Urban Water Demand in California to 2100: Incorporating Climate Change

Juliet Christian-Smith, Matthew Heberger, and Lucy Allen

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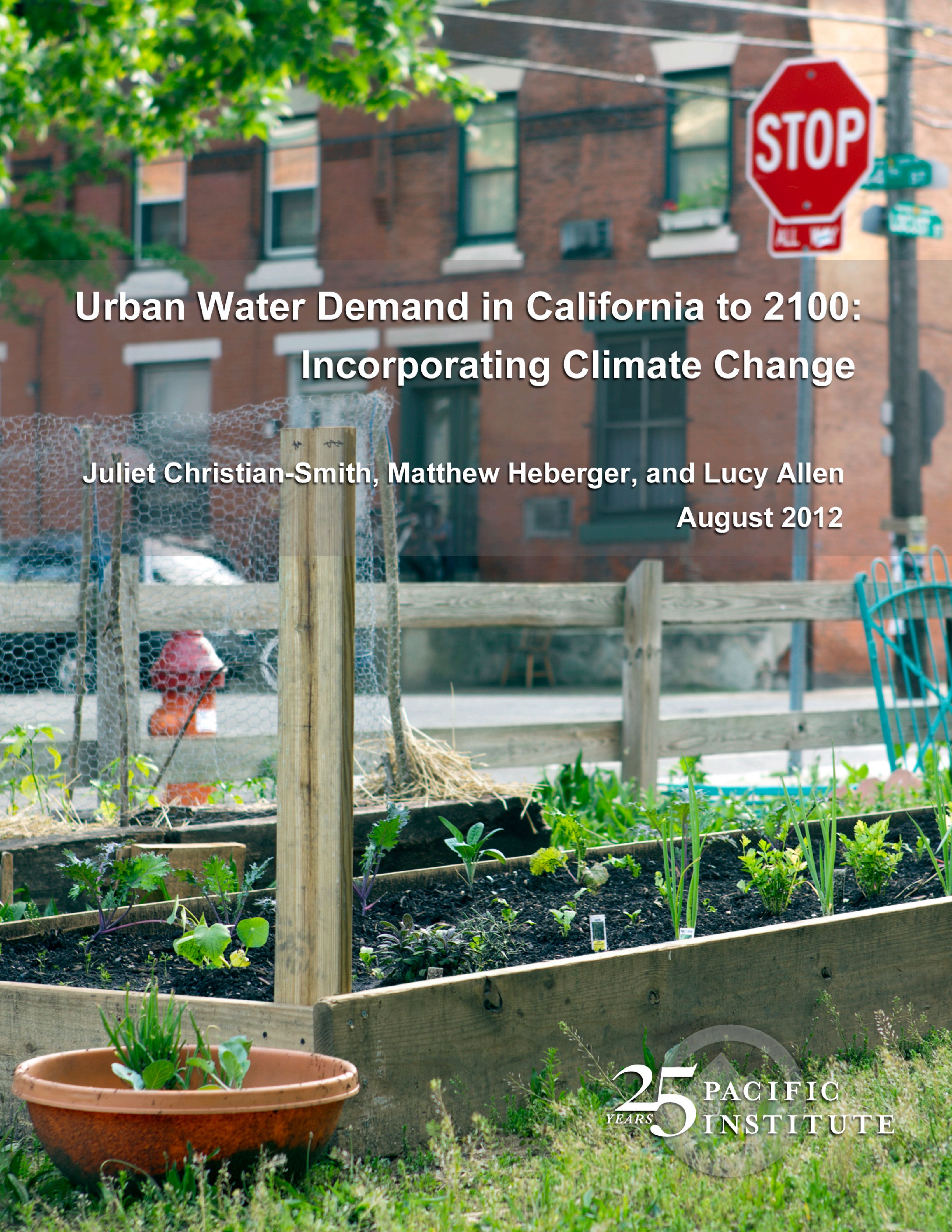

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List of Acronyms and Abbreviations

A2	a medium-high greenhouse-gas emissions scenario developed by the IPCC
AB	Assembly Bill (to designate state laws such as AB 1881 of 2010)
B1	a low greenhouse-gas emissions scenario developed by the IPCC
CCSM	Community Climate System Model, a global climate model maintained by the US National Center for Atmospheric Research (NCAR)
CII	Commercial, industrial, and institutional
CNRM-CM3	Global climate model maintained by France's Center for National Weather Research
CUWCC	California Urban Water Conservation Council
DOF	California Department of Finance
DWR	California Department of Water Resources
e	irrigation efficiency
eGRID	Emissions and Generation Resource Integrated Database
EPA	US Environmental Protection Agency
ET	evapotranspiration
ET_0	reference crop evapotranspiration
ged	gallons per employee per day
GFDL CM2	Global climate model maintained by the Geophysical Fluid Dynamics Laboratory at the US National Oceanic and Atmospheric Administration (NOAA)
GIS	Geographic Information System
gpcd	gallons per capita per day
gpd	gallons per day
gphd	gallons per household per day
H.R.	House of Representatives (used to designate a bill or law, e.g. H.R. 776 of 1992)

I	reference crop irrigation demand
ICLUS	Integrated Climate and Land Use Scenarios project
IPCC	Intergovernmental Panel on Climate Change
k_c	crop coefficient
kWh	kilowatt-hour
maf	million acre-feet
MG	million gallons
MWELO	Model Water Efficient Landscape Ordinance
NAICS	North American Industry Classification System
NCAR PCM	The Parallel Climate Model, maintained by the US National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
P	precipitation
p	plant factor
PET	potential evapotranspiration
PPIC	Public Policy Institute of California
SB	Senate Bill (to designate state laws such as SB 221 of 2007)
SCVWD	Santa Clara Valley Water District
SIC	Standard Industrial Classification
SIO	Scripps Institution of Oceanography
SRES	Special Report on Emissions Scenarios
SWRCB	California State Water Resources Control Board
UCSD	University of California at San Diego
USBR	United States Bureau of Reclamation
WBIC	Weather-based irrigation controller

Urban Water Demand in California to 2100: Incorporating Climate Change

Introduction

Global climate change poses risks to California's water resources, though most recent research has focused on supply-side changes including reduced snowpack, earlier snowmelt, and more extreme floods and droughts. Yet along with these shifts in the quantity, timing, and reliability of freshwater supplies, climate change will also have important impacts on water demand. Fifteen years ago, an American Water Works Association committee on climate change found that climate change "could also alter water demand, supply, and quality" (AWWA 1997). In 2007, the Association of Metropolitan Water Agencies commissioned a study on the impacts of climate change on water agency operations. The authors concluded that the impacts are likely to be significant, and will increase the cost of operations for most utilities. When it comes to climate impacts in the next 20-50 years, "utility planners will have to grapple with many of them prospectively rather than as phenomena that are already observable" (Cromwell et al. 2007).

