Appendix A: Technical Documentation

Appendix A provides detailed technical documentation of the methods and assumptions used in the Pacific Institute report "California's Next Million Acre-Feet: Saving Water, Energy, and Money." This analysis explores how to capture 1 million acre-feet of potential water savings (only a fraction of the conservation potential statewide). We divide these savings between agriculture and urban uses, with approximately 70% of the savings derived from the agricultural sector and 30% from the urban sector.

Water Savings

Residential Sector

Table 1 shows the water savings for the residential devices. Estimates for toilets and clothes washers are based upon the California Urban Water Conservation Council (CUWCC) device savings estimates. These savings are used to determine compliance with the CUWCC Best Management Practices under the Flex Track Option (for more information about the CUWCC, see www.cuwcc.org). Water savings for faucet aerators are based upon data from the U.S. Environmental Protection Agency. Such estimates were not available for showerheads.

For showerheads, we develop the potential water savings using an end-use analysis based upon device flow rate and frequency of use. For this analysis, we assume the replacement of a 2.5-gallon per minute (gpm) showerhead with a model that uses 1.5 gpm. DeOreo et al. (2010) found that the average person takes 4.9 showers per week and that the average shower duration is 9 minutes. Based on a Brown and Caldwell (1984) study, Vickers (2001) estimates that showers are rarely opened at 100% but are maintained at an average throttle factor of 67 percent. The number of persons per household (pph) is based on the 2005 U.S. Census and is estimated at 2.87 pph for California. We assume that households have two showers but that both devices are upgraded to more efficient models (thus the cost of the measure is doubled). The calculation that we use to estimate annual water savings is:

(2.5 gpm – 1.5 gpm) x 67% throttle factor x 9 minutes per shower x 4.9 showers per person per week x 52 weeks per year x 2.87 persons per household = 4,422 gallons per year

Table 1. Water savings assumptions for residential toilets and clothes washers.

Device	Annual Water Savings (gallons)	Device Lifetime (yrs)	Source(s)
High-efficiency toilet (single-Family)	7,700	25	CUWCC 2009
High-efficiency toilet (multi-family)	9,710	25	CUWCC 2009
Clothes washer	10,200	16	CUWCC 2009
Showerheads (1.5 gpm)	4,422	8	See text
Faucet aerator (1.5 gpm)	629	5	EPA 2007

Note: gpm = gallons per minute; water savings estimates rounded to 3 significant digits

Commercial Sector

For the commercial sector, the potential water and energy savings are based on a review of studies that have quantified such savings (Table 2), including the U.S. Environmental Protection Agency's EnergyStar calculator for food steamers, clothes washers, and dishwashers (EPA 2009a, 2009b, 2009c, 2009d) and studies conducted and compiled by the CUWCC (CUWCC 2005, 2010).

Table 2. Savings estimates for commercial devices.

Device	Estimated annual savings (gallons)	Source(s)
Pre-rinse spray valve	50,000	CUWCC 2005
Connectionless/boilerless food steamer	160,000	EPA 2009a
Commercial dishwasher	50,000	EPA 2009d
Commercial clothes washer	38,000	EPA 2009b
Commercial urinal	22,500	EPA 2009c
Commercial toilets	13,600	CUWCC 2010
Cooling tower pH controllers	1,300,000	CUWCC 2010
Pressurized water brooms	50,000	CUWCC 2010

Note: Estimates rounded to 3 significant figures.

Agricultural Sector

For the agricultural sector, the potential water savings, as a percent of total water use, are based on a review of studies that have quantified such savings (Table 3), including research from the University of California Cooperative Extension. These percent savings were then applied to the baseline agricultural water use by crop type and by hydrologic region for 2000 (a normal water year), from the California Department of Water Resources Annual Land and Water Use Data.

Table 3. Savings estimates for agricultural water conservation and efficiency measures.

Measure	Applied to	Applied water savings (%)	Source(s)
Irrigation scheduling	20% of vegetable, orchard, and vineyard acreage	13%	Eching 2002
Regulated deficit irrigation	30% of almond and pistachio acreage	20% (for almonds and pistachios)	Goldhamer et al. 2006 Goldhamer and Beede 2004 Goldhamer et al. 2003

Our estimate of the potential water savings associated with conversion to more efficient irrigation technologies is based on a shift from baseline irrigation methods (Table 4) to an efficient irrigation technology scenario (Table 5). The efficient irrigation technology scenario moves only a portion of the acreage currently in flood irrigation to sprinkler irrigation, and a portion of the acreage currently in sprinkler irrigation to micro or drip irrigation. This scenario was first developed in Cooley et al. 2008, and modified here by excluding field crops. Ten percent of orchard and vineyard acreage and 15% of vegetable acreage remains flood irrigated in the efficient irrigation technology scenario. In addition, the savings are only calculated for three hydrologic regions (Sacramento River, San Joaquin River, and Tulare Lake). It is therefore a fairly conservative estimate of potential water savings.

Table 4. Irrigation method by crop type in 2001 (in percentage of irrigated acres).

	Flood	Sprinkler	Micro/Drip
Vegetables	42.9%	36.0%	21.1%
Orchards	20.3%	16.2%	63.5%
Vineyards	20.8%	8.7%	70.5%

Source: Orang et al. 2005

Table 5. Irrigation method by crop type in the efficient irrigation technology scenario (in percentage of irrigated acres).

