-4.0%**

5.3 Implication for meter replacement

As has been illustrated in the previous section, it would be prudent to base the time for the replacement of a meter on the combined percentage of under-registration and non-registration. To determine the cost effective time to replace the meters under the three percentages provided in **Table 10**, an excel spreadsheet was used. The optimum timing for replacing domestic meters was calculated using net present value (NPV) for a range of annual consumption volumes. The analysis was based on:

- a meter replacement costs of $100,
- a discount rate of 7%, and
- a rising block tariff structure of the following:
  <440 L/day (<161 kL/yr) = 1.77$/kL
  <880 L/day (<321 kL/yr) = 2.10$/kL
  >880 L/day (>321 kL/yr) = 3.10$/kL

For the consumption greater than 3000 kL, the annual increase in percentage error was continued at the same annual rate used to reach the 3000+ kL. For example, an annual consumption 250kL would take 12 years to reach 3000kL, therefore the annual increase in percentage error for the combined losses would be calculated as (-4.0 less -0.6)/(12-1) = -0.31%/year (assuming a linear relationship).

Table 11: Outcome of meter replacement analysis

kL/year	Year for meter exchange based on NPV		
	Non-registration	Under-registration	Combined
150	0	0	0
200	0	0	0
250	0	0	11
300	11	0	10
350	10	0	10
400	10	0	9
450	9	11	9
500	9	11	9

The results indicate that for these sets of values, it is not cost effective to replace domestic meters before they reach 250kL/year. For this volume of consumption, the economically optimum time to replace the meter would be in year 11. This is based on the combined effect of the non- and under-registered volume. As can be seen in **Table 11** and following graphs, the two types of unregistered volume on their own however, indicate that a better NPV is achieved by not replacing the meter.

For consumption volumes between 300 kL/year and 400 kL/year, the losses resulting from non-registration are high enough to warrant the meter to be replaced, whereas basing the replacement solely on under-registration would indicate that the meters do not need replacing, since it would cost the utility more to replace the meter than the value of the lost revenue through under-registration.

The inclusion of non-registration in the consideration for meter replacement has the effect of bringing forward the replacement date based on registered volume. Depending on the meter replacement cost, batch meter test results and the price of water for a specific water utility, slightly varying results will be obtained. By continually updating the replacement policy based on new meter test data, a more accurate replacement policy can be developed based on the optimum NPV of the lost revenue.

