A closer look at measured night flows in sectorised networks

R P Warren*

*Tynemarch Systems Engineering Ltd, Crossways House, 54-60 South Street, Dorking, Surrey, RH4 2HQ, UK, www.tynemarch.co.uk

rwarren@tynemarch.co.uk

Keywords: night leakage; customer use; UK

Introduction

In many countries various forms of network sectorisation are established and can deliver significant benefits in saving leakage and many other benefits such as understanding network demands and providing opportunities for pressure management. Sectors may be of any size but the most common implementation is the District Metered Area (DMA), typically a few hundred to a few thousand properties.

This paper looks at some of the benefits and issues associated with sectorisation, in particular the limitations of the approach as the sector sizes become smaller and leakage levels are reduced. Some new approaches to separating customer night consumption from the measured night flows are also considered.

This paper is partly based on recent research on separation of leakage from night flows that was funded by UK Water Industry Research Ltd (UKWIR).

UKWIR study

The UKWIR study was part of an ongoing programme of research across all areas of the water industry. The main study objective was to identify the limitations of current methodologies for separating leakage from night flows and to assess the opportunities for improving the approach (UKWIR, in publication).

Why use sectorisation?

Where a DMA or any sectorisation is established, it is possible to obtain flow profiles in the night when customer demand is least and leakage is dominant and to use these to determine leakage levels.

The overriding purpose of the leakage estimate may be:

1. To identify a relative change in the sector that may prompt active leakage control (ALC) effort
2. To compare several sectors for changes to identify the sector that is the most likely to benefit from ALC intervention
3. To determine an unbiased estimate of leakage that can be used for reporting overall leakage levels

These purposes represent increasingly more exacting requirements. For purpose 1 it is only necessary to examine the differences in night flows provided the assumption of similar customer night consumption holds, however further analysis is required if night consumption is variable. For purpose 2 it will be necessary to make some estimate of customer night consumption to determine leakage levels, and for purpose 3 it will be necessary to ensure that the allowances for customer consumption are unbiased. For larger sectors or sectors at a higher level than the DMA only limited benefits can be obtained from purposes 1 and 2.

In countries such as the UK, there is increasing reliance on sector information to maintain the network at low levels of leakage and for many companies DMA sizes have become progressively smaller to achieve this aim. Smaller DMAs provide more detailed data but are also more difficult to analyse and require a higher metering specification.

Customer night flow characteristics

Domestic or household customers are usually significant in number within a DMA and have daily or night demands that are within a relatively narrow range. They are thus amenable to modelling statistically.

Whilst some household customers use large amounts of water occasionally or seasonally for outdoor use, the range of flow rates remains relatively small compared to commercial or non-household customer demands. In addition, non-households may be few in number within a DMA and statistical approaches may have more limited success. The focus of this paper is on DMAs which supply largely household properties.

An important feature of household night consumption is the intermittent nature of the flows. This arises from the occurrence of use events (e.g. toilet flushing, washing machine use) with gaps between events. The graph below illustrates the intermittent nature of flows at night on a small DMA.

