Appendix A.

Monthly Analysis

Prepared for

California Department of Water Resources

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Overview

This appendix describes the data and methods used to estimate residential indoor per capita water use (Ri-gpcd) with urban water supplier monthly billing data. Residential indoor water use is not directly metered and therefore must be inferred. Traditionally, the standard approach has been to assume that water use in the minimum winter consumption month is entirely indoor water use (Billings and Jones 2008). However, in California winter irrigation is common, especially in Southern California. Estimates of indoor water use based on the winter minimum consumption month will therefore overstate indoor water use unless adjustments are made to remove outdoor water use. The monthly billing data analysis used four different methods to adjust winter water use for outdoor consumption.

The first method is called the **Minimum Month Method (MMM)**. It uses monthly billing data assuming that the lowest-use month (February) represents indoor residential use. The difference between water use in other months and the lowest-use month is considered to be outdoor use. The MMM results are included for informational purposes only. The MMM analysis does not remove winter irrigation in the lowest-use month and can overestimate indoor water use, especially where winter irrigation is quite significant such as in Southern California. Results from the MMM analysis are only provided as a reference because MMM is commonly used to infer Ri-gpcd.

The second method is called the **Seasonal Adjustment Method (SAM)**. It uses billing data from dedicated irrigation meters to infer residential winter irrigation water use. The key assumption used in this method is that for a given location the seasonality of residential and non-residential irrigation is broadly similar. This identifying assumption is used to infer winter residential irrigation, which is not directly observable, from non-residential irrigation served by dedicated irrigation meters, which is directly observable. Removing the inferred amount of winter irrigation from winter minimum month consumption provides an estimate of indoor water use.

The third method is called the **Landscape Adjustment Method (LAM)**. It uses household-level data on irrigated landscape area to infer residential winter irrigation water use. This method relies on the fact that winter irrigation is positively correlated with landscape area. More landscape area means increased winter irrigation and vice versa. A statistical model is used to estimate this relationship while controlling for other factors affecting winter water use. Once this relationship is determined, the statistical model is used to construct a counterfactual prediction of winter water use assuming each household in the sample has zero irrigated landscape area. This counterfactual prediction provides an estimate of indoor water use.

The fourth method is called the **Rainfall Adjustment Method (RAM)**. It uses data on rainfall to infer residential winter irrigation water use. This method relies on the fact that winter irrigation is negatively correlated with rainfall. More rainfall means less winter irrigation and vice versa. A statistical model is used to estimate this relationship while controlling for other factors affecting winter water use. Once the relationship is determined, the statistical model is used to construct a counterfactual prediction of winter water use assuming rainfall is at the upper end of its historical range when outdoor water use would be expected to be zero or very close to it. This counterfactual prediction provides an estimate of indoor water use.

The remainder of this appendix describes the data and procedures to estimate Ri-gpcd using these methods and summarizes the resultant estimates of residential indoor water use.

Data Sources

The data sources used to produce the estimates of residential indoor water use are described in this section.

Utility Billing Data

Customer-level billing data was collected from the 18 retail water suppliers listed in Table A2-1. The location of each supplier is shown in Figure A2-1. The billing data span the period January 2011 to June 2020. Not every water supplier provided billing data for the entire period. The table shows the period each supplier's data covered. Meter counts vary over this period due to growth in the number of customers served. The table shows the maximum number of meters represented in the data for each supplier. California Water Service (CWS) does not have a dedicated landscape meter service class. However, CWS flags meters that are primarily used for landscape irrigation in its billing data. The landscape meter counts in the table for CWS districts are based on these flagged meters. Meter service points were mapped to census tracts. The table shows the number of census tracts wholly or partially within the water supplier service boundary. A census tract was included in the analysis only if it contained a sufficient number of meters from which to estimate average indoor water use. Thus, the census tract count in the table provides an upper-bound of the number of census tracts contributed by each supplier.

Table A2-1. Retail Water Supplier Indoor Residential Water Use Study Participants

Retail Water Supplier	Billing Freq	Data Range	SFR Meters	MFR Meters	IRR Meters	Census Tracts	Landscape Area
1	M	1/13-12/20	19,404	539	613	37	DWR
2	M	1/16-12/19	116,170	8,734	1,138	116	DWR
3	M	1/16-12/19	19,075	2,791	465	25	DWR
4*	M	1/15-4/20	90,913	2,985	2,360	67	OWN
5	M	1/11-12/19	55,041	1,206	188	61	OWN
6	M	1/11-12/19	17,019	187	53	23	OWN
7	M	1/11-12/19	25,435	1,004	726	27	OWN
8	M	1/11-12/19	20,871	736	9	42	OWN
9*	M	1/11-6/20	17,141	100	246	14	OWN
10	M	1/11-12/19	22,930	225	38	22	OWN
11	M	1/11-12/19	24,643	435	329	35	OWN
12*	M	1/11-6/20	14,068	178	90	18	OWN
13	M	1/11-12/19	39,241	416	17	46	OWN
14	M	1/11-12/19	40,198	990	0	25	OWN
15*	M	1/11-6/20	141,562	4,135	2,325	118	OWN
16	M	1/11-12/19	100,607	3,136	7,783	66	OWN
17	M	1/11-12/19	33,875	15,541	2,538	50	OWN
18	B	1/12-12/19	9,856	834	379	31	DWR

* Retail Water Supplier data used to estimate impact of Covid-19 on residential water use.

M = Monthly B = Bimonthly

Meter count is the maximum number of meters in the data range.

Census Tracts is the count of census tracts wholly or partially within the water supplier's service boundary.

Figure A2-1. Location of Retail Water Supplier Study Participants

Landscape Area and Weather Data

The LAM and RAM methods utilize data on landscape area and rainfall/air temperature. Landscape area data were provided by the retail water supplier if it was available. Otherwise, it was drawn from DWR's Residential Landscape Area Study. Weather data were collected from either National Oceanic and Atmospheric Administration (NOAA) or California Irrigation

Management Information System (CIMIS) weather stations proximate to each service area.[1]

Household Occupancy Data

Average single- and multi-family household occupancy was estimated for each census tract in California using 2018 American Community Survey (ACS) 5-year estimates of population in occupied housing and the number of occupied housing units. The housing and population estimates were drawn from ACS data series B25032 and B25033, respectively. These data series break the estimates down by tenure (owner or renter) and number of housing units in structure (1 detached, 1 attached, 2 or 3, etc.), which makes it possible to estimate average occupancy of single- and multi-family dwellings.

Data Validation

Data used in the monthly analysis were first checked for consistency and errors. Utility billing data, in particular, were carefully screened. This step was important because utility billing data can be noisy due to the presence of estimated meter reads, erroneous meter reads, extreme meter reads caused by leaks, and missed meter reads. Additionally, billing corrections may result in negative meter reads.

Billing data meeting any of the following conditions were excluded from the analysis:

1) Missing consumption value
2) Negative consumption value
3) Outlier consumption value
4) Monthly read covers less than 12 or more than 45 days
5) Bimonthly read covers less than 24 or more than 90 days
6) Meter in service for less than one year

[1] Operations of some of the stations listed in Table A2-1 were disrupted by COVID-19 shelter-in-place orders starting in March 2020. To evaluate the effects of these orders on residential water use, supplemental weather data from stations still operating normally was also collected.

7) Meter could not be matched to census tract
8) Less than 30 meters in census tract (single-family only)

A consumption value was flagged as an outlier if it was more than 3 standard deviations from the monthly mean consumption value on the log scale.[2] Additionally, a meter was flagged as potentially misclassified if its average water use was more than 3 standard deviations from the sample mean water use on the log scale.[3]

Methods

This section describes in greater detail the methods used to estimate residential indoor water use, average household occupancy, and Ri-gpcd. It also discusses the calculation of the margins of error attached to the Ri-gpcd estimates.

Indoor Water Use Estimation: Minimum Month Method

The Minimum Month Method uses billing data from residential accounts. This method assumes that water use in the lowest-use month (February) represents indoor water use. Water use for the remaining months that is above the lowest-use month is considered outdoor use.

Indoor Water Use Estimation: Seasonal Adjustment Method

The Seasonal Adjustment Method (SAM) uses billing data from dedicated irrigation meters to infer residential winter irrigation water use. This method starts by recognizing that residential water use in any month t (W_t) can be decomposed into indoor (IN) and outdoor (OUT) components.

$$W_t = IN_t + OUT_t \tag{1}$$

[2] Residential billing data roughly follows a log-normal distribution. The log transformed data is therefore approximately normally distributed. Under a normal distribution, the 99.7th percentile is 3 standard deviations above the mean.
[3] It is not uncommon for meters to be incorrectly classified in billing data. The usage pattern of misclassified meters often differs from correctly classified meters.

Let IRR_t represent water use by dedicated irrigation meters in any month t and denote the minimum winter consumption month as t=w and the maximum summer consumption month as t=s. The key identifying assumption this method makes is that the ratio (R) of summer outdoor water use (OUT_S) to winter outdoor water use (OUT_W) is the same for residential and dedicated irrigation customers for summer (IRR_S) and winter use (IRR_W).

$$\frac{OUT_s}{OUT_w} \equiv \frac{IRR_s}{IRR_w} \equiv R \qquad (2)$$

Using equation (2), indoor residential water use (IN) in the maximum summer consumption month (W_S) can be expressed as:

$$W_s = IN + R \cdot OUT_w \qquad (3)$$

Substituting equation (3) into equation (1) and rearranging terms gives the SAM formula for estimating residential indoor water use with W_W being the minimum winter consumption month.

$$IN = \frac{1}{(1-R)}(W_s - R \cdot W_w) \qquad (4)$$

Notice that all the variables on the right-hand-side of equation (4) are observable quantities. W_s and W_w are calculated with residential billing data and R is calculated with dedicated irrigation meter billing data.

This study used February for the minimum winter consumption month and August for the maximum summer consumption month. This was applied across all the retail water suppliers and years represented in the study for the sake of consistency. This choice was informed by an analysis of weather-normalized monthly water use. While the minimum and maximum months may deviate from February and August from time to time, once water use is weather normalized it is nearly always the case that minimum and maximum water use occur in February and August, respectively.

The margin of error (MOE) of the SAM indoor water use estimate is calculated from the sample statistics. This approximation treats R as a constant:

$$MOE(IN_{SAM}) \approx \left[\left((1+R)\cdot MOE(W_w)\right)^2 - 2\hat{\rho}R(1+R)\cdot MOE(W_w)\cdot MOE(W_s) + \left(R\cdot MOE(W_s)\right)^2\right]^{1/2} \quad (5)$$

where $\hat{\rho}$ is the estimated correlation between W_w and W_s.

Indoor Water Use Estimation: Landscape Adjustment Method

The Landscape Adjustment Method (LAM) uses household-level data on irrigated landscape area to infer residential winter irrigation water use. A statistical model is used to estimate this relationship while controlling for other factors affecting water use. Once this relationship is determined, the statistical model is used to construct a counterfactual prediction of winter water use assuming each household in the sample has zero irrigated landscape area. This counterfactual prediction provides an estimate of indoor water use. The LAM estimation strategy is illustrated in Figure A2-2.

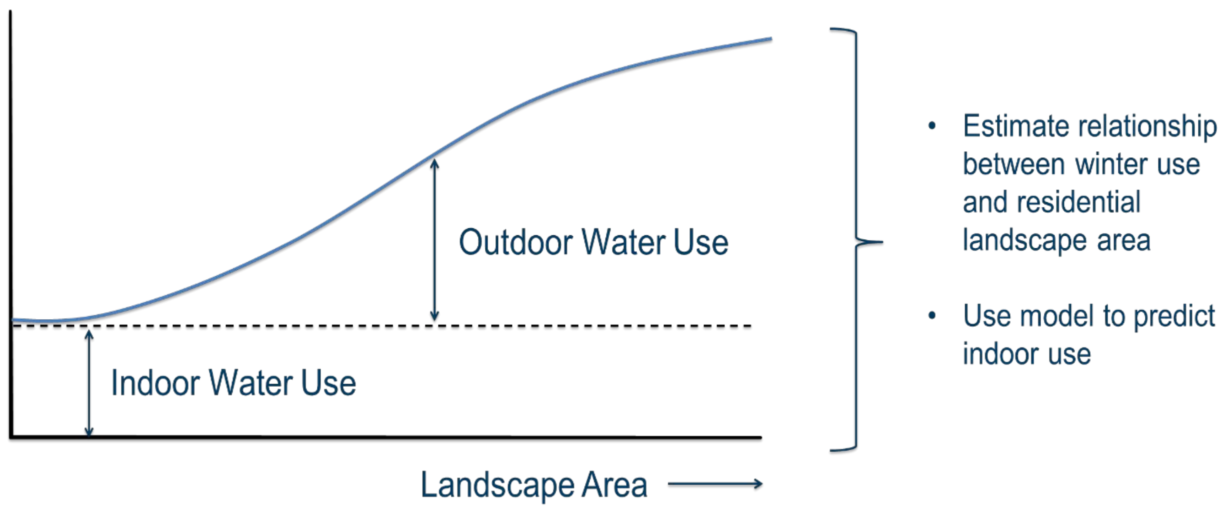

Figure A2-2. Depiction of LAM Indoor water Use Estimation Strategy

The statistical model is specified as:

$$W_{it} = \alpha + \beta_1 AREA_i + \beta_2 RAIN_t + \beta_3 RAIN_{t-1} + \beta_4 TEMP_t + \sum \delta_j D_{jt} + \sum \lambda_k T_k + e_{it} \quad (6)$$

Where W_{it} is estimated household water use, $AREA_i$ is measured landscape area, $RAIN_t$ is monthly rainfall, and $TEMP_t$ is average daily maximum air temperature, β estimates the effect of LAM on water use. The D_{jt} indicate when drought water use restrictions were in effect and the δ_j capture the effects of those restrictions on water use. The T_k are census tract indicator variables and the λ_k coefficients capture the effects of census-tract-level heterogeneity on water use.

Daily weather data are used to calculate the rainfall and temperature variables. The weather data are first log transformed and then 30-day sums (rainfall) and averages (temperature) are calculated. These are demeaned and paired to the meter read dates in the billing data series.[4] Thus the constructed variables measure the deviations from average rainfall and temperature in each meter read period.

Following estimation, the model is used to predict household water use in the sampled census tracts under the counterfactual assumption that every household's landscape area is equal to zero.

Indoor Water Use Estimation: Rainfall Adjustment Method

The Rainfall Adjustment Method (RAM) uses the same statistical model of household water use but estimates indoor water use based on a different counterfactual assumption. Whereas LAM makes the counterfactual assumption that landscape area is equal to zero, RAM assumes that rainfall

[4] More detail on weather variable construction is provided in the section on the impacts of COVID-19 shelter-in-place orders on residential water use.

is at the upper-limit of its historical range.[5] The RAM estimation strategy is illustrated in Figure A2-3.

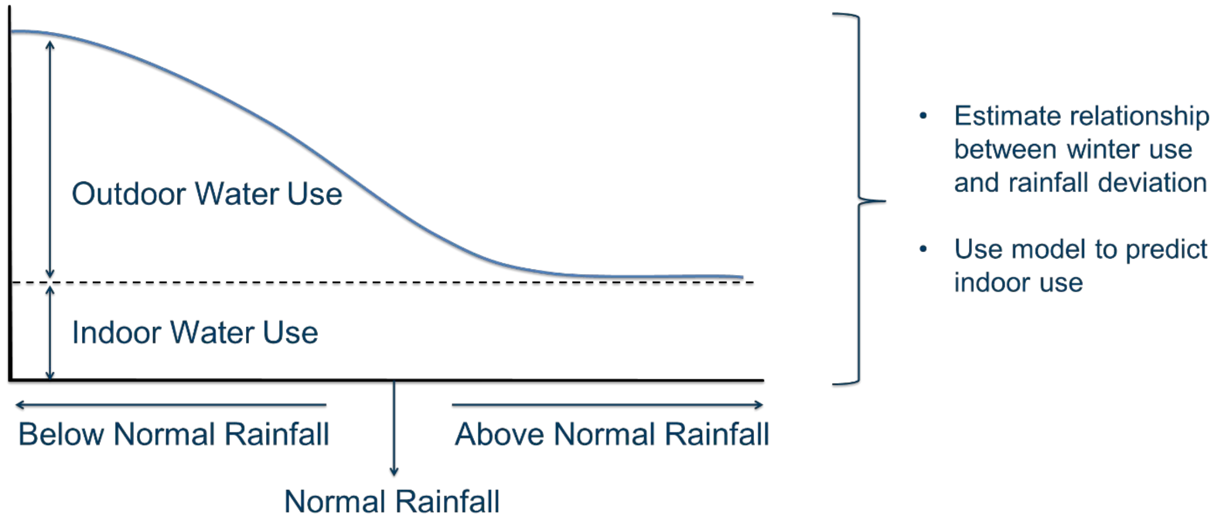

Figure A2-3. Depiction of RAM Indoor Water Use Estimation Strategy

The statistical model was estimated using Stata, but any commercial or open-source statistical software package could be used to implement these two methods. Stata's margins command, however, provides a convenient way to calculate the counterfactual predictions and their margins of error.

Indoor Water Use Estimation: Average Household Occupancy

Average household occupancy, or persons per household (PPH), was estimated with 2018 ACS data. Single-family PPH was calculated by dividing the population in occupied (attached or detached) single-unit structures by the number of housing units in these structures. Likewise, multi-family PPH was calculated by dividing the population in occupied multi-unit structures by the number of housing units in these structures. Figure A2-4 shows the distributions of the single- and multi-family PPH estimates. The statewide mean single- and multi-family estimates are 3.21 and 2.45, respectively.

[5] In desert regions, temperature was also adjusted to the lower end of its historical range to construct the counterfactual water use prediction.

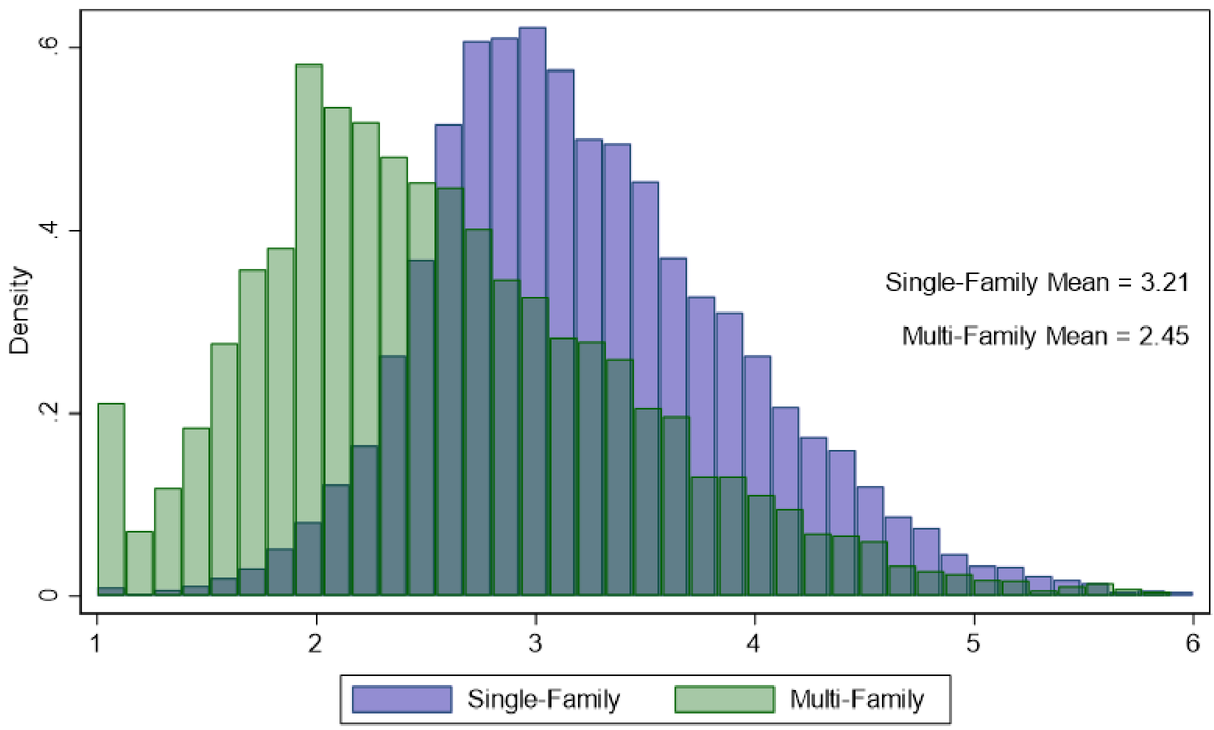

Figure A2-4. Distributions of Census Tract PPH Estimates

The PPH estimates are based on sampled population and housing units and thus are subject to sampling error. The Census Bureau publishes margins of error for overall PPH, but not for single- and multi-family PPH. Therefore, it was necessary to approximate them. To do this it is noted that overall PPH is a weighted average of single- and multi-family PPH:

$$PPH_{all} = A \cdot PPH_{sf} + B \cdot PPH_{mf} \tag{7}$$

where A and B are the share of single- and multi-family housing units in each census tract. By the properties of variance (VAR), it is the case that

$$VAR(PPH_{all}) \approx A^2 \cdot VAR(PPH_{sf}) + B^2 \cdot VAR(PPH_{mf}) \tag{8}$$

If $VAR(PPH_{sf}) \approx VAR(PPH_{mf})$ is assumed, then equation:

(8) reduces to:

$$VAR(PPH_{all}) \approx \sigma^2(A^2 + B^2) \text{ or } \sigma^2 \approx VAR(PPH_{all})/(A^2 + B^2) \tag{9}$$

and[6]

$$MOE(PPH_{SFR}) \approx MOE(PPH_{MFR}) \approx MOE(PPH_{All})/\sqrt{(A^2 + B^2)} \qquad (10)$$

The magnitude of the PPH margin of error varies by census tract, but generally is on the order of +/- 9 percent.[7]

Indoor Water Use Estimation: Ri-gpcd

A household's Ri-gpcd$_i$ is equal to the ratio of its daily indoor water use (GPD$_i$) to its occupancy (PPH$_i$):

$$Ri\text{-}gpcd_i = \frac{GPD_i}{PPH_i} \qquad (11)$$

Given a sample of households, the research objective is to estimate expected Ri-gpcd:

$$Expected\ RI\text{-}GPCD_i = E\left(\frac{GPD_i}{PPH_i}\right) \qquad (12)$$

Estimating equation (12), however, requires occupancy data for the sampled households. While some study participants had occupancy data, most did not. Additionally, the occupancy data provided by those that had it included default estimates for most households which limited its usefulness.

Therefore, it was necessary to approximate expected Ri-gpcd by dividing the indoor water use estimates by average household occupancy derived from Census data. It can be shown that $\frac{E(GPD_i)}{E(PPH_i)}$ is likely to be a biased estimator of $E\left(\frac{GPD_i}{PPH_i}\right)$. A better approximation is:[8]

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[6] Census Bureau calculates MOE as $MOE(Estimate) = 1.645\sqrt{VAR(Estimate)}$

[7] At the 90% level of statistical confidence which is used by the Census Bureau for published ACS estimates.

[8] These approximations are based on first and second order Taylor expansions of the ratio of two random variables.

$$MOE(PPH_{SFR}) \approx MOE(PPH_{MFR}) \approx MOE(PPH_{All})/\sqrt{(A^2 + B^2)} \tag{13}$$

Estimates of $E(GPD_i)$, $E(PPH_i)$, and $VAR(PPH_i)$ in equation (13) come from the estimation of indoor water use and average household occupancy described above. An estimate of $COV(GPD_i, PPH_i)$ was derived from a sample of households with both water use and household occupancy data.[9] The magnitude of the bias correction varies by census tract, but typically does not exceed 2 percent.

The margin of error (MOE) of the estimate is approximated using the margins of error for GPD and PPH and an estimate of the correlation between GPD and PPH. This approximation is based on a first order Taylor expansion of the variance of the ratio of two random variables:

$$MOE(Ri\text{-}gpcd) \approx$$

$$\frac{GPD}{PPH}\left[\left(\frac{MOE(GPD)}{GPD}\right)^2 - 2\frac{\hat{\theta} \cdot MOE(GPD) \cdot MOE(PPH)}{GPD \cdot PPH} + \left(\frac{MOE(PPH)}{PPH}\right)^2\right]^{1/2} \tag{14}$$

where GPD and PPH are the estimates of mean daily water use and mean household occupancy, respectively. The magnitude of the margin of error varies by census tract, but typically is on the order of +/- 8 percent.[10]

Results

Ri-gpcd Estimates

Estimation results for single- and multi-family households are summarized in Tables A2-2 and A2-3, respectively. These estimates span the post-drought years 2017-2019. The tables show the mean of the census-tract-level estimates as well as the 25^{th}, 50^{th} (median), and 75^{th} percentile estimates.

With single-family meters, average water use per meter is equivalent to average water use per dwelling, which is what is used to estimate gpcd.

[9] Excluding the households with default estimates of household occupancy.
[10] At the 90% level of statistical confidence.

This is not the case with multi-family meters. The number of dwelling units served by each multi-family meter also is needed. Most of the study participants did not have this information and multi-family gpcd estimates could not be developed for them. Table A2-3 therefore shows the multi-family estimates only for the retail water suppliers with data on the number of dwelling units served by multi-family meters.

For the overall single-family sample, the mean estimate of indoor water use is 52 Ri-gpcd. The median estimate is 50 Ri-gpcd using the SAM method and 48 Ri-gpcd using the LAM and RAM methods.

For the overall multi-family sample, the mean estimate of indoor water use is 49 Ri-gpcd under the SAM and RAM methods and 50 Ri-gpcd under the LAM method. The median estimate is 48 Ri-gpcd under the SAM and LAM methods and 46 Ri-gpcd under the RAM method.

Discussion

There are several limitations to the data and estimation methods that bear mentioning. First, the methods used to infer residential indoor water use from monthly billing data work best where winter outdoor water use is minimal. Method performance may degrade somewhat in the southern portions of the state where winter irrigation is more common and in service areas where outdoor water use may be especially heavy. In particular, judging based on the magnitude of Ri-gpcd estimates, the LAM and RAM methods do not appear to have removed all outdoor water use in a couple of the desert Suppliers.

Second, a prerequisite to using the LAM and RAM methods are disaggregated billing data and parcel-level measurements of landscape area. These methods require the ability to work with large datasets, potentially with millions or tens of millions of records, which generally requires specialized statistical software. The SAM method, by contrast, can be implemented either with aggregated or disaggregated billing data and does not require landscape area measurement data to implement. Thus, the SAM method has a much lower data burden than the LAM and RAM methods.

Third, estimation of gpcd with multi-family data requires data on the number of dwelling units served by the sampled multi-family meters. Many utilities do not have this information. In this study, only 5 of the 18 retail water suppliers had data on the number of multi-family dwelling units served by their multi-family meters.

Fourth, Ri-gpcd is not stationary. It is subject to secular trends in water use efficiency as well as the effects of transitory events such as restrictions on water use during droughts and the current COVID-19 pandemic, which is discussed in the next section. This means that periodic updating of Ri-gpcd estimates will be required in order to track the evolution of residential indoor water use over time.

This is illustrated in Figure A2-5 which shows the change in the mean SAM estimate of single-family Ri-gpcd over the 2011-19 estimation period. The pre-drought period spans 2011-13; the Vol20 period covers 2014 when the Governor issued an executive order calling for a voluntary 20 percent reduction in urban water use; the Mandate period covers 2015-16 when the state conservation mandate was in effect; and the post-drought period covers 2017-19. It is clear that the state conservation mandate had a large, but transitory, impact on Ri-gpcd. Following the end of the state conservation mandate, residential indoor water use recovered almost to its pre-drought level.

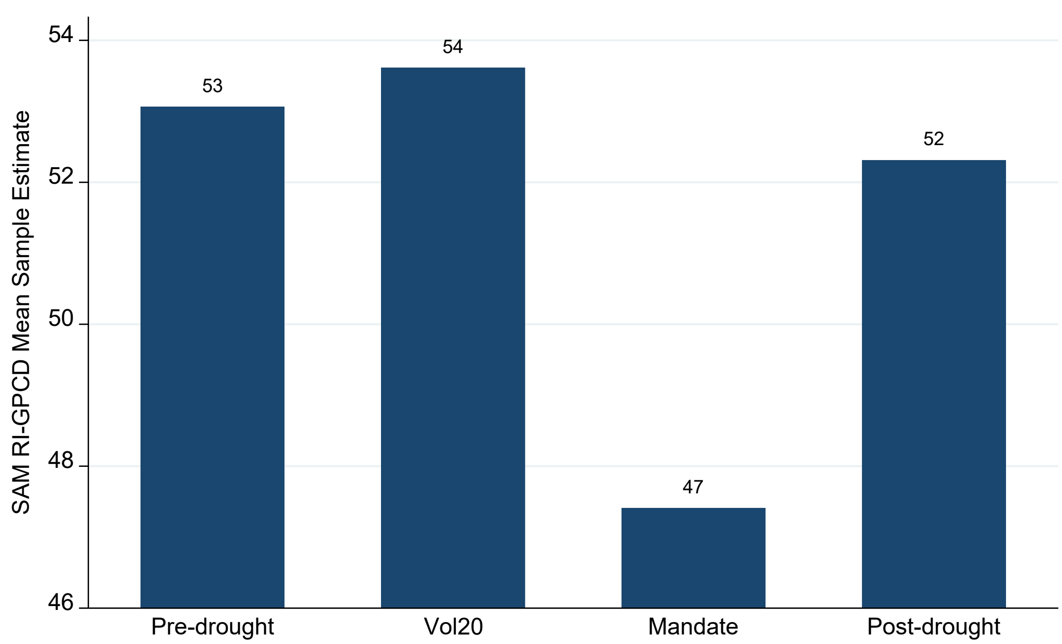

Figure A2-5. Mean of Single-Family SAM Ri-gpcd Estimates by Period

Table A2-2. Single-Family Ri-gpcd Estimates by Estimation Method for the Post-Drought Period (2017-2019)

Retail Water Supplier	MMM Mean	MMM P25	MMM P50	MMM P75	SAM Mean	SAM P25	SAM P50	SAM P75	LAM Mean	LAM P25	LAM P50	LAM P75	LAM Mean	RAM P25	RAM P50	RAM P75
1	70	56	68	82	51	48	50	54	47	45	47	49	52	49	53	53
2	64	46	56	79	54	49	53	58	47	44	47	50	49	45	48	52
3	62	52	65	71	39	36	38	41	36	35	36	38	35	34	35	38
4	64	58	64	71	69	55	67	79	102	87	102	117	93	75	96	108
5	52	46	51	57	43	37	42	49	59	53	57	63	54	47	52	57
6	108	73	93	118	38	34	38	44	55	51	54	59	52	47	52	58
7	49	42	48	55	45	38	44	50	55	51	55	59	53	49	53	56
8	41	37	41	42	55	47	57	63	60	57	59	63	55	52	55	59
9	51	45	51	56	43	38	48	56	51	47	50	55	47	43	46	50
10	64	53	64	73	43	38	48	56	95	86	96	106	80	61	81	91
11	61	57	60	65	44	39	44	49	47	42	45	52	44	39	42	48
12	61	56	59	66	40	37	39	41	38	37	37	39	35	34	34	36
13	40	38	40	42	48	44	47	52	48	43	48	53	44	40	44	48
14	130	96	122	150	38	33	37	43	40	38	39	42	62	57	60	64
15	54	45	52	60	48	42	47	52	50	45	50	54	44	40	43	49
16	60	51	54	65	61	51	59	68	40	36	40	43	52	44	50	57
17	76	58	70	88	63	54	60	71	64	56	61	74	60	51	58	65
18	44	39	44	48	39	35	40	43	39	35	41	41	40	36	42	43
Full Sample	**68**	**50**	**59**	**73**	**52**	**43**	**50**	**59**	**52**	**41**	**48**	**56**	**52**	**42**	**48**	**56**

P25 = 25th Percentile Estimate, P50 = 50th Percentile Estimate, P75 = 75th Percentile Estimate

Table A2-3. Multi-Family Ri-gpcd Estimates by Estimation Method for the Post-Drought Period (2017-2019)

Retail Water Supplier	MMM Mean	MMM P25	MMM P50	MMM P75	SAM Mean	SAM P25	SAM P50	SAM P75	LAM Mean	LAM P25	LAM P50	LAM P75	RAM Mean	RAM P25	RAM P50	RAM P75
2	63	53	61	72	60	51	57	67	64	55	61	71	63	55	60	70
3	42	38	41	44	41	37	40	43	39	36	38	39	38	36	37	38
15	45	38	47	52	39	35	39	45	42	40	40	48	38	35	35	43
16	50	45	49	54	50	45	49	53	49	43	48	52	48	42	47	51
18	49	45	49	51	48	44	48	51	43	38	42	48	43	38	42	48
Full Sample	**54**	**42**	**49**	**59**	**49**	**39**	**48**	**56**	**50**	**40**	**48**	**60**	**49**	**37**	**46**	**60**

P25 = 25th Percentile Estimate, P50 = 50th Percentile Estimate, P75 = 75th Percentile Estimate

Effect of COVID-19 on Ri-gpcd

Additional monthly billing data was collected from four of the retail water suppliers (see Table A2-1) in order to analyze the effect that COVID-19 shelter-in-place orders are having on residential water use. These data extended through June 2020 in three cases and through April 2020 in one.

The following random effects panel model of single-family monthly water use was estimated to analyze the impact of the shelter-in-place orders on residential water use.

$$GPD_{it} = \alpha + \boldsymbol{S}'\boldsymbol{\beta_S} + \boldsymbol{W}'\boldsymbol{\beta_W} + \boldsymbol{D}'\boldsymbol{\beta_D} + \beta_{SIP}SIP_t + u_i + e_{it} \quad (15)$$

where GPD_{it} is daily water use by household i in period t, $\boldsymbol{S}'\boldsymbol{\beta_S}$ and $\boldsymbol{W}'\boldsymbol{\beta_W}$ are the seasonal and weather components of the model, $\boldsymbol{D}'\boldsymbol{\beta_D}$ is the model's drought component, and SIP is an indicator variable that takes the value 1 in months with COVID-19 shelter-in-place orders and zero otherwise. The coefficient β_{SIP} estimates the effect of the shelter-in-place orders on water use.

The model error is comprised of two parts: u_i which accounts for heterogeneity in household water use due to unobserved time-invariant household characteristics and e_{it} which accounts for random noise in the data.

The seasonal component is specified in continuous time as a Fourier series of sines and cosines.[11]

$$S_t = \frac{1}{30}\sum_{d=t-29}^{t}\sum_{j=1}^{4}\left[sin\left(\frac{2\pi jd}{365}\right) + cos\left(\frac{2\pi jd}{365}\right)\right] \quad (16)$$

[11] The use of a Fourier series to model seasonality in a regression context dates back to Hannon (1960).

The weather component is based on records of daily rainfall and maximum air temperature and is specified as:

$$W_t = (R_t - \hat{R}_t) + (T_t - \hat{T}_t) \tag{17}$$

where

$$R_t = ln\left(1 + \sum_{d=t-29}^{t} Rain_d\right) \text{ and } T_t = ln\left(\frac{1}{30}\sum_{d=t-29}^{t} Temp_d\right) \tag{18}$$

and $\hat{R}_t$ and $\hat{T}_t$ are the expected 30-day total rainfall and average maximum daily temperature for date t. These are constructed by regressing R_t against the seasonal harmonics and regressing T_t against the seasonal harmonics and R_t. Lagged rainfall and seasonal interactions are included in the final model specification.

This "departure-from-mean" construction of the weather variables ensures a separation between the model's seasonal and weather components. The seasonal component captures the effect of "average" weather through the year on residential water use while the weather component captures the effect on water use when weather departs from normal.

The models' drought component is simply a series of indicator variables denoting pre-drought, drought, and post-drought periods. These variables capture the impact of water use restrictions during the drought on household water use.

COVID-19 Results

Results from the monthly water use models as well as from models estimated with hourly AMI data are summarized in Table A2-4.[12] With the exception of Supplier Number 9, the results cluster between 3 and 5 gpcd. It is unclear why Supplier Number 9 impacts are so much larger.[13] The

[12] See Appendix B for a description of the AMI hourly analysis.
[13] One hypothesis is the high proportion of two-income, commuter households in Livermore, which would be expected to maximize the contrast between pre- and post-COVID residential water use.

mean effect is 4.9 gpcd when the result for Supplier Number 9 is included and 3.4 gpcd when it is excluded.

Discussion

The effect on residential water use of the COVID-19 shelter-in-place orders is on the order of 3-5 gpcd. In terms of magnitude, this is roughly equivalent to 2-3 extra toilet flushes per person. Extra toilet flushing may in fact explain most of the observed uptick in residential water use. It is likely more than coincidence that the 20 homes that were data-logged for this study in March 2020, following the shelter-in-place orders, registered an average toilet flush rate of 8 flushes per person per day, which is 3 more flushes than has been recorded in previous data-logging studies.[14]

These analyses provide strong empirical evidence that the shelter-in-place orders have resulted in increased residential water use. Moreover, the increase appears to be primarily related to indoor water use in the form of additional toilet flushing. How long is this increase likely to persist? That is something that can only be speculated about. It can be expected to diminish as more businesses and schools reopen or resume normal operations. However, this may still be far off on the horizon and will depend on when effective COVID-19 vaccines become universally available. Even then, it is not guaranteed that businesses and schools will revert to operating as they did before the pandemic. Much has been written about the possibility that the pandemic will result in fundamental and lasting changes in how people work and attend school. In this regard, it may be similar to how severe droughts impact residential water use. Most of the drought impact is transitory, but some amount proves to be long-lasting or permanent. The same may turn out to be the case with COVID-19.

Table A2-4. Increase in Single-Family Water Use following COVID-19 Shelter-in-Place Orders

Retail Water Supplier	Per Household (GPD)	Per Person (gpcd)
Monthly Model Results		
Supplier No. 4	7.2 (1.1)	3.0

[14] See Mayer et al. (1998), Mayer et al. (2011), and Mayer et al. (2016).

Retail Water Supplier	Per Household (GPD)	Per Person (gpcd)
Supplier No. 9	35.9 (2.9)	12.2
Supplier No. 12	12.6 (1.4)	3.7
Supplier No. 15	11.1 (0.3)	2.9
Hourly Model Results		
Supplier No. 1	13.3 (1.3)	4.5
Supplier No. 18	8.8 (0.9)	3.1
	Mean Effect	4.9
	Excluding No. 9	3.4

Standard error of estimate in parentheses

Appendix B.
Hourly (AMI) Analysis

Prepared for

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By

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Water Use Efficiency Branch

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Introduction & Background

The State of California's 2018 water conservation bills, AB 1668 and SB 606, mandate the setting of standards for residential indoor water use. In order to determine estimates of *Ri-gpcd*, cost-effective methodologies are needed to quantify current residential indoor water use for the state's urban water customers. One approach to quantify residential indoor water use is referred to as water use disaggregation. Using this approach, previous studies have been able to derive reasonably accurate water use [15]s [16],[17] Previous studies have used data at the read or billing period level to conduct disaggregation.

This section describes disaggregation methodologies applied to advanced meter infrastructure (AMI) data to determine estimates of indoor residential water use gallons per capita per day (*Ri-gpcd*) for the purpose of informing a state-wide indoor residential water standard. This section includes the project background, descriptions of the methodologies, description of the data, overview of results, and concludes with a section describing key insights from the study.

In this component of the study, high-frequency meter data at hourly intervals is used to conduct the water-use disaggregation. This effort represents one of the first published attempts of using AMI data for the purposes of water-use disaggregation. Hourly AMI data provides higher data resolution necessary to better identify and estimate the volume of water being used indoor versus the volume of water being used outdoors (such as for landscaping). This type of disaggregation analysis can be used by water suppliers, and also by state regulators, as a cost-effective means to quantify indoor water use and to set water use performance measures.

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[15] Carboni, D., Gluhak, A., Mccann, J.A., and Beach, T.H. (2016) "Contextualizing Water Use in Residential Settings: A Survey of Non-Intrusive Techniques and Approaches". *Sensors* 16:738.

[17] Non-intrusive refers to applying data science techniques on existing meter hardware, and not installing new water monitoring devices.

The hourly research team has a proven track record in using disaggregation techniques for water consumption analysis for both residential and non-residential sectors.[18,19] For this project, the research team first applied its disaggregation methodologies on a pre-study sample using AMI data from a small California-based data set to calibrate and validate the methodologies. Next, and as presented in this report, these methodologies were used to disaggregate water usage for four water suppliers with AMI data and produce *Ri-gpcd* estimates. These methodologies are described below.

Methodologies

Four modeling approaches are used to infer *Ri- gpcd* from the hourly water consumption data. Each modeling approach estimates *Ri-gpcd* for each residential metered account in the dataset.

Average Day Approach*:* The most common approach to estimating residential indoor use is inferring it from the month in which the minimum amount of water is used. In California, February is typically the lowest water-use month. The first approach aggregates hourly data to the monthly level to simulate the situation where higher resolution data is not available. Average daily February total residential water use is computed and used as a benchmark for indoor water use:

$$\bar{w}_i^{feb} = \frac{\sum_h w_{ih} * \mathbf{1}_{feb}}{n_{feb}} \qquad (1)$$

where w_{ih} represents the amount of water that customer i consumes at each hour, h. The indicator variable, 1_{feb}, takes a value of 1 for the month of February and 0 otherwise, and n_{feb}represents the number of days in February.

[18] Christine Boyle, Shadi Eskaf, and Mary Tiger (2011) "Mining Water Billing Data to Build Customer Relationships" *Journal of American Water Works Association,* November 2011.

[19] Tiger, M., Boyle, CE., Eskaf, S., Hughes, J., Jutras, RM (2016) “A Better Understanding of Nonresidential Water Customers Through Analysis” *Journal of American Water Works Association,* January. 108:A.

Next, each month's indoor water usage $W^I_{i,month}$ is determined by comparing each account's total monthly residential water use to the amount of water used during February, adjusted for the number of days in the month:

$$\boldsymbol{W^I_{i,month}} = \mathbf{min}\,(\boldsymbol{W_i^{Feb\ adj.}}, \boldsymbol{W_{i,month}}) \quad (2)$$

where

$$\boldsymbol{W_{i,month}} = \sum\nolimits_h \boldsymbol{w_{ih}} * \mathbf{1}_{\boldsymbol{month}} \quad (3)$$

$$\boldsymbol{W_i^{Feb\ adj.}} = \boldsymbol{\overline{w}_i^{feb}} * \boldsymbol{n_{month}} \quad (4)$$

In this approach, the total residential water use above the adjusted February amount is considered outdoor water use. Total amount of indoor water used during calendar year 2019, $W^{I,2019}$, is the sum of the monthly indoor totals:

$$\boldsymbol{W^I_{i,2019}} = \sum\nolimits_{month} \boldsymbol{W^I_{i,month}} \quad (5)$$

Calendar Month Approach*:* One disadvantage of the previous methodology is that it assumes that total residential use during February is assumed to be indoor residential use. To address this disadvantage, this second approach takes advantage of higher resolution data available at the daily level and classifies some of the total residential use during the month of February as outdoor water use. Each daily total residential water use in February is compared with the average daily total residential water use during February. As with previous methodology, each customer's average daily usage is computed and used as a benchmark for their indoor use:

$$\boldsymbol{\overline{w}_i^{feb}} = \frac{\sum_h \boldsymbol{w_{ih}} * \mathbf{1}_{\boldsymbol{feb}}}{\boldsymbol{n_{feb}}} \quad (6)$$

where w_{ih} represents the amount of water that customer i consumes at each hour, h. The indicator variable, 1_{feb}, takes a value of 1 for the month of February and 0 otherwise, and n_{feb}represents the number of days in February.

Next, indoor water use for each day is determined by comparing each customer's daily totals, $W_{i,day}$, to the average daily February usage:

$$\boldsymbol{W^I_{i,day}} = \mathbf{min}\,(\boldsymbol{W_{i,day}}, \boldsymbol{\overline{w}_i^{feb}}) \quad (7)$$

where

$$\boldsymbol{W_{i,day}} = \sum_{\boldsymbol{h}} \boldsymbol{w_{ih}} * \boldsymbol{1_{date}} \quad (8)$$

For all other months during the year where the daily total residential use exceeds the calculated average February daily use, the portion of total residential water use above the Calendar Month average for that day is treated as outdoor. The total amount of indoor water used during calendar year 2019, $W^{I,2019}$, is the sum of the monthly indoor water use totals:

$$\boldsymbol{W^{I}_{i,2019}} = \sum_{\boldsymbol{day}} \boldsymbol{W^{I}_{i,day}} \quad (9)$$

Threshold Approaches: Another approach is to analyze data at the hourly level. Previous studies have found that even under congested water use conditions (multiple appliances or water fixtures running within the same hour of the day), indoor residential water use seldom exceeds 100 gallons per hour (gph).[20] More recent end-use evaluation of homes in a Supplier in Northern CA exhibited a threshold of ~45gph (see Appendix C Pilot End Use Analysis). Moreover, the Pilot end-use study suggests that simultaneous outdoor and indoor usage is relatively uncommon.

In this approach, indoor residential use is disaggregated from outdoor residential use by using a set of thresholds as hourly cutoffs. All of the hourly water use below the cutoff is considered indoor use. In this study, three thresholds are evaluated. First, a threshold of 100 gph is used to yield an upper bound of indoor water use. Second, a threshold of 45 gph is used to yield a lower-bound estimate of indoor water use. Third, a threshold of 75 gph is also used to represent a typical home. For each customer, i, the total amount of indoor water used during calendar year 2019, $W^{I,2019}$, is computed for each of the three thresholds, $t \in \{45,75,100\}$, as:

$$\boldsymbol{W^{I}_{i,2019}} = \sum_{\boldsymbol{h}} \boldsymbol{w_{ih}} * \boldsymbol{1_{t}} \quad (10)$$

where w_{ih} represents the amount of water that customer i consumes at each hour, h. The indicator variable, 1_t, takes a value of 1 if w_{ih} is less than or equal to the threshold value and 0 otherwise.

[20] DeOreo, *et al* (2011). *California Single-family Water Use Efficiency Study.* AquaCraft Engineers. Denver, CO.

Profile Approaches: Each customer account's maximum indoor hourly amount may vary based on the number of occupants in the home, water fixtures, and other household-specific characteristics. In some instances, applying a particular threshold as described in the Threshold Approaches may overestimate the amount of indoor water use for some homes while underestimating the amount for other homes. To address this, a profile-based approach is used to determine a customer-specific threshold.

In this approach, each customer's daily total residential water use patterns are grouped together using a time-series clustering algorithm based on similarities in how much water is used during each hour of the day to produce "Profiles."[21] The resulting profiles are useful insofar as they summarize sets of days in which customers use water in particular ways and can be used to distinguish days in which water is only used indoors versus other days where water is also used outdoors.

Profiles that correspond to indoor only usage are distinguished by first sorting usage profiles based on the magnitude of its global maximum (highest peaking value). Second, the difference between each profile's highest peaking value and the next profile's highest peaking value is computed. Third, each profile is weighted based on the relative number of days the profile is observed. Each profile is then assigned a score, computed as the product of the differences in peaking values and the profile's weight. The profile with the highest score is then treated as the marginal indoor residential water use profile. All profiles with lower global maxima are also considered indoor residential water use whereas profiles with higher global maxima are considered to be a mix of indoor and outdoor water use, or outdoor water use only.[22] Given that indoor residential water use seldom exceeds 100 gph,[23] profiles with peaking values above 100 are automatically treated as having some outdoor usage.

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[21] The algorithm is allowed to create at most 20 usage profiles for each customer.

[22] *Outdoor only* days are *Indoor + Outdoor* days in which most of the day (20 hours) is 0 and high peak (over 150 gallons).

[23] DeOreo, *et al* (2011). *California Single-family Water Use Efficiency Study.* AquaCraft Engineers. Denver, CO.

A customer-specific numerical threshold value, t_i, is then computed based on their indoor residential water use profiles. This threshold is then used to disaggregate indoor usage for that particular customer account. Specifically, the numerical threshold value is based on the 99th percentile of hourly usage values on days that correspond to indoor water use only days. Disaggregating indoor water use from outdoor water use then follows the same procedure as the numerical approach previously discussed. For each customer, i, the total amount of indoor residential water used during calendar year 2019, $W^{I,2019}$, is calculated using threshold, t_i:

$$\boldsymbol{W^{I}_{i,2019} = \sum_h w_{ih} * 1_{t_i}} \quad (11)$$

where w_{ih} represents the amount of water that customer i consumes at each hour, h. The indicator variable, 1_{t_i}, takes a value of 1 if w_{ih} is less than or equal to the customer-specific threshold value and 0 otherwise.

Leaks are generally classified as indoor water use. To understand the extent of leaks on Ri-gpcd, a leak filter was also applied for single-family customers.[24] Leaks are defined as a minimum of 36 hours of continuous usage. The hourly amount of water defined as a leak is the minimum amount of water used during the leak period. Ri-gpcd estimates are provided with and without the leak filter. Ri-gpcd estimates not using the leak filter are used as the final estimates as they are directly comparable to the results from the other methodologies.

For each method, Ri-gpcd is calculated for each account in two steps. First, each customer account's indoor gallons per day, GPD_i, is calculated as:

$$\boldsymbol{GPD_i = \frac{W^{I}_{i,2019}}{2019\ Days_i}} \quad (12)$$

Next, $RI - GPCD_i$ is then calculated as:

$$\boldsymbol{RI - GPCD_i = \frac{\frac{GPD_i}{Number\ of\ dwelling\ units}}{Census\ estimate\ of\ persons\ per\ dwelling\ unit}} \quad (13)$$

[24] A leak filter was not applied for multifamily residential customers.

The estimate of persons per dwelling unit is customer class (single family vs multi-family) specific.

Data & Validation

Data inputs for the residential indoor water use gallons per capita per day estimates include:

Hourly AMI data, for residential accounts only, from four water suppliers between January 1, 2019 through December 31, 2019). The number of residential accounts analyzed for each water supplier is listed in Table B-1 below.

Additional hourly customer data through March 2020 was analyzed for Suppliers 1 and 4 to estimate impacts of COVID-19 shelter-in-place orders on indoor residential water use.

Population per household are consistent with the approach described in Appendix A, using the American Community Survey Census Tract 5-year population estimates from 2018, for all census tracts within the four participating water suppliers.

Table B-5. Summary of Single-Family Data by Water Supplier

Single-Family	**Count of Tracts Analyzed**	**Number of Accounts**
Supplier 1	14	12,910
Supplier 2	106	119,854
Supplier 3	110	133,706
Supplier 4	21	9,152

Table B-6. Summary of Multi-Family Data by Water Supplier

Multi-Family	**Count of Tracts Analyzed**	**Number of Accounts**
Supplier 2	73	2,455
Supplier 3	72	1,670

Multi-Family	Count of Tracts Analyzed	Number of Accounts
Supplier 4	20	959

Multiple data validation and verification steps were performed on the data to ensure the hourly data corresponded to the data used for the monthly analysis. By aggregating the AMI data to each customer's bill periods and compare those values to the values in the monthly values.

We remove anomalous data observations that result from meter malfunctions (mechanical or communication errors) as such outliers do not reflect customer water use behavior. Data validation rules include the following:

Days are omitted if:

1. One or more hourly reads is negative;
2. Multiple/conflicting hourly reads for a given hour;
3. Hourly reads exceed meter's safe maximum operating condition (SMOC);[25]
4. Full 24 period of reads not available;
5. Each account must have at least 30 days of non-zero usage during the 2019 calendar year.

These rules serve to filter out problematic data and produce a clean data set on which to conduct the Ri-gpcd hourly data disaggregation. The cleaned data is then segmented by customer class and census tract.[26] Only residential accounts, including single-family dwelling units and multi-family dwelling units, are included in this study.

[25] SMOC for various meter sizes are defined following water utility guidance. Specifically, SMOC 5/8" meter is 20GPM, 3/4" meter is 30GPM for 3/4", 50GPM for 1" meter.
[26] Tract-level estimates are not reported for tracts with 30 or less single-family customers to safeguard personally identifiable information.

Results

Single Family Results

Estimates for tract level estimates of single-family residential accounts, by Supplier, are reported in Tables B-2 through B-4. Results show variation in *Ri-gpcd* for single-family residential customers across the four Suppliers. Single family customers in Suppliers 3 and 4 have lower Ri-gpcd than single family customers in Suppliers 1 and 2. All four methodologies used yield similar patterns of variation.

Table B-7. Hourly Single-family Ri-gpcd Estimates per Supplier: Average Day and Calendar Month Approaches

Supplier	Average Day* gpcd	Calendar Month* gpcd
1	41.6 (5.5)	44.3 (6.4)
2	56.2 (5.0)	56.0 (5.5)
3	36.4 (6.1)	38.5 (6.3)
4	48.0 (8.4)	52.6 (9.6)

*Standard errors are in parenthesis

Table B-8. Hourly Single-family Ri-gpcd Estimates per Supplier: Threshold Approaches

Supplier	45 gph* gpcd	75 gph* gpcd	100 gph* gpcd
1	34.8 (4.8)	43.8 (5.8)	47.5 (6.2)
2	44.9 (4.8)	56.5 (5.5)	62.1 (6.4)
3	35.7 (5.5)	41.7 (6.5)	44.3 (7.0)
4	43.8 (7.3)	54.5 (9.0)	59.0 (10.0)

*Standard errors are in parenthesis

Table B-9. Hourly Single-family Ri-gpcd Estimates per Supplier: Profile Approaches

Supplier	No Leak Filter* gpcd	Leak Filter* gpcd
1	45.6 (5.9)	44.5 (5.6)
2	57.8 (5.8)	51.9 (5.3)
3	41.5 (6.4)	40.6 (6.0)
4	55.7 (9.2)	49.7 (7.2)

*Standard errors are in parenthesis

Tract-level estimates for each of the four methodologies are summarized for all four suppliers in Figures 1 through 3. These figures are useful for two reasons. First, it is a convenient way to inspect the internal consistency of the estimates across the various methodologies. In each of these figures, results for the Profile approach (without the application of a leak filter) are plotted on the x-axis and the results for other approaches are plotted on the y-axis. The dashed diagonal line represents perfect correspondence. The closer the points are to the diagonal line, the higher the correspondence across methodologies. Second, these figures are also a convenient way to inspect variation in *Ri-gpcd* estimates across tracts for each water supplier.

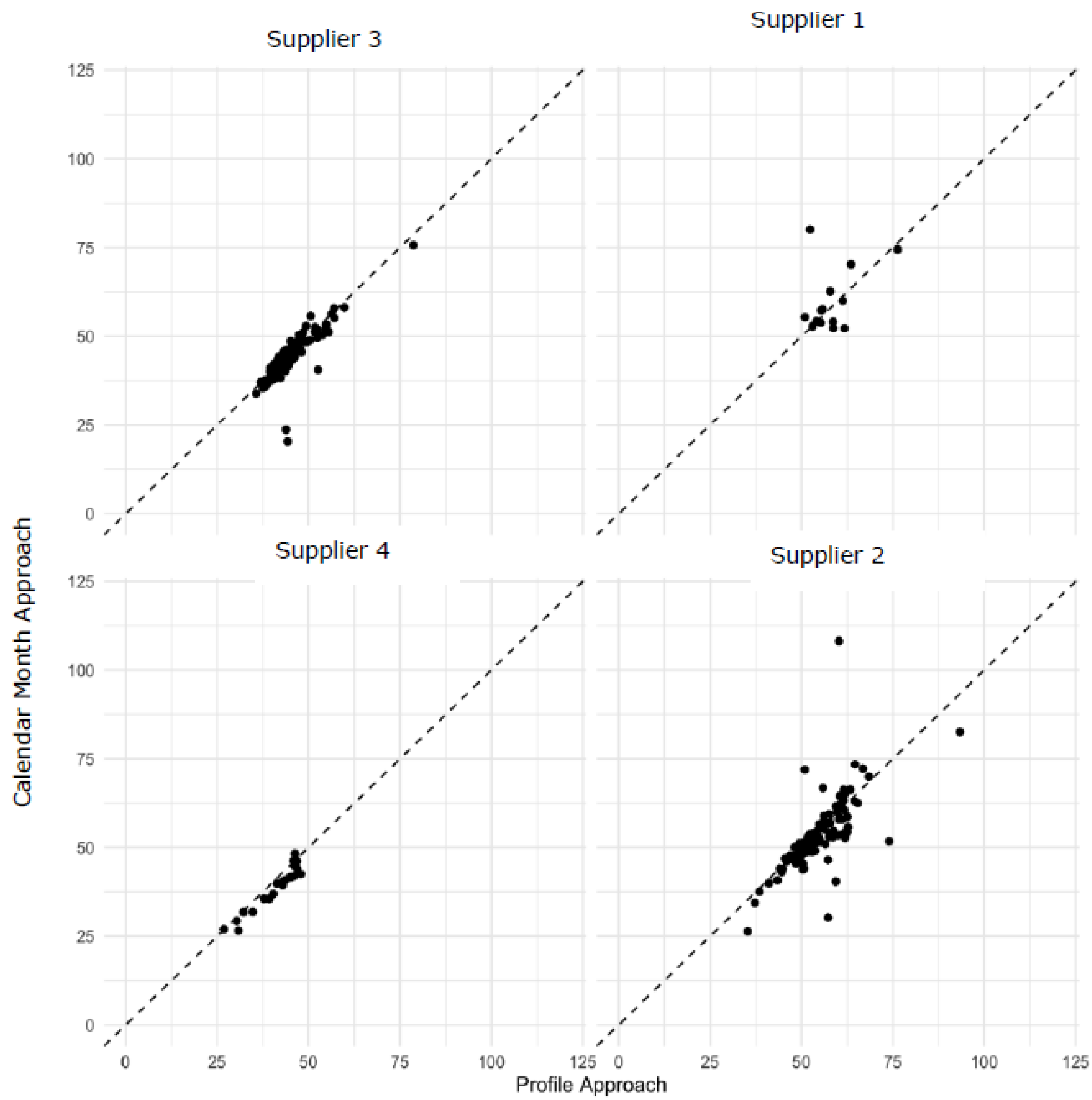

Figure 6. Comparison of Profile Approach and Calendar Month Ri-gpcd Tract-level Estimates

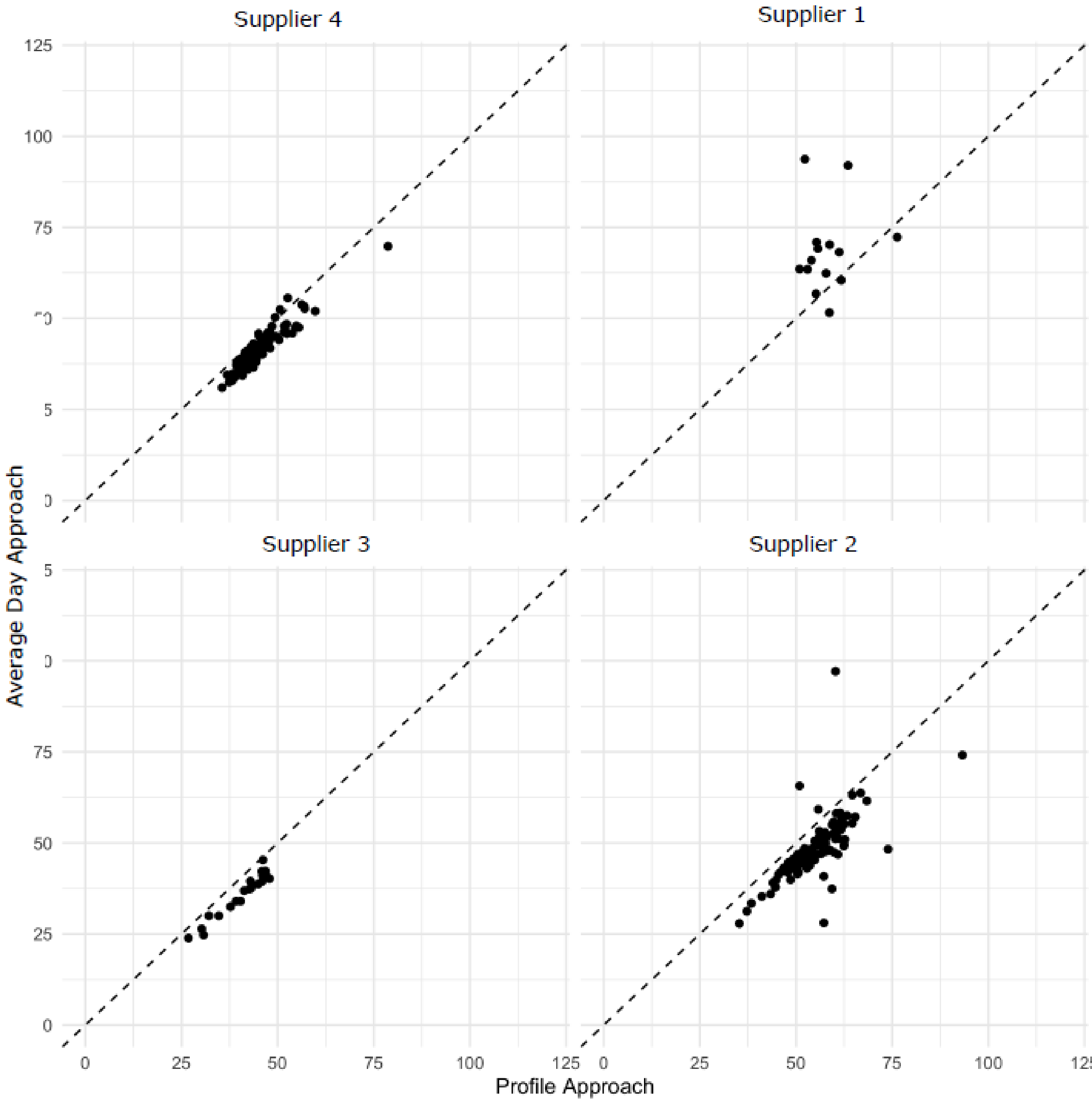

Figure 7. Comparison of Profile and Average Day Approach Ri-gpcd Tract-level Estimates

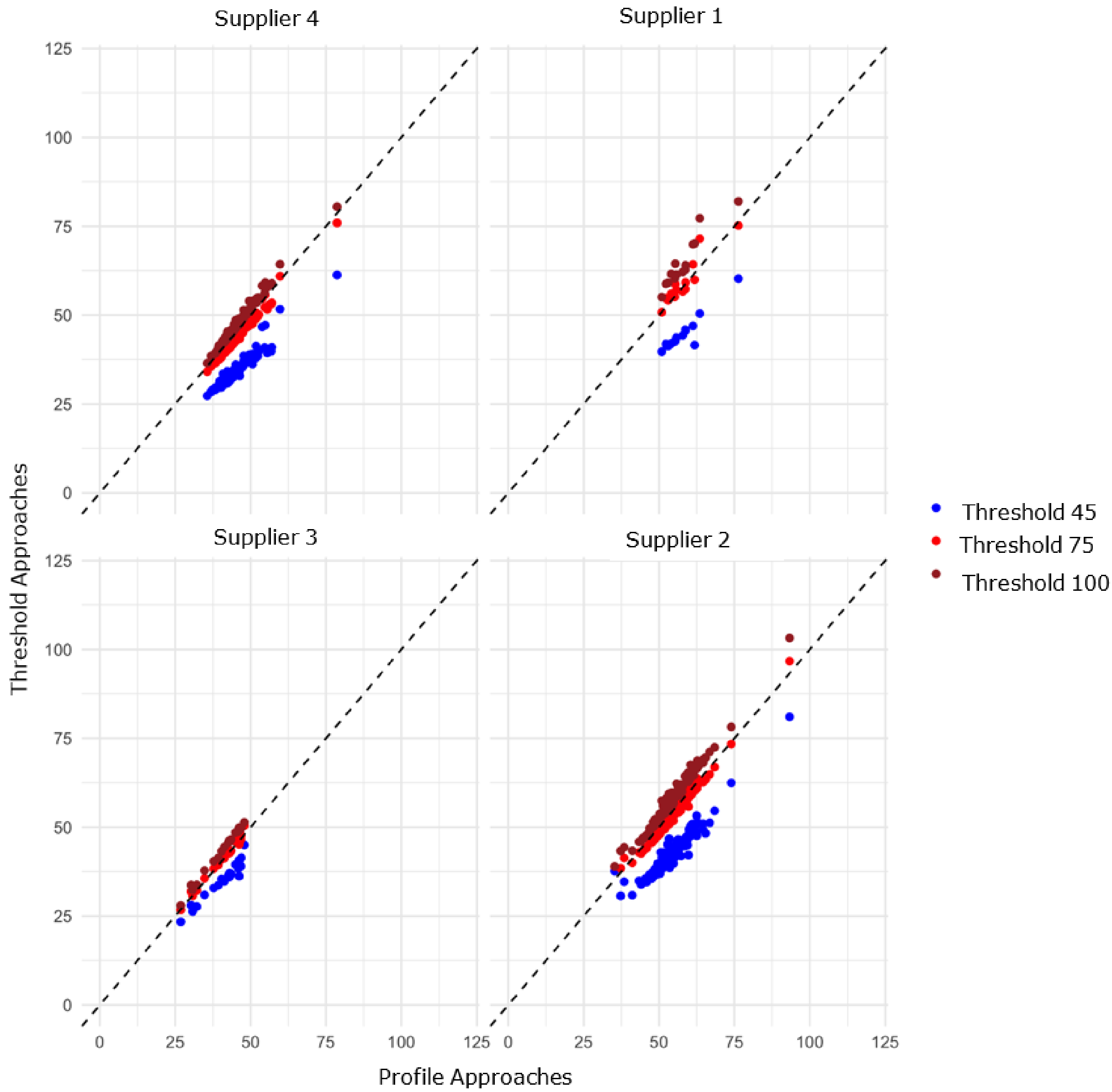

Figure 8. Comparison of Profile and Numerical Approaches GPCD Tract-level Estimates

Results from single-family customers also indicate variation in indoor water usage between summer and winter months, with more water being used during summer months. As shown in Figure 4, the seasonal pattern is particularly evident in in two of the communities studied, namely Suppliers 1 and 2, and salient across all methodologies used. The seasonal pattern is also observed in Suppliers 3 and 4, albeit to a lesser extent. Potential explanations for this seasonal variability include unobserved increases in occupancy (e.g. children home from school) or behavioral factors (e.g. use of swamp coolers).