In particular, increased temperatures and altered precipitation patterns will affect plant evaporation and transpiration (ET) rates and thus total outdoor water use. At the same time, a variety of other factors will continue to influence water demand, including population growth; development patterns (where the population grows); changes to the state's employment patterns (manufacturing jobs being replaced by service jobs); and ongoing water conservation and efficiency programs (for example, the Model Landscape Ordinance and The Water Conservation Act of 2009, which mandates a 20% reduction in per capita water use by 2020).

Responses to changing climate and development patterns can have a significant impact on how much water we use in the future (DWR et al. 2010). For this study, the Pacific Institute has developed a computer model to integrate many of these factors into a simulation of California's future urban water use to the year 2100. Urban water use refers to water used in cities and suburbs, and in homes in rural areas. It is a large category that represents most water use other than agriculture and mining. It includes residential, commercial, industrial, and institutional uses.

We conduct several sensitivity analyses to analyze how future urban water demand is likely to respond to changes in climate, population, and conservation efforts. Our urban water use simulation model can be used as a tool for California water managers to compare different possible futures by altering the greenhouse gas emissions scenario (A2 or B1 emissions scenarios); population projections; the level of implementation of various conservation and efficiency measures; and other factors.

The California Water Plan process increasingly explores scenarios of alternative water futures as a way to better understand the scope of water problems and the ability of various water response packages to address those problems. The most recent Water Plan (DWR 2009) explicitly addressed three possible future scenarios (described in more detail below), but recommended that additional efforts be made to expand both the scope and detail of the scenarios. In recent years, the Pacific Institute has developed several independent assessments of the potential for water conservation and efficiency improvements to reduce statewide water demand. In particular, the Institute has developed estimates of urban efficiency potential (Gleick et al. 2003), which have been incorporated into the most recent California Water Plans (DWR 2005; DWR 2009).Here, we expand on that work with a simulation model that utilizes much of the data gathered in previous reports to model current and potential future urban water demand.

These scenario approaches are not "predictions" – rather they are tools that can be widely used to test hypotheses, data, and assumptions on urban demand and potential response strategies. In addition, new modules related to climate change and its impacts on water demand, an area of growing interest, are incorporated. The tool will make it easier for state agencies, water utilities, and others to explore scenarios of future water use, identify possible efficiency options, and capture water conservation and efficiency opportunities.

Overview of Water Use in California

In 2005, California used about 40.2 million acre-feet of water, according to estimates published by the state (DWR 2011). Of this, roughly 78% (31.2 million acre-feet) was used by the agricultural sector, while the remaining 22% (9 million acre-feet) was used by urban users. Urban water use includes indoor and outdoor residential water use and water used in the production of goods and services (often referred to as commercial, institutional, and industrial use).

There is no definitive source that accurately reports water use in California. We have relied on estimates and modeling studies performed by various state and federal agencies. The US Geological Survey estimates freshwater use in the United States every five years. According to their latest report (Kenny et al. 2009), in 2005, California withdrew 7,550 million gallons per day of freshwater for public supply, industrial, and domestic use. This is equivalent to 8.5 million acre feet (maf), or 212 gallons per capita per day (gpcd), based on an estimated 2005 population of 35.66 million (Schwarm 2012).

In Table 1, we show historical estimates of urban water use published by DWR for the years from 1972 to 2005. We calculated the average per-person water use in acre-feet per year by dividing overall water use by population. Urban water use appears to have grown along with the state's population (Figure 1). Water use declined during the drought in the 1990s, but appears to have rebounded. Aside from the drought years, per-person urban water use does not appear to have changed significantly over time (Figure 2). From 2000 to 2005, per capita water use averaged 0.257 acre-feet per year, or 229 gpcd. Note that this is somewhat higher than average per capita water use in 1972, which averaged 0.245 acre-feet per year (219 gpcd). There is insufficient evidence to state that there has been a statistically significant increase; the data appear to show that statewide average per capita urban water use has changed little over the period from 1972 to 2005.

Table 1. Historic estimates of urban water use in California

Year	Urban Water Use (maf/year)	Population (millions)	Water Factor (AF/person·yr)
1972	5.04	20.6	0.245
1975	5.07	21.8	0.233
1980	5.76	23.8	0.242
1985	6.59	26.1	0.252
1989	7.36	29.1	0.253
1990	7.24	30.0	0.241
1991	6.45	30.6	0.211
1992	5.79	31.3	0.185
1993	6.88	31.7	0.217
1994	7.57	32.1	0.236
1995	7.27	32.1	0.227
1998	7.84	32.7	0.240
2000	8.86	34.0	0.261
2001	8.62	34.5	0.250
2002	9.00	34.9	0.260
2003	9.00	35.4	0.254
2004	10.08	35.8	0.266
2005	9.05	36.0	0.251

Source: Urban Water Use estimates from DWR spreadsheet *Statewide Water Balance (1998-2005)* (DWR 2011). Population estimates from California Department of Finance spreadsheet *E-7. California Population Estimates* (DOF 2011).
Note: Water factors calculated by the authors.