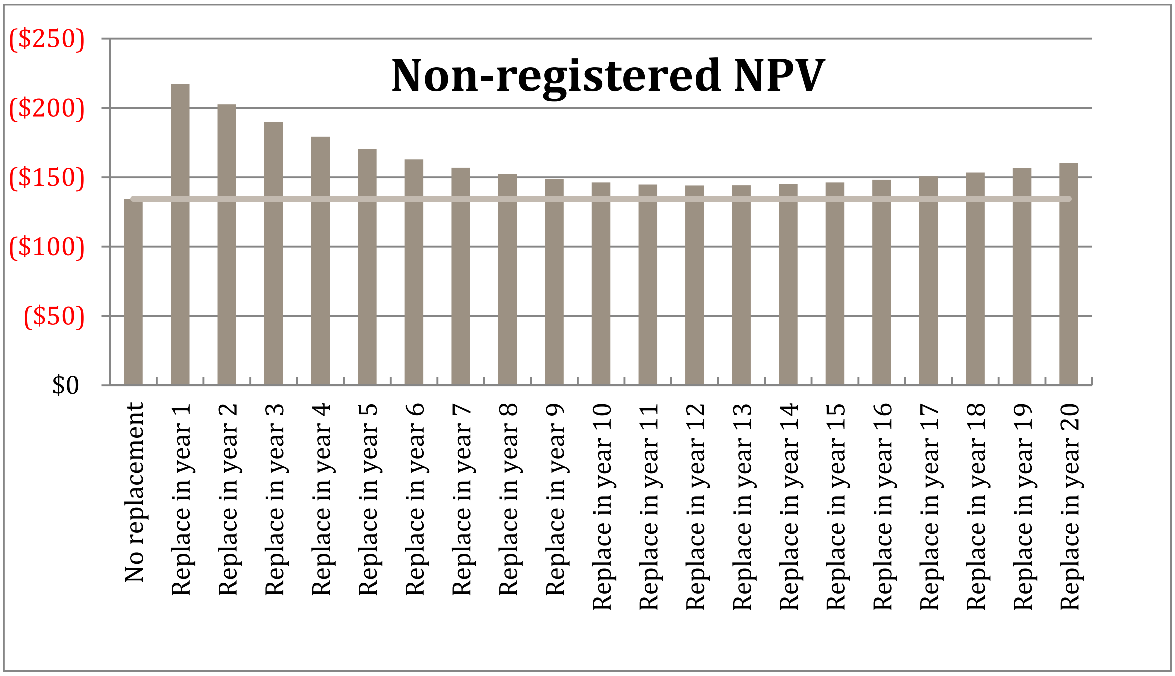


Figure 5: Meter replacement based non-registered NPV

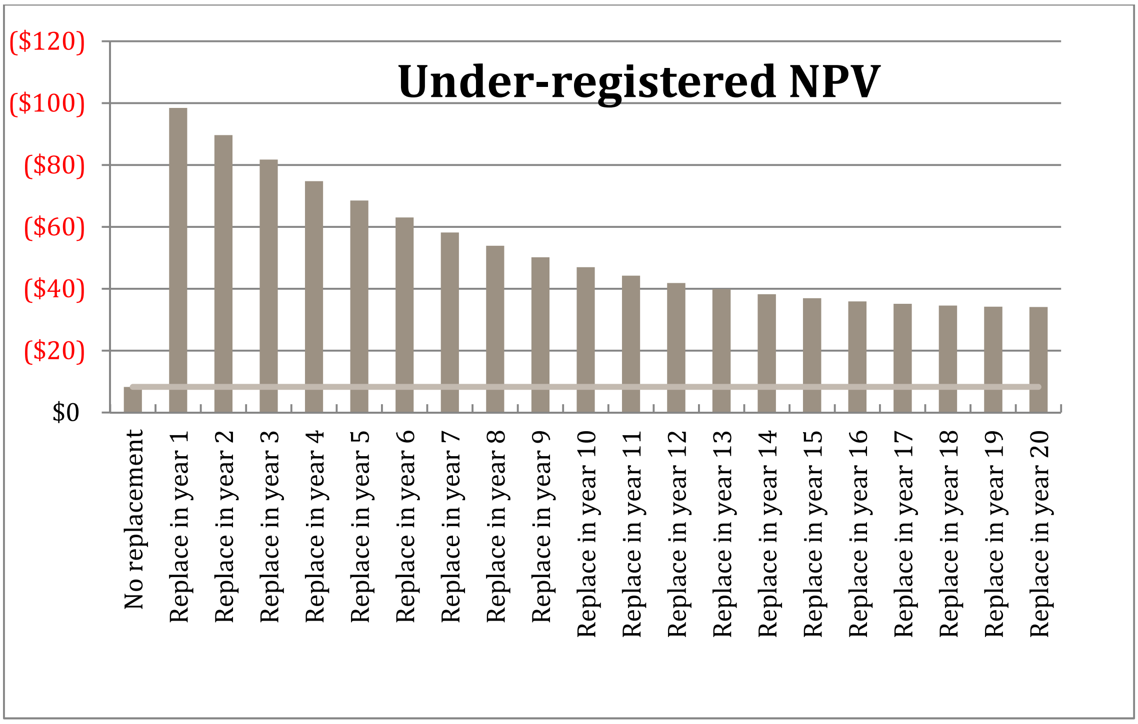


Figure 6: Meter replacement based under-registered NPV

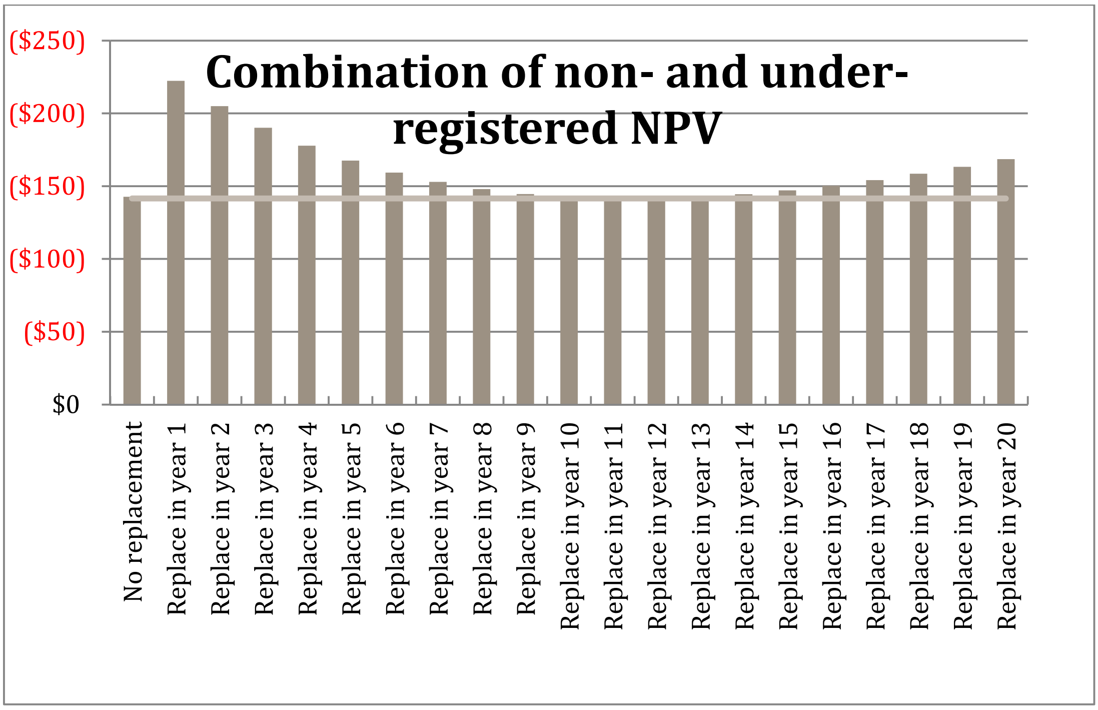


Figure 7: Meter replacement based combined unregistered NPV

6 Recommendations

When considering unregistered metered volumes for domestic meters, it is recommended that both forms discussed in this report be considered together, viz.:

unregistered volume = non-registered volume + under-registered volume

This will have implications for both non-revenue water accounting and for setting guidelines and policies for the replacement of domestic meters. The percentages for each registration group will vary for each utility based on meter type, network and operating conditions and annual volumes passing through the meter.

6.1 Non-revenue water considerations

In order to fully account for the non-revenue water due to errors in the registration of domestic water consumption, **both the non- and under-registration of the meters should be considered**. As has been illustrated, the volume of unregistered water increases with increased meter use. Therefore using an average for a fleet of meters is not reliable enough, and improved estimates can be achieved by **assessing the losses per registration group**.

6.2 Meter replacement guidelines

When preparing a meter replacement policy, **consideration of both the non- and under-registration** components of the unregistered volume should be made. As has been illustrated with the available data, the percentage of non-registered volume increased more significantly with higher total registered volumes as compared with under-registration. Therefore non-registration should not be neglected.