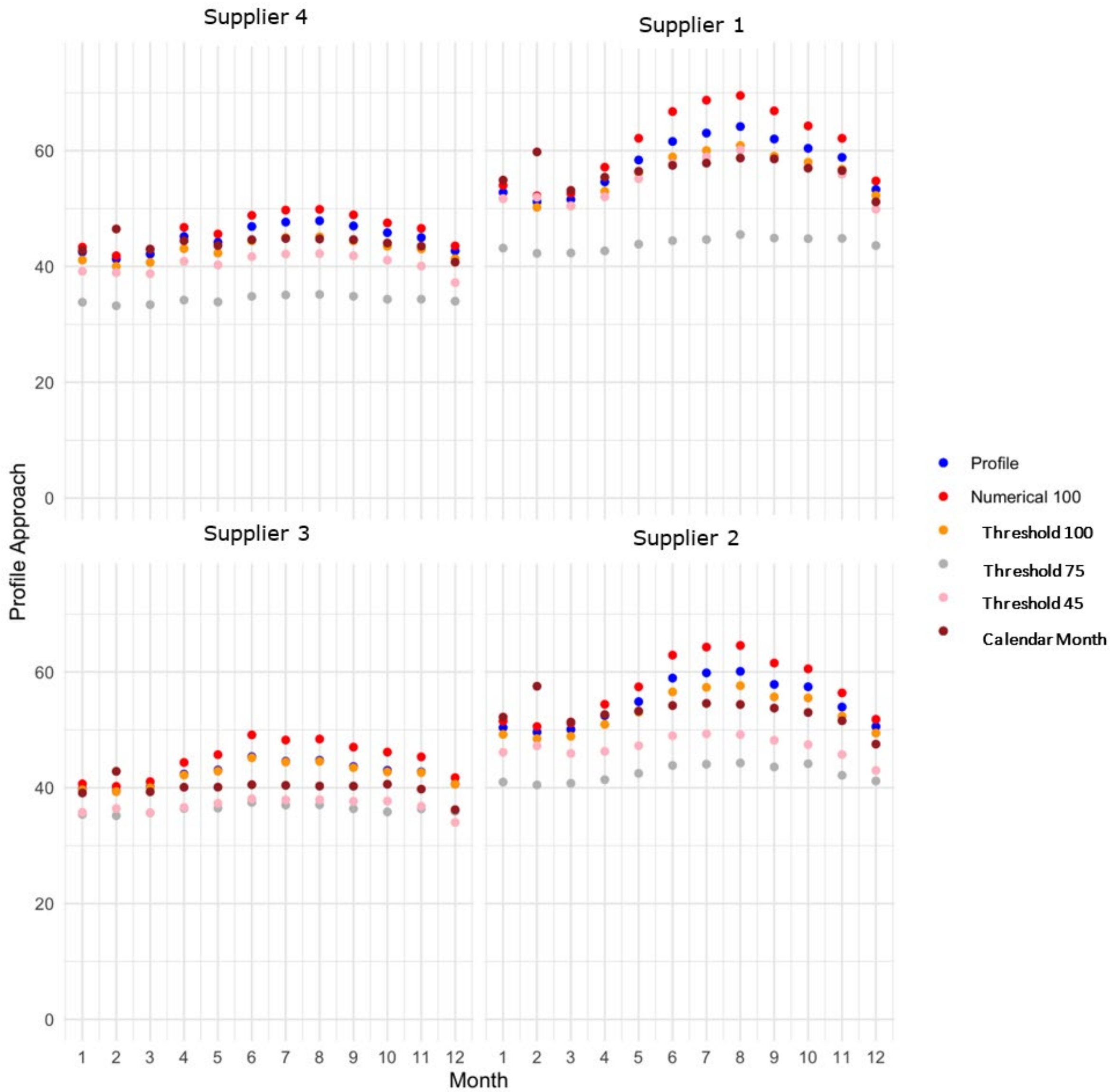

Figure 9. Comparison of Profile and Threshold Approaches Ri-gpcd Tract-level Estimates

Multi-Family Results

A subset of the methods described above are used to disaggregate for multi-family residences. Namely, minimum month, calendar month, and profile approaches are used. Numerical approaches are not used to study multi-family accounts because of the variation in the number of dwelling units associated with each account. Further research is needed to understand how to determine what thresholds may be appropriate to apply based on property characteristics.

Estimates for multi-family residential customers, shown in Table B-5, are generally similar in magnitude to estimates for single-family residential customer accounts shown in Table B-2 and B-4.[27]

Table B-5. Multi-Family Indoor GPCD Estimates by Supplier

Supplier	Average Day Approach	Calendar Month Approach	Profile Approach (No Leak Filter)
2	60.3	62.4	43.6
3	50.3	51.9	42.3
4	42.8	43.4	40.5

Limitations

There are several data limitations that should be noted. First, though the high-resolution data afforded by hourly AMI data represents an improvement over monthly data, it is still too coarse to detect specific uses that may be related to outdoor water usage. For instance, it is not possible to detect water used by drip irrigation systems. Additionally, it would not be possible to determine how customers may be using water from specific indoor fixtures or for specific purposes. For instance, it would not be possible to distinguish between customers filling watering cans for outdoor plants and other indoor uses.

Second, this study uses estimates of household size at the tract level. Though these estimates are decent approximations and would provide consistent estimate with a large enough sample, deviations from this estimate at the household level may under- or over-estimate indoor residential use.

Third, it is not uncommon for certain accounts to be misclassified as either being single-family when, in fact, they are a multi-family account or vice-versa. In this study, we use customer-class specific estimates of the number

[27] It was not possible provide estimates for Supplier 1 due to the lack of information regarding dwelling units associated with each account.

of persons per dwelling unit. Accordingly, the misclassification of customer accounts may also result in under- or over-estimating indoor residential use.

Lastly, to estimate measures of indoor water usage, data regarding the number of dwelling units is required. This information is especially important for producing estimates for multi-family accounts. In this study, it was not possible to produce estimates for Supplier 1's multi-family accounts due to the lack of these data.

Impacts of COVID-19 on Indoor Residential Water Use

Additional data from January through the end of March 2020 was provided for Suppliers 1 and 4. These data are used to estimate impacts of COVID-19 shelter-in-place (SIP) orders on indoor water use.

A particular challenge in parsing out the effect of COVID-19 is the lack of a control group. In an ideal scenario, one would not only compare changes in water usage before and after the imposition of SIP orders, but also compare water usage in a location affected by COVID-19 SIP order to a similar location that was not affected. This latter comparison is particularly important to control for potential changes in water usage that would be expected for the time period especially as in the imposition of SIP orders coincides with potential changes in usage behavior in March.

One way this issue is addressed is by using historical data. Analyzing data for the same location and time of year enables controlling for temporal trends in usage. For Supplier 1, data is used from January through March 2019-2020 for Supplier 4 data is used from January through March 2018-2020. Methodologically, this is accomplished by using a customer-level fixed effects model given by the following equation:

$$\widehat{RI_{ijt}} = \sum_j \beta_j SIP_j + \sum_j \theta_j Z_t + \sum_j \delta_j X_{jt} + \alpha_i + \epsilon_{ijt} \quad (14)$$

where single family residential accounts are indexed by i, water supplier is indexed by j, and time is indexed by t. The dependent variable represents each single-family account's estimated value of indoor water used at a daily level using the methodologies described above. Models are estimated using measures of GPD as well GPCD. The variable SIP is a dummy variable, coded as 1 in location j once SIP went into effect and 0 otherwise.[28] The coefficient of interest β_j represents the overall daily increase in water usage at the customer account level after SIP went into effect for customers served by water supplier j.

The vector Z represents several time-based controls. First, day fixed effects are included to capture inherent variation in how water used over the course of the week. Second, month fixed effects are included to capture natural changes in water usage over the course of the first three months of the year. Third, year fixed effects are included to capture changes in level of water used across years. The vector X represents additional controls, namely average temperature and precipitation taken from the nearest weather station for each water supplier j.

The longitudinal nature of the data is leveraged to control for time-invariant unobserved characteristics at the account level that may be correlated with water usage (e.g. home's square footage, numbers of bedrooms and bathrooms, its number of occupants). These characteristics are represented by the fixed effect α. Lastly, ε_{it} is an error term that captures unobservable shocks to water demand that accounts may experience during on any given day.

As shown in Table 4Table B-6, daily indoor usage increased by 8.75 gallons per household in Supplier 4 (3.10 gallons per person) and 13.31 gallons per household for Supplier 1 (4.54 gallon per person), all else equal, following the introduction of SIP orders. This is roughly equivalent to approximately three extra toilet flushes per home per day.

Table B-106. Changes in Single Family Residential Indoor Water Use Following Shelter in Place Orders

Supplier	Change in Water Use Per household	Change in Water Use Per person
Supplier 1	13.31***	4.54***
	(1.30)	(0.465)

[28] A shelter in place order for Supplier 4 was issued on March 16, 2020. A shelter in place order for Supplier 1 was ordered on March 19, 2020.

Supplier	Change in Water Use Per household	Change in Water Use Per person
Supplier 4	8.75***	3.10***
	(0.860)	(0.350)
Notes: Models control for precipitation, temperature, and a host of time fixed effects. *** p<0.01, ** p<0.05, * p<0.1		

Insights

This study is one of the first published attempts to use hourly AMI data to produce estimates of *Ri-GPCD* and elicited several insights. First, hourly data, can be used to produce reliable estimates of *Ri-GPCD* at the customer account level non-intrusively and cost-efficiently. All methodologies produce reasonably similar estimates of *Ri-GPCD* with a high degree of internal consistency.

Second, AMI data can be used to identify home occupancy trends and seasonal customers. The higher resolution data enables the study of how customers water use patterns over the course of any given day and consequently, over the course of any given week or month. Under monthly data, analysts typically assume that water usage is constant during a given read period. In reality, the distribution of water usage may vary over the course of the read period. For instance, customers may not be home during the week but home on the weekends using large volumes of water. AMI data can be used to identify days when customers use no water and identify variation in water usage that can be informative about the customer.

Lastly, findings indicate that indoor water usage may increase during summer months in some communities. Potential explanations for this seasonal variability include unobserved increases in occupancy (e.g. children home from school) or behavioral factors (e.g. use of swamp coolers). Though more research is needed to better understand this effect, this result has practical implications for the data used to produce estimates of *Ri-gpcd*. Namely, only selecting one month of the year to estimate indoor water use may lead to under- or over- estimation of *Ri-gpcd*, too low in the winter and too high in the summer. This difference can be as high as 10 gpcd.

Though this study emphasizes one potential way water suppliers can leverage their AMI data, there are many more applications of AMI data that water utilities could leverage. Other potential applications include, but are not limited to, advanced demand modeling, leak detection, time-of-use pricing, water restrictions monitoring, water budget customer alerts, and identifying seasonal residents. Care for data cleaning and filtering must be applied, yet the application of AMI data for solving complex utility problems presents an exciting frontier in utility management.

Appendix C.
Pilot Residential End Use Study

Prepared for

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California Department of Water Resources

Water Use Efficiency Branch

September 2020

Introduction

As part of its research into residential water demands pursuant to Section 10609.4(b) of the California Water Code, the Department of Water Resources (DWR) conducted a pilot residential end use study for one Supplier in Northern California with 20 volunteer single-family participants.[29] In this pilot study, AMI water meters at each of the 20 participating homes was fitted with a Flume Smart Home Water Monitor device capable of continuously measuring flow at 5-second increments for at least 30 days from each home during late June and August 2020.

Using the same basic approach employed in previous Residential End Uses of Water studies (1999, 2019), which employed portable flow recorders to collect high-resolution 10-second interval flow data and then used software to disaggregated the data sets into component end uses[30]. The Residential End Uses of Water studies had statistically representative samples of more than 1,100 homes (1999) and 700 homes (2016) carefully selected from participating utilities across the US and Canada. In contrast this pilot study included a small sample of volunteer participants and was undertaken by DWR to establish to feasibility and utility of end use research to better understand where and how water is used in California homes. It should also be noted that data in this pilot study were collected during the hot and dry summer of 2020 with pandemic conditions compelling employers to require people to work from home and socially distant from others to prevent and slow the spread of COVID-19 infections.

In this pilot study, continuous, 5-second flow data were collected for 30-days using devices manufactured by Flume. Each individual 30-day flow data set was disaggregated into component water use events using specialized software developed by an Australian firm, Autoflow. A database containing a table of 525,029 individual disaggregated end uses, by customer, was delivered to the project team as the key deliverable. This database includes

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[29] The end use analysis was paired with an hourly analysis of summed end-use meter reads and presented in Appendix B.

[30] Mayer, P.W., W.B. DeOreo, et. al. 1999. Residential End Uses of Water. American Water Works Association Research Foundation, Denver, CO.; DeOreo, W.B., P. Mayer, J. Kiefer, and B. Dziegielewski. 2016. Residential End Uses of Water, Version 2. Water Research Foundation. Denver, CO

every indoor and outdoor water use (e.g. toilet flush, faucet draw, shower, clothes washer cycle, leak, etc.) measured over 30-days from 20 homes.

During the study, DWR's consulting expert Peter Mayer who was co-principal investigator of the 1999 and 2016 Residential End Uses of Water studies, advised Autoflow's Australian engineers regarding typical American flow parameters and settings likely to be associated with individual fixtures and devices to help improve the ability accurately disaggregate water use into end uses. Mr. Mayer also conducted final quality assurance and control checks on the end use dataset by customer and prepared the summary analysis of the end use data presented in this appendix.

The Flume/Autoflow pilot residential end use study quantified the volume of water used for each discreet water use within the 20-home sample. The analysis and results in this appendix are not intended to and could not possibly be representative of the diversity of residential use within the State of California. This pilot study was conducted with one Supplier to validate the results of the hourly and monthly disaggregation techniques and prove the usefulness of the end use analysis approach in combination with more readily available data sets for future indoor and outdoor water use studies.

Research Approach

The goal of this pilot study was to collect and analyze detailed water use data from a sample of 20 homes from one urban water supplier in California and compare it with monthly and hourly disaggregation results. The Supplier was a participant in both the monthly and hourly DWR Indoor Residential Water Use Studies and agreed to participate in the pilot end use study. Time was short and the COVID-19 pandemic delayed the study implementation adhering to local social distancing government regulations. A group of 20 single-family volunteer participants were solicited with the assistance of Supplier staff in a non-random sample.

Participating households completed a detailed online survey which included information on the number and ages of residents and an inventory of all water using fixtures, appliances, and features in the home. The primary purpose of this survey was to assist in the end use disaggregation by providing information about the presence of specific water using devices and appurtenances like evaporative cooling or backyard swimming pool. A copy of the survey is provided at the end of this appendix.

Installation of the Flume devices was scheduled in advance with each participant. A Flume device was strapped to the existing utility water meter located outside each home in a meter pit. A bridging device, typically installed in the garage, connects the Flume device to the household internet service and allows for the transfer of data. An example of a Flume device attached to a residential size water meter is shown in Figure C-1 and Figure C-2.

Figure C-10: Flume water monitor device installed on a Sensus water meter in a laboratory setting.

Figure C-11: Flume water monitor device

The 20-particpating homes were spread out across the Supplier and represented a range of typical single-family homes. Installation of the Flume units was managed following local guidance on COVID-19 social distancing requirements.

The 20 Flume devices were installed over a three-day period in late June and collected 5-second data for the end use study from June 26, 2020 through August 4, 2020. At the conclusion of the study, the Flume devices and access to the Flume application were provided to the study participants. During the study period, Flume real time data sharing with the customers during the study was disabled to avoid influence on demand.

Once the individual data sets were assembled, engineers from Flume verified the quality and accuracy of the 5-second data recorded by the Flume devices by comparing the measured volumes against hourly meter readings made by the Supplier’s water meter reading system. The volumetric checks showed more than 99% correspondence in volumetric measurement aggregated at the hourly level.

Quality-verified 5-second data sets and survey responses were provided by Flume to Australian research partner Khoi Nguyen, Ph.D. of Autoflow for disaggregation into component end uses.[31] Over a period of approximately two weeks, Autoflow processed and analyzed the datasets, disaggregating the 5-second flow trace into a data set of component end use events where each discreet water use is classified ("Toilet", "Shower", "Faucet", "Clothes washer", "Irrigation", "Leak", and so on) and fundamental statistics such as volume and flow rate are provided. A screenshot from Autoflow's software is shown in Figure C-3.

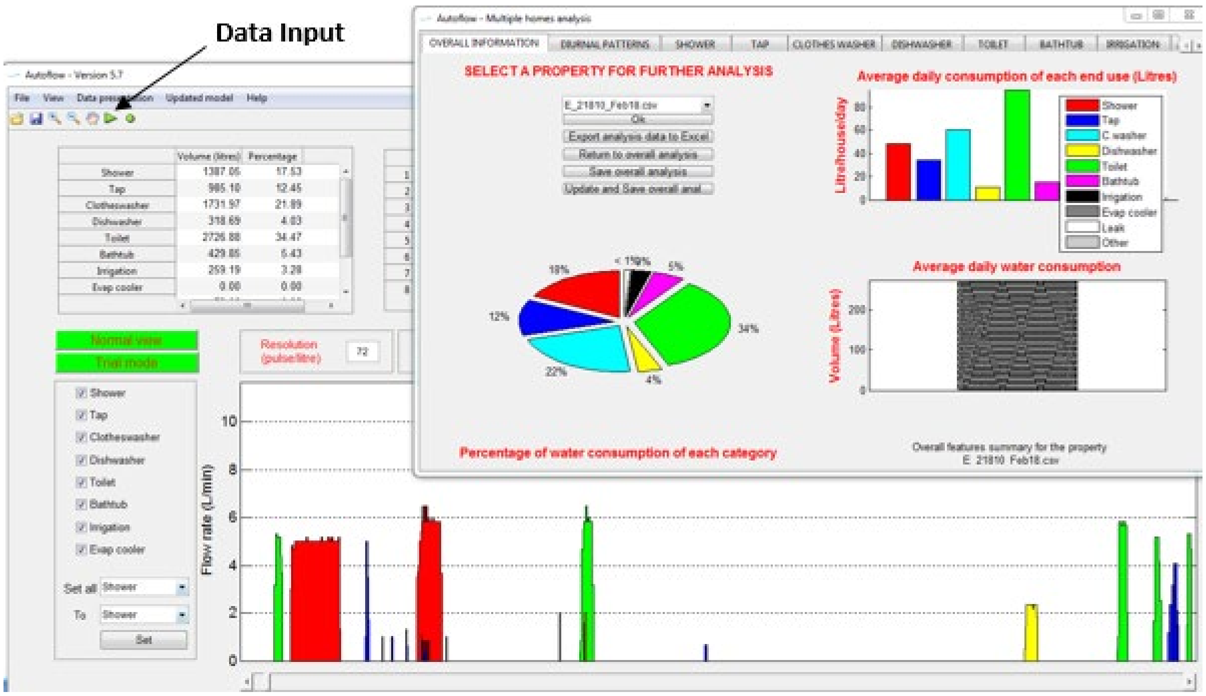

Figure C-12: Autoflow software screenshot showing disaggregation of end use events with high-resolution flow data.

During the end use disaggregation process, Autoflow provided preliminary results with Peter Mayer of WaterDM advising Autoflow regarding flow

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[31] Nguyen was a student of Professor Rodney Stewart at Griffith University near Brisbane when his team conducted a series of residential end us studies to help with drought management in the wake of the Australian "millennial drought" of the early 2000s. Through the process of conducting these studies, Prof. Stewart and his students purchased a copy of Aquacraft's end use disaggregation software and Peter Mayer travelled to Australia and conducted a multi-day training in end use analysis. Subsequently the Autoflow team developed their own software for disaggregating water use into component end uses and this is what was used to disaggregated end uses in this study.

parameters and numerical threshold adjustments to be made prior to the final analysis. Once the final disaggregated end use data set was received, WaterDM conducted final QA/QC on the end use dataset, prepared the summary analysis and results, and this report.

Results

Caveat - 2020 Summertime and Pandemic Conditions

The data in this pilot study were collected during the hot and dry summer of 2020 under pandemic conditions when a public health crisis necessitated that people stay home and socially distant from others to prevent and slow the spread of COVID-19 infections. Businesses mandated employees to work from home instead of in the office, and gatherings of more than 6 people were strongly discouraged by government. Due to these guidelines, many people spent more time at and around home when compared with historical norms. The results presented in this section reflect the influence of both significant factors.

Indoor and Outdoor Use During Data Collection Period

The volume of indoor and outdoor water use at each of the 20 homes is shown in Table C-1 and Figure C-4.

Table C-11: Data collection dates and indoor, outdoor, and total use at 20-homes

Site	Start Data Collection	End Data Collection	Indoor Volume (gal)	Outdoor Volume (gal)	Total Volume (gal)
1	26-Jun-20	05-Aug-20	4,411	32,599	37,011
2	26-Jun-20	04-Aug-20	6,400	2,450	8,850
3	26-Jun-20	04-Aug-20	3,955	23,454	27,409
4	26-Jun-20	04-Aug-20	4,970	15,613	20,583
5	26-Jun-20	04-Aug-20	5,149	18,208	23,356
6	26-Jun-20	04-Aug-20	2,743	23,664	26,406
7	26-Jun-20	04-Aug-20	5,062	9,026	14,088

Site	Start Data Collection	End Data Collection	Indoor Volume (gal)	Outdoor Volume (gal)	Total Volume (gal)
8	26-Jun-20	04-Aug-20	7,792	8,681	16,473
9	26-Jun-20	04-Aug-20	6,436	28,293	34,729
10	29-Jun-20	04-Aug-20	3,382	22,452	25,834
11	26-Jun-20	03-Aug-20	3,597	136,484	140,081
12	26-Jun-20	04-Aug-20	6,994	19,356	26,350
13	26-Jun-20	04-Aug-20	4,861	15,321	20,183
14	26-Jun-20	04-Aug-20	7,144	17,208	24,352
15	26-Jun-20	04-Aug-20	6,947	40,055	47,002
16	26-Jun-20	04-Aug-20	3,288	7,382	10,670
17	26-Jun-20	04-Aug-20	4,941	8,084	13,025
18	26-Jun-20	04-Aug-20	5,139	8,493	13,632
19	26-Jun-20	04-Aug-20	4,017	3,567	7,584
20	26-Jun-20	04-Aug-20	3,299	39,006	42,305
Total			100,527	479,397	579,924
% of Total			17.3%	82.7%	100%

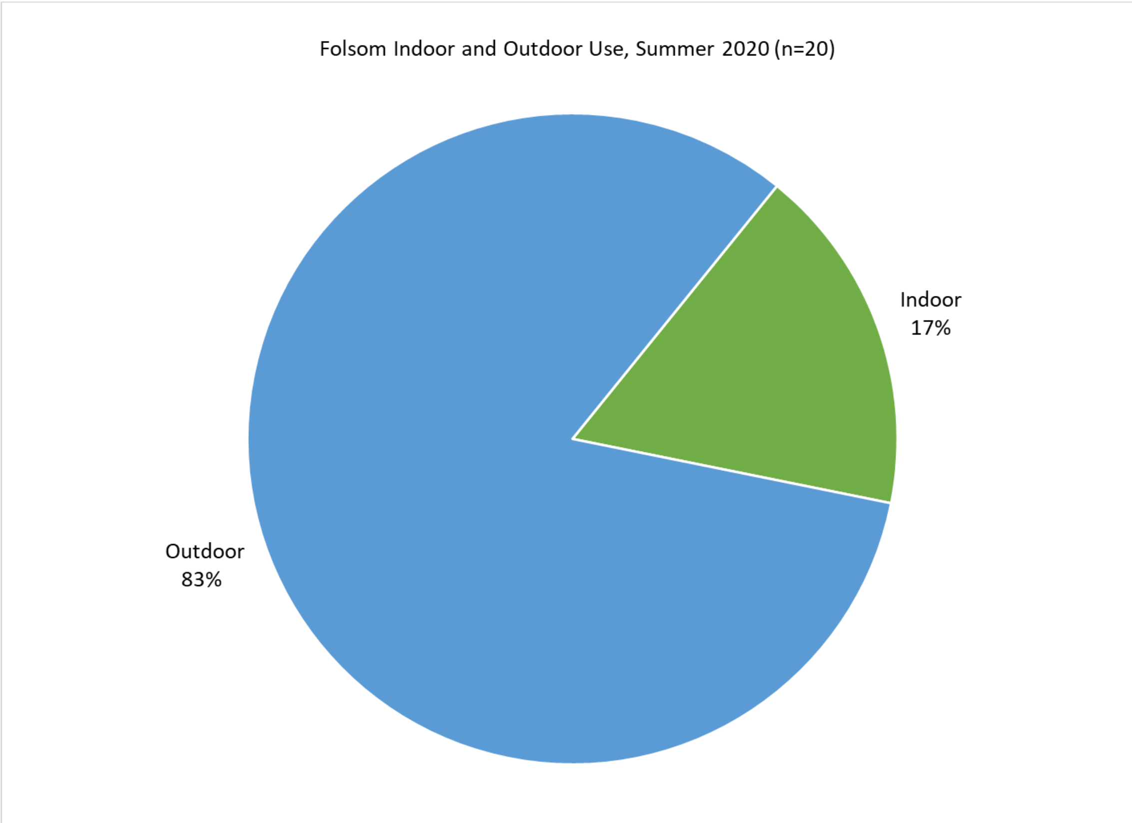

Figure C-13: Indoor and outdoor water use during summertime data collection period from the 20 homes

An average of 39 complete days of water consumption data were used to develop the study results, on average the study group used 17% indoor and 83% outdoor over the study period. Figure 5 shows a frequency distribution of indoor and outdoor daily use recorded during this study period for all 20 participants. Indoor use ranged between 25 and 300 gallons per day, while outdoor use ranged from 0 to more than 5,000 gallons per day on a few occasions during this study.

The end use analysis techniques employed in this study enabled the disaggregation of indoor and outdoor water uses for each day 5-second flow data were collected, even if irrigation systems ran continuously for hours or on variable schedules.

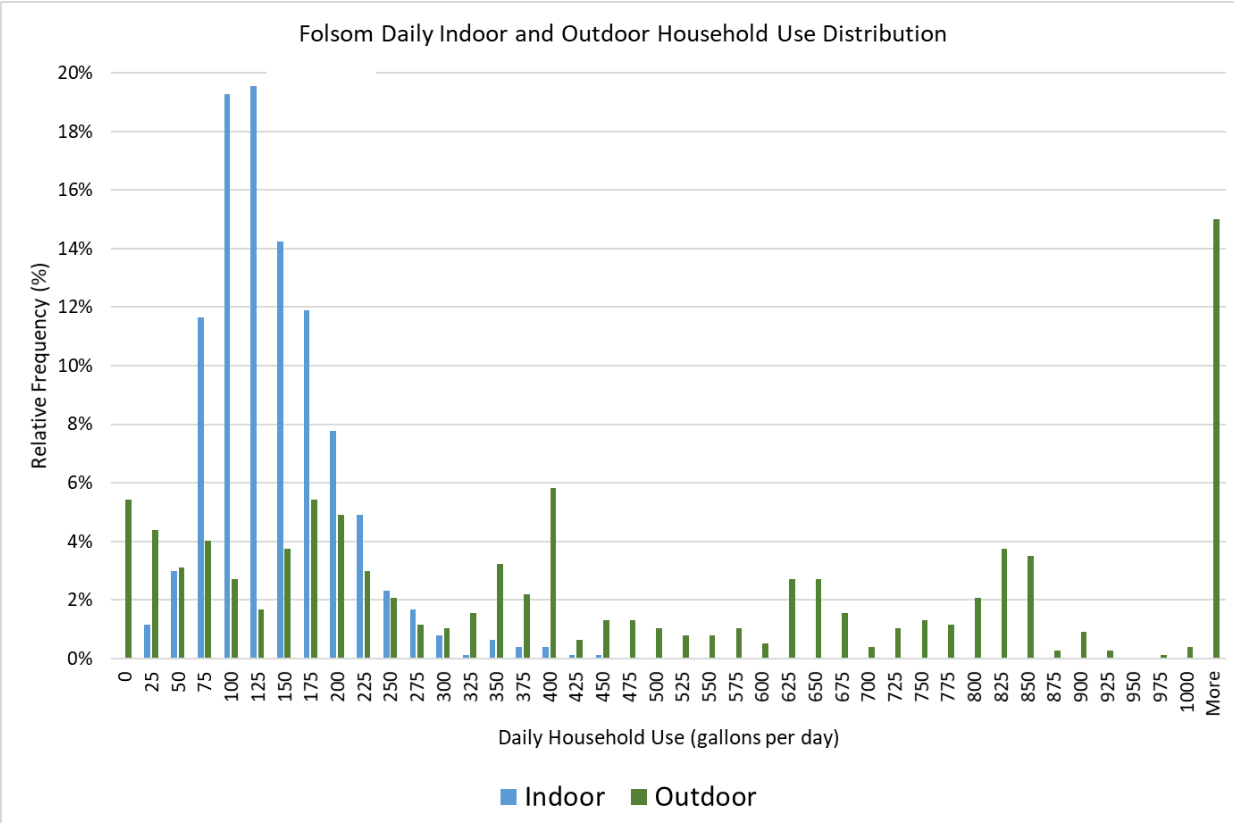

Figure 14: Frequency distribution of daily indoor and outdoor use

Indoor Per Capita Use

The study group had an average of 3.0 residents per household with a range from 1 to 5 residents. Per capita use was calculated by household and averaged across the 20-home sample. The average indoor per capita water use for each end use category is shown in Table C-2 and Figure C-6.

Indoor water use averaged 50.8 gpcd. Showering and toilet flushing were the highest end use categories, accounting for more than 51% of the indoor total. Faucets accounted for nearly 22.5% of the indoor total. Leakage accounted for more than 10% of indoor per capita use in these homes.

Table C-12: Indoor per capita water use by category

Category	*Indoor Per Capita Use (Ri-gpcd)*	% of Indoor
Bathtub	1.6	3.2%

Category	*Indoor Per Capita Use (Ri-gpcd)*	% of Indoor
Clothes washer	4.6	9.1%
Dishwasher	1.0	2.0%
Evaporative cooler	0.2	0.3%
Faucet	11.4	22.5%
Leak	5.5	10.8%
Other/misc*	0.4	0.7%
Shower	13.3	26.1%
Toilet	12.9	25.3%
Total	50.8	100.0%

*Other/misc includes indoor usage that could not be categorized during end use disaggregation.

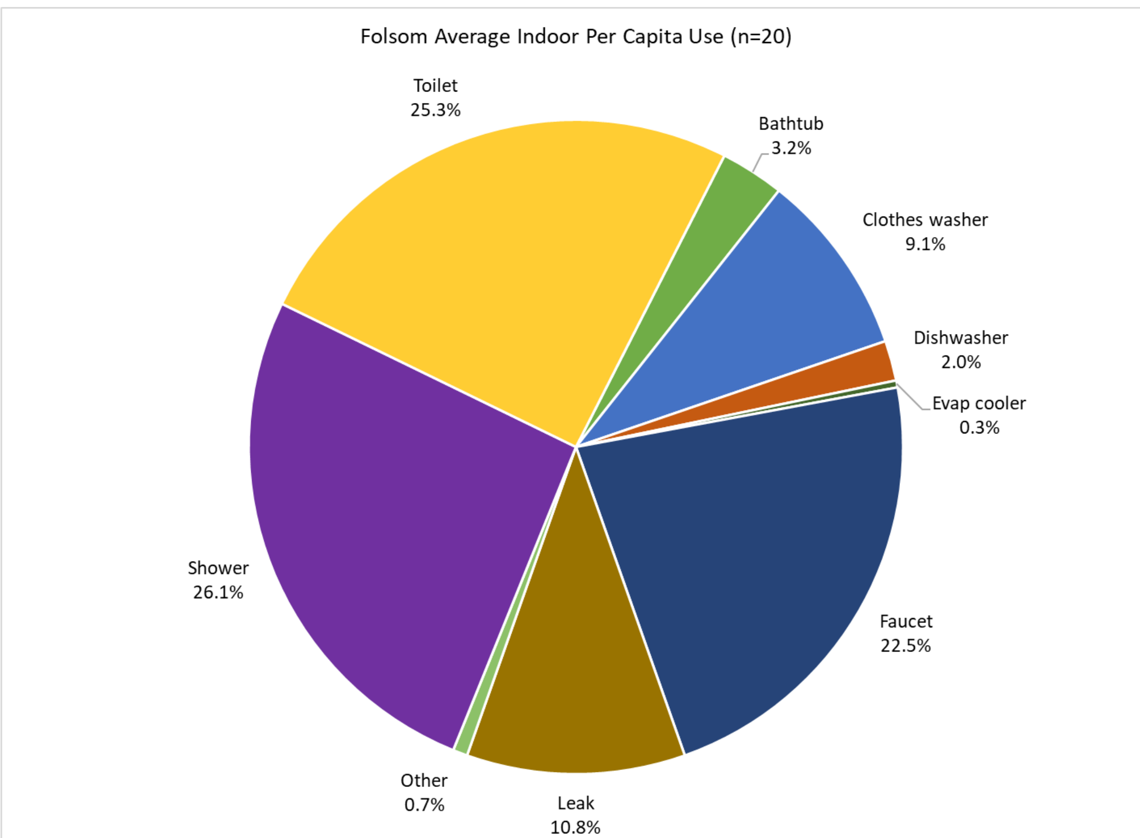

Figure C-15: Average indoor per capita water use by category

Table C-3 compares per capita use measured from this pilot study against the per capita use from the 2016 Residential End Uses of Water Study (REUWS 2016). Many per capita use comparisons are remarkably similar including baths and faucets. The biggest difference is in clothes washing, which was almost twice as high in the REUWS.

Table C-13: Indoor per capita use comparison, Pilot end Use study and REUWS 2

Category	Ri-gpcd Northern CA Supplier	Ri-gpcd REUWS 2016[32]
Bathtub	1.6	1.5
Clothes washer	4.6	9.6
Dishwasher	1.0	0.7
Evaporative cooler	0.2	
Faucet	11.4	11.1
Leak	5.5	7.9
Other/misc*	0.4	2.5
Shower	13.3	11.1
Toilet	12.9	14.2
Total	50.8	58.6

*Other/misc includes indoor usage that could not be categorized during end use disaggregation.

Some of the differences and similarities in per capita use are explained more by behavior differences observed between the two study groups such as increased flushing and showering frequency in this pilot study, rather than changes in fixture efficiency, which is also evident. The next sections look closely at several end use categories and examines fixture efficiency and utilization in this pilot study.

Toilets

A total 17,615 individual toilet flush events were measured during the study period. The average flush volume was 1.5 gallons per flush and people

[32] DeOreo, W.B., P. Mayer, J. Kiefer, and B. Dziegielewski. 2016. Residential End Uses of Water, Version 2. Water Research Foundation. Denver, CO

flushed the toilet 8.5 times per day on average. A representation of toilet flush volumes is shown in Table C-4 and compared with results from the 2016 Residential End Uses of Water (REUWS 2016) end use study. A frequency distribution of flush volumes is shown in Figure C-7. Very few flush volumes in this study exceeded 3 gallons per flush (gpf), but there were still a few older toilets present.

Both the 1999 and 2016 Residential End Uses of Water studies measured an average of 5.1 flushes per person per day on average, so the finding of 8.5 flushes per person per day for this Supplier likely shows the impact of the COVID-19 pandemic stay-at-home requirements.

Table C-14: Toilet flush volume statistics

Statistic	Pilot end-use Study	REUWS 2016	Units
Average	1.5	2.6	gallons per flush (gpf)
Std. Dev.	0.2	1.0	gpf
Median	1.4	2.3	gpf
Sample (n)	17,615	124,685	flushes
Average Flushing Frequency	8.5	5.0	flushes/person/day
Average Daily per capita toilet use:	12.9	14.2	gpcd

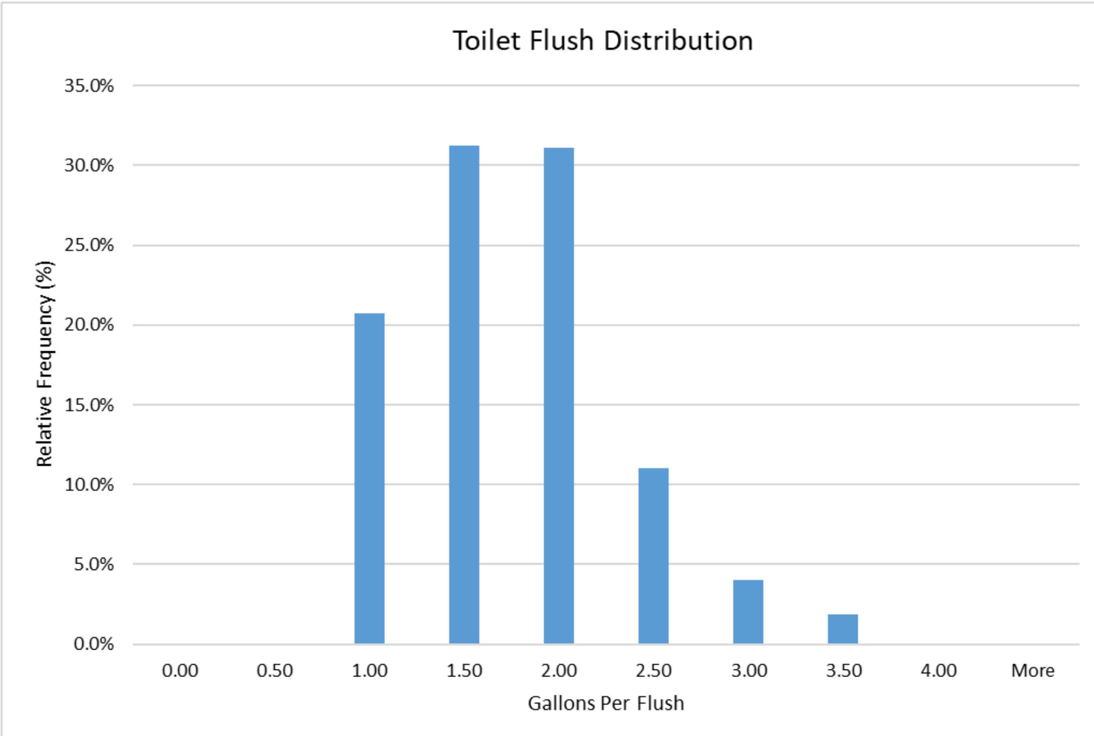

Figure C-16: Distribution of toilet flush volume from the Pilot Study (n = 17,615)

The average flush volume of toilets in this study group, 1.5 gpf, is among the lowest measured to date in an American residential end use study. But because of increased flushing frequency likely due the pandemic, there was only a 1.3 gpcd difference in per capita toilet usage from the REUWS 2016. The additional 3.5 flushes per person day increased the total gpcd in this pilot study by approximately 5.3 gpcd. Assuming that this set of 20 homes had used the same, pre-pandemic, flushing frequency measured in the REUWS 2016 (5.0 vs. 8.5 flushes/person/day), the average indoor daily use would be approximately 45 gpcd.

Showers

A total of 2,327 shower events were measured during the data collection period. Shower statistics are shown in Table C-5 and the distribution of shower volume is shown in Figure C-8. The average shower volume in this study used 11.7 gallons at a typical flow rate of 2.1 gpm. Study sample shower volumes ranged from 5–15 gallons with an average of 1.1 showers per person per day.

Table C-15: Shower statistics

Statistic	Pilot End-Use Study	REUWS 2016	Units
Shower Volume Average	11.7	15.8	gal/shower
Shower Volume: Std Dev.	7.0	6.8	gal
Shower Volume Median	10.0	15.0	gal
Shower Flow Rate Average	2.1	2.1	gpm
Shower Flow Rate Std Dev.	0.9	0.6	gpm
Shower Flow Rate Median	1.6	2.0	gpm
Showering Frequency Average	1.1	0.7	Showers/person/day
Daily per capita shower use Average	13.3	11.1	gpcd

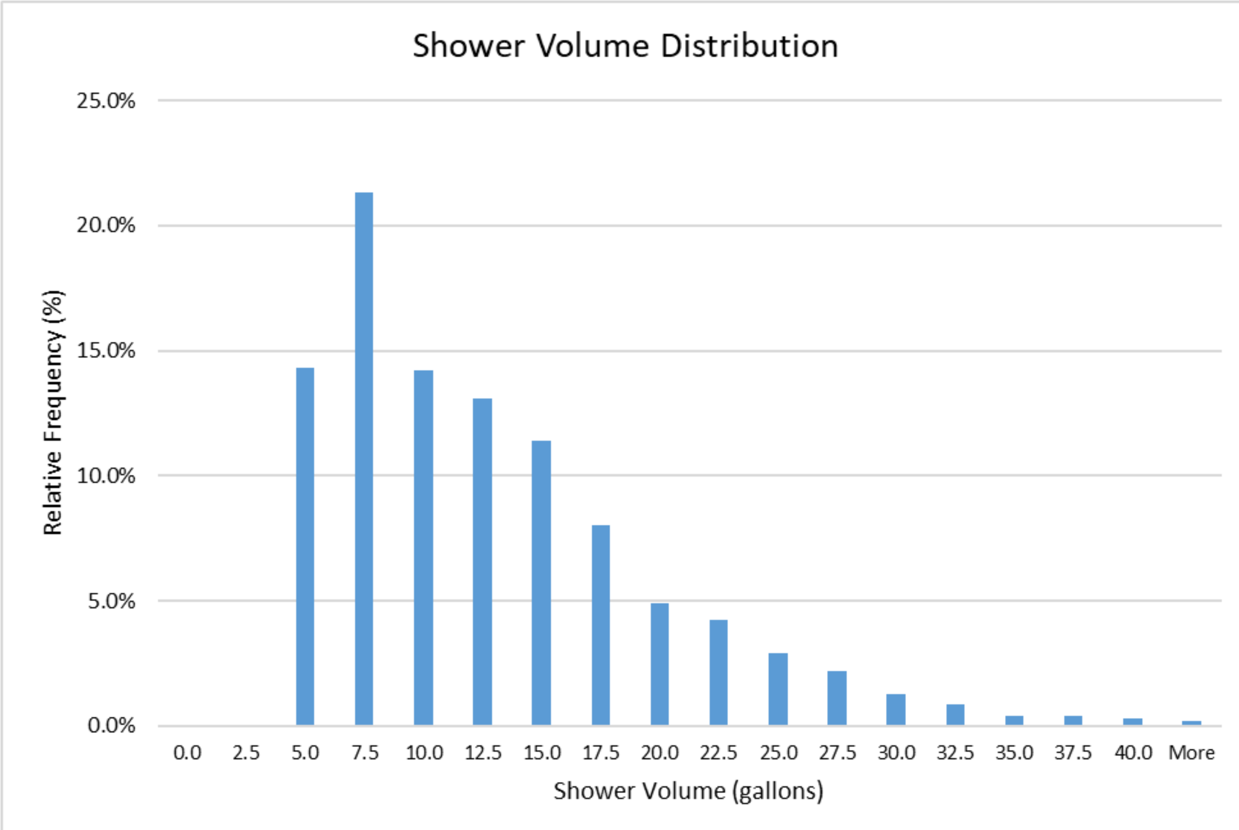

Figure C-17: Distribution of shower volume in this Pilot Study (n=2,327 showers)

Compared with the REUWS 2016, the study participant showers were shorter and used less water although the flow rates were similar. The biggest difference was in showering frequency which was more than 30% higher with an average of 1.1 showers per person per day compared with 0.7 in the REUWS 2016. Because of the increased shower use frequency, gpcd associated with shower usage was higher in this pilot study than in the REUWS 2016, even though the average volume per shower was lower.

Clothes washers and Dishwashers

All 20 homes in this pilot study used a clothes washer at least once during the study period, but only 9 of the 20 homes used their dishwasher during the study period. The average clothes washer used 24.3 gallons per load with load volumes ranging from a minimum of 10.5 gallons to a maximum of 47.4 gallons. An average of 0.2 loads of laundry per person per day was measured. Clothes washer statistics are shown in Table C-6.

Table C-16: Clothes washer load statistics, Pilot End-Use Study (n = 20 homes)

Clothes Washer	Pilot Study Gallons/ Load	Pilot Study Loads/ person/day	REUWS 2016, Gallons/ Load	REUWS 2016, Loads/ person/day
Average	24.3	0.2	28.1	0.3
Std. Dev.	9.7	0.1	14.7	0.1

The average clothes washer run in the REUWS 2016 (calculated on a per household basis over a two-week data collection period) used 28.1 gallons per load with 0.3 loads of laundry per person per day.

Dishwasher statistics were calculated across the nine homes that used a dishwasher during the study period. Dishwasher statistics are shown in Table C-7. The average dishwasher used 4.2 gallons per load with load volumes ranging from 1.9 gallons up to 7.2 gallons. An average of 0.4 loads of dishes per person per day was measured.

Table C-17: Dishwasher load statistics, Pilot End-Use Study (n = 9 homes)

Dishwasher	Pilot Study Gallons/ Load	Pilot Study Loads/ person/day	REUWS 2016, Gallons/ Load	REUWS 2016, Loads/ person/day
Average	4.2	0.4	6.1	0.1
Std. Dev.	1.8	0.4	1.4	0.1

The average dishwasher load in the REUWS 2016 used 6.1 gallons and participants in the study used 0.1 loads per person per day.

Leaks

Eleven of the 20 homes in this Pilot End-Use study had leaks measurable with the Flume/Autoflow technology during the study period. Across the sample, leakage averaged 5.5 gpcd and accounted for more than 10% of indoor per capita use. Compared with the 2016 Residential End Uses of

Water study as shown in Table C-3, per capita leakage was lower in this Pilot End-Use study than in the national end use study by 2.4 gpcd.

Similar to previous studies, leakage is unequally distributed across customers and a comparatively small number of homes contributed most of the leakage volume. The average daily leakage volume was 23.2 gallons per household per day, but one household from this pilot study averaged 321.8 gallons of leakage per day.

Figure C-9 is a frequency distribution of daily leakage from the study: 9 of 20 homes had no leakage. Of the total number of observed days, more than 45% of days had zero leakage and 10% of days leakage exceeded 40 gallons per household per day and on 1.3% of days, leakage exceeded 125 gallons per household per day. Persistent, high-volume leakage that occurred at a small number of homes contributed most significantly to the total leakage volume.

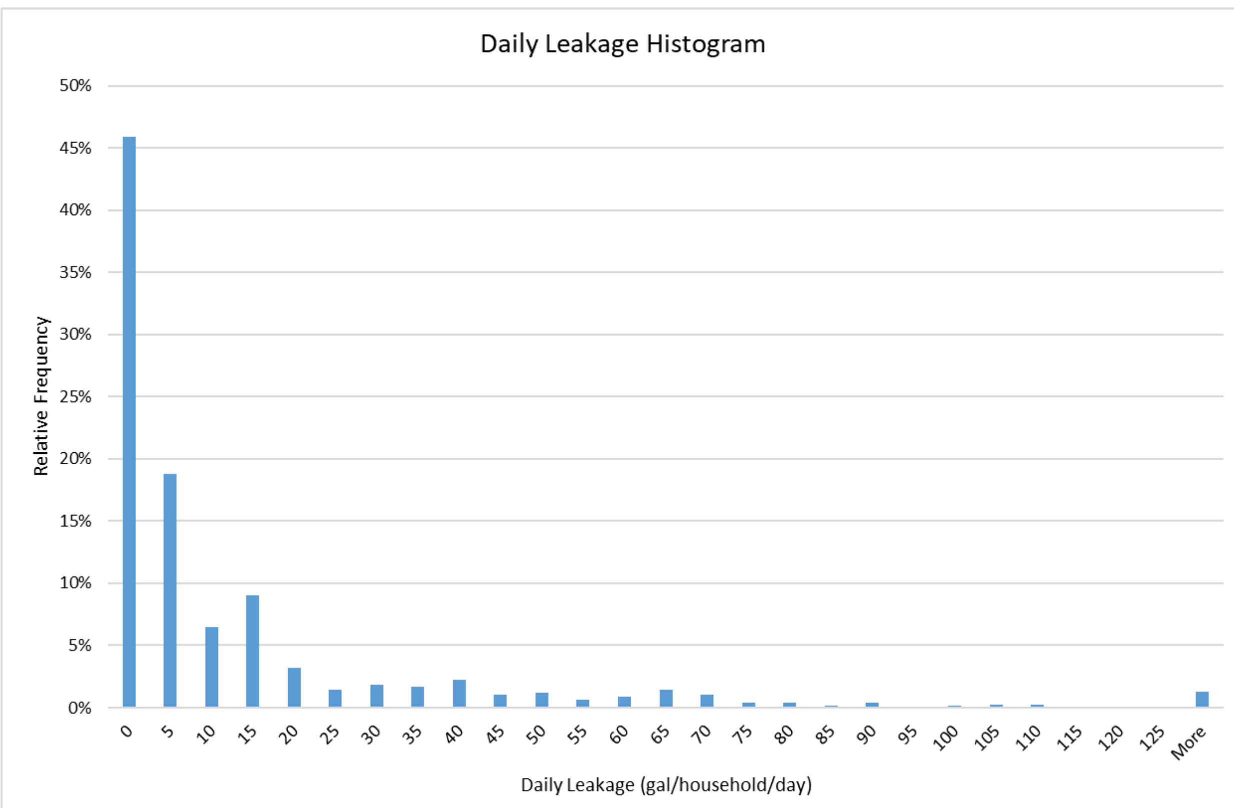

Figure C-18: Frequency distribution of daily leakage, End-Use Study (n=20 homes)

The Supplier in this pilot study uses an automated customer leakage detection program that uses hourly meter reads to determine continuous usage is occurring indicating a leak might be happening and alerts customers. It was found that of the 6 homes in the 20-home sample, including 5 of the highest leakage participants, were flagged by the Supplier’s database leak alert system which is capable of identifying large leaks accurately.

Summary and Recommendations

As part of its research into residential water demands pursuant to Section 10609.4(b) of the California Water Code, the Department of Water Resources (DWR) successfully conducted a pilot residential end use study with a Northern CA Supplier with 20 volunteer single-family participants. In this study, the water meter at each of the 20 participating homes was fitted with a Flume Smart Home Water Monitor device capable of measuring flow every 5-seconds and data were collected continuously for at least 30 days from each home during July and August 2020.

The DWR end-use pilot study included a small sample of volunteer participants and was undertaken by DWR to establish to feasibility and utility of end use research to better understand where and how water is used in California homes. The results show that end use research using currently available technology and software can be successfully conducted and that data can be collected continuously for longer periods of time than in previous studies. Larger studies in the future can implement this approach to better understand residential water use patterns and efficiency.

The end-use pilot study uses the same basic approach employed in previous Residential End Uses of Water studies (1999, 2019), which employed portable flow recorders to collect high-resolution 10-second interval flow data and then used software to disaggregated the data sets into component end uses . The Residential End Uses of Water studies had statistically representative samples of more than 1,100 homes (1999) and 700 homes (2016) carefully selected from participating utilities across the US and Canada. It should also be noted that data in this pilot study were collected during the hot and dry summer of 2020 under pandemic conditions when a public health crisis necessitated that people stay home and socially distant from others to prevent and slow the spread of COVID-19 infections.

In the 2020 end-use pilot study, continuous, 5-second flow data were collected for 30-days using devices manufactured by Flume. Each individual 30-day flow data set was disaggregated into component water use events using specialized software developed by an Australian firm, Autoflow. A database containing a table of 525,029 individual disaggregated end uses, by customer, was delivered to the project team as the key deliverable. This database includes every water use (e.g. toilet flush, faucet draw, shower, clothes washer cycle, leak, etc.) measured over 30-days from 20 homes. The data in this study were collected during the hot and dry summer of 2020 under pandemic conditions when a public health crisis necessitated that people stay home and indoors as much as possible. The results presented in this report reflect the influence of both significant factors.

Among this 20-home sample, indoor water use averaged 50.8 gpcd. Showering and toilet flushing were the highest end use categories, accounting for more than 51% of the indoor total. Faucets accounted for nearly 22.5% of the indoor total. Leakage accounted for more than 10% of indoor per capita use in these homes.

The average flush volume amount the 20 participating homes was 1.5 gallons per flush and people flushed the toilet 8.5 times per day on average. Both the 1999 and 2016 Residential End Uses of Water studies measured an average of 5.1 flushes per person per day on average, so the finding of 8.5 flushes per person per day from this pilot study likely shows the impact of the COVID-19 pandemic stay-at-home requirements.

The average shower in this study used 11.7 gallons and was taken at a typical flow rate of 2.1 gpm. Typical shower volumes ranged from 5 – 15 gallons. Study residents took an average of 1.1 showers per person per day. Compared with the REUWS, showers were shorter and used less water for this pilot study although the flow rates were similar. The biggest difference was in showering frequency which was more than 30% higher for this pilot study with an average of 1.1 showers per person per day compared with 0.7 in the REUWS.

All 20 homes in the pilot study used a clothes washer at least once during the study period, but only 9 of the 20 homes had observable dishwasher runs. The average clothes washer run used 24.3 gallons per load and load volumes ranged from a minimum of 10.5 gallons at one study home up to 47.4 gallons at another. An average of 0.2 loads of laundry per person per day was measured.

The average clothes washer run in the REUWS (calculated on a per household basis) used 28.1 gallons per load and the participants ran 0.3 loads of laundry per person.

Dishwasher statistics were calculated across the nine homes that used a dishwasher during the study period. The average dishwasher run used 4.2 gallons per load and load volumes ranged from a minimum of 1.9 gallons at one study home up to 7.2 gallons at another. An average of 0.4 loads of dishes per person per day was measured. The average dishwasher load in the REUWS used 6.1 gallons and participants in the study use just 0.1 loads of dishes per person per day.

Eleven of the 20 homes in this pilot study had measurable leaks during the study period. Across the sample, leakage averaged 5.5 gpcd and accounted for more than 10% of indoor per capita use. Compared with the 2016 REUWS, per capita leakage was lower in this pilot study than in the national end use study by 2.4 gpcd.

Recommendations

This 20-home pilot residential end use study provides extraordinary detail about water use in this small set of homes. For the State of California, this research provides detailed information on the efficiency level of homes as well as information on the future level of efficiency that might be approved. Expanding this research with larger samples and broader geographic reach across California will help decision makers understand the future trajectory of residential water use and what will be required to further reduce usage.

The Flume Smart Home Water Monitor devices coupled with Autoflow disaggregation software and capability enabled high resolution flow data to be collected for more than 30-days and quickly and accurately analyzed.

These technologies represent a significant improvement compared with flow recording technologies used in past research and as it result it is now possible to conduct end use studies more swiftly and at lower cost.

Previous end use studies like the REUWS and all other Aquacraft studies relied on battery powered flow recorders with limited by memory capacity that allowed just 14 days of data at a time to be collected before manual downloading and recharge was required. This time limitation is no longer a constraint with the Flume technology. The costs associated with data collection and analysis using Flume are significantly lower than for end use studies using portable flow recorders.

Even with a small sample size, this pilot study shed light on important topics such as changes in behaviors and water use in response to the pandemic. For example, the detailed end use data collected in this study showed that increased frequency of toilet flushing, and shower usage increased average per capita use. These data also showed that the homes in this pilot study were largely equipped with efficient toilets based on the measured flush volumes. End use analysis delivers essential information needed for planning and implementing cost-effective water efficiency programs into the future.

DWR and water providers should partner and continue to implement strategic end use studies to further understanding of residential demand patterns and future efficiency potential. These studies should be conducted periodically, and demand changes monitored over time to provide the best available demand data to inform decision makers. Future studies should also collect data from individually sub-metered multifamily apartments as well as detached single-family homes to further understanding of water use in the multifamily sector.

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Appendix C-1.
Pilot Residential End Use Study Survey Questions

Prepared for

California Department of Water Resources

By

Peter Mayer, WaterDM

State of CA - DWR: Indoor Residential Water Use Study

* Required

1. First Name & Last Name *

2. Street Address where Flume Unit will be: *

3. Please indicate how many of each of the following types of water-using appliances or fixtures you have in your home. Please circle the appropriate number for each. *

	None (0)	1	2	3	4	5	6 or more
Toilets	○	○	○	○	○	○	○
Bathtub with shower	○	○	○	○	○	○	○
Standard bathtub only	○	○	○	○	○	○	○
Large bathtub with jets	○	○	○	○	○	○	○
Shower stall only	○	○	○	○	○	○	○
Indoor utility / garage sink	○	○	○	○	○	○	○

4/23/2021

4. Please indicate whether you have any of the following inside your home. Please check the appropriate box for each. *

	Yes	No
Garbage Disposal	◯	◯
Automatic Ice Maker	◯	◯
Dishwashing machine	◯	◯
Water & energy efficient (EnergyStar) clothes washing machine	◯	◯
Tankless water heater	◯	◯
On-demand hot water system (recirculating pump	◯	◯
Evaporative/swamp cooler	◯	◯
Whole house humidifier (usually attached to furnace)	◯	◯
A "whole house" water treatment system like a water softener or a reverse osmosis system	◯	◯
Fish aquarium larger than 50 gallons	◯	◯
Pets (e.g., dogs, cats, or other medium to large size animal)	◯	◯
Indoor spa or hot tub with jets (if hot tub is NOT usually filled with water, indicate "no")	◯	◯
A built-in indoor water feature (like a water fountain or water pond)	◯	◯

	Yes	No
Indoor garden or greenhouse	◯	◯

5. Do you have any water-using appliances and fixtures that were not listed in Questions #3 and #4 *

- ◯ No
- ◯ Yes - Please Describe
- ◯ Other

6. How many of the toilets in your home are one of the following *

	None	1	2	3	4 or more	Don't know
1.6 gallons/6.1 liters	◯	◯	◯	◯	◯	◯
1.28 gallons/4.84 liters or less	◯	◯	◯	◯	◯	◯
Dual Flush (~1.6/0.8 gallons/ 6.1/0.3 liters)	◯	◯	◯	◯	◯	◯

7. How many of the showers in your home have any of the following? *

	None (0)	1	2	3	4 or more	Don't Know
Multiple showerheads	◯	◯	◯	◯	◯	◯
Rain panels	◯	◯	◯	◯	◯	◯
Handheld sprayer	◯	◯	◯	◯	◯	◯

4/23/2021

8. Please indicate whether you have replaced any of the following in the past 10 years. Please check the appropriate box for each. *

	Yes	No
Toilets	◯	◯
Showerheads	◯	◯
Clothes washer	◯	◯
Dishwasher	◯	◯

9. Please indicate whether you have any of the following. (Please check all that apply.)

- ☐ Leaking toilet (you can hear it running when not in use)
- ☐ Dripping faucet
- ☐ Leaks in your swimming pool system
- ☐ Leaks in your irrigation system
- ☐ Other water leaks
- ☐ None of the Above
- ☐ ____________

  Other

4/23/2021

10. In addition to the water purchased from your water utility, do you use any of the following sources of water for your outdoor water needs? (Please check all that apply.)