	Flood	Sprinkler	Micro/Drip
Vegetables	15%	35%	50%
Orchards	10%	20%	70%
Vineyards	10%	10%	80%

Source: Cooley et al. 2008

Landscape

Agronomists and hydrologists estimate crop water demand, or theoretical irrigation requirements, using the concept of evapotranspiration. Evapotranspiration, or ET, is a combination of evaporation of water from the soil and plant surfaces, and transpiration, which is water lost by the plant through stomata, or openings in its leaves. During daylight hours, plants open stomata to take in carbon dioxide and, in so doing, lose water vapor, a process referred to as "transpiration." Transpiration losses increase under hot and dry conditions such that the plant must take up more water through its roots in order to survive and grow.

Potential evapotranspiration, or PET, is the evapotranspiration that would occur for a given crop with an ample supply of water. PET is affected by hydro-climatic factors, including air temperature, wind speed, humidity, solar radiation, and cloud cover. Actual evapotranspiration will equal PET in wet conditions, where water is abundantly available. Under drier conditions, ET will be some fraction of PET. On an annual basis, natural evapotranspiration in California is usually less than PET, which will only occur when water is abundantly available.

Monthly Irrigation Requirement

We estimate the monthly crop irrigation water requirement using a simple water balance model that has only two inputs: the long-term average monthly PET and precipitation for areas in California. For each month, we calculate the net irrigation requirement using the field water balance method. We follow equation 27.2.32 in the Handbook of Hydrology (Maidment 1993):

$$I = \underset{losses}{ET_{crop}} - \underset{gains}{(P + G + W)} \tag{1}$$

I is the monthly irrigation requirement, ET_{crop} is the evapotranspiration for a cropped area, P is the monthly precipitation, G is the groundwater contribution, and W is the stored water at the beginning of the month. We ignore the terms G and W, assuming that they are negligible for household landscapes and the relatively long time scale of one month.

We develop an estimate of annual irrigation use that is appropriate in warm climates, where irrigation may take place year round.

$$I_{Annual} = \sum_{t=1}^{12} \max\left(PET_t - P_t\right),\ 0) \tag{2}$$

The application of equation 2 is shown in Figure 1. The plot shows natural moisture demand, and is patterned after the "water balance charts" that were shown in the California Water Atlas (Kahrl ed. 1979). In months where precipitation exceeds the PET, the plants' water needs are fully met without irrigation and the irrigation requirement is zero. The location shown in Figure 1 (zip code 06111, Pyramid Lake in southern California) is marked by hot, dry summers where PET is high, and most of the precipitation occurs during the winter months. The height of the green bars indicates the water deficit that needs to be fulfilled by irrigation water to meet plant water needs.

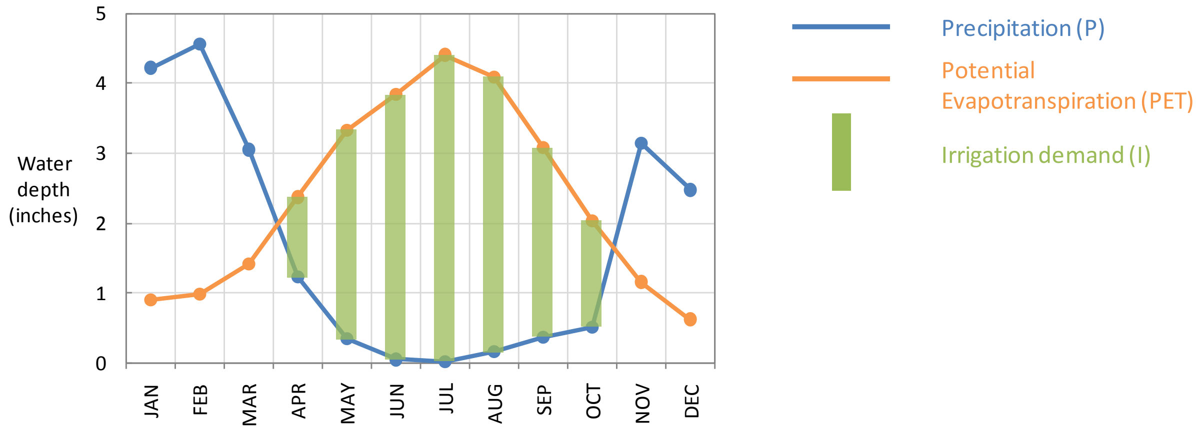

Figure 1 Monthly water deficit as a proxy for irrigation demand

In this simplified model, we assume that for vegetated areas, all of the precipitation infiltrates into the soil and that there is no runoff. We also assume that no water percolates deep underground where it is unavailable for uptake by plant roots. In reality, runoff and percolation can be significant fluxes of water. In practice, ignoring the runoff and percolation means that our model may slightly overestimate the quantity of rainfall that is available to fulfill plant water demand and underestimate irrigation requirements. Our simplified model also does not account for precipitation that falls as snow. Snow will not infiltrate into the soil and may not melt for several months. This is a further source of inaccuracy in our model.