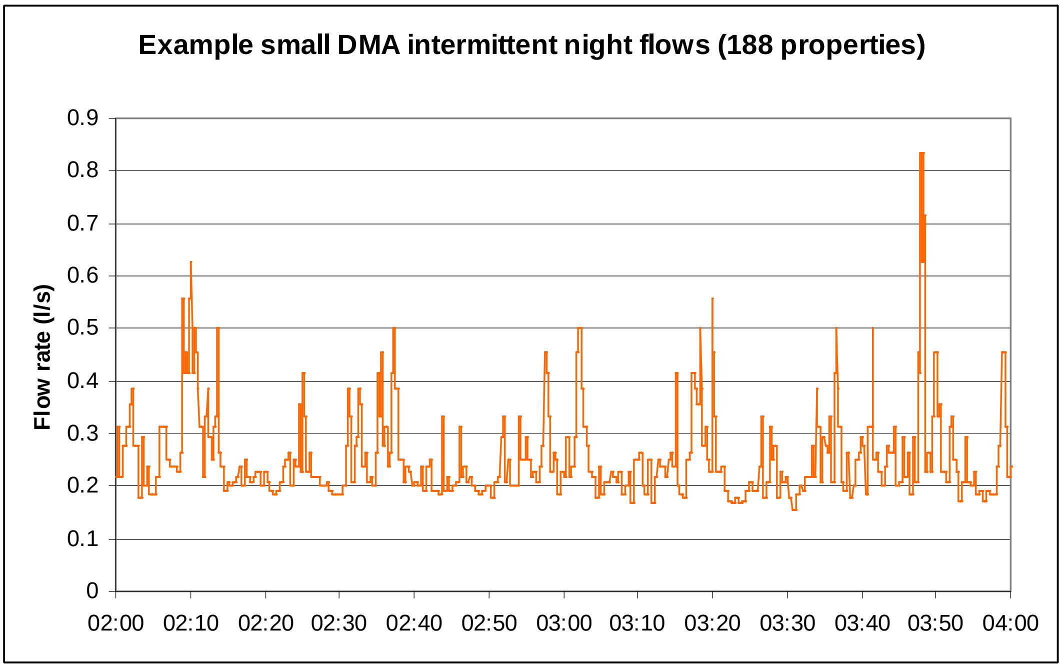


Figure 1 Detailed night flow pattern in a small UK DMA

This feature suggests that there may be benefit from using a smaller interval to analyse night flows and this is discussed later in the paper.

DMA design

DMA design may be constrained in some countries by regulations for fire flows and emergency use and designs must account for water quality issues that may arise when limiting the flow routes through the network. These are fundamental issues that are fully considered in the IWA DMA Guidance Notes (IWA/Water Loss Task Force, 2007) and are not considered further in this paper.

The DMA design must also ensure that adequate metering is in place to record the flows, particularly the low flows at night. This is generally achieved at design, but experience in the UK shows that DMA flows reduce through:

- leakage reduction
- non-household demand reductions (e.g. factory closure)
- DMA resizing

It is evident that a periodic review is necessary to confirm the fitness for purpose of the metering installation as the initial design assumptions change. Inappropriate meters will under-register and provide misleading leakage data.

Checking DMA design

A simple approach to checking the installation without recourse to zonal flow data is to express the minimum design flow, Q_{min}, of the meter in litres/property/hour and compare it to the zonal flows. For example,

- a DMA of N = 1000 properties,
- supplied by a single meter with a design Q_{min} of 0.278 l/s (1000 l/h),
- will have a Q_{min}/N of 1 l/prop/h.

This figure indicates the lowest leakage level that can be tolerated before the meter under-registers and can be compared directly to the leakage levels experienced. Thresholds can be set to indicate whether under-registration is not a problem, is definitely a problem or is indeterminate and will depend on current leakage levels. For multiply-metered zones some proportioning of the night flows will be necessary. More sophisticated tests can be applied using the actual night flows.

Whilst flows below Q_{min} indicate definite failure, flows above Q_{min} are not necessarily satisfactory. For a 15-minute recording interval, the intermittent nature of night flows means that there are periods when the instantaneous flow rate is below the average level. The graph below uses short-interval flow recording to indicate the actual under-registration against nominal meter characteristics. The average flows above Q_{min} under-register more than expected because of periods at flow rates lower than Q_{min}, while the flows below Q_{min} under-register less than expected because of those periods where the flow peaks register more fully.