- ☐ No additional sources of water used
- ☐ Well water
- ☐ Canal/ditch
- ☐ Stream/river
- ☐ Rain barrel or cistern (rainwater harvesting)
- ☐ Directing roof/rain water towards plants in the yard
- ☐ Gray water reuse from indoor fixtures
- ☐ Other

11. About how much of your outdoor landscape is watered by hand/manually? *

- ○ All of it (100%)
- ○ More than half
- ○ Less than half
- ○ None

12. Do you have an in-ground irrigation/sprinkling system? *

- ○ Yes
- ○ No

13. Does your in-ground irrigation system have the following? (Please check all that apply.) *

- ☐ Automatic timer
- ☐ Weather-based irrigation controller (WBIC) or "smart" controller
- ☐ Master valve
- ☐ Back flow preventer
- ☐ Drip irrigation, micro spray and/or bubbler
- ☐ Sensor based system
- ☐ Other

14. Does your home have an outdoor ___? (Please check all that apply.) *

- ☐ Spa
- ☐ Hot tub
- ☐ Fountain/water feature
- ☐ Pond
- ☐ Pool
- ☐ Other

4/23/2021

15. On average, about how often does your household do each of the following? *

	Never	More than once a week	About once a week	About twice a month	About once a month	Less than a month	Don't know
Wash a car / personal vehicle at home	◯	◯	◯	◯	◯	◯	◯
Use a hose to clean the sidewalks and driveways around your home	◯	◯	◯	◯	◯	◯	◯

16. About how many times per week does someone take a bath (in a bathtub) in your household? *

◯ None

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5 or more

17. Is your household responsible for paying the water bill, OR does a landlord or homeowners' association pay it? *

◯ Household pays

◯ Landlord or a homeowner's association pays

◯ Don't know

18. When was your home built? *

- Before 1979
- 1980 - 1999
- After 1999

19. In what year did you move to this home? *

20. How many bedrooms does this house have? *

- 1
- 2
- 3
- 4
- 5
- 6 or more

21. How many people, including yourself, live full time (>50%) at this address? *

4/23/2021

22. How many people, including yourself, live full time (>50%) at this address? *

	None	1	2	3	4	5 or more
Adults, including yourself (age 18+)	◯	◯	◯	◯	◯	◯
Teenagers (age 13-17)	◯	◯	◯	◯	◯	◯
Children (age <12)	◯	◯	◯	◯	◯	◯

23. What number of adults & children living at this address are usually at home during the day on a weekday (i.e., NOT at work or school outside the home)? *

◯ None

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5 or more

24. Over the next 30 days, what number of adults & children are expected to be at home during the day at this address (i.e., NOT at work or school outside the home)? *

◯ None (0)

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5

4/23/2021

Appendix D. List of Partner Agencies

Prepared for

California Department of Water Resources

By

California Department of Water Resources

California Department of Water Resources

Water Use Efficiency Branch

April 2020

Partner Agencies (18 Suppliers):

City of Folsom, City of Sacramento, City of Santa Cruz, Coachella Valley Water District, Eastern Municipal Water District, Irvine Ranch Water District, Moulton Niguel Water District, Redwood City, California Water Service (CWS) Bakersfield, CWS Bear Gulch, CWS Chico, CWS East L.A., CWS Livermore, CWS Palos Verdes, CWS Salinas, CWS South S.F., CWS Stockton, and CWS Visalia

eAR Distribution Analysis (157 Suppliers)

Adelanto City of, Alameda County Water District, Alco Water Service, Anaheim City of, Antioch City of, Arvin Community Services District, Atascadero Mutual Water Company, Beaumont-Cherry Valley Water District, Benicia City of, Brea City of, Brentwood City of, Burlingame City of, Camarillo City of, Camrosa Water District, Carlsbad Municipal Water District, Carmichael Water District, Cerritos City of, Chino City of, Chino Hills City of, Citrus Heights Water District, Cloverdale, Clovis City of, Coastside County Water District, Contra Costa Water District, Cucamonga Valley Water District, Daly City, Davis City of, Desert Water Agency, Diablo Water District, East Bay Municipal Utilities District, Eastern Municipal Water District, El Dorado Irrigation District, El Toro Water District, Escondido City of, Estero Municipal Improvement District, Fairfield City of, Folsom City of, Fountain Valley City of, Fresno City of, Fullerton City of, Gilroy City of, Glendale City of, Golden State Water Company Artesia, Golden State Water Company Bay Point, Golden State Water Company Bell-Bell Gardens, Golden State Water Company Claremont, Golden State Water Company Cordova, Golden State Water Company Culver City, Golden State Water Company Florence Graham, Golden State Water Company Norwalk, Golden State Water Company San Dimas, Golden State Water Company Southwest, Goleta Water District, Greenfield City of, Hayward City of, Healdsburg City of, Helix Water District, Hemet City of, Hi-Desert Water District, Humboldt Community Service District, Indio City of, Irvine Ranch Water District, Jurupa Community Service District, La Habra City of Public Works, Laguna Beach County Water District, Lake Hemet Municipal Water District, Lakeside Water District, Lakewood City of, Lathrop City of, Lincoln City of, Linda County Water District, Livermore City of Division of Water Resources, Long Beach City of, Los Banos City of, Madera City of, Manhattan Beach City of, Manteca City of, Marina Coast Water District, Menlo Park City of, Modesto City of, Monrovia City of, Monte Vista Water District, Moulton Niguel Water District, Mountain View City of, Napa City of, Newport Beach City of, Norco City of, North Coast County Water District, Oakdale City of, Olivenhain Municipal Water District, Ontario City of, Orange Vale Water Company, Oxnard City of, Padre Dam Municipal Water District, Palmdale Water District, Palo Alto City of, Paramount City of, Paso Robles City of, Patterson City of, Pismo Beach City of, Pittsburg City of, Pomona City of, Port Hueneme City of, Quartz Hill Water District, Rancho California Water District, Redwood City, Rialto City of, Riverside City of, Roseville City of, San Bernardino City of, San Bernardino County Service Area 64, San Clemente City of, San Diego City of, San Dieguito Water District, San Francisco Public Utilities Commission, San Gabriel County Water District, San Jose City of, San Lorenzo Valley Water District, San Luis Obispo City of, Santa Ana City of, Santa Barbara City of, Santa Clarita Valley Water District, Santa Cruz City of, Santa Margarita Water District, Santa Maria City of, Santa Monica City of, Santa Paula City of, Santa Rosa City of, Sonoma City of, Soquel Creek Water District, Suburban Water Systems San Jose Hills, Suisun-Solano Water Authority, Sunnyslope County Water District, Sunnyvale City of, Sweetwater Authority, Tehachapi City of, Trabuco Canyon Water District, Tracy City of, Triunfo Sanitation District/Oak Park Water Services District, Tulare City of, Turlock City of, Ukiah City of, Vacaville City of, Vallecitos Water District, Vallejo City of, Ventura County Waterworks District No 1, Ventura County Waterworks District No. 8, Victorville Water District, Walnut Valley Water District, Wasco City of, Watsonville City of, West Valley Water District, Western Municipal Water District of Riverside, Windsor Town of, Woodland City of, Yorba Linda Water District, and Yuba City

Appendix E.
Sampling Strategy

Prepared for

California Department of Water Resources

By

Anil Bamezai, PhD, Western Policy Research

California Department of Water Resources

Water Use Efficiency Branch

April 2020

Introduction

DWR developed a census-tract based analytic approach for statewide indoor residential (Ri-gpcd) water use estimation. In development of this approach several objectives were simultaneously considered in developing a robust study plan. These objectives included:

1. Minimize the number of Suppliers in the study while achieving good representation of the whole state.
2. Favor where possible Suppliers with already developed parcel-level landscape area estimates to facilitate a model-based approach for indoor demand estimation.
3. Avoid Suppliers with known data problems (e.g., highly seasonal population, large numbers of private wells, large group quarter populations, etc.)

Stratification: The Big Picture

As per the census, there are a total of 7,982 tracts in California with nonzero housing units (8,057 tracts in all). Using each agency's boundary in a GIS tool, DWR developed a linkage file mapping tract's to water Suppliers. This mapping exercise revealed that 5,101 tracts lie wholly within Supplier boundaries, while the remaining tracts are split between two or more water Suppliers. To keep Supplier selection independent of its neighboring Suppliers, we focus on these "wholly-within" tracts for developing tract-level estimates of indoor residential gpcd.

To evaluate the representativeness of the selected tracts we must have metrics to describe a tract's characteristics insofar they impact residential GPCD. Three metrics were used to determine this: (1) age distribution of the housing stock; (2) disadvantaged community status; and (3) size of the retired population. The first two metrics are expected to be correlated with the types of plumbing fixtures, appliances, and leaks that are prevalent in California homes, which in turn affect indoor gpcd. The metric that characterizes the size of the retired population is intended to capture time spent at home by a tract's population, which also likely affects indoor gpcd.

From the American Community Survey (ACS), we obtained the following five measures for characterizing each tract:

1. Percent of housing units built in 2000 or later
2. Percent of housing units built between 1980 and 1999
3. Percent of housing units built in 1979 or earlier
4. Median household income in the tract
5. Percent of population over 65 years of age

The proportion of housing built within the above three age bands varies across tracts. Each of these three proportions is independently converted into three percentile bins (<=25th percentile, 25-75th percentile, >75th percentile). For example, the proportion of housing units built in 2000 or later has a median value of 5.7% across all tracts, a 25th percentile value of 1.9% and a 75th percentile value of 13.8%. The proportion of housing units built in 1979 or earlier has a median value of 74.5%, a 25th percentile value of 47.1% and a 75th percentile value of 84.8%. By flagging each tract as falling within three percentile categories on each of the three housing share measures gives us a potential of 27 bins (3x3x3) for characterizing the mix of housing stock by age.

Tracts are classified as being disadvantaged if the median household income in a tract is 80% or below the median household income across all of the tracts in California. A correlation with tract level poverty measures shows that the 80% threshold is a good method of capturing a tract's disadvantaged status. This flag splits the population of tracts into two groups, disadvantaged, or not.

Tracts are flagged as having a large share of the over-65 population if this share exceeds 18% of the tract's total population. The median share of the over-65 population across all tracts is approximately 12.5%. The 18% threshold identifies the top 20% of all tracts based on this measure. Like the disadvantaged community status, this flag also splits all the tracts into two groups.

The strata are constructed using all possible combinations of these percentile bins for a maximum of 108 strata (3x3x3x2x2). Many of the "potential" strata do not have any tracts associated with the classification because several combinations of these characteristics do not exist in practice. For example, a tract cannot have a mix of housing where each of the three age bands (1979 and before, 1980-1999, and post-2000) exceed their respective 75^{th} percentiles because then the sum of the age of housing shares would exceed 100%. The study's stratification scheme yields a total of 54 strata, which is sufficiently large to keep the leverage of any single strata manageable.

The best sampling design would separate the tracts into many more strata such that each strata's leverage on the overall statewide baseline indoor residential gpcd is minimized. However, finding Suppliers within the study scope and suitable data to complete a finer stratification of the census tracts is difficult. Therefore, a compromise between a coarse and fine stratification is needed to accomplish the study objective of estimating baseline Statewide indoor residential water use. The vast majority of these strata include less than 4% of all tracts, meaning any bias in estimated indoor per-capita use in the strata will not have excessive influence on the statewide average. Another way to assess whether the study design is adequately balanced is to assess how many water agencies exist that can contribute tracts to all strata, and how many agencies exist whose participation is necessary. In the stratification design, there is not a single California water agency that can contribute tracts to fit each of the selected strata, an indication that the tract population has been stratified to a degree that successful implementation requires participation by a diverse mix of Suppliers, as should be the case. Supplier flexibility is also maintained because no individual Supplier's participation is mandatory to successfully implement this study design.

The nomenclature by which each strata is identified is through a 5 number code, e.g., "ct11311" or "ct32121", etc.) with "ct" denoting census tract.

1. The first digit indicates the percentile bin for the share of housing built in 2000 or later (the number 1 indicates bottom 25^{th} percentile, 2 indicates between the 25^{th} and 75^{th} percentile, and 3 indicates above 75^{th} percentile). The numbering classification is similarly used for the shares of homes between 1980 and 1999, and for housing built during and earlier than 1979 as described below.

2. The second digit represents percentiles of the housing unit share built between 1980 and 1999 (1, 2, or 3)
3. The third digit is for the housing unit share built during 1979 or earlier (1, 2, or 3).
4. The fourth digit represents a tract's disadvantaged community status (1 indicates disadvantaged, 2 indicates not disadvantaged)
5. The fifth digit indicates a large over-65 population associated with the tract (1 indicates over-65 population share is 18% or below, 2 indicates above)
6. The fourth and fifth digits may in a few instances be coded as "0." This indicates that the total number of tracts falling into these strata was so low that stratification on said variable was not attempted.

Table E-1 shows the 54 strata classifications and how the 7,982 tracts within California are sorted into each of the 54 strata. The table also shows the 5,000 plus census tracts wholly-within water Suppliers are classified by strata, and the classification of the 453 wholly-within tracts from the 18-Supplier sample used to develop the Statewide Baseline Ri-gpcd estimate are classified by strata. The 18 Suppliers selected for the study failed to produce candidate tracts in the case of three strata. These void strata were combined with other strata to yield a final 51-strata sampling design.

Table E-1. Strata Classification of Census Tracts in California

Strata Classification:	Total No. of Tracts in California	Wholly-within tracts from all Urban Water Suppliers	Wholly-within Tracts from 18-Suppliers
ct11311	204	169	25
ct11312	19	16	2
ct11321	498	378	12
ct11322	195	155	13
ct12211	217	172	6
ct12212	18	12	-
ct12221	224	165	8
ct12222	97	62	8
ct12310	103	89	5
ct12321	134	97	7

Strata Classification:	Total No. of Tracts in California	Wholly-within tracts from all Urban Water Suppliers	Wholly-within Tracts from 18-Suppliers
ct12322	47	38	2
ct13110	14	8	2
ct13121	98	77	15
ct13122	19	14	2
ct13210	33	23	4
ct13221	57	42	3
ct13222	19	10	1
ct21210	68	56	6
ct21221	72	51	3
ct21222	36	23	2
ct21311	196	168	26
ct21312	15	13	3
ct21321	324	265	12
ct21322	154	115	3
ct22211	731	526	34
ct22212	122	50	6
ct22221	870	594	20
ct22222	386	179	7
ct22310	48	38	5
ct22321	38	27	1
ct22322	20	15	2
ct23110	119	60	17
ct23121	319	211	40
ct23122	92	38	5
ct23210	158	98	6
ct23221	152	92	5
ct23222	71	34	3
ct31100	107	56	10
ct31210	51	42	6

Strata Classification:	Total No. of Tracts in California	Wholly-within tracts from all Urban Water Suppliers	Wholly-within Tracts from 18-Suppliers
ct31221	43	31	1
ct31222	14	13	1
ct32111	78	34	1
ct32112	21	8	1
ct32121	264	93	20
ct32122	42	13	5
ct32211	183	93	16
ct32212	51	12	-
ct32221	218	119	1
ct32222	79	27	3
ct33111	143	83	16
ct33112	37	10	7
ct33121	490	236	37
ct33122	153	43	7
ct33200	21	8	-
Total:	**7,982**	**5,101**	**453**

Appendix F.

Projected Statewide and County-Level Effects of Plumbing Codes and Appliance Standards on Indoor GPCD

Prepared for

California Department of Water Resources

By

David Mitchell, M. Cubed

California Department of Water Resources

Water Use Efficiency Branch

August 2016

Summary of Findings

M.Cubed was retained by DWR and the State Water Board to project future reductions in indoor water use from plumbing codes and appliance standards. The projections were developed with dynamic plumbing fixture inventory growth and replacement models and Department of Finance (DOF) forecasts of county-level population and housing growth. Model performance was benchmarked against empirical estimates of average plumbing fixture efficiency and water use where such estimates were available. Key modeling results include:

- Relative to a 2015 baseline efficiency level, plumbing codes and appliance standards are projected to reduce M&I per capita water use by 9 to 10 GPCD by 2040. This equates to a savings in statewide M&I water use in 2040 of between 465 and 538 thousand acre-feet (TAF). Estimated reductions in M&I GPCD by county are provided in Attachment 3. These results are discussed in more detail in Section 5.3.

- Approximately two-thirds of projected water savings are associated with toilets and urinals and one-third with clothes washers. As discussed in Section 2.3, significant reductions in shower and faucet water use are not anticipated. Clothes washers are expected to have the greatest impact in the single-family sector, where clothes washer ownership rates are highest. These results are discussed in more detail in Sections 5.1-5.3.

- More than half (57 percent) of the projected reduction in water use is expected to come from the single-family residential sector. Approximately 20 percent is expected to come from the multi-family residential sector. The remaining, 23 percent is associated with non-residential toilets, urinals, and commercial clothes washers. These results are discussed in more detail in Sections 5.1-5.3.

- Plumbing codes and appliance standards, by themselves, are projected to reduce statewide R-GPCD by approximately 7.6 gallons by 2040.[33] In 2015, indoor R-GPCD averaged about 59 gallons per day, so the

[33] R-GPCD is average per capita water use in the single- and multi-family residential sectors.

projected reduction by 2040 is equivalent to about 13 percent of current R-GPCD. These results are discussed in more detail in Section 5.4. Estimated reductions in R-GPCD by hydrologic region and county are provided in Section 5.5.

- R-GPCD in new homes fitted with EPA WaterSense labeled products averages 36 gallons (DeOreo, et al., 2011). The difference in indoor water use between the average residence in California and such a home is about 23 GPCD. Plumbing codes and appliance standards on their own are projected to reduce this difference by a third to 15 GPCD by 2040.

- The results from this study can be used to inform projections of baseline indoor R-GPCD over time. These baselines, in turn, can be used in the development of indoor R-GPCD reduction targets. The county-level estimates will enable the baselines to reflect regional differences due to age of the housing stock, differences in projected population and housing growth, differences in household density, and other factors affecting residential indoor water use, though the modeling done for this study suggests the impact of such differences on projected R-GPCD savings is not large across extensive geographic areas such as counties or hydrologic regions. They may be more significant across smaller geographic units such as utility service areas. The models developed for this study can easily be adapted to small geographic units of analysis.

- The study results can also help policymakers understand the underlying rate of transformation of the existing inventory of non-efficient plumbing fixtures. Because the models developed for this study are dynamic, they provide insight into how fast or slow appliance efficiency can be expected to change over time under existing codes and standards. This can be useful for establishing timeframes for meeting water use targets.

Introduction and Overview

Efficiency standards for toilets, urinals, clothes washers, and showerheads have had a significant impact on indoor water use overtime. For example, average daily per capita water use in single-family households for toilets and clothes washers has decreased by 23 and 36 percent, respectively, since 1999.[34] These changes have largely been powered by national and state-level water use efficiency standards for toilets and clothes washers.

Going forward, efficiency standards for indoor water using fixtures and appliances will continue to reduce indoor water demands. Nationally, the latest residential end uses of water study estimated that 54% of existing washers, 63% of toilets, and 20% of showerheads are low efficiency. As these fixtures turnover, additional gains in indoor water use efficiency will be realized.[35]

Executive Order B-37-16 directs the Department of Water Resources (DWR) and State Water Board to:

> [D]evelop new water use efficiency targets as part of a long-term conservation framework for urban water agencies. These targets go beyond the 20 percent reduction in per capita urban water use by 2020 that was embodied in SB X7-7 of 2009, and will be customized to fit the unique conditions of each water supplier.

In carrying out this charge, it will be important to have a good understanding of how plumbing codes and appliance standards are likely to impact indoor water use over time.

Scope of Work

M.Cubed was retained by DWR and the State Water Board to develop data and models to estimate the potential additional water savings through 2040

[34] Water Research Foundation (2016). Residential End Uses of Water, Version 2. PDF Report #4209b.
[35] Saturation rates in California, particularly for toilets, are higher than national rates, but significant potential remains.

due to the ongoing effects of plumbing codes and appliance standards. This work was divided into the following four tasks:

1. Data Collection
2. Model Development, Estimation, and Benchmarking
3. County-level and Statewide Water Savings Analysis
4. Report of Findings and Conclusions

This Technical Memorandum's (TM) purpose is to (1) describe the methodology and data used to project future water savings from plumbing codes and appliance standards for California's 58 counties; (2) benchmark model performance against empirical estimates of historical plumbing fixture average efficiency and water use where such estimates are available; (3) summarize model results in terms of aggregate and per capita water demand reduction by county and statewide; and (4) discuss the potential uses and policy implications of these results.

Organization of TM

The remainder of this TM is organized as follows. Section 2 provides a review of the plumbing codes and appliance standards modeled for this analysis. Section 3 presents the methodology and data used to model plumbing fixture and appliance inventories, growth and replacement, average efficiencies, and water use. Section 4 discusses the model results and how they compare to empirical estimates of historical average fixture efficiencies. Section 5 summarizes projected aggregate and per capita water savings. Section 6 provides a summary and conclusions of this research.

Plumbing Codes and Appliance Efficiency Standards

This section discusses existing state and national plumbing codes and appliance standards, including timing and enforcement, particularly as it relates to SB 407 plumbing retrofit requirements.

Existing Codes and Standards

The following plumbing codes and appliance standards form the basis for the estimated volumes of future indoor water savings:

- AB 715, enacted in 2007, requires that any toilet or urinal sold or installed in California on or after January 1, 2014 cannot have a flush rating exceeding 1.28 and 0.5 gallons per flush, respectively. AB 715 superseded the state's previous standards for toilet and urinal water use set in 1991 of 1.6 and 1.0 gallons per flush, respectively. On April 8, 2015, in response to the Governor's Emergency Drought Response Executive Order (EO B-29-15), the California Energy Commission approved new standards for urinals requiring that they not consume more than 0.125 gallons per flush, 75% less than the standard set by AB 715.

- Water use standards for residential and commercial clothes washers and dishwashers are established by the U.S. Department of Energy through its authority under the federal Energy Policy and Conservation Act. Water use efficiency is summarized by the water factor for the appliance which measures the gallons of water used per cycle per cubic foot of capacity. A typical top-loading residential clothes washer manufactured in the 1990s had a water factor of about 12 – meaning a typical washer manufactured in that time period used about 12 gallons of water per wash cycle per cubic foot of capacity. Most residential washers have capacities between 3 and 4 cubic feet, so a typical washer manufactured in the 1990s used between 36 and 48 gallons of water per cycle. In 2015, the allowable water factor for top- and front-loading residential clothes was reduced to 8.4 and 4.7, respectively. In 2018, the water factor standard for top-loading residential clothes washers will be reduced to 6.5. In 2010 the allowable water factor for top- and front-loading commercial clothes washers was reduced to 8.5 and 5.5, respectively. The maximum water factor for Energy Star compliant top- and front-loading washers is currently 3.7 and 4.3, respectively. EPA estimates that Energy Star washers comprised at least 60 percent of the residential market and 30 percent of the commercial market in 2011.[36] An Energy Star compliant washer uses about two-thirds less water per cycle than washers manufactured in the 1990s. Federal dishwasher water use efficiency standards were last updated in 2013. The maximum water use for standard and compact sized dishwashers is 5.0 and 3.5 gallons per cycle, respectively.

- New construction and renovations in California are now subject to CalGreen Code requirements. CalGreen includes prescriptive indoor provisions for maximum water consumption of plumbing fixtures and fittings in new and renovated properties. CalGreen also allows for an optional performance path to compliance, which requires an overall aggregate 20% reduction in indoor water use from a calculated baseline using a set of worksheets

[36] EPA Energy Star Unit Shipment and Market Penetration Report Calendar Year 2011 Summary.

provided with the CalGreen guidelines. However, regardless of whether a prescriptive or performance path approach is taken to comply with CalGreen requirements, the state and federal plumbing fixture and appliance efficiency standards described previously establish maximum water use rates for toilets, urinals, showerheads, and clothes washers. New construction and renovated buildings can choose to use fixtures and appliances that are more efficient than required by these standards, but not less efficient.

- SB 407, enacted in 2009, mandates that all buildings in California come up to current State plumbing fixture standards within this decade. This law establishes requirements that residential and commercial property built and available for use on or before January 1, 1994 replace plumbing fixtures that are not water conserving, defined as "noncompliant plumbing fixtures" as follows:
    - any toilet manufactured to use more than 1.6 gallons of water per flush;
    - any urinal manufactured to use more than one gallon of water per flush;
    - any showerhead manufactured to have a flow capacity of more than 2.5 gallons of water per minute; and
    - any interior faucet that emits more than 2.2 gallons of water per minute.

  For single-family residential property, the compliance date is January 1, 2017. For multi-family and commercial property, it is January 1, 2019. In advance of these dates, the law requires effective January 1, 2014 for building alterations and improvements to all residential and commercial property that water-conserving plumbing fixtures replace all noncompliant plumbing fixtures as a condition for issuance of a certificate of final completion and occupancy or final permit approval by the local building department.

- SB 407 also requires effective January 1, 2017 that a seller or transferor of single-family residential property disclose to the purchaser or transferee, in writing, the specified requirements for replacing plumbing fixtures and whether the real property includes noncompliant plumbing. Similar disclosure requirements go into effect for multi-family and commercial transactions January 1, 2019. SB 837, passed in 2011, reinforces the disclosure requirement by amending the statutorily required transfer disclosure statement to include disclosure about whether the property is in compliance with SB 407 requirements. If enforced, these two laws effectively require retrofit of non-compliant plumbing fixtures upon resale or major remodeling for single-family residential properties effective January 1, 2017 and for multi-family and commercial properties effective January 1, 2019.

SB 407 Implementation

Retrofitting of non-compliant plumbing fixtures is supposed to be completed by January 1, 2017, for single-family residences and by January 1, 2019, for multi-family and commercial buildings. SB 407 relies on local enforcement of its provisions and rates of compliance across counties is unknown and likely to vary significantly. For this study, three scenarios for SB 407 implementation are modeled:

1. No enforcement scenario – Under this scenario, the models assume SB 407 has no impact on the rate of replacement of toilets and urinals. SB 407 is treated as a tiger with no teeth.
2. Retrofit-on-resale scenario – Under this scenario, SB 407 is treated as being equivalent to a statewide retrofit-on-resale requirement. The rate of replacement of non-compliant toilets is accelerated beyond what would be expected through natural replacement of plumbing fixtures alone.
3. Full compliance – Under this scenario, full compliance with SB 407 is assumed.

Scenarios 1 and 3 provide lower- and upper-bounds on the possible impact SB 407 could have on the rate of replacement of non-compliant fixtures. Neither scenario is considered likely. It is already the case that some city and county building departments are conditioning permit approval on replacement of non-compliant fixtures, so some level of enforcement is already occurring. It is also extremely unlikely that full compliance will be achieved by the law’s deadlines for compliance. Given the strengthening of the property disclosure requirements under SB 837, whereby a seller or transferor must disclose whether the property is in compliance with SB 407 on the statutorily required disclosure form, the second scenario seems the most plausible. Estimates are provided for each scenario, which in effect provide lower-bound, upper-bound, and most likely estimates of plumbing code impacts on indoor water use.

Landscape Efficiency Standards

California has also adopted requirements affecting the design and water use of residential and commercial landscaping. Because this study pertains only to the effect of plumbing codes and appliance standards on indoor water use, these requirements are not discussed further in this TM.

Study Focus is on Toilets, Urinals, and Clothes Washers

Single-family residential indoor water use is distributed among the end uses shown in Table 1. The four primary end uses are toilets, showers, faucets, and clothes washers. Together, they account for 80 percent of residential indoor water use.

Table 18. Distribution of Single-Family Indoor Water Use by End Use

End Use	GPCD	% of Indoor Use
Toilet	14.2	24%
Shower	11.1	19%
Faucet	11.1	19%
Clothes Washer	9.6	16%
Leaks	7.9	13%
Other	2.5	4%
Bath	1.5	3%
Dishwasher	0.7	1%
Total	58.6	100%

Source: Water Research Foundation (2016). Residential End Uses of Water Study, Version 2: Executive Report. Figure 5.

Plumbing codes and appliance efficiency standards have the potential to impact each of the four main end uses to varying degrees. For this study, the focus was placed on changes in water use for toilets, urinals, and clothes washers, and not on showers and faucets. Even though showers and faucets are significant residential indoor end uses, comprising 38 percent of total indoor water use, end use studies have shown that efficiency standards have had minimal impact on per capita usage rates over the last 15 plus years.[37]

[37] Water Research Foundation (2016). Residential End Uses of Water, Version 2. PDF Report #4209b.

For example, whereas single-family per capita water use for toilets and clothes washers decreased by 23 and 36 percent, respectively, between 1999 and 2016, per capita shower and faucet use did not change at all, according to the Water Research Foundation's 2016 Residential End Uses of Water Study.

There are several possible reasons for this. In the case of faucets, one explanation is the nature of the end use. In many instances faucets are used for filling other things, such as pots, kettles, pitchers, glasses, etc. The amount of water used is primarily determined by what is being filled rather than the flow rate of the faucet.[38] In the case of showers, 75 percent of homes met or exceeded showerhead efficiency standards in 1999, leaving little room for further gain.[39] Between then and now, the number of homes with efficient showerheads is estimated to have increased by only 5 percent to 80 percent overall.[40] Compare this to clothes washers which went from 6 percent efficient to 46 percent efficient over the same time period. Likewise toilets, which went from 9 percent efficient to 37 percent efficient.[41] Thus, in the case of showerheads, there may be little further saving to be realized unless showering behavior changes significantly, which the end use studies suggest is not occurring.[42]

This study also did not devote modeling effort to changes in dishwasher water use due to appliance standards. Although the end use studies do show that average per capita water use has decreased by 30 percent between 1999 and 2016, the share of indoor water use for automatic dishwashers is only one percent, as shown in Table 1. Thus, while there may be potential for further efficiency gains for automatic dishwashers, such

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[38] There are obvious exceptions, such as when hot water is used, in which case the water may be left to flow while the water heats up.
[39] Water Research Foundation (2016). Residential End Uses of Water Study, Version 2: Executive Report. Figure 6.
[40] Ibid.
[41] Ibid.
[42] The residential end uses studies measured an average shower duration of 7.8 minutes in both 1999 and 2016. Confidence intervals for these means indicate they are not statistically different. The average number of showers per person per day was 0.66 in 1999 and 0.69 in 2016. Confidence intervals were not provided for these means, but it is unlikely the estimates are statistically different.

gains are not expected to have a major impact on overall indoor water use in the way that toilets and clothes washers are.

For these reasons, modeling effort for this study was focused on toilets and clothes washers in the case of residential indoor water use, and toilets, urinals, and clothes washers in the case of non-residential indoor water use.

Even though the empirical evidence to date on shower and faucet use in residential settings does not suggest that plumbing codes for these fixtures have had a significant impact on per capita water use, it is possible they may do so in the future. This may especially be the case for faucets in commercial settings, where there is evidence that non-compliance with existing standards is high.[43] The estimated changes in per capita water use due to plumbing codes and appliance standard presented in this report are therefore conservative. It is more likely they somewhat understate rather than overstate savings potential.

Methodology and Data

This study uses dynamic plumbing fixture and appliance inventory growth and replacement models to estimate water use for toilets, urinals, and clothes washers. The models are based on the same methodology used by the Alliance for Water Efficiency's (AWE) Water Conservation Tracking Tool, Version 3, to estimate water savings from plumbing codes and appliance standards.[44] However, unlike the AWE model, which is designed to evaluate individual service areas or an aggregation of multiple service areas, the models for this study are capable of separately estimating fixture and appliance water use for California's 58 counties simultaneously.

The models are implemented in Excel and contained in a single Excel workbook.[45] Separate models are provided for single-family residential, multi-family residential, and non-residential plumbing fixture and appliance inventories and water use. The models operate on an annual time-step that

[43] City of Santa Cruz (2013).
[44] http://www.allianceforwaterefficiency.org/Tracking-Tool.aspx
[45] The underlying methodology could be implemented in other computational platforms, such as R or Mathlab, for example, if there were need to do so.

runs through 2040. The starting year is 1990 for the toilet and urinal models and 2005 for the clothes washer models.

Base Year for Estimating Future Water Savings

Estimating future water savings requires establishing a base year against which changes in water use are measured. This study uses 2015 as the base year. This means that estimated changes in per capita water use over time are based on the difference between estimated future per capita water use and per capita water use in 2015. Aggregate water savings are calculated by multiplying these differences by future population. For example, if toilet water use for single-family households is estimated to be 12 GPCD in 2015 and 8 GPCD in 2030, the expected change in per capita water use between 2015 and 2030 due to improvements in average toilet efficiency is simply 12 - 8, or 4 GPCD. If the population residing in single-family households is projected to be 100,000 in 2030, then the total reduction in single-family residential water use in 2030 because of the improvements in average toilet efficiency since 2015 is simply (12 - 8) x 100,000, or 0.4 million gallons per day (MGD). The annual water savings in 2030 is 0.4 MGD x 365, or 146 million gallons (MG), which is equivalent to 448 acre-feet (AF).

Model Specifications

In this section, the mathematical structure of the models is presented. Following this, the data and assumptions used to implement the models are described.

Single-Family Residential Toilet Model

The single-family toilet model is a simple inventory growth and replacement model. Despite its simple structure, it nonetheless replicates empirical estimates of average toilet efficiencies quite closely. The model assumes the inventory of toilets using water is governed by the size of the occupied housing stock. The total number of toilets using water is taken as the product of the number of occupied housing units and the average number of toilets per household. Thus projected growth in the stock of toilets is driven by forecasts of growth in occupied housing units.[46]

The model assumes toilets fall into one of three categories: (1) 3.5+ gallons per flush (gpf) toilets, (2) ULFTs rated 1.6 gpf, and (3) HETs rated 1.28 gpf or less.

The following variables are used to define the relevant quantities in the model:

H_t	Number of occupied housing units in year t
ΔH_t	Change in the number of occupied housing units from t-1 to t
TPH	Average number of toilets per household
P_t	Population in year t
R	Average rate of toilet replacement as a percent of the existing stock
S	Average rate of resale of existing housing units
T_t	Number of toilets of all types in year t
$T_t^{3.5+}$	Number of 3.5+ gpf toilets in year t
T_t^{ULFT}	Number of ULFT toilets in year t

[46] The models use forecasts of occupied housing units from Department of Finance (DOF). The use of occupied housing units introduces a complication in the fixture water use accounting since at the county level the annual change in the number of occupied housing units can be negative in some years. This may occur because of economic conditions (e.g. the 2007-10 uptick in residential foreclosures) or because some parts of California are estimated to be losing population (e.g. Alpine County). When occupied housing units decrease from one year to another, the model assumes the toilets associated with this decrease are idled. The model keeps a running total of these idled fixtures for each county. If occupied housing subsequently increases, the model first absorbs the idled toilets and associates any residual increase with the installation of new fixtures. This accounting is not shown in the equations presented below because it would significantly complicate the presentation of the model's structure.

T_t^{HET}	Number of HET toilets in year t
F_t	Average gallons per flush of all toilets in year t
$F^{3.5+}$	Average gallons per flush of 3.5+ gpf toilets
F^{ULFT}	Average gallons per flush of ULFT toilets
F^{HET}	Average gallons per flush of HET toilets
FPD	Average residential flushes per day per person
$GPCD_t^{Toilets}$	Average daily per capita water use for toilet flushing in year t
$W_t^{Toilets}$	Total daily water use for toilet flushing in year t

The inventory of 3.5+ gpf toilets is determined as follows:

$$T_t^{3.5+} = H_t \cdot TPH \qquad t = 1990$$

$$T_t^{3.5+} = T_{t-1}^{3.5+}(1 - r) \qquad 1991 \leq t < 2017$$

The model assumes all toilets flush at 3.5+ gallons in 1990. This is a simplification since ULFTs were commercially available starting in the 1980s. However, ULFTs had a very low share of residential toilets in 1990, which is safely ignored. Starting in 1991, 3.5+ toilets could no longer be purchased or installed in California.[47] Between 1991 and 2017, the model assumes the inventory of 3.5+ toilets is slowly replaced by ULFTs and HETs. The rate of this replacement is determined by the parameter r.

SB 407 comes into play in 2017. As previously discussed, three scenarios are modeled. Scenario 1 assumes no enforcement, so replacement is treated the same as for the earlier period. Scenario 2 assumes SB 407 acts like a retrofit-on-resale requirement. Replacement of 3.5+ toilets is governed by

[47] This too is not quite true since California allowed existing inventories of 3.5+ toilets to be liquidated, which meant one could purchase a 3.5+ toilet in 1991 and probably into 1992.

the parameters r and s.[48] Scenario 3 assumes full compliance. Thus the model assumes all remaining 3.5+ toilets are replaced in 2017.

Scenario 1: No enforcement	$T_t^{3.5+} = T_{t-1}^{3.5+}(1-r)$	$t \geq 2017$
Scenario 2: Retrofit-on-resale	$T_t^{3.5+} = T_{t-1}^{3.5+}(1-s)(1-r)$	$t \geq 2017$
Scenario 3: Full compliance	$T_t^{3.5+} = 0$	$t \geq 2017$

The model assumes ULFTs enter the inventory starting in 1991. Between 1991 and 2013 the model assumes all new toilets are ULFTs and when 3.5+ toilets go out of service they are replaced with ULFTs. Starting in 2014, new and replaced toilets must be HET in California. The model assumes the stock of ULFTs is slowly replaced by HETs starting in 2014, as governed by the parameter r.

$$T_t^{ULFT} = 0 \qquad t < 1991$$

$$T_t^{ULFT} = T_{t-1}^{ULFT} + \Delta H_t \times TPH + rT_{t-1}^{3.5+} \qquad 1991 \leq t < 2014$$

$$T_t^{ULFT} = T_{t-1}^{ULFT}(1-r) \qquad t \geq 2014$$

[48] An equivalent way to express the replacement of 3.5+ toilets under the retrofit-on-resale scenario is: $T_t^{3.5+} = T_{t-1}^{3.5+} - rT_{t-1}^{3.5+} - sT_{t-1}^{3.5+} + rsT_{t-1}^{3.5+}$, which says the number of toilets in year t equals the number in year t-1 less the number that are replaced naturally, less the number that are replaced via resale, plus an adjustment so as not to double count toilets as replaced both ways.

Note that SB 407 does not affect the replacement of ULFTs, since it only requires replacement of a toilet if it has a rated flush volume greater than 1.6 gpf.

HETs enter the model starting in 2014. For the period 2014 to 2016, the growth in HETs is determined by the growth in the housing stock and the natural replacement of 3.5+ and ULFT toilets.

$$T_t^{HET} = 0 \qquad t < 2014$$

$$T_t^{HET} = T_{t-1}^{HET} + \Delta H_t \cdot TPH + r(T_{t-1}^{3.5+} + T_{t-1}^{ULFT}) \qquad 2014 \leq t \leq 2016$$

Starting in 2017, the inventory of HETs also depends on the SB 407 implementation scenario.

Scenario 1: No enforcement	$T_t^{HET} = T_{t-1}^{HET} + \Delta H_t \cdot TPH + r(T_{t-1}^{3.5+} + T_{t-1}^{ULFT})$	$t \geq 2017$
Scenario 2: Retrofit-on-resale	$T_t^{HET} = T_{t-1}^{HET} + \Delta H_t \cdot TPH + rT_{t-1}^{ULFT} + T_{t-1}^{3.5+}[1-(1-s)(1-r)]$	$t \geq 2017$
Scenario 3: Full compliance	$T_t^{HET} = T_{t-1}^{HET} + \Delta H_t \cdot TPH + rT_{t-1}^{ULFT} + T_{2016}^{3.5+}$	$t \geq 2017$

Average flush volume of all toilets in year t is a function of the number of toilets in each category in year t and the average flush volume within the category.

$$F_t = \frac{F^{3.5+} \cdot T_t^{3.5+} + F^{ULFT} \cdot T_t^{ULFT} + F^{HET} \cdot T_t^{HET}}{T_t}$$

Average daily per capita water use for toilets in year t is the product of the average flush volume and the average flushes per person.

$GPCD_t^{Toilet} = F_t \cdot FPD$

Total daily water use for toilets in year t is the product of the average daily per capita water use for toilets and the population.

$W_t^{Toilet} = P_t \cdot GPCD_t^{Toilet}$

Multi-Family Residential Toilet Model

The multi-family residential toilet model structure is identical to the single-family model. The only difference is SB 407 effects start in 2019 instead of 2017.

Non-Residential Toilet Model

The non-residential toilet model structure is nearly identical to the single- and multi-family residential models. Like the multi-family model, SB 407 effects start in 2019 instead of 2017. The stock of non-residential toilets is also calculated differently. The stock of non-residential toilets in 1992 is taken from the CUWCC CII toilet database. This database estimates the total number of toilets in 1992 by zip code using the methodology outlined in the CUWCC CII ULFT Savings Study (2001). The zip-code level estimates are aggregated to county level. The model then assumes the toilet stock grows at the same rate as county population.

Urinal Model

The urinal inventory model has the same basic structure as the non-residential toilet model. The total number of urinals is assumed to equal one-fourth the inventory of non-residential toilets, per Koeller (2006). Urinals are divided into three categories: (1) 1.0 gpf urinals, (2) 0.5 gpf urinals, and (3) 0.125 gpf urinals. New and replaced urinals are assumed to be 1 gpf between 1990 and 2013, 0.5 gpf in 2014 and 2015, per AB 715, and 0.125 gpf thereafter, per California Energy Commission standards adopted in 2015.

The urinal model does not estimate SB 407 effects. SB 407 requires replacement of any urinal in pre-1994 buildings with a flush rating greater than 1.0 gpf by January 1, 2019. However, estimates of the share of urinals with flush ratings exceeding 1.0 gpf were not available for this study. While there are certainly urinals flushing more than 1.0 gpf in California, their share of the total inventory is believed to be very small and SB 407 effects, could they have been estimated, were not expected to be large.

Residential Clothes Washer Model

The residential clothes washer model, like the residential toilet model, is an inventory growth and replacement model. Because of the different types of clothes washers available to consumers and the phasing of federal clothes washer efficiency standards, it has a somewhat more complicated structure than the residential toilet model.

The model classifies a washer as either conventional or high-efficiency (HEW). HEW washers may be either front-loading (FL) or top-loading (TL). Whether a newly purchased washer is conventional or HEW and FL or TL is governed by market shares used by the model. These market shares change over time and are taken primarily from Department of Energy clothes washer market forecasts (DOE, 2010). The water factor associated with a HEW FL and TL washers is governed by the phasing in of federal clothes washer efficiency standards. These change over time, as discussed in Section 2.

When an existing washer reaching the end of its useful life is replaced, it may be replaced by either a conventional or HEW washer, depending on time-period, market share, and governing efficiency code. The washer may be FL or TL, depending on assumed market share. The model does not assume that FL washers are only replaced by new FL washers and TL washers are replaced only by new TL washers. The mix of FL and TL washers changes over time in the model as a function of the market shares for FL and TL washers.

A washer is an in-unit washer if it is used within an individual housing unit. All single-family washers are treated as in-unit washers. A washer is a common area washer if it is shared by multiple housing units. Most multi-family properties have a mix of in-unit and common area washers. This model pertains only to the water use of in-unit washers. The estimation of water used by common area and commercial coin-op washers is discussed in Section 3.3.6.

The following variables are used to define the relevant quantities in the model:

H_t	Number of occupied housing units in year t
ΔH_t	Change between years t-1 and t in the number of occupied housing units
WPH	Average number of washers per household[49]
COINPCT	Percent of households without washer that use commercial coin-op washers
CAPACITY	Average capacity of a residential clothes washer, in cubic feet
P_t	Population in year t
r	Average rate of washer replacement as a percent of the existing stock
C_t	Number of clothes washers of all types in year t
C_t^{conv}	Number of conventional clothes washers in year t
C_t^{FL}	Number of FL HEW clothes washers in year t
C_t^{TL}	Number of TL HEW clothes washers in year t
M_t^{conv}	Market share of conventional washers in year t
M_t^{FL}	Market share of HEW FL washers in year t

[49] This is a number between 0 and 1 and represents the rate of ownership of washers. For example, a WPH of 0.95 indicates that 95 percent of households have a clothes washer.

M_t^{TL}	Market share of HEW TL washers in year t
WF_t	Average water factor of all clothes washers in year t
GPL_t	Average gallons per load of laundry in year t
LPD	Average clothes washer loads per day per person
$GPCD_t^{Washer}$	Average daily per capita water use for clothes washers in year t, in gallons
W_t^{Washer}	Total daily water use for clothes washers in year t, in gallons

$C_t \equiv C_t^{conv} + C_t^{FL} + C_t^{TL}$ and $M_t^{conv} + M_t^{FL} + M_t^{TL} \equiv 1$

The number of conventional washers in year t is equal to the number of conventional washers in year t-1 that do not fail plus the number of washers of all types in year t-1 that fail and are replaced with conventional washers plus the number of new conventional washers.[50]

$$C_t^{conv} = C_{t-1}^{conv} \cdot (1 - r) + r \cdot C_{t-1} \cdot M_t^{conv} + \Delta H_t \cdot WPH \cdot M_t^{conv}$$

[50] As with toilets, because the model uses estimates and projections of occupied housing units, it is possible to have a negative change in occupied housing units from one year to another. In this case the clothes washers associated with these housing units are assumed to be removed from the inventory of all clothes washers. Unlike for toilets, the model does not assume these removed washers come back into the inventory later. If a subsequent change in occupied housing units is positive, the model assumes new washers are acquired for these housing units. This assumption is made because clothes washers are portable and are often relocated when a household moves to a new location. Thus the model assumes that if households leave a region, they take their washers with them. Obviously, this will not always be the case, especially in the case of rented properties, but the model assumes it is more likely than not to be the case.

Similarly, the number of HEW FL (TL) washers in year t is equal to the number of HEW FL (TL) washers in year t-1 that do not fail plus the number of washers of all types in year t-1 that fail and are replaced with HEW FL (TL) washers plus the number of new HEW FL (TL) washers.[51]

$$C_t^{FL} = C_{t-1}^{FL} \cdot (1 - r) + r \cdot C_{t-1} \cdot M_t^{FL} + \Delta H_t \cdot WPH \cdot M_t^{FL}$$

$$C_t^{TL} = C_{t-1}^{TL} \cdot (1 - r) + r \cdot C_{t-1} \cdot M_t^{TL} + \Delta H_t \cdot WPH \cdot M_t^{TL}$$

The model assumes the average water factor of conventional washers is 11 in all time periods. The average water factor of new FL and TL washers varies over time. In the starting year of 2005, the FL and TL average water factors of the existing stock of HEW washers are assumed to be 7.0 and 8.5, respectively. These values were selected to calibrate the model to the average water use of HEW and conventional washers circa 2005 based on end use study results. The average water factor of new FL washers is assumed to be 6.0 for the period 2005 to 2014 and 4.5 thereafter. The average water factor for new TL washers is assumed to be 8.0 for the period 2005 to 2017 and 6.0 thereafter. Thus, the washer inventory is allocated into six water factor categories:

1. WF 11.0 – average water factor of conventional washers
2. WF 8.5 – average water factor of HEW TL washers purchased prior to 2005
3. WF 8.0 – average water factor of HEW TL washers purchased between 2005 and 2017
4. WF 7.0 – average water factor of HEW FL washers purchased prior to 2005
5. WF 6.0 – average water factor of HEW TL washers purchased after 2017 and HEW FL washers purchased between 2005 and 2014
6. WF 4.5 – average water factor of HEW FL washers purchased after 2014

The model allocates new washers to these water factor categories depending on time period and whether the new washer is conventional, FL, or TL. The number of washers in each category that fail each year is governed by the

[51] Note that adding these three equations together yields the identity that the number of washers of all types in year t equals the number of washers of all types in year t-1 plus the number of washers of all types in new homes.

replacement parameter, r. Through these two processes, the model maintains a running total of active washers in each of the six categories.

Let i = 1,…,6 be the index of water factor categories, the average water factor for the stock of washers in year t is:

$WF_t = \sum_{i=1}^{6} \frac{WF_i \cdot C_t^{WF_i}}{C_t}$, where $C_t^{WF_i}$ is the number of washers in WF category i in year t.

The average water use per load of laundry in gallons in year t is:

$$GPL_t = WF_t \cdot CAPACITY$$

Total daily water use for in-unit clothes washers in year t is the product of the average gallons per load and the daily number of loads. The daily number of loads is equal to the product of the fraction of households with clothes washers, the population, and the average loads per person per day in homes with clothes washers.

$$W_t^{Washer} = GPL_t \cdot WPH \cdot P_t \cdot LPD$$

The average daily water use per person for in-unit clothes washers in year t is equal to total daily water use by in-unit clothes washers divided by the population using in-unit clothes washers. This is the same as gallons per load multiplied by loads per day per person:

$$GPCD_t^{Washer} = GPL_t \cdot LPD$$

Multi-family Common Area and Commercial Coin-Op Clothes Washer Water Use

Data on the number of multi-family common area and commercial coin-op clothes washers in California is scant. This study did not attempt to directly estimate this category of water use with an inventory growth and replacement model. Instead, the study approximates the annual water use by multi-family common area and commercial coin-op clothes washers by assuming that the single- and multi-family residential population without in-unit clothes washers would use a similar amount of water for clothes washing on a per capita basis as the population with in-unit washers.[52] Under this assumption, the GPCD for common area and coin-op clothes washers is assumed to be the same as shown above and the total daily water use for these washers is estimated as:

$$W_t^{CommonWasher} = GPL_t \cdot (1 - WPH) \cdot (1 - COINPCT) \cdot P_t \cdot LPD$$

$$W_t^{CoinOpWasher} = GPL_t \cdot (1 - WPH) \cdot COINPCT \cdot P_t \cdot LPD$$

Data and Assumptions

In this section, the data and assumptions used to implement the toilet, urinal, and clothes washer models are reviewed.

County Population and Housing Estimates

Historical and projected occupied housing units for single- and multi-family residences come from the following sources:

- 1990-2010: DOF E-8 Historical Population and Housing Estimates
- 2011-2015: DOF E-5 Population and Housing Estimates
- 2016-2030: DOF P-4 Projected Households. DOF projections are in 5-year increments. Linear interpolation is used for years between the DOF projections. The DOF projections are for total households. Single-family households are estimated by multiplying total households by the ratio of single-family to total households in 2015.[53] Multi-family households are estimated as the residual between total households and single-family households.
- 2031-2040: Total households are estimated from DOF P-1 population projection scaled by the ratio of household to total population in 2030 (from DOF P-4) and then divided by the average persons per household in 2030. Single-family households are estimated by multiplying total households by the ratio of single-family to total

[52] This is likely to somewhat overstate water use by common area and commercial coin-op washers for at least two reasons. First, households using common area and coin-op washers may use washers less frequently because of the time, inconvenience, and expense involved. Second, common area and commercial washers may be more efficient, on average, than residential washers because they typically have larger capacities and are changed out more frequently.

[53] The share of single-family households as a share of total households was estimated for each year in the period 1990-2015 and found to be very stable for most counties.

households in 2015. Multi-family households are estimated as the residual between total households and single-family households. DOF population projections are in 5-year increments. Linear interpolation is used for years between the DOF projections.

Historical and projected total and household population comes from the following sources:

- 1990-2010: DOF E-8 Historical Population and Housing Estimates
- 2011-2015: DOF E-5 Population and Housing Estimates
- 2016-2030: DOF P-4 State and County Projected Households, Household Population, Group Quarters, and Persons per Household. DOF projections are in 5-year increments. Linear interpolation is used for years between the DOF projections.
- 2031-2040: DOF P-1 Total Population Projections for California and Counties. DOF projections are in 5-year increments. Linear interpolation is used for years between the DOF projections. Household population is calculated by multiplying the DOF P-1 projections by the ratio of household to total population in 2030 from DOF P-4.

Historical and projected average persons per households (PPH) comes from the following sources:

- PPH for total housing units is calculated by dividing total household population by total housing units.
- PPH for single-family housing units is calculated as follows: Let ρ be the county's ratio of single-family to multi-family PPH calculated from Census 2000 data, P_t be total household population, SFR_t be total single-family housing units, and MFR_t be total multi-family housing units, then

$$PPH_t^{SFR} = P_t/(SFR_t + \rho MFR_t)$$

- PPH for multi-family housing units is calculated as:

$$PPH_t^{MFR} = P_t/\left(MFR_t + \frac{1}{\rho}SFR_t\right)$$

Historical and projected population in single- and multi-family housing is calculated by multiplying the housing units in each category of its respective estimate of PPH.

Average Toilets and Clothes Washers per Household

The average number of toilets and clothes washers per household in single- and multi-family housing units are estimated from the 2011 American Housing Survey Public Use Micro Sample Data for the eight SMSAs in the data file located in California. County-level estimates are set to the estimates for the most proximate SMSA. The estimates are provided in Attachment 1.

Common Area and Coin-Op Washer Usage Rates

Households that do not have an in-unit washer are assumed to do their washing at an on-premise common area washing room or at an off premise commercial coin-op laundry. All single-family households without washers are assumed to use off premise commercial coin-op laundries. Seventy-two percent of multi-family households without in-unit washers are assumed to use on premise common area washers and 28 percent are assumed to use off premise commercial coin-op laundries. The assumptions for multi-family are based on results of a 2013 survey of multi-family renters conducted by the Coin Laundry Association.[54]

Average Residential Clothes Washer Capacity

The clothes washer models assume in-unit clothes washers have an average capacity of 3.5 cubic feet.

Average Daily Toilet, Urinal, and Clothes Washer Usage

A resident of a household is assumed to flush toilets in the household an average of 5 times per day. This value is taken from the 2016 Residential End Uses of Water Study.

Households with washers are assumed to do an average of 0.31 loads of laundry per person per day. This value is the average of the usage rates reported in the 1999, 2010, and 2016 Residential End Uses of Water Studies.

[54] http://www.coinlaundry.org/blogs/bob-nieman/2015/01/26/taking-a-new-route

The non-residential toilet model estimates an average toilet flush rate for each county based on water savings estimates from the CUWCC CII ULFT Savings Study (2001). The average flush rate for a county is calculated as the weighted average flush rate across ten end-use categories: hotels, health services, offices, retail/wholesale, industrial, government, schools, and other. The flush rate for each category is calculated by dividing the estimated daily water savings from replacing a 3.5+ gpf toilet with a ULFT toilet in this category by the assumed difference in flush volumes between the replaced toilet and the ULFT. For this calculation it was assumed the replaced toilet had an average flush volume of 3.85 gpf and the replacement ULFT had and average flush volume of 1.9 gpf. The estimated average daily flush rates for non-residential toilets by county are provided in Attachment 2.

Data on flush rates of non-residential urinals is scant. The model estimates urinal water use using the approach suggested by Vickers (2001), which bases it on the level of male employment in a region. Vickers (2001) reports an average usage of two flushes per day per male worker. Total daily urinal flushes in the model is therefore equal to twice the level of male employment. Male employment is assumed to equal 53 percent of county employment.[55] This yields an average daily flush rate of about 28 flushes per urinal statewide. Note the model does not attempt to estimate urinal water use by non-workers in restaurants, bars, and other public spaces. Therefore, the model likely provides a conservative estimate of urinal water use.

Average Toilet Water Use by Toilet Category

The toilet replacement models assume the following average water use per flush by toilet category:

Toilet Category	Average Use per Flush (gal)
3.5+	3.85
ULFT	1.90
HET	1.30

[55] Based on BLS employment data for California.

These amounts are based on the distribution of toilet flush volumes reported in the 2016 Residential End Uses of Water Study.

Toilet and Clothes Washer Replacement Rates

The toilet and clothes washer annual replacement rates used in the models are 4.0 and 7.1 percent, respectively. These rates are equivalent to average useful lives of 25 and 14 years, respectively. A 25-year average useful life for toilets is a standard assumption and empirical estimates from plumbing fixture saturation studies have confirmed its reasonableness. A 14-year average useful life for residential clothes washers is based on clothes washer industry estimates.

Clothes Washer Market Shares

Market shares for conventional, HEW TL, and HEW FL clothes washers are based on Department of Energy market assessments developed during its energy and water efficiency standards setting for residential clothes washers. These shares are shown in Table 2.

Table 19. Clothes Washer Market Share Assumptions

Year	Conventional	HEW FL	HEW TL
2006	50%	10%	40%
2007	45%	17%	39%
2008	35%	26%	39%
2009	25%	38%	38%
2010	15%	51%	34%
2011	10%	54%	36%
2012	10%	54%	36%
2013	10%	54%	36%
2014	10%	54%	36%
2015-2040	0%	60%	40%

Property Resale Rates

Long-term average property resale rates are used in the toilet models to estimate SB 407 toilet replacement effects under Scenario 2 where SB 407 is modeled as equivalent to a retrofit-on-resale requirement. Average resale rates for single- and multi-family housing units by hydrologic region for the period 1990-1998 are used to estimate the long-run average resale rates of residential housing units in the models. The resale data was originally developed by Dataquick for the CUWCC in the early 2000s when CUWCC was modeling residential retrofit-on-resale water savings for toilet, faucet, and showerhead programs. Estimates of commercial property resale rates were not available for this study. For purposes of estimating SB 407 effects under Scenario 2, the non-residential toilet model assumes commercial resale rates are the same as for the multi-family sector. The property resale rates assumed for each county are provided in Attachment 1.

Model Results and Comparisons to Empirical Benchmarks

In this section, model results are compared to empirical estimates of average fixture water use, where such estimates are available.

Model Estimates of Average Water Use

Model estimates of historical average water use for toilets and washers are given in Table 3. Toilet estimates span the period 1990-2015. Clothes washer estimates span the period 2005-2015. The estimates in Table 3 are statewide averages.

Table 20. Model Estimates of Average Water Use by Plumbing Fixture

Year	Toilets (gal/flush) SFR	Toilets (gal/flush) MFR	Toilets (gal/flush) Non-Res	Urinals (gal/flush)Non-Res	Clothes Washers (gal/load)SFR	Clothes Washers (gal/load)MFR
1990	3.85	3.85	3.85	1.00		
1991	3.74	3.75	3.75	1.00		
1992	3.65	3.65	3.65	1.00		
1993	3.56	3.57	3.55	1.00		
1994	3.47	3.50	3.48	1.00		
1995	3.39	3.43	3.40	1.00		
1996	3.32	3.37	3.33	1.00		
1997	3.24	3.31	3.26	1.00		
1998	3.18	3.25	3.19	1.00		
1999	3.11	3.19	3.12	1.00		
2000	3.04	3.13	3.05	1.00		
2001	2.99	3.08	2.99	1.00		
2002	2.93	3.02	2.93	1.00		
2003	2.88	2.97	2.88	1.00		
2004	2.83	2.92	2.83	1.00		
2005	2.78	2.87	2.79	1.00	35.7	35.7
2006	2.73	2.83	2.75	1.00	35.4	35.4
2007	2.69	2.78	2.71	1.00	35.0	35.0
2008	2.65	2.74	2.67	1.00	34.6	34.6
2009	2.62	2.70	2.64	1.00	34.0	34.0
2010	2.59	2.67	2.60	1.00	33.4	33.4
2011	2.56	2.63	2.57	1.00	32.8	32.8
2012	2.53	2.60	2.54	1.00	32.3	32.2
2013	2.50	2.57	2.50	1.00	31.7	31.7
2014	2.45	2.50	2.45	0.98	31.2	31.2

Year	Toilets (gal/flush) SFR	Toilets (gal/flush) MFR	Toilets (gal/flush) Non-Res	Urinals (gal/flush)Non-Res	Clothes Washers (gal/loa d)SFR	Clothes Washers (gal/loa d)MFR
2015	2.40	2.45	2.39	0.95	30.5	30.3

End Use Studies and Benchmarks

Results from three separate water end-use studies of single-family households spanning a 17-year period are used as benchmarks for assessing residential toilet and clothes washer model performance. The end-use study benchmarks are based on data-logging that records end-use events and associated water volumes for samples of single-family households. The first end-use study, published in 1999, sampled households throughout North America, including California. The second study, published in 2011, was specific to California. The third study, published in 2016, sampled households outside of California.[56] The 1999 study measured household water end-uses over the period 1996-98. The 2011 study measured water end-uses over the period 2005-08. The 2016 study measured household water end-uses over the period 2012-13.

Comparison of model results to end-use benchmarks is limited to the single-family sector models. While water end-uses of multi-family and commercial sectors have been studied to a limited extent, the sample sizes in these studies are small and the results are not sufficiently general to provide reliable benchmarks.

Because data logging for each end-use study spanned multiple years, the model results are averaged over the data logging period before they are compared to the end-use benchmark. For example, the 2016 study benchmarks are compared to the average model results for 2012-13 because data logging took place in 2012 and 2013.

[56] Households were sampled in six locations: Denver CO, Fort Collins CO, San Antonio TX, Scottsdale AZ, Clayton County GA, Tacoma WA, and the City of Waterloo and the Peel Region in Southern Ontario.

