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Establishing meter under registration on domestic premises with roof tanks

D. Pearson[a,*], N. Preston[b], A. Al-Naimi[c] and C. Smith[c]

[a] David Pearson Consultancy Ltd, Cliff Road, Acton Bridge, Northwich, Cheshire, CW8 3QY, UK

[b] NJJP Ltd, Warrington, UK

[c] Public Authority for Electricity and Water, Muscat, Oman

*Corresponding author. E-mail: david.dpc@btinternet.com

Abstract

The Public Authority for Electricity and Water in Oman carried out an initial estimate of legitimate domestic night consumption (LDNC) based on an assessment of night consumption surveys of over 1,500 premises. However, no allowance for meter under-registration (MUR) had been applied in the assessment. This paper reports on a study to identify MUR in Oman, which can be applied to the results of the survey for LDNC. All premises in Oman are required to have a roof tank in order for customers to maintain their supply in the case of mains water supply interruptions. Regulations require that the roof tanks provide at least two days' storage. It is believed that roof tanks could have a significant impact on MUR due to the long 'tails' generated by the operation of the ball valve controlling the refilling of the roof tank. It was therefore decided that a study should be carried out to review the main drivers for MUR and the likely level of MUR to be expected in Oman, particularly at low flows such as those experienced at night time when a single toilet is flushed. In regards to the sample of properties included in the MUR survey, it was suspected that in the case of apartment blocks, the revenue meters will normally be located after the roof tank, in which case the roof tank will not influence MUR. This study sought to confirm this. Half the premises were fitted with an unmeasured flow reducer on a bypass so that the potential of such devices to reduce MUR could be investigated. Oman has continuous water supply. There were no supply interruptions during the study. The paper describes details of the plumbing arrangements developed for the study and the results established as part of the programme. It also takes the opportunity to report on the level of daily and night consumption experienced on the study area.

Key words: legitimate night consumption, meter under-registration, roof tanks

INTRODUCTION

As part of a programme to improve the reliability of the assessment of real losses, and hence support effective leakage control in Oman, the Public Authority for Electricity and Water (PAEW) needed to generate robust estimates of legitimate domestic night consumption (LDNC) to assist in the interpretation of night flows into district metered areas. LDNC is estimated by assessing night use on a sample of properties using the existing revenue meters.

A programme was designed to investigate the potential MUR and what impact this might have on the assessment of LDNC. The programme was designed to sample 50 premises with typical roof tanks, including apartments with the revenue meter after the roof tank. Other variables encompassed in the study included multiple roof tanks, different roof tank sizes, different meter manufacturers and different ages of meters. In order to assess the meter under-registration (MUR), high grade ultrasonic

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meters were plumbed in series with the existing revenue meters. Both meters were then logged for several weeks. Unfortunately, it was found that only 39 of the existing revenue meters could be logged.

PROCEDURE

A high performance, non-intrusive flow meter was selected. The one selected was a $Q_3$2.5 m3/hr R400 (ISO 4064_1_2014 2014) ultrasonic meter manufactured by Diehl, known as a Hydrus meter. These meters were plumbed in series after the existing revenue meter with the intention of not changing the performance of the existing meter. All the existing revenue meters were $Q_3$2.5 m3/hr R160 and thus had a higher starting flow than the Hydrus meter.

The existing revenue meters were of two different types and from four different manufacturers. The relative split is shown in Table 1. The distribution of meter age is shown in Table 2.

Table 1 | Distribution of existing mechanical meter stock in the study area

Meter Manufacturer	%	Type
Manufacturer 1	33%	Rotary Piston
Manufacturer 2 – Model 1	44%	Positive Displacement
Manufacturer 2 – Model 2	15%	Rotary Piston
Manufacturer 3	8%	Rotary Piston

Table 2 | Distribution of meter age of existing mechanical meters

Age (yrs)	%
3	52%
4	6%
6	6%
7	15%
8	9%
9	12%

Figure 1 shows a typical plumbing arrangement both diagrammatically and also on site.

A low power radio network was used to collect the data from each installation and then transmit the data to a web portal on the internet.