Using equation 2, we develop an estimate of irrigation demand for each zip code in California. We perform the analysis in a digital map using Geographic Information Systems (GIS) software from ESRI. The important input layers are monthly precipitation and evapotranspiration. All outputs are initially reported by zip code. We obtain zip code boundaries from ESRI Data & Maps. We create a new GIS point layer of zip codes by converting the point at the centroid of each zip code polygon to a new feature. Many US zip codes represent post office boxes; these are not included in the analysis. It should also be noted that new zip codes are created every year as the population grows and moves. The datasets we used were created in 2006.

Evaporation & Evapotranspiration

We use estimates of reference evapotranspiration from a digital dataset published by the California Department of Water Resources (Figure 2). This map of evapotranspiration zones is based on data from the California Irrigation Management System, or CIMIS. There are 18 zones within the state, which represent areas of similar climate. The agency reports monthly average reference ET for each zone based on measurements from the network of 120 measurement stations deployed since 1982 (DWR 2009).

We obtain a GIS shapefile of the ET zone boundaries from DWR staff. We determine the ET zone for each zip code by overlaying the zip code centroids and the ET zone polygons using an intersect operation in ArcGIS. The resulting database table is exported to Microsoft Excel, and lookup functions are used to assign monthly ET values.

Monthly Precipitation

Next, we sought monthly precipitation datasets. We find that the highest spatial accuracy among readily available data layers is from the PRISM project (Oregon State University 2009). The PRISM researchers created a spatial distribution of point measurements of rainfall for the time period 1997 to 2004. The rainfall values are distributed using the PRISM model, developed by Christopher Daly, Director of the Spatial Climate Analysis Service, and documented in a series of reports and journal articles, e.g. Daly 2008. The resolution of the raster datasets is approximately 2 km, i.e. each pixel covers about 4 km^2, or slightly more than 1 square mile. We download monthly average precipitation data layers for January through December, and in order to analyze these layers in the map, we convert them from ASCII Grid to ESRI Grid format using the ASCII to Raster conversion tool in ArcToolbox.

The zip code centroids are assigned a set of attributes for monthly and annual precipitation in GIS. We use the free ArcGIS extension Hawth's Tools, and its Intersect Points tool. Figure shows the precipitation map for the month of February, with darker shades of blue indicating greater rainfall depth.

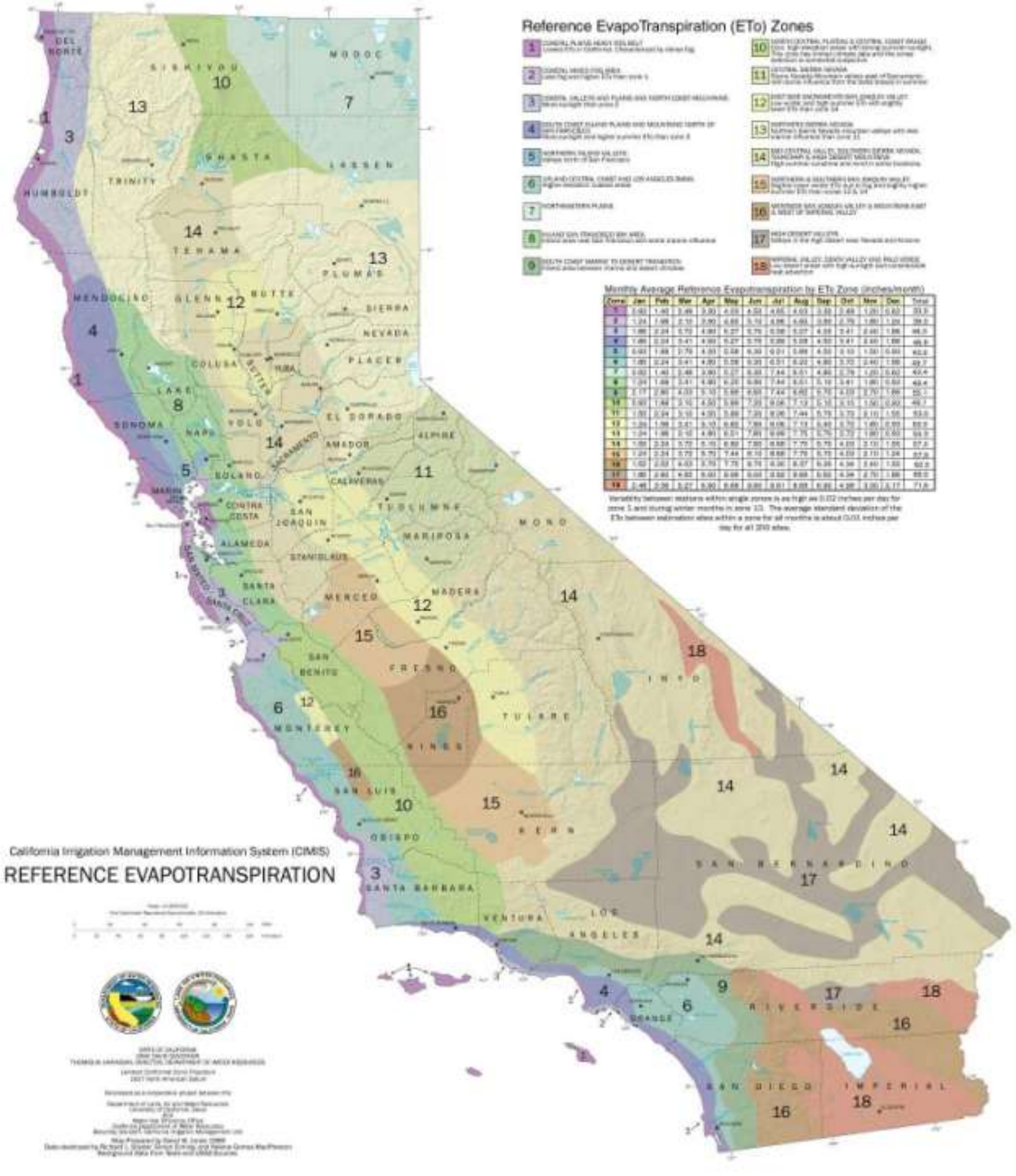

Figure 2 Reference evapotranspiration zones in California.