Single-Family Toilet Benchmark Comparison

Table 4 compares the single-family toilet model estimates of average toilet water use per flush to the end-use study benchmarks. In the case of the 1999 end use study, the benchmark is calculated from the sample of households located in California only. The 2011 study benchmark is also based only on California homes. The 2016 study did not include California homes in the data-logging sample. It is expected that average toilet water use measured in the 2016 study would be somewhat higher than for California, which mandated ULFTs sooner and has made significant investments in toilet replacement programs.

The model estimates are within +/- 2.5 percent of the three end use study benchmarks. As expected, the model's estimate is somewhat less than the 2016 study benchmark, which is based on toilets in homes outside of California. The 2011 end-use study benchmark, which is based on the largest sample of California homes of the three end-use studies, shows the closest correspondence with the model estimate, differing by less than 2 percent. Despite the simple structure of the toilet inventory growth and replacement model, it provides a close correspondence with available empirical benchmarks of average toilet water use.

Table 21. Comparison of Single-Family Toilet Model Results to End-Use Study Benchmarks

End Use Study Publish Year	Data Logging Period	End Use Study Benchmark (gal/flush)	Model Estimate (gal/flush)	% Diff
2016	2012-13	2.58	2.51	-2.5%
2011	2005-08	2.76	2.71	-1.8%
1999	1996-98	3.17	3.25	2.4%

Notes: the 1999 and 2011 benchmarks are based on homes in California. The 2016 benchmark is based on homes outside of California.

Single-Family Clothes Washer Benchmark Comparison

Table 5 compares the single-family clothes washer model estimates of average water use per load to the end-use study benchmarks. The model estimates are within +/- 3.2 percent of the two relevant end use study benchmarks. As with the single-family toilet model, the washer model replicates the end-use study benchmarks fairly closely, despite its simple structure.

Table 22. Comparison of Single-Family Clothes Washer Model Results to End-Use Study Benchmarks

End Use Study Publish Year	Data Logging Period	End Use Study Benchmark (gal/load)	Model Estimate (gal/load)	% Diff
2016	2012-13	31.0	32.0	3.2%
2011	2005-08	36.0	35.2	-2.4%

Notes: the 2011 benchmark is based on homes in California. The 2016 benchmark is based on homes outside of California.

Projected Water Savings

In this section, projected effects of plumbing codes and appliance standards on total M&I water demand and GPCD are presented. The statewide effects are presented here and the county-level effects are presented in Attachment 3. As discussed above, all savings effects are measured relative to a 2015 baseline efficiency level.

Single-Family Sector

Table 6 summarizes the projected effects of plumbing codes and appliance standards on single-family water use under SB 407 scenario 2. Aggregate water savings are projected to reach about 291 TAF in 2040. Approximately 60 percent of the savings is associated with toilet plumbing codes and 40 percent with clothes washer efficiency standards. Relative to the 2015 baseline, single-family per capita demand is reduced by 7.6 GPCD by 2040.

County-level GPCD effects vary, with a minimum 2040 reduction of 6.7 GPCD and a maximum reduction of 8.6 GPCD (see Attachment 3 for county-level estimates).

Table 7 summarizes the projected statewide effects for each SB 407 scenario. Recall that scenario 1 assumes SB 407 has no impact on toilet replacement, scenario 2 assumes it has the same effect as a retrofit-on-resale requirement, and scenario 3 assumes it achieves full compliance within its stated deadlines.

In the long-run, there is not much difference in model results between scenarios 2 and 3. It is a question of timing. Assuming full compliance by the stated deadlines of SB 407 has a significant impact on single-family residential water use in the near-term. The GPCD reduction in 2020 under scenario 3 is 79 percent greater than under scenario 2. By 2030, the differential has decreased to 15 percent, and by 2040, it is only 5 percent. As discussed in Section 3.2, scenarios 1 and 3 bound the potential effect of SB 407 on residential water use, but neither scenario is considered very likely. Scenario 2 is believed to provide the best estimate of potential SB 407 effects on single-family water use.

Projected rates of fixture saturation for single-family toilets and clothes washers are shown in Figures 1-3. Figure 2 shows the division of clothes washers between conventional and high-efficiency categories. Figure 3 shows a more detailed break-down by water factor. Clothes washers with a water factor of 11 are classified in the model as conventional washers. All figures are based on SB 407 implementation scenario 2.

Table 23. Statewide Effect of Plumbing Codes and Appliance Standards on Single-Family Water Use: SB 407 scenario 2

Year	2020	2025	2030	2035	2040
Single-Family Population	29,298,916	30,611,455	31,908,231	33,159,820	34,286,582
Water Savings (AF) - Toilets	57,325	99,271	130,939	155,365	174,208
Water Savings (AF) - Clothes Washers	38,418	67,327	88,795	105,016	117,237

Year	2020	2025	2030	2035	2040
Water Savings (AF) - Total	95,743	166,598	219,735	260,381	291,445
GPCD Reduction - Toilets	1.7	2.9	3.7	4.2	4.5
GPCD Reduction - Clothes Washers	1.2	2.0	2.5	2.8	3.1
GPCD Reduction - Total	2.9	4.9	6.1	7.0	7.6
County Range of Total GPCD Reduction - Min	2.7	4.4	5.5	6.2	6.7
County Range of Total GPCD Reduction - Max	4.0	6.2	7.4	8.1	8.6

Table 24. Statewide Effect of Plumbing Codes and Appliance Standards on Single-Family Water Use by SB 407 Scenario

Year	2020	2025	2030	2035	2040
Total Savings (AF) – SB 407 Scenario 1	82,200	144,087	193,776	234,175	266,734
Total Savings (AF) – SB 407 Scenario 2	95,743	166,598	219,735	260,381	291,445
Total Savings (AF) – SB 407 Scenario 3	171,435	216,870	253,131	282,568	306,189
GPCD Reduction SB 407 Scenario 1	2.5	4.2	5.4	6.3	6.9
GPCD Reduction SB 407 Scenario 2	2.9	4.9	6.1	7.0	7.6
GPCD Reduction SB 407 Scenario 3	5.2	6.3	7.1	7.6	8.0

Figure 19. Projected Percent of Single-Family Toilet Inventory by Toilet Type

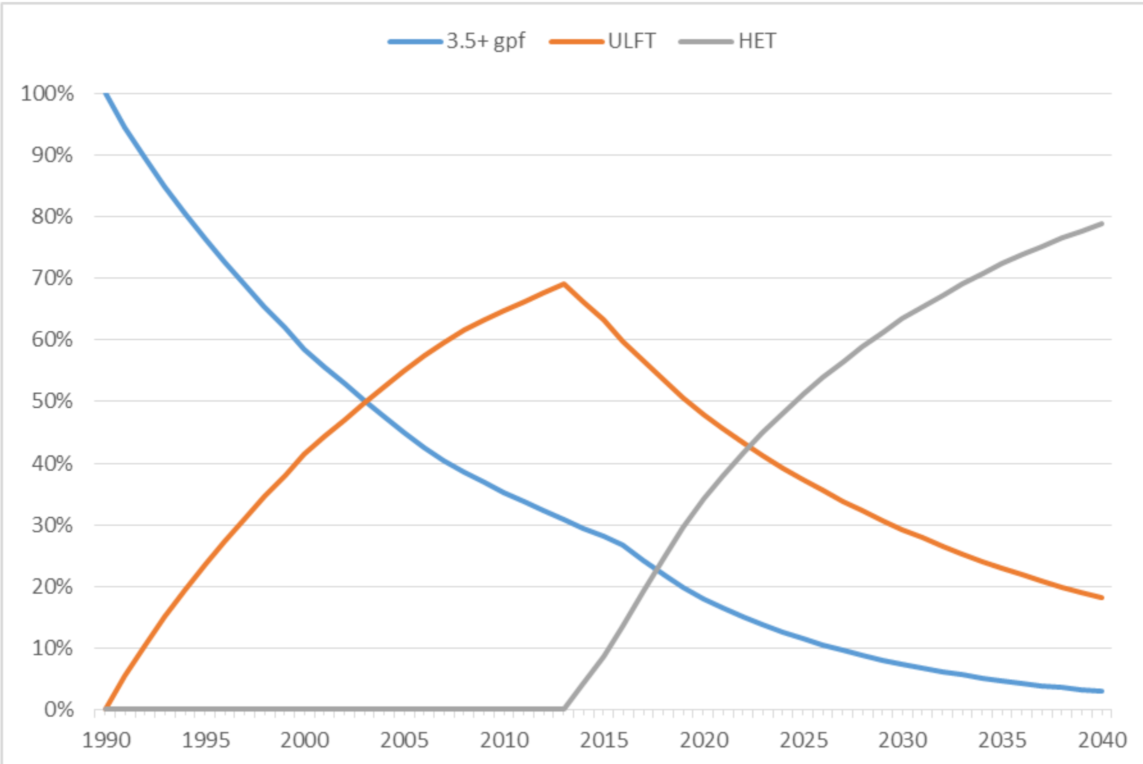


Figure 20. Projected Percent of Conventional and HEW Single-Family Clothes Washers

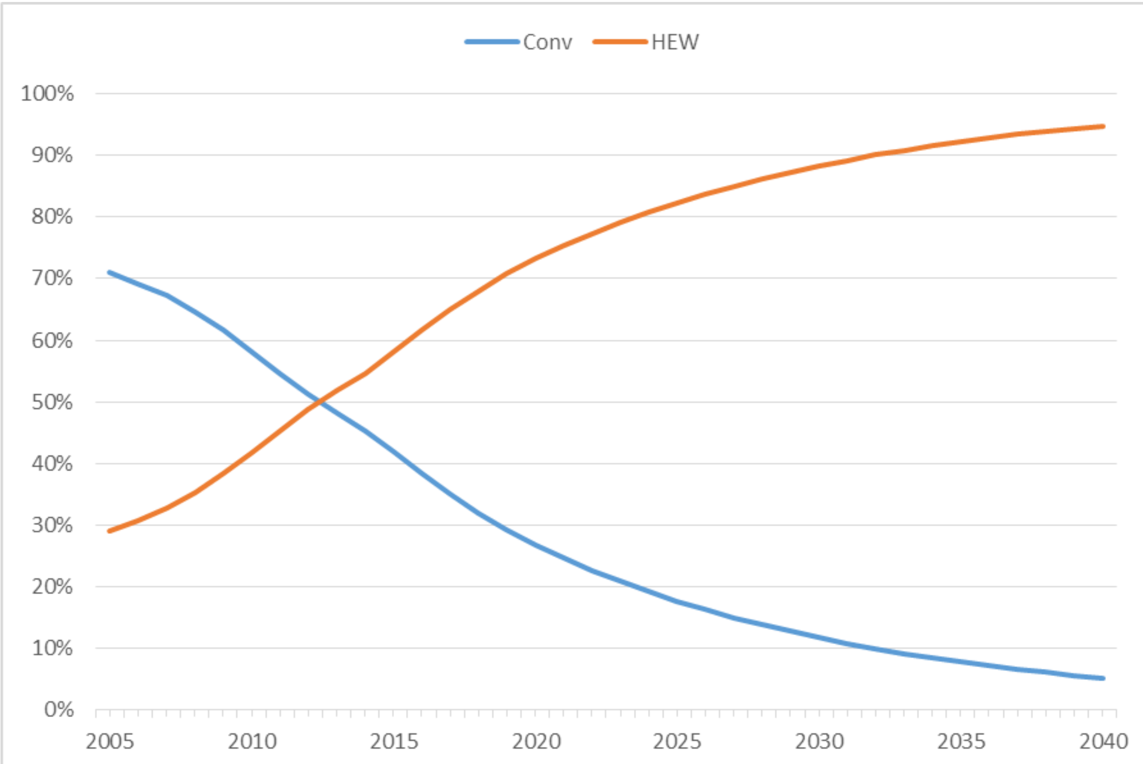
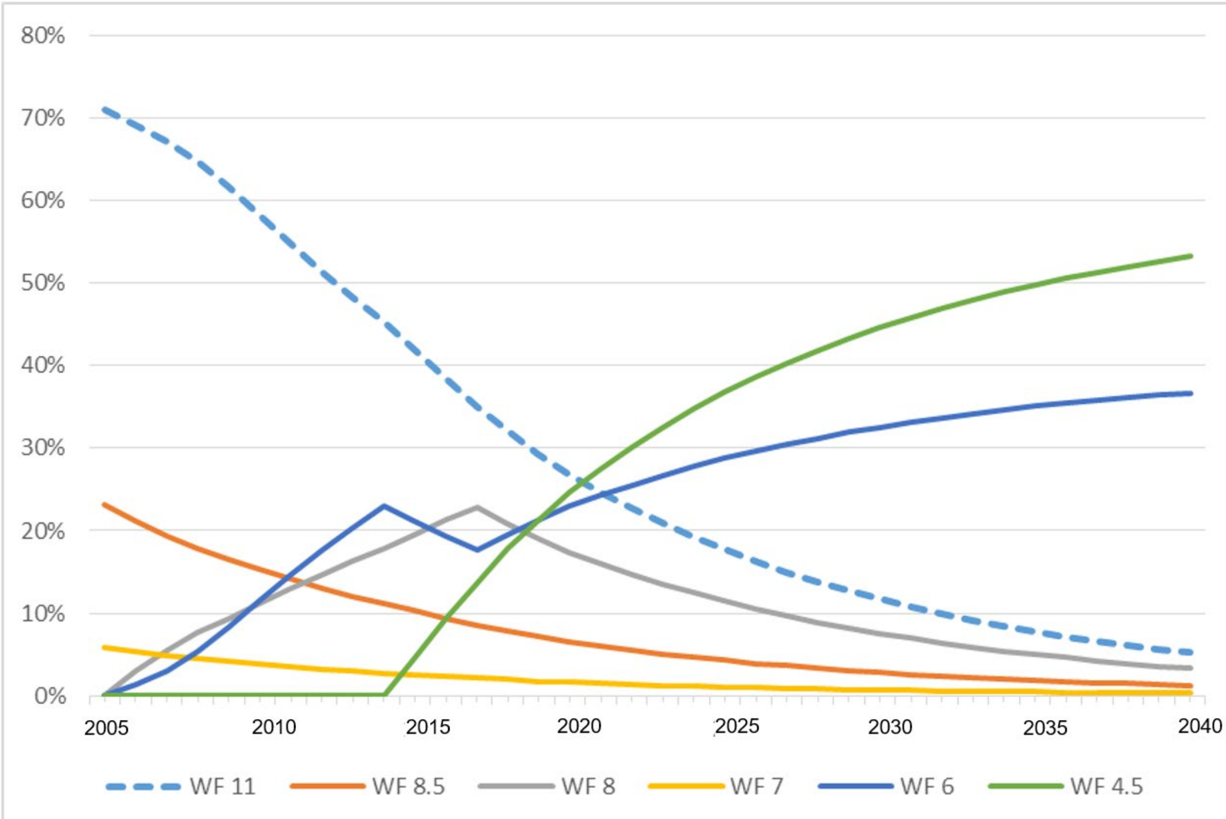


Figure 21. Projected Percent of Single-Family Clothes Washers by Water Factor



Multi-Family Sector

Table 8 summarize the statewide projections for the multi-family sector. Aggregate water savings are projected to reach just over 100 TAF in 2040. Approximately 64 percent of the savings is associated with toilet plumbing codes and 36 percent with clothes washer efficiency standards. Relative to the 2015 baseline, multi-family per capita demand is reduced by 7.5 GPCD by 2040. County-level GPCD effects vary, with a minimum 2040 reduction of 6.2 GPCD and a maximum reduction of 8.0 GPCD (see Attachment 3 for county-level estimates).

Table 9 summarizes the projected statewide effects for each SB 407 scenario. Aggregate water savings in 2040 range between 90 and 105 TAF. Per capita water savings in 2040 range between 6.7 and 7.9 GPCD. As with single-family, the SB 407 compliance assumption primarily affects the timing of the savings. In 2020, scenario 3 savings are double scenario 2 savings. By 2040, they differ by just five percent.

Projected rates of fixture saturation for multi-family toilets and clothes washers are shown in Figures 4-6. Figure 5 shows the division of clothes washers between conventional and high-efficiency categories. Figure 6 shows a more detailed break-down by water factor. Clothes washers with a water factor of 11 are classified in the model as conventional washers. All figures are based on SB 407 implementation scenario 2.

Table 25. Statewide Effect of Plumbing Codes and Appliance Standards on Multi-Family Water Use: SB 407 Scenario 2

Year	2020	2025	2030	2035	2040
Single-Family Population	10,451,798	10,848,737	11,228,510	11,587,861	11,913,514
Water Savings (AF)- Toilets	19,523	36,830	49,002	57,818	64,337
Water Savings (AF)- Clothes Washers	11,970	20,930	27,486	32,347	35,972
Water Savings (AF)- Total	31,493	57,760	76,488	90,165	100,309
GPCD Reduction - Toilets	1.7	3.0	3.9	4.5	4.8
GPCD Reduction - Clothes Washers	1.0	1.7	2.2	2.5	2.7
GPCD Reduction - Total	2.7	4.8	6.1	6.9	7.5
County Range of Total GPCD Reduction - Min	2.3	4.0	5.1	5.8	6.2
County Range of Total GPCD Reduction - Max	3.2	5.5	6.7	7.4	8.0

Table 26. Statewide Effect of Plumbing Codes and Appliance Standards on Multi-Family Water Use by SB 407 Scenario

Year	2020	2025	2030	2035	2040
Total Savings (AF) SB 407 Scenario 1	27,906	48,806	65,470	78,883	89,686
Total Savings (AF) SB 407 Scenario 2	31,493	57,760	76,488	90,165	100,309
Total Savings (AF) SB 407 Scenario 3	63,088	77,508	88,873	97,965	105,245

Year	2020	2025	2030	2035	2040
GPCD Reduction SB407 Scenario 1	2.4	4.0	5.2	6.1	6.7
GPCD Reduction SB407 Scenario 2	2.7	4.8	6.1	6.9	7.5
GPCD Reduction SB407 Scenario 3	5.4	6.4	7.1	7.5	7.9

Figure 22. Projected Percent of Multi-Family Toilet Inventory by Toilet Type

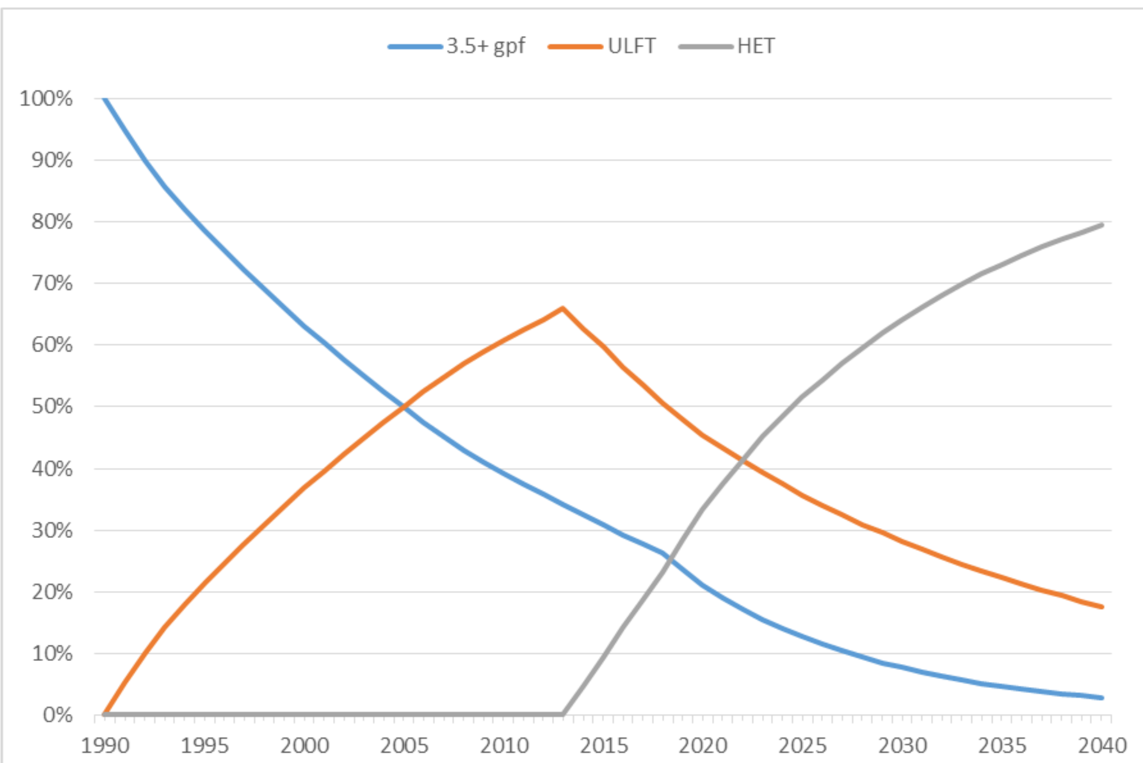


Figure 23. Projected Percent of Conventional and HEW Multi-Family Clothes Washers

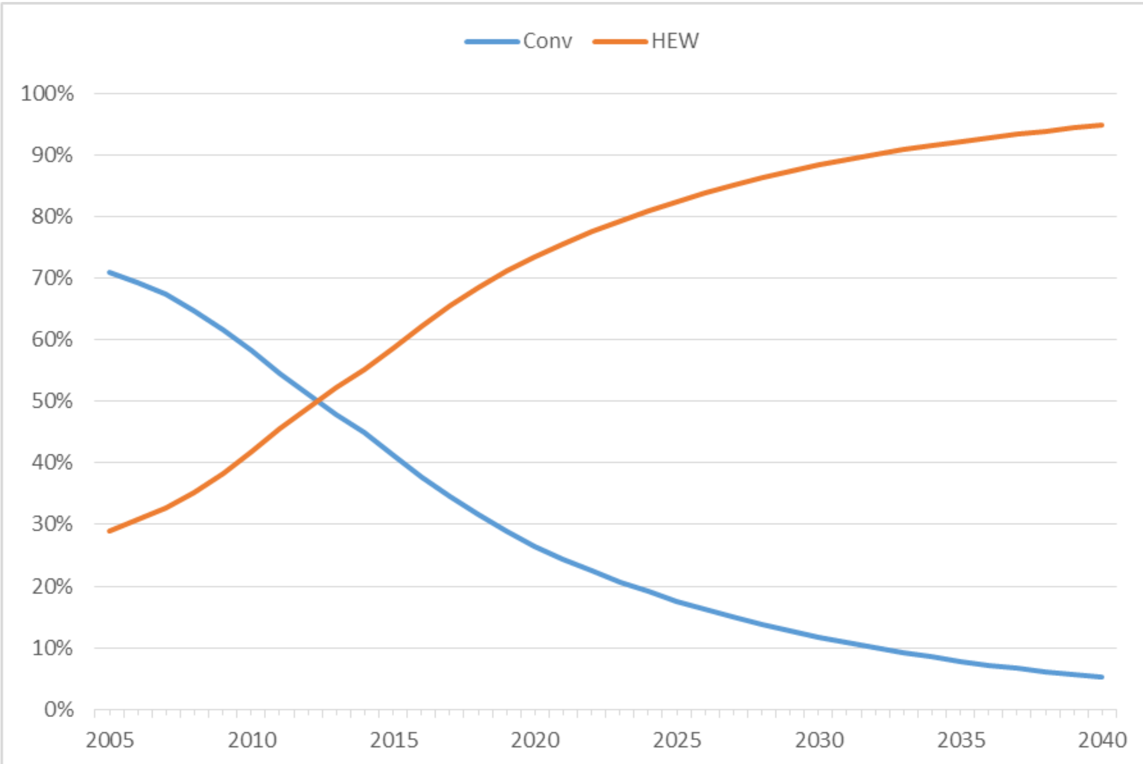
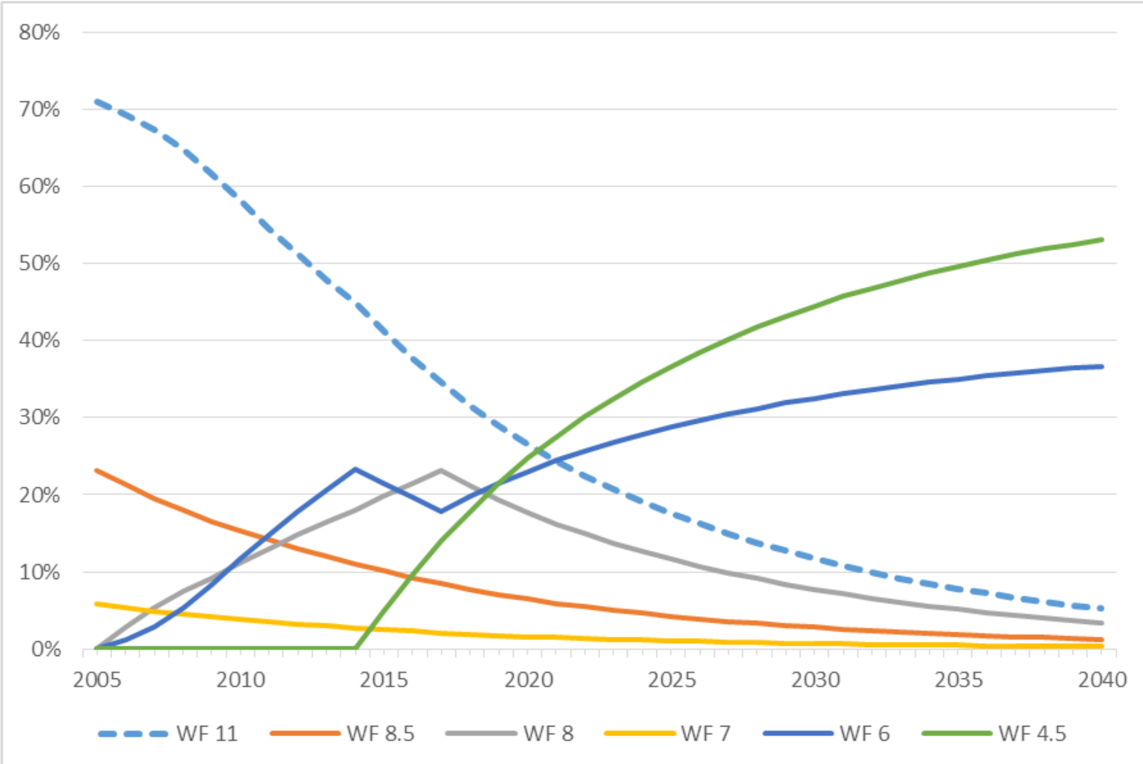


Figure 24. Projected Percent of Multi-Family Clothes Washers by Water Factor



Combined Residential and Non-Residential Sectors

Table 10 summarizes the total estimated statewide effects of plumbing codes and appliance standards. These effects are based on changes in residential toilet and clothes washer water use discussed in the previous two sections, plus non-residential water use for coin-op clothes, toilets, and urinals.

Note that the GPCD reduction estimates presented in this section are based on total population, which includes population in both households and group quarters. In Section 5.2, the GPCD estimates were calculated using the single-family household population, and in Section 5.3, they were calculated using the multi-family population. Thus, it is important to be mindful that each section is using a different population in the denominator of the GPCD calculation and therefore the GPCD estimates in these three sections cannot be directly compared.

Aggregate water savings are projected to reach more than 512 TAF in 2040 under SB 407 scenario 2. Approximately two-thirds of the savings is associated with toilet/urinal plumbing codes and one-third with clothes washer efficiency standards. Relative to the 2015 baseline, M&I per capita demand is reduced by 9.7 GPCD by 2040. County-level GPCD effects vary, with a minimum 2040 reduction of 7.4 GPCD and a maximum reduction of 12.4 GPCD (see Attachment 3 for county-level estimates).

As with the single- and multi-family results, the effect of the SB 407 scenario, as shown in Table 11, is primarily one of timing. In the long-run, the differences between the three scenarios are not large, but in the near-term they are. For the reasons discussed in Section 3.2, scenario 2 is believed to provide the best estimate of the future effect of SB 407 on M&I water use.

Table 27. Statewide Effect of Plumbing Codes and Appliance Standards on M&I Water Use: SB 407 scenario 2

Year	2020	2025	2030	2035	2040
Total Population	40,616,702	42,373,655	44,099,585	45,747,645	47,233,240
Water Savings (AF) - Toilets & Urinals	104,687	190,218	253,626	301,817	338,745
Water Savings (AF) - Clothes Washers 1/	57,187	100,163	131,938	155,812	173,741
Water Savings (AF) - Total	161,874	290,381	385,563	457,630	512,486
GPCD Reduction - Toilets & Urinals	2.3	4.0	5.1	5.9	6.4
GPCD Reduction - Clothes Washers 1/	1.3	2.1	2.7	3.0	3.3
GPCD Reduction - Total	3.6	6.1	7.8	8.9	9.7
County Range of Total GPCD Reduction Min	2.8	4.7	6.0	6.8	7.4
County Range of Total GPCD Reduction Max	5.4	8.8	10.7	11.7	12.4

1/ Includes savings from in-unit residential, common area, and coin-op washers.

Table 28. Statewide Effect of Plumbing Codes and Appliance Standards on M&I Water Use by SB 407 Scenario

Year	2020	2025	2030	2035	2040
Total Savings (AF) SB 407 Scenario 1	140,824	249,119	336,509	407,756	465,476
Total Savings (AF) SB 407 Scenario 2	161,874	290,381	385,563	457,630	512,486
Total Savings (AF) SB 407 Scenario 3	304,661	382,748	445,478	496,603	537,912
GPCD Reduction SB 407 Scenario 1	3.1	5.2	6.8	8.0	8.8
GPCD Reduction SB 407 Scenario 2	3.6	6.1	7.8	8.9	9.7
GPCD Reduction SB 407 Scenario 3	6.7	8.1	9.0	9.7	10.2

Projected Reduction in R-GPCD

More than three-quarters of the projected reduction in water use is expected to occur in the single- and multi-family residential sectors. Data on residential per capita water use (R-GPCD) is collected by the State Water Board on a monthly basis. During the current drought, the State Water Board used R-GPCD as the basis for setting water supplier conservation targets.

Indoor R-GPCD currently averages about 59 gallons per day.[57] By 2040, plumbing codes and appliance standards are projected to reduce indoor R-GPCD by 7.6 gallons, or about 13 percent of current indoor R-GPCD. The expected change in indoor R-GPCD by year is shown in Table 12. Estimated

[57] See Table 1.

reductions in R-GPCD by county are provided in Attachment 4 and discussed in the next section.

Indoor single-family residential water use in new homes fitted with EPA WaterSense labeled products averages 36 GPCD (DeOreo, et al., 2011). The difference in indoor water use between the average residence in California and such a home is about 23 GPCD. Plumbing codes and appliance standards on their own are projected to reduce this difference by a third to 15 GPCD by 2040.

Table 29. Change in 2015 Baseline Indoor R-GPCD Due to Plumbing Codes and Appliance Standards

Year	2020	2025	2030	2035	2040
2015 Baseline Indoor R-GPCD	58.6	58.6	58.6	58.6	58.6
Reduction Due to Codes and Standards	2.9	4.8	6.1	7.0	7.6
Indoor R-GPCD After Adjusting for Codes and Standards	55.7	53.8	52.5	51.6	51.0
% Reduction from 2015 Baseline	5%	8%	10%	12%	13%

Geographic Variability in Projected R-GPCD Reduction

Projected savings vary to some degree by county. These differences are driven by differences in the age of the housing stock, the projected rate of growth in the county, and, for SB 407 scenario 2, the rate of property resale.

Effect of Housing Stock Age on Project Water Savings

Housing stock age has a significant effect on projected water savings for toilets. Figure 7 plots the projected reduction in R-GPCD from toilet standards against the percent of a county's 2014 housing stock constructed before 1990.[58] Projected savings are positively correlated with housing

[58] Data on the distribution of housing stock age is from the 2014 American Community Survey Five-Year Estimates.

stock age. Toilet standards are projected to have a bigger effect on R-GPCD in counties with older housing stocks. Approximately 65 percent of the variation across counties in projected savings from toilets is explained by differences in housing stock age. This same relationship does not hold for clothes washers, as seen in Figure 8. Housing stock age is not a significant driver of projected water savings in the case of clothes washers. Clothes washers have much shorter average lifespans than toilets and they are mobile. Both factors help to decouple the age of the house from the age of its clothes washer.

Housing stock age is positively correlated with total savings, but the effect is not very large. This is shown in Figure 9, where R-GPCD savings in 2040 is plotted against the percent of the housing stock in 2014 constructed before 1990. The difference in the expected reduction in R-GPCD by 2040 between a county with 60 percent of its 2014 housing stock constructed before 1990 and one with 90 percent is only 0.67 GPCD.

Figure 25. Effect of Housing Stock Age on Toilet Water Savings from Efficiency Standards

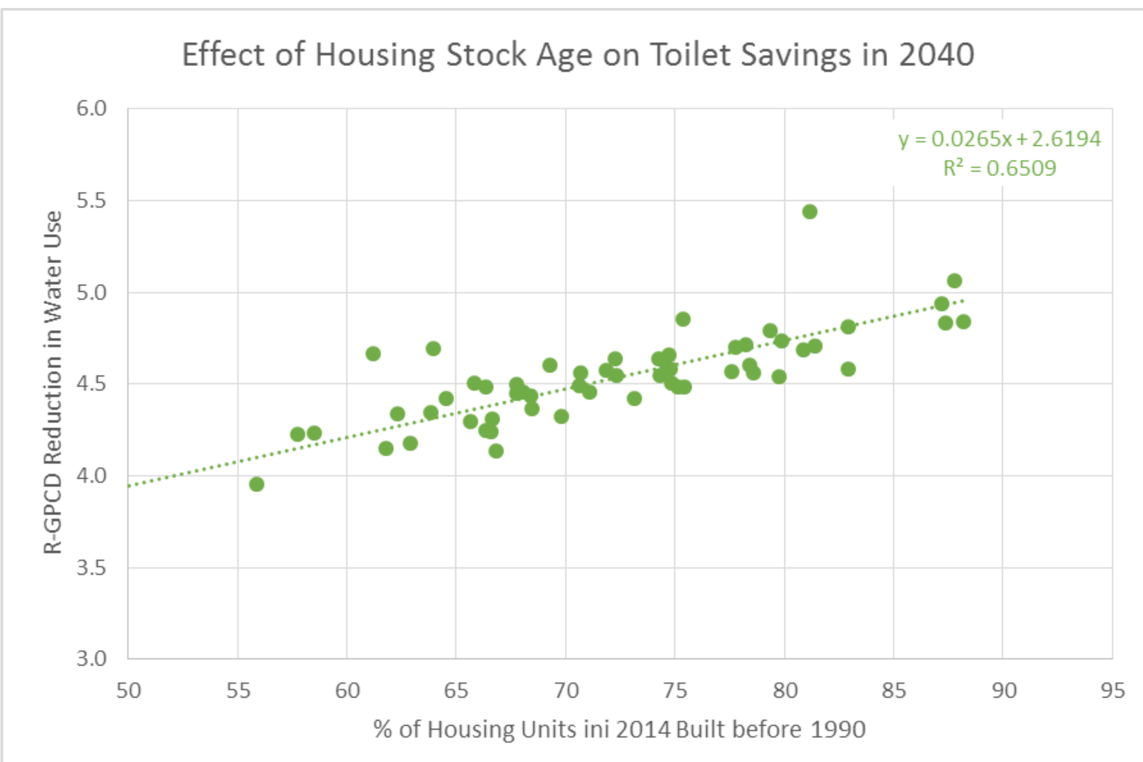


Figure 26. Effect of Housing Stock Age on Clothes Washer Water Savings from Efficiency Codes

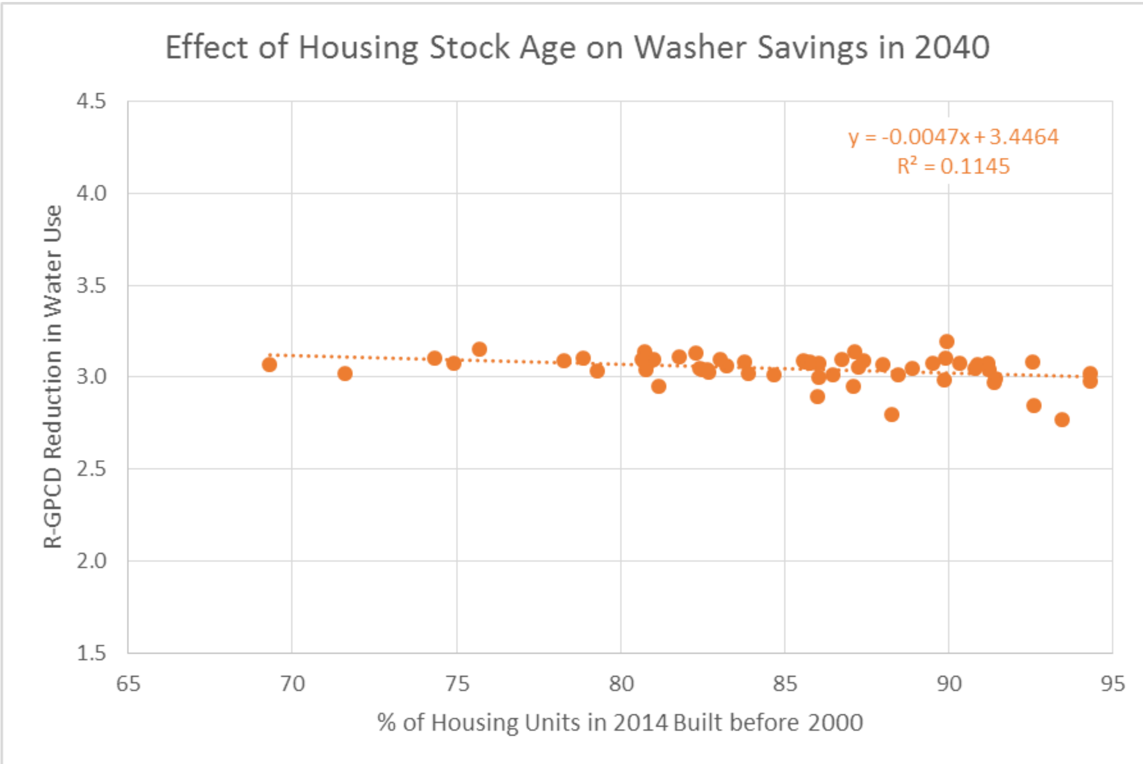
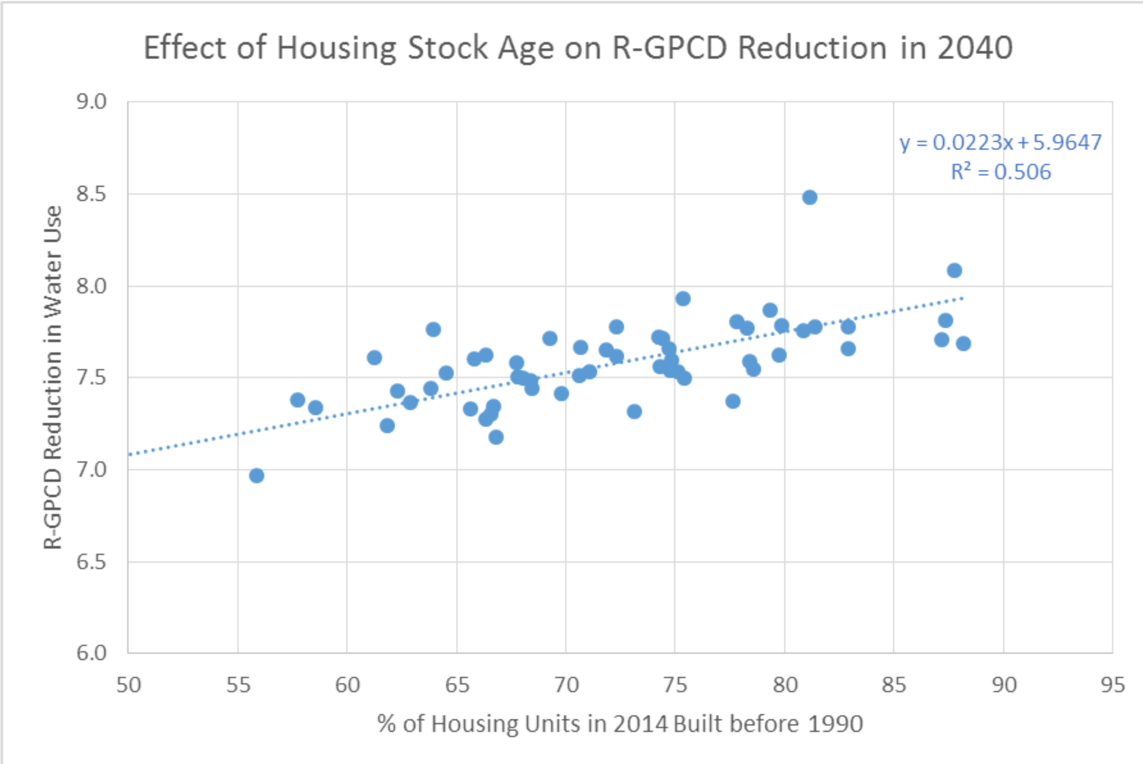


Figure 27. Effect of Housing Stock Age on R-GPCD Reduction from Efficiency Codes



R-GPCD Reduction by Hydrologic Region and County

Table 13 groups counties by primary hydrologic region and shows the average R-GPCD reduction and variability for each grouping.[59] The differences across hydrologic regions are small and likely well within the model's error.

Table 14 shows the average R-GPCD reduction in 2040 for each county within a hydrologic region. The largest county differences occur in the Sacramento River and South Lahontan hydrologic regions. But even in these two cases, the county-level differences are not large. It does not appear that differences in expected savings from plumbing codes and appliance

[59] Some counties are in more than one hydrologic region. This study defines the county's primary hydrologic region as the one in which the majority of population is located.

standards would provide a strong justification for regionally differentiating urban water use reduction goals and targets.

Table 30. Projected 2040 R-GPCD Reduction by Hydrologic Region

Hydrologic Region	Number of Counties	Average R-GPCD Reduction	Standard Deviation	Minimum	Maximum
Central Coast	5	7.6	0.2	7.4	7.8
Colorado River	1	7.3	0.0	7.3	7.3
North Coast	6	7.6	0.1	7.5	7.8
North Lahontan	2	7.7	0.1	7.6	7.8
Sacramento River	16	7.5	0.3	6.7	7.9
San Francisco Bay	8	7.8	0.2	7.6	8.1
San Joaquin River	8	7.4	0.1	7.2	7.6
South Coast	6	7.4	0.2	7.0	7.7
South Lahontan	2	7.9	0.6	7.3	8.5
Tulare Lake	4	7.5	0.1	7.4	7.6
Statewide	**58**	**7.6**	**0.3**	**6.7**	**8.5**

Table 31. Projected 2040 R-GPCD Reduction by County

Hydrologic Region /County	Average R-GPCD Reduction in 2040	Standard Deviation	Minimum	Maximum
Central Coast	**7.6**	**0.2**	**7.4**	**7.8**
Monterey	7.8			
San Benito	7.4			
San Luis Obispo	7.4			
Santa Barbara	7.8			
Santa Cruz	7.7			
Colorado River	**7.3**	**0.0**	**7.3**	**7.3**

Hydrologic Region /County	Average R-GPCD Reduction in 2040	Standard Deviation	Minimum	Maximum
Imperial	7.3			
North Coast	**7.6**	**0.1**	**7.5**	**7.8**
Del Norte	7.5			
Humboldt	7.5			
Mendocino	7.8			
Siskiyou	7.8			
Sonoma	7.5			
Trinity	7.7			
North Lahontan	**7.7**	**0.1**	**7.6**	**7.8**
Alpine	7.6			
Lassen	7.8			
Sacramento River	**7.5**	**0.3**	**6.7**	**7.9**
Butte	7.7			
Colusa	7.7			
El Dorado	7.2			
Glenn	7.9			
Lake	7.6			
Modoc	7.8			
Nevada	7.4			
Placer	6.7			
Plumas	7.6			
Sacramento	7.5			
Shasta	7.7			
Sierra	7.6			
Sutter	7.6			
Tehama	7.5			

Hydrologic Region /County	Average R-GPCD Reduction in 2040	Standard Deviation	Minimum	Maximum
Yolo	7.3			
Yuba	7.8			
San Francisco Bay	**7.8**	**0.2**	**7.6**	**8.1**
Alameda	7.8			
Contra Costa	7.6			
Marin	7.8			
Napa	7.7			
San Francisco	7.7			
San Mateo	8.1			
Santa Clara	7.9			
Solano	7.7			
San Joaquin River	**7.4**	**0.1**	**7.2**	**7.6**
Amador	7.3			
Calaveras	7.2			
Madera	7.4			
Mariposa	7.3			
Merced	7.4			
San Joaquin	7.3			
Stanislaus	7.6			
Tuolumne	7.5			
South Coast	**7.4**	**0.2**	**7.0**	**7.7**
Los Angeles	7.7			
Orange	7.6			
Riverside	7.0			
San Bernardino	7.5			
San Diego	7.5			

Hydrologic Region /County	Average R-GPCD Reduction in 2040	Standard Deviation	Minimum	Maximum
Ventura	7.4			
South Lahontan	**7.9**	**0.6**	**7.3**	**8.5**
Inyo	8.5			
Mono	7.3			
Tulare Lake	**7.5**	**0.1**	**7.4**	**7.6**
Fresno	7.5			
Kern	7.5			
Kings	7.4			
Tulare	7.6			
Statewide	**7.6**	**0.3**	**6.7**	**8.5**

Summary and Conclusions

This analysis indicates that plumbing codes and appliance standards will temper growth in M&I water use in California over the next several decades, just as they have done over the previous 25 years. Plumbing codes and appliance standards are projected to annually save between 465 and 538 TAF statewide by 2040. This translates to a reduction of between 9 and 10 gallons per person per day.

The results from this study can be used to inform projections of baseline indoor R-GPCD over time. These baselines, in turn, can be used in the development of indoor R-GPCD reduction targets. The county-level estimates will enable the baselines to reflect regional differences due to age of the housing stock, differences in projected population and housing growth, differences in household density, and other factors affecting residential indoor water use, though the modeling done for this study suggests the impact of such differences on projected GPCD savings are not large across large areas such as counties or hydrologic regions. They may be more significant across smaller geographic units such as utility service areas. The models developed for this study can easily be adapted to small geographic units of analysis.

The study results can also help policymakers understand the underlying rate of transformation of the existing inventory of non-efficient plumbing fixtures. Because the models developed for this study are dynamic, they provide insight into how fast or slow appliance efficiency can be expected to change over time under existing codes and standards. This can be useful for establishing timeframes for meeting water use targets. One of the goals of setting targets is to accelerate transformation of inefficient fixtures to efficient fixtures. However, in order to ensure realistic time-frames for doing this, it is necessary to have an understanding of the underlying "natural" rate of transformation. The models developed for this study provide one way in which this understanding can be developed.

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Attachment 1. Plumbing Fixture Ownership and Property Resale Rates by County

County	SMSA Association	Avg Toilets Per Housing Unit SFR	Avg Toilets Per Housing Unit MFR	In Unit Washer Ownership Rate SFR	In Unit Washer Ownership Rate MFR	Property Resale Rate SFR	Property Resale Rate MFR
Alameda	'5775'	2.238	1.396	0.912	0.354	0.039	0.058
Alpine	'6920'	2.164	1.380	0.925	0.420	0.033	0.051
Amador	6920'	2.240	1.457	0.911	0.388	0.034	0.026
Butte	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Calaveras	6920'	2.240	1.457	0.911	0.388	0.034	0.026
Colusa	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Contra Costa	'7360'	2.290	1.330	0.918	0.290	0.039	0.058
Del Norte	6920'	2.240	1.457	0.911	0.388	0.038	0.032
El Dorado	6920'	2.240	1.457	0.911	0.388	0.037	0.037
Fresno	'6920'	2.164	1.380	0.925	0.420	0.040	0.038
Glenn	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Humboldt	6920'	2.240	1.457	0.911	0.388	0.038	0.032
Imperial	'6780'	2.240	1.457	0.911	0.388	0.022	0.012
Inyo	'6780'	2.240	1.457	0.911	0.388	0.111	0.123
Kern	'6920'	2.164	1.380	0.925	0.420	0.040	0.038
Kings	'6920'	2.164	1.380	0.925	0.420	0.040	0.038
Lake	'6920'	2.164	1.380	0.925	0.420	0.037	0.037

County	SMSA Association	Avg Toilets Per Housing Unit SFR	Avg Toilets Per Housing Unit MFR	In Unit Washer Ownership Rate SFR	In Unit Washer Ownership Rate MFR	Property Resale Rate SFR	Property Resale Rate MFR
Lassen	'6920'	2.164	1.380	0.925	0.420	0.033	0.051
Los Angeles	'4480'	2.103	1.372	0.850	0.260	0.042	0.056
Madera	'6920'	2.164	1.380	0.925	0.420	0.034	0.026
Marin	'7360'	2.290	1.330	0.918	0.290	0.039	0.058
Mariposa	6920'	2.240	1.457	0.911	0.388	0.034	0.026
Mendocino	'6920'	2.164	1.380	0.925	0.420	0.038	0.032
Merced	'6920'	2.164	1.380	0.925	0.420	0.034	0.026
Modoc	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Mono	6920'	2.240	1.457	0.911	0.388	0.111	0.123
Monterey	'7400'	2.361	1.333	0.946	0.356	0.033	0.012
Napa	'7360'	2.290	1.330	0.918	0.290	0.039	0.058
Nevada	6920'	2.240	1.457	0.911	0.388	0.037	0.037
Orange	'0360'	2.551	1.494	0.938	0.339	0.042	0.056
Placer	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Plumas	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Riverside	'6780'	2.240	1.457	0.911	0.388	0.042	0.056
Sacramento	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
San Benito	'7400'	2.361	1.333	0.946	0.356	0.033	0.012
San Bernardino	'6780'	2.240	1.457	0.911	0.388	0.042	0.056

County	SMSA Association	Avg Toilets Per Housing Unit SFR	Avg Toilets Per Housing Unit MFR	In Unit Washer Ownership Rate SFR	In Unit Washer Ownership Rate MFR	Property Resale Rate SFR	Property Resale Rate MFR
San Diego	'7320'	2.386	1.440	0.915	0.362	0.042	0.056
San Francisco	'7360'	2.290	1.330	0.918	0.290	0.039	0.058
San Joaquin	6920'	2.240	1.457	0.911	0.388	0.034	0.026
San Luis Obispo	'7400'	2.361	1.333	0.946	0.356	0.033	0.012
San Mateo	'7360'	2.290	1.330	0.918	0.290	0.039	0.058
Santa Barbara	'7400'	2.361	1.333	0.946	0.356	0.033	0.012
Santa Clara	'7400'	2.361	1.333	0.946	0.356	0.039	0.058
Santa Cruz	'7400'	2.361	1.333	0.946	0.356	0.033	0.012
Shasta	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Sierra	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Siskiyou	'6920'	2.164	1.380	0.925	0.420	0.038	0.032
Solano	'6920'	2.164	1.380	0.925	0.420	0.039	0.058
Sonoma	'7360'	2.290	1.330	0.918	0.290	0.038	0.032
Stanislaus	'6920'	2.164	1.380	0.925	0.420	0.034	0.026
Sutter	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Tehama	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Trinity	'6920'	2.164	1.380	0.925	0.420	0.038	0.032
Tulare	'6920'	2.164	1.380	0.925	0.420	0.040	0.038

County	SMSA Association	Avg Toilets Per Housing Unit SFR	Avg Toilets Per Housing Unit MFR	In Unit Washer Ownership Rate SFR	In Unit Washer Ownership Rate MFR	Property Resale Rate SFR	Property Resale Rate MFR
Tuolumne	6920'	2.240	1.457	0.911	0.388	0.034	0.026
Ventura	'4480'	2.103	1.372	0.850	0.260	0.042	0.056
Yolo	'6920'	2.164	1.380	0.925	0.420	0.037	0.037
Yuba	'6920'	2.164	1.380	0.925	0.420	0.037	0.037

Attachment 2. Data for Calculation of Average Flush Rate for Non-Residential Toilets CUWCC 1992 Toilet Inventory by County and Sector

	Hotels	Restaurant	Health Care	Offices	Retail/ Wholesale	Other	Industrial	Churches	Gov't	Schools
Avg Flushes 1/	7.6	22.4	10.0	9.5	19.0	8.6	11.0	13.3	11.9	8.6
GPD Savings 2/	16	47	21	20	40	18	23	28	25	18

County	Hotels	Restaurant	Health Care	Offices	Retail/ Wholesale	Other	Industrial	Churches	Gov't	Schools	Avg. Flushes per Day 3/
Alameda	17,096	4,949	21,068	47,700	42,809	11,174	13,804	2,748	3,894	7,322	12.3
Alpine	337	2	4	17	16	9	0	13	18	5	8.6
Amador	1,124	127	487	392	1,205	230	247	87	124	164	12.3
Butte	1,579	724	3,821	3,409	6,805	2,056	1,081	366	519	1,098	13.0
Calaveras	730	111	283	331	989	330	139	64	91	222	12.5
Colusa	337	69	147	123	466	230	96	32	45	143	12.3
Contra Costa	3,113	2,731	13,435	28,377	26,146	7,284	4,340	1,532	2,171	5,037	12.6
Del Norte	1,124	114	247	198	723	92	126	67	94	185	11.8
El Dorado	5,450	429	1,220	1,658	3,697	1,349	526	351	498	926	11.5
Fresno	8,752	2,296	11,635	14,351	21,667	4,335	4,075	1,171	1,660	5,557	12.6
Glenn	225	80	133	200	663	99	163	31	44	122	13.6

County	Hotels	Restaurant	Health Care	Offices	Retail/ Wholesale	Other	Industrial	Churches	Gov't	Schools	Avg. Flushes per Day 3/
Humboldt	3,877	534	2,246	2,117	5,017	1,239	1,217	355	503	544	12.4
Imperial	1,348	327	936	1,137	3,910	443	258	171	242	1,138	13.5
Inyo	1,742	128	359	236	1,022	212	219	101	143	119	11.6
Kern	7,445	1,862	7,452	11,392	16,723	2,689	1,883	895	1,268	4,525	12.6
Kings	730	256	898	621	2,295	438	418	112	159	818	13.1
Lake	1,236	171	628	668	1,558	371	130	106	150	345	12.4
Lassen	899	93	314	250	770	154	144	62	89	184	12.0
Los Angeles	120,819	31,228	153,767	305,617	268,243	121,124	105,028	19,176	27,177	56,675	11.9
Madera	1,011	242	828	937	2,274	487	614	130	184	721	12.7
Marin	3,387	1,219	5,173	12,435	11,190	3,489	1,406	705	999	1,091	12.5
Mariposa	1,124	40	62	151	518	170	44	58	82	84	11.1
Mendocino	4,720	358	1,284	1,219	3,689	736	840	312	442	572	11.9
Merced	1,405	450	1,942	1,656	4,506	823	1,033	232	329	1,429	13.0
Modoc	281	37	22	62	313	34	36	19	27	60	12.9
Mono	2,528	143	75	244	513	184	22	112	158	61	10.2
Monterey	11,548	1,478	4,597	6,891	12,283	2,347	1,366	905	1,283	2,139	12.2
Napa	4,443	521	2,372	2,250	3,964	1,426	1,137	331	469	642	11.8
Nevada	1,967	337	1,479	1,950	3,219	1,123	650	223	317	602	12.3

County	Hotels	Restaurant	Health Care	Offices	Retail/ Wholesale	Other	Industrial	Churches	Gov't	Schools	Avg. Flushes per Day 3/
Orange	57,938	10,701	52,997	111,864	84,645	21,463	33,422	6,291	8,916	12,578	11.8
Placer	2,247	970	3,627	4,207	6,861	2,290	1,331	417	590	1,186	12.8
Plumas	1,180	90	276	308	803	136	171	74	104	132	11.7
Riverside	17,413	3,347	12,244	16,729	28,959	7,343	4,254	1,690	2,395	7,839	12.4
Sacramento	10,889	4,355	15,728	36,929	34,414	9,460	4,730	2,061	2,920	7,007	12.5
San Benito	393	111	274	310	997	202	253	52	73	293	13.1
San Bernardino	17,580	4,628	17,331	23,851	41,516	9,425	9,934	2,282	3,234	11,400	12.6
San Diego	64,398	9,971	39,462	85,781	81,261	20,212	18,503	5,350	7,583	15,263	11.9
San Francisco	43,553	5,042	12,407	62,808	32,023	9,741	6,514	2,786	3,948	2,906	11.2
San Joaquin	4,600	1,467	7,839	7,942	14,277	3,187	3,657	769	1,090	3,346	12.7
San Luis Obispo	7,620	1,072	3,868	4,580	8,224	2,088	1,182	629	892	959	12.2
San Mateo	16,112	2,640	10,319	28,874	24,120	6,508	6,010	1,619	2,294	3,454	12.0
Santa Barbara	10,545	1,621	5,253	12,337	14,135	3,413	3,066	954	1,353	2,088	12.2
Santa Clara	26,682	5,973	23,249	72,675	49,194	13,010	27,612	3,755	5,322	8,726	11.9
Santa Cruz	4,141	1,019	4,165	6,084	8,447	2,761	1,967	569	807	1,317	12.4
Shasta	3,184	645	3,261	3,264	6,153	1,403	1,024	359	509	1,086	12.6
Sierra	169	7	17	19	59	0	45	9	12	26	10.7
Siskiyou	2,304	211	575	454	1,710	409	342	147	209	329	11.9

County	Hotels	Restaurant	Health Care	Offices	Retail/ Wholesale	Other	Industrial	Churches	Gov't	Schools	Avg. Flushes per Day 3/
Solano	2,609	1,161	4,007	5,345	10,100	2,340	1,403	499	707	2,450	13.1
Sonoma	6,774	1,621	8,347	10,758	14,904	4,599	3,602	957	1,357	2,222	12.4
Stanislaus	3,537	1,187	6,007	5,616	12,247	2,610	3,268	615	872	2,666	12.9
Sutter	454	232	845	999	2,334	460	315	104	148	506	13.4
Tehama	1,236	163	478	510	1,491	285	356	102	144	347	12.4
Trinity	1,011	55	62	112	418	98	113	51	73	79	11.0
Tulare	3,427	881	3,996	3,852	8,882	1,743	1,852	448	635	2,159	12.9
Tuolumne	1,629	245	563	841	1,954	601	286	137	194	302	12.4
Ventura	6,751	2,243	11,071	20,307	20,622	5,732	5,513	1,287	1,825	4,357	12.3
Yolo	2,720	559	1,475	2,886	4,393	1,050	1,087	252	357	887	12.5
Yuba	778	167	400	367	1,322	295	293	74	105	463	12.7

1/ Average flushes per day equal to GPD Savings divided by (3.9-1.8)
2/ GPD savings from CUWCC CII ULFT Savings Study (2001)
3/ Average flushes per day is a toilet population weighted average of the average daily flushes for toilets in each of the ten sectors.