The replacement interval will vary between brands and sizes of meters and will also depend on the operating conditions of the meter.

6.3 Further research opportunities

The research in this report is based on a limited sample size. To better understand the implications of non-registration for assessing non-revenue water and developing meter replacement guidelines, further work is required to:

1. More rigorously test a statistically relevant sample of meters at very low flows (a range below 5L/hr) for a range of brands and total registrations, to improve the confidence associated with the non-registration percentage losses (this would be ideal for a masters thesis project).
2. Collate and analyse a statistically relevant sample of under-registration test data for a range of meter types and total registrations, in order to provide default values for under-registration. This work could be done on a utility by utility basis.
3. Improve the understanding of domestic user profiles.

These outputs will assist NRW calculations and meter replacement policies.

The outputs of the research in this report and any future further work, in consultation with meter manufacturers, should be used to inform the WSAA Handbook and related guidelines.

7 References

Arregui, F. J., Cabrera, E., Cobacho, R. and García-Serra, J. (2006), 'Reducing apparent losses caused by meters inaccuracies', in *Water Practice & Technology*, vol. 1. IWA Publishing.

Arregui, F., Cabrera Jr., E., Cobacho, R. and García-Serra, J. (2005), 'Key factors affecting water meter accuracy', *Proceedings of Leakage 2005 Conference*, Halifax.