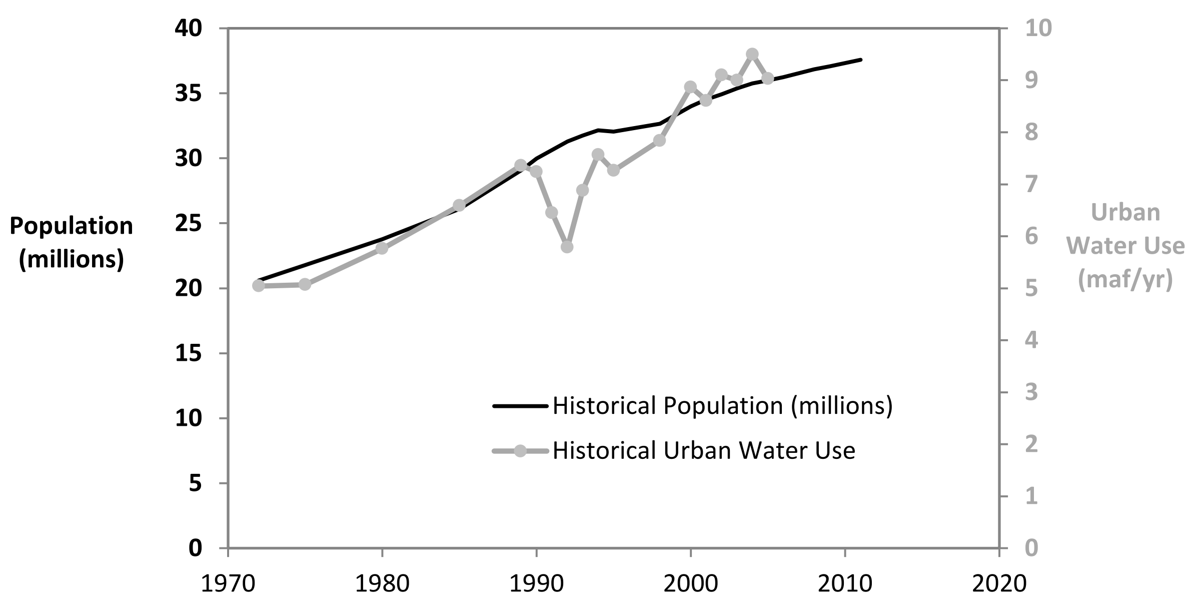


Figure 1. Historical population and urban water use in California from 1972 to 2005

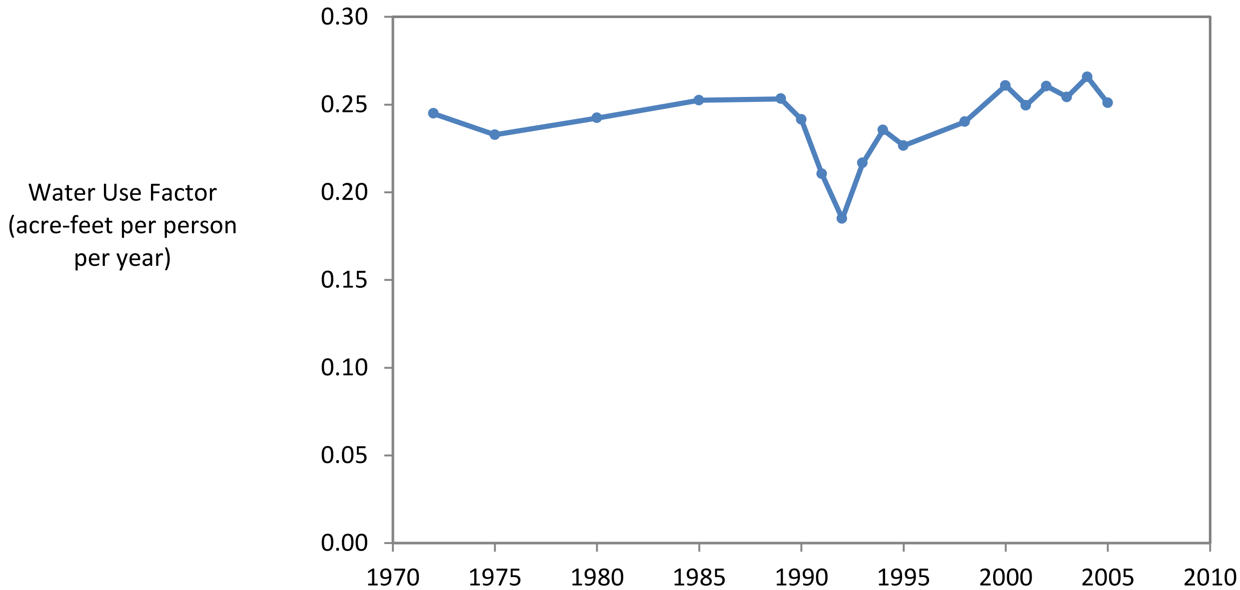


Figure 2. Historical water factors (urban water use per person in acre-feet per year) for California from 1972 to 2005

In 2010, the Governor's 20x2020 Task Force estimated urban water use at 192 gpcd (DWR et al. 2010), a figure lower than both DWR and the USGS. However, this number varies greatly by hydrologic region due to different climates, urban development patterns, commercial and industrial sectors, and other factors (Table 2). A lack of comprehensive and accurate data describing baseline water use hampers our ability to confidently project future water use; if we don't know exactly where we are today, how can we forecast where we might go in the future?

Table 2. Estimated urban water use in 2005 in gallons per capita per day (gpcd) by Hydrologic Region.

	Hydrologic Regions									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8***	**9**	**10**
Residential	115	103	109	126	174	159	180		176	255
Commercial and Institutional	18	19	17	23	25	27	23		19	38
Industrial	8	17	8	9	21	32	43		11	3
Un-Reported Water (leaks)	24	18	20	22	33	30	39		31	50
Total	165	157	154	180	253	248	285	243	237	346

Source: DWR et al. 2010, Figure ES-1
Note: * Region 8 does not have enough usable data in the Public Water Systems Survey (PWSS) database to compute for baseline values by sector.

Water managers typically group water users into classes; the two largest classes are residential and commercial, institutional, and industrial (CII). These user-classes can be further divided into subsectors. Residential users are typically divided into single-family and multi-family homes, and the CII sector can be divided into categories such as schools, factories, hotels, restaurants, and food processors, among others.

