Residential Night Consumption – Assessment, Choice of Scaling Units and Calculation of Variability

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Abstract

The best practice Water Balance terminology introduced in 1999 is now widely used internationally. The need for a best practice terminology for components of Minimum Night Flow (MNF) has now also been addressed by the Night Flow Analysis Team of the Water Loss Specialist Group, as shown in Figure 1.

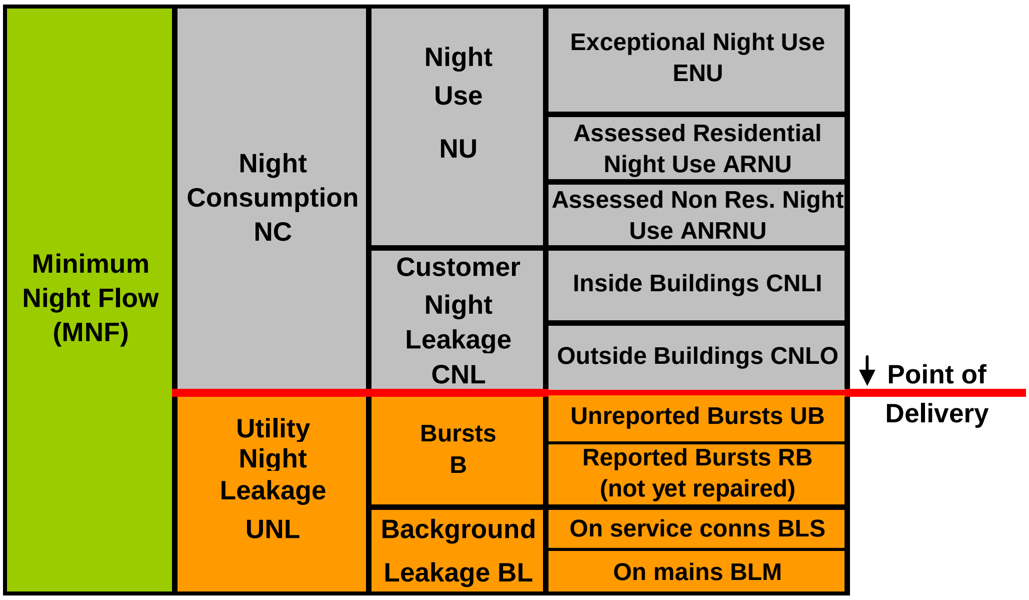


Figure 1 Components of Minimum Night Flow. Source: WLSG Night Flow Team: (2010)

Utility Night Leakage (UNL) is derived by deducting estimates of **Night Consumption** (NC, passing the **Point of Delivery**) from measured Minimum Night Flow (MNF).

Night Consumption (NC) includes **Night Use** (NU) + **Customer Night Leakage** (CNL)

Night Use (NU) includes:

- '***Exceptional***' Night Use: the sum of individual uses above a chosen threshold flow rate, generally somewhere between 100 and 500 litres/hour
- '***Assessed'*** Night Use – the sum of all small night use individually less than the threshold, with separate Residential and Non-Residential components

Customer Night Leakage CNL includes components

- '***Inside Buildings'*** – from toilets, taps, plumbing systems, storage tanks
- '***Outside Buildings'*** – from external pipes, Point of Delivery to buildings

Estimates of Night Consumption are usually derived from analysis of sample readings at night of metered residential and non-residential properties. The results are analysed and then expressed as an average 'per property', 'per service connection' or 'per person' basis, depending upon custom and practice in different countries, for example:

- UK, 1994 (Managing Leakage Report E, 1994): assessed residential night use 1.7 litres/household/hour, non-residential households Groups A to E, averages 1 to 60 litres/non-household/hour, weighted average 7.4 litres/non-household/hour
- Malaysia (1990's): residential night use 5 litres/property/hour
- Germany (DVGW, 2003), Austria (OVGW 2009): minimum night consumption 0.4 to 0.8 litres/person/hour, 2000 to 40000 people per district, no industrial night use

However, in practice the various components of Night Consumption are not fixed, but vary widely. both systematically and randomly, with time of year, night of the week, time of night and duration of MNF measurement. Given this diversity of international situations and units, it is unsurprising that no international 'standard' figure for night consumption has ever been identified; nor is it likely to be.

The increasing availability of Smart Metering technology now provides excellent opportunities for improving our understanding of night consumption. However, the full benefit will not be realised without:

- a practical process for selecting when to measure MNFs to assess Utility Night Leakage; this also defines times and durations of night consumption investigations
- an improved understanding of night consumption components and their variability
- a logical method for selecting appropriate units for night consumption, depending upon local or national circumstances

This paper proposes some approaches for achieving these outcomes, with particular reference to assessments of residential night consumption, for potential application to a wide variety of international situations.