Source: http://www.cimis.water.ca.gov/cimis/images/etomap.jpg

Figure 3 Monthly precipitation depth for the conterminous 48 states from the PRISM process.

Crop Coefficients and Water Use

We now have an estimate for every zip code of irrigation water requirements in an average year for a reference crop. A reference crop is well-watered grass; specifically, reference ET (E_{rc}) is defined as “the rate of evapotranspiration from an extensive surface of 8 to 15 cm (3.1 to 5.9 in) tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water” (Handbook of Hydrology, page 27.29, quoting Doorenbos and Pruitt, 1977). To account for differences in water requirements among different crops, a crop coefficient, k_c, is used.

$$E_{crop} = k_c \cdot E_{rc}$$

By the definition above, the crop coefficient for well-watered grass is 1.0.

In choosing crop coefficients, we follow guidelines from EPA as well as the California Landscape Contractors Association (CLCA), reported in Table 6, below. CLCA developed water budget standards for the state of California as part of the development of the California Model Water Efficient Landscape Ordinance (CLCA 2008). The crop coefficients are derived from Costello and Jones (1994).

Table 6. Crop Coefficients for urban landscapes.

	Lawn	Shrubs/ Trees	Efficient Landscaping
EPA WaterSense	0.8	0.5	None reported
California Landscape Contractors Association	0.8	0.5–0.6	0.3

Irrigation Efficiency

Irrigation efficiency is the ratio of water beneficially used divided by the water applied. The efficiency of an irrigation system depends on the system characteristics and management practices. Well-designed and maintained systems will have a higher efficiency. For instance, if an irrigation system is optimized and performing at theoretical 100% efficiency, this means that all water makes its way to the plants root zone, and the exact amount of water required is applied. In reality, there are a number ofways that water is lost during irrigation, such as percolation, runoff, and wind. The Handbook of Hydrology (page 27.33) reports field application efficiencies range from 0.5 to 0.8. Typical efficiencies for different irrigation methods are shown in Table 7 (from Brouwer et al. 1989).

Table 7. Typical irrigation efficiencies for different irrigation methods.

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

We follow the California Model Water-Efficient Landscape Ordinance in selecting an Average Irrigation System Efficiency equal to 0.71. If a landscape requires 1” of water in a week, then the irrigation requirement is 1 inch/0.71 = 1.41 inches.

The theoretical efficiency for a given technology reported above assumes a professionally-operated irrigation system. At the household level, some irrigators may apply more or less than the optimal amount of water. To describe whether an individual is over- or under-watering, analysts have defined the *application ratio* as the actual water applied divided by the theoretical irrigation water requirement.

Recent evidence indicates that householders apply water in many different ratios, with approximately equal numbers of households under-watering and over-watering. There is also some evidence that the mean application ratio is about one, meaning that the average household applies the amount of water needed to fill the needs of a well-watered grass crop. (DeOreo et al. 2010). By omitting this factor from our analysis, we assume an application ratio of one.

Water Savings

Thus far, precipitation, evapotranspiration, and irrigation water requirement are expressed as depths in inches. Our method for calculating irrigation water savings is very similar to guidance recently developed by EPA’s WaterSense program for certifying landscape water use. We assume that the irrigation requirements can be lowered by replacing lawn with low-water-use plants. Water savings are calculated by replacing a portion of the original landscape with a lower crop coefficient, 0.3, based on California Landscape Contractors Association’s estimate (Table

6). This permits the irrigator to use a lower application ratio while still maintaining healthy plants.

We calculate the potential water savings as the difference between the average theoretical application depth for lawn, and the depth that would be applied to low-water-use plants. The potential irrigation water savings ($I_{savings}$) is the difference in irrigation depth:

$$I_{savings} = I_{grass} - I_{efficient}$$

$$\mathrm{I_{savings}} = 0.8\mathrm{E_{rc}} - 0.3\mathrm{E_{rc}}$$

$$\mathrm{I_{savings}} = 0.5\ \mathrm{E_{rc}}$$

We calculate the potential irrigation water savings in inches for converted landscape areas for each zip code.

To convert depths to a volume of water saved per year per square foot of lawn replaced, we converted as follows:

$$\begin{array}{c}\text{Annual Savings}\\ \text{per ft}^2\text{ lawn converted}\end{array} = \mathrm{I}_{savings}\left(\frac{in}{year}\right) \times \frac{1\ ft}{12\ in} \times 1\ ft^2 \times \frac{7.48\ gal}{ft^3} = 0.623\ I\ \frac{gal}{ft^2 \cdot year}$$

For example, in zip code 90012 (Los Angeles), the annual irrigation requirement is 36.5 inches, and the annual savings for replacing one square foot of lawn is 11.4 gallons. Replacing one acre of lawn (43,560 ft²) in Los Angeles with water-efficient landscaping would yield a savings of 500,000 gallons per year, or the equivalent or 1.5 acre feet per year.

