Drought Plan 2022
Annex 5: Effectiveness of drought restrictions

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from Southern Water

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Abbreviations

DI	Distribution Input
EA	Environment Agency
EODR	Effectiveness of Demand Restrictions
MDO	Minimum Deployable Output
NEUB	Non-essential Use Ban
SWS	Southern Water
TUB	Temporary Use Ban
WRZ	Water Resource Zone

1. Introduction

This annex describes an assessment of the impacts of the demand restrictions that were applied by Southern Water (SWS) during the 2005-06 drought. The analysis is based on an empirical model of household demand that accounts for both weather influences and the effect of metering on demand. The 2012 drought event was not considered due to the exceptionally high rainfall that occurred almost immediately after the Temporary Use Ban (TUB) was introduced.

2. Data sources

The following data sources were used in the analysis:

- Daily Distribution Input (DI) data from 2001 to 2015 inclusive, aggregated according to supply area. The analysis was originally going to be carried out at a Water Resource Zone (WRZ) level. However, there were some data issues that meant the inter-zonal transfers are not reliably represented at this level, particularly post 2010. The aggregated supply area data (Western, Central and Eastern) are reliable and have therefore been used. The one exception to this is the Isle of Wight (IOW) WRZ, where the separation in DI from the Hampshire WRZs in the Western area was reliable. This allowed the IOW WRZ to be used as a 'control' data set, representing a WRZ where there have been very high levels of metering for some considerable time.
- Monthly leakage calculations from 2001 to 2015 inclusive.
- Annual average non-household demand based on regulatory return data from 2001 to 2015 inclusive.
- Daily rainfall for the Lower Itchen, Ditchling Road, and Canterbury rain gauges from 2001 to 2015 inclusive.
- Daily mean air temperature for the Wiggonholt site from 2001 to 2015 inclusive.

3. Methodology

The methodology used is broadly in line with the Environment Agency (EA) Drought Demand Modelling Guidance (i.e. additive multiple linear regression models based on temperature and household demand) although it contained two key enhancements that made the resultant models suitable for SWS purposes:

- Rather than use sunshine hours, which generally act as a proxy for the time of the year and have a large degree of auto-correlation with temperature, three sub-models were set up to represent the October to March (winter), April to July (spring/early summer) and August to September (late summer) conditions. This was found to accurately emulate the inherently smaller response to weather that occurs within most of our region during the August and September periods (presumably due to summer holiday effects that continue into September), and accounted for the clear difference in demand response observed between the late winter/early spring period and the 'spring growing season' (April and May).
- As we have metered over 87% of our household customers, the simple additive linear model proposed by the EA guidance was not able to reflect the demand response seen at high levels of metering. In particular, it is evident at the higher levels of metering (i.e. beyond 40%) achieved by our metering programme that there is a large reduction in the summer peak usage that reduces the peak to average demand ratio. This can be clearly seen in the data for the Eastern area (Figure 1). This model therefore contained a non-linear response to metering that was accounted for in two

ways; an additive component applied to the underlying demand and a multiplicative function that was applied to the weather response component of the model.

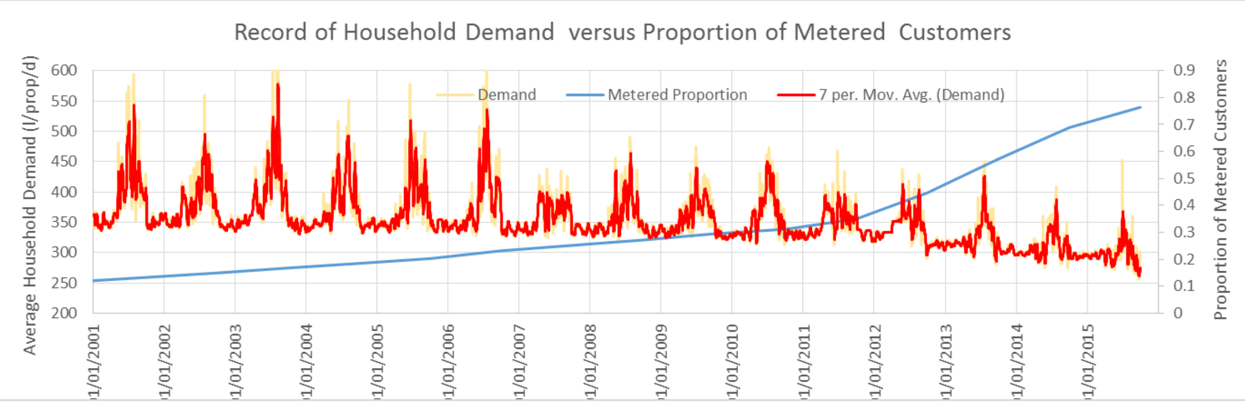

Figure 1: An illustration of the link between household meter penetration and demand (Eastern area).