CIEM (2011a) *Experimental study on meter registration accuracy at low flow rates and benefits of UFR implementation*, Technical Report 2, Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters [prepared for the Smart Water Fund], Centre for Infrastructure Engineering and Management, Griffith University

CIEM (2011b) *Determining average volumes of residential water consumption in flow rate interval categories*, Technical Report 1, Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters [prepared for the Smart Water Fund], Centre for Infrastructure Engineering and Management, Griffith University

NMI Recommendation R 49-1 (2009a). *Water meters intended for the metering of cold potable water and hot water,* Part 1: Metrological and Technical Requirements, National Measurement Institute, Sydney, April 2009

NMI Recommendation R 49-2 (2009b). *Water meters intended for the metering of cold potable water and hot water,* Part 2: Test methods, National Measurement Institute, Sydney, April 2009

Water Services Association of Australia, National Water Commission and the NWI Parties 2010, *National Performance Framework: 2009–10 urban performance reporting indicators and definitions handbook*.

Water Services Association of Australia, National Water Commission and the NWI Parties 2006, *National Performance Framework: 2005–06 urban performance reporting indicators and definitions handbook*.

WBW (2009) Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters [prepared for the Smart Water Fund], Wide Bay Water, November 2009

WBW (2011), Understanding Apparent Water Losses Through Non-Registration of Domestic Water Meters Stage 2 Refining the Predictions from Stage 1 [prepared for the Smart Water Fund], Wide Bay Water, July 2011

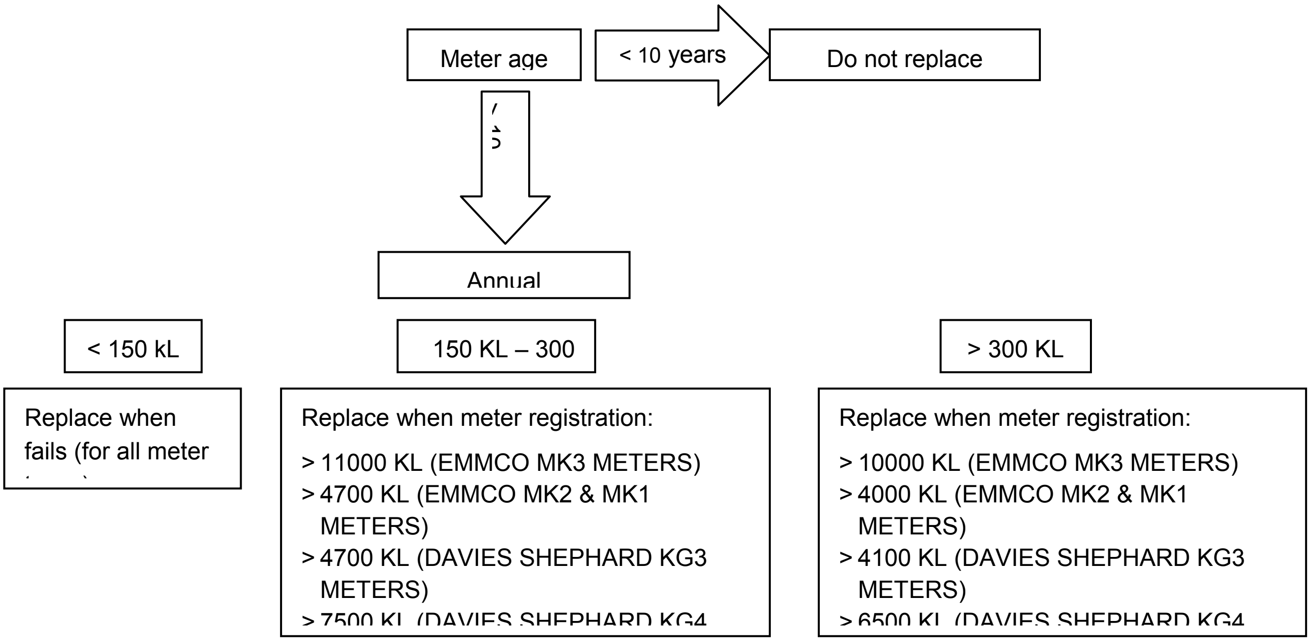
Appendix 1: South East Water meter policy

DRIVERS:

- Achieving an adequate (>10,5% internal rate of return after tax) return on investment
- Compliance with legislative/contract requirements. (no meter may overregister >2%)
  NOTE: City West Water says that the National Measurement Regulations 1999, NMI R 49 AS 3565 state that the maximum error should be +-4%, original document not accessible.