Results

We estimate the amount of water that could be saved by converting one square foot of grass to low-water use vegetation ranges from 4.7 gal/ft²·yr in Crescent City to 30 gal/ft²·yr in the Imperial Valley (Table 6). A map showing the average annual savings is shown in Figure 4. The figure also shows water deficit plots for select locations in the state.

In the northern California city of Eureka, the total average annual precipitation exceeds the total annual PET. However, PET is highest during summer months when precipitation is at its lowest, creating a soil moisture deficit and a modest irrigation demand of 17 inches per year. Replacing one square foot of irrigated grass with low-water use plants saves 4.7 gallons per year. At the opposite extreme is the city of El Centro in the Colorado Desert in Southern California, also known as the Imperial Valley. The city receives scant rainfall, less than 3 inches on average, but has high PET year-round, ranging from 2” in January to over 9” in summer months. In total, the year-round irrigation demand is 69 inches, or 5.8 feet. A lawn replacement program in this location can save 30 gallons per square foot per year.

Landscape replacement programs will save the most water in areas with high landscape water demand. While the report only includes the results of landscape replacement programs in six counties, we have developed estimates of water demand and potential savings for every zip code in the state (Figure 4). To develop an average for each county in the state (Table 8), we have taken a weighted average based on the population of each zip code. This approach gives more influence to areas with greater numbers of residents.

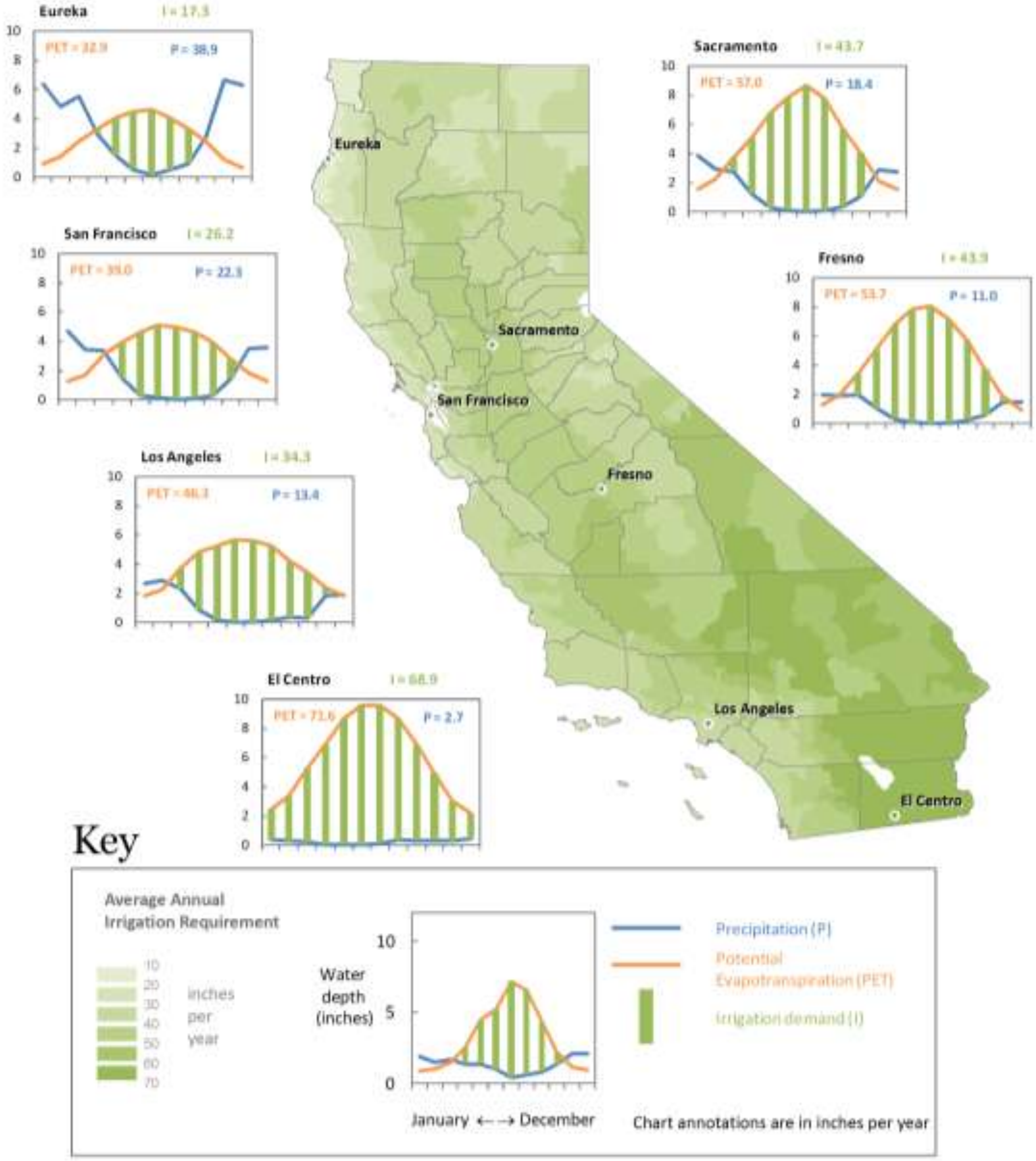

Figure 4 Average annual theoretical irrigation requirement for lawn by zip code for California

Table 8. Potential average annual water savings from converting lawn to water-efficient landscaping, by county.