While California's urban water use has grown steadily with population, some areas of the state have succeeded in lowering per capita water use. For example, in 2011, urban water use in Los Angeles was 123 gpcd, among the lowest in the state (LA DWP 2012). Several factors have contributed to lower water use:

- **National building codes, plumbing codes, and appliance standards**. Plumbing appliance efficiency regulations, particularly The Energy Policy Act of 1992 (H.R. 776) contained several water conservation measures, requiring, among other things, that the maximum water use of new toilets sold in the U.S. be 1.6 gallons per flush, and the maximum flow rate of shower heads be 2.5 gallons per minute.
- **Statewide regulations mandating conserving practices.** Notable examples include a 2004 law requiring water suppliers to install water meters on all customer connections by 2025 (AB 2572); the imposition of water budgets and water-efficient landscaping on most new large landscapes (Model Landscape Ordinance AB 1881, 2010); and the requirement that water suppliers and local governments improve the coordination between land and water use planning through preparation of Urban Water Management Plans and Urban Water Shortage Contingency Analyses (SB 221 and SB 610, 2001).
- **Local efforts at improving water conservation and efficiency**. Many water utilities implement a set of conservation and efficiency programs, termed best management practices, outlined in the of California Urban Water Conservation Council's Memorandum of Understanding (CUWCC 2011).

It is likely that per capita use declined during the drought of 2007-2009, as it has in previous California droughts. The extent of the decrease is unknown, as there is a lag of up to five years before DWR publishes state water use estimates. Further, it is unclear whether water use will rebound to pre-drought levels, or whether some of the reduction will continue into the future.

Residential Water Use

Residences account for about two-thirds of urban water use; in 2005, residential use accounted for an estimated 66% of total urban water use in California (DWR 2011). A recent study of water use in California single-family residences provides detailed data on how water is used in California homes (DeOreo et al. 2011). The analysts used flow trace data,[1] as well as billing, survey and weather data, and aerial photo information, to study water use at 700 single family homes across ten water agencies in California. The flow trace data make it possible to collect data on how much water is used by various end-uses within the home. This study found that more than half (53%) of residential water use was for outdoor uses.

[1] Flow trace data was collected using portable data loggers attached to the water meters of each of the study homes. The loggers collected water flow readings at ten second intervals. The flow trace data provides information about how many gallons per day the home used, and can also be used to determine end uses such as toilet flushing, clothes washing, dishwashers, showers, irrigation, faucets and leaks. The DeOreo et al. (2011) report summarizes the results of the study, which began in 2005 and was completed in 2010.

Inside their homes, Californians used an average of 175 ± 8 gallons per household per day (DeOreo et al. 2011). The largest indoor uses were toilets and showers (each accounted for 20% of indoor use), followed by faucets (19%) and clothes washers (18%), as shown in Figure 3 (adapted from DeOreo et al. 2011, 132).

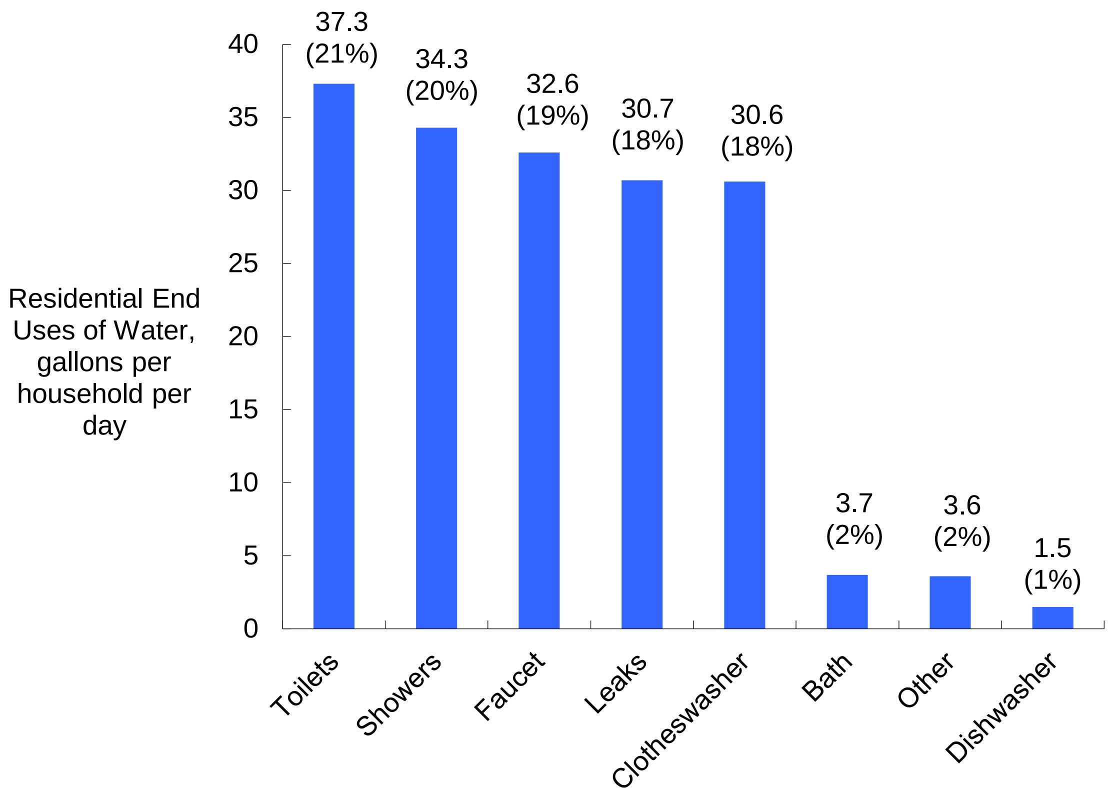


Figure 3. Residential end uses of water (values are gallons per household per day, followed by percent of total)
Source: DeOreo et al. 2011, 132

Commercial, Institutional, and Industrial Water Use

Definitions of CII water use vary widely, but we adopt the following as in the report *Waste Not, Want Not* (Gleick et al. 2003, 78-79):

> Commercial: Private facilities providing or distributing a product or service, such as hotels, restaurants, or office buildings. This description excludes multi-family residences and agricultural uses.
>
> Institutional: Public facilities dedicated to public service including schools, courthouses, government buildings, and hospitals.
>
> Industrial: Facilities that mostly manufacture or process materials as defined by the Standard Industrial Classification (SIC) code numbers 2000 through 3999.