METER REPLACEMENT STRATEGY:

Replace any meter that over-register >2%, then follow procedure below.



(Note: It would generally not be financially viable for South East Water to replace meters under registering by less than 3%)

INPUTS TO THE MODEL, THIS REPLACEMENT STRATEGY IS BASED ON:

- cost of new meter (depends on the volume of meters bought by SEW)
- cost of installation of meter (depends on the volume of meters bought by SEW)
- the income from the scrap value of meter
- domestic water and waste-water tariffs
- annual customer water consumption
- the depreciation rate
- company tax rate
- the weighted accuracy of the meter to be replaced
- the weighted accuracy of the new meter
- an accuracy decay rate for the new meter
- the evaluation period

Note: An actual revenue increase of a replacement model cannot be determined accurately, as the volume of consumption for any one-year can vary due to climatic conditions, home improvements and/or changes in occupancy numbers.

DATE:

Developed in 1996 and approved at the Board meeting, 24 November 1997, reviewed every 3 years (latest available update is from Jan. 2004) to match changes to business drivers (water and waste-water tariffs, cost of meters, discount rates, etc). The policy will also be reviewed if the business drivers change dramatically, or any changes happen in legislative/customer contract requirements.

METERS EXCHANGED/YEAR:

Around 5,000 faulty meters were exchanged in 2003 (proportion of faulty meters compared to the overall fleet has not changed significantly from 1997 to 2001, average 0,9%)

FREQUENCY OF REPLACEMENT PROGRAMMES:

Yearly

ISSUES:

Customers do experience an increase in their water usage bill after a meter exchange, triggering some customers to request that their meter be accuracy tested.

OUTCOME LAST POLICY REVIEW (JAN. 2003):

- SEW is confident that the current policy appears to successfully address the exchange of broken meters and those that have a high NRV
- additional meter sampling and testing is required to build up an up-to-date profile of meter performance

OF INTEREST TO THIS PROJECT:

- At present, the amount of non-revenue water due to under registered low volume water flow of 20mm water meters is forecast at some one million kilolitres. The capital injection required to recover $1.3 million in non-revenue water is estimated at some $20 million, which is commercially unacceptable. It is suggested that South East Water has reached a level of non-revenue water, which satisfies the current meter replacement strategy of ensuring an adequate return on investment is achieved.

Appendix 2: Yarra Valley Water meter policy

DRIVERS:

All meters are then targeted for replacement when they have achieved the Company's expected rate of return.

METER REPLACEMENT STRATEGY:

Meters are replaced when they reach their replacement threshold, which is 3685kL for all 20mm meters

INPUTS TO THE MODEL, THIS REPLACEMENT STRATEGY IS BASED ON:

- Meter cost (including replacement)
- Meter size and model
- Total usage
- Weighted accuracy of the old meter
- Weighted accuracy of the old meter
- Average annual usage
- Water usage and SDC tariffs (price per kL)
- Rate of return

DATE:

The variable inputs are to be reviewed and updated annually as part of the business planning process.

METERS EXCHANGED/YEAR:

About 1000 of 20mm meters replaced because they had reached their replacement threshold (according to City West water, YVW currently replaces 2,6% of the meter fleet/year)

FREQUENCY OF REPLACEMENT PROGRAMMES:

Annually

Appendix 3: City West Water meter policy

DRIVERS:

- Meet legislative requirements (no meter may be faulty by more than +- 4% NOTE: this is according to National Measurement Regulations 1999, NMI R 49 AS 3565, original document not assessed (Costs 70$) this contradicts with SEW, setting 2% as a threshold)
- Maintain unaccounted water at acceptable levels
- Provide accurate consumption data for a variety of business processes

METER REPLACEMENT STRATEGY:

20 mm meters are replaced as soon as the consumption reaches 4200kL

INPUTS TO THE MODEL, THIS REPLACEMENT STRATEGY IS BASED ON:

- Type of meter
- Flow rate
- Pressure
- Volume of water passed through
- Economic limit

DATE:

2010

METERS EXCHANGED/YEAR:

3740 were exchanged in 2009/2010 (currently replaces 6% of their fleet)

FREQUENCY OF REPLACEMENT PROGRAMMES:

Yearly

Note: CWW collaborates with YVW for meter testing

Appendix 4: Calculating unregistered volumes: Sample A

The following table represents the calculation of the average non- and under-registration for a sample of 71100 meters (equally split between Actaris and Elster) from City West Water with a range of total registered volumes. The combined average effect on unregistered volume has also been calculated, based on an average price of $1.77/kL.