County	Gallons per square foot	County	Gallons per square foot
Alameda	13.4	Orange	15.7
Alpine	14.8	Placer	17.7
Amador	16.7	Plumas	15.9
Butte	16.5	Riverside	19.5
Calaveras	15.7	Sacramento	19.0
Colusa	18.6	San Benito	16.4
Contra Costa	15.5	San Bernardino	19.4
Del Norte	7.2	San Diego	15.8
El Dorado	16.8	San Francisco	11.2
Fresno	19.9	San Joaquin	19.0
Glenn	18.9	San Luis Obispo	15.4
Humboldt	7.9	San Mateo	13.2
Imperial	30.2	Santa Barbara	14.7
Inyo	22.5	Santa Clara	16.4
Kern	22.5	Santa Cruz	11.0
Kings	23.4	Shasta	16.2
Lake	15.2	Sierra	15.0
Lassen	17.0	Siskiyou	15.2
Los Angeles	16.5	Solano	16.3
Madera	19.1	Sonoma	13.6
Marin	12.6	Stanislaus	19.5
Mariposa	16.0	Sutter	18.4
Mendocino	12.7	Tehama	18.2
Merced	20.1	Trinity	16.1
Modoc	14.2	Tulare	19.4
Mono	20.3	Tuolumne	15.5
Monterey	14.5	Ventura	16.3
Napa	15.1	Yolo	19.2
Nevada	15.7	Yuba	18.3

Discussion and Limitations

One shortcoming of our analysis is that it is based on a theoretical average year, rather than any actual year in the climatic record. Actual irrigation needs in a given year may be lower or higher due to changes in precipitation, temperature, cloud cover, or other climate variables. We recommend future work to repeat this analysis using actual monthly data from the climate record to back-cast actual irrigation demands for the past. This would give a better estimate of the variability of water demand, and how it responds to dry and wet years. Further, a more sophisticated analysis might look at how urban outdoor demand will respond to climate change in the future.

The input datasets are of limited spatial resolution and accuracy. As climate researchers and meteorologists produce more detailed datasets in the future, this analysis should be expanded and refined. Inaccuracy also comes from the limitations of our modeling technique. Our simplified monthly water balance model does not include the complexities of snowfall, runoff, deep percolation, or irrigation system management (e.g., distribution uniformity, pump efficiency). The advantages of this technique are its ease of use, and that it does not require calibration. A more sophisticated model could more explicitly account for soil moisture, perhaps relying on GIS soils datasets for input data.

Energy Savings

Many of the water conservation and efficiency devices reduce the amount of water that requires heating in homes and businesses, thereby providing substantial end use energy savings. Additionally, capturing, treating, and conveying water also requires energy, referred to as embedded energy. Thus, saving water produces embedded energy savings as well. We calculate the end use and embedded energy savings from the water conservation and efficiency measures identified in this analysis. Below, we describe our methodology for each calculation.

End-Use Energy Savings

Table 6 provides estimates of the end-use energy savings for each measure. For the residential measures that save hot water, electricity and natural gas savings were estimated using the following equations:

electricity savings (kWh per gallon per degree F) = ((1 kWh/3,412 BTUs) x (8.34 lbs per gallon) x 1 BTU/lb ºF))/(90% efficiency) = 0.002707 kWh per gallon per ºF

natural gas savings (therms per gallon per degree F) = ((1 therm/10^5 BTUs) x (8.34 lbs per gallon) x 1 BTU/lb ºF))/(55% efficiency) = 0.000152 therms per gallon per ºF

For showerheads, we assume that temperatures are raised from 60ºF to 105ºF. For faucets we assume temperatures are raised 60ºF to 80ºF. For clothes washers, we assume that 40% of the water savings are from hot water with temperatures that were raised from 60ºF to 130ºF. Energy savings for the measures from the commercial and industrial sectors were based on various reports, as indicated in Table 9.

Table 9. Device end-use energy savings.

Measure	Annual End-Use Energy Savings (per device)		Notes
	If Water Heated by Electricity[7]	If Water Heated by Natural Gas[8]	
	(kWh)	(therms)	
Residential toilet (1.28 gpf)	-	-	
Showerhead (1.5 gpm)	539	30	1
Residential front-loading clothes washer	774	37	2
Faucet aerator (1.5 gpm)	34	2	3
Pre-rinse spray valve (1.0 gpm)	7,600	330	4
Connectionless food steamer	4,419	334	5
Commercial dishwasher	13,950	608	6
Commercial front-loading clothes washer	2,880	138	2
Commercial urinal (0.5 gpf)	-	-	
Commercial toilet (1.28 gpf)	-	-	
Cooling tower pH controller	-	-	
Pressurized water broom	-	-	
Replace lawn with low-water-use plants	-	-	

Notes/Sources:

(1) Calculated. Assume raising temperature from 60ºF to 105ºF.

(2) Calculated. Assume 40% of water savings is hot water and that the temperature of this water is raised from 60ºF to 130 ºF.

(3) Calculated. Assume raising temperature from 60ºF to 80ºF.

(4) Energy savings based on estimates provided in CUWCC 2005.