Data Selection

Seasonal Influences

The data selection process commences with examination of the annual pattern of daily inflows (and MNFs, and pressure, if available). When systems are subject to substantial increases in exceptional night use or significant changes in population, the analysis of MNFs to identify Utility Night Leakage is usually compromised. So the first objective is to identify times of year when 'windows of opportunity' occur for MNF measurements that are ***not*** subject to these additional unquantifiable components of night consumption.

Figure 2 (LAPMET software, 2011) shows seasonal profiles for a Pressure Managed Zone (PMZ) in Australia, where the 'window of opportunity' is limited to 2 to 3 months in June to September (winter in the southern hemisphere).

Figure 3 shows minimum and maximum daily inflows to a PMZ in Northern Italy, where the 6-month 'window' occurs between October and April, so March and November are good choices for MNF measurements to assess trends in Rate of Rise of unreported leakage (this is also true in countries where freezing conditions persist during the winter).

In many parts of the UK, there is no consistent seasonal increase in exceptional night use through garden watering, except in occasional dry periods in summer, so night flow analysis is carried out continuously throughout the year.

It can be clearly seen from these few examples that the criteria for selecting night flows for analysis should always be based on inspection of local data, rather than blindly following the practice of other countries (or Utilities within a country) with different climates and seasonal consumption patterns.

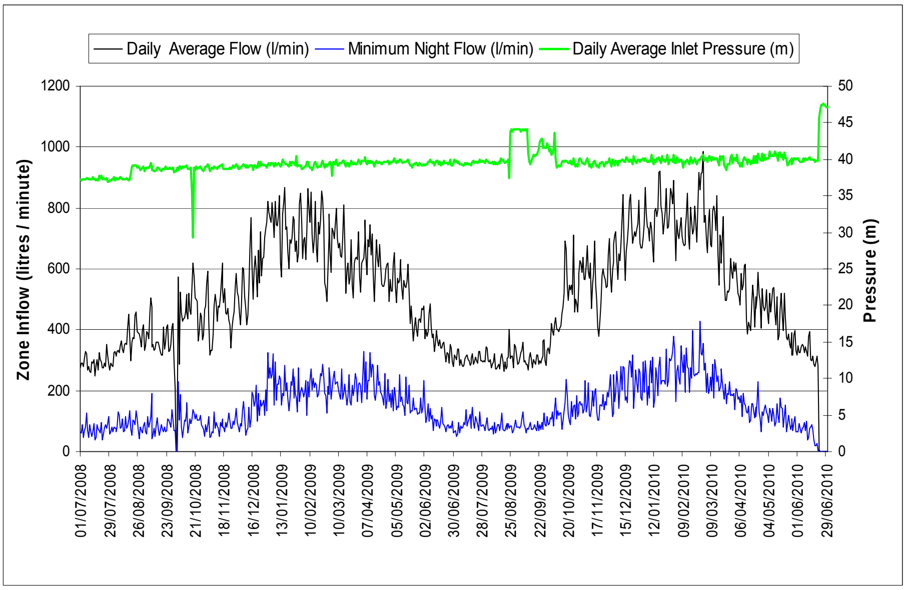


Figure 2: Seasonal Inflows and MNFs to an Australian PMZ Source: Water Corporation