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Total / Average	
Total average volume measured per year	6,970	1,526	1,027	703	421	264	864	11,778	ML
Number of meters	48407	8535	5619	3183	1782	1065	2523	71114	sample
Average annual volume per meter	144	179	183	221	236	248	343	166	kL
% distribution of sample	68%	12%	8%	4%	3%	1%	4%	100%	by meter numbers
% distribution of sample	59%	13%	9%	6%	4%	2%	7%	100%	by meter volume
Non-registered:									
% of non-registered/ measured volume	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%	-1.50%	
Non-registered volume	- 69,588	- 21,709	- 18,968	- 15,969	- 11,335	- 8,234	- 30,595	- 176,398	kL
Adjusted volume	7,039	1,548	1,046	719	432	272	895,	11,955	ML
Average annual adjusted volume per meter	145	181	186	226	243	256	355	168	kL
Loss of revenue per year	- 123,171	- 38,425	- 33,573	- 28,265	- 20,063	- 14,574	- 54,153	- 312,224	$ for sample
Average lost revenue per meter per year	-2.54	-4.50	-5.97	-8.88	-11.26	-13.68	-21.46	-4.39	$ per flow meter
Under-registered:									
% of under-registered/ measured volume	0.40%	0.30%	0.20%	0.10%	-0.30%	-0.40%	-0.40%	0.25%	
Under-registered volume	27,881	4,581	2,056	704	-1,263	-1,057	-3,458	29,443	kL
Adjusted volume	6,942	1,522	1,025	703	422	265	867	11,749	ML
Average annual adjusted volume per meter	143	178	183	221	237	249	344	165	kL
Loss of revenue per year	49,349	8,108	3,639	1,246	- 2,236	- 1,871	- 6,121	52,113	$ for sample
Average lost revenue per meter per year	1.02	0.95	0.65	0.39	-1.25	-1.76	-2.43	0.73	$ per flow meter
Combined unregistered:									
% of combined	-0.60%	-1.12%	-1.65%	-2.17%	-2.99%	-3.52%	-3.94%	-1.25%	

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Total / Average	
unregistered volume									
Combined unregistered volume	- 41,708	- 17,128	- 16,912	- 15,265	- 12,598	- 9,291	- 34,053	- 146,955	kL
Adjusted volume	7,011	1,543	1,044	719	433	273	898	11,925	ML
Average annual adjusted volume per meter	145	181	186	226	243	257	356	168	kL
Loss of revenue per year	- 73,822	- 30,317	- 29,934	- 27,019	- 22,299	- 16,445	- 60,274	- 260,110	$ for sample
Average lost revenue per meter per year	-1.53	-3.55	-5.33	-8.49	-12.51	-15.44	-23.89	- 3.66	$ per flow meter