(5) Energy savings based on estimates provided in EPA 2009a.

(6) EPA 2010

(7) We assume water heating uses 0.00271 kWh per gallon per ºF for an electric water heater with a 90% efficiency level.

(8) We assume heating requires 0.000152 therms per gallon per ºF for a natural gas heater with a 55% efficiency level.

Embedded Energy Savings

Energy requirements for capturing, treating, and conveying water are referred to as embedded energy. Water conservation and efficiency reduces the volume of water that must be pumped and treated, thereby providing significant embedded energy savings. In order to quantify these savings, we multiplied the volume of water conserved by the energy intensity of water. Energy intensity is defined as the total energy requirements for a given volume of water or wastewater and is often expressed in units of kWh per million gallons or, for natural gas, in units of therms per million gallons.

Table 10 provides energy intensity estimates for various segments of the water and wastewater cycle in Northern and Southern California. Energy intensity is higher for water in Southern California because much of this water is imported across long distances and over steep terrain. Note that the energy intensity of water used indoors is higher than that used outdoor because it is subject to wastewater treatment. For this analysis, we assume that water used indoors has an energy intensity of 5,400 kWh per million gallons in Northern California and 13,000 kWh per million gallons in Southern California. Water used outdoors has an energy intensity of 3,500 kWh per million gallons in Northern California and 11,100 kWh per million gallons in Southern California.

Table 10. Energy intensity estimates (in kilowatt-hours per million gallons) for Northern and Southern California.

	Indoor Uses (kWh/MG)		Outdoor Uses (kWh/MG)	
	Northern California	Southern California	Northern California	Southern California
Water Supply and Conveyance	2,117	9,727	2,117	9,727
Water Treatment	111	111	111	111
Water Distribution	1,272	1,272	1,272	1,272
Wastewater Treatment	1,911	1,911	-	-
Regional Total	5,411	13,022	3,500	11,111

Source: Navigant Consulting, Inc. 2006.

We use 2008 regional population estimates for Northern and Southern California to produce a population weighted statewide energy intensity estimate. Based on this calculation, we estimate that the average energy intensity of water used outdoors is 8,100 kWh per million gallons, while that used outdoors is 10,100 kWh per million gallons (Table 11). To determine the embedded energy savings, we multiply the indoor and outdoor water savings by the appropriate statewide energy intensity estimates (Table 12).

Table 11. Population weighted average energy intensity estimates (in kilowatt-hours per million gallons) for California.

	Population	Indoor Water (kWh/MG)	Outdoor Water (kWh/MG)
Northern California	14,334,052	5,411	3,500
Southern California	22,422,614	13,022	11,111
State	36,756,666	10,054	8,143

Source: Population estimates for July 1, 2008 from U.S. Census Bureau 2009.

Table 12. Embedded energy savings (in million kWh per year).

Measure	Indoor Water Savings (AF)	Outdoor Water Savings (AF)	Embedded Energy Savings (million kWh per year)
Residential Toilet (1.28 gpf)	93,500		306
Showerhead (1.5 gpm)	47,500		156
Residential front-loading clothes washer	13,300		43.6
Faucet aerator (1.5 gpm)	6,750		22.1
Pre-rinse spray valves	3,070		10.1
Connectionless food steamer	3,440		11.3
Commercial dishwasher	1,300		4.27
Commercial clothes washer	10,500		34.3
Commercial urinal (0.5 gpf)	51,800		170
Commercial toilet (1.28 gpf)	31,300		103
Cooling tower pH controllers	21,900		71.8
Pressurized water brooms		7,670	20.3
Replace lawn with low-water-use plants		28,400	75.4

Note: All numbers rounded to three significant figures.

Total Energy Savings

Table 13 summarizes the embedded and end-use energy savings. Based on US Census Bureau (2007), we assume that 44% of water heaters are electric and the remaining 56% are natural gas. We estimate that the water conservation and efficiency measures described in this analysis would save 2,300 million kWh and 86.8 million therms of natural gas each year (Table 10). This is equivalent to the annual electricity requirements of 309,000 average California households. Nearly 55% of these savings are a result of end use savings and the remaining 45% are a result of reductions in embedded energy.

Table 13. Embedded and end-use energy savings.

Measure	Embedded Energy Savings (million kWh per year)	End Use Energy Savings (million kWh per year)	End Use Energy Savings (million therms per year)
Residential Toilet (1.28 gpf)	306	-	-
Showerhead (1.5 gpm)	156	830	59.3
Residential front-loading clothes washer	43.6	145	8.86
Faucet aerator (1.5 gpm)	22.1	52.4	3.75
Pre-rinse spray valves	10.1	66.8	3.70
Connectionless food steamer	11.3	13.6	1.31
Commercial dishwasher	4.27	52.1	2.90
Commercial clothes washer	34.3	114	6.98
Commercial urinal (0.5 gpf)	170	-	-
Commercial toilet (1.28 gpf)	103	-	-
Cooling tower pH controllers	71.8	-	-
Pressurized water brooms	20.3	-	-
Replace lawn with low-water-use plants	75.4	-	-
Total Savings	**1,030**	**1,270**	**86.8**

Note: All numbers rounded to three significant figures. We assume 44% of water heaters are electric and the remaining 56% are natural gas based on U.S. Census Bureau 2007.