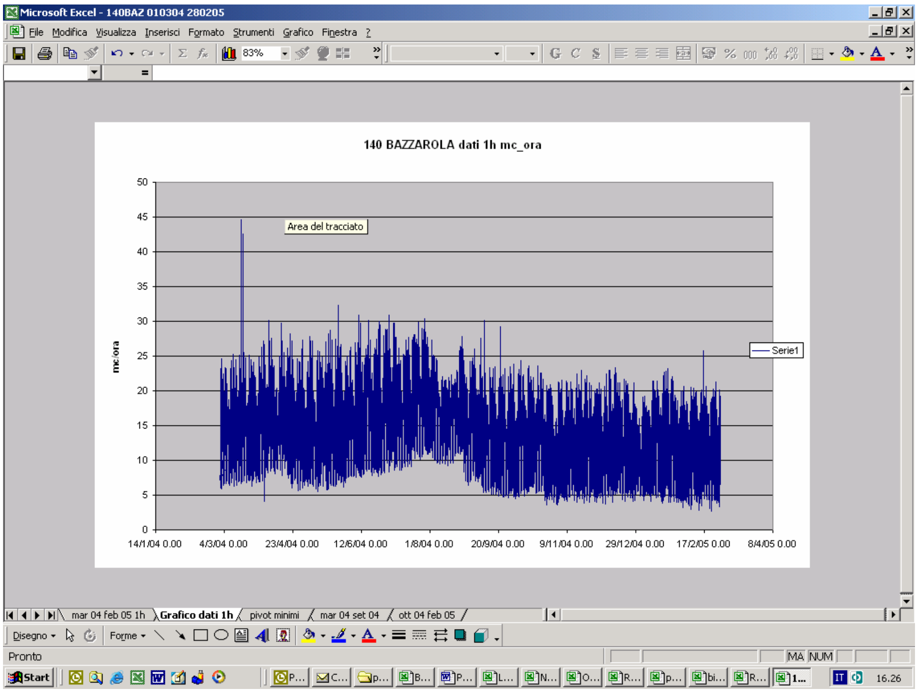


Figure 3: Seasonal Daily Max and Min Inflows to an Italian PMZ Source: IREN Utility

Day of Week, Time of Night and Duration of MNF Considerations

Zone inflows are usually recorded as averages in litres/second over 1, 5 or 15 minute periods. The lowest MNF does not occur during the same time period each night, even in a single Zone. Reasons for this variation can include:

- differences and changes in individual components of night consumption
- coarse discrimination of volume recorded per pulse on the Zone Meter
- MNFs of linked Zones may occur at different times of night

• pressure (which influences leak flow rates) can also change, particularly in pumped or flow modulated Zones.

Some practitioners prefer to identify the lowest rolling 60 minute MNF each night (e.g. from 02.45 to 03.45 one night, then from 03.00 to 04.00 the next). However, a simpler practical solution is to calculate MNFs as average values over fixed hours (00 to 01, 01 to 02 etc.) in litres/sec to 2 decimal places, and then convert them to m^3/hour.

This approach also means that MNFs on District Meters can be compared with Smart Metering data, which is used for identifying Night Consumption by direct measurement, and is usually recorded in hourly blocks (00 to 01 hrs, 01 to 02 hrs etc.).

Figure 4 shows hourly average residential night consumption derived from Smart Metering data for 2008-09 Water Year for 2844 stand-alone residential connections, in 4 Zones with external metering at the property line, in an Australian Utility (Cole, 2011). The top curve shows the annual average for each hour of the night. The two middle curves show hourly averages excluding hourly consumption greater that 600 litres/hour, and 300 litres/hour (considered as the upper limit for indoor consumption). The averages in the lowest curve exclude hourly values more than 100 litres/hour, (and less than 10 litres/hour, as data is stored in 10 litre increments).

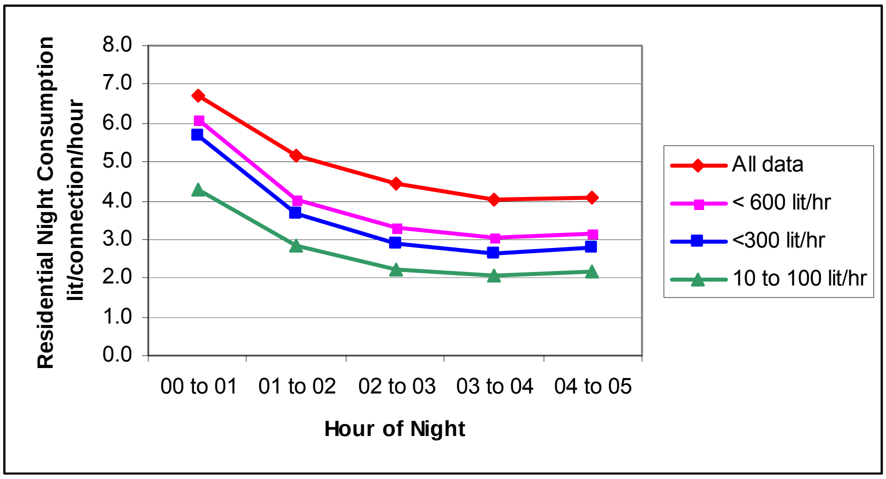


Figure 4: Wide Bay Water Smart Metering Data Analysis Source: Cole (2011)

All the curves show that the minimum average residential night consumption in these Zones occurs between 03 and 04 hours, and that the figure selected for deducting from MNF (to derive Utility Night Leakage) is strongly influenced by:

- the time period over which MNFs are measured (or assumed to occur)
- the presence of relatively high consumption in a small percentage of residences

Figure 4 clearly demonstrates that the time period that is chosen for measurement of MNFs significantly influences the appropriate figure to be used for assessed night consumption, when calculating Utility Night Leakage. So the 'fixed hour' selected for MNF should be the hour when minimum night consumption typically occurs. In different countries, this could be anytime from 00 to 01 hours to 05 to 06 hours, depending upon factors such as latitude, climate, society, religion, and factors such as age of residents, urban/rural, presence or absence of storage tanks etc.