The CII sector accounted for about 25% of total California urban water use in 2005,[2] based on estimates by the Department of Water Resources. Yet, data on water use by industry in California are extremely limited and are not reported in California Water Plans. Gleick et al. (2003) provides the most recent reliable estimate of water use by industry statewide, which found that commercial and institutional water uses account for approximately 72% of CII water use and that offices, schools, and golf courses are among the most water intensive in that category (Table 3).

Table 3. Commercial and industrial water uses

Commercial Water Use (AF/year)		Industrial Water Use (AF/Year)	
Schools	251,000	Dairy Processing	17,000
Hotels	30,000	Meat Processing	15,000
Restaurants	163,000	Fruit and Vegetable Processing	70,000
Retail	153,000	Beverage Processing	57,000
Offices	339,000	Refining	84,000
Hospitals	37,000	High Tech	75,000
Golf Courses	229,000	Paper	22,000
Laundries	30,000	Textiles	29,000
		Fabricated Metals	20,000
Unexamined Commercial	621,000	Unexamined Industrial	276,000
Total Commercial	**1,852,000**	**Total Industrial**	**665,000**

Source: Gleick et al. (2003), Table 4-1

Projecting Future Water Demand

Demand forecasts are often used by local and state governments to inform policies and decision making. For example, in California, the Department of Water Resources has published forecasts of future water demand every five years in the California Water Plan, also known as Bulletin 160. In the past, these projections were based on the assumption that the past is an accurate predictor of the future. "Historical records were generally used to establish trends, such as population growth, that were assumed to continue into the future" (DWR 2009, 5–6). As shown in Figure 4, the state has routinely projected larger increases in water use than have actually occurred (Gleick, Cooley, and Groves 2005).

[2] This estimate includes the "large landscape" category, defined by the Department of Water Resources as, "the: "The water used to irrigate recreational and large landscape areas such as golf courses, parks, play fields, highway medians, and cemeteries." (DWR 2009).

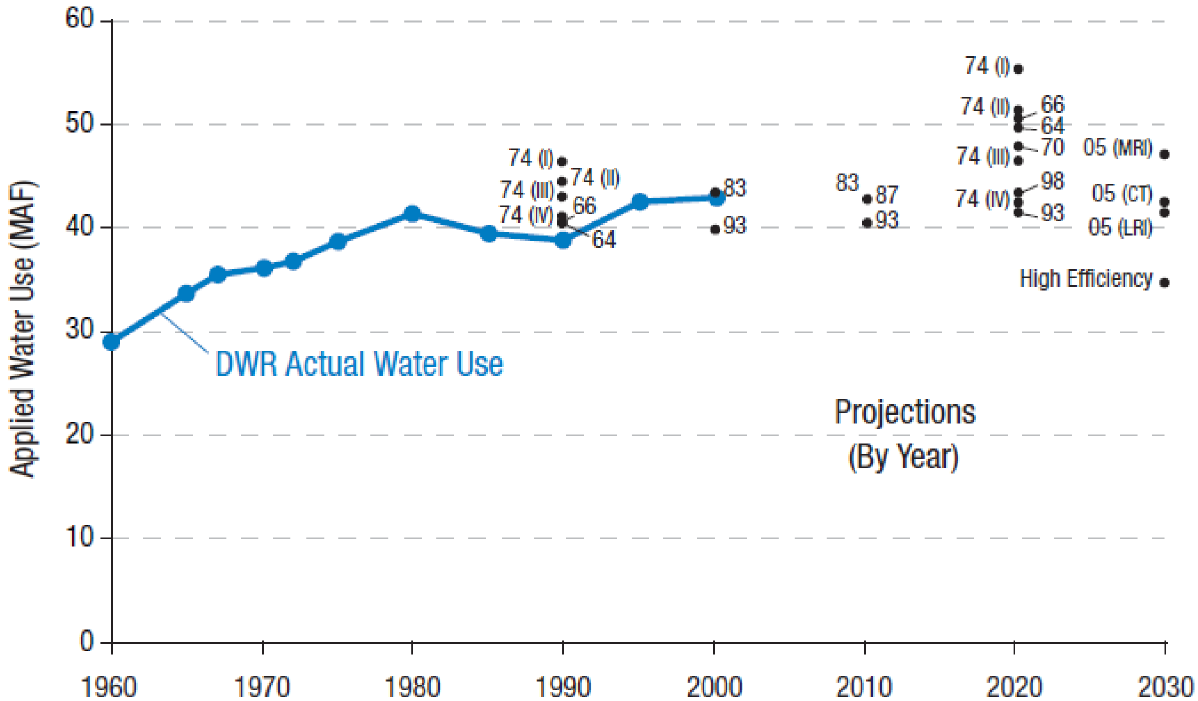


Figure 4. Projections of total water demands in California
Source: Gleick et al. (2005), Figure ES-2
Note: Each Water Plan Update makes one or more projections of future demand. The number next to each projection refers to the year in which the projection was made. The 1974 Water Plan Update evaluated four scenarios for future demand, represented by Roman numerals I-IV. The 2005 Water Plan Update evaluates three scenarios of future demand: Current Trends (CT); More Resource Intensive (MRI); and Less Resource Intensive (LRI).

In order to project how much water urban users might require in the future, the simplest and most traditional means of forecasting future water demand has been to estimate current per capita water consumption, and multiply this by the expected future population (McMahon 1993). This approach, which is often used by regional planners, has several obvious shortcomings. Yet, in California, historical data show a strong correlation between urban water use and population for the past three decades. Figure 5 plots urban water use from 1972 to 2005, using data compiled by DWR staff various editions of the *California Water Plan Update* (DWR 2011). Population data comes from the U.S. Census Bureau, which estimates population every 10 years, and the California Department of Finance, which provides estimates for the years in between.