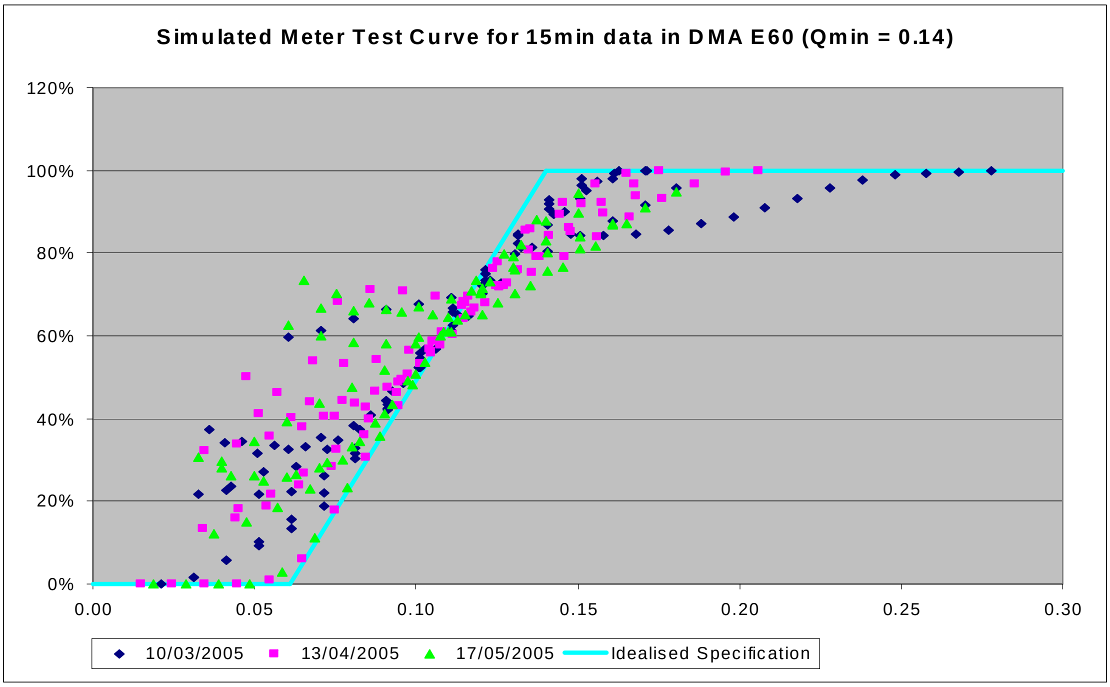


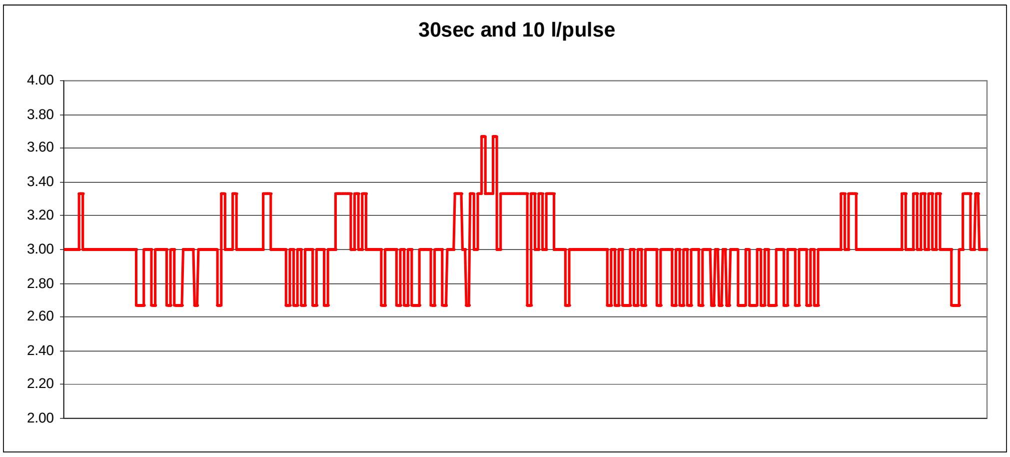
Figure 2 Simulated recorded v actual intermittent flows at low level in a mechanical meter

Pulse size limitations

Most DMA meters provide a pulse output to the logger when a volume of flow has been recorded. The pulse size becomes important if smaller intervals are to be used for the analysis. Inappropriate pulse sizes will lead to coarse discrimination of the night flows. The pulse size can be compared to the expected night consumption as follows:

- Calculate the DMA average night consumption volume expected in the interval of recording.
- (e.g. 1000 properties at 2 l/prop/h during a 15 minute interval is 500 litres)
- Compare this to the pulse size (e.g. 100 litres)
- If the ratio of pulse size to consumption volume is high (e.g. over > 25%) there may be problems in discrimination and increased uncertainty of the result.