Observed household demand was calculated for each day using the following equation:

Household demand = DI – Non-household demand[1] – Leakage[2]

[1]Non-household demand figure is based on mid-year to mid-year linear trend using the annual returns data
[2]Leakage figure is interpolated based on mid-month to mid-month operational leakage estimate

The regression analysis was carried out using standard good practice and a number of different model formats were tested. The preferred model format was derived based on graphical demand responses to individual explanatory factors followed by rapid testing in the miniTab statistical package. The following model format was found to represent both the best statistical fit and the most plausible explanation of the response to metering (which included the metering sensitivity response described later):

$$D = A + [\![Meter]\!]^B + (1/[\![Meter]\!]^C) \times ((D([\![Temp>10)]\!]^2 + E(dry\ day) + F(\log rain7) + G(\log rain30))$$

Where:
D = household demand (l/prop/d)
A to G are regression constants
Meter = proportion of households that are metered
Temp>10 = number of degrees above 10°C in each day (min = 0 at 10 degrees)
Dry day = no rainfall on that day stated as a binary 1 (no rain) or zero (some rain)
log rain7, 30 = logarithm of the total rainfall over the last 7 or 30 days [14 days were tested, but not found to be statistically significant]

For each model in each area all factors were tested and those that were not statistically significant (i.e. -2>‘T’ stat<2) were not included in the final model. For example, the Central area winter model did not have a statistically significant response to any of the weather-related components. A summary of the model coefficients that were derived is provided in Table 1. 2005 and 2006 were excluded from the data set used to construct the model, as the model was designed to provide estimates of household demand without demand restrictions in place.

Table 1: Summary of calculated model coefficients (zero values indicate the explanatory factor was not statistically significant so not used).

Area	Model (time of year)	A (underlying demand l/prop/d)	B (meter)	C (meter power)	D (meter weather response)	E (temp)	F (dry day)	G (Log Rain7)	H (Log Rain30)
IOW	Summer	418.2	0.0	0.0	0.0	0.9	11.4	-11.6	-9.6
	Winter	385.4	0.0	0.0	0.0	0.0	0.0	-4.9	-9.6
Western	Spring/ Early Summer	422.5	-104.6	0.60	0.3	0.6	12.9	-15.0	-12.0
	Late Summer	387.6	-110.6	0.60	0.3	0.5	9.5	-12.0	-4.9
	Winter	390.0	-75.0	0.60	0.0	0.0	0.0	-2.1	-14.9
Central	Spring/ Early Summer	451.4	-116.3	0.40	0.2	0.6	2.7	-17.6	-17.3
	Late Summer	370.5	-77.3	0.40	0.2	0.4	7.7	-10.5	-0.2
	Winter	360.0	-55.0	0.40	0.2	0.4	0.0	0.0	0.0
Eastern	Spring/ Early Summer	473.0	-200.5	0.55	0.3	0.7	0.0	-23.2	0.0
	Late Summer	437.7	-180.4	0.55	0.3	0.7	0.0	-14.0	0.0
	Winter	405.0	-120.0	0.55	0.3	0.0	0.0	-9.1	0.0

The demand response in each area was then tested in two ways to derive the estimates of the effectiveness of demand restrictions:

- The empirical model outputs for 2005 and 2006 were compared against the actual recorded values to evaluate the differences that can be attributed to the restrictions that were in place. Any systematic bias in modelled versus actual by month was accounted for when making the comparison.
- The model was reset to estimate the equivalent size that the 2005 and 2006 summer peak would have been if the proportion of measured properties had been 80% during that drought. As there is clear evidence that the size of the summer peak relative to underlying demand has reduced as a result of metering, the benefits of demand restrictions will have reduced accordingly. This analysis was carried out based on a comparison of the peak to average ratio across the whole of the summer period with the metering at the time and with current levels of metering.

4. Results and analysis

A comparison of the modelled versus observed demand for each month is provided in Figure 2 to Figure 5. As can be seen, the model provides an excellent weekly fit in all areas for periods of 'normal' (unrestricted) demand (covariance>0.99 and R2>0.82) and readily accounts for the impact of metering both on underlying demand and on the size of the peak. The impact of the 2005-06 demand restrictions and the 2008-09 financial crisis are both evident in the mainland areas. Data from the IOW indicate that there was no significant time-based trend across this period, although it is notable that the IOW also demonstrated no response to either the 2005-06 drought publicity or the 2008-09 financial crisis. Although there may have been some shift in behaviour over time in the mainland areas that was not reflected in the IOW, the evidence from this 'control' WRZ suggests that the trend-based behaviour observed in the three mainland areas is mostly associated with metering and specific events such as the demand restrictions during the droughts and the 2008-09 financial crisis, rather than a time-based behavioural trend.