Attachment 3. Plumbing Code and Appliance Standard Effects by County

Single-Family Effects

	Single Family Population 2020	Single Family Population 2025	Single Family Population 2030	Single Family Population 2035	Single Family Population 2040
Statewide	29,298,916	30,611,455	31,908,231	33,159,820	34,286,582
County					
Alameda	1,126,018	1,179,849	1,227,795	1,274,340	1,323,277
Alpine	714	733	732	717	692
Amador	32,901	34,326	35,281	35,917	36,267
Butte	192,296	200,728	207,615	214,147	217,149
Calaveras	46,827	49,195	50,994	52,528	53,455
Colusa	20,830	22,144	23,369	24,497	25,466
Contra Costa	938,142	984,285	1,030,233	1,078,860	1,126,508
Del Norte	22,398	22,840	23,204	23,309	23,302
El Dorado	168,894	174,297	178,276	181,917	184,101
Fresno	804,160	861,257	915,149	966,905	1,015,032
Glenn	25,803	26,899	27,898	28,824	29,626
Humboldt	113,508	114,847	115,040	113,995	112,794
Imperial	163,368	180,129	194,494	208,093	220,413
Inyo	17,234	17,565	17,735	17,728	17,656
Kern	801,544	881,448	962,482	1,045,759	1,130,239
Kings	123,204	132,567	141,619	150,786	160,476
Lake	64,511	68,834	72,596	76,118	78,945
Lassen	25,076	25,803	26,282	26,739	26,984
Los Angeles	6,589,721	6,756,158	6,899,762	7,024,690	7,130,402
Madera	144,317	157,706	170,787	184,684	198,580
Marin	193,748	194,327	195,710	198,138	200,837

	Single Family Population 2020	Single Family Population 2025	Single Family Population 2030	Single Family Population 2035	Single Family Population 2040
Mariposa	17,453	18,541	18,994	19,286	19,225
Mendocino	77,271	78,782	79,926	80,658	81,205
Merced	238,658	258,552	279,514	300,846	321,973
Modoc	8,967	9,121	9,116	9,091	9,052
Mono	7,422	7,717	7,960	8,192	8,267
Monterey	321,641	333,358	343,449	352,382	360,322
Napa	115,317	118,949	122,564	125,581	128,030
Nevada	92,846	96,138	98,593	100,503	102,018
Orange	2,201,715	2,243,704	2,280,973	2,313,159	2,339,603
Placer	341,211	362,593	385,367	411,568	438,886
Plumas	18,120	18,199	18,082	17,794	17,315
Riverside	2,109,275	2,266,348	2,437,522	2,599,012	2,736,443
Sacramento	1,202,596	1,268,648	1,338,432	1,410,540	1,479,252
San Benito	54,273	58,488	62,872	67,120	71,001
San Bernardino	1,827,567	1,941,898	2,064,096	2,181,876	2,284,620
San Diego	2,258,546	2,329,831	2,400,878	2,465,527	2,525,919
San Francisco	374,526	391,596	406,324	418,131	431,003
San Joaquin	633,981	680,305	738,773	799,242	857,825
San Luis Obispo	227,242	235,000	241,194	247,711	247,890
San Mateo	562,094	579,376	595,170	612,886	632,398
Santa Barbara	322,438	334,619	346,496	359,083	363,717
Santa Clara	1,390,365	1,453,031	1,517,181	1,581,943	1,644,285
Santa Cruz	219,061	225,737	230,697	235,579	235,490
Shasta	158,855	165,717	171,204	175,944	179,667
Sierra	3,052	2,972	2,890	2,807	2,722
Siskiyou	40,791	41,299	41,494	41,439	40,970
Solano	365,917	384,174	403,302	423,428	440,789

	Single Family Population 2020	Single Family Population 2025	Single Family Population 2030	Single Family Population 2035	Single Family Population 2040
Sonoma	429,619	447,948	464,720	480,193	494,095
Stanislaus	492,046	524,197	555,522	584,568	613,043
Sutter	86,356	92,326	98,617	105,613	112,761
Tehama	59,863	61,625	63,206	64,484	65,100
Trinity	13,010	13,259	13,315	13,229	13,031
Tulare	430,263	463,443	499,489	532,216	561,800
Tuolumne	48,051	49,139	50,151	51,045	51,269
Ventura	710,039	731,519	751,316	769,281	782,499
Yolo	156,228	164,729	173,268	184,435	190,202
Yuba	67,024	72,639	78,511	84,738	90,692

SFR-GPCD Reduction Relative to 2015 in the Years 2020, 2025, 2030, 2035, and 2040

	SFR-GPCD Reduction Relative to 2015 in 2020	SFR-GPCD Reduction Relative to 2015 in 2025	SFR-GPCD Reduction Relative to 2015 in 2030	SFR-GPCD Reduction Relative to 2015 in 2035	SFR-GPCD Reduction Relative to 2015 in 2040
Statewide	2.9	4.9	6.1	7.0	7.6
County Variation Mean	2.9	4.9	6.1	7.0	7.6
County Variation St.Dev.	0.2	0.3	0.3	0.3	0.3
County Variation Min	2.7	4.4	5.5	6.2	6.7
County Variation Max	4.0	6.2	7.4	8.1	8.6
County					
Alameda	3.0	5.0	6.3	7.2	7.8
Alpine	2.9	5.1	6.5	7.4	8.1
Amador	2.7	4.6	5.9	6.7	7.3
Butte	3.1	5.1	6.3	7.2	7.7
Calaveras	2.9	4.7	5.9	6.7	7.2
Colusa	3.3	5.2	6.5	7.3	7.8
Contra Costa	2.9	4.8	6.1	7.0	7.6
Del Norte	2.9	4.9	6.1	7.0	7.6
El Dorado	2.8	4.6	5.8	6.6	7.2

	SFR-GPCD Reduction Relative to 2015 in 2020	SFR-GPCD Reduction Relative to 2015 in 2025	SFR-GPCD Reduction Relative to 2015 in 2030	SFR-GPCD Reduction Relative to 2015 in 2035	SFR-GPCD Reduction Relative to 2015 in 2040
Fresno	3.0	4.9	6.1	6.9	7.5
Glenn	3.1	5.1	6.5	7.4	8.0
Humboldt	3.0	4.9	6.2	7.0	7.6
Imperial	3.3	5.1	6.2	6.9	7.4
Inyo	4.0	6.2	7.4	8.1	8.6
Kern	3.2	5.0	6.2	7.0	7.5
Kings	2.9	4.8	6.1	6.9	7.4
Lake	2.9	5.0	6.3	7.1	7.7
Lassen	3.1	5.0	6.3	7.2	7.8
Los Angeles	2.9	4.9	6.2	7.1	7.7
Madera	3.0	4.9	6.1	6.9	7.4
Marin	2.9	4.8	6.2	7.2	7.8
Mariposa	2.7	4.8	6.0	6.8	7.3
Mendocino	2.9	4.9	6.2	7.2	7.8
Merced	2.8	4.8	6.0	6.9	7.4
Modoc	2.7	4.8	6.2	7.1	7.8
Mono	3.2	5.3	6.5	7.2	7.6
Monterey	3.0	5.0	6.4	7.3	7.9

	SFR-GPCD Reduction Relative to 2015 in 2020	SFR-GPCD Reduction Relative to 2015 in 2025	SFR-GPCD Reduction Relative to 2015 in 2030	SFR-GPCD Reduction Relative to 2015 in 2035	SFR-GPCD Reduction Relative to 2015 in 2040
Napa	2.9	4.9	6.2	7.1	7.7
Nevada	2.9	4.8	6.1	6.9	7.5
Orange	2.9	4.9	6.2	7.1	7.7
Placer	2.7	4.4	5.5	6.2	6.7
Plumas	2.7	4.6	6.0	6.9	7.6
Riverside	2.7	4.5	5.7	6.4	6.9
Sacramento	2.9	4.8	6.1	6.9	7.5
San Benito	2.9	4.8	6.1	6.9	7.5
San Bernardino	2.8	4.8	6.1	6.9	7.5
San Diego	2.9	4.8	6.1	7.0	7.6
San Francisco	3.0	5.0	6.3	7.2	7.8
San Joaquin	2.7	4.6	5.8	6.7	7.2
San Luis Obispo	2.8	4.7	6.0	6.9	7.5
San Mateo	3.2	5.2	6.6	7.5	8.2
Santa Barbara	3.0	5.0	6.4	7.4	8.0
Santa Clara	3.1	5.2	6.6	7.5	8.1
Santa Cruz	3.0	5.0	6.3	7.2	7.8
Shasta	3.0	5.0	6.3	7.1	7.7

	SFR-GPCD Reduction Relative to 2015 in 2020	SFR-GPCD Reduction Relative to 2015 in 2025	SFR-GPCD Reduction Relative to 2015 in 2030	SFR-GPCD Reduction Relative to 2015 in 2035	SFR-GPCD Reduction Relative to 2015 in 2040
Sierra	2.7	4.6	6.0	6.9	7.6
Siskiyou	3.0	5.0	6.3	7.2	7.9
Solano	3.0	4.9	6.2	7.0	7.6
Sonoma	2.9	4.8	6.1	7.0	7.6
Stanislaus	3.0	4.9	6.2	7.0	7.6
Sutter	3.0	4.9	6.2	7.0	7.6
Tehama	2.8	4.7	6.0	6.9	7.5
Trinity	3.1	5.1	6.3	7.2	7.8
Tulare	3.1	5.0	6.3	7.1	7.6
Tuolumne	2.7	4.7	6.1	7.0	7.6
Ventura	2.7	4.6	5.9	6.8	7.4
Yolo	2.9	4.7	6.0	6.8	7.4
Yuba	3.0	5.0	6.4	7.2	7.8

Multi-Family Effects

	Multi-Family Population in 2020	Multi-Family Population in 2025	Multi-Family Population in 2030	Multi-Family Population in 2035	Multi-Family Population in 2040
Statewide	10,451,798	10,848,737	11,228,510	11,587,861	11,913,514
Alameda	513,823	538,387	560,265	581,505	603,836
Alpine	552	566	566	555	534
Amador	1,829	1,908	1,961	1,996	2,016
Butte	39,674	41,414	42,834	44,182	44,801
Calaveras	1,611	1,693	1,754	1,807	1,839
Colusa	3,199	3,401	3,589	3,762	3,911
Contra Costa	217,247	227,932	238,572	249,833	260,867
Del Norte	3,141	3,203	3,254	3,269	3,267
El Dorado	20,314	20,964	21,442	21,880	22,143
Fresno	232,550	249,061	264,645	279,612	293,530
Glenn	4,314	4,497	4,664	4,819	4,953
Humboldt	20,736	20,980	21,016	20,825	20,606
Imperial	36,530	40,278	43,490	46,531	49,286
Inyo	1,988	2,026	2,046	2,045	2,037
Kern	147,591	162,304	177,226	192,560	208,115
Kings	22,076	23,753	25,375	27,017	28,754
Lake	5,121	5,464	5,763	6,042	6,267
Lassen	1,586	1,631	1,662	1,691	1,706
Los Angeles	3,663,348	3,755,873	3,835,706	3,905,156	3,963,923
Madera	19,585	21,402	23,177	25,063	26,949
Marin	57,190	57,361	57,769	58,486	59,283
Mariposa	1,083	1,151	1,179	1,197	1,193
Mendocino	11,290	11,510	11,678	11,785	11,865
Merced	45,059	48,815	52,773	56,801	60,789
Modoc	367	374	374	373	371

	Multi-Family Population in 2020	Multi-Family Population in 2025	Multi-Family Population in 2030	Multi-Family Population in 2035	Multi-Family Population in 2040
Mono	7,460	7,757	8,001	8,234	8,309
Monterey	102,956	106,706	109,936	112,795	115,337
Napa	26,560	27,396	28,229	28,924	29,488
Nevada	7,783	8,058	8,264	8,424	8,551
Orange	995,779	1,014,769	1,031,625	1,046,182	1,058,142
Placer	50,953	54,146	57,546	61,459	65,538
Plumas	893	897	891	877	853
Riverside	329,972	354,544	381,322	406,586	428,085
Sacramento	327,106	345,072	364,054	383,667	402,357
San Benito	8,819	9,504	10,217	10,907	11,538
San Bernardino	357,040	379,376	403,249	426,259	446,331
San Diego	1,014,668	1,046,693	1,078,611	1,107,655	1,134,787
San Francisco	491,890	514,310	533,653	549,159	566,065
San Joaquin	117,393	125,970	136,797	147,993	158,841
San Luis Obispo	39,489	40,837	41,913	43,045	43,076
San Mateo	205,782	212,110	217,892	224,377	231,520
Santa Barbara	115,302	119,657	123,904	128,406	130,063
Santa Clara	548,814	573,549	598,872	624,434	649,043
Santa Cruz	52,004	53,589	54,766	55,925	55,904
Shasta	26,077	27,204	28,104	28,882	29,494
Sierra	88	86	84	81	79
Siskiyou	4,977	5,039	5,063	5,056	4,999
Solano	75,845	79,630	83,594	87,766	91,365
Sonoma	83,498	87,061	90,321	93,328	96,030
Stanislaus	74,818	79,707	84,470	88,887	93,217
Sutter	17,577	18,792	20,072	21,497	22,951
Tehama	6,577	6,770	6,944	7,084	7,152

	Multi-Family Population in 2020	Multi-Family Population in 2025	Multi-Family Population in 2030	Multi-Family Population in 2035	Multi-Family Population in 2040
Trinity	855	872	875	870	857
Tulare	62,905	67,756	73,026	77,810	82,136
Tuolumne	3,699	3,783	3,860	3,929	3,946
Ventura	155,612	160,320	164,658	168,595	171,492
Yolo	53,589	56,506	59,434	63,265	65,244
Yuba	13,217	14,324	15,483	16,710	17,885

MFR-GPCD Reduction Relative to 2015 in the Years 2020, 2025, 2030, 2035, and 2040 by County

	MFR-GPCD Reduction Relative to 2015 in 2020	MFR-GPCD Reduction Relative to 2015 in 2025	MFR-GPCD Reduction Relative to 2015 in 2030	MFR-GPCD Reduction Relative to 2015 in 2035	MFR-GPCD Reduction Relative to 2015 in 2040
Statewide	2.7	4.8	6.1	6.9	7.5
Mean	2.7	4.8	6.1	6.9	7.5
St.Dev.	0.2	0.3	0.3	0.4	0.4
Min	2.3	4.0	5.1	5.8	6.2
Max	3.2	5.5	6.7	7.4	8.0
County					
Alameda	2.8	5.0	6.3	7.2	7.7
Alpine	2.4	4.4	5.6	6.4	7.0
Amador	2.4	4.4	5.7	6.5	7.1
Butte	2.9	4.9	6.2	7.0	7.6
Calaveras	2.9	4.9	6.2	7.1	7.7
Colusa	2.7	4.5	5.6	6.4	6.8
Contra Costa	2.7	4.8	6.1	7.0	7.5
Del Norte	2.5	4.3	5.5	6.3	6.9
El Dorado	2.7	4.5	5.8	6.6	7.2

	MFR-GPCD Reduction Relative to 2015 in 2020	MFR-GPCD Reduction Relative to 2015 in 2025	MFR-GPCD Reduction Relative to 2015 in 2030	MFR-GPCD Reduction Relative to 2015 in 2035	MFR-GPCD Reduction Relative to 2015 in 2040
Fresno	2.8	4.8	6.1	7.0	7.6
Glenn	2.7	4.7	6.1	7.0	7.6
Humboldt	2.6	4.4	5.6	6.4	7.0
Imperial	3.1	4.8	5.9	6.6	7.1
Inyo	3.2	5.5	6.7	7.3	7.8
Kern	3.0	5.0	6.2	7.0	7.5
Kings	2.7	4.8	6.1	6.9	7.5
Lake	2.4	4.2	5.4	6.1	6.6
Lassen	2.8	5.1	6.5	7.4	8.0
Los Angeles	2.7	4.8	6.2	7.1	7.7
Madera	2.8	4.6	5.8	6.6	7.1
Marin	2.5	4.7	6.1	7.0	7.7
Mariposa	2.3	4.0	5.2	5.9	6.4
Mendocino	2.6	4.6	5.9	6.8	7.5
Merced	2.7	4.6	6.0	6.8	7.4
Modoc	2.4	4.5	6.0	7.0	7.7
Mono	2.7	4.8	5.9	6.6	7.0
Monterey	2.6	4.4	5.7	6.7	7.3
Napa	2.7	4.7	6.0	6.9	7.5
Nevada	2.5	4.3	5.5	6.3	6.9
Orange	2.6	4.7	6.0	6.8	7.4
Placer	2.4	4.0	5.1	5.8	6.2
Plumas	2.5	4.5	6.0	7.0	7.7
Riverside	2.7	4.7	6.0	6.7	7.2
Sacramento	2.8	4.8	6.1	7.0	7.6
San Benito	2.6	4.3	5.5	6.3	6.9
San Bernardino	2.7	4.8	6.2	7.0	7.6

	MFR-GPCD Reduction Relative to 2015 in 2020	MFR-GPCD Reduction Relative to 2015 in 2025	MFR-GPCD Reduction Relative to 2015 in 2030	MFR-GPCD Reduction Relative to 2015 in 2035	MFR-GPCD Reduction Relative to 2015 in 2040
San Diego	2.7	4.7	6.0	6.8	7.4
San Francisco	2.7	4.9	6.2	7.0	7.6
San Joaquin	2.7	4.8	6.2	7.2	7.8
San Luis Obispo	2.5	4.3	5.5	6.5	7.1
San Mateo	2.9	5.0	6.4	7.3	7.9
Santa Barbara	2.6	4.4	5.7	6.6	7.2
Santa Clara	2.7	4.6	5.9	6.7	7.2
Santa Cruz	2.4	4.2	5.4	6.3	6.9
Shasta	2.7	4.6	5.9	6.8	7.3
Sierra	2.5	4.6	6.0	7.0	7.7
Siskiyou	2.4	4.2	5.5	6.3	6.9
Solano	2.9	5.1	6.5	7.3	7.9
Sonoma	2.5	4.3	5.5	6.4	7.0
Stanislaus	2.9	4.8	6.1	7.0	7.6
Sutter	2.9	4.9	6.2	7.1	7.7
Tehama	2.5	4.6	5.9	6.9	7.5
Trinity	2.4	4.0	5.1	5.9	6.4
Tulare	2.8	4.8	6.0	6.9	7.4
Tuolumne	2.3	4.1	5.4	6.3	6.9
Ventura	2.5	4.5	5.8	6.7	7.3
Yolo	2.6	4.5	5.8	6.7	7.3
Yuba	2.8	5.0	6.3	7.2	7.8

Total Effects, including Common Area and Coin-Op Clothes Washers and Non-Residential Toilets and Urinals

	Total Population 2020	Total Population 2025	Total Population 2030	Total Population 2035	Total Population 2040
Statewide	40,616,702	42,373,655	44,099,585	45,747,645	47,233,240
Alameda	1,682,642	1,763,556	1,835,884	1,905,482	1,978,656
Alpine	1,290	1,323	1,322	1,296	1,249
Amador	39,114	40,834	41,991	42,748	43,165
Butte	237,027	247,492	256,092	264,150	267,852
Calaveras	48,940	51,421	53,308	54,912	55,881
Colusa	24,270	25,806	27,243	28,558	29,688
Contra Costa	1,166,281	1,223,830	1,281,265	1,341,741	1,400,999
Del Norte	29,204	29,798	30,281	30,418	30,408
El Dorado	190,850	196,978	201,508	205,624	208,092
Fresno	1,055,541	1,130,696	1,201,749	1,269,714	1,332,913
Glenn	30,440	31,736	32,920	34,013	34,959
Humboldt	139,107	140,784	141,061	139,780	138,307
Imperial	212,134	233,964	252,665	270,331	286,336
Inyo	19,652	20,037	20,243	20,235	20,153
Kern	989,868	1,088,782	1,189,065	1,291,947	1,396,314
Kings	167,479	180,333	192,731	205,206	218,394
Lake	70,758	75,515	79,668	83,532	86,635
Lassen	36,247	37,347	38,057	38,719	39,073
Los Angeles	10,429,648	10,695,097	10,925,298	11,123,113	11,290,501
Madera	173,251	189,380	205,132	221,824	238,514
Marin	259,756	260,618	262,582	265,840	269,462
Mariposa	19,258	20,463	20,966	21,288	21,221
Mendocino	90,551	92,340	93,707	94,565	95,207
Merced	288,944	313,074	338,513	364,348	389,934

	Total Population 2020	Total Population 2025	Total Population 2030	Total Population 2035	Total Population 2040
Modoc	9,669	9,839	9,839	9,812	9,770
Mono	15,103	15,705	16,199	16,671	16,823
Monterey	446,198	462,607	476,771	489,171	500,194
Napa	146,872	151,573	156,298	160,146	163,269
Nevada	101,780	105,407	108,129	110,224	111,885
Orange	3,244,594	3,307,127	3,363,054	3,410,509	3,449,498
Placer	396,267	421,174	447,753	478,196	509,936
Plumas	19,266	19,354	19,235	18,929	18,419
Riverside	2,477,634	2,662,495	2,864,062	3,053,812	3,215,291
Sacramento	1,554,422	1,640,092	1,730,742	1,823,985	1,912,838
San Benito	63,406	68,337	73,470	78,434	82,969
San Bernardino	2,226,102	2,365,725	2,515,044	2,658,556	2,783,746
San Diego	3,378,184	3,485,623	3,592,840	3,689,585	3,779,961
San Francisco	891,823	932,744	968,199	996,332	1,027,004
San Joaquin	766,586	822,771	893,737	966,889	1,037,761
San Luis Obispo	283,706	293,496	301,324	309,465	309,689
San Mateo	776,984	801,037	823,140	847,641	874,626
Santa Barbara	455,839	473,184	490,107	507,912	514,466
Santa Clara	1,971,008	2,060,189	2,151,631	2,243,474	2,331,887
Santa Cruz	282,195	290,870	297,334	303,626	303,512
Shasta	187,598	195,735	202,265	207,865	212,264
Sierra	3,170	3,088	3,005	2,918	2,830
Siskiyou	46,230	46,811	47,039	46,976	46,445
Solano	454,746	477,540	501,436	526,460	548,046
Sonoma	523,421	545,882	566,511	585,373	602,320
Stanislaus	573,542	611,129	647,830	681,703	714,910
Sutter	105,048	112,330	120,015	128,530	137,228

	Total Population 2020	Total Population 2025	Total Population 2030	Total Population 2035	Total Population 2040
Tehama	67,285	69,275	71,067	72,504	73,196
Trinity	14,238	14,514	14,577	14,484	14,267
Tulare	498,267	536,766	578,635	616,547	650,819
Tuolumne	56,024	57,317	58,517	59,560	59,821
Ventura	876,346	902,978	927,585	949,765	966,084
Yolo	219,408	231,413	243,471	259,163	267,268
Yuba	81,489	88,324	95,473	103,044	110,285

Total Effects, including Common Area and Coin-Op Clothes Washers and Non-Residential Toilets and Urinals

	GPCD Reduction Relative to 2015 in 2020	GPCD Reduction Relative to 2015 in 2025	GPCD Reduction Relative to 2015 in 2030	GPCD Reduction Relative to 2015 in 2035	GPCD Reduction Relative to 2015 in 2040
Statewide	3.6	6.1	7.8	8.9	9.7
County Variation					
Mean	3.6	6.1	7.8	8.9	9.7
St.Dev.	0.4	0.6	0.8	0.8	0.9
Min	2.8	4.7	6.0	6.8	7.4
Max	5.4	8.8	10.7	11.7	12.4
County					
Alameda	3.7	6.4	8.1	9.2	10.0
Alpine	3.9	7.1	9.1	10.5	11.4
Amador	3.0	5.3	6.9	7.9	8.6
Butte	3.7	6.2	7.9	9.0	9.7
Calaveras	3.5	5.8	7.3	8.3	9.0
Colusa	3.9	6.3	7.9	8.9	9.6

	GPCD Reduction Relative to 2015 in 2020	GPCD Reduction Relative to 2015 in 2025	GPCD Reduction Relative to 2015 in 2030	GPCD Reduction Relative to 2015 in 2035	GPCD Reduction Relative to 2015 in 2040
Contra Costa	3.6	6.1	7.7	8.9	9.6
Del Norte	3.1	5.2	6.7	7.7	8.4
El Dorado	3.4	5.8	7.3	8.4	9.1
Fresno	3.6	6.0	7.5	8.6	9.3
Glenn	3.6	6.0	7.7	8.8	9.6
Humboldt	3.6	6.1	7.7	8.9	9.7
Imperial	3.8	5.8	7.1	8.0	8.5
Inyo	5.4	8.8	10.7	11.7	12.4
Kern	3.7	6.0	7.4	8.4	9.0
Kings	3.0	5.0	6.4	7.3	7.9
Lake	3.5	6.0	7.6	8.7	9.4
Lassen	2.8	4.7	6.0	6.8	7.4
Los Angeles	3.6	6.3	8.2	9.4	10.2
Madera	3.4	5.5	6.9	7.8	8.5
Marin	3.6	6.4	8.3	9.6	10.5
Mariposa	3.4	5.9	7.5	8.5	9.3
Mendocino	3.7	6.3	8.1	9.4	10.3
Merced	3.3	5.6	7.1	8.2	8.8
Modoc	3.2	5.6	7.3	8.4	9.3
Mono	4.7	8.2	10.1	11.2	11.9
Monterey	3.4	5.8	7.5	8.7	9.5
Napa	3.6	6.2	8.0	9.2	10.0
Nevada	3.6	6.2	7.9	9.0	9.8
Orange	3.6	6.3	8.0	9.2	10.0
Placer	3.3	5.5	6.9	7.9	8.6
Plumas	3.4	5.9	7.7	9.0	9.9

	GPCD Reduction Relative to 2015 in 2020	GPCD Reduction Relative to 2015 in 2025	GPCD Reduction Relative to 2015 in 2030	GPCD Reduction Relative to 2015 in 2035	GPCD Reduction Relative to 2015 in 2040
Riverside	3.2	5.4	6.9	7.8	8.4
Sacramento	3.5	6.0	7.6	8.7	9.5
San Benito	3.4	5.7	7.2	8.2	8.9
San Bernardino	3.4	5.8	7.4	8.5	9.2
San Diego	3.5	6.1	7.7	8.9	9.6
San Francisco	4.0	7.2	9.2	10.5	11.4
San Joaquin	3.2	5.6	7.2	8.3	9.0
San Luis Obispo	3.3	5.6	7.2	8.4	9.1
San Mateo	3.9	6.8	8.6	9.9	10.7
Santa Barbara	3.5	6.0	7.7	8.9	9.7
Santa Clara	3.8	6.5	8.3	9.5	10.2
Santa Cruz	3.4	5.8	7.5	8.7	9.5
Shasta	3.7	6.2	7.9	9.1	9.8
Sierra	3.2	5.6	7.3	8.5	9.3
Siskiyou	3.7	6.3	8.0	9.2	10.1
Solano	3.5	6.0	7.6	8.6	9.3
Sonoma	3.5	6.0	7.7	8.9	9.7
Stanislaus	3.6	5.9	7.5	8.6	9.3
Sutter	3.6	6.0	7.6	8.7	9.4
Tehama	3.3	5.7	7.3	8.4	9.1
Trinity	3.7	6.2	7.8	9.0	9.8
Tulare	3.6	6.0	7.5	8.5	9.2
Tuolumne	3.1	5.5	7.2	8.4	9.2
Ventura	3.4	6.0	7.7	8.9	9.7
Yolo	3.3	5.6	7.1	8.2	8.9
Yuba	3.5	5.9	7.5	8.6	9.2

Attachment 4. R-GPCD Reduction by County

	R-GPCD Reduction Relative to 2015 in 2020	R-GPCD Reduction Relative to 2015 in 2025	R-GPCD Reduction Relative to 2015 in 2030	R-GPCD Reduction Relative to 2015 in 2035	R-GPCD Reduction Relative to 2015 in 2040
Statewide	2.9	4.8	6.1	7.0	7.6
County Variation					
Mean	2.9	4.8	6.1	7.0	7.6
St.Dev.	0.2	0.2	0.2	0.2	0.3
Min	2.7	4.3	5.4	6.2	6.7
Max	4.0	6.1	7.3	8.0	8.5
County					
Alameda	3.0	5.0	6.3	7.2	7.8
Alpine	2.7	4.8	6.1	7.0	7.6
Amador	2.7	4.6	5.9	6.7	7.3
Butte	3.0	5.0	6.3	7.2	7.7
Calaveras	2.9	4.7	5.9	6.7	7.2
Colusa	3.2	5.1	6.4	7.2	7.7
Contra Costa	2.9	4.8	6.1	7.0	7.6
Del Norte	2.9	4.8	6.0	6.9	7.5
El Dorado	2.8	4.6	5.8	6.6	7.2
Fresno	2.9	4.9	6.1	7.0	7.5
Glenn	3.0	5.1	6.4	7.3	7.9
Humboldt	2.9	4.8	6.1	6.9	7.5
Imperial	3.3	5.0	6.1	6.9	7.3
Inyo	4.0	6.1	7.3	8.0	8.5
Kern	3.2	5.0	6.2	7.0	7.5
Kings	2.9	4.8	6.1	6.9	7.4
Lake	2.9	4.9	6.2	7.0	7.6
Lassen	3.1	5.0	6.3	7.2	7.8

	R-GPCD Reduction Relative to 2015 in 2020	R-GPCD Reduction Relative to 2015 in 2025	R-GPCD Reduction Relative to 2015 in 2030	R-GPCD Reduction Relative to 2015 in 2035	R-GPCD Reduction Relative to 2015 in 2040
Los Angeles	2.8	4.8	6.2	7.1	7.7
Madera	3.0	4.9	6.1	6.9	7.4
Marin	2.8	4.8	6.2	7.1	7.8
Mariposa	2.7	4.7	5.9	6.7	7.3
Mendocino	2.9	4.9	6.2	7.1	7.8
Merced	2.8	4.7	6.0	6.9	7.4
Modoc	2.7	4.8	6.2	7.1	7.8
Mono	2.9	5.0	6.2	6.9	7.3
Monterey	2.9	4.9	6.2	7.2	7.8
Napa	2.9	4.8	6.2	7.1	7.7
Nevada	2.8	4.8	6.0	6.9	7.4
Orange	2.8	4.8	6.1	7.0	7.6
Placer	2.7	4.3	5.4	6.2	6.7
Plumas	2.7	4.6	6.0	6.9	7.6
Riverside	2.7	4.5	5.7	6.5	7.0
Sacramento	2.9	4.8	6.1	7.0	7.5
San Benito	2.9	4.8	6.0	6.8	7.4
San Bernardino	2.8	4.8	6.1	7.0	7.5
San Diego	2.8	4.8	6.1	7.0	7.5
San Francisco	2.9	4.9	6.3	7.1	7.7
San Joaquin	2.7	4.6	5.9	6.8	7.3
San Luis Obispo	2.8	4.7	6.0	6.8	7.4
San Mateo	3.1	5.2	6.6	7.5	8.1
Santa Barbara	2.9	4.9	6.2	7.2	7.8
Santa Clara	3.0	5.0	6.4	7.3	7.9
Santa Cruz	2.9	4.8	6.1	7.0	7.7
Shasta	3.0	4.9	6.2	7.1	7.7

	R-GPCD Reduction Relative to 2015 in 2020	R-GPCD Reduction Relative to 2015 in 2025	R-GPCD Reduction Relative to 2015 in 2030	R-GPCD Reduction Relative to 2015 in 2035	R-GPCD Reduction Relative to 2015 in 2040
Sierra	2.7	4.6	6.0	6.9	7.6
Siskiyou	2.9	4.9	6.2	7.1	7.8
Solano	3.0	5.0	6.3	7.1	7.7
Sonoma	2.8	4.7	6.0	6.9	7.5
Stanislaus	3.0	4.9	6.2	7.0	7.6
Sutter	3.0	4.9	6.2	7.1	7.6
Tehama	2.8	4.7	6.0	6.9	7.5
Trinity	3.1	5.0	6.3	7.1	7.7
Tulare	3.0	5.0	6.3	7.1	7.6
Tuolumne	2.7	4.7	6.0	6.9	7.5
Ventura	2.7	4.6	5.9	6.8	7.4
Yolo	2.8	4.7	5.9	6.8	7.3
Yuba	3.0	5.0	6.4	7.2	7.8

Appendix G. Statewide Baseline Estimate

Prepared for

California Department of Water Resources

By

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California Department of Water Resources

Water Use Efficiency Branch

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This appendix describes the development of the Statewide Baseline Estimates and modeling results.

PURPOSE AND OBJECTIVES

After tract-level estimates of indoor residential per-capita demand (Ri-gpcd) are developed from household level billing histories, it was necessary to aggregate these tract level Ri-gpcd estimates with the objective of developing a statewide average, and understand how tract characteristics correlate with observed variation in Ri-gpcd across tracts. To accomplish the latter goal requires estimation of regression models that relate tract-level estimates of Ri-gpcd to tract characteristics.

Appendix E describes how 18 water Suppliers distributed across California were selected for this study. These 18 Suppliers yield Ri-gpcd estimates using customer level data for roughly 450 census tracts that lie wholly within one of these 18 Suppliers. Only tracts that are "wholly-within" an Suppliers boundary are used for developing statewide estimates which removes selection bias in a tract's estimate of Ri-gpcd. Any statewide bias that remains on account of the analyzed "wholly within" tracts not fully representing the state, is handled via stratification and strata-based weighting to correct for imbalances.

ANALYSIS STRATEGIES

Two broad approaches are available to aggregate tract level Ri-gpcd estimates to obtain statewide averages: (1) a Non-parametric or Strata-Based approach; and (2) a Parametric or Correlation Based regression model approach applied to each of the monthly disaggregation methods: seasonal adjustment method (SAM), rainfall adjustment method (RAM), and landscape adjustment method (LAM). The minimum month method (MMM) is provided for information only as this is commonly used by Suppliers to estimate indoor residential water use.

The Department's baseline central tendency analyses placed each census tract in California within a strata classification (bin) based on the demographic characteristics likely to be associated with indoor residential water use patterns. Statewide, there are a total of 7,982 tracts in California with nonzero housing units (8,057 total tracts including those without any housing units); 5,101 tracts lie wholly within Supplier boundaries, while the remaining 2,881 tracts are split between two or more Suppliers. Only data from tracts that were wholly-within a Supplier's boundary were used for developing the Baseline Analysis because of difficulties with population and characteristics when splitting tracts. Although disaggregation was conducted using individual customer-level data, summing up the water use to the census tract level and using tract population values provides a more defensible Ri-gpcd calculation.[60]

Nonparametric Approach (Strata-Based Approach)

The Strata-Based Approach divided up all 7,982 tracts within California and classified them into 'strata' or 'bins' based on similarity across their housing and demographic characteristics (as derived from the ACS data). Tracts were grouped into 51 different strata based on the level of similarity in their ACS tract characteristics including the representation of population over 65, age of housing stock, and median household income.

- **Age of housing stock.** Age of housing is well-documented as affecting indoor residential water use because of housing codes in effect at the time of construction, as well as wear and tear on household water infrastructure fixtures and appliances causing replacement with more water-efficient options over time.
- **Median Household Income and Disadvantaged Community Status.** Higher economic status may indicate a greater likelihood of home improvements that could reduce indoor residential water use. Alternatively, wealthier homes may exhibit greater saturation of water-using fixtures such as hot tubs and jacuzzis leading to greater indoor use.

[60] Treating households as the basic unit of analysis was abandoned on account of the cost and time to implement such a study design, requiring collection of household level characteristics for each account and for the duration of the time period analyzed.

- **Population over 65.** The population over 65 is expected to capture situations where customers are home during the day and may show higher residential water use.

A weighted average from tract-level estimates is derived for each strata using tract population as the weight. This becomes the best estimate of Ri-gpcd at the level of a strata. Next, the strata-level estimates are aggregated to the state with strata population serving as the weight. Tract-level mean estimates also have an associated standard error. These also can be aggregated (assuming independence of standard errors across tracts) to generate a confidence interval around the statewide average estimate. For example, a 'bin' may be created for all tracts with median plus or minus 25 percent: population over 65, median household income, and housing built after 2000. Some of the tracts in this bin would have estimated Ri-gpcd, some would not.

The advantage of a Strata-Based approach is that there are minimal assumptions made about what is causing variation in tract-level estimates of per-capita indoor residential use. Suppliers were prudently selected for producing the tract-level estimates leading to robust statewide estimates with the Strata Based Approach.

Parametric Approach (Correlation Based Approach)

Using the same 18-Supplier tract estimates, correlations using regression models were developed based on American Community Survey (ACS) tract characteristics as opposed to strata classifications. For example, instead of using a 'bin' average for all tracts within the strata, the tract estimates were correlated with each tract's actual percent population over 65, median household income, and housing built after 2000. A regression equation was developed to model the relationships between factor percentages and tract estimate Ri-gpcd.

The resulting equations were then applied to all other census tracts where customer-level data was not obtained and tract Ri-gpcd's were not directly estimated. The predicted tract-level Ri-gpcd's were then be rolled-up into a statewide average with tract population serving as the weight. Similar to the Strata-Based approach, error terms from the analyzed tract-level data were carried through to provide confidence intervals for the statewide Baseline.

Mapping tracts to Supplier boundaries was a key data layer developed to support judicious Supplier selection in the first place. Suppliers were selected to ensure a mix of tracts, exhibiting many different combinations of the above four variables, with sufficient variation in tract characteristics to build a linear regression model. All these considerations were considered during the study design phase.

The Correlation Based model includes the following tract characteristics as independent variables to explore their role in explaining variation in Ri-gpcd across tracts:

1. Proportion of tract housing by year of construction (post 2000, 1980-1999, 1979 and earlier)

2. Median household income

3. Proportion of population over 65

4. Total residential per-capita demand (R-gpcd)

The main advantage with the Correlation Based Approach is that it allows for the exploration of drivers that can explain variation in Ri-gpcd across tracts, which can provide meaningful ancillary policy insights. With the model, Ri-gpcd can be predicted (along with associated forecast error) for all remaining tracts which were not sampled based on tract characteristics. These tract-level the predictions can be rolled up into a statewide average with tract population serving as the weight, and the tract level forecast errors can also be rolled up to generate a confidence interval around the statewide average. These predictions can also be aggregated to produce Supplier-level estimates since mapping of tracts to Supplier boundaries is known.

Both the Strata-Based and Correlation Based approaches were expected to produce similar estimates of statewide average Ri-gpcd. Good statewide Ri-gpcd predictions from the Correlation Based approach, however, assumes the availability of a “good” model, which is a fundamental weakness when compared to the Strata-Based method. The Correlation Based approach has more assumptions in the equations used to estimate Ri-gpcd than the Strata Based approach.

RESULTS

Nonparametric Results (Strata Based Approach)

Table G-1 shows statewide average estimates of per-capita indoor residential use obtained from the nonparametric rollup method. Three years of data are averaged (2017-2019) to generate a robust post-drought estimate. The tract-level estimates are developed using four estimation methods while only three alternative estimation methods (SAM, LAM, and RAM) are used in the statewide estimates. The estimates are comparable across the SAM, LAM, and RAM estimation methods, and the 95% confidence intervals are also quite narrow. The MMM results is shown for informational purposes only.

Table G-1. Strata Based Approach – Statewide Baseline Ri-gpcd Estimates

Estimation Method	Ri-gpcd (Average of 2017 - 2019)	95% Confidence Interval
MMM	62.5	± 1.9
SAM	49.5	± 1.0
LAM	52.2	± 1.6
RAM	51.5	± 1.4

A table showing the estimated Ri-gpcd for each of the 54 strata for the SAM, LAM, and RAM are included at the end of this Appendix in Table G-5. A description of the Strata Identification numbers associated with each Strata is in Appendix E.

Parametric Results (Correlation Based Results and Discussion)

Tract level estimates of Ri-gpcd are modeled as a function of four key variables using linear regression. The purpose is to estimate the coefficients of the model (α, β, μ, π, Ω).

$$\text{Ri-gpcd} = \alpha + \beta.H + \mu.I + \pi.O + \Omega.R + \varepsilon \quad (1)$$

Where,

Ri-gpcd is tract level estimate of indoor residential per-capita water use obtained using (SAM, LAM, RAM)
H is proportion of housing in a tract built after year 2000 (0-100%)
I is median household income in tract (expressed in thousands of dollars)
O is proportion of tract population over the age of 65 (0-100%)
R is total residential per-capita demand (R-gpcd) in a tract
ε is random error

Tract level housing, income, and demographic data were obtained from the American Community Survey (ACS2018-5YR).

Table G-2 shows coefficients associated with the key independent variables developed from each of the models. The dependent variable is tract-level estimate of Ri-gpcd derived from the SAM, LAM, and RAM. The independent variables describe the influence of the characteristic on Ri-gpcd.

Table G-2. Correlation Based -Dependent Variables: Tract level estimate of Ri-gpcd by Method

Independent Variable	SAM Coefficient (t-statistic)	LAM Coefficient (t-statistic)	RAM Coefficient (t-statistic)
Proportion of Tract Housing Built After 2000 (0-100%)	-0.061* (-4.45)	-0.026 (-1.53)	-0.046* (-3.52)
Median Household Income in Tract ($1,000's)	0.005 (0.67)	0.003 (0.30)	0.036* (4.63)
Proportion of Tract Population Above 65 (0-100%)	0.304* (10.56)	0.452* (13.33)	0.500* (16.38)
R-gpcd of Tract	0.046* (5.78)	0.139* (14.12)	0.119* (14.86)
Constant	42.19 (47.16)	31.15 (29.62)	30.03 (35.14)
R-Squared Value	0.16	0.37	0.44

*indicates that the coefficient is statistically significant at 5% level

The t-statistic for the independent variable is shown in parenthesis
NOTE: Models are estimated from Ri-gpcd from 453 census tracts, averaging 2017, 2018, and 2019 Ri-gpcd per tract

Negative coefficients associated with the proportion of tract housing indicate that tracts with a greater percentage of newer housing have lower Ri-gpcd. The difference between tracts with no (0%) post-2000 housing and 100% **post-2000 housing is expected to be 6.1 gpcd lower with the SAM, and 4.6 gpcd lower with the RAM**. With the LAM the effect of housing age on Ri-gpcd appears to be insignificant. The impact of pre-2000 housing age categories was also examined (i.e., housing built pre-1979 and housing built between 1980 and 1999) though the differences associated with indoor residential use are not statistically significant. Only the post-2000 housing stock exhibits greater indoor water-use efficiency. Indoor water-use efficiency in pre-2000 households may have gradually equalized on account of natural turnover of plumbing fixtures and appliances over time.

The impact of median household income is small but positive, implying that **indoor residential water use increases with income**. However, this only appears to be statistically significant with the RAM. The coefficient associated with the RAM-approach for household income suggests that for every $10,000 increase in tract household income, Ri-gpcd rises by 0.3 gpcd, a relatively weak effect.

The clearest and most consistent driver of Ri-gpcd variation across tracts is the share of the over-65 population within the tract. This coefficient for the SAM, RAM, and LAM is substantial and consistently significant: **for every 10% increase in the share of the over-65 population within a tract, Ri-gpcd increases by 3, 4.5, or 5 gpcd across the three approaches**. Alternatively stated, in a tract where 30% of the population is over-65 the indoor per-capita demand is expected to be higher by 6 to 10 gpcd compared with a tract where only 10% of the population is over 65.

The last independent variable included in these models is total residential per-capita demand (i.e., indoor plus outdoor residential use, or R-gpcd). A reasonable assumption is that variations in R-gpcd are associated with the outdoor use component. Including R-gpcd in the SAM, LAM, and RAM tests each model's efficiency of removing outdoor water use. In general, this variable has a small coefficient. For every increase of 10 R-gpcd, the models suggest that Ri-gpcd increases by 0.5 gpcd under SAM and slightly above 1 gpcd with the LAM and RAM. A higher overall R-gpcd can be partially attributed to higher indoor use, while most R-gpcd use is outside which is what the models indicate.

Table G-3. Correlation Based Approach Statewide Estimate Baseline Results

Method	Average Ri-gpcd	95% Confidence Interval
SAM	50.5	± 0.26
LAM*	50.9	-
RAM	50.7	± 0.23

*95% Confidence Interval not estimated for LAM

Of the three approaches, the RAM approach performs the best (highest R-squared, with coefficients that are reasonable and significant). The SAM approach also produces reasonable and significant coefficients, but the model's explanatory power is low. The LAM approach does not perform as well, as the model is unable to detect a post-2000 housing effect or income effect on Ri-gpcd, and the R-gpcd coefficient is the greatest. Because the LAM does not perform well, the 95% confidence interval was not estimated.

These three models were used to predict Ri-gpcd for all the state's census tracts, which were aggregated to a statewide average. The models were used to evaluate the impact of setting the indoor standard at alternative levels. For example, a series of "what-ifs" can be evaluated, such as, if the indoor standard is set at X gpcd, what proportion of the state's population will be effectively constrained by the standard?

The Correlation-based approach can be used to detect which tract characteristics are important predictors of variation in Ri-gpcd.

Figure G-1 shows the statewide cumulative distribution of tracts by predicted Ri-gpcd for the correlation-based approach. The statewide average estimate from each approach matches quite well with the strata-based results shown in Table G-4. The spread of Ri-gpcd tract estimates around the statewide average, however, varies by Ri-gpcd estimation method (SAM, LAM, or RAM). The spread is the smallest with the SAM method and largest with the RAM method. This is a direct result of each model's explanatory power as discussed earlier. The tract level model for the SAM method has the lowest R-squared value which causes model predictions to be the most compressed around the average. The RAM method produces the widest dispersion because in this model tract characteristics are able to explain a greater share of the variation in Ri-gpcd across tracts.

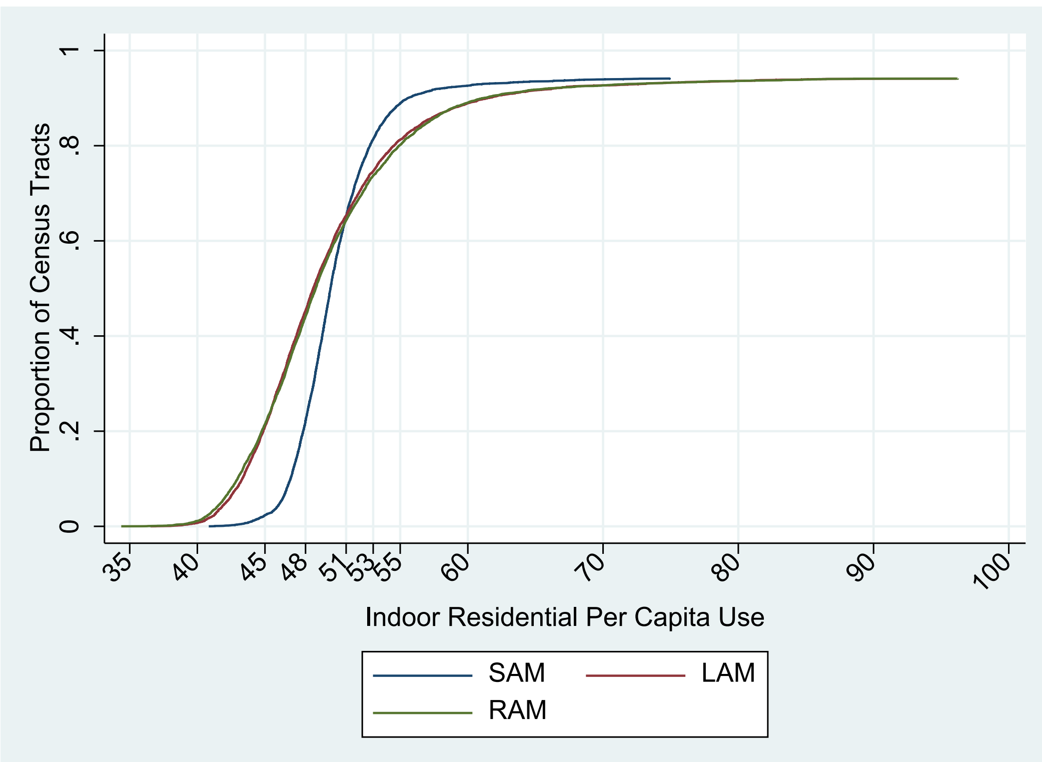

Figure G-1. Correlation Based Estimates: Distribution of Tract Ri-gpcd by Estimation Method

Another way to examine variation in Ri-gpcd is at the Supplier level instead of at the tract level. Since a Supplier may have a mix of tracts, some with higher Ri-gpcd and some with lower, the dispersion of Ri-gpcd estimates should be lower at the Supplier level than at the tract level.

Figure G-2 shows the statewide cumulative distribution of Suppliers by predicted Ri-gpcd. Supplier level estimates are derived by aggregating Ri-gpcd estimates across tracts lying in a respective Supplier's service area, weighted by tract population. For tracts split between two or more Suppliers, the portion of geographic area lying within a Supplier's boundary is used to determine the share of the tract population to be counted toward a respective Supplier. The RAM method generates the widest level of dispersion across Suppliers, for reasons discussed earlier.

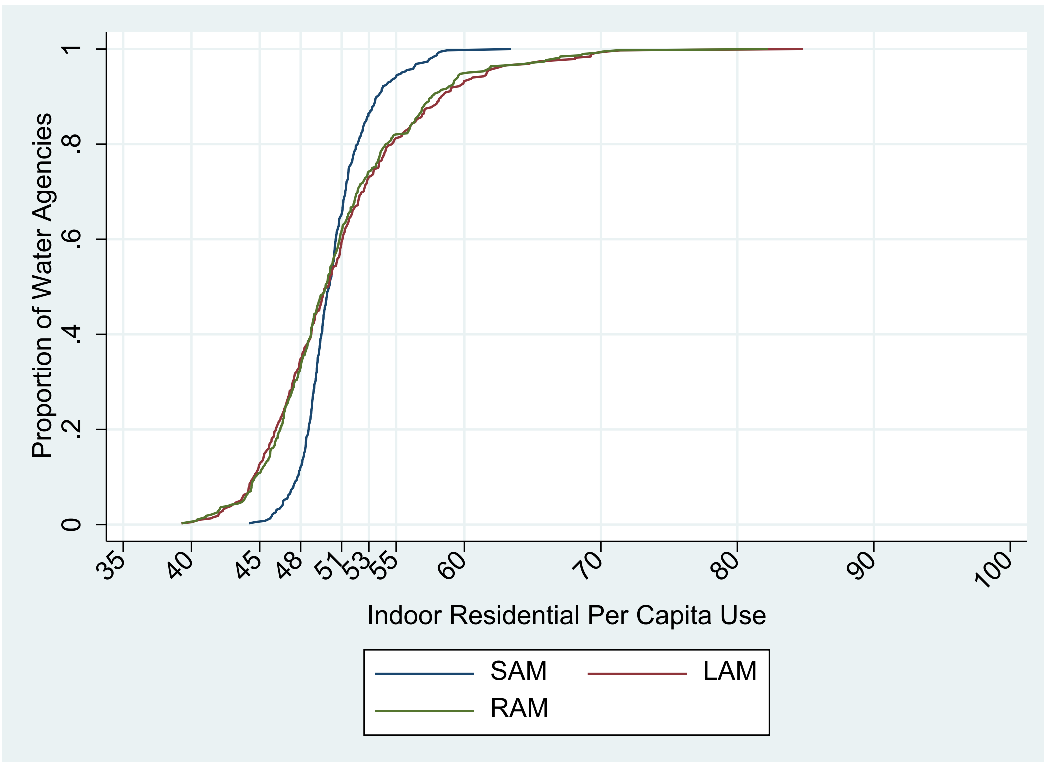

Figure G-2. Correlation Based Estimates: Distribution of Supplier Ri-gpcd by Estimation Method

Comparison of the Strata-Based and Correlation-Based Estimates

Table G-4 shows a comparison of the statewide average estimates of Ri-gpcd obtained from the Strata-Based and Correlation Based approaches applied to tract level estimates generated by the three methods (SAM, LAM, RAM). The differences across approaches and methods are small, suggesting that current Ri-gpcd statewide is roughly in the range of 49-52 gpcd.

Table G-4. Comparison of Strata-Based and Correlation-Based Statewide Baseline Ri-gpcd Estimates

Method	Ri-gpcd Strata-Based Approach	Ri-gpcd Correlation Based Approach
MMM	62.5	-
SAM	49.5	50.5
LAM	52.2	50.9
RAM	51.5	50.7

Confidence intervals for the Correlation Based Approach are tighter than the Strata Based Approach because additional census information is used to make tract level predictions. Tract estimates from the Strata-based approach are preferred over the Correlation Based Approach because there are fewer assumptions made about the relationships of indoor water use to tract characteristics. Estimates of Supplier Ri-gpcd using the tract Ri-gpcd estimates could only be developed using the Correlation based approach; the strata based approach had some strata which did not have enough tracts to develop a confident supplier level estimate of Ri-gpcd. Both approaches are good at estimating statewide Ri-gpcd.

Across all three methods, however, there remained a suspicion that the tails of the distribution are being understated (on account of low model R-squared value), which is why supplemental analyses were undertaken using Supplier-level consumption data from the electronic Annual Report (eAR). This supplemental analysis is presented in the main report and in Appendix H.

Table G-5. Population Weighted Ri-gpcd estimated by Strata for SAM, LAM, and RAM

Strata ID	SAM Ri-gpcd	LAM Ri-gpcd	RAM Ri-gpcd
11311	51.6	54.5	52.1
11312	52.0	50.1	50.3
11321	51.5	54.3	52.8
11322	57.3	64.4	67.1
12211	53.5	57.0	55.7
12221	51.9	51.1	52.7
12222	53.9	55.2	56.1
12310	51.4	52.4	51.3
12321	50.5	48.9	50.4
12322	53.5	54.7	54.8
13110	49.0	48.1	46.5
13121	51.8	52.1	52.5
13122	53.6	54.2	56.2
13210	50.3	52.4	50.2
13221	52.8	54.7	54.3
13222	52.6	52.7	54.5
21210	48.7	50.8	47.9
21221	52.6	54.2	59.1
21222	60.7	70.5	70.7
21311	49.9	52.5	49.9
21312	51.1	48.9	48.8
21321	52.4	55.5	54.1
21322	58.3	66.5	68.1
22211	51.9	55.0	53.3
22212	55.0	57.7	63.5

Strata ID	SAM Ri-gpcd	LAM Ri-gpcd	RAM Ri-gpcd
22221	50.9	53.9	52.3
22222	57.9	66.2	67.7
22310	49.9	45.6	45.6
22321	48.7	46.7	46.3
22322	52.9	53.7	54.7
23110	48.5	48.3	45.9
23121	53.8	57.6	57.4
23121	53.8	57.6	57.4
23122	52.7	54.0	55.3
23210	48.3	48.0	45.4
23221	50.6	49.5	50.4
23222	56.8	66.3	64.1
31100	46.8	54.3	54.3
31210	54.2	56.6	62.3
31221	48.7	48.7	47.5
31222	53.3	55.5	60.1
32111	53.0	63.8	59.7
32112	52.6	57.3	56.3
32121	48.3	53.1	50.9
32122	63.0	78.6	77.8
32211	49.7	54.0	50.9
32221	47.8	43.2	44.5
32222	52.6	53.2	53.9
33111	49.5	52.2	50.0
33112	61.6	74.7	72.6
33121	50.9	52.7	51.8
33122	68.6	84.7	84.8

Appendix H. Distribution Analysis (eAR Data)

Prepared for

California Department of Water Resources

By

IRWUS Study Team

California Department of Water Resources

Water Use Efficiency Branch

April 2020

To characterize the diversity and distribution of indoor water use by urban retail water suppliers (Suppliers) across California, the DWR team analyzed Ri-gpcd using monthly data reported annually to the State Water Resources Control Board (State Water Board) by Suppliers through the Water Board's electronic Annual Report (eAR) system.

This analysis was deemed necessary because one drawback of the Baseline Central Tendencies (Strata Based and Correlation Based approaches) analysis is that while the tract level estimates from the 18-Suppliers perform well at estimating **statewide average** indoor residential water use in gallons per capita per day (Ri-gpcd), the distribution of Ri-gpcd **of individual urban retail water suppliers** (Suppliers) is not characterized well with that data set; Ri-gpcd estimates for non-study-participant Suppliers tend to be more centered around the mean for each estimation method. In order to inform policy decisions, a good representation of the Supplier distribution (range of Ri-gpcd's) is needed to examine the impact of any standard.

Therefore, the DWR team analyzed Ri-gpcd using monthly data reported annually to the State Water Resources Control Board (State Water Board) by Suppliers through the Water Board's annual electronic Annual Report (eAR) system.

Only one of the disaggregation methods that was used for the Baseline Central Tendencies could be used with the eAR dataset, the Seasonal Adjustment Method (SAM), described below. This analysis was conducted on cleaned and complete data reported by Suppliers for the post-drought record (2017, 2018, and 2019), which yielded results for 157 Suppliers. Results were compared with the hourly and monthly customer-level disaggregation methods of estimated Ri-gpcd to confirm suitability of this analysis using the Supplier-level (eAR) data.

California eAR Dataset

Section 116530 of the California Health and Safety Code (CHSC) specifies that a public water system shall submit a technical report to the CDPH [now the Division of Drinking Water (DDW)] when requested. DDW has established an annual requirement for every public water system under DDW jurisdiction or Local Primacy Agency (LPA) jurisdiction (i.e., County Environmental Health Departments) to annually submit a technical report specifying operational information for the prior calendar year.

California offers two different electronic reporting portal options: one for small and one for large sized utilities. All water providers, regardless of size, must report annually on a wide range of system and consumption data through the online reporting system.[61] Data reported through the eAR that are relevant to this study are: monthly metered consumption for each customer category (including monthly single-family residential consumption); the number of customer accounts by category (including the number of single-family residential accounts and total population); and, monthly consumption from dedicated landscape irrigation accounts.

Seasonal Adjustment Method Data Requirements

Calculation of Ri-gpcd [using the Seasonal Adjustment Method (SAM) approach described in Appendix A – Monthly Analysis] require these three critical pieces of data that are reported in the eAR system, plus population data from American Housing Survey:

1. Monthly single-family residential demand (consumption)

2. Number of single-family meters/accounts

3. Monthly dedicated landscape irrigation meter demand (consumption)

4. Average persons per single-family household (from California Department of Finance [DOF] and U.S. Census American Community Survey [ACS])

The single-family residential population can be estimated for each Supplier by pairing the reported number of single-family accounts for each Supplier with estimates of the average persons per household from the ACS.[62]

[61] Electronic Annual Report (EAR), CA State Water Resources Control Board http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/ear.html

[62] https://www.census.gov/programs-surveys/ahs.html

Single-family accounts multiplied by persons per household provided a reasonable estimate of the single-family residential population.

The SAM approach uses monthly consumption from the dedicated irrigation meter accounts to infer residential winter irrigation water use. The key assumption in this method is that, for a given location, the seasonality and thus the ratio of maximum and minimum month water use of residential and non-residential irrigation is broadly similar. This identifying assumption is used to infer winter residential irrigation. Removing the inferred amount of winter irrigation from the winter minimum month total residential water use provides an estimate of the indoor residential water use.

Data Cleaning and Post-Processing

The eAR dataset is subject to input errors that had to be cleaned prior to use. Additionally, only data from Suppliers with all three years of data and both single-family residential water use and dedicated irrigation meter water use could be used.

The basic rules for cleaning the dataset were as follows:

1. Exclude any Supplier that does not report dedicated irrigation meter totals by month.

2. Exclude any Supplier with eAR data that is missing data from known Public Water Systems (PWSs) associated with that Supplier.

3. Confirm that values are reported for the same PWSs and Supplier in 2017, 2018, and 2019. Exclude Suppliers that do not have data from all three years for all associated PWSs.

4. The population and connections by supplier are from reported eAR data; suspicious values or big changes from year to year reports were flagged and checked. If changes could not be reasonably explained, the Supplier was excluded from the analysis.

5. Number of days per month used for all Suppliers was **30.41** (365 days divided by 12 months) to standardize Ri-gpcd estimates across

Suppliers and because meter read data may not exactly coincide with calendar months.

Post-Processing:

1. Exclude Suppliers where the SAM analysis could not be performed (e.g., division by 0) for any of the three years.

2. Exclude Suppliers with Ri-gpcd estimates below 20 gpcd and above 150 gpcd as outliers for any of the three years.

3. Only include Suppliers that met all requirements for all three SAM variation analyses (see section below for a description of the variations).

Starting with 407 suppliers in California, after data cleaning and post-processing, the number of suppliers used to characterize Ri-gpcd distribution by Supplier was 157.

Indoor Water Use Estimation: SAM Summary

The Seasonal Adjustment Method (SAM) uses billing data from dedicated irrigation meters to infer residential winter irrigation water use. This method starts by recognizing that residential water use in any month, t, can be decomposed into indoor and outdoor components.

$$W_t = IN_t + OUT_t \quad (1)$$

Where W = total residential water use, IN = indoor residential water use and OUT = outdoor residential water use, with subscript t denoting the specific month.

The key identifying assumption this method makes is that the ratio of summer to winter outdoor water use is the same for residential and dedicated irrigation customers and can be used as an adjustment factor.

$$\frac{OUT_s}{OUT_w} \equiv \frac{IRR_s}{IRR_w} \equiv R \qquad (2)$$

Where R is the irrigation adjustment factor, and IRR represents monthly water use by dedicated irrigation meters with subscript w representing the minimum winter consumption month and subscript s representing the maximum summer consumption month.

Using equation (2), residential water use (W) in the maximum summer consumption month (s) can be expressed as:

$$W_s = IN + R \cdot OUT_w \qquad (3)$$

Substituting equation (3) into equation (1) and rearranging terms gives the SAM formula for estimating indoor residential water use:

$$IN = \frac{1}{(1-R)}(W_s - R \cdot W_w) \qquad (4)$$

Notice that all the variables on the right-hand-side of equation 4 are observable quantities. W_s and W_w are based on residential billing data and R is based on dedicated irrigation meter billing data.

In the monthly disaggregation of customer-level data for the Baseline Central Tendencies analysis, February was used for the minimum winter consumption month and August for the maximum summer consumption month. This was applied across all Suppliers and years represented in the study for the sake of consistent treatment of the customer-level data. Use of different minimum and maximum months was explored but did not result in any substantial differences. While the minimum and maximum months may deviate from February and August from time to time, once water use is weather normalized it is nearly always the case that minimum and maximum water use occur in February and August, respectively.

However, for the Distribution analysis, three variations of the SAM analysis were conducted because consistency could more easily be maintained with the smaller dataset and there is no preponderance of evidence to suggest one variation or another of the SAM was better for any given Supplier when using the Supplier-level dataset (eAR). These variations consisted of how the minimum and maximum months were selected as follows:

1. **SAM version 1.** February as the minimum consumption month and August as the maximum consumption month – consistent with the Baseline Central Tendencies Analysis.

2. **SAM version 2.** Winter minimum Single-Family total residential water use month (picking the month used in the equation with the least total residential water use between the months of January to April) and summer maximum residential water use month (picking the month used in the equation with the highest total residential water use between the months of June to September).

3. **SAM version 3.** Winter minimum dedicated irrigation meter water use month (picking the month used in the equation with the least water use measured by dedicated irrigation meters between the months of January to April) and summer maximum dedicated irrigation meter water use month (picking the month used in the equation with the highest water use measured by dedicated irrigation meters between the months of June and September).

The DWR team carefully applied the three SAM variations to the cleaned eAR Supplier-level data set provided by the State Water Board for 2017, 2018, and 2019. Using this data set it was possible to calculate average Ri-gpcd for 157 Suppliers, serving more than 11,000,0000 single-family residential customers across the state and a total residential population of more than 18,000,000. An average of SAM versions 1, 2, and 3 was used to characterize the single-family Ri-gpcd for each Supplier in the Distribution analysis.

Projected Future Conditions

Projected future water use was estimated starting with the average SAM estimates of Ri-gpcd by Supplier with county-level values for passive conservation effects deducted over time. The passive conservation effects were the expected decline in indoor residential water use from appliance turnover, implementation of plumbing code water use efficiency requirements, and expected new housing (Appendix F [Mitchell, 2016]). Suppliers were assigned the expected reductions for 2025 and 2030 for the county in which their service area resides. This decline was expressed in gpcd and therefore, potential changing population was not a factor.

Results

The 3-year (2017-2019) average Ri-gpcd and other relevant statistics are presented in Table H-1. Using the average SAM approach, the average Ri-gpcd varied by as much as 13% from year to year (2017 to 2018). The total population from the 157 Suppliers included from the eAR data was 18,168,471 people (about 46% of the total estimated Supplier Population in 2019; 36,948,056). The average Ri-gpcd from the Distribution analysis is 50.8, with a range in Ri-gpcd annual variability from + 26.9 Ri-gpcd to - 25.0 Ri-gpcd across all 157 suppliers. While the average from the Distribution Analysis is similar to the Central Tendencies Analysis there can still be significant annual variability in Supplier Ri-gpcd.