When the interval is reduced this effect becomes more obviously apparent. Pulse size constraints can be a limitation on the use of shorter intervals. The graphs below indicate the effects of pulse size discrimination.



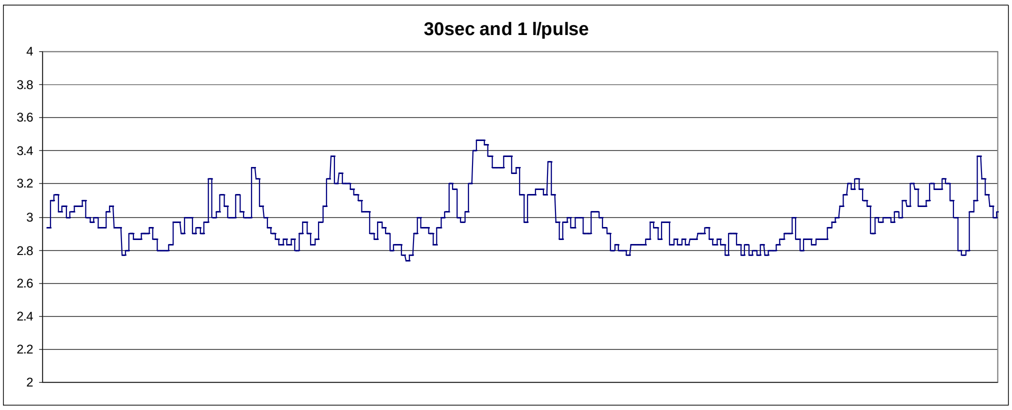


Figure 3 Effects of discrimination with different pulse sizes at short intervals

Reduced interval analysis – intermittent use

Logged data has conventionally been recorded at 15-minute intervals. This is a compromise between the need for more detail and the overhead of storing more data from shorter intervals. Current and anticipated improvements in data recording technology offer an opportunity to use shorter intervals if there is advantage in doing so.

If reduced intervals are used in smaller areas, there is an opportunity to observe lower minimum flow levels as gaps between use events occur. For larger areas such gaps may not be evident as the frequency of use events causes them to overlap.

The night leakage approach seeks to observe flows when the consumption is at a minimum. The use of reduced intervals follows this principle by observing the period when the consumption is at a minimum. Clearly if this approach is used the corresponding consumption allowances will also need to be reduced. By determining night flows that are closer to the actual leakage levels the measurement and allowance uncertainties in the estimate may also reduce.

An intermittent use allowance (IUA) is required to allow for the consumption events that overlap as the DMA size increases. This has been estimated from simulation on a set of DMAs for which valid data at a 1–second interval has been obtained. Each of the DMAs used had periods without intermittent use allowing a base flow to be determined. The simulation randomly combined the DMAs to develop the allowance. An equation of the following form was developed.

$$IUA_t = c_t + a_t N^{b_t}$$

In this equation *a, b* and *c* are coefficients for a given interval *t.* N is the number of properties and the resultant IUA is in l/h for the DMA. The family of curves for varying intervals is shown in the following graph.