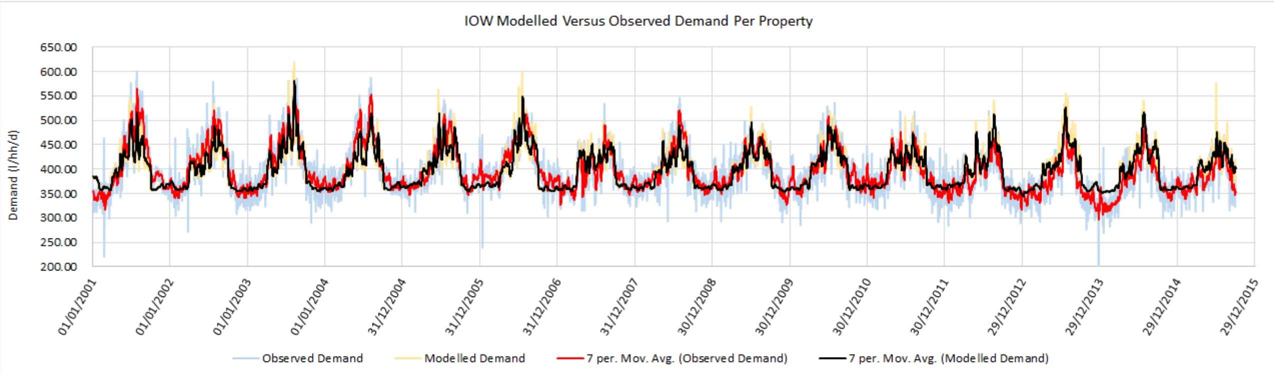

Figure 2: Observed vs modelled demand on the IOW.

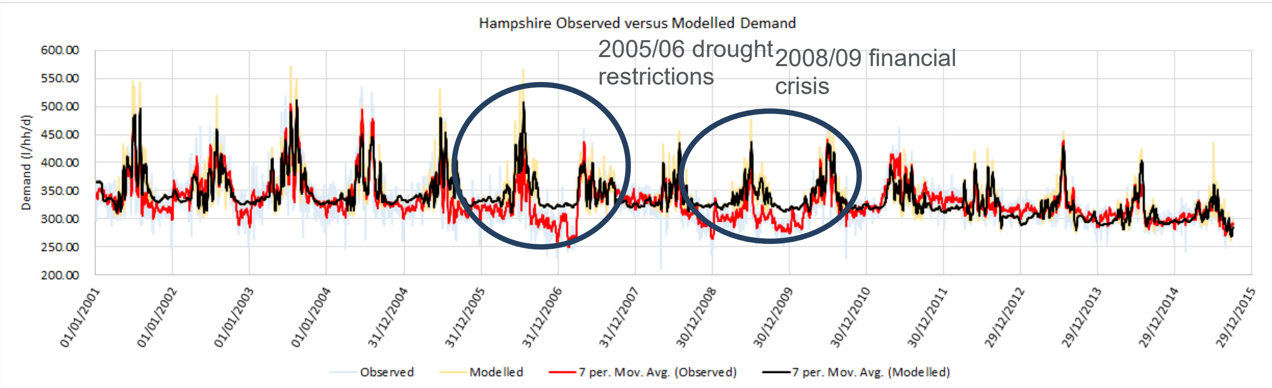

Figure 3: Observed vs modelled demand for the Western area (excluding the IOW).

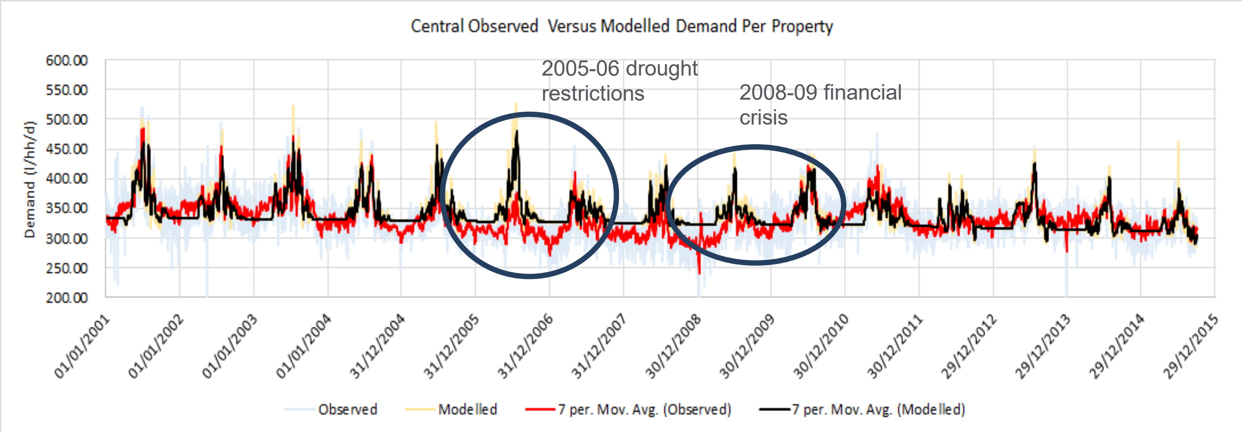

Figure 4: Observed vs modelled demand for the Central area.