It's essential to identify the typical 'hour of MNF' for each Zone. For most systems that are not subject to pumping or advanced pressure control, this can be done with a simple analysis of hourly measured MNFs during the 'window of opportunity',

Table 1 shows such an analysis for a PMZ in Queensland, Australia. The ‘fixed hour’ of lowest night flow was identified for each night in a 7 week period, for each day of the week. With only a few exceptions, hourly MNFs in this Zone occur from 02 and 03 hours on weekdays (Monday to Friday) but from 03 and 04 at weekends (Saturday and Sunday).

Table 1: Identification of Fixed Hour of Minimum Night Flow for a Queensland PMZ

Day of the week	Week 1 6>12 July	Week 2 13>19 July	Week 3 20>26 July	Week 4 27J>2 Aug	Week 5 3>9 Aug	Week 6 10>16 Aug	Week 7 17>24Aug
Monday	02 to 03	02 to 03	02 to 03	02 to 03	**01 to 02**	02 to 03	**03 to 04**
Tuesday	02 to 03	02 to 03	02 to 03	02 to 03	**01 to 02**	02 to 03	02 to 03
Wedneday	02 to 03	02 to 03	02 to 03	02 to 03	**01 to 02**	02 to 03	**03 to 04**
Thursday	02 to 03	02 to 03	02 to 03	02 to 03	02 to 03	02 to 03	02 to 03
Friday	02 to 03	02 to 03	02 to 03	02 to 03	02 to 03	**03 to 04**	02 to 03
Saturday	03 to 04	03 to 04	**02 to 03**	03 to 04	03 to 04	03 to 04	03 to 04
Sunday	03 to 04	03 to 04	03 to 04	03 to 04	03 to 04	03 to 04	03 to 04

Period	01 to 02	02 to 03	03 to 04	04 to 05
Monday to Friday	3	**29**	3	0
Saturday and Sunday	0	1	**13**	**0**
Monday to Sunday	3	**30**	16	0

Colour Coding of Cells
Data Entry
Calculated

Source: LAPMET software, 2011

Smart metering data can also be used to show how and why the timing and magnitude of the lowest MNF can vary between weekdays and weekends. An End Use Study of residential consumption data in Queensland (Willis et al, 2009; Willis et al 2011), using high resolution loggers with 72 pulses per litre and 10 second timing interval, with a flow trace analysis software tool, allowed night consumption to be split into individual water use events. The overnight events were later analysed (Lambert, 2009) and show why hourly MNFs occur later at weekends than on weekdays. This was primarily due to a higher percentage of people staying up later at night and being ‘active’ in using water for personal hygiene at weekends (Figure 5). Household appliances (washing machines, dishwashers) were also operated slightly more frequently later at night at weekends.

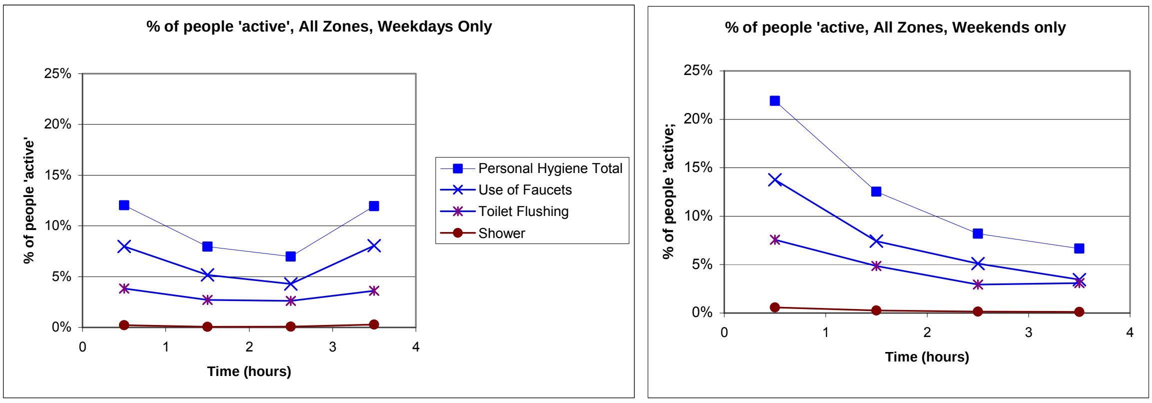


Figure 5: Residential personal night use profiles, per household and per person

Source: Lambert (2009)

This produces different characteristic MNF profiles for weekdays and weekends (Figure 6). So, for detailed analysis of night flows in these residential areas, it is considered preferable to use only the MNFs measured during a predetermined fixed hour on weekdays during the seasonal window of lowest MNFs. The median value of the 5 weekday MNFs is likely to be more consistent for monitoring trends than the average value, as the average value is more influenced by exceptional events such as bursts.