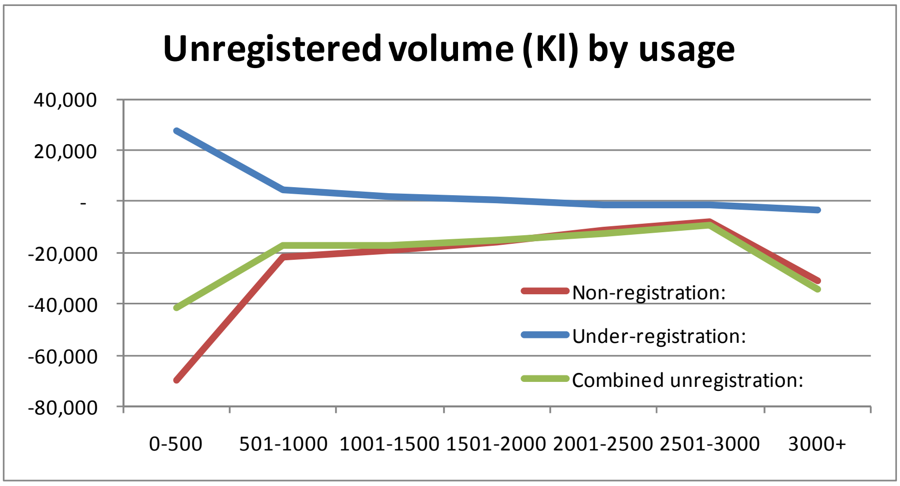


Figure 8: Total unregistered volume per registration group

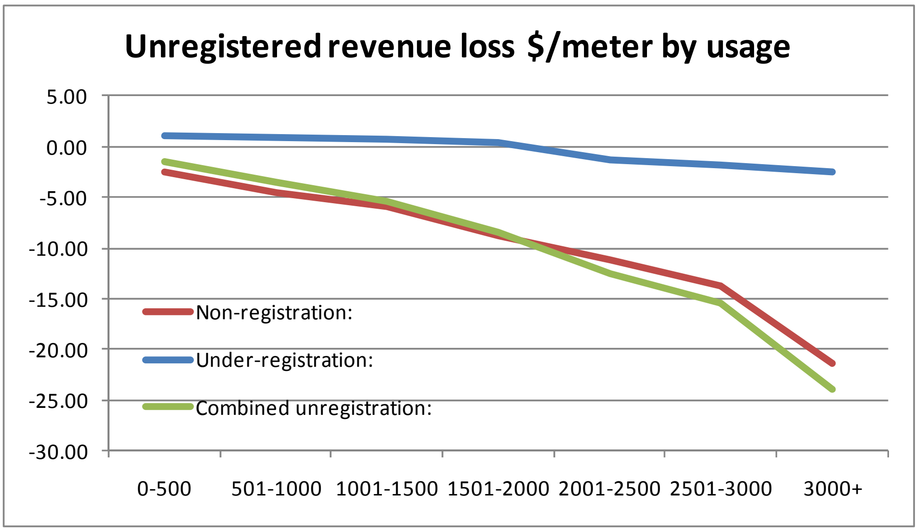


Figure 9: Annual lost revenue per meter

Appendix 5: Calculating unregistered volumes: Sample B

The following table represents the calculation of the average non- and under-registration for a sample of 49360 meters (Davies Sheppard - Elster) from City West Water with a range of total registered volumes. The combined average effect on unregistered volume has also been calculated. The cost have been based on an average price of $1.77/kL.

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Total / Average	
Total average volume measured per year	19	68	190	419	670	825	4,200	6,394	ML
Number of meters	232	1265	2669	4797	6554	7034	26808	49359	sample
Average annual volume per meter	83	54	71	87	102	117	157	130	kL
% distribution of sample	0.5%	3%	5%	10%	13%	14%	54%	100%	by meter numbers
% distribution of sample	0.3%	1%	3%	7%	10%	13%	66%	100%	by meter volume
Non-registered:									
% of non-registered/ measured volume	-1.0%	-1.4%	-1.8%	-2.3%	-2.7%	-3.1%	-3.5%	-3.23%	
Non-registered volume	-193	-974	-3,518	-9,519	-18,056	-25,714	-148,639	-206,613	kL
Adjusted volume	19	69	194	429	688	851	4,348	6,600	ML
Average annual adjusted volume per meter	84	55	73	89	105	121	162	134	kL
Loss of revenue per year	- 342	- 1,72	- 6,22	- 16,84	- 31,95	- 45,51	- 263,09	- 365,70	$ for sample
Average lost revenue per meter per year	-1.47	-1.36	-2.33	-3.51	-4.88	-6.47	-9.81	- 7.41	$ per flow meter
Under-registered:									
% of under-registered/ measured volume	0.40%	0.30%	0.20%	0.10%	-0.30%	-0.40%	-0.40%	-0.33%	
Under-registered volume	77	206	381	420	-2,012	-3,301	-16,800	-21,030	kL
Adjusted volume	19	68	190	419	672	828	4,216	6,415	ML
Average annual adjusted volume per meter	83	54	71	87	103	118	157	130	kL
Loss of revenue per year	137	364	675	743	- 3,51	- 5,84	- 29,73	- 37,22	$ for sample
Average lost revenue per meter per year	0.59	0.29	0.25	0.15	-0.54	-0.83	-1.11	- 0.75	$ per flow meter
Combined unregistered:									
% of combined	-0.60%	-1.12%	-1.65%	-2.17%	-2.99%	-3.52%	-3.94%	-3.56%	