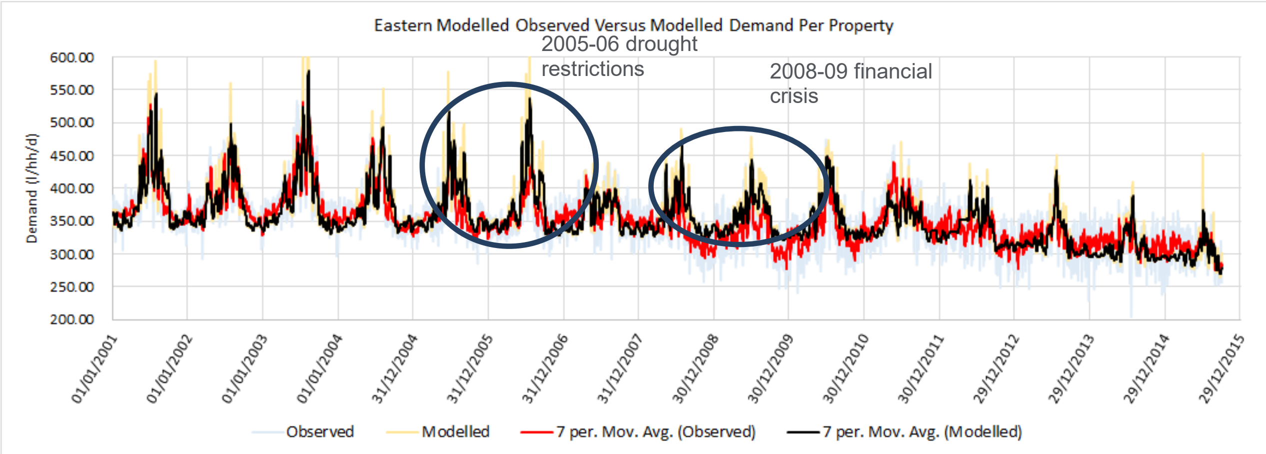

Figure 5: Observed vs modelled demand for the Eastern area.

An analysis of the amount of monthly bias from the model (if 2005-06 and 2008-09 are excluded) is provided in Figure 6 to Figure 8 below (bias = observed/modelled average for each month). As can be seen the models are accurate to within +3% for almost all months.

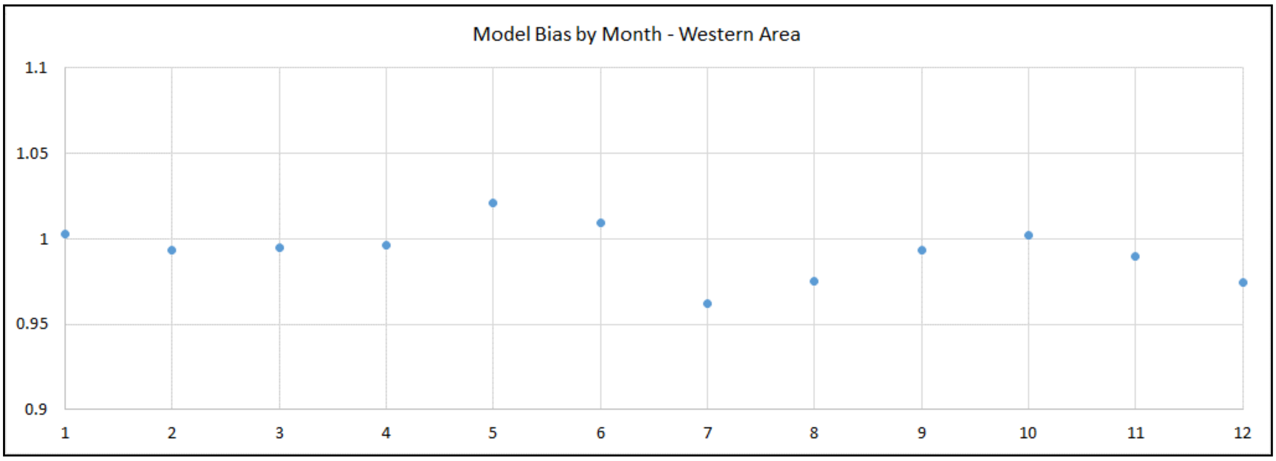

Figure 6: Model bias by month - Western area.

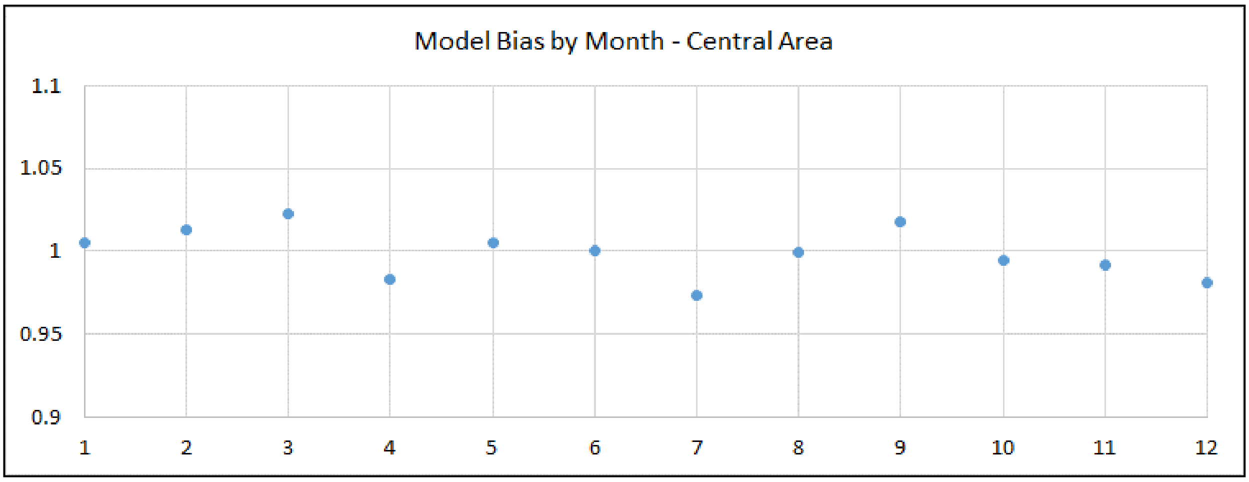

Figure 7: Model bias by month - Central area.