The existing revenue meters were fitted with the relevant manufacturer's pulse sensors. These generally transmitted a pulse for each litre registered by the meter. However, it was found that the older models only transmitted pulses of 5 litres. These pulses were also transmitted to the web portal via the low power radio network.

RESULTS

The data on the Hydrus meters was available at 1-minute intervals. This was then aggregated to 15-minute totals to align with the data available from the existing revenue meters. Both daily total and hourly MUR have been analysed.

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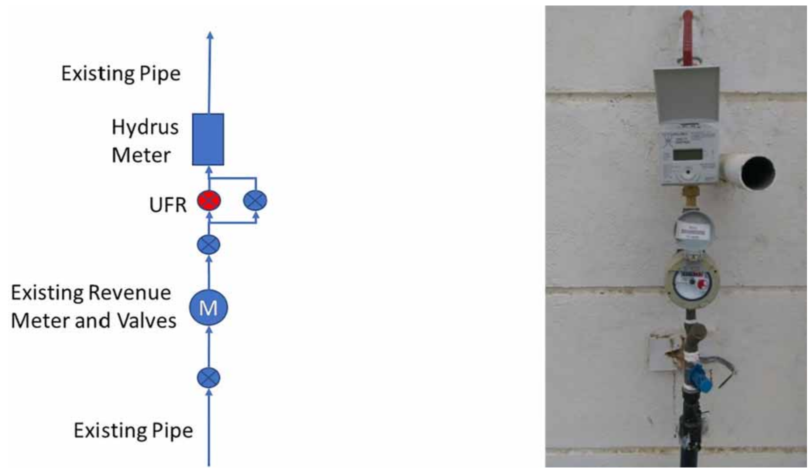

Figure 1 | Typical plumbing arrangement.

MUR was defined as:

$$MUR = (Volume_{Hydrus} - Volume_{Mechanical})/Volume_{Hydrus}$$

Thus, the correction for MUR is given by:

$$Estimated\ Actual\ Flow = Recorded\ Flow/(1 - MUR)$$

RESULTS – DAILY MUR

Daily MUR for individual meters

Figure 2 shows a plot of the individual daily MUR by meter. The plot is a derivative of the Box-Whisker presentation, where the median and the upper and lower quartile values are shown as the 'boxes' and the range of the maximum and minimum values are shown as the 'whiskers'. This shows that generally MUR is very low, but there are situations when it can be very high.

The worst cases, in terms of median and range of MUR, were investigated further by comparing the 15-minute traces for the existing revenue meter and the associated Hydrus meter at these premises.

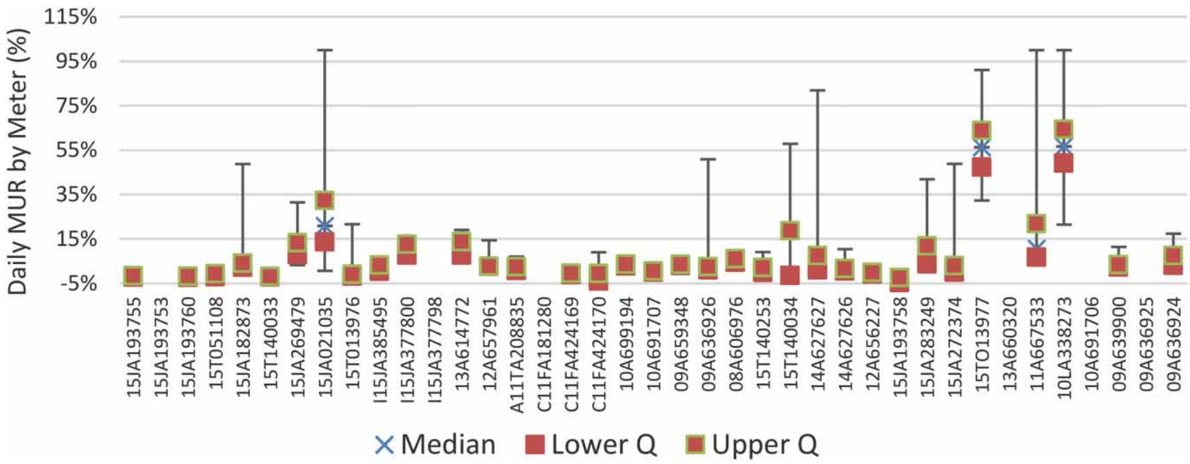

Figure 2 | Individual meter daily MUR.