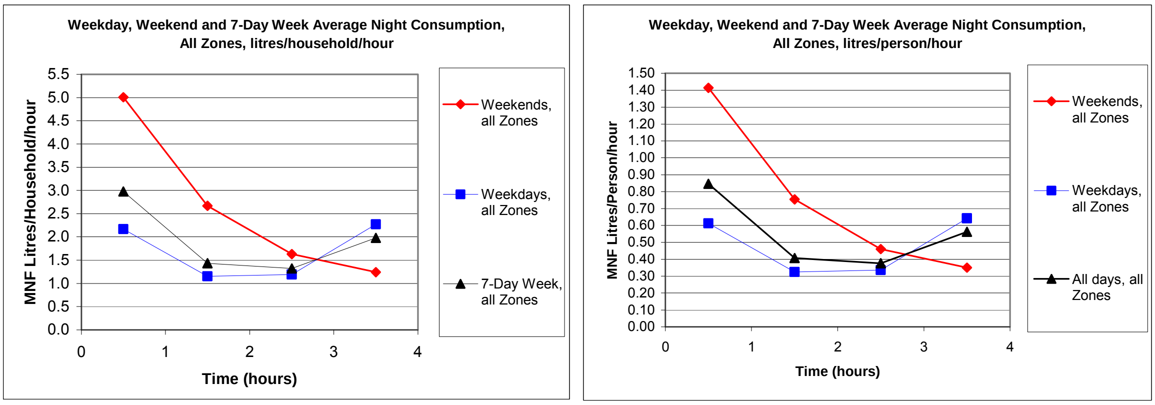


Figure 6: Influence % of 'active' residents on MNFs, on weekdays (Mon-Fri) and weekends (Sat-Sun)

Source: Lambert (2009)

The actual days of the week that are classified as weekdays and weekends will of course vary in different countries with different religious days and social customs.

Data Analysis, Variability and Influence of Sample Size

Interpreting Sample Measurements of Night Consumption

Sample field measurements of Night Consumption should be taken during the 'seasonal 'window of opportunity' and close to the 'Hour of Minimum Night Flow' that have been identified for the system under review. For each selected property and meter, two successive cumulative meter readings (to the nearest 1 litre) are taken at recorded times approximately one hour apart; this usually limits the number of meters read in the sample to around 100. The average night consumption through each meter is then calculated in litres/hour.

Figure 7 shows a typical bar chart of the results, for a sample of 128 residential properties in the ASEAN region, externally metered at the property line, between 03 and 04 hours, which produced an average of 5.9 litres/service connection/hour, with a range of 0 to 128 litres/connection/hour.

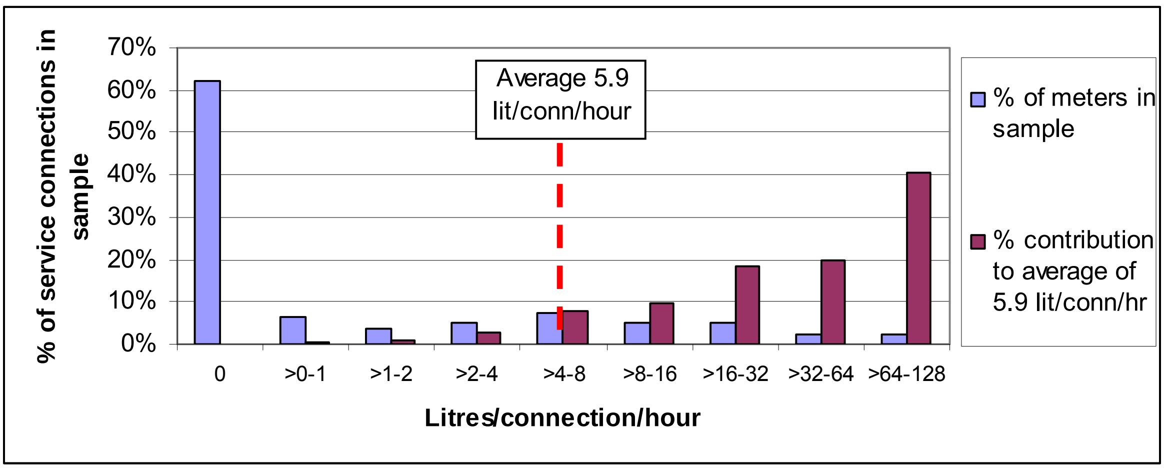


Figure 7: Example results from a Residential night consumption sample

The key point to note is that this is **NOT** a 'normal' or 'Gaussian' probability distribution, with half the readings lower (and half higher) than the average of 5.9

litres/connection/hour. Some 60% of the meters have recorded zero consumption, so only 40% are 'active' in use and/or leakage of water during the hour of lowest MNF. However, just ***4%*** of these meters, with a night consumption of more than 64 litres/connection/hour, were responsible for ***60%*** of the average night consumption. This feature means that the average night consumption derived from a relatively small sample of residential meters is rather unstable, and can vary widely from one sample set to another.