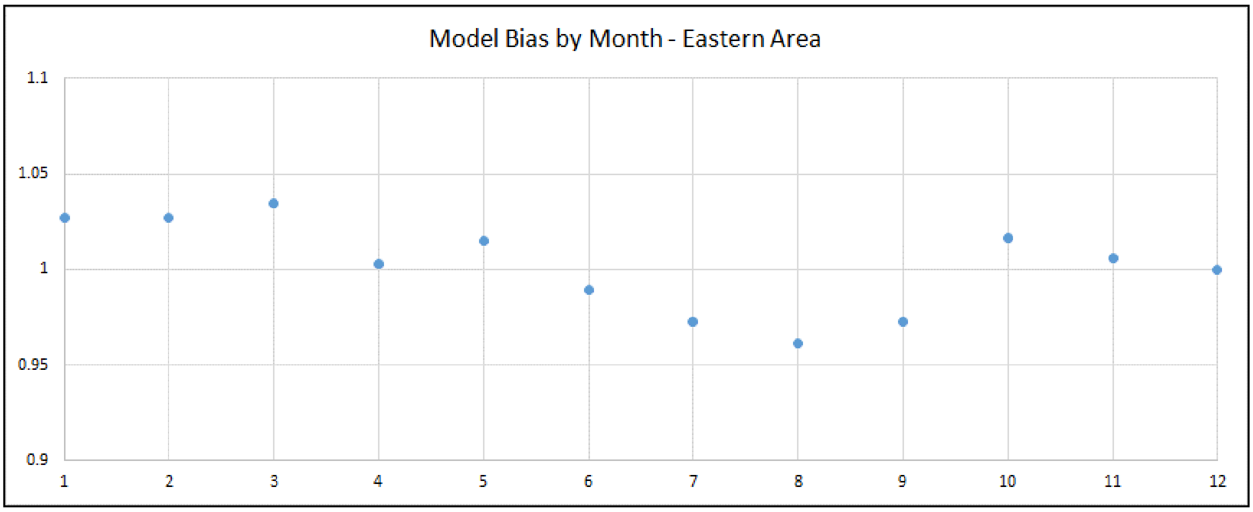

Figure 8: Model bias by month – Eastern area.

An analysis of the modelled demand if metering was a constant 80% for the whole period across the three areas is provided in Figure 9 to Figure 11.

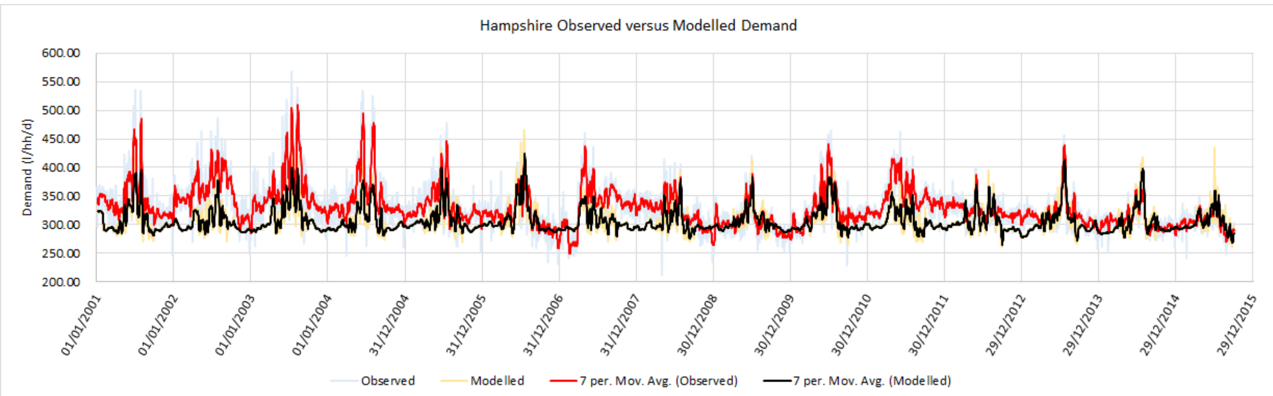

Figure 9: Estimate of demand for a constant 80% metered population area – Western area (excluding the IOW).