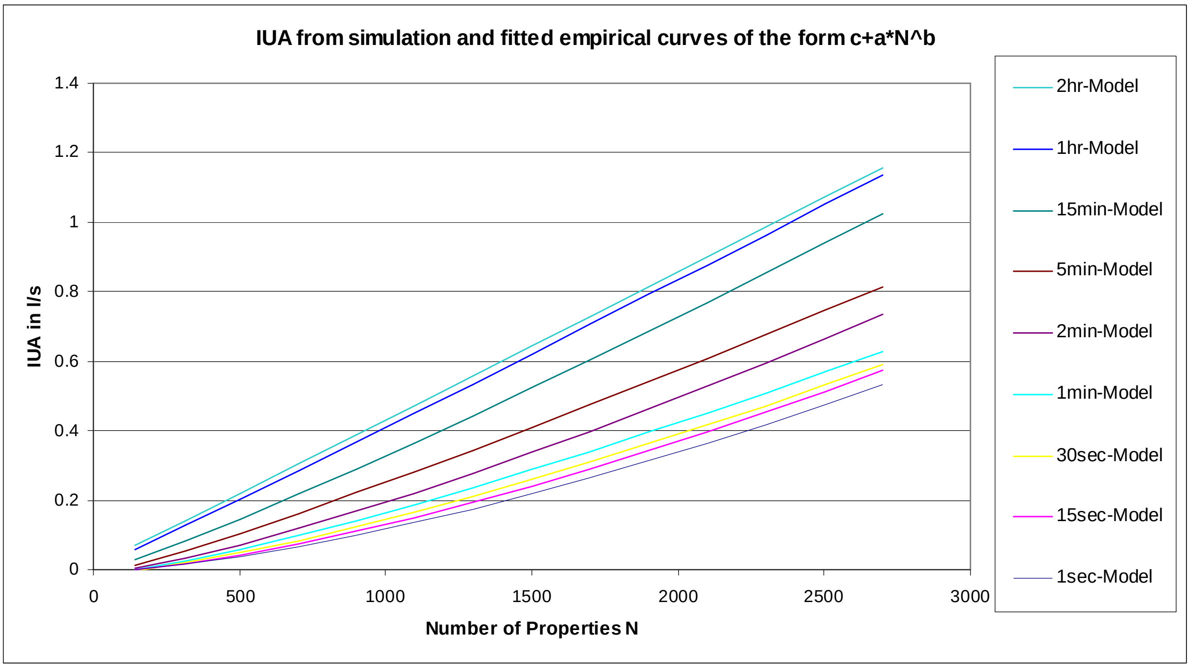


Figure 4 Intermittent user allowance (IUA) from simulation on a UK DMA set

The line becomes approximately linear as the interval increases and *b* tends to 1, but at shorter intervals and for smaller DMAs a non-linear profile can be observed.

The parameter values will vary internationally depending on the demand patterns of the households observed. In the UK much of the flow arises from devices such toilet flushes and washing machine use. In countries with fewer or different devices in use the intermittent pattern will lead to different allowances.

Reduced interval analysis – continuous use

The IUA analysis does not account for the presence of consumption that runs continuously through the night and a further continuous use allowance (CUA) is necessary. For this analysis it is necessary to review the behaviour of individual logged properties and their night-to-night changes. The IUA statistic is dependent on the recording interval within the night; the analogous "interval" for the CUA is the number of nights.

Analysis of the persistence of continuous use was carried out. The frequency of the continuous users is shown in the following graph developed from a logged survey of individual households.

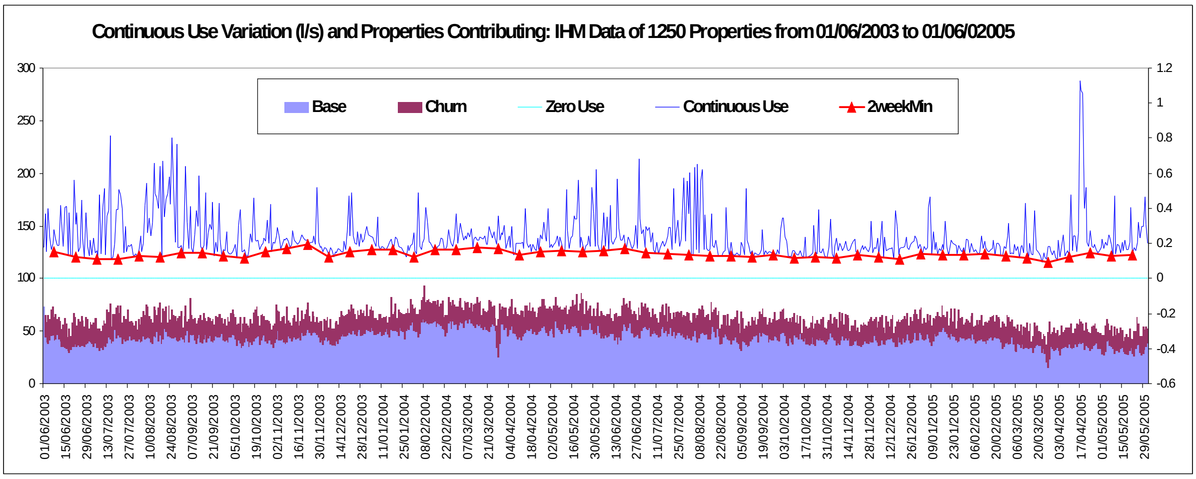


Figure 5 Persistence of households showing continuous night flows by count and flow rate