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Figure 3 shows the trace of 15-minute readings on a typical day for the revenue meter 15TO13977 compared to that of the associated Hydrus meter.

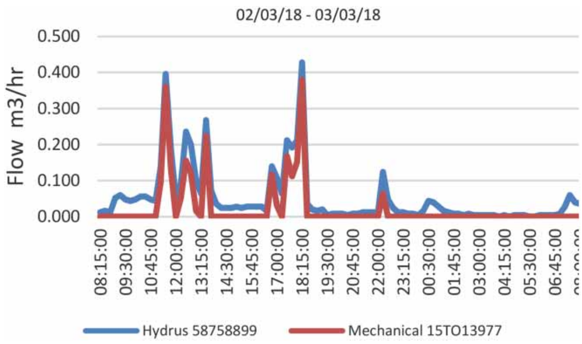

Figure 3 | Daily trace for meter 15TO13977 compared to associated Hydrus meter.

The trace shows that most flows during customer use are under-recorded, but that this under-recording increases dramatically at low flows. There are long periods when the revenue meter is not recording any flow, but the Hydrus meter shows that water is still flowing into the property. The phenomenon shown by the meter is probably due to grains of sand being stuck within the mechanical revenue meter, which then impedes the rotation of the piston. This causes severe MUR.

In the case of another meter it was found that MUR changed dramatically for the period from 10th February to 23rd February. Prior to and after this period the meter performed well with MUR slightly negative. This change in MUR was investigated further by reviewing the 15 min traces. It appears that a grain of sand lodged in the meter on 10th February and affected the meter performance in registering low flows. The grain of sand would then appear to have then been dislodged on 23rd February and the meter returned to normal performance.

Investigations were carried out to establish whether any specific relationships between MUR and some of the other parameters (e.g. meter age, meter manufacturer, roof tanks (Rizzo & Cilia 2005) and the unmeasured flow reducer (UFR) (Fantozzi *et al.* 2009) could be identified. These analyses were carried out by assembling data into cohorts to reflect the parameter being investigated. It was found that the difference in MUR due to these factors was at least one order of magnitude less than the impact of sticking meters.

Variation of average daily MUR

Figure 4 shows the daily variation of the average daily MUR across all sites over the period of the study.

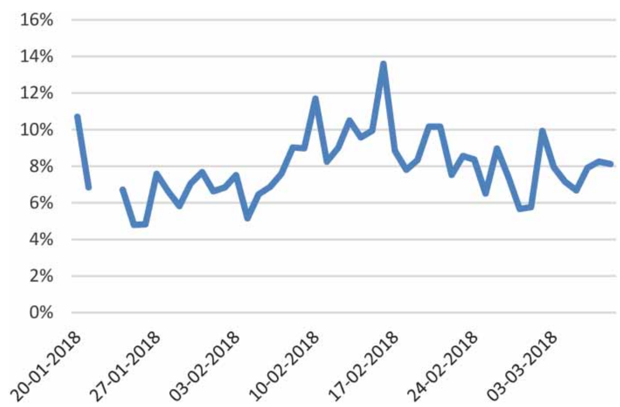

Figure 4 | Graph of daily MUR during study period.

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The reason for the slightly higher MUR during the period from 10/02/18 to 23/02/18 was due to a meter sticking during this period as discussed earlier. The median daily MUR with all the meters is 8.5%. When the 10 'sticking meters' with high MUR are excluded the median daily MUR is 1.2%. This shows that the phenomenon of 'sticking' meters had a significant impact on MUR. The fact that 10 meters in a sample of 39 meters have been found to exhibit this phenomenon means that it is a significant driver of MUR in Oman, despite the fact that the meters were fitted with filters.