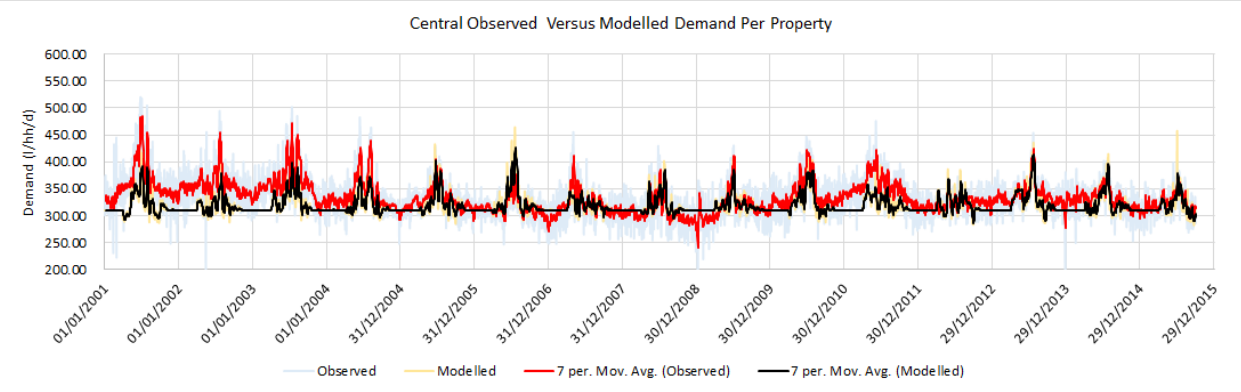

Figure 10: Estimate of demand for a constant 80% metered population area – Central area.

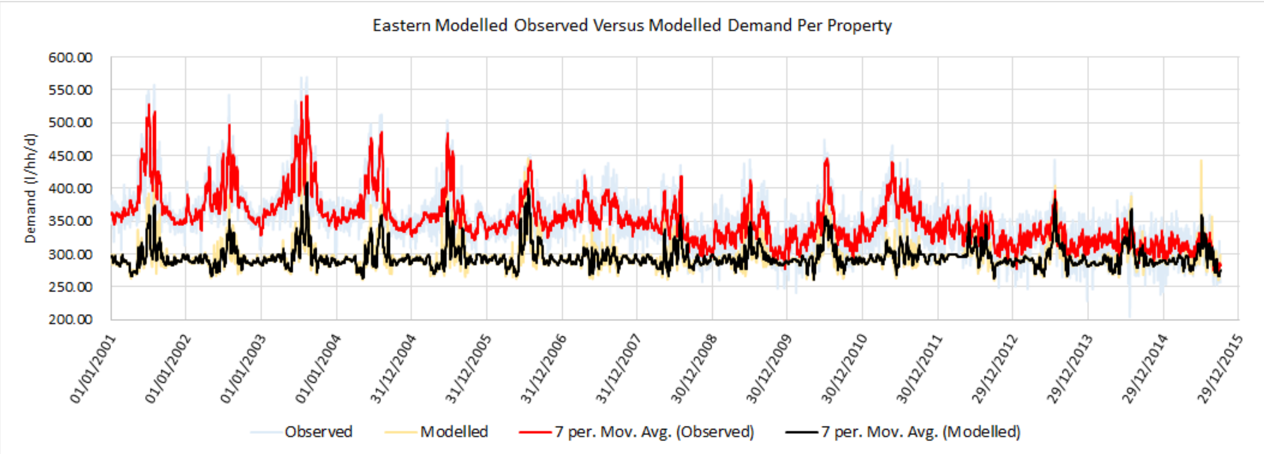

Figure 11: Estimate of demand for a constant 80% metered population area – Eastern area.

Overall, the above analyses show that:

- Metering seems to have had a much larger effect on the Eastern area that the other two areas. As well as affecting the underlying demand more, the relative impact on the peak demand is also much higher when compared with the Central and Western areas. In the Eastern area the overall summer peak for a 2005-06 style event (theoretical, without demand restrictions) has reduced by around 60%, compared with a 35% reduction in the Central and Western areas. A small amount of this is due to a smaller actual measured population at the time (circa 23% versus 26% in Western and Central areas at the end of 2006) but the majority represents a different behavioural response.
- The model format continues to provide logical results even when this high level of stress test is applied, even though there are non-linear and multiplicative terms within the model.

Figure 12 to Figure 14 show the expected versus modelled results with bias correction for the three areas. The IOW is not shown as Figure 2 clearly demonstrates that there was no response to either the 2005 hosepipe ban or the publicity surrounding the 2006 Non-Essential Use Bans (NEUBs).

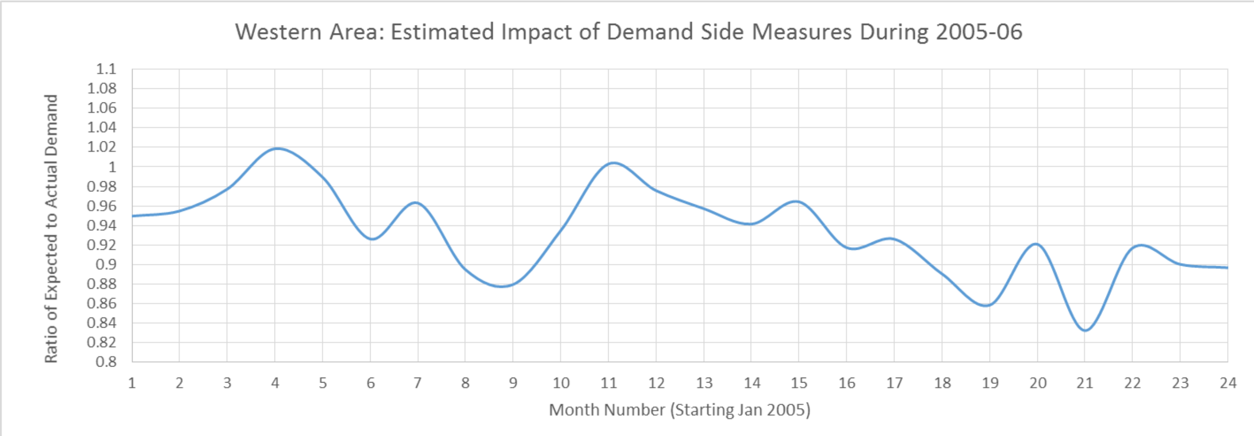

Figure 12: Estimate of demand restriction impacts during the 2005-06 event – Western area (excluding the IOW).

