Appendix B: Seasonality and Model Fit

Seasonality can dominate goodness-of-fit statistics in time series with strong seasonal cycles. To assess the impact of seasonal trends on model fit, a seasonal trend decomposition analysis was performed and the model applied to the trend only and trend plus remainder water use time series. The analysis was performed using the seasonal trend decomposition function in R (STL, Core Development Team, 2014), recently applied in studies of per capita water use (Gonzales & Ajami, 2017; Hester & Larson, 2016). As seen in Figure 1, this analysis decomposes per capita water use into three components: seasonal, trend and remainder.

Figure 1: Seasonal Trend Decomposition of Per Capita Water Use

Following the procedure applied by Gonzales and Ajami (2017), the four candidate models are calibrated and tested using on the trend component of the data identified by the STL analysis. Figure 2 and Table 1 compare the four candidate models calibrated to fit the observed trend. Similar to the model comparison in the article using the full per capita use data, the price only model performs poorly and the addition of the regulatory change and stress response improves model performance on all metrics. The goodness-of-fit statistics, with the exception of calibration RMSE, are better than those for the model comparison presented in the text. This is unsurprising because the remainder component is not included.

Figure 2: Comparison of Per Capita Water Use Models Applied to Observed Trend

Table 1: Per Capita Water Use Model Comparison Statistics for Observed Trend

Calibration Statistics

Water Consumption Eqn.	**RMSE**	**% Bias**	**NSE**	**R2**
f(Price)	114.24	10.3	-0.42	-5.17
f(Price + Reg. Trend)	79.77	7.2	0.32	-0.37
f(Reg. Trend + Stress Response)	38.71	2.8	0.86	0.86
f(Price, Reg. Trend + Stress Response)	**27.81**	**1.1**	**0.93**	**0.94**

Validation Statistics

Water Consumption Eqn.	**RMSE**	**% Bias**	**NSE**	**R2**
f(Price)	126.69	12.7	-0.84	-6.21
f(Price + Reg. Trend)	88.90	9.0	0.11	-0.66
f(Reg. Trend + Stress Response)	37.86	3.2	0.85	0.86
f(Price, Reg. Trend + Stress Response)	**28.76**	**1.8**	**0.93**	**0.94**

Lastly, the model calibration and comparison is repeated for the per capita use data with only the seasonal cycle removed. This is equivalent to the trend plus the remainder. The goodness-of-fit statistics are poorer for this version than the model comparison with only the observed trend (Fig. 3 Table 2). RMSE and R2 are consistently poorer than those for the original model comparison with raw per capita use data, though percent bias is improved. There are two reasons for this poorer model fit. First, seasonal variation increases the total variance to be explained. As a result, the inter-annual change in water use becomes a smaller percent of overall variance. Therefore, once the seasonal cycle is effectively modeled, any unexplained inter-annual variance appears smaller. Second, the seasonal model used in this work is based on observed monthly temperature so it accounts for deviations from monthly mean temperature. The seasonal model also accounts for the

change in amplitude of the seasonal cycle with decreasing outdoor demand. It is this change in amplitude which leads to the quasi-seasonal cycle in the remainder.

The seasonal trend decomposition and subsequent model fit comparison, demonstrate that goodness-of-fit statistics do not overestimate the fit for the original model comparison conducted. Critically, the ranking of the candidate models remains unchanged across all analyses.

Figure 3: Comparison of Per Capita Water Use Models Applied to Observed Trend and Remainder

Table 2: Per Capita Water Use Model Comparison Statistics for Observed Trend and Remainder

Calibration Statistics

Water Consumption Eqn.	**RMSE**	**% Bias**	**NSE**	**R2**
f(Price)	134.91	11.8	-0.67	-7.39
f(Price + Reg. Trend)	99.92	8.2	0.10	-1.03
f(Reg. Trend + Stress Response)	62.81	3.0	0.68	0.69
f(Price, Reg. Trend + Stress Response)	**56.99**	**1.5**	**0.76**	**0.78**

Validation Statistics

Water Consumption Eqn.	**RMSE**	**% Bias**	**NSE**	**R2**
f(Price)	147.74	14.5	-1.22	-8.52
f(Price + Reg. Trend)	109.26	10.3	-0.20	-1.37
f(Reg. Trend + Stress Response)	64.08	3.5	0.62	0.67
f(Price, Reg. Trend + Stress Response)	**60.76**	**2.3**	**0.69**	**0.76**