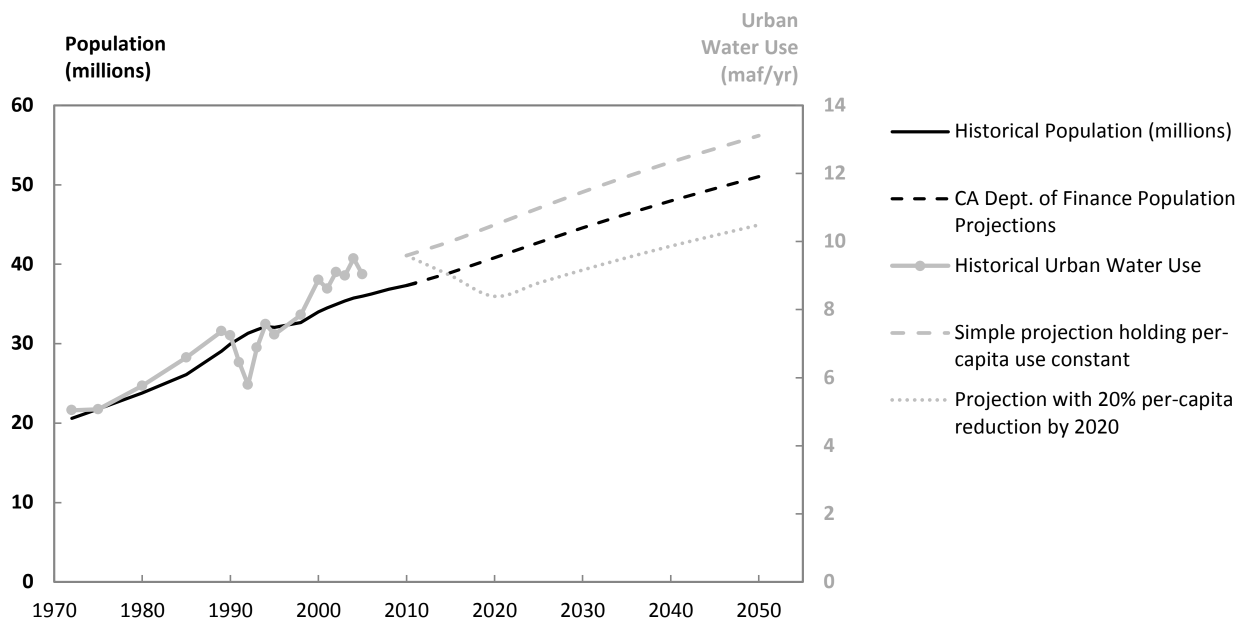


Figure 5. California's population and urban water use from 1972 to present (solid lines), with simple linear forecasts. The dashed line assumes current patterns of water use hold steady, and the dotted line shows the effect of a 20% reduction by 2020 with no further improvements thereafter

We can use this relationship to make simple, first-order estimates of future water use. Population growth appears to follow a simple linear trend for the past 40 years, which we extrapolate into the future. Per capita water use in 2005 was 225 gallons per capita per day (gpcd). Projecting both time series into the future, in 2050 we have 60 million people consuming 15.5 million acre-feet of water. If the state is able to achieve the goal of a 20% per capita reduction in water use by the year 2020 (in accordance with The Water Conservation Act of 2009), water use will decline in the short term, because per capita water use is declining faster than population is growing. After 2020, if per capita water use remains at a reduced level, population growth still leads to an increase in urban water use over the next three decades; however, that the rate of increase, represented by the slope of the dotted grey line, is not as great as in the business-as-usual scenario, represented by the dashed grey line. One might consider all other methods for forecasting demand to be enhancements of this simple method. In the following sections, we describe how our model represents an advance over this simplistic method of forecasting future demand by taking into consideration dynamic factors, such as climatic changes, technological changes, and behavioral changes.

Scenario-Based Planning

These traditional approaches have some serious limitations in their fundamental assumptions about future per capita water use. For example, they typically assume no changes in the performance or penetration of water-efficient technologies. They do not account for potential behavioral changes or for preferences in culture and preferences over time. After criticisms that the California Water Plan efforts were inappropriately ignoring the potential for efficiency and focusing on single projections of the future (see Gleick 1995), more recent California Water Plans have introduced a long-term analytic effort to develop multiple and more sophisticated scenarios of water supply and demand.

Scenario-based planning is premised on the idea that while we cannot predict the future, we can gain insight by comparing different potential future scenarios:

> "Analysts and decision makers often construct scenarios to better understand the consequences of choices or policies on a wide range of plausible future conditions. This is particularly useful when there are great uncertainties about how the future may evolve, or when the stakes are especially high. Sometimes scenarios explore outcomes that are unlikely or incongruent with current decisions and policies. Sometimes these scenarios are purely descriptive and are designed to study outcomes that had not previously been considered. Sometimes the scenarios are quantitative and represent discrete outcomes drawn from a range of possible futures" (Gleick et al. 2003).

Scenario-based planning allows the user to compare the outcome of alternative plans and policies. For instance, the most recent California Water Plan (DWR 2009) compared three scenarios – one based on "current trends," one modeled "slow and strategic growth," and one modeled "expansive growth." Future water demands for each scenario varied greatly, declining by 2.5 maf in the slow and strategic growth scenario, and increasing by 6maf in the expansive growth scenario, as each was influenced by different assumptions about future population growth and background water conservation water savings. The Water Plan analysts used a simple model of conservation, assuming per capita reductions of 5%, 10%, and 15% by 2050 for the Expansive Growth, Current Trends, and Slow and Strategic Growth scenarios, respectively (DWR 2009, 5–32).

Incorporating Climate Change

In addition, for the first time, the California Water Plan 2009 incorporated uncertainty associated with climate change, shown below in Figure 6. The change in water demand shown by the solid bar assumes a repeat of historical hydrology while the hatched bars show the increases in water demand when considering 12 different climate change scenarios (DWR 2009, Figure 5–6). The importance of including climate change is clear based on these results:

> "When climate change is factored in, *all scenarios show higher annual water demands than under a repeat of historical climate*. For example, with climate change the range of annual water demand for the Expansive Growth scenario was from about 6.5 million to above 9 million acre-feet per year, between 0.5 and 3 million acre-feet higher than when considering a repeat of historical climate. This reflects changes in water demand for future climate scenarios that are either warmer or drier or both warmer and drier." (Italics added.)