RESULTS – HOURLY MUR

Analysis of hourly MUR

The previous section discussed the analysis of daily MUR. This is relevant, say, to billing where the question is whether the existing revenue meter reading is reflecting the true total volumetric consumption by the customer. When it comes to the subject of the assessment of LDNC, this is taken over a one-hour period in the middle of the night. This is currently normally established by carrying out a survey on a large sample of premises. Two readings of the existing revenue meter, approximately one hour apart, are taken to estimate the consumption during a 1 hr period, say, between 3:00am and 4:00am. In order to make the process more practical and strike a compromise with the resources required, the readings are usually taken approximately one hour apart in the period between 2:30am to 5:00am.

Flows are significantly lower during the night with consumption generally being simply for flushing a toilet and washing hands. It is expected, therefore, that the MUR during the period of measuring the LDNC could be significantly higher than the daily MUR.

Figure 5 shows the trace of the 1 hr rolling average (RA) for a meter together with the associated Hydrus. The 1 hr RA flow has been used rather than the 15-minute flow as this is relevant for the calculation of hourly MUR. The graph also shows the hourly MUR. A review of Figure 5 shows that the MUR can be 100% since the revenue meter is recording no flow while the ultrasonic meter is recording flows.

Figure 5 shows that the MUR ranges from 0% when the customer consumption peaks at nearly 0.2 m3/hr, to 100% when the mechanical meter stalls.

Fixed 1 hr (3:00am to 4:00am) hourly MUR

Hourly meter under registration was evaluated by calculating the rolling one-hour flows starting each quarter of an hour throughout the day for both the revenue meter and the Hydrus meter.

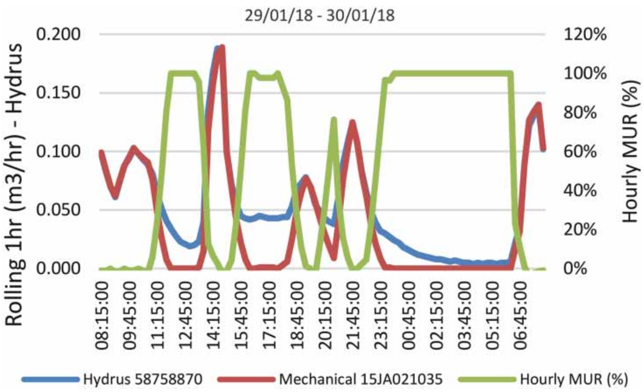

Figure 5 | 1 hr rolling average trace for meter 15JA021035, associated Hydrus and MUR.

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Figure 6 shows a trace of the overall night flow and the associated MUR in the one-hour period from 3:00am to 4:00am for each night from 19th January to 8th March.

Figure 6 shows that the average MUR varies between about 10% and 45%, with an average of 28%. When the 10 'worst' meters were removed the MUR varied between −2% and 20%, with an average of 10%.

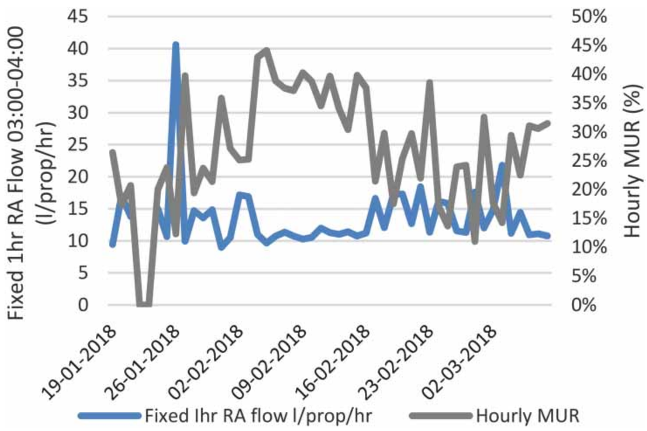

Figure 6 | Trace of night flow and MUR for 1 hr period 3:00am to 4:00am for all meters.

The spikiness of the night flow was investigated. It was found that these spikes were due to high night flows on odd meters on the occasional night. One event was investigated in more detail. Figure 7 shows the trace for one of the premises where both meters were being logged.