Table H-37: Indoor residential gallons per capita per day, calculated using eAR data, 2017-2019

Ri-gpcd	2017	2018	2019	3-Year Average
Average	53.3	46.6	53.1	50.8
Median	50.2	44.7	50.6	48.3
Minimum	27.6	23.9	28.3	27.8
Maximum	123.8	121.5	140.8	128.7
Standard deviation	13.8	**12.6**	13.7	12.5
Count of providers	157	157	157	157

Figure H-1 shows the distribution of 3-year average Supplier Ri-gpcd's (bars) and cumulative distribution (line) and Table H-2. Number of Suppliers by Ri-gpcd bin from eAR data, 2017 to 2019 average shows the number of Suppliers by bin.

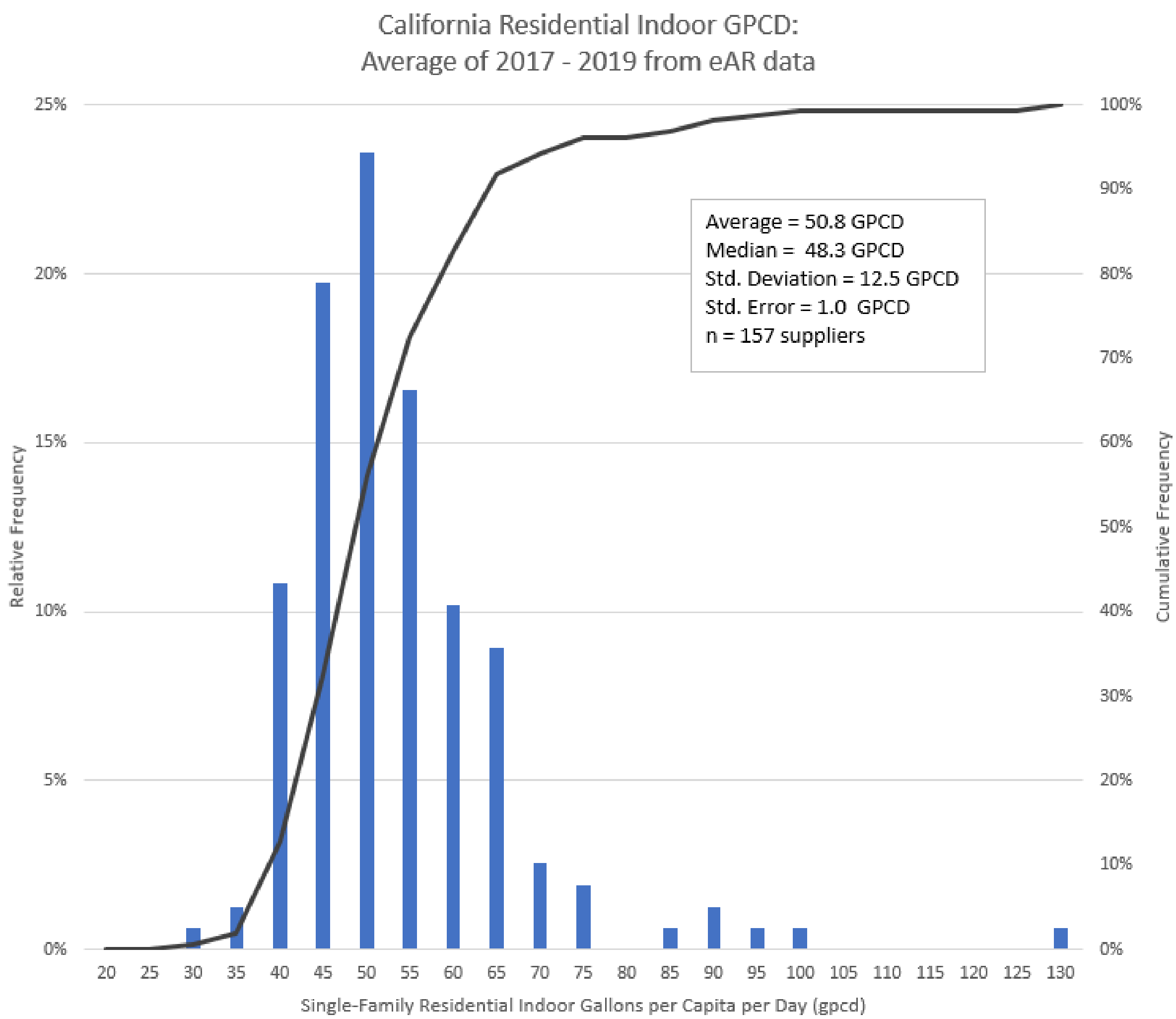

Figure H-30: Frequency distribution of California Ri-gpcd from eAR data, 3-year average (2017 - 2019)

Table H-38. Number of Suppliers by Ri-gpcd bin from eAR data, 3-year average (2017 to 2019)

Ri-gpcd	No. of Suppliers
0	-
5	-
10	-
15	-
20	-
25	-
30	1
35	2
40	17
45	31
50	37
55	26
60	16
65	14
70	4
75	3
80	-
85	1
90	2
95	1
100	1
105	-
110	-
115	-
120	-
125	-
130	1
Total	**157**

Potential Effects of Standards

Potential effects of any standard were estimated using the Decision Support Tool (DSS Tool) described and displayed in the main report Section 4.2. There are three important assumptions in the estimated effects:

1. Urban retail suppliers with estimated service area Ri-gpcd above the standard drop down to the standard. This assumption means that estimated effects may be high because:
    - Suppliers do not have to meet individual standards that make up the overall water use objective; they may accommodate an exceedance of any single standard by being sufficiently under one of the other standards so long as their overall water use does not exceed the water use objective.
    - It is very possible that a variance[63] is applicable for suppliers with high Ri-gpcd. If a variance is granted, water use may not decrease.
    - High Ri-gpcd in the dataset may have occurred because of incomplete separation of indoor from outdoor residential water use or inaccurate population counts.
2. Urban retail suppliers with estimated service area Ri-gpcd below the standard remain the same. This assumption means that estimated effects may be high because:
    - Similar to the above situation, a supplier may use their lower Ri-gpcd to accommodate exceedance of one of the other standards, so long as their overall water use does not exceed the water use objective.
    - Low Ri-gpcd in the dataset may have occurred because the model underestimated the amount of outdoor water use.
3. There was a hard bottom of 35 Ri-gpcd, the indoor residential water use of an efficient house (refer to Appendix F - Projected Statewide and County-Level Effects of Plumbing Codes and Appliance Standards on Indoor GPCD) when adjusting for expected passive conservation. In other words, if applying the expected passive conservation reduction to estimate the future Ri-gpcd resulted in an Ri-gpcd below

[63] Eight variances are identified in Water Code §10609.14. Variances will essentially be 'extra credit' for unique uses of water that have a significant effect on the urban retail water supplier's water use objective. The Department is currently working on the studies and recommendations for variances that will be adopted into regulation by the Water Board. If a variance is applied for and approved by the Water Board, it will allow the supplier to use more water without exceeding the water use objective.

35 gpcd, the Supplier was assigned an Ri-gpcd of 35.

In this analysis, population was assumed to remain the same in 2025 and 2030. This assumption means that estimated 2025 and 2030 effects may be low because the standard effects on average Ri-gpcd and water savings quantities were population weighted.

Detailed Results

Comparison of Distribution Analysis and Baseline Analysis

The Distribution Analysis and Correlation-based Baseline Analysis for Suppliers were only able to match Ri-gpcd estimates from 148 of the 157 Suppliers. This is because the correlation-based Baseline Analysis could not be conducted for some Suppliers due to service area and tract boundary issues. A description of the Landscape Adjustment Method (LAM) and Rainfall Adjustment Method (RAM) is discussed in Appendix A - Monthly Analysis. SAM Ri-gpcd results from the Suppliers used in the Distribution Analysis are presented in Table 4. Comparison of Supplier Ri-GPCD for eAR And Strata Based SAM, LAM, RAM Estimation Methods for 157 Suppliers.

As seen in Table H-6, in many cases there was good agreement between the analyses when estimated Ri-gpcd's are close to the central tendencies (average and median). However, because the Baseline analysis did not capture the distribution well, as estimated Supplier Ri-gpcd moves away from the central tendencies, the standard deviation between the analyses increases.

Note that because aggregate Supplier-level data was used for the Distribution Analysis, margins of error are not available for each Supplier Ri-gpcd estimate.

Below is an alphabetical list of 157 Suppliers included in the Distribution Analysis, the results shown in Table 4 are randomized so the alphabetical list of Suppliers does not coincide with the estimates of indoor residential use estimates.

List of 157 Suppliers in eAR Analysis: Adelanto City of, Alameda County Water District, Alco Water Service, Anaheim City of, Antioch City of, Arvin

Community Services District, Atascadero Mutual Water Company, Beaumont-Cherry Valley Water District, Benicia City of, Brea City of, Brentwood City of, Burlingame City of, Camarillo City of, Camrosa Water District, Carlsbad Municipal Water District, Carmichael Water District, Cerritos City of, Chino City of, Chino Hills City of, Citrus Heights Water District, Cloverdale, Clovis City of, Coastside County Water District, Contra Costa Water District, Cucamonga Valley Water District, Daly City, Davis City of, Desert Water Agency, Diablo Water District, East Bay Municipal Utilities District, Eastern Municipal Water District, El Dorado Irrigation District, El Toro Water District, Escondido City of, Estero Municipal Improvement District, Fairfield City of, Folsom City of, Fountain Valley City of, Fresno City of, Fullerton City of, Gilroy City of, Glendale City of, Golden State Water Company Artesia, Golden State Water Company Bay Point, Golden State Water Company Bell-Bell Gardens, Golden State Water Company Claremont, Golden State Water Company Cordova, Golden State Water Company Culver City, Golden State Water Company Florence Graham, Golden State Water Company Norwalk, Golden State Water Company San Dimas, Golden State Water Company Southwest, Goleta Water District, Greenfield City of, Hayward City of, Healdsburg City of, Helix Water District, Hemet City of, Hi-Desert Water District, Humboldt Community Service District, Indio City of, Irvine Ranch Water District, Jurupa Community Service District, La Habra City of Public Works, Laguna Beach County Water District, Lake Hemet Municipal Water District, Lakeside Water District, Lakewood City of, Lathrop City of, Lincoln City of, Linda County Water District, Livermore City of Division of Water Resources, Long Beach City of, Los Banos City of, Madera City of, Manhattan Beach City of, Manteca City of, Marina Coast Water District, Menlo Park City of, Modesto City of, Monrovia City of, Monte Vista Water District, Moulton Niguel Water District, Mountain View City of, Napa City of, Newport Beach City of, Norco City of, North Coast County Water District, Oakdale City of, Olivenhain Municipal Water District, Ontario City of, Orange Vale Water Company, Oxnard City of, Padre Dam Municipal Water District, Palmdale Water District, Palo Alto City of, Paramount City of, Paso Robles City of, Patterson City of, Pismo Beach City of, Pittsburg City of, Pomona City of, Port Hueneme City of, Quartz Hill Water District, Rancho California Water District, Redwood City, Rialto City of, Riverside City of, Roseville City of, San Bernardino City of, San Bernardino County Service Area 64, San Clemente City of, San Diego City of, San Dieguito Water District, San Francisco Public Utilities Commission, San Gabriel County Water

District, San Jose City of, San Lorenzo Valley Water District, San Luis Obispo City of, Santa Ana City of, Santa Barbara City of, Santa Clarita Valley Water District, Santa Cruz City of, Santa Margarita Water District, Santa Maria City of, Santa Monica City of, Santa Paula City of, Santa Rosa City of, Sonoma City of, Soquel Creek Water District, Suburban Water Systems San Jose Hills, Suisun-Solano Water Authority, Sunnyslope County Water District, Sunnyvale City of, Sweetwater Authority, Tehachapi City of, Trabuco Canyon Water District, Tracy City of, Triunfo Sanitation District/Oak Park Water Services District, Tulare City of, Turlock City of, Ukiah City of, Vacaville City of, Vallecitos Water District, Vallejo City of, Ventura County Waterworks District No 1, Ventura County Waterworks District No. 8, Victorville Water District, Walnut Valley Water District, Wasco City of, Watsonville City of, West Valley Water District, Western Municipal Water District of Riverside, Windsor Town of, Woodland City of, Yorba Linda Water District, and Yuba City

Table H-39. Comparison of Supplier Ri-gpcd for eAR SAM and Correlation Based SAM, LAM, RAM Estimation Methods

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
1	46.2	49.2	46.2	48.1
2	47.5	47.3	45.5	44.5
3	55.1	48.9	46.7	46.7
4	50.4	48.1	46.6	46.8
5	43.9	45.8	43.6	42.0
6	48.0	51.2	52.0	51.9
7	43.1	51.3	58.5	56.2
8	50.7	50.5	47.9	49.4
9	59.9	50.2	50.1	50.7
10	46.6	49.6	46.1	48.5
11	61.2	51.2	51.2	52.1

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
12	92.7	53.4	57.2	58.1
13	61.4	50.3	50.9	51.5
14	70.0	54.8	60.2	59.1
15	50.7	53.5	55.3	56.0
16	60.4	50.0	50.7	51.0
17	51.7	53.1	57.1	55.9
18	51.5	50.5	54.9	53.7
19	40.3	49.4	45.9	48.4
20	52.2	50.6	49.7	50.6
21	59.0	49.5	51.2	50.7
22	41.4	49.7	45.7	47.3
23	34.9	49.1	48.4	47.9
24	128.7	56.9	64.9	63.3
25	50.7	46.8	45.9	45.8
26	52.0	49.6	46.9	48.0
27	37.3	48.0	48.6	47.6
28	52.4	53.4	58.6	58.2
29	62.0	56.5	58.5	59.5
30	37.6	48.4	46.0	45.7
31	59.5	50.5	47.5	50.3
32	40.9	48.6	47.4	47.5
33	54.3	51.3	58.0	57.3
34	48.9	49.9	47.2	48.1
35	53.5	50.5	52.6	51.1
36	63.7	50.4	50.3	50.2
37	40.9	48.3	46.2	46.8

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
38	57.9	51.1	50.1	50.5
39	37.6	49.4	46.6	46.7
40	34.7	46.7	42.0	41.4
41	45.2	46.7	41.6	41.1
42	68.5	54.7	59.0	59.2
43	48.1	53.0	57.9	56.6
44	51.8	50.5	48.0	49.2
45	44.0	46.5	41.4	40.7
46	41.5	48.6	45.0	45.2
47	57.8	52.5	53.7	54.0
48	43.7	48.4	44.5	44.4
49	46.5	48.5	44.2	45.3
50	39.0	45.4	42.0	41.0
51	38.1	47.8	43.0	43.9
52	55.6	52.5	52.9	53.6
53	58.8	49.6	47.5	47.4
54	39.1	51.8	50.9	50.3
55	43.8	50.1	49.2	48.5
56	48.3	49.9	54.1	52.2
57	52.7	47.6	45.3	46.3
58	50.6	48.1	51.9	50.6
59	51.6	50.2	49.0	49.2
60	85.1	53.9	54.3	56.5
61	47.9	50.6	51.1	50.1
62	44.3	49.7	47.9	48.1
63	45.1	50.2	48.1	49.0

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
64	44.4	44.2	46.0	44.4
65	48.2	51.7	57.6	56.9
66	53.3	49.0	52.2	49.8
67	45.1	48.8	47.7	49.2
68	51.3	48.4	44.6	44.7
69	51.0	47.9	48.5	46.9
70	47.1	47.1	45.2	44.0
71	55.1	50.8	49.7	52.6
72	63.5	48.3	49.6	48.6
73	43.6	47.9	44.2	44.4
74	46.4	49.8	47.5	49.3
75	41.9	51.5	54.8	53.2
76	56.2	51.3	52.3	52.1
77	41.4	49.0	47.4	46.9
78	48.8	51.1	50.9	52.0
79	45.8	48.4	44.5	46.6
80	43.3	50.8	49.6	50.4
81	70.2	53.2	54.1	56.0
82	65.5	52.6	58.0	56.9
83	39.8	49.2	44.4	46.7
84	85.5	50.5	53.7	54.4
85	37.4	48.2	46.7	46.1
86	52.8	54.3	60.6	59.2
87	45.3	47.0	42.6	42.9
88	42.7	50.5	49.2	49.7
89	58.1	48.6	48.7	47.4

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
90	49.2	51.3	50.7	53.5
91	40.6	47.1	42.3	42.1
92	46.4	49.8	50.1	49.7
93	49.4	46.0	44.8	43.8
94	50.8	54.3	55.7	56.7
95	44.9	48.7	47.0	46.8
96	36.3	48.0	44.7	44.4
97	41.4	48.2	44.2	44.6
98	81.9	53.4	61.6	59.7
99	61.2	50.8	58.2	56.4
100	39.4	49.0	45.3	47.0
101	64.3	49.1	48.7	47.6
102	49.6	49.7	51.1	51.0
103	47.7	49.3	49.5	48.0
104	60.4	51.4	52.7	52.7
105	63.0	51.1	50.3	51.5
106	48.8	48.4	45.1	45.7
107	52.3	51.9	53.3	53.8
108	47.8	48.7	43.8	45.8
109	61.5	49.5	46.3	46.5
110	57.0	48.9	46.8	48.8
111	27.8	51.5	50.7	51.7
112	44.3	48.1	44.1	44.2
113	40.2	50.5	47.9	48.9
114	72.7	50.2	52.7	52.3
115	39.0	48.4	43.7	44.6

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
116	63.9	48.8	48.6	50.0
117	41.8	47.7	44.9	44.4
118	95.4	50.6	48.7	49.8
119	51.3	49.6	48.8	48.2
120	40.6	49.4	46.9	47.3
121	42.6	54.6	56.6	57.4
122	37.5	50.5	47.0	48.4
123	43.9	47.9	44.9	45.1
124	42.9	49.3	47.9	48.5
125	47.8	48.6	44.9	47.1
126	46.6	49.1	45.8	45.8
127	35.3	51.5	54.4	53.0
128	50.3	48.8	47.4	49.1
129	46.0	47.5	48.4	47.8
130	47.9	52.4	54.7	56.4
131	47.6	49.0	50.4	48.8
132	53.7	50.4	52.7	51.4
133	45.6	50.6	49.4	48.9
134	48.4	50.4	50.8	50.9
135	50.0	49.2	49.1	49.0
136	44.9	46.2	45.7	46.5
137	56.0	51.1	53.4	53.5
138	57.3	51.1	52.4	52.9
139	57.2	47.3	48.3	46.4
140	61.9	52.3	53.8	54.2
141	44.1	45.8	43.2	41.7

Supplier	Distribution Analysis (eAR) SAM (Ri-gpcd)	Correlation-Based SAM (Supplier Ri-gpcd)	Correlation-Based LAM (Supplier Ri-gpcd)	Correlation-Based RAM (Supplier Ri-gpcd)
142	42.9	47.7	44.3	44.1
143	47.4	49.3	50.9	49.8
144	57.7	49.7	51.8	50.7
145	39.0	49.5	47.8	48.5
146	46.6	49.2	48.1	47.8
147	63.8	52.7	56.0	56.9
148	39.8	50.8	52.4	51.4
149	41.9	-	-	-
150	45.8	-	-	-
151	51.4	-	-	-
152	38.4	-	-	-
153	49.2	-	-	-
154	50.5	-	-	-
155	66.4	-	-	-
156	38.7	-	-	-
157	69.1	-	-	-

Effects of Standards on Current and Projected Estimated Ri-gpcd Distribution

Results from the 157 Suppliers are assumed to be representative of all 407 Suppliers Ri-gpcd. The indoor residential water use estimates are evaluated independently of the other standards (outdoor residential, Commercial / Institutional / Industrial (CII) Landscapes, Losses, Variances, and Bonus incentives) that make up a Suppliers water use objective.

The effects of standards set in Water Code 10609.4(a) on the population served for all 407 Suppliers are shown in Tables H-5, H-6, and H-7 for 2020, 2025, and 2030 respectively. The new statewide average in the tables assume that all Suppliers above the Ri-gpcd standard drop down to the standard and the ones below stay below the standard following the predicted decline for passive conservation. The tables show the effect of various Ri-gpcd standards above and below the standards set in Water Code and are evaluated with the accompanying new statewide Ri-gpcd average and percent of Suppliers and population affected. Accompanying the summary tables are Figures H-2, H-3, and H-4 showing the distribution of Ri-gpcd from the 157 Suppliers, with Suppliers above the standard shown in red and those below the standard in blue for 2020, 2025 and 2030 respectively.

Evaluating the Water Code standard in 2020 of 55 Ri-gpcd, a new statewide Ri-gpcd average is estimated to be 48.6, down from the current Baseline of 51.1, 27 percent of Suppliers would be affected with a water savings of approximately 90 thousand Acre-feet per year (TAF/yr). In 2025 with the code standard of 52.5 Ri-gpcd, 27 percent of Suppliers would be affected a new statewide Ri-gpcd average of 46.0 and a water savings of approximately 90 TAF/yr. In 2030 evaluating the code standard of 50.0 Ri-gpcd, 28 percent of Suppliers would be affected with a new statewide average of 44.3 and a water savings of approximately 163 TAF/yr.

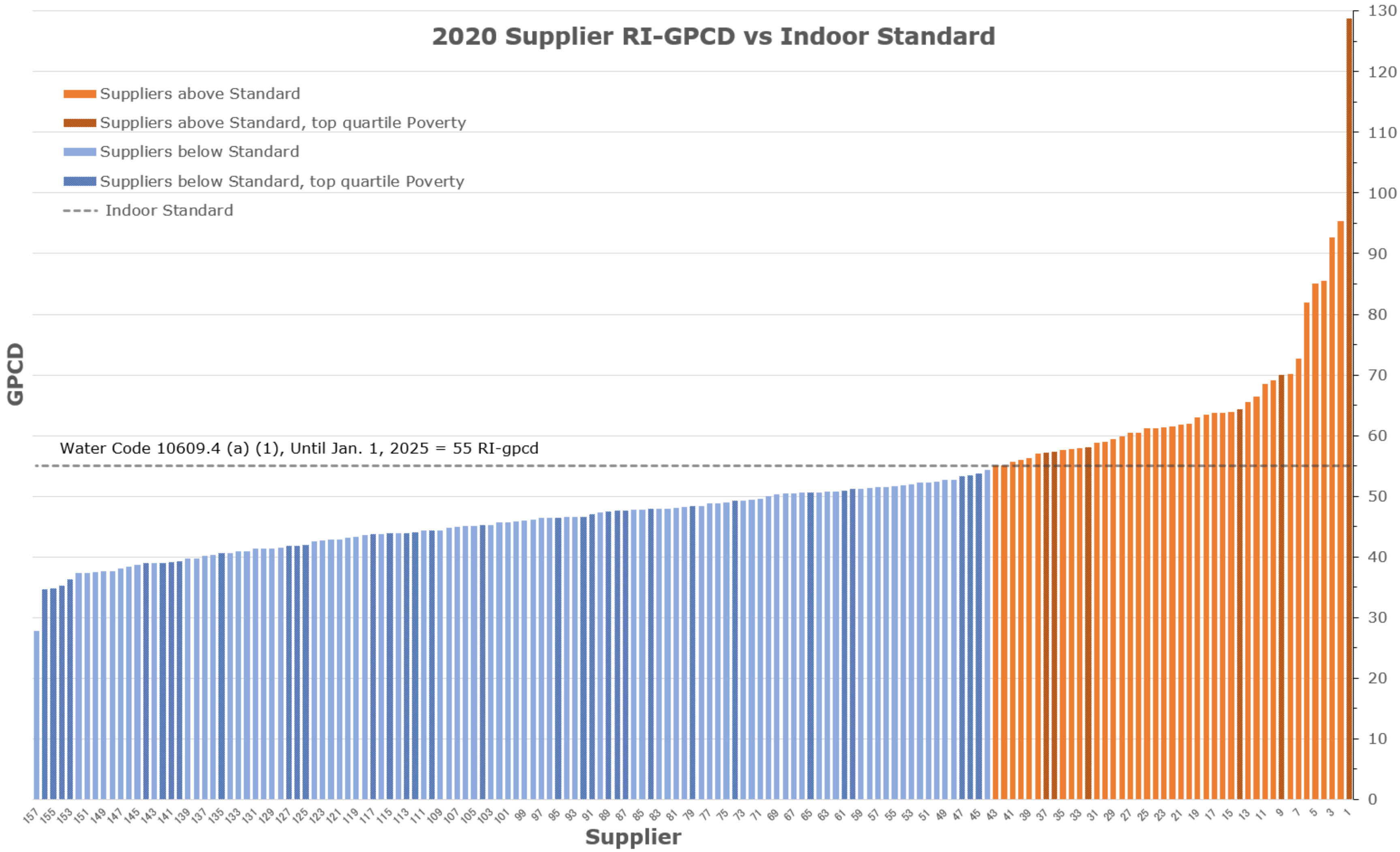

Figure H-31. Supplier Estimated Ri-gpcd Distribution for Current Conditions (Average of 2017, 2018, and 2019). This figure includes the line for the Water Code standard. Values in red exceed the standard and values in blue do not.

Table H-40. Potential Effects of Standards on Estimated 2020-2025 Ri-gpcd Distribution And Statewide Average

Ri-gpcd Standard Tested	New Average Ri-gpcd	Water Savings, *acre-feet per year*	Suppliers Above Standard, %	Suppliers > 5 Ri-gpcd Above Standard, %	Population Above the Standard, %
57	49.0	72,839	24	12	20
56	48.8	81,231	25	16	21
55	**48.6**	**89,883**	**27**	**17**	**23**
54	48.4	99,429	28	19	23
53	48.1	109,854	30	20	27
52	47.8	122,006	34	24	39
51	47.4	139,036	38	25	44
50	47.0	157,914	44	27	47
49	46.5	177,716	47	28	49
48	45.9	201,108	52	30	59
47	45.3	228,208	58	34	68
46	44.6	257,058	63	38	73
45	43.8	287,670	68	44	76
44	43.0	319,486	71	47	77
43	42.3	352,435	76	52	81

*Where bold values indicate water supplier level standards defined in California Water Code 10609.4(a)

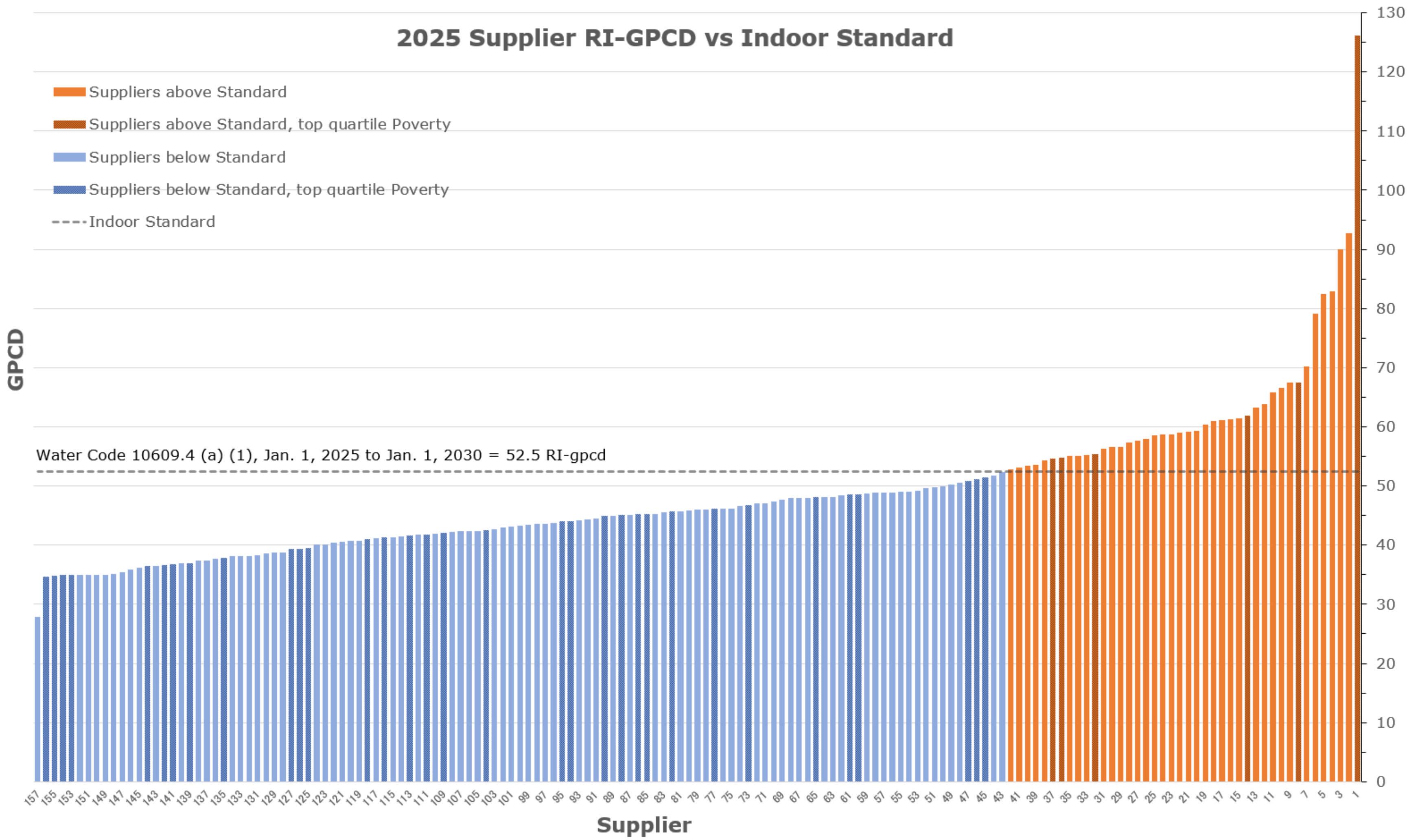

Figure H-32. Supplier Estimated RI-gpcd Distribution for 2025. This figure includes the line for the Water Code standard. Values in red exceed the standard and values in blue do not.

Table H-41. Potential Effects of Standards on Estimated 2025-2030 Ri-gpcd Distribution and Statewide Average

Ri-gpcd Standard Tested	New Average Ri-gpcd	Water Savings, *acre-feet per year*	Suppliers Above Standard, %	Suppliers > 5 Ri-gpcd Above Standard, %	Population Above the Standard, %
54	46.3	76,447	24	14	20
53	46.1	84,906	26	17	21
52.5	**46.0**	**89,522**	**27**	**17**	**23**
52	45.9	94,261	27	18	23
51	45.7	104,095	29	20	27
50	45.4	115,728	31	22	29
49	45.1	128,583	35	24	33
48	44.7	145,881	42	26	46
47	44.2	165,277	46	27	48
46	43.7	186,134	50	29	58
45	43.1	210,907	56	31	62
44	42.4	238,249	60	35	70
43	41.7	267,908	65	42	74
42	41.0	299,045	69	46	77
41	40.2	331,227	75	50	78

*Where bold values indicate water supplier level standards defined in California Water Code 10609.4(a)

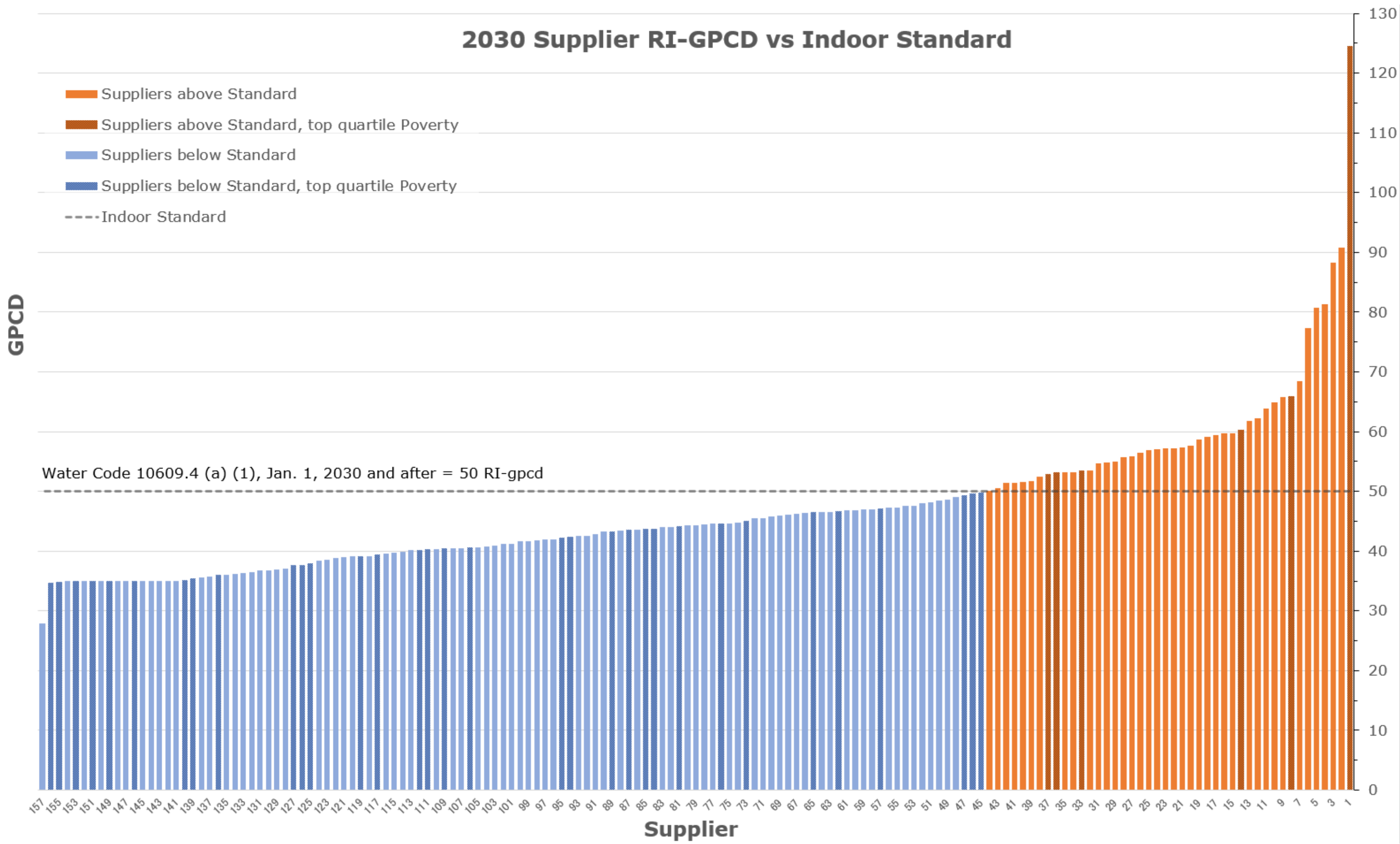

Figure H-33. Supplier Estimated Ri-gpcd Distribution for 2030. This figure includes the line for the Water Code standard. Values in red exceed the standard and values in blue do not.

Table H-42. Potential Effects of Standards on Estimated 2030+ Ri-gpcd Distribution And Statewide Average

Ri-gpcd Standard Tested	New Average Ri-gpcd	Water Savings, *acre-feet per year*	Suppliers Above Standard, %	Suppliers > 5 Ri-gpcd Above Standard, %	Population Above the Standard, %
52	44.7	78,861	24	15	20
51	44.5	87,692	27	17	23
50	**44.3**	**97,166**	**28**	**18**	**23**
49	44.0	107,760	31	20	29
48	43.7	120,080	33	23	31
47	43.4	133,352	36	21	33
46	43.0	151,142	43	27	47
45	42.5	170,816	46	28	48
44	41.9	193,410	52	31	59
43	41.3	218,844	57	33	63
42	40.7	246,540	61	36	71
41	39.9	276,556	65	43	74
40	39.2	308,106	72	46	78
39	38.4	340,515	76	52	80

*Where bold values indicate water supplier level standards defined in California Water Code 10609.4(a)

Conclusions

California's annual Supplier data reporting system provides an acceptable data set for characterizing the distribution of Ri-gpcd as a comparison against other approaches. When accurately reported, these data can be used to implement the Seasonal Adjustment Method (SAM) for calculating Ri-gpcd for each provider in California if dedicated irrigation meter data is also reported. This approach can be implemented by individual providers as a method for tracking Ri-gpcd trends over time.

Reference:

Mitchell, David M., *Re: Projected Statewide and County-Level Effects of Plumbing Codes and Appliance Standards on Indoor GPCD*, M Cubed, August 30, 2016

Appendix I. Potential Benefits and Impacts of Changing Ri-gpcd

Prepared for

California Department of Water Resources

By

Brown and Caldwell

California Department of Water Resources

Water Use Efficiency Branch

September 2020

Brown and Caldwell

FINAL REPORT

Potential Benefits and Impacts of a Changing Standard for Indoor Residential Water Use

September 30, 2020

Potential Benefits and Impacts of a Changing Standard for Indoor Residential Water Use

Prepared for

CA Department of Water Resources, Sacramento, CA

September 30, 2020

Project 155335

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- Tiffany Tran, Staff Engineer
- Wendy Broley, Technical Advisor
- Helene Baribeau, Technical Reviewer
- Cindy Paulson, Quality Control Reviewer

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AB	Assembly Bill
ac-ft	acre-feet
afy	acre-feet per year
AMI	advanced metering infrastructure
AWPF	advanced water purification facility
AWWA	American Water Works Association
BAWSCA	Bay Area Water Supply and Conservation Agency
BC	Brown and Caldwell
BOD	biological oxygen demand
CDC	Center for Disease Control and Prevention
cfs	cubic feet per second
CII	Commercial, industrial, and institutional
CIP	capital improvement program
CUWA	California Urban Water Agencies
CWC	California Water Code
DBP	disinfectant by-product
DWR	Department of Water Resources
EBMUD	East Bay Municipal Utility District
ESPRI	Environmental Science Policy & Research Institute
$FeCI_3$	ferric chloride
fy	fiscal year
GHG	greenhouse gas
GWRS	groundwater replenishment systems
H_2S	hydrogen sulfide
IAPMO	International Association of Plumbing and Mechanical Officials
IEUA	Inland Empire Utility Agency
LADWP	Los Angeles Department of Water and Power
LASAN	Los Angeles, Bureau of Sanitation
MG	million gallons
mgd	million gallons per day
mg/L	milligram(s) per liter
MWDOC	Municipal Water District of Orange County
NaOCI	sodium hypochlorite
NESWTF	Northeast Surface Water Treatment Facility
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
OCSD	Orange County Sanitation District

OCWD	Orange County Water District
PLWTP	Point Loma Wastewater Treatment Plant
R-gpcd	Total residential (indoor + outdoor) water use in gallons per capita per day
Ri-gpcd	Indoor residential water use in gallons per capita per day
RARE	Richmond Advanced Recycled Expansion
RCP	reinforced concrete pipe
RWRF	Regional Wastewater Reclamation Facility
SB	Senate Bill
SCWD	Soquel Creek Water District
SCWWTF	Santa Cruz Wastewater Treatment Facility
SESWTF	Southeast Surface Water Treatment Facility
SFPUC	San Francisco Public Utilities Commission
SF RWS	San Francisco Regional Water System
SGMA	Sustainable Groundwater Management Act
SSB	sanitary sewer blockages
SSO	sanitary sewer overflows
State Water Board	State Water Resources Control Board
SVCW	Silicon Valley Clean Water
TDS	total dissolved solids
THM	trihalomethanes
TOC	total organic carbon
TSS	total suspended solids
TUD	Tuolumne Utilities District
UV-AOP	ultraviolet advanced oxidation process
UWMP	Urban Water Management Plans
Valley Water	Santa Clara Valley Water District
VVWRA	Victor Valley Wastewater Reclamation Authority
WCWD	West County Wastewater District
WDO	Water Demand Offset
WRF	Water Research Foundation
WUE	water use efficiency
WTP	water treatment plant
WWTP	wastewater treatment plant

Glossary

R-gpcd	Total residential (indoor and outdoor) water use in gallons per capita per day
Ri-gpcd	Indoor residential water use in gallons per capita per day
urban retail water supplier	A water supplier, either publicly or privately owned, that directly provides potable municipal water to more than 3,000 end users or that supplies more than 3,000 acre-feet of potable water annually at retail for municipal purposes
urban water use efficiency standards	The standards effective through CWC §10609.4 (indoor residential use) or adopted by State Water Board (outdoor residential, water loss, and CII outdoor irrigation of landscape areas with dedicated meters) pursuant to CWC §10609.2.
urban water use objective	An estimate of aggregate efficient water use for the previous year based on adopted water use efficiency standards and local service area characteristics for that year
disinfectant demand	Reactions between disinfectants and microbial, organic and inorganic constituents
disinfectant decay	The natural decay of disinfectants over time

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Executive Summary

Water is essential to the way of life in California, and water providers are continuously working to develop long-term strategies to maintain water supply reliability for their communities. In 2018, the California State Legislature enacted legislation to establish a foundation for long-term improvements in water efficiency and drought planning.

Context and Study Objectives

In 2018, Assembly Bill (AB) 1668 and Senate Bill (SB) 606 set default standards for indoor residential use (Ri) starting at 55 gallons per capita daily (Ri-gpcd), decreasing to 52.5 Ri-gpcd from 2025 through 2030, and further decreasing to 50 Ri-gpcd from 2030 and onward. This legislation also directed the Department of Water Resources (DWR), in coordination with the State Water Resources Control Board (State Water Board), to conduct necessary studies and investigations to analyze the benefits and impacts of how the changing standard for indoor residential water use will impact water and wastewater management, including potable water usage, wastewater, recycling and reuse systems, infrastructure, operations, and supplies. DWR and the State Water Board may also jointly recommend a standard for indoor residential water use that more appropriately reflects best practices (Water Code section 10609.4(a)(3)).

A report on the results of the studies and investigations shall be made to the chairpersons of the relevant policy committees of each house of the Legislature by January 1, 2021. This study satisfies that requirement by qualitatively assessing the collective benefits and impacts of a changing indoor residential water use standard. Per the Water Code, the focus is on indoor residential use, which is water that travels through utility infrastructure systems (see Figure ES-1, next page). This study is based on a review of the literature, as well as case study interviews of water and wastewater systems in California.

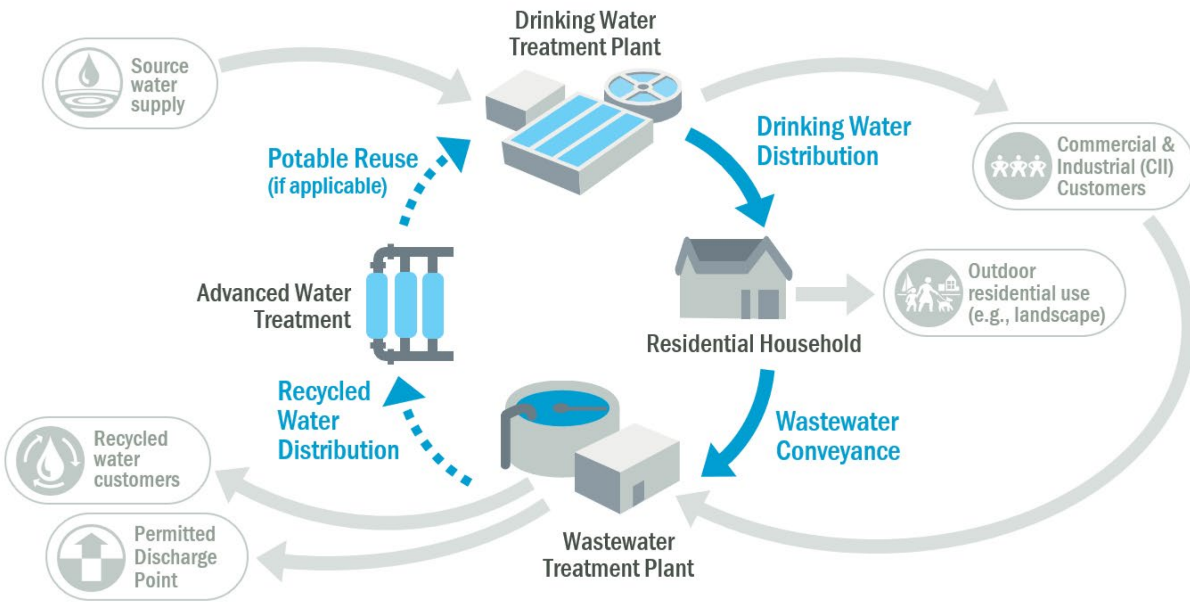

Figure ES-1. Indoor residential water use uses and generates flow that remains within utility infrastructure systems, which is shown in blue.

Key Takeaways & Potential Future Refinements

- Public utilities can and will adapt to a changing Ri-gpcd standard. However, it will require time and money.
- Public utilities across California have demonstrated their ability to adapt to adverse impacts of a changing Ri-gpcd through a variety of mitigation strategies. However, these adaptations require time and money, the extent of which will depend on utility-specific characteristics.
- The purpose of this study was to conduct a qualitative assessment of the benefits and impacts of a changing Ri-gpcd standard, as quantifiable data are not yet available. This study could be enriched through the collection of more quantifiable data. A data set that includes more utilities and unique system characteristics, which exacerbate or reduce impacts of adverse effects, is warranted. Based on improved understanding of impacts, utilities can help inform a realistic timeframe for standards implementation or the funding needs to support adjustment to the changing Ri-gpcd standard.

- There are benefits and adverse impacts from a changing Ri-gpcd standard on water and wastewater management due to the interconnectedness of these systems.

- Water and wastewater systems exist within an interconnected cycle, and changes in one area of the cycle will have a ripple effect throughout. A changing Ri-gpcd standard not only alters hydraulics (e.g., total volumes and velocities), but also water and wastewater quality, energy use, operation and maintenance (O&M) requirements, planning, and design.

- The benefits are similar for water and wastewater systems, as reduction in total volumes allow for reductions in treatment cost and energy use, and excess capacity to support growth or defer capital investment for expansion. However, adverse impacts vary greatly, reflecting the differences in water and wastewater system infrastructure needs and expectations.

- The acknowledgment of adverse impacts is not to imply that emphasis on conservation and water use efficiency should be relaxed, or that potable water use remains the same or increase to avoid impacts. Rather, it is to acknowledge the interconnections between water use, wastewater generation, and recycled water production, and how changes within the cycle will have implications.

- Though indoor residential use is a factor in water and wastewater flows, impacts on utilities are also a function of the following factors:

    - **Diverse utility characteristics and conditions**. Multiple characteristics influence a utility’s vulnerability to adverse impacts, such as population served, age and condition of existing infrastructure, materials of construction, and utility rate structures.

    - **Magnitude of effect**. If indoor residential water use is already low, overall effects of a changing standard may be minimal. Alternatively, a significant decrease in indoor residential water use to meet a changing standard may have more substantial adverse impacts.

    - **Other water use sectors.** The COVID-19 pandemic has driven measurable increases in residential water use, along with a concurrent decrease in commercial, industrial, and institutional (CII) water use. The overall net effect for many utilities has been reduced system flows, even with increasing residential use. During drought conditions, water use reductions are experienced in most water use sectors, which can further compound effects.

As this study is a qualitative assessment and not intended to arrive at quantifiable thresholds for the Ri-gpcd, it is recommended that future studies take site-specific factors and unique characteristics into consideration.

Approach and Methodology

This study is an analysis of the benefits and impacts of how a changing standard for indoor residential water use could impact water and wastewater management, including potable water usage, wastewater, recycling and reuse systems, infrastructure, operations, and supplies. Per Water Code 10609.4, a report on the results of the studies and investigations shall be made to the Legislature by January 1, 2021.

Given that utilities are still actively adapting to the 55 Ri-gpcd standard, this analysis examines utility experiences during a prior time of significantly reduced indoor residential per capita use – the recent drought from 2012 to 2016. This study details utility experience captured in literature, most notably, prior assessments by the California Urban Water Agencies (CUWA), a non-profit organization of 11 major urban water agencies serving two-thirds of the state's population. In 2017, CUWA published the white paper *"Adapting to Change: Utility Systems and Declining Flows*", which documented utility experience during the 2015-16 emergency regulations for water conservation. While the dramatic measures taken during the drought were specifically to address the emergency, understanding the benefits and adverse impacts experienced during those periods of lower water use can provide insight into the effects of an indoor residential water use standard set around those levels.

Case study interviews were also conducted as part of this work to reflect current (2020) experience with reduced indoor residential per capita use. These interviews provide insight on the potential benefits and adverse impacts, as the utilities selected continue to operate close to the reduced per capita use achieved during the recent drought. The utilities that participated included East Bay Municipal Utility District (EBMUD), the City of San Diego, Soquel Creek Water District (SCWD), and the City of Fresno. These utilities represent a diverse set of experiences, reflecting variations in geography, source supplies, service area size, and topography. Figure ES-2 shows the four utilities that were interviewed, as well as other utilities included herein from literature.

Figure ES-2. Utility experiences throughout California on benefits and impacts are referenced in this study. R-gpcd shown is based on 2019 values and are only reported by urban water retailers.

Summary of Benefits and Adverse Impacts

Existing literature and utility experience demonstrate real benefits from reduced per capita indoor residential water use, as well as significant adverse impacts to water, wastewater, and recycled water systems. These benefits and adverse impacts are summarized in the Tables ES-1 and ES-2 through ES-4, respectively. Benefits are further discussed in Section 2 and adverse impacts are presented in Section 3.

Table ES-1. Potential Benefits for Water and Wastewater Utilities.

Section #	Effect	Description	Benefit to Utility
2.1.1	Adaptations to the effects of climate change	Enables existing supplies to support potential population growth without an immediate need for water treatment plant expansion or investments in supplemental supplies	Improved regional self-reliance, water service reliability, and cost savings
2.2.1	Decreased water treatment and pumping costs	Lower water demand decreases treatment chemical uses and associated costs to produce drinking water, and lowers energy required to pump water in distribution systems	Cost savings for water utilities through reduced chemical purchase and energy usage
2.2.2	Deferred capital investment	Remaining capacity can allow for deferral of capital investment costs to expand existing water or wastewater treatment plant	Deferred capital spent for water or wastewater utilities
2.2.3	Reduced energy usage for wastewater systems	Reduced water demand and wastewater production results in lower energy usage associated with reduced pumping and treatment process needs	Cost savings from reduced energy usage for pumping

Table ES-2. Potential Adverse Impacts for Water Utilities

Section #	Effect	Description	Potential Adaptation Strategies & Impact on Utility
3.1.2	Deterioration of water quality	Increased retention time in the water distribution system creates treatment and potential public health and safety implications from increases in disinfectant by-product (DBP) formation, microbial activity, and change in aesthetic characteristics such as taste and odor	Increased operational costs from flushing, additional chemical usage or O&M, or possible increased risk to health and safety[1]
3.1.	Stranded assets and stagnation in storage facilities	Reduced water demand may result in stranded assets such as underused water treatment plants or unused capacity in distribution systems and storage facilities	Economic impact from unused assets as well as operations and maintenance (O&M) labor and costs to continue maintaining underused infrastructure[1]
3.5	Reductions in revenue from reduced water sales	Reduced water demand can result in lower total water sales, which makes it challenging for utilities to cover baseline O&M costs	Economic impact from reduced revenue and need to increase customer rates to compensate

[1]Increased retention time results from systems oversized for current conditions. Utilities are updating demand projections, but there are considerations in water system sizing (e.g., peak hour, maximum day, and fire flows) that may limit a utility's ability to adapt through downsizing to match reduced water demand.

Table ES-3. Potential Adverse Impacts for Wastewater Utilities

Section #	Effect	Description	Potential Adaptation Strategies & Impact on Utility
3.2.1	Increased sewer gas production	Increasing sewer gas production such as hydrogen sulfide (H2S) concentrations can create public health and safety impacts from increase in odor production and build-up of noxious gasses	Increased costs from increased purchase of odor mitigation materials and associated O&M
3.2.2	Accelerated rate of corrosion in sewer pipes and manholes	Higher H2S concentrations accelerate the rate of corrosion in sewer pipes, especially concrete, leading to faster rate of failure	Increased costs from additional O&M and accelerated need for capital improvement program (CIP) projects for infrastructure rehabilitation or replacement
3.2.3	Increased occurrence of sewer blockages and overflows	Increased solids concentrations exacerbate blockages in sewers, resulting in clogged pipes, loss of sewer serviceability, sanitary sewer overflows	Increased costs for additional O&M and public health & safety impacts if unaddressed
3.3.1, 3.3.2	Degradation of wastewater influent quality	Increasing contaminant concentrations in wastewater influent such as higher ammonia, biological oxygen demand (BOD), and total suspended solids (TSS) can stress loading-based treatment processes and increase concentrations in wastewater effluent	Reduced treatment capacity and increased treatment costs to continue meeting discharge requirements

Table ES-4. Potential Adverse Impacts for Recycled Water Projects

Section #	Effect	Description	Potential Adaptation Strategies & Impact on Utility
3.4.1	Reductions in recycled water quantity	Reductions in wastewater influent subsequently reduce the volumes of recycled water that can be produced, limiting a utility's ability to offset potable reuse with recycled water	Increased reliance on potable water instead of recycled water, reducing regional self-reliance
3.4.2	Deterioration of recycled water quality	Changes in wastewater effluent quality adversely affect recycled water quality, which has downstream impacts on recycled water users with specific water quality criteria	Increased costs of recycled water, particularly if supply needs to be supplemented with potable water or if additional pretreatment is needed

Influence of Utility Characteristics on Potential Adverse Impacts

Based on the research and case study interviews, specific utility characteristics can either increase a utility's resiliency or exacerbate adverse impacts from reduced per capita indoor residential water use. This is summarized in Table ES-5 and discussed further in Section 5. The utility characteristics described do not represent an exhaustive list, but rather a starting point for future research and quantifiable data collection.

Table ES-5a. Utility Characteristics That Can Contribute to Adverse Impacts: Water Utilities

Section #	Adverse Impact	Utility Characteristics
3.1.1	Deterioration of water quality due to increased retention time in distribution system	• **Age of infrastructure.** Systems appropriately designed for higher historical flow rates can become oversized, resulting in longer retention times and higher water age. Design criteria that support higher flow rates (e.g., flat slopes, turns and pumping) may not work well for lower flow conditions and can exacerbate water quality. Older systems may also experience more corrosion and deterioration. In such systems, any changes in flow conditions may lead to water quality deterioration, including contaminant leaching. • **Topography, size, and density of service area.** Systems that serve large, flat, and low-density areas require water to travel longer, increasing the potential for longer distribution system retention times. • **Infrastructure material.** Systems with pipes made of iron, lead, copper and other metals may be more susceptible to problematic metal release from increased retention time.
3.1.2	Stranded assets and stagnation challenges from reduced water quantity	• **Magnitude of change from initial design parameters.** Similar to the above, water treatment plants and storage facilities sized for historically greater water demands may become oversized, resulting in water stagnation or excess infrastructure that could exist as stranded assets.

Section #	Adverse Impact	Utility Characteristics
3.5	Reductions in revenue from reduced water sales	• **Rate structure.** Utilities with rate structures tied to volumetric use may experience more financial volatility as customers reduce water use.

Table ES-5b. Utility Characteristics That Can Contribute to Adverse Impacts: Wastewater Utilities

Section #	Adverse Impact	Utility Characteristics
3.2.1, 3.2.2	Increase in odors and accelerated corrosion from higher sewer gas concentrations	• **Age of infrastructure.** Utilities with older infrastructure may be more susceptible to odor, leakage, and accelerated corrosion as pipelines have deteriorated and corroded over time. • **Topography, size, and density of service area.** Long stretches of flat pipeline provide more time for H_2S production, exacerbating odor production and corrosion. • **Infrastructure material.** Sewer systems constructed of materials sensitive to corrosion, such as concrete, will experience adverse effects of accelerated corrosion most heavily.
3.2.3	Increase occurrence of sewer blockages and overflows	• **Pipeline diameters.** Pipelines with smaller diameters are more easily clogged and thus more susceptible to sanitary sewer blockages and associated overflows. • **Conveyance system design parameters.** Pipelines with more flow constraint conditions (turns, material roughness, use of lift stations, and other features) may be more susceptible to blockages.

Section #	Adverse Impact	Utility Characteristics
3.3.1, 3.3.2	Impacts on wastewater effluent quality and increased chemical use from degradation of wastewater influent quality	• **Customer demographic.** Utilities with large percentages of residential customers will experience larger changes in both wastewater quality and quantity. • **WWTP treatment process.** WWTPs that use treatment processes that have loading limitations, such as activated sludge, nutrient removal, and biosolids handling, will be more sensitive to increasing loads in influent wastewater. • **National Pollutant Discharge Elimination System (NPDES) permit requirements and discharge point.** WWTPs that discharge into sensitive water bodies with strict NPDES discharge limits may require more operational adjustments and may struggle to maintain margins of safety that enable consistent compliance with effluent requirements.

Table ES-5c. Utility Characteristics That Can Contribute to Adverse Impacts: Recycled Water Utilities

Section #	Adverse Impact	Utility Characteristics
3.4.1	Deterioration in recycled water quality from worsened wastewater effluent quality	• **Customer demographic and end-uses.** Systems that serve customers that require high water quality (e.g., industrial processes, golf courses, or potable reuse) could be more susceptible to the impacts of increasing concentrations in wastewater effluent. • **Existing or planned investments.** Changes in wastewater quality will more greatly impact projects that are actively in design or construction phases.

Section #	Adverse Impact	Utility Characteristics
3.4.2	Limiting the offset of potable use from reductions in recycled water production volumes	• **Water supply source.** Utilities that use recycled water to supplement a sensitive or scarce source supply will be more impacted by reductions in recycled water production. • **Discharge requirements.** WWTP discharge criteria that require a minimum flow to the receiving water body reduces the amount of wastewater available for reuse if total wastewater flows decrease, limiting the production of recycled water.

1.0 Background and Approach

Water is essential to the way of life in California, and utilities are working to develop long-term strategies to maintain water supply reliability for their communities. In 2018, the California State Legislature enacted legislation that strives to establish a foundation for long-term improvements in water use efficiency and drought planning.

1.1 Nexus to Urban Water Use Objectives

In 2018, AB 1668 and SB 606 set default standards for indoor residential use starting at 55 Ri-gpcd, decreasing to 52.5 Ri-gpcd from 2025 through 2030, and further decreasing to 50 Ri-gpcd from 2030 and onward. This legislation also directed the DWR, in coordination with the State Water Board, to conduct necessary studies and investigations to analyze the benefits and impacts of how the changing standard for indoor residential water use will impact water and wastewater management. DWR and the State Water Board may also jointly recommend a standard for indoor residential water use that more appropriately reflects best practices (Water Code Section 10609.4(a)(3)).

The legislation also directed DWR to conduct studies and provide recommendations, in coordination with the State Water Board, on water use standards for outdoor residential use, water losses, and CII outdoor landscape areas with dedicated irrigation meters (DWR 2018). These standards are not individually enforceable, but rather, are components of an urban retail water supplier's total urban water use objective, as shown in Figure 1-1 on the next page.

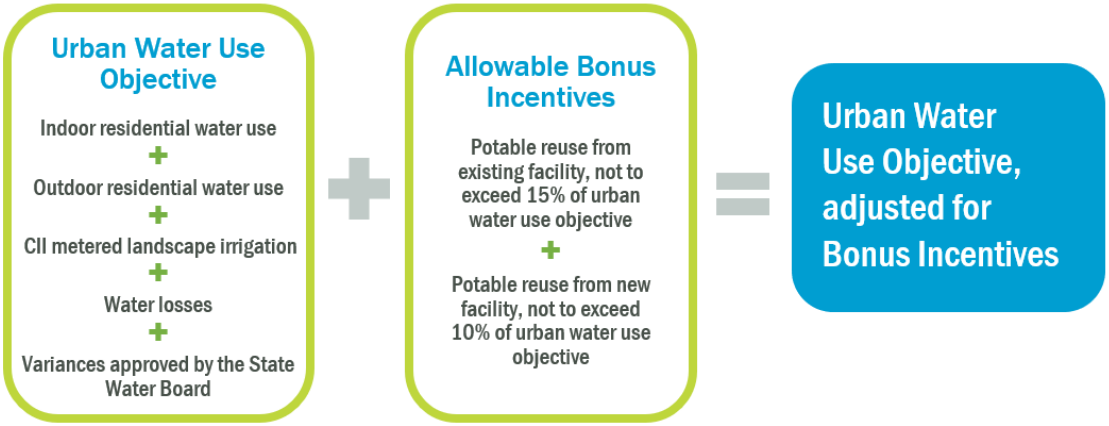

Figure 1-1. The indoor residential water use standard is one component of an urban retail water supplier's urban water use objective.

Source: DWR 2018

The urban water use objective applies to retail water suppliers and is calculated annually, based on the adopted water use standards and local service area characteristics for the previous year (Water Code Section 10609(a)). Each urban retail water supplier calculates a unique gallon per capita per day annual objective. The objective is subject to annual reporting and used in comparison to the actual aggregate water use in the previous year. Urban water suppliers are required to stay within their annual water use objective for their service areas. Beginning in 2024, the State Water Board has authority to enforce the aggregate water use objective, but individual standards compliance will not be enforced.

1.1.1 Purpose of Study

Unlike the water use standards that are still to be adopted for outdoor residential use, water losses, and CII outdoor landscape areas, the legislature set the current standard for indoor residential use at 55 Ri-gpcd. The standard is set to decrease to 52.5 Ri-gpcd beginning in 2025 and will further decrease to 50 Ri-gpcd by 2030. Per the legislation, the Ri-gpcd studies and investigation must "include an analysis of the benefits and impacts of how the changing standard for indoor residential water use will impact water and wastewater management, including potable water usage, wastewater, recycling and reuse systems, infrastructure, operations and supplies" (California Water Code [Water Code] Section 10609.4).

A report on the results of the studies and investigations shall be made to the chairpersons of the relevant policy committees of each house of the Legislature by January 1, 2021. This study satisfies that requirement by qualitatively assessing the collective impacts of a changing indoor residential water use standard. Per the Water Code, the focus is on the impacts of indoor residential use, which is what travels through utility infrastructure systems (see Figure 1-2, next page).