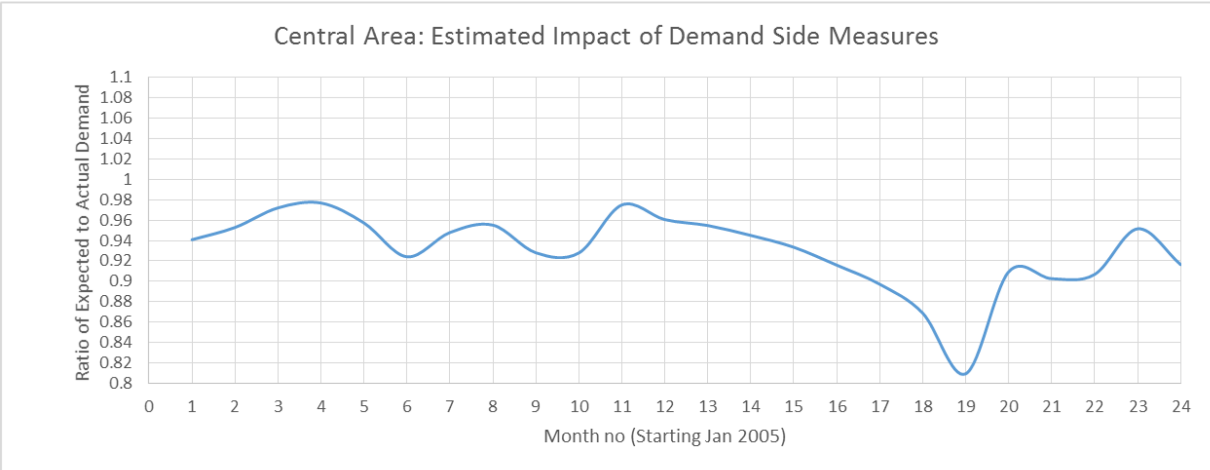

Figure 13: Estimate of demand restriction impacts during the 2005-06 event – Central area.

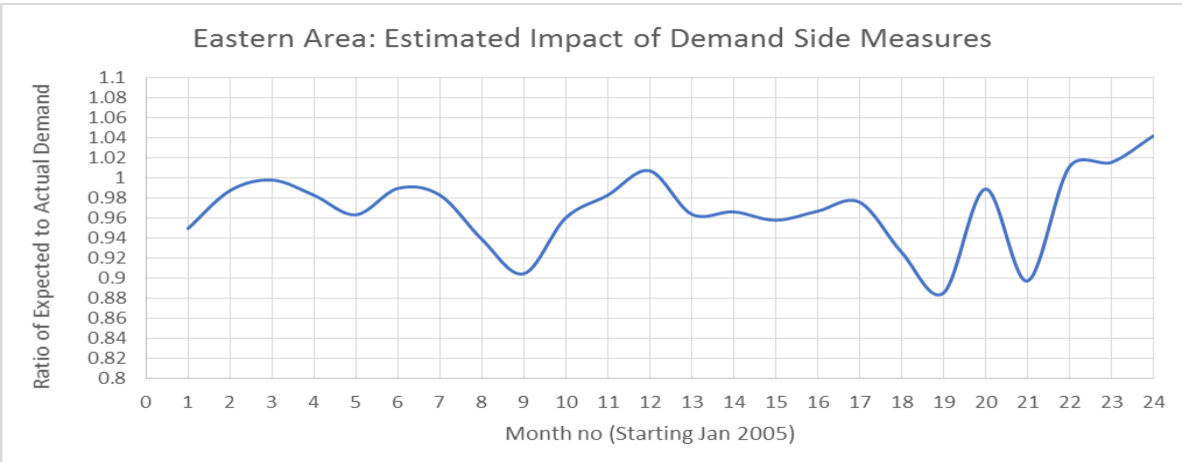

Figure 14: Estimate of demand restriction impacts during the 2005-06 event – Eastern area.

These effectiveness of restrictions figures show that:

- The Western and Central areas demonstrate a continuous time-based trend that was similar in magnitude, even though a NEUB was not actually put in place in Hampshire. The results for November-December 2006 in Western area (Hampshire) and December 2006 in Central area should be viewed with caution, as Figure 3 and Figure 5 indicate apparent demand measurement errors around that time (likely associated with leakage and/or non-household use fluctuations not accounted for in the simple trend-based interpolations used in this analysis). However, it is apparent that the effects of the publicity surrounding the drought were cumulative over the two-year period, without any notable stepped change as a result of the NEUB. This makes an exact evaluation of the impact of NEUBs difficult, as it appears that a rapidly introduced ban might not have the same impact as the longer sequence of events and publicity generated during the 2005-06 drought.
- The Eastern area displayed similar levels of response to the Western and Central areas to the 2005 hosepipe ban, but very little response to the NEUB. The reasons for this are not known but are likely to be associated in some way with the different attitudes to water saving as demonstrated in the response to metering discussed previously.