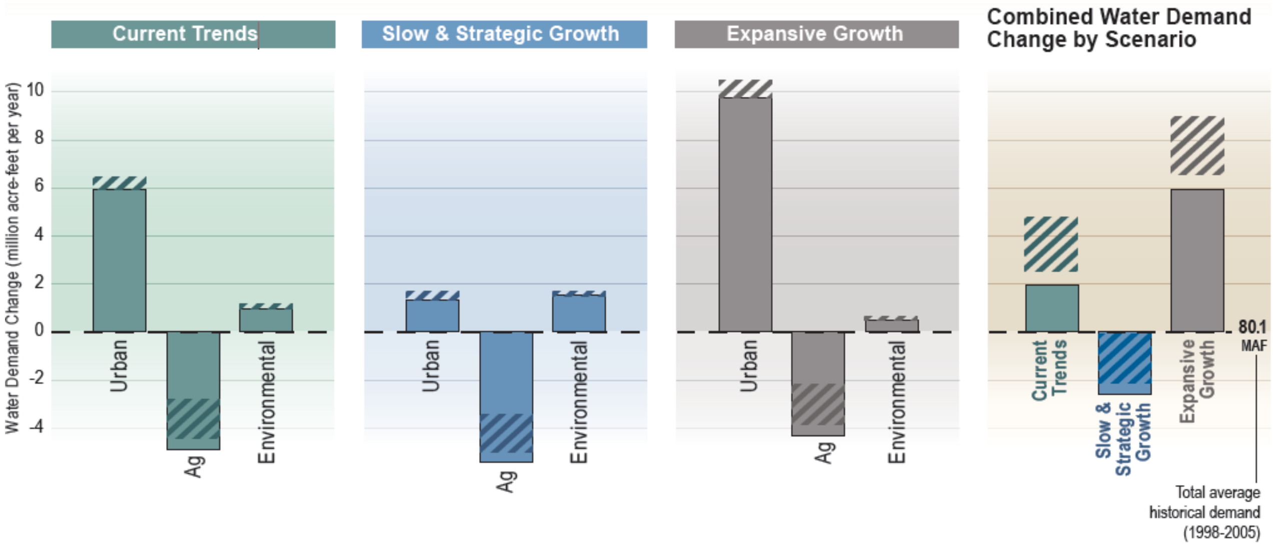


Figure 6. Change in future statewide water demand by scenario in Bulletin 160-09
Source: DWR (2009), pg 5-32.
Note: The change in water demand shown is the difference between the average demands for 2043–2050 (projected future) and 1998–2005 (historical).

The Department of Water Resources is currently developing the California Water Plan 2013, which will also develop multiple scenarios and incorporate uncertainty associated with climate change. Yet, the models used in the Water Plan are typically not public and therefore cannot be modified by users. The model that the Pacific Institute has developed complements the Water Plan efforts in that it is available free of charge on the Institute's website and is intended to allow regions and localities to be able to run their own scenarios at various smaller scales – from water supplier service areas to counties to hydrologic regions. In addition, the model generates projections out to 2100, rather than ending in 2050, allowing for a longer-term planning horizon. Finally, the model is excel-spreadsheet based and offers a user-friendly user interface.

Analytical Approach

The model developed here is a scenario-based water demand simulation tool, intended to be used by regional planning agencies and individual water utilities who can utilize this tool to evaluate and report on climate change impacts on water demand in their service areas. Using Microsoft Excel spreadsheets as the platform, the model simulates future urban water demand in California to the year 2100. The model is useful for constructing scenarios based on a series of user-defined inputs on urban water demand. It is important to emphasize that the model does not make predictions but simulates future water demand based on user-defined scenarios.

The model allows the user to choose among various inputs, including:

- four global climate models: CCSM, NCAR PCM.1, GFDL CM2 1.1., CNRM, or an average of all four;
- three climate scenarios: static climate (based on 1960-1990); SRES B1 (low greenhouse gas emissions); and SRES A2 (medium-high greenhouse gas emissions, see Figure 7);
- two potential evapotranspiration estimation methods: Hamon and Hargreaves;

- eight population projections: California Department of Finance, EPA ICLUS A1, EPA ICLUS B1, EPA ICLUS A2, EPA ICLUS B2, PPIC High, PPIC Middle, PPIC Low; and user defined,
- the choice of running the model once with fixed parameters entered by the user (deterministic mode); or
- the ability to run the model many times in "Monte Carlo" mode, where each parameter will be resampled and will be reported within 90% confidence intervals, capturing some of the uncertainty.