This analysis is meant to satisfy the Water Code by presenting a qualitative benefit and impacts assessment associated with a changing indoor residential water use standard. Given the limited quantifiable information currently available, this analysis cannot and is not intended to arrive at or comment on a recommended threshold for per capita water consumption beyond which water, wastewater, and reuse systems may experience significant adverse impacts.

1.2 The Potential Effects of a Changing Indoor Ri-gpcd Standard

Water, wastewater, and recycled water systems are interconnected and a change in one part of the cycle can trigger impacts, both positive and negative, on other parts of the system. In most cases, water that is used outdoors for irrigation is not typically recaptured and instead "lost" through evapotranspiration or percolation (except for areas where water naturally percolate into groundwater aquifers). When water is used indoors, it is flushed down a drain and then conveyed through the sewer system to the WWTP. Treated WWTP effluent can be discharged or conveyed to a recycling or reuse treatment facility to be treated further. The interconnected nature of water and wastewater distribution, conveyance, and treatment infrastructure is often referred to as the urban water cycle (Figure 1-2, next page).

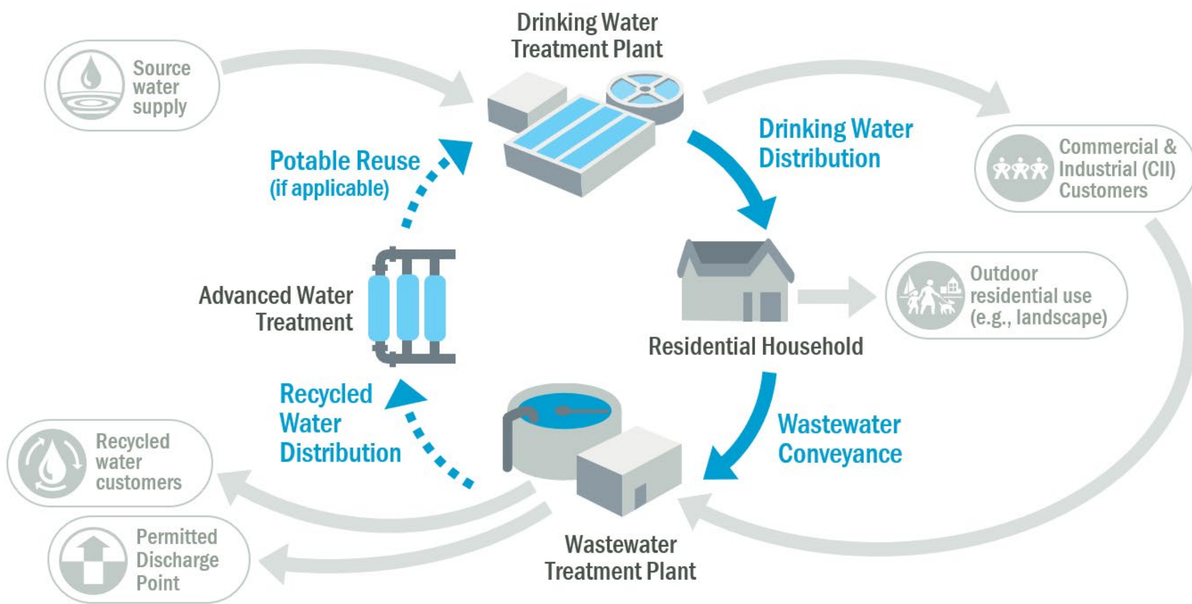

Figure 1-2. Indoor residential water use generates water that remains within the urban water cycle, shown in blue.

Furthermore, effects of a changing indoor residential water use standard, if lower than existing conditions, may result in less water used and less wastewater and recycled water generated, depending upon the concurrent population growth and development. Reductions in indoor water use result from both short-term conservation efforts (i.e., behavior changes in response to drought or emergency) and long-term water use efficiency for lasting, sustainable effects. While some utilities use the term "conservation" to describe both short-term and long-term strategies, this study distinguishes between conservation as an emergency response to drought (drought conservation) and water use efficiency (WUE) as a long-term strategy for lasting demand reductions, such as low-flow plumbing fixtures and appliances.

The significant reduction in water demand due to drought conservation during the 2012-2016 drought brought to light unintended consequences of reduced water use that rippled throughout California's water, recycled water, and wastewater systems. The drought response included reductions in both indoor and outdoor use. Reduced indoor water demands affect total volumes and velocities within both drinking water and wastewater systems, setting these systems up to experience changes in quality, treatment, and operational and maintenance needs. Wastewater agencies produce highly treated water that is increasingly recycled and reused as a water supply. While it is still only a small portion of overall water use, the use of recycled water has nearly tripled since the 1980s—and continues to rise as water agencies seek to meet the demands of a growing population and improve the resilience of their water supplies (PPIC 2019).

1.3 Considerations for a Changing Ri-gpcd Standard

The Ri-gpcd standard is expected to have lasting effects on future water management practices throughout California, and there are various factors to consider.

1.3.1 Challenges in Quantifying Actual Ri-gpcd

In order to assess benefits and impacts of a changing standard, it is important to have an idea of the magnitude of change. While the indoor and outdoor residential water use standards are defined separately in the urban water use objective, most residential customers do not have separate meters that differentiate between indoor and outdoor use. As such, determining the specific Ri-gpcd for utilities is challenging since most utilities only obtain monthly or bi-monthly water usage records and do not separately meter indoor and outdoor use. For state reporting, some utilities provide an assumed percentage (e.g., 50 percent indoor, 50 percent outdoor) (City of San Diego 2020), but that is often an estimate that is not substantiated by specific meter records. Other utilities may look to water use in winter months as a representative baseline for predominantly indoor use.

Given Ri-gpcd is often not measured by utilities, total (indoor + outdoor) R-gpcd, shown in Figure 1-2, serves as context around the current 55 Ri-gpcd standard and any recommended standard. These Ri-gpcd values are from the dataset as reported to the State Water Board on a monthly basis. However, this varies for each supplier and each associated wastewater and recycled water facility.

1.3.2 Interconnections with Other Regulatory Actions

Utility efforts to continually provide safe and affordable water and wastewater services are driven and informed by developing regulations. Often, these regulations are developed in parallel with each other with separately defined goals, and they have the potential to conflict. For example, if indoor residential water use flows are reduced, the water available to meet reuse goals for some agencies will be reduced. This is not to say that the reuse goals should not be modified since reducing potable water use is of prime importance; it is to illuminate the potential for conflicts and enhances the need to provide flexibility in interconnected regulations and policies based on various situations.

This work is one element of the overall conversation around water supply reliability and water use efficiency. DWR and the State Water Board are working on a variety of regulations that interconnect, and it is important to consider their cumulative impacts. Other important state-wide policies to consider are described here.

- **State Water Board recycled water goals.** Per the Recycled Water Policy (2018), the State Water Board adopted goals to increase the use of recycled water from 714,000 acre-feet per year (afy) in 2015 to 1.5 million afy by 2020 and to 2.5 million afy by 2030 (State Water Board 2018). This is important as production of recycled water requires a supply of wastewater influent, which will be influenced by the Ri-gpcd standard. Determination of the amount of wastewater that is available to recycle in California has been identified in the WateReuse California Action Plan as a key item in advancing water reuse (WateReuse CA 2019). The ongoing Water Research Foundation (WRF) project 4962 titled "Identifying the Amount of Wastewater That Is Available and Feasible to Recycle in California" seeks to quantify this value to help refine existing recycled water goals.

- **Onsite reuse regulatory development.** The California Water Code (CWC) Section 13558 requires the State Water Board to adopt regulations for risk-based water quality standards for the onsite treatment and reuse of non-potable water on or before December 1, 2022. Section 13558 also requires the Department of Housing and

Community Development to develop any necessary corresponding building standards to support the risk-based water quality standards on or before December 1, 2023. The development of onsite reuse diverts water, but not necessarily solids, out of the wastewater collection system, which can have downstream adverse impacts on centralized wastewater and recycled water facilities. Greater adoption of onsite reuse has the potential to exacerbate many of the adverse impacts to water and wastewater systems. Lower indoor use combined with onsite reuse may lead to even less water flowing through the potable distribution system, which cascades into lower wastewater volumes entering into wastewater systems (CUWA 2019).

- **Sustainable Groundwater Management Act (SGMA).** SGMA requires governments and water agencies of high and medium priority basins to halt overdraft and bring groundwater basins into balanced levels of pumping and recharge. A lower Ri-gpcd standard could have a variety of impacts on a water utility that is also working to meet compliance with SGMA, depending on the characteristics of the basin. Reduced demand could lead to reduced pumping that lessens the strain of overdraft in a basin. Alternatively, it could have a negative impact for utilities that are relying on wastewater effluent or recycled water from another agency for groundwater recharge or to minimize the need for groundwater pumping.

- **Delta Stewardship Council Policy WR P1.** WR P1 aims to reduce reliance on the Delta through improved regional self-reliance. Exports from, transfers through, or water used in the Delta will only be allowed to water suppliers that have adequately demonstrated reduced reliance on the Delta and adequately contributed to improved regional self-reliance. Similar to SGMA, this demonstration of reduced reliance could be supported by reduced per capita residential use that lowers total demand or be negatively impacted if they are leveraging recycled water to offset potable use.

1.3.3 Human Behavioral and Cultural Changes

Human behavioral and cultural changes or shifts in water use and reuse may exacerbate or mitigate changing indoor residential water use standards benefits and impacts. As seen with COVID-19, stay-at-home orders and business shutdowns during pandemic onset prompted changes in municipal water demand. Given lags in collecting and analyzing water-use data and a lack of precedent experience, details demonstrating expected changes are currently limited. Available data suggest residential water demand increased while commercial/industrial use decreased, as would be expected. The effect of the COVID-19 pandemic on total water demand varies from community to community, and a key factor includes the relative proportion of residential and non-residential water uses (Cooley et al. 2020).

The **San Francisco Public Utilities Commission (SFPUC)** was tracking the shift in water use trends by comparing water use to the seven weeks before San Francisco's shelter-in-place restrictions began in March 2020. The subsequent weeks after the restrictions went into effect saw commercial use down by 50 percent as compared to the seven-week period before, and overall total water use reduced by eight percent in April 2020 as compared to March 2020 (SFPUC 2020). This reduction in commercial use continued in July 2020, as commercial use remained down by 38 percent and residential use up by 11 percent when compared to pre-restrictions. While there was an initial decrease in overall water demand in April 2020, the percent changes in July 2020 offset each other and there was a rebound of water demand to pre-COVID volumes (SFPUC 2020).

The shift to people working at home due to COVID-19 may have a substantial effect on impacts associated with a changing indoor residential water use standard by shifting water use from one sector to another and by an overall reduction in total water use. For example, many suppliers are seeing their commercial water use going down, contributing to lost revenue that is not offset by the increase in residential water use revenue. Additionally, if commercial water use declines, there will be less commercial water to supplement total wastewater volumes if indoor residential water use decreases, leading to potential water quality effects. It is currently unknown what the magnitude of these effects are or how persistent current changes will be. However, some longer-term adjustments may be needed as commercial properties may experience reduced occupancy for an extended period.

1.4 Approach and Methodology

This study is an analysis of the benefits and impacts of how the changing standard for indoor residential water use will impact water and wastewater management, including potable water usage, wastewater, recycling and reuse systems, infrastructure, operations, and supplies. Per Water Code 10609.4, a report on the results of the studies and investigations shall be made to the Legislature by January 1, 2021.

Utilities are still actively adapting to the 55 Ri-gpcd standard, so this analysis instead examines utility experiences during another time of significantly reduced indoor residential per capita use – the recent drought from 2012 to 2016. This study details utility experience captured in literature, most notably, prior assessments conducted as part of the CUWA white paper *"Adapting to Change: Utility Systems and Declining Flows*", which documented utility experience during the 2015-16 emergency regulations for water conservation. While the dramatic measures taken during the drought were specifically to address the emergency, understanding the benefits and adverse impacts experienced during those periods of lower water use can provide insight into the effects of an indoor residential water use standard set around those levels.

Case study interviews were also conducted as part of this work to reflect current (2020) experience with reduced indoor residential per capita use. These interviews provide insight on the potential benefits and adverse impacts, as the utilities selected continue to operate close to the reduced per capita use achieved during the recent drought. The utilities that participated included EBMUD, the City of San Diego, SCWD, and the City of Fresno. These utilities represent a diverse set of experiences in geography, source supplies, service area size, and topography. Figure 1-3 shows the four utilities that were interviewed, as well as other utilities included herein from literature.

Figure 1-3. Utility experiences throughout California on benefits and impacts are referenced in this study. R-gpcd shown is based on 2019 values and are only reported by urban water retailers.

2.0 Benefits of a Changing Ri-gpcd Standard

There are various factors that contribute to the quality and quantity of water and wastewater experienced by utilities, including customer demographic, per capita use, and population growth. As directed by the legislation, this study is focused on the change of one variable – indoor residential per capita water use (Ri-gpcd).

This study presents the benefits of a changing Ri-gpcd standard by examining the benefits experienced during another instance of significantly reduced per capita use – the drought in 2012 to 2016. Drought conservation and WUE are defined as the short-term behavior changes during drought emergencies and long-term strategies for sustained demand reductions for this analysis. They are both strategies to support the reliability of water supplies as they stretch available resources to support community demand for potable and non-potable needs.

2.1 Water Supply Benefits: Adapting to the Effect of Climate Change

As climate change brings about a warmer and more variable climate, it exacerbates challenges faced by water agencies, namely the availability of long-term water supplies. Climate change affects California’s water resources, and despite the state’s aggressive climate policies, these impacts will continue to worsen. The snowpack in the Sierra Nevada mountains, which provides about a third of California’s water supplies is projected to potentially shrink by 79 percent under a high emissions scenario (Rhoades 2018). This reduces the reliability of water supplies that depend on the snowpack and potentially increases demand for other water sources such as groundwater.

Precipitation falling as rain instead of snow is also worsened by climate change, exacerbating flood risks and adding additional challenges for water supply reliability (Rhoades 2018). Variable weather patterns with more extreme weather events will also result in greater flood risks, while droughts will likely become longer and increase in severity. Sea levels will continue to rise, threatening the stability of the Sacramento/San Joaquin Bay Delta levees and requiring more fresh water to mitigate saltwater intrusion into coastal aquifers.

Droughts are also a recurring feature of California's climate, and climate change due to anthropogenic warming will substantially increase the likelihood of extreme California droughts (Williams et al 2015). The four-year period between fall 2011 and fall 2015 was the driest since record keeping began in 1895, with 2014 and 2015 being the two hottest years in the state's recorded history. Precipitation in 2016 was average in northern California but this was not enough to eliminate the severe water deficit. In the face of these challenges, utilities are working to increase their water supply reliability through both portfolio diversification and demand reduction through WUE strategies.

2.2.1 Increased Water Supply Resiliency through both Diversification and WUE

To mitigate the issues exacerbated by climate change and increase resiliency, water utilities can work to reduce water demand, secure additional supply options, and increase diversification of their water source portfolio. Water systems have several strategies to diversify their water portfolio including purchase of supplemental supplies, interconnections between water systems, construction of additional water treatment and reuse systems, urban stormwater capture projects, groundwater banking, regional conjunctive use projects, and seawater desalination.

Decreasing water demand is supported through investments in water conservation measures and programs that promote WUE. Long-term WUE measures include replacing inefficient fixtures and devices such as toilets, dishwashers, clothes washers, faucets, and showerheads with devices that use less water. There are also outdoor WUE measures, such as efficient irrigation practices like drip and subsurface irrigation and efficient spray nozzles. These measures are proven to be effective when implemented at a large scale, often through building codes, ordinances, rebate programs, and conservation education programs. Such reductions in water use and water demand can result in a decrease or deferral of capital costs, either to expand existing infrastructure or develop new water sources, which is discussed further in Section 2.2.2. The effectiveness of any demand reduction program, however, will depend on the current level of efficient device saturation and customer water conserving practices.

A study on the 10 largest urban retailers in California found that the reduction in per capita water demand was substantial enough to reduce total demand in spite of population growth (Abraham et al. 2020). This investment in water use efficiency and subsequent reduction in water use has been successfully achieved by utilities throughout California, as demonstrated in the examples below.

The **Bay Area Water Supply and Conservation Agency (BAWSCA)** was created in 2003 to represent the interests of over 1.8 million people and 40,000 CII accounts in 24 cities and water districts, and two private utilities that purchase water on a wholesale basis from the San Francisco Regional Water System (SF RWS). Their service area stretches multiple counties in the Bay Area, providing regional water supply planning, resource development, and conservation program services. Due to their reduced per capita use, total water use has declined despite population growth (Figure 2-1).

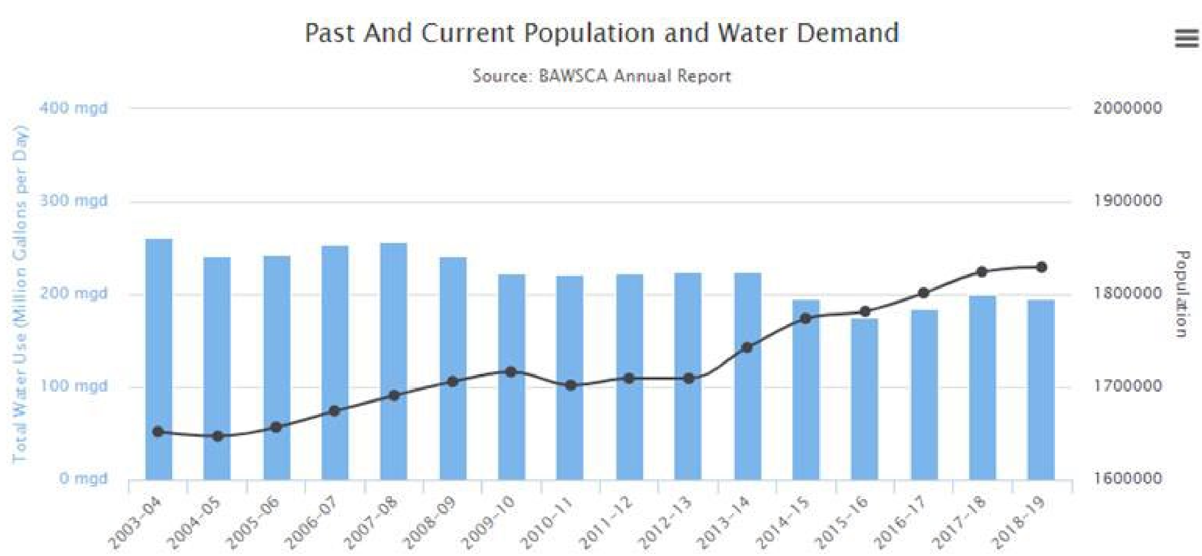

Figure 2-1. Due to reductions in per capita use, total water use in BAWSCA has declined despite population growth. *(Source: BAWSCA 2015)*

In their 2015 Long-Term Reliable Water Supply Strategy Report, BAWSCA identified that though their normal year water supply is sufficient through 2040, there could be up to a 15 percent supply shortfall (approximately 43 mgd or 48,000 acre-feet per year) in drought years (BAWSCA 2015). A 2020 study reevaluated the trends in demand and conservation projections through 2045 and found that although the region is set to experience a 31 percent population increase and 24 percent employment increase, the region's demand will only increase by 25 percent. This was in part because of the water savings potential of 24 WUE measures, which was anticipated to yield an additional 37.3 mgd of savings by 2045. This would shrink the water supply shortfall by over 85 percent. With the active and passive efficiency measures in place for the region, BAWSCA is projected to see a 46 percent reduction in R-gpcd in 2045 compared to 1986 levels (BAWSCA 2020).

The same aggressive reductions in water use were experienced in Southern California. The **Municipal Water District of Orange County (MWDOC)** develops, implements, and evaluates WUE programs that significantly improve water supply reliability for Orange County. MWDOC serves 3.2 million Orange County residents through 28 retail water agencies. Water use efficiency is an integral component of their overall water supply portfolio, and the least expensive water source. In addition to securing a cost-effective, reliable source of water supply, other benefits of WUE include runoff reduction, pollution prevention, and energy savings. MWDOC's WUE programs include educational materials, performance reporting, water use surveys, and a variety of consumer incentives for indoor and outdoor water-efficient devices for residents and businesses throughout Orange County. Through a multi-agency approach, Orange County saves more than 17.1 billion gallons of water each year (MWDOC 2020).

While WUE strategies decrease total water demand (assuming population has not increased), utilities will still need to continue increasing resiliency to climate change by diversifying their water portfolios (Gonzales 2019). A portfolio solely focused on reducing residential per capita use may experience a phenomenon called demand hardening, defined as the loss of demand elasticity during a drought (Howe 2007). As households become more efficient over time, the total water savings that can be achieved by utilities through individual behavior changes is reduced. This can limit a utility's ability to achieve significant reductions during times of drought emergency (Dilling 2019).

2.2 Water & Wastewater Benefits: Reductions in Utility Costs

A changing indoor residential water use standard may reduce overall water supply demand, depending on the concurrent population growth and development. This may contribute to reduced utility costs for both capital investments for new supplies and operations and management (O&M), such as energy and chemical usage for water treatment.

2.2.1 Decreased Water Treatment and Pumping Costs

If total water demand is reduced through conservation and WUE efforts, there will be less water needing treatment at the water supply treatment plants. Lower flow volumes require less treatment chemicals such as coagulants, flocculants, filter aids, disinfectants, corrosion inhibitors, and several others, leading to reduction in treatment costs. Lower total water demands also reduce the pumping requirements with an associated decrease in costs and greenhouse gas (GHG) emissions. In California, as much as 20 percent of the state's electricity consumption is used for pumping, treating, collecting, and discharging water and wastewater (Congressional Research Service 2013).

Soquel Creek Water District (SCWD) saved $10,000 in yearly costs for its coagulant (ferric chloride) and disinfectant (sodium hypochlorite) in 2016 as compared to 2013 due to lower total water demand. Energy usage also declined 28 percent from 2013 to 2016, reducing total annual energy costs by $60,000. The long-term changes due to investments in water efficiency by customers has maintained the lower per capita use achieved during the drought, and their current yearly energy usage remains close to 2016 values.

2.2.2 Deferred Capital Investment

Significant reductions in water use can also result in the reduction or deferral of large capital costs, either to expand existing infrastructure or develop new water sources. Reduction in total water demand allow water utilities to leave capacity in the existing facilities and defer capital costs for expansion or investment in new infrastructure.

According to a 2018 study, the **Los Angeles Department of Water and Power (LADWP)** maintained their overall water use within a range of 500,000 to 700,000 afy from 1990 to 2016 even as population increased from 3.5 to 4 million people (Figure 2-2). Per capita usage decreased from 180 gpcd to 106 gpcd and allowed LADWP to avoid approximately $11 billion in costs from 1990 to 2016 that would have come from having to purchase additional water to serve the additional 500,000 more customers.

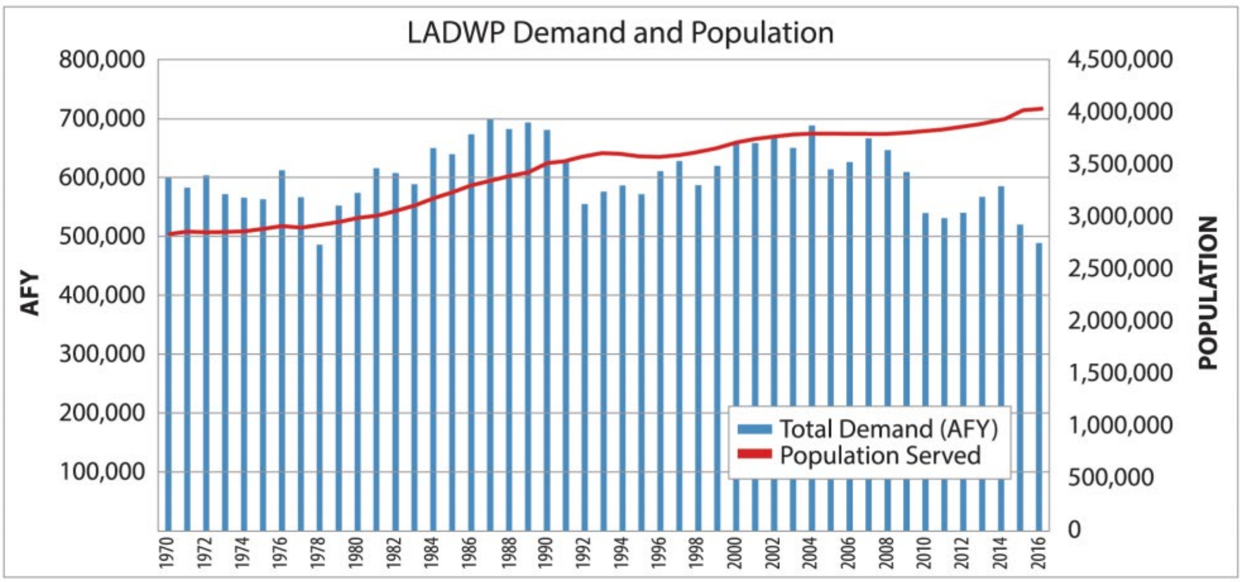

Figure 2-2. Due to reductions in per capita use, total water use in LADWP's service area has declined despite population growth (AWE *2018).*

Source: AWE 2018

This resulted in customer bills that were nearly 27 percent lower in 2018 than they would have been without the department's WUE efforts (AWE 2018). Customers can also experience a reduction in energy costs as they use less residential hot water per capita. However, this reduction in customer bills results in reduced revenue to LADWP, which is an adverse impact described further in Section 3.5.

2.2.3 Reduced Energy Usage for Wastewater Systems

There are a few notable benefits that reduced indoor residential water use may have on wastewater conveyance and treatment systems. Similar to water supply treatment, a changing standard could result in reduced influent flows to WWTPs, which may leave capacity in the existing plant for future growth and defers the need for additional capital investment costs. Lower flow volumes can also lower energy costs due to reduced pumping to WWTPs and to discharge points, which lower GHG emissions. In contrast to drinking water facilities, however, reduced wastewater flow do not translate to reduced chemical costs because contaminants tend to be more concentrated (see Section 3.3 for additional information).

For example, the treated effluent at **Los Angeles, Bureau of Sanitation's (LASAN)** Hyperion Water Reclamation Plant is typically pumped five miles to the ocean outfall with large discharge pumps. Since wastewater volumes have decreased, the energy required to pump the wastewater has also declined. Fifteen years ago, the treated effluent pumps operated daily to discharge effluent through the outfall. Now, the treated effluent can flow by gravity, and the pumps are only necessary when it rains, resulting in significant energy savings (CUWA 2017).

3.0 Adverse Impacts from a Changing Ri-gpcd Standard

Adverse impacts can be experienced from a variety of conditions associated with a changing Ri-gpcd standard. Similar to potential benefits, potential water and wastewater system impacts will depend on the magnitude of the changing standard and what effect that will have on system flows quantity and quality.

When discussing adverse impacts, it is not to imply that emphasis on conservation of potable water should be relaxed, or that potable water use should remain the same or increase to avoid impacts. Rather, this section is meant to acknowledge the interconnections and trade-offs between water use, wastewater generation, and recycled water production and how changes in one element of the cycle can have downstream implications.

3.1 Impacts on Water Treatment and Distribution

A changing Ri-gpcd standard could result in a reduction of per capita water use in a water supplier's service area. This reduction in per capita use could be offset by increasing service area population, resulting in minimal changes to overall water demand. However, where a reduced Ri-gpcd standard does result in less demand and increased retention time in the distribution system, both the quantity of water produced by treatment facilities and quality of water delivered to customers can be adversely impacted.

Many of the adverse impacts described are a result of a system that may now be oversized for current conditions. Utilities are already updating demand projections to better prepare for the future, but there are various considerations in system water sizing that may limit a utility's ability to adapt through downsizing to match reduced water demand.

3.1.1 Design Criteria for Water System Sizing

Industry standards for sizing water distribution infrastructure exist to ensure there are adequate pressures, flow velocities, and capacity to meet the demand required for emergency and fire flow requirements within the system (AWWA 2014). An undersized system risks having insufficient flow to suppress fires in the service area, and an oversized system may see water quality deterioration due to increased retention time in distribution pipelines.

Water distribution systems are sized using a capacity-based approach, with future demand scenarios and economies of scale often driving sizing decisions to provide hydraulic reliability and maintain system-wide positive pressures (Kelley 1994). The following factors are considered when properly sizing water distribution systems (Roberts and Hall 2017):

1. Peak hour demands: the hour of highest water demand in each day, typically in the morning or evening

2. Maximum day demands: the day of highest water demand in each year, typically in the summer

3. Fire flows: an additional 500-3,500 gallons per minute flow on top of peak hour or maximum day use. These are often the dominant factor in pipe sizing.

Distribution systems were designed per these factors based on values at the time of design and best available demand projections. If per capita use declines, systems may now experience flow rates lower than originally planned. However, the commitment to still deliver fire flows may constrain a water agency's ability to further downsize to match reduced flow rates.

Utilities are continuing to update water projections in their planning efforts, as historical projections tended to overestimate future demands due to higher than actual estimates of per capita demand and population growth. For example, a study examined demand projections for 10 large urban water suppliers in California through information provided in Urban Water Management Plans (UWMPs) (Abraham et al. 2020). It was found that on average, water suppliers projected that per capita demand would decline by less than one percent per year. However, actual per capita demand declined twice as fast. To improve planning projections, researchers recommended not only updating input data, but also examining the underlying trends and assumptions within the models (Abraham et al. 2020).

3.1.2 Deterioration in Water Supply Quality

Adverse water quality effects are primarily related to increased retention time of water (i.e., water age) in the distribution system. Under normal use conditions, the uninterrupted flow of tap water helps preserve water quality. Systems designed for expected flow rates may result in longer retention times with a lower Ri-gpcd standard.

Because water age is strongly associated with water quality, water age is often used as a surrogate for a number of water quality parameters (Roberts and Hall 2017). Table 3-1 summarizes water quality effects that may result from increased water age, and each impact is further discussed below.

Table 3-1. Summary of Water Quality Effects that May Result from Increased Water Age (AWWA 2017)

Issue	Water Quality Effects that May Result
Biological Issues	• Microbial growth • Potential presence of pathogens and undesirable microorganisms such as nitrifying bacteria among others
Chemical Issues	• Disinfectant decay • Disinfection by-products (DBP) formation and change in speciation • Corrosion and metal release • Change in pH, dissolved oxygen, and other chemical characteristics
Physical and Aesthetic Issues	• Temperature increases • Increased turbidity and sediment deposition • Changes in taste, odor, and color

Impacts from Biological Factors

Impacts from biological factors include microbial growth, potential presence of pathogens, and increased nitrification. Even after treatment and disinfection, neither the drinking water nor the distribution system are free of microorganisms. Microorganisms in drinking water distribution systems may occur as coliform bacteria, nitrifying microorganisms, corrosion-related bacteria, waterborne pathogens, and others (Friedman et al. 2017). Microbial growth in distribution systems represents a form of water quality degradation that can be responsible for nitrification, corrosion, taste and odor episodes, as well as other unfavorable water quality conditions.

Disinfectant residuals are used to preserve water quality by: 1) inactivating microorganisms that may pass through treatment processes, 2) controlling microbial growth in the distribution system, and 3) protecting water from potential contamination that may occur from pipe breaks, cross connections, and similar situations (Baribeau et al. 2017). When disinfectant residuals are too low, microorganisms can multiply, with the majority of the growth occurring in biofilms attached to pipe walls.

Nitrification is a microbial process that is particularly challenging in chloraminated (treated) drinking water (AWWA 2013). Nitrification can be responsible for a variety of water quality challenges including increased microbial growth and degradation of disinfectant residual. Preventing and controlling nitrification can be a significant operational burden as it may require frequent monitoring, pipe flushing, and limitation in storage reservoir usage to minimize water age. Unless it is used for other purposes (e.g., aquifer recharge), flushing represents a loss of treated water and may be concerning to customers when emphasizing conservation and water use efficiency.

Adaptation strategies and utility impact. Strategies to improve disinfectants residuals throughout the distribution system include higher disinfectant doses at treatment facilities and/or implementation of booster chlorination stations. However, chlorination station installations are expensive and require additional O&M and costs. Utilities could also explore optimization of water treatment strategies such as using alternative disinfectants that are more stable and/or form fewer DBPs (Baribeau et al. 2017).

An adaptation strategy to address deterioration in water quality is increased flushing. However, flushing may represent a loss of water and a significant cost if water cannot be used for other purposes and may be concerning to customers when emphasizing conservation and water use efficiency. For example, the **San Diego County Water Authority (SDCWA)** supplies water over significant distances to its 24 member agencies in San Diego County. Due to increased detention time in the distribution system, chlorine residuals were degrading – especially in the system extremities. To restore the disinfectant residual and continue delivering high-quality water to member agencies, SDCWA increased flushing from their treated water system through their raw water pipelines. This was particularly exacerbated during the drought, and the rate of flushing increased as much as 10 times. Previously, SDCWA was flushing only five to 10 cubic feet per second (cfs) two to three times per year. During the most recent drought, flushing increased to 20 to 30 cfs daily. The cost associated with flushing and retreating the water resulted in a lost surcharge from $200,000 to over $2 million per year (CUWA 2017).

Changes in Chemical Characteristics

DBPs represent a vast array of chemical constituents that are grouped by classes; over 700 DBPs have now been identified in drinking water (Richardson 2020). Although the fate of DBPs is species-specific, most DBPs are formed at the water treatment facilities when disinfectants are introduced throughout the treatment processes, and DBPs typically continue to form as water travels in the distribution system. The main DBPs encountered in drinking water present health risks and are therefore regulated. Increased water age resulting from reduced flow rates may lead to higher DBP concentrations and difficulties for water systems to comply with drinking water regulations.

As water ages in distribution systems, other changes in water quality may occur that can lead to increases in water temperature, changes in pH and alkalinity, decreases in dissolved oxygen concentrations, and many others. Some of these are directly linked to corrosion and release of metals (e.g., lead, copper, iron, and zinc) from distribution system pipes and other infrastructure. Lead and copper are regulated contaminants in drinking water, and lead is particularly concerning because of its health effects, mainly for children.

Adaptation strategies and utility impacts. Controlling DBP formation and corrosion is complex and strategies need to be carefully examined. Options include adjusting pH and/or alkalinity or adding chemicals such as corrosion inhibitors, requiring operational changes or increasing chemical costs. Implementation of these strategies require thoughtful evaluations involving desktop analyses, bench-scale testing and/or pilot testing. Because corrosion is a process that develops slowly, these studies need to be conducted over a long time period without immediate results and are therefore costly.

The **Santa Clara Valley Water District** (Valley Water) experienced increased DBP formation due to increased water age during the drought. While the drought resulted in other factors that may affect water supply flow rates (e.g., higher temperatures, reduced outdoor water use, and other factors), it remains useful to look at what happened to water quality during this period of low water use. Valley Water provides water services in Silicon Valley among other areas. During the drought, demand for water production was reduced and flows velocities slowed within the distribution system. Retailers furthest from the water treatment plant were most affected by trihalomethanes (THM) formation because of the increased water age. To mitigate this, Valley Water increased their chemical usage to address higher total organic carbon (TOC) concentrations, which resulted in an additional cost of $150,000. Minimum flow rates were also established with each of the retailers to maintain a continuous flow of water through the system.

Deterioration of Aesthetic Characteristics

Drinking water is expected to be clear and odorless, and customers often relate water taste, odor, and color to the safety of their water (Mackey 2004). As water moves through distribution systems, it accumulates particulates and dissolved substances that may affect aesthetic characteristics such as taste, odor, and color. Longer retention time can exacerbate this process (Sutherland 2017).

Adaptation strategies and utility impact. Strategies to improve aesthetic characteristics once water has entered the distribution system vary widely and largely depend on the source of the taste, odor, or color (Sutherland 2017). Controlling microbial growth and biofilm formation are recommended but may be difficult to maintain in reduced flow conditions. Improving source water protection, optimizing water treatment processes and limiting corrosion help preserve aesthetic characteristics. In extreme situations, changing material or lining of distribution system pipes or storage facilities may be necessary. In all cases, limiting water age in the distribution system is recommended (Sutherland 2017). All of these result in increased costs to the utility.

3.1.3 Stranded Assets and Stagnation in Storage Facilities

As mentioned in Section 2, one of the benefits of reduced water demand is the ability for water providers to support continued population growth without having to expand existing infrastructure or develop new water supply sources. However, reduced total water demand may question the need to operate water treatment facilities on a continuous basis.

For example, systems with multiple water supply sources or treatment facilities may be able to rely on larger water sources or treatment plants and limit the use of secondary facilities or facilities that are only used to meet peak demand. Operating water treatment plants at fractions of their capacities may not be financially sustainable. Ultimately, water systems may face the decision of having to decommission water sources or treatment facilities, which represent important/costly stranded assets.

This is also applicable to storage facilities, such as reservoirs and tanks that are used to ensure a constant supply of water to customers despite fluctuating demand. Storage facilities also support emergency and fire flow requirements, which represent an important portion of storage capacity in some systems. Reductions in total water demand can also decrease water velocity use, which may lead to water stagnation in storage tanks, remote areas, and or dead-end mains.

Adaptation strategies and utility impact. A number of strategies are available to maintain water quality in storage facilities including strengthening water quality monitoring, and include increasing turnover rates through cycling, deploying passive or active mixing devices to limit stratification, reconfiguring inlets and outlets, and flushing. All of these strategies require increased investment from utilities. Water systems with distribution system storage capacities that become inconsistent with reduced water demands may also find themselves having to eliminate redundant storage facilities, either seasonally or permanently. Permanently removing a tank from service represents a stranded asset.

Retrofitting existing infrastructure is also an adaptation strategy but can be costly. In those instances, utilities have applied other adaptation strategies such as implementation of booster chlorination stations in the distribution system, and alternative operational strategies such as increasing flushing at dead ends to limit water age. Corrective methods are available but may be complex and time consuming. These methods include reconfiguring the distribution system by opening or closing valves and allowing water to flow through boundaries of pressure zones to improve water circulation through the affected areas (Roberts and Hall 2017).

The **East Bay Municipal Utility District (EBMUD)** has relied on its Central Reservoir since 1909. This reservoir is used to store finished water and has a capacity of 154 MG. Despite population growth, water use per person has reduced to the point where the required capacity is now only 50 MG, one-third of the original reservoir capacity. As the Central Reservoir required rehabilitation, it was judged that replacing the Central Reservoir with three tanks of 17 MG each would be more appropriate to satisfy current water demand. More details specific to EBMUD can be found in Section 4.2.

3.2 Impacts on Wastewater Conveyance Systems

Wastewater pipelines are typically sized to convey average, peaking, and maximum flow rates for utilities, either by gravity or pressurized systems (Maryland 2013). Pipelines are also sized or sloped to achieve effective scouring velocities between 2 to 8 feet per second to mitigate against solids buildup (EPA 2000).

As the liquid content of wastewater decreases from reduced indoor residential water use, the solids mass and wastewater chemicals remain the same resulting in higher concentrations of solids and chemicals in wastewater. A changing Ri-gpcd standard use could increase effluent concentrations within the wastewater collection system unless other discharges (e.g., infiltration/interflow, CII wastewater) are high enough to dilute the indoor residential wastewater.

Higher concentrations could reduce intended scouring velocities, as well as contribute to physical, chemical, and biochemical effects such as increases in odor production, accelerated corrosion, and blockages. Major factors contributing to adverse effects include:

- Increased concentration of solids and organic material. More concentrated sewage can create blockages and generate increased levels of H_2S, which can accelerate corrosion and increase foul air emissions and nuisance odor complaints. These effects are exacerbated by lower flow rates.

- Increased residence time. Lower velocities equate to longer residence times, enabling microbes in wastewater to consume oxygen over a longer period of time, leading to anaerobic conditions. These anaerobic conditions accelerate the rate of corrosive sulfide production.

3.2.1 Increased Sewer Gas Production and Build-up

Sewer odors are dominated by H_2S gas, which is formed by a biochemical reduction of sulfate and is easily recognizable by its characteristic rotten egg odor. As residential per capita use decreases and solids concentrations increase, higher H_2S concentrations can cause potential health impacts and contribute to increased production of offensive sewer odors. Potential health impacts due to H_2S build-up at low concentrations include irritation of the eyes, nose, throat, and respiratory system (OSHA 2005). Higher concentrations can cause more dramatic impacts such as shock, convulsions, or an inability to breathe. In addition, H_2S is a highly flammable gas that can be explosive (OSHA 2005).

These impacts can be exacerbated in long stretches of pipelines and manholes that allow for longer retention times (time for biochemical processes to occur) and more points where sewer gases can escape to the surface. Wastewater utilities are aware of these impacts and proactively employ mitigation strategies as preventative measures to prevent build-up.

Adaptation strategies and utility impacts. Mitigating odors and H_2S build-up often requires application of chemicals like Bioxide® (i.e., calcium nitrate) or iron chloride, which results in higher costs. A study conducted in 2017 by the **City of San Diego** found a correlation between the decrease in average reported total residential water use and Bioxide® use at specific pump stations. The study reviewed odor injection points that had consistently used Bioxide® from 2010 to 2017 to control odor production. The study found that increases in Bioxide® purchases (by the gallon) coincided with a decrease in average water usage from 2013 through 2017. The gallons purchased for five injection points doubled from 88,000 to 160,000 gallons as average total residential water use decreased from 71 to 62 gpcd (City of San Diego 2018). This indicates that lower residential water use can contribute to increased sewer gas production and higher cost for wastewater facilities.

This increase in the need for chemical mitigation was also experienced by the **Los Angeles, Bureau of Sanitation** (LASAN). LASAN similarly experienced an increase in H_2S concentrations when total residential water use decreased, which led to an increase in odor production and complaints. To address this, LASAN increased the rate of chemical injection and planned to upsize three of their seven existing carbon scrubbers (CUWA 2017). While other factors may have contributed to the sewer gas production, the strong negative correlation between sewer gas production and residential water use indicates that reduced residential water use is an important contributing factor.

3.2.2 Accelerated Rate of Corrosion in Sewer Pipes

Corrosion in the conveyance system occurs when the free water surface releases H_2S to the atmosphere during anaerobic conditions and is adsorbed by moist sewer pipes. On the pipe surface, H_2S is converted to sulfuric acid, which corrodes unlined pipes. Accelerated corrosion in unlined pipes leads to a faster rate of structural failure. The primary failure mode for metal pipes is internal or external corrosion, which leads to holes in the pipe wall. Cast iron is particularly brittle, making it susceptible to cracking and subsequent collapse.

Corrosion is also often the major factor in the failure of unlined reinforced concrete pipe, which typically fails after the interior surface of the pipe wall has deteriorated to a point where the reinforcing steel is exposed (Feeny et al. 2009). Deterioration of sewer pipes and manholes can create structural defects that result in service failures or contamination of surrounding soils (EPA 1991). This deterioration is also witnessed in concrete manhole frames and covers, which can pose a risk to the community if covers dislocate due to heavy traffic.

Adaptation strategies and utility impact. Corrosion can be addressed through various strategies, including rehabilitation and replacement of damaged pipelines, epoxy coating exposed concrete, or installation of cathodic protection. Most utilities already examine and maintain their systems through these methods, but an accelerated rate of corrosion due to increasing H_2S concentrations can incur rapid cost increases and higher costs than originally planned or budgeted.

This accelerated deterioration in concrete structures was witnessed by the **Victor Valley Wastewater Reclamation Authority** (VVWRA)**.** During the drought, VVWRA experienced increased H_2S concentrations which accelerated the rate of corrosion and degradation of existing infrastructure, especially at their concrete manholes. To address these adverse effects, VVWRA implemented operational improvements and began coating their manholes in epoxy. To proactively mitigate future corrosion, VVWRA also updated its specifications in manhole coatings to include epoxy coatings and evaluated alternative materials to concrete. This investment in epoxy coating cost VVWRA $300,000 per year from 2012 through 2017 (CUWA 2017).

Other drought factors, including higher temperatures, may have contributed to the increased H_2S concentrations and corrosion, however the concurrent decline from reduced residential water use are an important factor and the drought conditions can be used to shed light on potential impacts from a changing indoor residential water use standard.

3.2.3 Increased Occurrence of Sewer Blockages and Overflows

Standards used for hydraulic design include requirements of minimum slopes for various pipe diameters to achieve scouring velocities that minimize debris accumulation. These design standards are based on expected sewer flows and concentrations at the time the facility was built. A changing indoor residential standard could result in wastewater volume and concentrations entering the residential wastewater conveyance systems that are below the design parameters.

Debris accumulation results in sanitary sewer blockages (SSBs), the primary cause of loss in sewer serviceability. A number of factors can contribute to debris accumulation, including root intrusion; increase in fats, oils, and grease; and pipe sags (Feeney et al., 2009). Increased solids concentration in wastewater can also potentially contribute to debris in the wastewater conveyance system and increase the occurrence of sanitary sewer overflow (SSO) and blockages. SSO and blockages can result in service failures and require additional O&M labor and costs to resolve.

A study conducted by **Yarra Valley Water**, a water retailer in Australia, examined causes of blockages within the sewer network. Yarra Valley traditionally has a high number of blockages, which is exacerbated by significant tree root intrusion and aging infrastructure (Yarra Valley Water 2011). Yarra Valley also examined the correlation between water consumption per household with the number of SSBs (Figure 3-1), indicating that lower water consumption can exacerbate and increase the rate of SSBs (Yarra Valley Water 2011).

The rate of SSOs and SSBs is not a function of only Ri-gpcd, which is demonstrated by **Westernport Water**. The average annual household consumption in Westernport is 71 kL (18,700 gal), which is lower than Yarra Valley's 144 kL (38,000 gal) (Essential Services Commission [ESC] Victoria

2010). However, the frequency of sewer blockages reported by Westernport was also lower at 4.4 blockages per 100 kilometers (62 miles) of pipe as compared to Yarra Valley's 45.5 blockages per 100 kilometers (62 miles) (ESC Victoria 2010). This demonstrates that utility-specific characteristics, such as aging infrastructure, can influence the magnitude of impact from reduced Ri-gpcd.

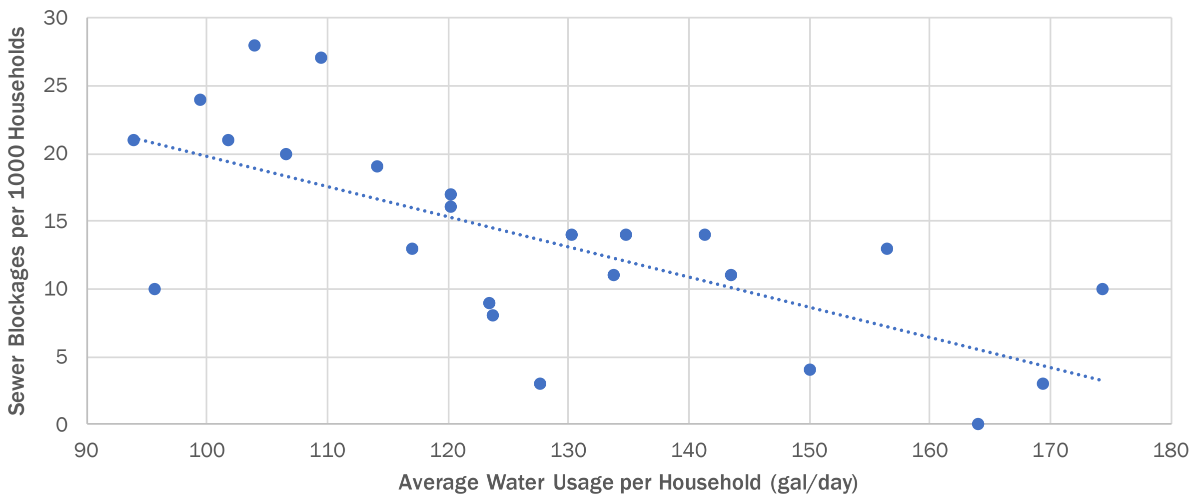

Figure 3-1. Trends indicate that lower water consumption can exacerbate and increase the occurrence of sewer blockages.

Source: Adapted from Yarra Valley Water, 2011

Adaptation strategies and utility impact. Strategies to address solids build-up that increase the occurrence of SSBSSBs and SSOs include increased flushing of sewer mains and proactive maintenance. An increase in blockages due to reduced indoor residential water use was experienced by the **Tuolumne Utilities District** (TUD) as a result of reduced wastewater volumes that occurred during the drought along with other contributing drought factors including root intrusion. 65 percent of TUD's conveyance system consists of smaller diameter pipes 4 to 6 inches in diameter, which increased the potential for blockages. The combined effect of reduced water use during the drought and other factors led to an increase in required maintenance. To address these impacts, TUD increased maintenance of the collection system and monitoring of trouble areas. TUD also implemented a proactive pipe patching system to counter the increased root intrusion; the pipe is cleaned and cured with a fiberglass material that acts as an internal liner, which moves sewage more effectively (CUWA 2017).

3.3 Impacts on Wastewater Treatment

A decrease in Ri-gpcd leads to a reduction in total wastewater volume and an increase in contaminant concentrations. Reduced residential water use during the 2011-2016 drought is useful in understanding potential impacts associated with a changing indoor residential water use standard, even though other factors likely contributed to reduced water use and concentration impacts during the drought. Reduction in influent flow volumes and changes in influent water quality during the drought required many wastewater agencies to adapt aspects of the collection and treatment processes to meet regulatory requirements or resulted in challenges meeting quantities demanded by end users, including recycled water customers.

Adaptation to changing wastewater quantity and quality is a typical aspect of wastewater treatment system operations. However, the sustained lower drought-affected wastewater flow and quality required additional adaptive measures. Adaptations to ensure discharge water quality included changes to characteristics of the treatment process, like modifying the application of treatment chemicals or adjusting aeration controls.

The Public Policy Institute of California (PPIC) conducted a survey in 2019 regarding impacts experienced on wastewater treatment plants during the drought, and 35 percent experienced an increase in treatment cost, 34 percent implemented additional O&M labor, and 32 percent experienced an increase in capital costs (PPIC 2019).This was echoed in the CUWA Declining Flows white paper, where 48 percent of respondents indicated adverse impacts on wastewater treatment (CUWA 2017).

3.3.1 Higher Wastewater Contaminant Concentrations

Increasing wastewater contaminant concentrations can stress treatment processes if the amount of ammonia, total suspended solids (TSS), total dissolved solids (TDS), and organics (measured as biological oxygen demand [BOD]) increases beyond design specifications. This may potentially impact a plant's ability to meet discharge permit requirements and require wastewater treatment plants to adjust operation or invest in improvements or expansions earlier than planned.

Researchers at the University of California Riverside studied 34 plants throughout Southern California from 2013 to 2017 — a period that included extreme drought conditions. The analysis demonstrated that reduced indoor residential use reduced total effluent flow and increased effluent salinity (Schwabe 2020). The researchers observed that Ri-gpcd is negatively correlated to effluent TDS concentrations; that is, when Ri-gpcd decreases, TDS concentration increases. These results are indicative of declining indoor use that results in more concentrated, or less diluted, wastewater (Schwabe 2020).

These higher concentrations were also experienced by **Silicon Valley Clean Water (SVCW),** particularly regarding ammonia. The NPDES permit for SVCW's WWTP has a monthly average ammonia limit of 173 mg/L, and SVCW operates to maintain effluent concentrations consistently below this value (San Francisco Bay Regional Water Quality Control Board 2012). With reduced water usage during the drought, the 60-day average for primary effluent ammonia concentrations entering the WWTP increased from 30 mg/L in 2011 to 47 mg/L in 2016 (Sawyer et al. 2016). This was coupled with a parallel increase in 90-day average effluent ammonia concentrations, increasing from 30 mg/L to 52 mg/L in the same time frame. While this is still below SVCW's NPDES permit limit, this situation is concerning for utilities that are observing increased contaminant concentrations and potentially lower NPDES limits (Sawyer et al. 2016). A changing Ri-gpcd could also accelerate the increasing contaminant concentration trends, exacerbating the stress on treatment processes.

Reduced wastewater volumes can also have a detrimental impact on alkalinity requirements that support nitrification in WWTP processes. While contaminant concentrations increase with reduced Ri-gpcd, alkalinity concentrations remain relatively constant as alkalinity tends to originate from the source water and not produced by people (Sawyer et al. 2016). Specific ratios of alkalinity to ammonia are needed for nitrification to maintain pH in the effluent. As ammonia concentrations decrease, alkalinity limitations can potentially occur.

For example, the total wastewater influent volume at the **City of Santa Barbara's** El Estero WWTP decreased 12 percent between 2012-13 to 2014-15. During this time, influent ammonia concentrations increased by 32 percent, but influent alkalinity concentrations only increased by 4 percent (Sawyer et al. 2016). Based on the data from 2014, supplemental alkalinity would be required at times to maintain a pH above 6.0, which was necessary for effluent compliance (Sawyer et al. 2016). As such, chemical addition facilities were added to the design to provide supplemental alkalinity and increasing overall project cost (Sawyer et al. 2016).

Adaptation strategies and utility impact. Changing influent wastewater quality such as higher ammonia, BOD, and TSS required agencies to adjust their treatment plant operations. One-third of respondents to a 2019 PPIC survey reported problems in the treatment process, such as corrosive influent damaging equipment and less effective treatment processes (PPIC 2019). Utility managers overcame these challenges by applying more chemicals or increasing the intensity of aeration and sludge removal, resulting in increased costs for labor, materials, and energy (PPIC 2019).

3.4 Impacts on Recycled Water Projects

The reduction of Ri-gpcd during the drought serves as a surrogate for estimating potential effects of a changing Ri-gpcd standard that results in lower water use. During the drought, reduced residential water use resulted in reduced quantity and quality of wastewater for most of the state's wastewater agencies. In the PPIC 2019 survey, 40 percent of wastewater agencies that recycle wastewater reported that their ability to produce recycled water was impaired during the drought (PPIC 2019). This could be due to reduced demand for recycled water or a lack of recycled water supplies available for reuse.

Recycled water quantity and production is thus inherently linked to the availability of wastewater effluent. However, when discussing the impacts to recycled water systems, it is not to imply that the emphasis on conservation or water use efficiency should be relaxed to prevent impacts. Rather, it is meant to acknowledge the interconnections and trade-offs between wastewater generation and recycled water.

3.4.1 Reduction of Recycled Water Quantity

Many agencies have plans to increase water reuse to improve water supply reliability and resiliency. Reductions in indoor residential water use lowers total wastewater volumes, subsequently decreasing recycled water production. For recycled water projects that are targeting certain volumes of recycled water for both non-potable and potable reuse, a reduction in available wastewater may require supplemental supply from alternative sources. If alternative wastewater sources are unavailable, loss of recycled water production can hinder a utility's ability to offset potable water use. Utilities can employ various strategies to mitigate these impacts, including continuing to encourage outdoor conservation as that has less impact on wastewater production.

Adaptation strategies and utility impacts. Incorporating supplemental wastewater supplies was a strategy employed by **Orange County Water District** (OCWD) and **Orange County Sanitation District** (OCSD), who jointly manage the Groundwater Replenishment Systems (GWRS). GWRS was initially supplied by OCSD's Plant 1, which has higher quality effluent than what is produced by Plant 2. The total combined flow of Plants 1 and 2 has decreased from 240 mgd in the 2000s to 180 mgd in 2017. The final expansion to 130 mgd for GWRS was originally planned to be supplied by only Plant 1. However, the reduction in wastewater effluent will require supplemental flows from Plant 2. There are certain flows at Plant 2 that have much higher TDS concentrations, so OCWD and OCSD had to have invest $60 million to segregate these flows from those being conveyed to GWRS (CUWA 2017).

Many agencies use recycled water as a strategy to support industrial, agricultural, or commercial customers and offset potable water use in these sectors. For example, **Victor Valley Wastewater Reclamation Authority** (VVWRA) operates a conventional activated sludge facility that discharges into the Mojave River. Given the value of water in the Mojave area, VVWRA treats all wastewater effluent to Title 22 standards to maximize reuse potential. After being treated, the reclaimed water is sent to percolation ponds, reused, or discharged into the Mojave River. End-uses include reclaimed water for irrigation at golf courses and for industrial cooling towers (VVWRA 2020). The Mojave River is a terminal river that is bound by stringent water quality and quantity regulatory requirements. This includes base flow requirements of 8.2 mgd into the river set by the California Department of Fish and Wildlife. The reduced total flow volumes experienced by VVWRA decrease the amount of water available for recycling. The less recycled water is available for end-users, the more customers must rely on potable resources, which is groundwater in that area (CUWA 2017).

3.4.2 Increases in Recycled Water Salinity

As households become more water-efficient, either inspired by the changing Ri-gpcd standard or investments already made, wastewater that is discharged to sewers can have higher concentrations of salts. Salts are not typically removed in most wastewater treatment processes and subsequently make their way into recycled water. Saltier water may not be suitable for common recycled water applications such as irrigation of golf courses or salt-sensitive crops like avocados.

The effects to recycled water effluent quality and quantity from reduced residential water use were analyzed at **Inland Empire Utility Agency** (IEUA) Regional Water Recycling Plant 1 (RP1) via a report published in 2017 (Tran et al. 2017). The analysis showed that the combination of low-quality water supplies coupled with increases in conservation resulted in an increase in pollutants and TDS from 2011 to 2015. These pollutants included ions such as sodium, chloride, calcium, and nutrients, which saw increases between 8 to 16 percent (Tran et al. 2017).

Adaptation strategies and utility impact. Increasing salinity in recycled water could be addressed through additional treatment and blending of different quality effluents. At IEUA, different treatment trains were analyzed to improve wastewater effluent quality, and the most cost-effective solution was to blend effluent treated by membrane filtration (MF) with effluent treated through the MF and reverse osmosis (RO) (Tran et al. 2017). The incorporation of the desalination step can help to alleviate downstream salinity concerns but did increase treatment cost from $0.69/m^3 (264 gal) to $0.74/m^3 (Tran et al. 2017).

Utilities can also address increasing salinity by supplementing with potable water when necessary. The **San Francisco Public Utilities Commission**

(SFPUC) uses a centralized recycled water system to support large recycled water users such as public parks and golf courses, who are primarily located on the west side of SFPUC's service area (CUWA 2019). This recycled water system has the capability to be supplied via the potable water system instead if necessary, to address concerns in TDS (CUWA 2019). The coupled potable water system provides additional flexibility but undercuts the goals to support community needs with recycled water.

3.5 Reductions in Revenue

A changing Ri-gpcd standard that results in reduced indoor residential water use leads to less water being purchased from utilities, as well as less wastewater being produced. This decreases the revenue received by water, recycled water, and wastewater agencies. However, the magnitude of impact will depend on a number of factors including the type of rate structure and influence of Proposition 218, which specifies that water rates cannot exceed the cost of providing the service and requires new local taxes to be passed by two-thirds voter approval (PPIC 2018).

3.5.1 Financial Volatility if Water Use is Reduced

Planning for water use efficiency programs must be done carefully to mitigate revenue instability. The amount of revenue water service providers collect from customers is dictated by the rate structure, which are designed to achieve specific goals and are unique to each agency. Examples of water rate structures include flat rates (water revenue is independent of water use), uniform volumetric rates (revenue depends on water use), and block or tiered rates (revenue depends on water use and level of water use) (Pacific Institute 2013). Although flat rates provide the most stable revenue for agencies, they are uncommon in California, suggesting that volumetric rates that incentivize water use efficiency are important for most water agencies (Pacific Institute 2013).

During California's 2012-2016 drought, a 25-percent reduction in urban water use from 2013 levels caused more than 60 percent of all surveyed suppliers (173 California urban water suppliers) to experience declines in net financial positions by 2016 (Mitchell et al. 2017). For agencies with rates tied to volumetric charges, reduced water demand led to decreasing water sales that resulted in a direct reduction in revenue as shown in Figure 3-2. On the other hand, 35 percent of respondents said that the drought did not impair their net financial position (Mitchell et al. 2017). Investor-owned utilities were much more likely to report no impairment, as these supplies are not subject to Proposition 218 and were able to automatically implement surcharges to recover revenue shortfalls (Mitchell et al. 2017). Proposition 218's rate setting and public noticing requirements makes changing rates more complicated and less timely for public water suppliers, making them more vulnerable to revenue shortfalls from decreased water sales (Mitchell et al. 2017).

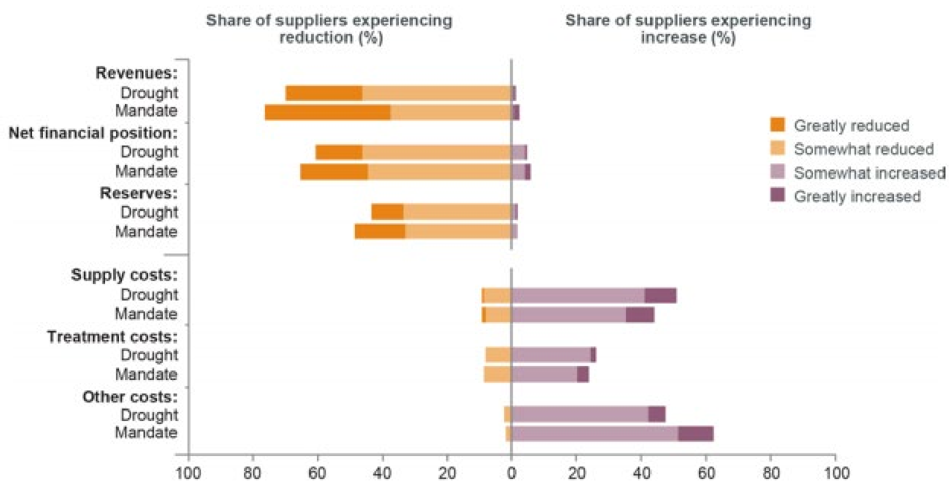

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Figure 3-2. A majority of surveyed suppliers experienced drops in revenue coupled with increased costs.

Source: PPIC 2016

In addition, many wastewater agencies derive at least some portion of their rate structure from a volumetric charge. Reduction in indoor urban water use therefore translated into reduced revenues coupled with increased costs in some cases (PPIC 2019).