Based on the demand responses observed at the time and the reduction in the summer peak volumes observed as a result of metering, a summary of the maximum, June-September (JJAS) and underlying demand (Minimum Deployable Output or MDO) that would be anticipated under current levels of metering is provided in Table 2 to Table 4.

Table 2: Estimated impacts of restrictions – Western area.

	At the time	Current metering levels
2005 (hosepipe ban)	10% max monthly	7% max monthly
	6% JJAS	4% JJAS
	2% MDO	1% MDO
2006 (hosepipe ban with NEUB) (NEUB publicity only)	15% max monthly	10% max monthly
	10% JJAS	7% JJAS
	4% MDO	3% MDO

Table 3: Estimated impacts of restrictions – Central area.

	At the time	Current metering levels
2005 (hosepipe ban)	8% max monthly	5% max monthly
	6% JJAS	4% JJAS
	3% MDO	2% MDO
2006 (hosepipe ban with NEUB)	18% max monthly	12% max monthly
	13% JJAS	8% JJAS
	5% MDO	3% MDO

Table 4: Estimated impacts of restrictions – Eastern area.

	At the time	Current metering levels
2005 (hosepipe ban)	10% max monthly	4% max monthly
	5% JJAS	2% JJAS
	1% MDO	Negligible MDO

	At the time	Current metering levels
2006 (hosepipe ban with NEUB)	11% max monthly	5% max monthly
	7% JJAS	3% JJAS
	2% MDO	1% MDO

For the Central and Western areas, the effects of hosepipe bans are similar and the impact of NEUBs is seen to almost double the hosepipe ban effects. However, as noted previously, a large proportion of this appears to be due to ongoing publicity that caused a time-based trend over the course of the drought. Some caution is therefore advised in the Central area, where major droughts only have a critical period of 12-18 months, and this time-based effect would not therefore occur in time to benefit the drought supply-demand balance. The 18% maximum monthly saving in July 2006 also appears to be an outlier and possibly represents a model over-response to the record-breaking temperatures encountered in that month. This has been accounted for within the recommended profiles of demand restriction benefits discussed below.

As shown in Table 4, the impacts of NEUBs appear to be much smaller in the Eastern area than the other two. Since the loss of peak demand is also much larger, this results in very small anticipated responses to both hosepipe bans and NEUBs within the Eastern area under current levels of metering.

Based on the above analysis, Table 5 to Table 7 provide the recommended profiles for the Effectiveness of Demand Restrictions (EODR) within each of the three areas under current levels of metering. Hosepipe bans introduced previously now come under TUBs. TUBs are therefore used in Tabel 5 to Table 7
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Table 5: Recommended EODR profile – Western area (excluding the IOW).

Month	TUBs	NEUBs
Jan-April	1%	3%
May-June	2%	4%
July-Aug	5%	8%
Sept	3%	4%
Oct-Dec	1%	3%

Table 6: Recommended EODR profile – Central area.

Month	TUBs	NEUBs
Jan-April	2%	3%
May-June	3%	5%
July-Aug	5%	8%
Sept	3%	5%
Oct-Dec	2%	3%

Table 7: Recommended EODR profile – Eastern area.

Month	TUBs	NEUBs
Jan-April	0%	1%
May-June	1%	1%
July-Aug	3%	4%
Sept	2%	2%
Oct-Dec	0%	1%

5. Conclusions

In broad terms, the methodology described in this annex followed the recommended methods contained within the EA Drought Demand Modelling Guidance report, with a minor change around the inclusion of time of year/sunshine hours as an explanatory factor. However, the models that were used contained a significant enhancement to allow a quantified analysis of the impact of metering on summer peak demand. This incorporation of a demonstrably stable and accurate, but non-linear and multiplicative form of regression model meant that the impacts of metering on both underlying demand and demand response to weather could be modelled, allowing the response of the current, mostly metered, customer base to restrictions to be quantified.

This form of modelling demonstrated that the ratio of summer demand to underlying (winter) demand has decreased as a result of increased meter penetration, with the relative size of the summer peak (as calculated relative to winter MDO demand) now approximately 35% smaller for the Western and Central areas and 60% smaller for the Eastern area than it was in the early to mid-2000s. This will affect the effectiveness of demand restrictions because discretionary use is clearly now smaller as a percentage of total demand (it is worth noting that there was no observable response to the 2005 hosepipe ban on the fully metered IOW).

The model was able to accurately estimate the impact of restrictions on demand during the 2005-06 drought event and provide an estimate of the likely change therein as a result of increased metering. The estimated profiles for the Western (excluding the IOW) and Central areas are now in the order of 1% rising to 5% for TUBs (winter to summer profiles) and 3% rising to 8% for TUBs plus NEUBs. The Eastern area is expected to have a much lower response, at 0% rising to 3% for TUBs and 1% rising to 4% for NEUBs.