Separating Customer Night Leakage from Night Use

When taking sample measurements of Night Consumption, it is preferable to try to separate Customer Night Leakage from Night Use, as just a few significant leaks after the Point of Delivery have a destabilising effect on calculated average night consumption.

If customer meters have a facility to show when through-flow is occurring, then during the two successive night flow readings one hour apart, recorded night consumption is:

- likely to be leakage if through-flow is recorded as occurring on both occasions
- likely to be night consumption if through-flow is not occurring on both occasions

An alternative approach is to revisit the meter locations with recorded night consumption and check for leaks shortly after the night consumption survey.

Figure 8 shows the results of a major survey for leaks after the meter, in a Queensland Utility, where Pressure Management Zones were being installed for 63,000 properties with customer meters located at the property line. Each meter was checked, and if the cumulative register was seen to be turning it was observed for 3 minutes to obtain a flow rate, which was then followed up to check if it was leakage.

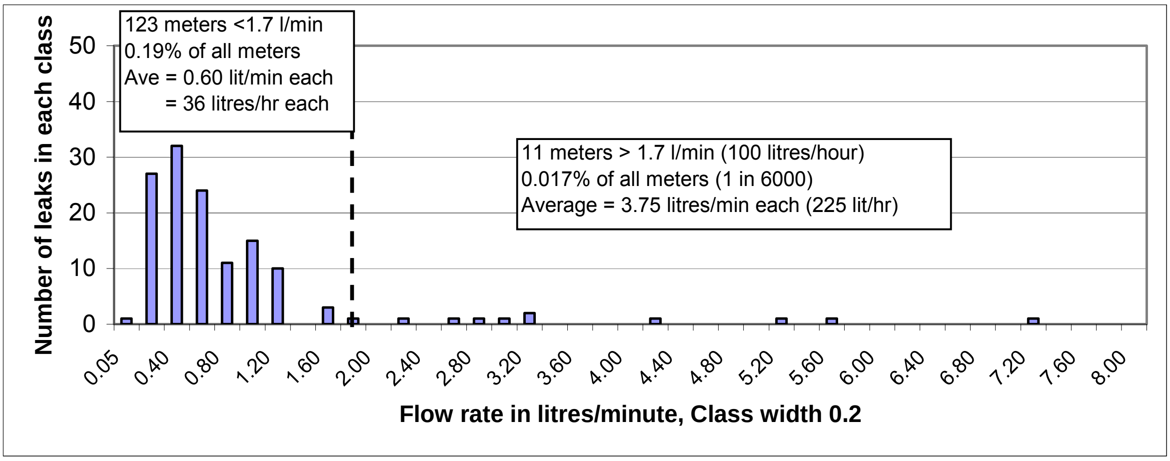


Figure 8: Residential leaks identified in 63,000 metered Queensland properties

Figure 8 shows that the leaks after the meter can be split into two populations:

- small leaks (10 to 100 litres/hour, in 0.19% of the properties; most of these were inside buildings (leaking toilets etc)
- larger leaks (> 100 litres/hour, average 225 litres/hour) in 0.017% of the properties; most of these were outside buildings (leaking service pipes)

Modelling Variability using the Binomial Distribution

As previously stated, a Normal (Gaussian) bell-shaped probability distribution is not appropriate for analysing Night Consumption data, as it does not explain or reproduce the high variability in consumption from night to night, especially in small samples.

The use of the Binomial or Multinomial distributions for night consumption analysis was proposed (by an author of this paper) and used in UK ‘Managing Leakage’ Report E ‘Interpreting Night Flows’ (1994). A brief explanation follows, of how to use the Binomial Distribution for analysing components of night use, using toilet flushing as an example.