The graph shows the statistics of the small subset of households that are using water continuously through any single night. Different households will contribute on different nights, but some households show persistent continuous flows. In the bottom section of the graph the count of these households is shown as small (about 50 out of 1250) and not varying significantly. The count is split into two parts: the upper (dark shaded) part shows those households where the continuous flow has persisted less than 14 days and the lower (lighter shaded) part those households where the continuous flow has persisted 14 days or over. This "churn" or turnover of households shows that the short-term flows, particularly those with high flow rate, appear in changing and different locations which allow them to be viewed statistically.

In the top section of the graph, the total flow from these households is shown. This shows that there is a base flow of households using a low continuous flow rate with a larger peaking flow from some households on some days. Two summer seasons can be identified where peaks occur. The minimum flow in a 14-day window is also shown and it can be seen to remove all of the peaks providing a stable base level of continuous flow. By seeking an allowance statistic of this kind the estimate of leakage can be more stable as it is unaffected by seasonal variations in continuous night use.

The 14-day period appears appropriate for the UK because of the intermittent nature of the summer weather. For countries with more persistent warm dry summers than the UK the period will require local review.

By considering a fixed period of 14 days a single equation for the CUA could be derived from simulations using the individual property logged data set. The form of the equation was made similar to the IUA, although in fact the intercept parameter, c, passes through the origin.

$$CUA = c + aN^b$$

In this equation *a, b* and *c* are coefficients for any interval, but relate to a minimum over 14-days. N is the number of properties and the resultant CUA is in l/h for the DMA. The curve is shown in the following graph.