Figure 7 shows that the flow was raised for approximately 10 hrs from 21:00 on 02/03/18 to 07:00 on 03/03/18. The raised flow was registered precisely on both the mechanical and the Hydrus meter for the period. This indicates that the data was real. Enquiries have ascertained that flows of this pattern have been experienced in recent trials in the UK, and these have been traced back to being due to sticking toilet cisterns. It is possible that it could be garden watering in Oman although it is considered that this is unlikely. The specific reason in this case could not be ascertained.

Further investigation showed that these events occurred relatively randomly, although there were some repeat events on some properties. There were approximately 25 such events out of a possible 2,500 possible meter-nights, i.e. a probability of occurrence of 1%. These 1% of events, however, accounted for 22% of the night consumption during the fixed 1 hr period between 3:00am and 4:00am.

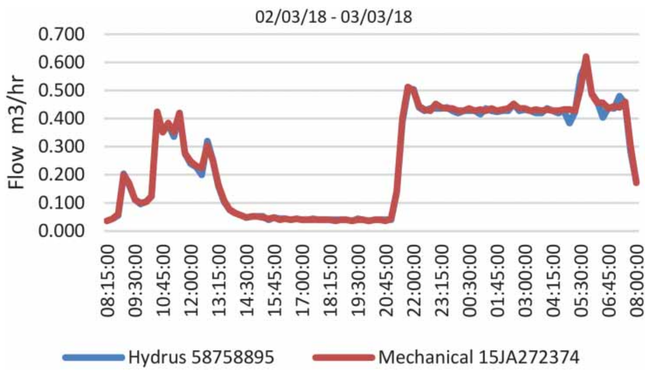

Figure 7 | Daily trace for meter 15JA272374 showing high consumption on the morning of 03/03/18.

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Variation of fixed period hourly MUR throughout the night

An investigation was carried out to see how the hourly MUR varied according to the fixed hour that was used. Figure 8 shows the variation of hourly MUR with the period of the fixed hour, when all the meters are included.

Figure 8 shows that the hourly MUR is highest during the minimum night flow period. It is relatively stable at about 28% for any one-hour period ending between 4:00am and 4:45am. When the 10 meters with the worst MUR were excluded, the hourly MUR was about 8%. This again shows the impact of the sticking meters on MUR.

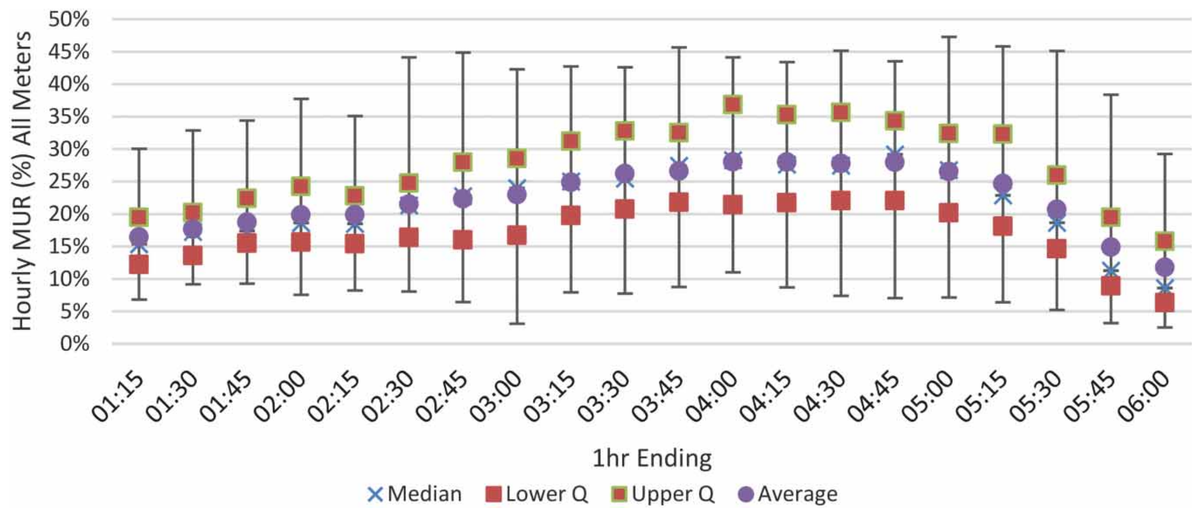

Figure 8 | Variation of hourly MUR with period of fixed hour – all meters.