Meter registration (kL)	0-500	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3000+	Total / Average	
unregistered volume									
Combined unregistered volume	- 116	- 769	- 3,137	- 9,099	- 20,068	- 29,016	- 165,439	- 227,643	kL
Adjusted volume	19	69	193	428	690	854	4,365	6,621	ML
Average annual adjusted volume per meter	84	55	73	89	105	121	163	134	kL
Loss of revenue per year	- 205	- 1,361	- 5,552	- 16,10	- 35,52	- 51,35	- 292,82	- 402,92	$ for sample
Average lost revenue per meter per year	-0.88	-1.08	-2.08	-3.36	-5.42	-7.30	-10.92	- 8.16	$ per flow meter

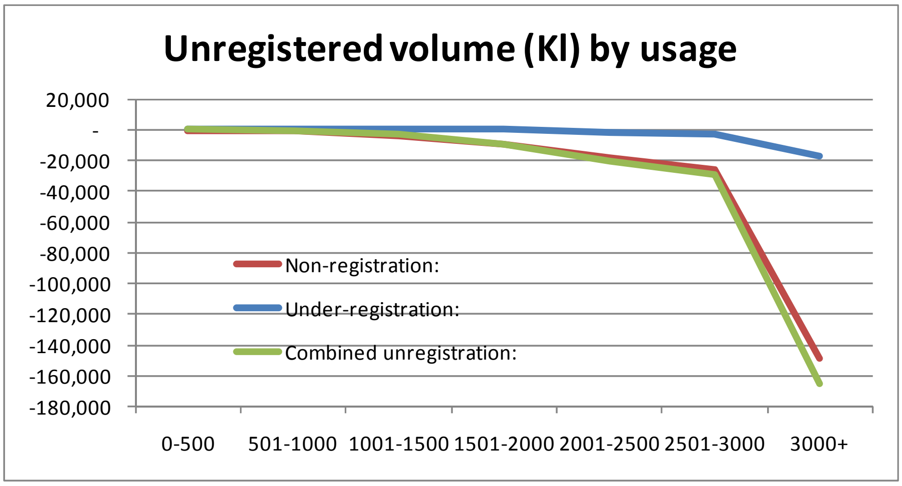


Figure 10: Total unregistered volume per registration group

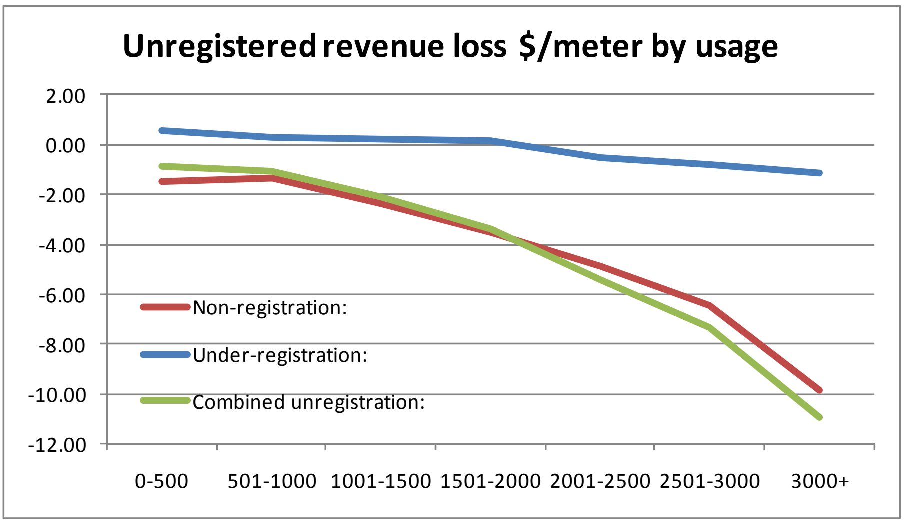


Figure 11: Annual lost revenue per meter