The average volume component of night use from toilet flushing (Vt) is the average number of people flushing a toilet during the hour of MNF, multiplied by the average volume (vt) flushed. i.e. Vt = N x p x vt, where:

- N is the total number of people in the Zone (e.g. 3000)
- p is the average % of residents that flush a toilet during the hour of MNF (e.g. 3 %).
- average number ‘active’ on a single night is N x p = 3000 x 3% = 90 people
- vt is the average volume of a toilet flush (e.g. 5 litres).
- Vt = 90 people x 5 litres = 450 litres or 0.15 litres/person/hour

A significant advantage of the Binomial distribution is that the standard deviation of the number of ‘active’ people on a single night is also easily calculated as √ {N x p x (1-p)}

- the standard deviation of the number ‘active’ each night is = √{3000 x 3% x 97%} = 9.3
- the standard deviation of Vt = 9.3 people x 5 litres = 47 litres or 0.016 litres/person/hour

Separate figures for proportion active (p) and ‘average volume’ can also be derived for use of faucets, showers, dish washers, clothes washers, irrigation, etc. (Lambert, 2009). The method can be applied using % of active people, or % of active properties.

Residential Night Consumption during the Hour of Minimum Night Flow

By selecting the hour of MNF for analysis during the seasonal ‘window’ when exceptional night use is likely to be at a minimum, the probability of relatively large individual uses of water at night can be significantly reduced. This leads to more stable estimates of MNF and associated estimates of night consumption, and therefore more reliable estimates of customer night leakage. The assessed residential night consumption is likely to be a large component of the night consumption, except in Zones where there is significant non-residential night consumption – in such cases it may be necessary to use MNFs on nights of the week when the non-residential consumption is lowest.

In the early 1990’s, international estimates of residential night consumption ranged from 1.7 litres/property/hour in the UK to around 3.0 in Canada, to 5.0 in Malaysia. The German Gas and Water Association (DVGW) then used 0.6 litres per person per hour.

Recognising that toilet flushing accounted for a significant part of these figures, one of the authors of this paper found, in 1995, that these international estimates for residential night consumption could be roughly approximated by assuming that 6% of the population initiated a toilet flush of X litres during the hour of minimum night flow. This quick prediction method allowed for wide variations of average occupants per household (2.5 to 10 occupants) and average toilet flush volume (then in the range 10 to 22 litres).

However, recent smart metering studies in Australia (Lambert, 2009) have indicated that the actual % of occupants flushing toilets during the hour of MNF is closer to 3%, rather than the previously derived estimate of 6%; the remainder of assessed residential night consumption during the hour of MNF is accounted for by other in-house uses of water at night (around 3% using 1 litre of water from taps, and infrequent use of showers and washing machines), and leaking toilets.

As low flush and dual flush toilets are installed in new properties, and retrofitted in older properties, it is more difficult to assess the average toilet flush volume at night. However, the Australian study suggested that during the hour of MNF around 50% of dual flush toilets flushed are low flush, so average flush volumes at night can be estimated.

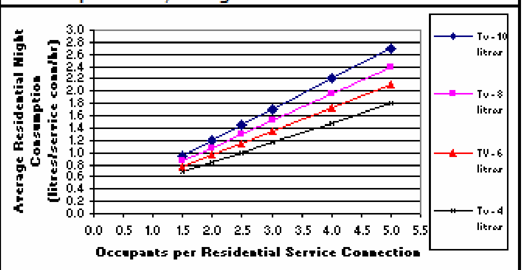
Figure 9 shows the latest component analysis approach being used to calculate Assessed Residential Night Consumption in Australia (WSAA, 2011; LAPMET 2011), where leakage is generally extremely low (most ILIs close to 1.0) .Residential properties are metered at the property line and include both apartment blocks and individual houses/bungalows in cities. The major parameters influencing assessed residential night consumption, and the effect of pressure on customer night leakage, are taken into account. The results are presented as Tables and Graphs on both a 'per service connection' and a 'per person' basis.

ASSESSED RESIDENTIAL NIGHT CONSUMPTION IN AUSTRALIA					
Predictions of Assessed Residential Night Consumption in Australia based on Smart Metering studies (Ref. 35, 2010; Guideline 8, 2011) are based on the equation **ARNC (litres/hour) = (A x Tv + B) x No + C x Ns x AZNP/50**					
(A x Tv + B) is Night use x No. of Occupants in Zone (No), and (C x Ns x AZNP/50) is leakage x No. of service connections (Ns)					
where the components of the equation and the recommended defaults are as follows:	Recommended Defaults				
□ A is the % of occupants flushing toilets during the hour of MNF	**3.0%**	3.0%, based on Ref. 35, 2010			
□ Tv is the average toilet flush volume in litres during the hour of MNF	**5.0**	Varies with cistern size and dual flush			
□ B is remaining in-house use (faucets, showers) & small leaks generated by night use	**0.20**	0.20 litres/occupant/hour (Guideline 8)			
□ C is the average of leaks after the meter at 50 metres Average Zone Night Pressure.	**0.20**	0.20 litres/conn/hour, (Guideline 8)			
If the number of occupants per service connection (No/Ns) =	**2.50**	and AZNP =	**50**	metres	
Then the Assessed Residential Night Consumption ARNC =	**1.08**	**l/conn/hr or**	**0.43**	**l/occupant/hr**	
sessed Residential Night Consumption calculated using the above parameters A, B, C are also shown below as Tables and Grap					