RESULTS – IDENTIFICATION OF LEAKS

An advantage of having short interval logging, i.e. 15-minute, as opposed to monthly manual meter reads, is that there is sufficient clarity to identify leaks on the properties. As an example, Figure 9 shows the trace for meter 15JA272374 and the associated Hydrus meter for a typical day. The lowest flow rate recorded was 0.024 m3/hr in just one 15-minute period immediately before the use event. At all other times the lowest flow was 0.028 m3/hr. This could be interpreted as showing the presence of a leak.

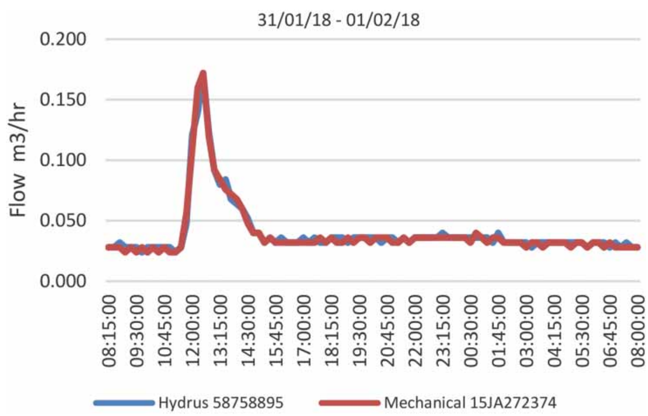

Figure 9 | Trace of meter 15JA272374 showing presence of a leak on the property.

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However, it can be difficult to tell whether very low flows are in fact leaks or whether it indicates that the roof tank is still filling, however slowly. In Figure 9 it can be seen that the flow runs at 0.034 m3/hr for about 10hours after the use before dropping down to just under 0.030 m3/hr after about 16 hours following use. Could it have continued dropping or is there a leak?

It is common for SMART meters to use a minimum threshold, of say 0.8 l/hr (0.0008 m^3/hr), in an attempt to remove the ambiguity of whether there is a leak or whether the tanks are still filling.

There are also issues of how to handle the variation across the period of record (in this case 50 days). It could be argued that the minimum should be used rather than say the median or average, but the absolute minimum may be too rigorous and may allow through specific events such as a valve being shut off. An inspection of some nil events showed that these could not be a true reflection and must be a manual intervention. In order to remove such events a measure such at the 5%tile or 20%tile may be considered more appropriate. Figure 10 shows the distribution of average, median, 5%tile and minimum flows for each of the Hydrus meters. This analysis uses the lowest 15 min flow recorded on each meter for each day during the study period. It can be seen that the absolute minimum flow during the period (indicated by the position of the base of the black bar on each meter) can be significantly lower than the 5%tile and it is probably unrealistic to use this as an assessment of leakage on the properties.