Cost Effectiveness Analysis

Economists use cost-effectiveness analysis to compare the unit cost of alternatives, for example, in dollars spent to obtain an additional acre-foot of water supply. Because each water conservation measure is an alternative to new or expanded water supply, conservation measures are considered cost-effective when their unit cost – called the cost of conserved water – is less than the unit cost of the lowest-cost option for new or expanded water supply.

Our cost-effectiveness analysis is done from a combined utility and customer perspective. We calculate the cost of conserved water based on the total investment required and any changes in operation and maintenance costs resulting from the investment.[1] We adopted this approach because it captures both the costs and benefits to the water supplier, which are eventually passed on to customers, as well as costs and benefits customers experience aside from what they pay for water service. This approach thus takes a broader view of the potential costs and benefits of water conservation and efficiency improvements than the agency perspective alone.

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[1] Savings on water bills are not included as the volume of water conserved is the denominator for the cost of conserved water calculation.

The cost parameters that affect our estimates of the cost of conserved water are the cost of the device, nominal and real interest rates, useful lifetime, changes in operation and maintenance (O&M) costs, and the average annual quantity of water conserved. For water conservation devices that reduce indoor water use, changes in O&M costs are related to reductions in water-related heating requirements and reductions in wastewater flows.[2] Ultimately, these reductions save the customer money through lower wastewater and energy bills. Changes in energy and wastewater costs are shown in Table 14. Note that energy savings are shown for customers with a gas or an electric water heater. To determine the average energy savings, we calculate a weighted average based upon the fraction of the population with gas or electric water heater.

Table 14. Changes in customer energy and wastewater costs per device.

Efficiency Measure	Changes in O&M Costs (per device)			Device Lifetime (years)
	Wastewater ($/yr)	Energy		
		If Water Heated by Electricity ($/yr)	If Water Heated by Natural Gas ($/year)	
Residential Toilet (1.28 gpf)	$0.66	-	-	25
Showerhead (1.5 gpm)	$0.76	$14.27	$6.43	8
Residential front-loading clothes washer	$6.44	$74.92	$28.93	16
Faucet aerator (1.5 gpm)	$0.62	$5.17	$2.33	5
Pre-rinse spray valves	$39.60	$998.26	$370.92	5
Connectionless food steamer	$158.40	$621.31	$375.22	12
Commercial dishwasher	$49.50	$1,961.37	$683.39	
Commercial clothes washer	$15.70	$48.09	$16.86	11
Commercial urinal (0.5 gpf)	$2.32	0	0	25
Commercial toilet (1.28 gpf)	$13.48	0	0	25
Cooling tower pH controllers	$1,284.60	0	0	5
Pressurized water brooms	0	0	0	5
Replace lawn with low-water-use plants	0	0	0	15

Note: For residential customers, we assume a price of $1.22 per therm for natural gas (EIA 2010a) and $0.15 per kWh for electricity (EIA 2010b). For commercial customers, we assume a price of $1.12 per therm for natural gas (EIA 2010a) and $0.14 per kWh for electricity (EIA 2010b). We assume an average wastewater rate in California of $0.99 per thousand gallons (Fisher et al. 2008).

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[2] See Chapter 5 of Gleick et al. 2003 for a detailed discussion of the economics of water conservation and efficiency improvements.

For most devices, we assume that the customer was in the market for a new device, and thus the cost is the cost difference between a new standard and new efficient device. For some devices, including faucet aerators, cooling tower pH controllers, water brooms, replacing lawn with low-water-use plants, and all of the agricultural measures, however, we assume that the customer would not have made the investment otherwise, and thus the cost is the full cost of the device. We conducted a literature review to estimate the device lifetime and cost. We also include the administrative cost for running a rebate program, which typically varies from about 10% to 30% of the rebate cost, depending on the measure under consideration (Table 15).

Table 15. Cost data for selected urban water conservation and efficiency measures

Conservation Measure	Device Cost ($/device)		Incremental Cost	Incremental Plus Administrative Cost
	Efficient	Standard		
Residential toilet (1.28 gpf)	$ 200	$ 150	$ 50	$ 63
Showerhead (1.5 gpm)	$ 40	$ 20	$ 20	$ 25
Residential front-loading clothes washer	$ 750	$ 492	$ 258	$ 323
Faucet aerator (1.5 gpm)	$ 8	$ -	$ 8	$ 10
Restaurant pre-rinse spray valve (1.0 gpm)	$ 70	$ 50	$ 20	$ 25
Connectionless food steamer	$ 6,000	$2,500 (elec.); $3,800 (natural gas)	$ 3,228	$ 4,035
Commercial dishwasher	$ 9,000	$ 6,950	$ 2,050	$ 2,563
Commercial front-loading clothes washer	$ 750	$ 492	$ 258	$ 323
Commercial urinal (0.5 gpf)	$ 550	$ 540	$ 10	$ 13
Commercial toilet (1.28 gpf)	$ 200	$ 150	$ 50	$ 63
Cooling tower pH controller	$ 2,250	$ -	$ 2,250	$ 2,813
Pressurized water broom	$ 250	$ -	$ 250	$ 313
Replace 1 acre of lawn with low-water-use plants	$ 43,560	$ -	$ 43,560	$ 54,450

Note: Costs shown for showerheads and faucet aerators are based upon replacing all devices within a single home. We assume that there are two devices per household.

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