Assessed Residential Night Consumption in Litres/service connection/hour

Average toilet flush volume Tv (litres)	Average Number of Occupants per service connection No/Ns					
	1.50	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**
3.0	**0.64**	**0.78**	**0.93**	**1.07**	**1.36**	**1.65**
4.0	**0.68**	**0.84**	**1.00**	**1.16**	**1.48**	**1.80**
5.0	**0.73**	**0.90**	**1.08**	**1.25**	**1.60**	**1.95**
6.0	**0.77**	**0.96**	**1.15**	**1.34**	**1.72**	**2.10**
7.0	**0.82**	**1.02**	**1.23**	**1.43**	**1.84**	**2.25**
8.0	**0.86**	**1.08**	**1.30**	**1.52**	**1.96**	**2.40**
9.0	**0.91**	**1.14**	**1.38**	**1.61**	**2.08**	**2.55**
10.0	**0.95**	**1.20**	**1.45**	**1.70**	**2.20**	**2.70**

Assessed Residential Night Consumption in litres/conn/hour; 3% of occupants active, other in-house use 0.2 l/person/hr, leakage after meter 0.2 l/conn/hr at 50 m



Assessed Residential Night Consumption in Litres/Occupant/hour

Average toilet flush volume Tv (litres)	Average Number of Occupants per service connection No/Ns					
	1.50	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**
3.0	**0.42**	**0.39**	**0.37**	**0.36**	**0.34**	**0.33**
4.0	**0.45**	**0.42**	**0.40**	**0.39**	**0.37**	**0.36**
5.0	**0.48**	**0.45**	**0.43**	**0.42**	**0.40**	**0.39**
6.0	**0.51**	**0.48**	**0.46**	**0.45**	**0.43**	**0.42**
7.0	**0.54**	**0.51**	**0.49**	**0.48**	**0.46**	**0.45**
8.0	**0.57**	**0.54**	**0.52**	**0.51**	**0.49**	**0.48**
9.0	**0.60**	**0.57**	**0.55**	**0.54**	**0.52**	**0.51**
10.0	**0.63**	**0.60**	**0.58**	**0.57**	**0.55**	**0.54**

Assessed Residential Night Consumption in litres/occupant/hr; 3% of occupants active, other in-house use 0.2 l/occupant/hr, leakage after meter 0.2 l/conn/hr at 50

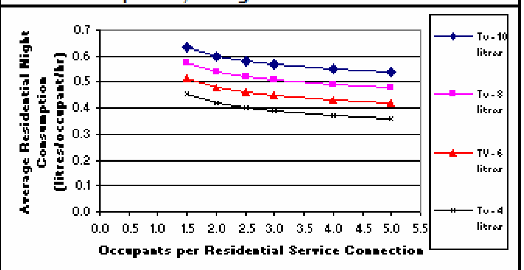


Figure 9: Calculation of Assessed Residential Night Consumption

Source: LAPMET software for WSAA PPS-3 Project, 2011

The 'per person' assessments in the lower graph of Figure 9 are consistent with the Austrian and German guideline values of 0.4 to 0.8 litres/person/hour, and demonstrate the influence of average toilet flush volume at night in low leakage residential properties.

Choice of Units for Expressing Night Consumption

This choice would appear to depend on whether the majority of night consumption during the hour of MNF is related to personal water use activities initiated by people (toilet flushing, showers, baths, use of taps, washing machines etc), or not. If so, and the number of residents is reliably known, then litres/person/hour is a logical choice; if not, litres connection/hour is likely to be more appropriate.

Summary

- A WLSG draft terminology for Minimum Night Flow components is now available
- Smart Metering provides opportunities for better understanding of Night Consumption
- Selection of MNFs to estimate Utility Night Leakage should be based on analysis of lowest seasonal, day of week and time of Night Consumption over a fixed hour
- Review annual pattern of daily inflows to identify ‘windows of opportunity’
- Identify fixed hour of MNF during windows of opportunity; use median of weekday MNFs only if weekend and weekday MNFs have different characteristics
- Attempt to separate Customer Night Leakage from Night Use
- Measurements of Night Consumption do not follow a Normal Distribution; calculate ‘% active’ and learn to use Binomial Distribution
- Calculate Assessed Residential Consumption using Spreadsheet component analysis
- Choice of units: litres/person/hour appropriate if personal night use is the dominant component of Night Consumption; otherwise use litres/connection/hour.

Acknowledgements

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