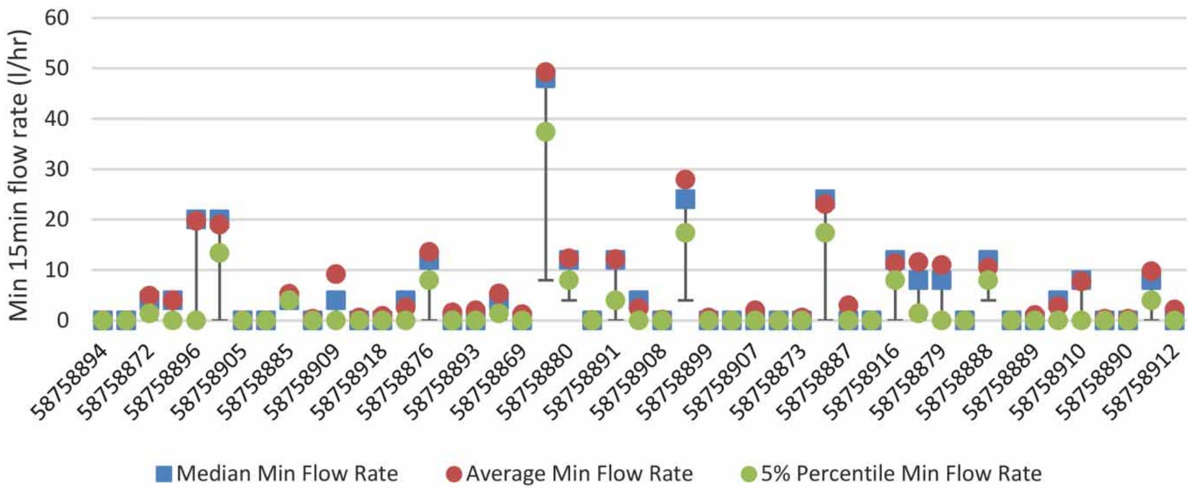

Figure 10 | Distribution of average, median and 5%tile minimum flows.

The sensitivity of the results was tested for these various options. The results are shown in Table 3.

It is suggested that the 5%tile of the spot values is probably a reasonable reflection of the true leakage position. In this case the leakage would be 2.7 l/prop/hr and 28% of properties would be considered to have leaks. This was despite the fact that any premise where an obvious leak was discerned at the time of the initial survey was not carried forward into the study.

Table 3 | Sensitivity test of leakage evaluation criteria

Threshold	Night Flow	Measure	Unit	Minimum	5%tile	20%tile
0.8 l/hr	Spot 15 min	Leakage	l/prop/hr	0.5	2.7	3.8
		No with leaks	% of properties	10%	28%	36%
	Rolling 1 hr	Leakage	l/prop/hr	2.5	4.0	5.2
		No with leaks	% of properties	28%	36%	48%

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RESULTS – NIGHT CONSUMPTION

Figure 11 shows the night consumption between 03:00am and 04:00am across all Hydrus meters during the study period up to 8th March divided by the number of properties.

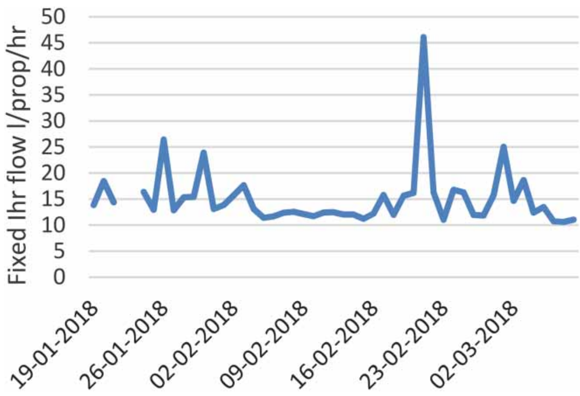

Figure 11 | Night consumption per property between 3:00am and 4:00 on all Hydrus meters.

As can be seen from Figure 11, the total night consumption on all premises has been relatively stable during the period of the study with an average night consumption of just over 12.5 l/prop/hr. This is from the Hydrus meters and therefore would not be subject to any adjustment for MUR. The higher level during some nights (including the very high one towards the end of February) are due to what were believed to be sticking cistern valve events discussed earlier.

RESULTS – DAILY CONSUMPTION

Figure 12 shows the average consumption on the properties during the study.

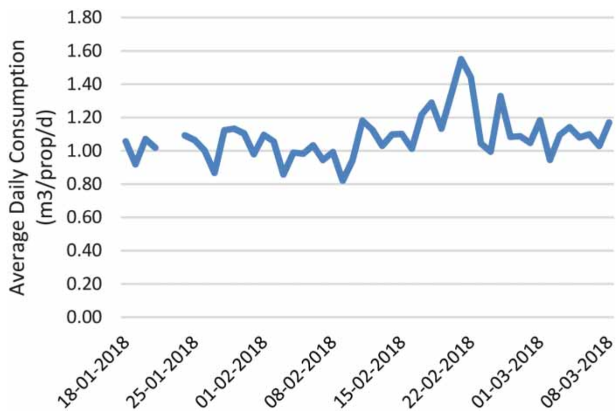

Figure 12 | Average consumption per property on all Hydrus meters.