3.5.2 Maintaining Customer Costs and Perception

Long term trends in water use have had long term impacts on water rates as well. A 2017 study on water rate trends surveyed 14 California counties and found that reduced usage from both drought restrictions and voluntary conservation efforts, as well as increased water costs and costs in general, have combined to increase water rates in the state since 2003 (Gaur and Diagne 2017). With a decrease in revenue from reduced volumetric charges, an increase in fixed charges is sometimes needed to make up the lost revenue. This can contribute to negative customer perception as lower water use does not necessarily translate into lower water bills.

Over the same period, median income remained stagnant, causing an increase in percentage of income needed for water. As this trend continues, customers below the median income will be disproportionately affected relative to customers with higher incomes (Gaur and Diagne 2017). It should be noted that a higher fixed charge will also have a greater impact on affordability for low-volume water users and provides less incentive to conserve (Gaur and Diagne 2017).

In addition, water is a rising cost industry as a result of expanding regulations, deteriorating infrastructure, as well as the cost of increased O&M. A 2019 CUWA study found that increasing costs have driven up residential water bills an average of seven percent per year from 2007 to 2014 as shown in Figure 3-3. The increase occurred at more than double the rate of inflation. In more recent years, bills declined due to emergency conservation during the drought. However, costs and water bills will begin to rise as the CUWA agencies invest in capital improvements (estimated at nearly $24 billion over the next 10 years) largely to address aging infrastructure, supply diversification, and other needs (CUWA 2019).

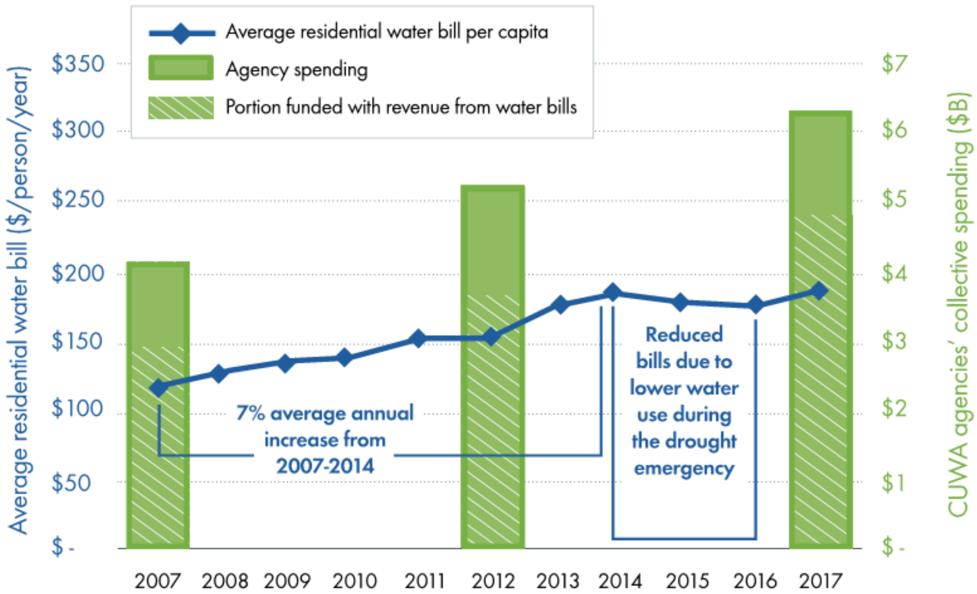

Figure 3-3. Reduced water use has impacts to revenue, which are needed to fund capital improvements.

Source: CUWA 2019

A strategy to mitigate negative customer perception of paying more for less is public outreach and education. This could include a clear communications strategy that explains that increases in water rates do not always mean increasing costs for all customers, as the water bills for efficient households may stay the same or even be reduced with volumetric pricing. The communications could also highlight the baseline O&M costs needed to transport and treat water, as well as the need to invest in projects that enhance supply diversification to increase climate change resiliency.

4.0 Case Studies

Four geographically diverse agencies participated in a case study to share the benefits and impacts they experienced at sustained reduced indoor residential water use. Representing a combination of water, wastewater, and recycled water systems, the agencies revealed the range of effects experienced as well as their technical, operational, and financial significance.

4.1 Case Study: Soquel Creek Water District & City of Santa Cruz

Soquel Creek Water District (SCWD) was founded in 1961 and located in mid-Santa Cruz County. SCWD has maintained water supply reliability through both reduced residential water use and investment in supplemental supplies. SCWD is investing in Pure Water Soquel, a groundwater replenishment program, as part of their water supply portfolio, which uses wastewater effluent from the City of Santa Cruz (Santa Cruz). Thus, the Santa Cruz wastewater treatment facility (SCWWTF) that feeds Pure Water Soquel has been included in this case study to present a fuller picture on the benefits and impacts of a changing Ri-gpcd.

4.1.1 Soquel Creek Water District Overview

SCWD provides water services to approximately 40,400 customers, and nearly 90 percent of them are residential and served via the Santa Cruz Mid-County Groundwater Basin. This water supply is designated by the state as a high-priority, critically overdrafted basin because the region relies 100 percent on this source as its sole source of supply (no state-imported water) and seawater contamination is actively occurring. In 2014, SCWD Board of Directors declared a Stage 3 Water Supply Shortage and Groundwater Emergency and has been requesting customers to reduce water use by 25 percent compared to 2013. SCWD manages 156 miles of pipe, 15 active groundwater wells, 18 storage tanks, and 80 groundwater monitoring wells. Their annual water production is approximately 3,334 acre-feet in 2018.

Highlights of SCWD's conservation programs include:

- Robust water conservation rebate program offering nearly 30 different indoor fixture and landscaping rebates
- Free Water-wise House Calls and the Go Green Program
- Water Demand Offset (WDO) Program. The WDO Program was implemented in 2003 and allows development to continue by requiring new development to offset their projected water demand by funding new conservation or supply projects within SCWD (SCWD 2019). The WDO

Policy (Resolution No. 19-18) requires development projects to offset approximately two times the amount of water they are projected to use so that there is a "net positive impact" on the District's water supply.

The SCWD employs a tiered rate structure in accordance with Proposition 218, which includes a monthly fixed service charge and a water quantity charge. Tier 1 reflects the amount of water the SCWD can safely supply to each household using the existing groundwater supply. Tier 2 represents water use that is above sustainable levels and requires the development of supplemental sources (i.e., potable reuse). There is a significant jump from Tier 1, $7.01 per unit of water (defined as 748 gallons), to Tier 2 at $31.82 per unit of water, which is reflective of these investments.

This supplemental water supply includes Pure Water Soquel, which is a groundwater replenishment and seawater intrusion prevention project. Santa Cruz will provide the tertiary effluent from the SCWWTF. The tertiary effluent will then go through membrane filtration, reverse osmosis, and ultraviolet light/advanced oxidation before being injected into the Santa Cruz Mid-County Groundwater Basin. Pure Water Soquel is intended to increase the sustainability of the SCWD’s groundwater supply, reduce the degree of overdraft conditions in the basin, prevent further seawater intrusion, and promote beneficial reuse by reducing discharge of treated wastewater by 25 percent.

4.1.2 City of Santa Cruz Overview

The wastewater system for the Santa Cruz is managed within the Public Works department and includes the SCWWTF. The SCWWTF was originally built in 1928 and designed to accommodate 17 mgd of average dry weather flow, and up to 81 mgd of peak wet weather flow. The treatment process at the SCWWTF includes primary treatment through bar screens, aerated grit chambers, and primary settling tanks. The primary effluent is then pumped to trickling filters, solids contact tanks, and secondary clarifiers with UV disinfection. The Pure Water Soquel project is then adding tertiary treatment to improve the quality of the wastewater before entering the advanced water purification process at SCWD.

4.1.3 Benefits of Reduced Residential Water Use

Driven by the reductions called for during the 2012–2016 drought, customers within SCWD dramatically reduced their water usage through both short-term behavior changes and long-term investments in water use efficiency. This was supported by SCWD's substantial conservation program, which offered a large variety of rebates to residential customers, including rebates for high efficiency clothes washers, drip irrigation retrofits, graywater to landscape, hot water recirculation systems, pool covers, pressure reducing valves, rain catchment, residential toilets, residential showerheads, turf replacement, and more (SCWD 2014). This supported substantial reduction of residential water use but was not without its costs.

This reduction in water use provided the following benefits for SCWD and Santa Cruz:

- **Reduced energy and chemical use for water treatment.** With lowered demands, less water needed to be pumped and treated for distribution. As such, chemicals used for treatment decreased, such as sodium hypochlorite (NaOCl) for disinfection and ferric chloride ($FeCl_3$) for coagulation, saving SCWD $10,000 in yearly chemical costs in 2016 as compared to 2013. Energy usage also declined 28 percent from 2013 to 2016, reducing total annual energy costs by $60,000. The long-term changes due to investments in water efficiency by customers has maintained the lower per capita use achieved during the drought, and their current yearly energy usage remains close to 2016 values.

- **Added flexibility in groundwater well pumping distribution.** SCWD manages 15 active wells within the groundwater aquifer. With the reduced demand, not all wells need to be active. This gives SCWD more flexibility to utilize the wells as appropriate to manage the groundwater basin. This flexibility is valuable as peak demand is close to their existing capacity and being able to use different wells to balance the groundwater basin supports operations.

- **Prevented the need to retrofit or expand existing groundwater wells.** The groundwater wells have become less efficient over the years.

However, the reduced demand means that SCWD can delay expenditures to improve the well reliability or drill new wells to increase their supplies.

- **Reduced overdraft in the groundwater basin, mitigating seawater intrusion.** SCWD is located right next to the ocean, where seawater intrusion into the groundwater basin is a concern. Reducing overdraft maintains pressure within the basin, mitigating further intrusion.

- **Increased community ethic around water use efficiency.** When SCWD first tried to pursue a source of supplemental supply, there was a desire from the community to conserve more. SCWD and the community worked together to reduce water use as the first step and have achieved significantly low per capita use. Now, with water conservation as a 'way of life' and the need to still protect the environment and develop additional water supplies, the community strongly supports the Pure Water Soquel investment since they have achieved what they could first through conservation.

4.1.4 Adverse Impacts of Reduced Residential Water Use

These successes in water conservation also have tangible adverse impacts, such as:

- **Reduced revenue per their tiered rate structure, resulting in rate increases and accompanying public education.** SCWD has a tiered rate structure that meets Proposition 218 requirements. As described above, there is a significant jump between Tier 1 and Tier 2. Due to reduced water demand, SCWD has also experienced a drop in revenue. However, as the costs to maintain and operate the water system remains unchanged, SCWD has had to increase overall rates every year for the past nine years.

- **Increasing wastewater effluent concentrations, requiring additional pretreatment.** Ammonia and nitrate concentrations increased in the wastewater influent and effluent that served the Pure Water Soquel program, triggering investment in additional pretreatment to improve influent advanced water purification facility (AWPF) quality. These increases resulted in the addition of pre-treatment (i.e., biologically activated filtration) in the advanced water treatment process, which may increase the overall cost of the program by 10 percent. This enhances the treatment process and supports protection of public health.

4.1.4 Key Takeaways

- Utilities that have limited source supplies and local emergency declarations as well as state mandates (such as SGMA) can experience more urgency to resolve supply and reliability issues and appreciate greater benefits from reduced demand due to conservation and WUE measures.

- Engaging the community early and often through outreach and public education can generate support through both increased conservation and the financial investment in alternative water supplies.

- Tiered rate structures serve as an effective strategy of encouraging conservation but have more significant impacts on revenue.

- Indirect potable water reuse projects like Pure Water Soquel require proactive planning and may include investments in pretreatment to account for increasing contaminant concentrations such as ammonia and nitrate.

4.2 Case Study: East Bay Municipal Utility District

The EBMUD is a large district that serves 1.4 million customers in portions of Alameda and Contra Costa Counties. EBMUD receives water from the Mokelumne River and collects it at the Pardee Reservoir, which has a capacity of roughly 200,000 ac-ft. They also store local run-off in East Bay reservoirs, which can be up to 21 mgd in a year of normal precipitation. This water is supplied to customers through an expansive distribution system that includes 165 distribution reservoirs, six water treatment plants, 130 pumping plants, and 4,300 miles of pipe. EBMUD also has a contract with the Bureau of Reclamation to purchase supplemental supply from the Sacramento River if necessary.

EBMUD also provides wastewater and recycled water services. Wastewater is collected throughout the East Bay in Northern California and centrally treated at their wastewater treatment plant in Oakland, CA. The wastewater treatment plant is sized for 320 mgd for primary treatment and 168 mgd for secondary treatment. On average, about 63 mgd of wastewater is treated daily. A portion of this wastewater then serves as the supply for their East Bayshore recycled water project. This recycled water supports mainly irrigation, which helps to offset potable water supply and reduce the discharge of treated wastewater into the San Francisco Bay. EBMUD has invested in infrastructure to provide over 9 mgd of recycled water and has a goal of increasing that to 20 mgd by 2040.

4.2.1 Benefits of Reduced Residential Water Use

EBMUD is conducting adaptive planning to continue delivering safe and reliable water supplies for their customers in the changing climate. Reduced water use provided the following benefits to enhance their water supply reliability:

- **Mitigated need to purchase supplemental supplies.** EBMUD has access to purchase supplemental supplies from the Sacramento River, if necessary, from the Bureau of Reclamation. These supplies are more expensive and require more energy to transport as compared to local sources as they are located miles away. By reducing water use and demand, EBMUD can serve their customers with only local supplies.

- **Reductions in energy use and associated GHG emissions due to decreased water demand**. With the water-energy nexus, moving less water also means using less energy. Water that is not used does not need to be treated or pumped to customers, reducing overall energy use.

- **Provides excess capacity to accommodate growth in EBMUD's wastewater treatment plant**. Average influent flows at the wastewater treatment plant used to be around 80 mgd, and they've now decreased to 50 mgd. As such, there is capacity to accommodate future population growth without the need to expand the plant.

4.2.2 Adverse Impacts of Reduced Residential Water Use

EBMUD experienced the following adverse impacts due to sustained reduced residential water use:

- **Took reservoirs offline as necessary to preserve water quality within the system.** EBMUD's water production was over 210 mgd in 1970 and water production dropped to below 130 mgd in 2015. Given this significant reduction in water production, the volumes in storage and flow rates through their distribution pipelines are significantly less than what the system was originally designed and constructed for. During low flow conditions, EBMUD closely monitors water quality effects such as nitrification due to increased water age and reduced turnover. For example, during the recent drought, EBMUD identified 24 reservoirs that were experiencing a degradation in water quality and quickly took them out of service. EBMUD is also addressing this risk over the long-term by retrofitting their 154 MG Central Reservoir to three tanks of 17 MG each.

- **Increased O&M to maintain high water quality.** With reduced water use, water was becoming stagnant at the extremities and dead ends within the system, such as cul-de-sacs. EBMUD implemented targeted flushing to address the issue coupled with a public education component to explain why flushing was necessary.

- **Increased costs to develop sources of supplemental wastewater supply to continue supporting recycled water customers.** EBMUD is dedicated to the use of recycled water to support industrial and commercial customers within their service area. Their current program has a production capacity of 9.2 mgd, with more than 80 percent of capacity serving industrial customers. EBMUD partners with West County Wastewater District (WCWD) to supply secondary effluent for use in its tertiary treatment plants that serve its industrial client. WCWD wastewater volumes have decreased by 2.7 mgd since 2002 and volumes during May through October are now inadequate to meet all of EBMUD's industrial demands. As such, EBMUD is exploring supplemental supply options with other partners, such as the City of Richmond, where the capital costs to upgrade treatment at the City of Richmond WWTP, expand EBMUD's Richmond Advanced Recycled Expansion (RARE) facility, and build recycled water conveyance totals up to $110 million.

- **Use of potable water during peak demand periods to supplement recycled water supply provided to industrial customers.** The North Richmond Recycled Water Project provides tertiary treated recycled water for industrial cooling towers. The RARE project utilizes advanced water treatment to provide higher-quality water for use in boilers for the manufacturing process. Given the decline in influent wastewater volumes, EBMUD has supplemented the recycled water provided to industrial customers with potable water to meet its contractual obligations.

- **Higher concentrations in salts and ammonia affect and limit recycled water customers.** Declining total volumes coupled with constant load result in higher concentrations of contaminants such as salts and ammonia. The higher salt concentration can potentially affect customers that use recycled water for landscape irrigation, as plants sensitive to high salt concentration can be harmed. High ammonia concentrations also limit industrial customers who have a desire to use recycled water but require water quality above and beyond the requirements of Title 22. EBMUD is working to increase their recycled water use to 20 mgd by 2040, and as such, are investing in a pilot study to understand what treatment processes can be used to improve recycled water quality.

4.2.3 Key Takeaways

- Systems that were appropriately designed during a time when demand was significantly higher can result in oversized systems that may be more susceptible to increased water age and their water quality effects. Utilities are already working to address those water quality challenges through mitigation strategies and long-term retrofits, which require additional capital and O&M costs.

- Reductions in water demand and wastewater production leaves excess capacity in treatment facilities to accommodate future population growth.

- Utilities want to support commercial/industrial customers with recycled water use to offset potable consumption but require the influent wastewater volumes to do so. Increasing contaminant concentrations and reductions in wastewater volumes can affect both recycled water quantity and quality, which will affect a utility’s ability to serve and recruit customers.

4.3 Case Study: City of Fresno

The City of Fresno (Fresno) provides public utilities services, including water, wastewater, and recycled water to approximately 500,000 customers over a 114 square mile area. Originally, the only source of water for the Fresno came from its Sole Source Aquifer which also supplies many communities within the San Joaquin Valley. However, growing demand and continued groundwater pumping utilizing up to 260 groundwater wells created an overdraft condition in the aquifer. To address and mitigate these conditions, Fresno commissioned its first 30-mgd northeast surface water treatment facility (NESWTF) in 2004 (which will eventually be expanded to its ultimate capacity of 60 mgd), a 4 mgd package surface water treatment facility (T-3 Facility) completed in 2013 (which has a build-out capacity of 8 mgd), and the 80 mgd southeast surface water treatment facility (SESWTF) that was completed in 2018.

These surface water treatment facilities utilize existing water allocations through contracts with the Bureau of Reclamation and Fresno Irrigation District. Fresno also maintains multiple finished water reservoirs and potable water storage tanks comprising over 22 MG of potable water storage capacity. Potable water is distributed to their customers through approximately 1,780 miles of pipeline throughout the city.

Fresno's Wastewater Management Division is responsible for the collection, conveyance, treatment, and reclamation of wastewater within the Fresno-Clovis metropolitan area. Wastewater travels through approximately 1,600 miles of sewer lines to the Fresno-Clovis Regional Wastewater Reclamation Facility (RWRF). The RWRF receives approximately 58 mgd of wastewater. Five mgd of this total influent is treated at a disinfected tertiary level and distributed to users of recycled water including farmland, a cemetery, and a public park. Approximately 1 percent of the 5 mgd volume is distributed outside of the RWRF for farm or landscape irrigation. The rest is treated to a secondary level and distributed to a percolation pond network sitting on 1,700 acres within the RWRF's boundary. Approximately 6 to 12 percent of the secondary effluent is distributed to farmers for direct reuse to irrigate non-food crops, such as cotton and alfalfa.

4.3.1 Benefits of Reduced Residential Water Use

Fresno has significantly reduced their historical per capita usage, decreasing from above 300 R-gpcd in 2000 to 190 R-gpcd in 2015. This reduction in use was supported by implementation of an aggressive public outreach and conservation program, and installation of water meters throughout Fresno that track and manage potable water use. Fresno has experienced the following benefits due to this sustained reduction:

- **Supported recharge of the Fresno Sole Source Aquifer.** Over the last 100 years, the water level in the aquifer has declined from 30 ft. to 130 ft. below ground level. Fresno is now on track to meet SGMA requirements and its 2035 water resource goals to re-establish historic groundwater levels and attain a balanced and sustainable water resources portfolio. These efforts include installation of water meters and diversifying their supply through the use of surface water treatment plants and expansion of its groundwater recharge and conservation programs. These measures coupled with the reduction in demand has allowed them to turn off a substantial number of their groundwater wells to aid in re-establishing historic groundwater levels.

- **Less demand requires less transport and treatment of water, reducing energy and chemical usage.** Historically, Fresno's surface water supplies utilized for surface water treatment had been provided by an open channel conveyance system that inherently contained opportunities for contamination through irrigation and storm water runoff, agricultural processes, and through accumulations of suspended materials from natural flora and fauna. These conditions most often required substantial chemical treatment at surface water treatment facilities. Currently, source water pipelines installed from the Friant Kern Canal to the City's 30-mgd NESWTF and from the Kings River to its 80-mgd SESWTF now provide substantial water quality protection from potential contamination and natural events, thus reducing needed chemical/disinfection treatment quantities at the water treatment facilities. This source water protection coupled with reduced demand decreases overall energy and chemical usage.

4.3.2 Adverse Impacts of Reduced Residential Water Use

The continuous and sustained declines in water use has also resulted in impacts on their systems, including:

- **Increase in odor complaints in the wastewater conveyance system, requiring increased investment for odor mitigation.** Fresno has had an increase in odor complaints driven by increasing H_2S concentrations. As such, they have invested in H_2S meters and placed them around the city to locate where specifically the odors are originating from. Fresno currently uses carbon filters throughout their collection system to address the odor complaints, and they have invested more money to purchase additional carbon filters to address the increasing odors. In fiscal year (FY) 2011 to FY 2015, Fresno spent on average ~$13,300 per year on carbon filters. From FY 2016 to FY 2020, that has increased to an average of ~$25,800 per year.

- **Loss of scouring velocity in wastewater pipelines, leading to an investment in a water tender truck.** With declines in wastewater production and long stretches of pipe, there is a loss of scouring velocity to move solids. Fresno invested in a water truck that uses recycled water to flush the sewers and scour the pipe. This was a strategic $135,000 investment that will be used in multiple ways to support Fresno in addition to just flushing. For example, Fresno staff will also use the water truck to help with dust control during construction and as a supplemental water source when cleaning large lines.

- **Accelerated corrosion in wastewater manhole frames and covers, triggering a change in cover type.** Fresno has been witnessing an accelerated rate of corrosion in manhole covers and bases. With this corrosion, manholes have started to release into the street as trucks and cars drive over them. As such, Fresno has begun to invest in switching out their manhole covers on mains 27 inches or bigger with those that have a locking feature and are equipped with a full-face gasket that helps maintain its position even with heavy traffic.

- **Increasing BOD concentrations at the WWTP, which is carefully watched by plant operators.** The RWRF is a permitted 91.5-mgd facility that currently treats an average of 56 mgd. The discharge permit for the RWRF is based on discharge capacity, which the RWRF is well below. While the influent volumes have declined, the BOD concentrations and associated loadings have increased. The capacity of the RWRF is 230,000 pounds of BOD, and the monthly maximum experienced to date has been 200,000 pounds in August/September of 2020. Thus, plant operators are carefully tracking BOD concentrations and their seasonal pattern.

4.3.3 Key Takeaways

- Reduced water demand from conservation and WUE can support recharge of local groundwater basins, helping utilities achieve water resource goals and SGMA requirements.

- Collection systems with long, minimally sloped pipelines are more prone to reduced scouring velocity, leading to contaminant build-up and increasing H_2S concentrations in the collection network. Mitigation measures, like the use of flushing trucks, can provide benefits to the utility beyond just addressing the impacts of reduced wastewater production.

- The WWTP have both hydraulic and loading capacities, and reduced total volumes may result in higher contaminant concentrations that push plants closer to their loading limit. The WWTP also has unique discharge permit requirements that can be based on flow, percent removal, or specific contaminant concentrations. Increasing concentrations are more likely to affect those with load or concentration requirements, and less likely for those with maximum flow limits.

4.4 Case Study: City of San Diego

The City of San Diego (San Diego) provides drinking water, wastewater, and recycled water services to 1.3 million people. Its drinking water system includes nine surface water reservoirs, three water treatment plants, 29 storage facilities and approximately 3,300 miles of pipes. San Diego also provides wastewater services to 2.3 million people and treats an average of 156 mgd of wastewater at its three wastewater treatment plants. San Diego has witnessed a decline in influent since 2006, especially at the Point Loma Wastewater Treatment Plant (PLWTP), which represents the end of the pipeline for San Diego County. Influent flows at the PLWTP specifically have decreased from an average of 170 mgd in 2006 to 140 mgd in 2017.

Local water availability has always been a challenge for San Diego due to its location in the dry Mediterranean climate of southern California. On average, San Diego imports 85 percent of its water from the Bay-Delta and the Colorado River. Given San Diego’s climate and current reliance on imported water, there is a concerted effort to diversify their water supply portfolio through a potable reuse program called Pure Water San Diego. Pure Water San Diego will treat wastewater effluent through advanced water treatment processes such as membrane filtration, reverse osmosis, and ultraviolet-advanced oxidation process (UV-AOP). The water will then be reintroduced into the potable water system through surface water augmentation.

4.4.1 Benefits of Reduced Residential Water Use

- **Improved self-reliance through reduced dependence and purchase of imported water.** San Diego has achieved significant water savings by encouraging reductions in residential water use. This includes continual investments in customer rebates, creating policies and ordinances to promote water conservation, and public information and education campaigns. San Diego is striving to reduce its dependence on imported water from 85 percent to approximately 50 percent by investing in Pure Water San Diego and additional conservation. In San Diego's 2015 UWMP, water conservation values were estimated based on a continuation of conservation incentive and rebate programs. The projected estimation was approximately 8,900 afy of water to be saved in 2020, and approximately 6,700 afy of water in 2025.

4.4.2 Adverse Impacts of Reduced Residential Water Use

- **Increase in odors in conveyance system, which City mitigates through increased Bioxide® purchase and use.** San Diego provides wastewater services to its population as well as 15 participating agencies. As such, wastewater must travel a significant distance until it reaches a wastewater treatment plant. With reductions in water use, there has been a loss of scouring velocity in the wastewater collection system and increase in H_2S concentrations. This has led to an increase in odors, which the City mitigates with odor mitigation products such as Bioxide®. There was an increase in Bioxide® purchase from roughly 156,000 gallons in FYI 2010 to 226,000 gallons in FY 2017, increasing costs by $150,500 (City of San Diego 2018). This also led to an increase in deliveries at six pump stations from around 120 deliveries in FY 2010 to over 160 in FY 2017 (City of San Diego 2018).

- **Increased chemical use to address increasing concentrations (e.g., BOD and TSS) in wastewater influent.** The PLWTP is located at the endpoint of San Diego's wastewater system. San Diego's other wastewater treatment plants, such as North City, South Bay, and the Metropolitan Biosolids Center, all have waste streams that flow to PLWTP. The PLWTP is considered an advanced primary treatment that uses chemical for enhanced treatment. Thus, the plant uses more chemical than most primary treatment plants and can achieve near secondary treatment results. The average flow at PLWTP was 170 mgd in 2006, and the flow has now decreased to around 140 mgd despite increases in population. This leads to increases in wastewater concentrations, which requires more chemical use to achieve the required BOD and TSS removal per their NPDES permit.

- Reductions to source influent flow volumes for the Pure Water Program, potentially impacting Pure Water Program goals and increasing costs. The available wastewater within the sewershed was projected to effectively size the Pure Water Program, which aimed to produce 42 mgd for reuse (30 mgd potable, plus 12 mgd recycled) for Phase 1 and 83 mgd for Phase 2. Production of wastewater effluent volumes lower than the modeled wastewater values will make it more difficult to meet Pure Water Program goals and may require additional investments to divert supplement wastewater volumes to the WWTPs sourcing the Pure Water Program. A theoretical cost developed for moving a pump station 2 miles south to access and pump supplemental flows estimated an increase of $20 million in capital costs and annual increase of $50,000 in electrical costs (City of San Diego 2018). The design of the pump station in question is already completed, so it is unlikely that the pump station will be moved. However, this demonstrates the potential cost impacts from reduced total wastewater volumes.

4.4.3 Key Takeaways

- The City's reliance on imported water means that the cost and/or availability of water supplies is beyond the realm of the utility's control. This motivates the desire to develop local water supplies through both non-potable and potable reuse.

- While energy usage at a WWTP may decrease due to lower wastewater volumes, chemical use will go up as the chemical volumes required are tied to wastewater concentrations and not quantity.

- Water reuse projects that have already been designed are more likely to be affected by a changing Ri-gpcd, as treatment processes have already been designed to specific wastewater quality and quantities. Projects that are in the planning phases can effectively adapt to changing conditions and account for reduced indoor residential water use.

5.0 Key Findings

Existing literature and utility experience demonstrate that reductions in residential water use offers real benefits to water, wastewater, and recycled water systems, as well as significant impacts. The following findings are organized within the context of water and wastewater utilities, providing a holistic perspective as utilities work to balance the benefits of water use efficiency against adverse impacts on their finances, infrastructure, water quality, and operations. These impacts are then framed against utility characteristics that can either increase a utility's resiliency to reduced indoor residential water use or exacerbate the adverse impacts. Identification of utility characteristics in this way highlights how these unique factors need to be considered when informing potential adjustments to the Ri-gpcd standard.

5.1 Benefits and Adverse Impacts on Water Utilities

Reductions in residential indoor water use provides real benefits to water utilities, and utilities with source supplies that are sensitive to the impacts of drought and climate change can experience greater urgency and benefit around reducing per capita water usage. Reduced Ri-gpcd enables them to stretch existing water sources to support population growth and defer some level of investment in supplemental water supplies and expansion of existing systems. It also supports a community ethic around wise water use and demonstrates a utility's commitment to maintaining an affordable, yet sustainable water supply. This can also help rally community support for more costly supplemental supplies, as the utility has shown effort to first reduce per capita use. Lower water demand and flow rates through water treatment facilities also translate into lower treatment and pumping costs, due to chemical and energy use.

However, reductions in indoor residential water use could result in adverse impacts that utilities need to address. Specific utility characteristics can either reduce or exacerbate these adverse impacts of reduced flows, and this information is described in Table 5-1. More information regarding each adverse impact can be found in the respective section indicated.

Table 5-1 Water Utility Characteristics That Can Contribute to Adverse Impacts

Section #	Adverse Effect	Utility Characteristics
3.1.2	Deterioration of water quality due to increased retention time in distribution system	**Age of infrastructure.** Systems historically designed during phases of high population growth or commercial and industrial activities can now be oversized for current low-flow scenarios. Newer systems that used more current projections that consider the changes from increased conservation and water use efficiency tend to be better adapted to low-flow conditions. Systems that are older may also experience more corrosion and associated deterioration, lending to increased contaminant leaching. **Topography, size, and density of service area.** Systems that serve a large service area or low-density population require water to travel longer distances. This increases the potential for deteriorating water quality in the extremities of water distribution systems. A compact, high-density service area typically experience lower water age and may be more resilient. **System capacity.** Water systems are sized to supply both water demands and emergency and fire flows, which may require water systems to maintain high volumes of water throughout the distribution system. A reduction in water usage may further increase water age and exacerbate its associated adverse impacts on water quality. **Infrastructure material.** As water ages in distribution systems, there is more potential for the release of metals such as lead and copper, which has impacts on public health. Systems with pipes made of iron, lead, copper and other metals may be more susceptible to problematic metal release from increased retention time. This dictates the need to strengthen control of corrosion and metal release in low-demand conditions.
3.1.3	Stranded assets and	**Magnitude of change from initial design parameters.** Water treatment plants and storage facilities that were sized during times of larger water

Section #	Adverse Effect	Utility Characteristics
	stagnation challenges from reduced water quantity	demand from higher per capita use or to support commercial/industry end-users may now be oversized due to investments in conservation and water use efficiency. As the necessary capacity has decreased, the excess infrastructure may result in stranded assets.
3.5	Reductions in revenue from reduced water sales	**Type of rate structure.** With successful reductions in Ri-gpcd also comes a reduction in revenue, especially for utilities with tiered rate structures that follow changes in volumetric use. However, utilities with rate structures less sensitive to the change in water demand, such as flat or straight volumetric rates, will have a more stable source of revenue.

5.2 Benefits and Adverse Impacts on Wastewater Utilities

Increased water use efficiency provides some benefits to wastewater utilities, such as a reduction in energy usage as less wastewater is needed to be pumped through the treatment process and to the discharge point. Decreased wastewater influent volumes also allow for additional wastewater treatment plant hydraulic capacity that can accommodate future population growth. However, it is the inverse for wastewater treatment plants as contaminant concentrations increase due to maintained loading capacities yet a decline in volume. Specific utility characteristics can similarly either reduce or exacerbate the adverse impacts of reduced indoor residential water use, and this is presented in Table 5-2.

Table 5-2. Wastewater Utility Characteristics that Lend to Resiliency or Vulnerability to Adverse Impacts

Section #	Adverse Impact	Utility Characteristics
3.2.1, 3.2.2	Increase in odors and accelerated corrosion from higher sewer gas concentrations	**Age of infrastructure.** Utilities with infrastructure constructed a long time ago may be more susceptible to odor leakage and accelerated corrosion as sewer pipelines have deteriorated and corroded over time. Infrastructure that is designed and constructed more recently, i.e., with consideration for lower water demands and reduced Ri-gpcd, may already be considering these potential impacts in their design criteria and thus be more resilient. **Topography, size, and density of service area.** In areas where wastewater move by gravity, long stretches of flat pipeline will provide more time for H_2S production, exacerbating odor production and corrosion. Systems with greater slopes, shorter distances, and high-density between wastewater production to treatment may be more resilient to increased odor production as wastewater is able to continue moving quickly through pipes. **Infrastructure material.** Non-epoxied concrete is sensitive to corrosion, and utilities have witnessed the greatest rate of corrosion at concrete manholes. Existing areas with concrete infrastructure will experience the adverse impacts of accelerated corrosion most heavily. Infrastructure that mitigates against corrosion, such as plastic pipe, steel, or epoxy, will be more resilient to accelerated corrosion.

Section #	Adverse Impact	Utility Characteristics
3.2.3	Increased occurrence of sewer blockages and overflows	**Pipeline diameters.** Pipelines with smaller diameters (e.g., 4 to 6 inches) are more easily clogged and thus more susceptible to sanitary sewer blockages and associated overflows. These blockages are exacerbated by increasing solids concentrations from reduced Ri-gpcd. Conversely, wastewater systems with substantially larger diameters may be less prone to blockages.
3.3.1,3.3.2	Impacts on wastewater effluent quality and increased chemical use from degradation of wastewater influent quality	**Customer demographic.** Utilities serve a unique make-up of customers, which is split between residential, commercial, or industrial. Those with greater percentages of commercial/industrial customers will experience less overall change in both wastewater quality and quantity as residential customers reduce their indoor water use. However, utilities with predominantly residential customers will experience greater shifts in quantity and contaminant concentrations, which can impact treatment plant operations. **WWTP treatment process.** As population remains stable, mass loadings also remain consistent. However, declining Ri-gpcd result in increased concentrations of organics, nutrients, and contaminants. WWTPs that use treatment processes that have loading limitations, such as activated sludge, nutrient removal, or biosolids handling, will be more sensitive to this increasing load in influent wastewater. Addressing this increased load could trigger changes in operations or increased chemical use to meet effluent quality targets. WWTPs with treatment processes that are driven hydraulically will be more resilient to changing wastewater quality.

Section #	Adverse Impact	Utility Characteristics
		NPDES permit requirements and discharge point. Increasing contaminant concentrations in the wastewater influent result in subsequently higher concentrations in the effluent. Thus, WWTPs that discharge into sensitive water bodies with strict NPDES discharge limits may require operational adjustments to continue meeting effluent requirements. This is particularly true for those with specific contaminant concentration limits that they have to meet. WWTPs that have NPDES permits that set hydraulic or percent removal targets will be more resilient to increases in wastewater influent.

5.3 Benefits and Adverse Impacts on Recycled Water Projects

An increased community ethic around conservation and water use efficiency can bolster the same ethic for use of recycled water. An understanding of water scarcity can also create community support for water reuse projects as utilities shift their reliance from imported to local supplies. However, the adverse impacts experienced on wastewater effluent quantity and quality subsequently affect the quantity and quality of recycled water projects. The specific utility characteristics that can influence or exacerbate the adverse impacts of reduced indoor residential water use are presented in Table 5-3.

Table 5-3. Characteristics that Lend to Resiliency or Vulnerability for Recycled Water Projects

Section #	Adverse Impact	Utility Characteristics
3.4.1	Limiting the offset of potable use from reductions in recycled water production	**Water supply source.** Recycled water serves as a way to offset potable use and continue to meet community demand. This is valuable in locations where potable supplies are limited and sensitive to climate change. Reductions in recycled water production can limit a utility's ability to offset potable consumption of supply sources. **Discharge requirements.** Limiting the offset of potable consumption can be further exacerbated by WWTP discharge requirements that are flow-based. For example, some WWTPs are required to discharge certain volumes to help maintain stream flows. Meeting this requirement reduces the amount of wastewater available for reuse, which is further impacted by reductions in wastewater influent.
3.4.2	Deterioration in recycled water quality from worsened wastewater effluent quality	**Customer demographic and end-uses**. The quality and quantity of recycled water to be produced is informed by customer demand and requirements. Systems that serve customers that require high-quality water quality (e.g., industrial processes or potable reuse) will be more susceptible to the impacts of increasing concentrations in wastewater effluent. **Existing or planned investments.** Utilities throughout California are planning, designing, or constructing water reuse projects. Reductions in wastewater influent volumes and changes in wastewater quality will more greatly impact projects that are already in design or under construction. Utilities that are still in the planning phase can more readily adapt and incorporate changes in wastewater quality and quantity into their design criteria.

5.4 Potential Future Refinement

Public utilities across California have demonstrated their ability to adapt to adverse impacts of a changing Ri-gpcd through a variety of mitigation strategies. However, these adaptations require time and money, the extent of which will depend on utility-specific characteristics.

This study is a qualitative assessment of the benefits and impacts of a changing Ri-gpcd standard, as quantifiable data specific to standards are not yet available. Instead, this study leveraged utility experiences during the recent drought as a surrogate to represent a changing Ri-gpcd in locations where indoor residential per capita water use was low or decreasing to identify benefits and impacts.

This qualitative assessment could be improved through the collection of quantifiable data. A data set that includes more utilities and unique system characteristics, which exacerbate or reduce impacts of adverse effects, is warranted. Characteristics that should be incorporated into future data sets could include system age, the magnitude of change between water system design criteria and the Ri-gpcd standard, customer demographic, service area topography, type of WWTP treatment process, and NPDES discharge permit requirements.

Based on this enhanced understanding, utilities can help inform a realistic timeframe for standards implementation or the funding needs to support adjustment to the changing Ri-gpcd standard.

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Appendix J. Efficient Indoor Water Use and Practices

Prepared for

California Department of Water Resources

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California State Water Resources Control Board

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Water Use Efficiency Branch

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Efficient Indoor Water Use and Practices

This appendix includes additional information to quantify efficient indoor residential water use and practices. The Department of Water Resources (the Department) and the State Water Resources Control Board (the State Water Board) recognize the work urban retail water suppliers have done and continue to do to promote water conservation, including measures to increase indoor residential water use efficiency. The Department and the State Water Board also recognize there is untapped potential and more Californians can do to make conservation a way of life.

The data and reports referenced in this appendix were collected before the COVID-19 pandemic. Shelter-in-place orders and remote work have affected urban water use patterns. According to one study, the water use of many households increased with more frequent hand washing and toilet flushing; in other households, it decreased as people washed fewer loads of laundry (P. Mayer, personal communication, January 2021). Another study suggests the pandemic may have resulted in a 1.4% increase in the residential water use sector, which the authors attribute to an increase in outdoor use (Li, 2021).

Efficient use

Starting in January 2024, California Water Code section 10609.20 directs each Urban Retail Water Supplier (URWS) to calculate an urban water use objective, which would be the sum of the following:

- Aggregate estimated efficient indoor residential water use.
- Aggregate estimated efficient outdoor residential water use.
- Aggregate estimated efficient outdoor irrigation of landscape areas with dedicated irrigation meters or equivalent technology in connection with CII water use.
- Aggregate estimated efficient water losses.
- Aggregate estimated water use in accordance with variances, as appropriate.

- A bonus incentive for potable reuse water, not to exceed 15 percent of the urban water supplier's water use objective.

At the household scale, efficient indoor residential water use practices include, but are not limited to, actions such as the installation and maintenance of efficient fixtures and appliances, minimizing leaks, ensuring the efficient distribution of hot water, reusing gray water on-site, and water efficient behaviors (e.g., minimizing shower time). At the supplier scale, these practices include, but are not limited to, actions such as education and outreach, leak detection, surveys, showerhead and aerator distribution, rebates, and advanced metering infrastructure (AMI) (CUWCC, 2008).

While the California Water Code does not quantitatively define *efficient indoor residential water use,* existing standards, studies undertaken for this report, and previous analyses suggest efficient indoor residential water use for homes equipped with efficient fixtures and appliances ranges from 24 to 39 gpcd at the household level and from 28 to 43 gpcd (refer to Figure 1) when averaged across the service areas of California urban retail water suppliers. These values will be explained and referenced in the following sections.

Efficient Indoor Residential Water Use in Households

Based on the latest efficiency standards adopted by the California Energy Commission (CEC), specifications adopted by the U.S. Environmental Protection Agency's ENERGYSTAR program, and use patterns documented in the 2016 Residential End Use Study (De Oreo et al. 2016), the water use of a typical home equipped with efficient fixtures and appliances is approximately 35 gpcd. Table J-1 shows the hypothetical water use of a typical home with and without efficient appliances and fixtures. The column on the left shows the hypothetical indoor water use of a typical home using older or less efficient appliances and fixtures. The column on the right shows the hypothetical indoor water use of a home that has ENERGYSTAR appliances (ENERGYSTAR, 2019) and fixtures that meet the most recent efficiency standards adopted by the CEC (77 FR 32307, CCR Title 20). Assumptions regarding indoor water use habits--for example, the average number of times a person flushes a toilet per day as 5--come from the

Water Research Foundation's 2016 Residential End Use study (De Oreo et al. 2016).

Table J-1: Comparing the hypothetical water use of example homes between older and less efficient appliances and fixtures, and newer, highly-efficient appliances and fixtures.

Use	Modeled water use for a typical home with inefficient appliances & fixtures	Modeled water use for a typical home with efficient appliances & fixtures
Toilet	18 gpcd (3.5 Gallons per flush)	6 gpcd (1.28 Gallons per flush)
Clothes Washer	11 gpcd (37 Gallons per load)	6 gpcd (19 Gallons per load)
Shower	7 gpcd (2.5 Gallons per minute)	6 gpcd (1.8 Gallons per minute)
Faucets	14 gpcd (2.2 Gallons per minute)	10 gpcd (1.5 Gallons per minute)
In-home Leaks [64]	2 gpcd	2 gpcd
Other [65]	2.5 gpcd	2.5 gpcd
Bath	1.5 gpcd	1.5 gpcd
Dishwasher	1 gpcd (9 Gallons per load)	0.4 gpcd (3.6 Gallons per load)
TOTAL	~55 gpcd	~35 gpcd

[64] According to REUS 2016, households leak 17 gallons per day, on average. That average is heavily skewed by households with large leakage rates. Most households leak less than 5 gallons per day. Assuming an average of 2.64 persons per household, the per capita share of leakage, for most households, is less than 2 gpcd.

[65] The “other” category includes evaporative cooling, humidification, water softening, and other uncategorized indoor uses.

Previous analyses have sought to understand efficient indoor water use in homes in California and across the country. In *Analysis of Water Use in New Single-Family Homes*, which includes homes in California cities such as Roseville, De Oreo et al. (2011) measured the indoor water use of WaterSense New Homes at 35.6 gpcd and existing homes retrofitted with water efficient devices at 39 gpcd. In *Residential End Uses of Water, Version 2*, the authors found that demand would drop to 37 gpcd for homes retrofitted with most recent industry-standard water efficient devices. If household leaks were reduced, demand would drop further to 34 gpcd. If toilets were flushed with greywater rather than potable water, demand would drop to 27.9 gpcd (De Oreo et al., 2016). In *Measuring Progress Toward Universal Access to Water and Sanitation in California* (2018), the Pacific Institute, extrapolating from 2018 appliance and fixture standards, estimated efficient indoor water use to be 37 gpcd (Feinstein, 2018). Based on leading edge flow ratings, meaning those even more efficient than current standards (e.g., toilets using just 0.8 gallons per flush), they estimated efficient indoor water use would be 24 gpcd (Feinstein, 2018). Table J-2 summarizes the efficient indoor residential water use rates that have been documented in previous analyses.

As seen above, customer best practices, such as the installation and maintenance of efficient fixtures and appliances, minimal leaks, the efficient distribution of hot water, and on-site reuse of grey water can contribute to efficient indoor residential water use rates ranging from 24 to 39 gpcd. Water use that falls within this range may be considered to reflect best practices at the household level.

Table J-2: Summary of efficient indoor residential water use rates at the household scale.

Efficiency Measure	R_i-gpcd	Year	Source
WaterSense New Home	36	2011	De Oreo et al. (2011)
Existing home retrofitted with water efficient devices	39	2011	De Oreo et al. (2011)
Existing home retrofitted with water efficient devices	37	2016	Residential End Uses of Water, Version 2
Existing home retrofitted with water efficient devices, plus leak detection	34	2016	Residential End Uses of Water, Version 2
Existing home retrofitted with water efficient devices, plus leak detection and greywater use	28	2016	De Oreo et al. (2016)
Extrapolation of existing fixture and appliance standards	37	2018	Pacific Institute
Leading edge flow rated appliances	24	2018	Pacific Institute

Efficient Indoor Residential Water Use at the Community Scale

As described in Section 2.0, the Department collected and analyzed monthly water data from customer accounts for 2017, 2018, and 2019--the three years following the last drought. The customer-level water use data was then aggregated to the geographic scale of census tracts. To calculate per capita use, the Department divided the aggregated census tract water use data by census tract population. Using four different methods (as described in Section 2.4), the Department estimated indoor residential water use for

18 Urban Retail Water Suppliers. One of those agencies is a municipal leader in water efficiency, with robust programs encouraging efficiency across sectors (e.g., rebates, audits, give-a-ways, resale ordinances, etc.) and effective messaging. Using each method, the Department estimated the average baseline indoor water use rate across this agency's entire service area was below 40 gpcd.

For the 17 other agencies participating in the Department's study, estimates of per capita use based on service area wide averages were not as low. In any given service area however, there exists a distribution of per capita use values. According to the Seasonal Adjustment Method, SAM[66], homes in the lowest water-using quartile tracts use 44 gpcd on average or less, with rates ranging from 34 to 58 gpcd. These data suggest that, even if an agency's average estimated indoor residential water use is high, there is a percentage of customers within their service area that appear to be using water more efficiently indoors, i.e., at rates more similar to those of the highly efficient homes modeled through the Water Research Foundation (2016) and Pacific Institute (Feinstein, 2018) studies. Table J-3 summarizes these data.

[66] As described in Appendix A, each of the methods used to calculate indoor residential have limitations. SAM, for example, may not accurately remove outdoor water use. For agencies that participated in the Department's study and have independently estimated l indoor residential use rates, SAM appears to overestimate indoor use.

Table J-3: Average and first-quartile indoor residential water use, using monthly data, and the percentage of the service area population associated with tracts averaging 44 gpcd or less.

Agency	Average Use (Ri-gpcd)	Lowest Water Using Quartile Tracts (Ri-gpcd)	% Population in Tracts Averaging 44 gpcd or Less
18 Agency Average	48	44.0	42%
Agency A	44.4	40.9	43%
Agency B	39.0	35.7	76%
Agency C	48.9	44.6	22%
Agency D	57.8	53.1	8%
Agency E	44.4	42.3	23%
Agency F	43.5	38.7	61%
Agency G	44.7	40.4	35%
Agency H	41.9	38.5	83%
Agency I	49.1	44.6	21%
Agency J	40.3	34.2	62%
Agency K	51.6	48.2	11%
Agency L	53.7	49.7	3%
Agency M	39.4	38.0	100%
Agency N	69.8	57.7	4%
Agency O	42.7	39.9	65%
Agency P	51.6	48.7	1%

Agency	Average Use (Ri-gpcd)	Lowest Water Using Quartile Tracts (Ri-gpcd)	% Population in Tracts Averaging 44 gpcd or Less
Agency Q	63.2	55.5	0%
Agency R	36.8	33.6	100%

As described in Section 2.3, the Department also collected and analyzed hourly water data from customer accounts for 4 of the 18 suppliers (Table J-4). According to SAM, tracts in the lowest water-using quartile used an average of 42 gpcd for these suppliers, with values ranging from 31 to 52 gpcd.

Table J-4: Service are average and first-quartile tracts indoor residential water use, using hourly data, and the percentage of the service area population associated with tracts averaging 44 gpcd or less.

Agency	Average Use (R_i-gpcd)	Lowest Water-Using Quartile Tracts (R_i-gpcd)	% Population in Tracts Averaging 44 gpcd or Less
4 Agency Average	47	42	43%
Agency K	57.9	51.6	0%
Agency L	51.4	46.8	9%
Agency 0	42.4	39.8	62%
Agency R	34.4	31.1	100%

As described in Section 5.0 of this report, the Department and the State Water Board also analyzed single-family water delivery volumes using data reported in the electronic Annual Report (eAR), according to the SAM. Based on this analysis of 2017-2019 data from 157 urban retail water suppliers, average and median indoor residential water are 51 and 48 gpcd, respectively. For urban retail water suppliers (Suppliers) at the lowest water using quartile, residential customers are estimated to be using 43 (or lower) gpcd indoors. Figure J-1 shows the residential water use continuum using Electronic Annual Report (eAR) data and SAM analysis.

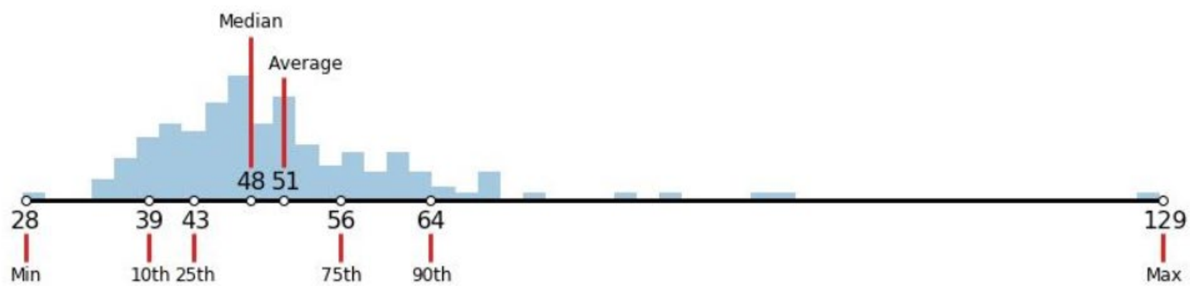

Figure J-1: Today's indoor residential water use continuum using data from the eAR and SAM, showing the 2017-2019 range in gpcd.

Alignment across these datasets does not explain why water use is 44 gpcd or less for tracts (Tables J-3 and J-4) and 43 gpcd for Suppliers (Figure J-1) at the 25th percentile. One explanation is that these customers and communities are using water more efficiently indoors. In-depth End Use studies would help us to better understand these trends.

Efficient Indoor Residential Water Use as Reported by Water Agencies

Some agencies have also independently sought to understand indoor residential water use trends in their service area (Table J-5). Based on a single-family residential end use study, the City of San Francisco estimates per capita residential use to be 44 gpcd, including both indoor and outdoor use (SFWPP, 2016). Using a combination of the minimum month method and the seasonal adjustment method, the Inland Empire Utility Agency (IEUA) estimated indoor residential use is 37 gpcd in housing built after 2013 (IEUA, 2016). The City of Santa Cruz used the minimum month method and estimated indoor residential water use to be 36 gpcd (B. Pink, personal communication, September 2020). In their draft Urban Water Management Plan, the City of Los Angeles estimates that on average, indoor use represents 49 - 56% and 70 - 80% of single-family and of multi-family residential use, respectively (LADWP, 2021 and T. McCarthy, personal communication, April 2021). The reported volume of deliveries by sector and service area characteristics, such as average number of persons per household, suggests LADWP's indoor residential water use is somewhere between 40 and 46 gpcd.[67]

Table J-5: Summary of efficient indoor residential use rates from various agency studies

Agency name	R_i-gpcd	Year	Method	Source
Santa Cruz	36	2020	Winter minimum	City of Santa Cruz
San Francisco WPP	44	2015	End Use study	City of San Francisco Water Conservation Plan
IEUA	37	2015	Winter Min/SAM	Inland Empire Utility Agency Integrated Water Resources Plan
LADWP	40-46	2021	Percent indoor/outdoor use based on an end use study, a saturation study, and sewage flow data.	LADWP 2021 UWMP drafts

[67] Single-family and multi-family water demand (FYE average 2016-2020), indoor and outdoor water use percentage breakdowns by sector (FYE average 2015-2020), and 2020 demographic projections for the LADWP service area (housing units and persons per household) from LADWP's Draft Urban Water Management Plan 2020 were used to calculate an indoor residential use of about 40 gpcd (LADWP 2021).

Efficient Indoor Residential Water Use in Australia

Australia provides a relevant comparative case study to California for understanding indoor water use trends. Like California, Australia is affluent and industrialized; it has also endured severe drought and invested considerable resources in managing water resources more efficiently. Several Australian states with characteristics akin to communities here in California have achieved efficient indoor water use rates across large areas.

In Australia, average indoor household water use was measured at 38 gpcd across southeast Queensland cities such as Brisbane and Gold Coast (Beal et al., 2012) and 35 gpcd in Adelaide, South Australia (Arbon et al., 2014). In Melbourne, Victoria, City West Water conducted two residential end use measurement studies in the last decade, documenting that average indoor residential water use ranges from 25 to 32 gpcd (City West Water, 2019). In the period immediately following the Millennium Drought, indoor residential water use averaged 25 gallons per person per day. Since then, indoor water use has increased; between 2017 and 2018, it averaged 32 gpcd (City West Water, 2019). Table J-6 below summarizes the total and fixture-specific water use trends.

Table J-6: Melbourne's average residential indoor water use according to City West Water's 2010-2012 and 2017-2018 residential end use studies.

Fixture	Residential End Use Study 2010-2012 (gpcd)	Residential End Use Study 2017-2018 (gpcd)
Shower	9	11
Toilet	7	9
Tap	3	5
Washing Machine	2	3
Bath	2	3
Leaks/drips	2	1
Dishwasher	0.05	0.1
Total	25	32

In August 2020, typically Melbourne's wettest month[68], water use was 33 gpcd (Melbourne Water, 2020), suggesting residents have been beating their "winter Target" of 130 liters (34 gallons) per day, even in the throes of the COVID-19 pandemic. During and following the Millennium Drought, Australian states and water purveyors set ambitious residential water consumption targets. "Target 155" initiatives encourage limiting household (indoor and outdoor) use to 155 liters (40 gallons) or less per person per day (Figure 2). Because demand varies depending on the season, Australia's water managers concluded that 155 liters would represent an ideal annual average (Fitzgerald, 2009). In Melbourne, the target is 130

[68] In areas like Melbourne, where winter precipitation eliminates the need for outdoor irrigation, winter water use is an imperfect, but reasonable gauge of indoor water use.

liters (34 gallons) in the winter and 190 liters (50 gallons) in the summer (Weinstein Bloome and de Guzman, 2017).

Figure J-2: Printed material used to encourage residents to conserve water (NY Times, 2016)

In drought or not, states such as South Australia, South East Queensland, and Victoria are institutionalizing efficient urban indoor water use. They demonstrate that with adequate funding, efficient levels of indoor water use are possible across large areas with big populations — and that such levels of water use are possible in places that resemble California, not only culturally and economically, but also climatically for some regions (e.g., Melbourne's climate is similar to San Jose's climate). Many California cities and suburbs developed around the same time as those in Australia, with parallel trajectories in terms of urban design and infrastructure. Perhaps most importantly, California and Australia share a need to prepare for longer and more intense periods of water scarcity. One key lesson from Australia's Millennium Drought and drought responses is that efficient indoor residential use is as achievable as it is important. Table J-7 summarizes the efficient indoor residential water use rates documented at the household and community scale in three regions in Australia.

Table J-7: Summary of efficient indoor residential use rates documented in Australia.

Ri-gpcd	Year	Location
38	2012	Southeast Queensland (e.g., Brisbane, Gold Coast, etc.), Queensland
35	2014	Adelaide, South Australia
25	2012	Melbourne, Victoria
32	2018	Melbourne, Victoria
33	2020	Melbourne, Victoria

Green Building Standards and Rating Systems

Several green building rating systems encourage efficient water use. While compliance with the standards may be voluntary (or partially voluntary), they may be used for new construction and existing homes. Leadership in Energy and Environmental Design (LEED) is the most widely used green building rating system in the world, but there are others and they all include criteria to ensure water is being used efficiently in new and existing homes. Table J-8a and J-8b, below, summarize the water criteria currently used by LEED, WaterSense, CalGreen, and Build It Green's Green Point Standard.

Table J-8a: Water use efficiency criteria for several efficiency program standards. Appliance and fixture efficiencies are generally measured in gallons per flush (gpf) or gallons per minute (gpm).

	CalGreen	Green Point Standard	WaterSense (Ver 2.0, 2019)	LEED* 1 pt	LEED* 2 pts	LEED* 3 pts
Toilets	1.28 gpf	1.28 gpf or less	1.28 gpf	1.28 gpf	1.1 gpf	0.8 gpf
Faucets	1.2 /1.8 gpm	1.5 gpm or less	1.5 gpm	1.5 gpm	1.5 gpm	1.0 gpm
Showerhead	1.8 gpm	2.0 gpm or less	2.5 gpm	2.0 gpm	1.75 gpm	1.5 gpm
Clothes washer	ENERGYSTAR (voluntary)	ENERGYSTAR	n/a	n/a	ENERGYSTAR'S IWF Top-loading, IWF ≤ 4.3 Front-loading, IWF ≤ 3.2	n/a
Dishwasher	ENERGYSTAR (voluntary)	ENERGYSTAR	n/a	n/a	n/a	n/a

*LEED = Leadership in Energy & Environmental Design, Vol. 4.1, updated January 10, 2020

Table J-8b: **Water use efficiency criteria for several efficiency program standards continued. Appliance and fixture efficiencies are generally measured in gallons per flush (gpf) or gallons per minute (gpm).**

	CalGreen	Green Point Standard	WaterSense (Ver 2.0, 2019)	Leadership in Energy & Environmental Design Vol 4.1, updated January 10, 2020
Leaks	n/a	No leaks	No leaks	The water pressure in the house must be tested, with no detectable water leaks; projects are recommended, but not required, to reduce water pressure in the house to 60 pounds per square inch.
Hot water delivery	On-demand hot water circulation system (voluntary)	Insulate all hot water pipes; locate water heater within 12 ft of all fixtures; and install on-demand circulation control pump.	n/a	Design and install an energy-efficient hot water distribution system; All heat traced piping must be insulated.
Other	Greywater reuse, rainwater capture (voluntary)	Greywater reuse, rainwater capture (innovation, extra pts)	Homes must be at least 30% more efficient than typical new construction	Water metering Water softeners must be demand initiated.

Other examples of customer water use efficiency criteria and ratings not summarized in Tables J-1a and J-1b include RESNET's HersH20[69], Water Efficiency Rating Score (WERS)©[70], and The Living Building Challenge[71]. Some certification schemes, such as the Living Building Challenge, have very robust requirements for existing buildings, calling both for responsible water use as well as buildings being "net positive" with respect to water. As used by energy resource managers, being net positive means making or using more than you take. Some Californians have already taken steps to this end and offset indoor and outdoor needs with greywater and captured rainwater.

As described in Appendix F, passive conservation is estimated to have contributed to an average statewide decrease in indoor residential water use of 0.58 gpcd per year from 2015 through 2020; from 2020 to 2025, passive conservation is expected to drive indoor gpcd down by a statewide average of 0.38 gpcd per year; and, from 2025 to 2030, by 0.26 gpcd per year (Mitchell 2016). These projections may underestimate passive conservation's role in the future because they do not account for ultra-high-efficiency fixtures and appliances (e.g., toilets that use 0.8 gpf) or even showerheads and faucets that meet today's standards[72]. However, these statewide estimates may also overestimate the passive conservation potential of communities that have low indoor residential water use rates today (e.g., San Francisco) and may underestimate the passive conservation potential of communities with high indoor residential water use rates today.

[69] Residential Energy Services Network. 2021. RESNET's Water Efficiency Rating System HERSH2O. Available at: https://www.resnet.us/about/hersh2o/. Accessed May 6, 2021.
[70] Water Efficiency Rating Score (WERS)©. Available at: https://www.wers.us/about-2/. Accessed May 6, 2021.
[71] International Living Future Institute.2021. Living Building Challenge. Available at: https://living-future.org/lbc/. Accessed May 6, 2021.
[72] The 2016 Mitchell analysis did not include ultra-efficient fixtures because they are not required by code; it did not include showerheads and faucets because end use studies have suggested more efficient showerheads and faucets result in relatively minimal savings.

Conclusion

Existing standards, studies undertaken for this report, and previous analyses suggest efficient indoor residential water use ranges from 24 to 39 gpcd at the household level. Many California households appear to be using water efficiently indoors, with use rates mirroring those of homes equipped with fixtures and appliances that meet current CEC standards and U.S. EPA ENERGYSTAR performance criteria.

Studies undertaken for this report and previous analyses suggest efficient indoor residential water use ranges from 28 to 43 gpcd when averaged across the service areas of California urban retail water suppliers. Using data from the electronic Annual Report, 25% of California Urban Retail Water Suppliers are estimated to have indoor residential water rates of 43 gpcd or less.

Section 10817 of the California Water Code defines “water use efficiency” as the efficient management of water resources for beneficial uses, preventing waste, or accomplishing additional benefits with the same amount of water. Using less water indoors to complete the same domestic tasks — without comprising water quality or the user experience — is a clear example of water use efficiency.

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