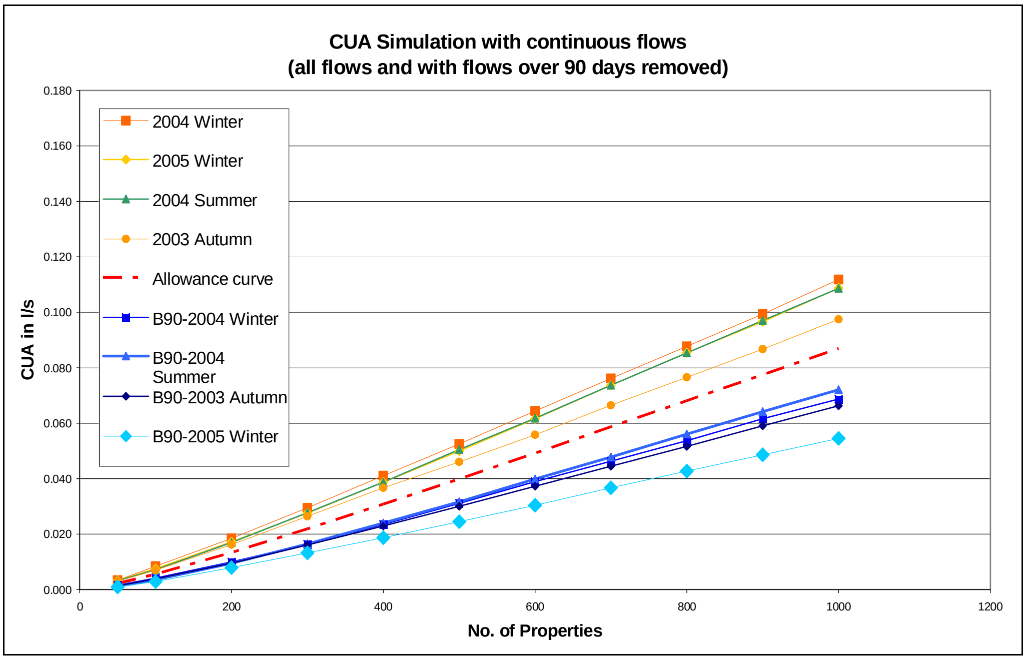


Figure 6 Continuous use allowance estimate from simulations

The single allowance curve (red, dashed line) was estimated from simulations which attempted to account for the possible effects of summer and winter and the inclusion or exclusion of potential service pipe leakage as the monitor was external. No significant difference was found between the seasons. The points above the allowance curve included continuous flows persisting greater than 90 days which may have been very small service pipe leaks (the identified leaks had already been excluded). The points below the allowance curve excluded the 90-day persistent flows and will also have excluded some consumption. The allowance curve is a best view from the current data for the CUA.

Related night flow statistics

It is important that the allowances relate directly to the night flow statistic that is used. Experience suggests that a variety of flow statistics are used (e.g. 7-day 50th percentile of the minimum rolling hour etc.) often without reference to the allowances that are compatible. In the simplest case a fixed 2-hour minimum night flow averaged across nights can be used with an average night consumption allowance for the same period. This has the advantage of robustness and simplicity, but is susceptible to customer consumption variations if used for operation leakage estimates (e.g. purposes 1 or 2 above). Other statistics are better at handling consumption variations, but require more complex consideration of the impact on the consumption allowances made.

For the IUA/CUA method, the compatible night flow statistic that should be used with the allowances is:

- within each night find the minimum valid value at the selected interval

- across 14 nights obtain the minimum valid value from the contributing nights

This estimate will provide consistent allowances that account for the size of the DMA and the interval of recording, achieving purposes 1-3 as identified above.

Benefits

The study demonstrates the potential of alternative approaches to night leakage estimation that account for:

- The characteristics of the components of night flows, both within the night and between nights.
- The composition of the DMA.
- The actual measurements made and the meter/logger combination used.

These considerations allow more consistent leakage estimates between DMAs and minimise uncertainty.

Limitations and further research

The methodology may be implemented in practice with only minor changes to data loggers and receiving systems. However it is recognised that this may be difficult for some organisations (e.g. where the software can only receive and process 15-minute data).

The method may be limited in effect for some DMAs where it is not possible to alter the meter or logger set-up. However it does provide information on the fitness for purpose of the current measurements and indicates where changes are needed to improve the leakage estimates.

The methodology is appropriate for DMAs with primarily household consumption. It is possible to accommodate non-household consumption within the DMA provided this is not excessive. Where non-households contribute the majority of night consumption the analysis will always be difficult unless customer logging is used. Further research into the characteristics of non-household night consumption is needed to allow for the inclusion of non-household properties.

The data sets used for the study were substantial and reasonably representative of UK conditions. However further data would allow a more definitive set of parameter values to be established for UK use. Studies on data sets from other countries would also be of interest to develop the method, particularly those countries with different consumption patterns and device use.

Conclusions

The project has demonstrated that there are opportunities to improve the estimation of DMA night leakage through the methodology presented.

The assumption that the DMA configuration and metering is fit for purpose is challenged and some checks on DMA suitability are provided.

The constraints imposed by the use of the standard 15-minute data recording interval are challenged and opportunities to use shorter intervals are proposed.

There is an expectation that the data from DMAs will meet the increasing requirements placed upon it. The work describes processes to ensure that all aspects of leakage analysis from meter specification through to analysis are able to meet these expectations. Further work is necessary to develop the method and ensure that the expectations can continue to be met.

Acknowledgements

The research related to this work was funded by UK Water Industry Research Ltd as part of their ongoing research programme. The report is due for publication shortly and will be available through the UKWIR web site (www.ukwir.org).

The author is grateful for kind permission of UKWIR to publish this paper. The opinions expressed in this paper are those of the author and do not necessarily represent those of UKWIR.

References

IWA/Water Loss Task Force, District metered Areas Guidance Notes, Version 1 February 2007 (Available from www.iwaom.org/wltf)

UKWIR (in publication) Separation of leakage and night use in district meter areas