Figure 12 shows that the average per property consumption was fairly stable during the period and averaged 1.08 m3 /property per day.

RESULTS – NIGHT CONSUMPTION AND USE

Although the primary purpose of this study was to better understand the issues around MUR and then to quantify values of MUR within PAEW, it is useful to look at the levels of night consumption and use

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measured in the study area. Table 4 shows the data for the study in comparison to that generally derived in the UK.

Table 4 | Comparison of night consumption and use data in the study area with UK data

Measure	Unit	PAEW	UK
Night consumption (NC)	l/prop/hr	12.6	2.2
Night leakage	l/prop/hr	2.7	0.5
Night use (NU)	l/prop/hr	9.9	1.7
Daily consumption	m3/prop/d	1.08	0.34
Av hourly consumption	l/prop/hr	44.89	13.96
NC/Av hourly consumption	%	28%	16%

Table 4 shows that the night consumption in Oman looks much higher than that experienced in the UK. This appears to be driven by the filling of roof tanks that extends over the night, be it at very low flow rate but on most properties. Even when an allowance is made for leakage, the higher night consumption is reflected in the night use which is much higher in Oman than in the UK. However, it has to be said that the value for night consumption used in the UK was based on limited studies carried out in 1993 (UKWIR 1993). Recent studies being carried out in the UK are indicating that private side leakage may have been severely underestimated in the previous studies (private communication).

The value for the night consumption expressed as a ratio to the equivalent hourly average rate for the daily consumption is 28%. Studies in other countries outside of the UK have indicated that night consumption values, expressed as a percentage of the equivalent daily rate, of 25% are not uncommon. In fact, a recent study in Bahrain has also derived a value of 28% (private communication). The value of 28% may therefore not be unreasonable.

CONCLUSIONS

The average daily MUR was assessed as 8.5%. This value was dominated by a number of meters that were sticking probably due to the presence of sand within the mechanism of the revenue meter. When the ten worst meters were excluded from the analysis then the daily MUR dropped to 1.2%. This shows the impact of the sticking meters on daily MUR. The impact significantly exceeded the impact of the age of the meter, the meter type or whether an UFR had been plumbed into the installation.

It is more common for studies of MUR to be carried by retrieving meters from the field and then testing the meters in a specialised laboratory. These types of test have the advantage of being cheaper than the approach taken in this study but they have the disadvantage that the meters are disturbed during the retrieval process, errors due to the actual field installation are not tested and it can be difficult to replicate the real in-situ consumption pattern. For this reason, the results are not always comparable. Tests carried out by the University of Valencia found errors of about 10% in meters over 4 years old (Arregui *et al.* 2014).

The average hourly MUR in the middle of the night was assessed at 35%. Again, this value was dominated by the sticking meters. When the analysis was repeated without these sticking meters the average hourly MUR was 8%. The hourly MUR was reasonably constant for any fixed hour ending between 4:00am and 4:45am.

Average night consumption on the premises included in the study was assessed at 12.6 l/prop/hr.

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Low flows extending throughout the day and night were identified by inspection of the flows. It was difficult to discern whether these were due to leaks or due to the roof tanks still filling albeit very slowly. Based on taking the 5%tile, in order to remove odd outlier events, of the minimum of the 15 min spot values the average leakage was estimated at 2.7 l/prop/hr. This means that legitimate night use was 9.9 l/prop/hr.

Average daily consumption in the study area was 1.08 m3 /prop/d, including void properties.

The night consumption is 28% of the daily consumption when this is expressed as the equivalent average hourly consumption rate.

The study involved a very small sample of premises, this was driven by the cost of carrying out such an exercise. The results are therefore not statistically robust enough to be considered for extrapolation to the full population of meters in Oman.

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