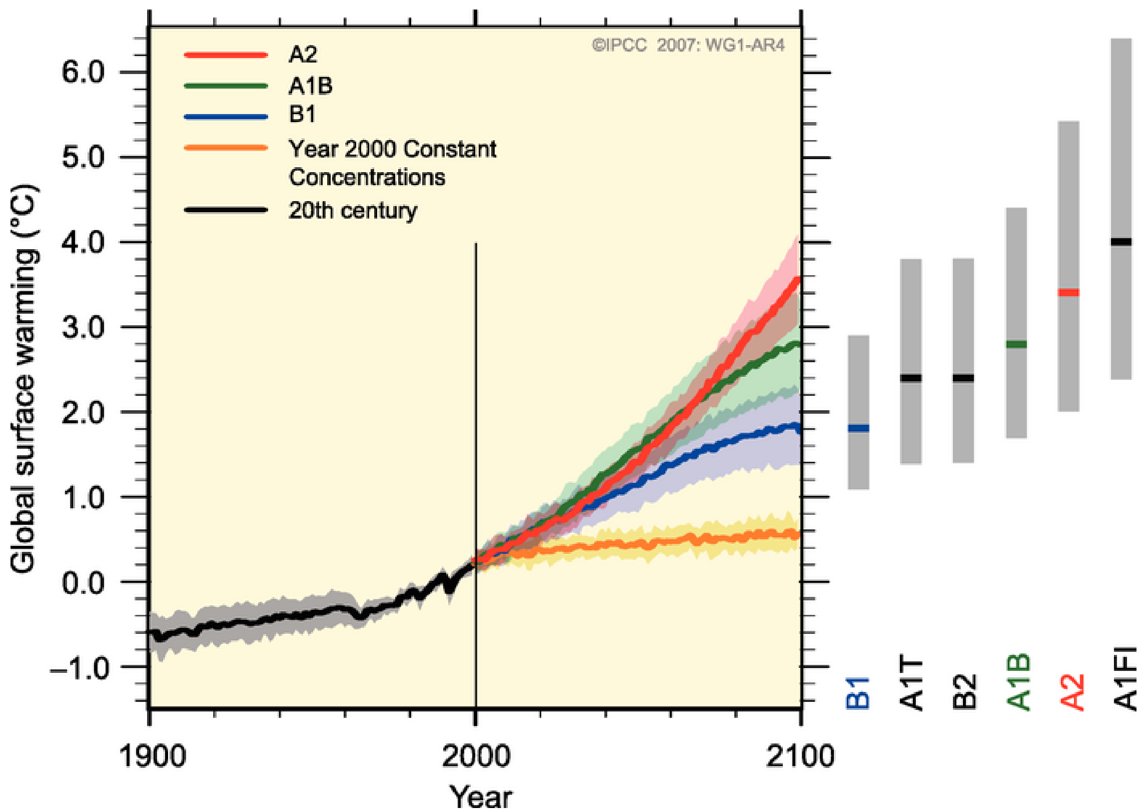


Figure 7. Modeled average surface warming under IPCC SRES Emission Scenarios
Source: IPCC (2007), Figure SPM.5.

Although the model can be customized, some initial model parameters are assigned default values. For instance, the annual uptake rate of water conservation and efficiency measures is set at a default rate of 3%[3] and the year in which efficiency programs end is set at a default of 2025.[4]

[3] The annual uptake rate of conservation fixtures varies between 1-3% (based on work of the CUWCC and DeOreo et al. 2011); we chose to use 3% given the state's current focus on increasing conservation and efficiency in order to meet the mandate of 20% per capita conservation by 2020 (SB x7-7).

[4] This assumes that efforts to achieve 20% per capita conservation by 2020 (SB x7-7) do not end exactly at the year 2020 but continue for several years afterwards.

Data sources and assumptions are noted throughout the model, typically as a comment associated with the spreadsheet cell and are also summarized in Appendices A-C.

The model can be run at various scales, from a customizable geographic scope (designed to allow individual water suppliers to isolate their service areas); at the county scale; at the hydrologic region; or statewide. Results are displayed as decadal averages from 2000-2009 to 2090-2099 and are always shown in comparison to a “static climate” (or the average of the climate from 1960 to 1999). This allows the user to quickly discern the impact of climate change, alone, on urban water demand. The results also describe the energy intensity of future water demand, allowing the user to understand how much additional energy – and greenhouse gas emissions – are associated with different scenarios.

Several factors are considered demand drivers or the primary forces that will determine water demand into the future:

- Population growth, based on projections by the California Department of Finance; the US Environmental Protection Agency (EPA); and the Public Policy Institute of California (PPIC);
- Development patterns, including where population growth occurs, what types of homes and landscaping people choose, and how and where commercial and industrial sectors grow or decline;
- Climate change and greenhouse gas emissions. Figure 7 shows the average land surface warming projected under a set of climate models under several scenarios (Figure SPM.5 in IPCC 2007). We have included projections of the B1 (low) and A2 (medium-high) scenarios, which forecast warming of 1.8ºC and 3.6ºC, respectively (or 3.2ºF and 6.5ºF, respectively).
- Water conservation and efficiency efforts.

Other variables are intended to reflect the effects of policy responses. Specifically, the user can model the impacts of:

- Higher (than natural replacement rate) levels of installation of water-efficient devices in the residential and CII sectors;
- Increased implementation of the Model Landscape Ordinance;
- Water-neutral development; and
- Changes in water prices. Please note that we strongly recommend that model users simulate *either* conservation or price changes, to avoid double-counting of water-use reductions. This is discussed in more detail below in the section *Interaction between Price Policies and Consumption* on page 35.

Scenario Parameters

In the following section, we describe how we developed inputs for the model. These include many model parameters, as well as future irrigation demand.

Irrigation Demand and Outdoor Water Use

Agronomists and hydrologists estimate crop water demand, or theoretical irrigation requirements, using estimates of evapotranspiration. Evapotranspiration (ET) is a combination of evaporation of water from soil and plant surfaces and transpiration, or water lost by the plant through openings in its leaves. In order to estimate future irrigation demand and outdoor water use, we calculated ET for future climate conditions. Our calculations were based on downscaled global climate model output created by researchers at the Scripps Institute of Oceanography at UC San Diego (UCSD/SIO). The climate data contained values for daily minimum, maximum, and average temperatures; precipitation; and other climatic variables. The development of these data are described in a recent article in the journal *Hydrology and Earth System Sciences* (Maurer et al. 2010) and are available on request from the Hydroclimate Group at UCSD/SIO. The downscaled data is arranged on a 96 x 92 grid where each grid cell is approximately 10 km^2. We used these data to create a gridded dataset of monthly theoretical average irrigation demand covering much of the western United States including California for the years 1950 to 2099.

Transpiration increases under hot and dry conditions, meaning 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 when water is not a limiting factor. PET is affected by hydro-climactic factors, including air temperature, wind speed, humidity, solar radiation, and cloud cover. Actual evapotranspiration (AET) will equal PET when water is abundantly available. Under drier conditions, AET will be some fraction of PET. On an annual basis, natural evapotranspiration is almost always less than PET unless supplemental irrigation water is made available during hot dry periods.

There are numerous ways to estimate PET. We reviewed and applied three formulas developed to estimate PET from commonly-available climate data empirical methods commonly used by hydrologists: Hamon, Hargreaves, and Thornthwaite. These are more readily calculated than more detailed methods like the Priestley-Taylor or the Penman-Monteith equations that require more detailed input data (Maidment 1993).

The Hamon equation (Hamon 1961) has been applied in recent water balance studies (Federer, Vorosmarty, and Fekete 1998). The equation’s inputs include latitude, solar declination, average monthly temperature, and the saturation vapor pressure, which can be readily calculated from temperature data. Hargreaves’s equation (Hargreaves 1974) uses total incoming extraterrestrial solar radiation, monthly average temperature, and the monthly minimum temperature. We also examined the Thornthwaite method (Thornthwaite and Mather 1957), which more recent research has shown can accurately estimate PET in California (Pereira and Pruitt 2004) but we found that the Thornthwaite method to be less accurate at high temperatures (above 94°F) and have not included this approach in the model. The results of our calculations are shown in Figure 8. This map shows annual average PET calculated by the Hargreaves method averaged over the years 1960-1990.

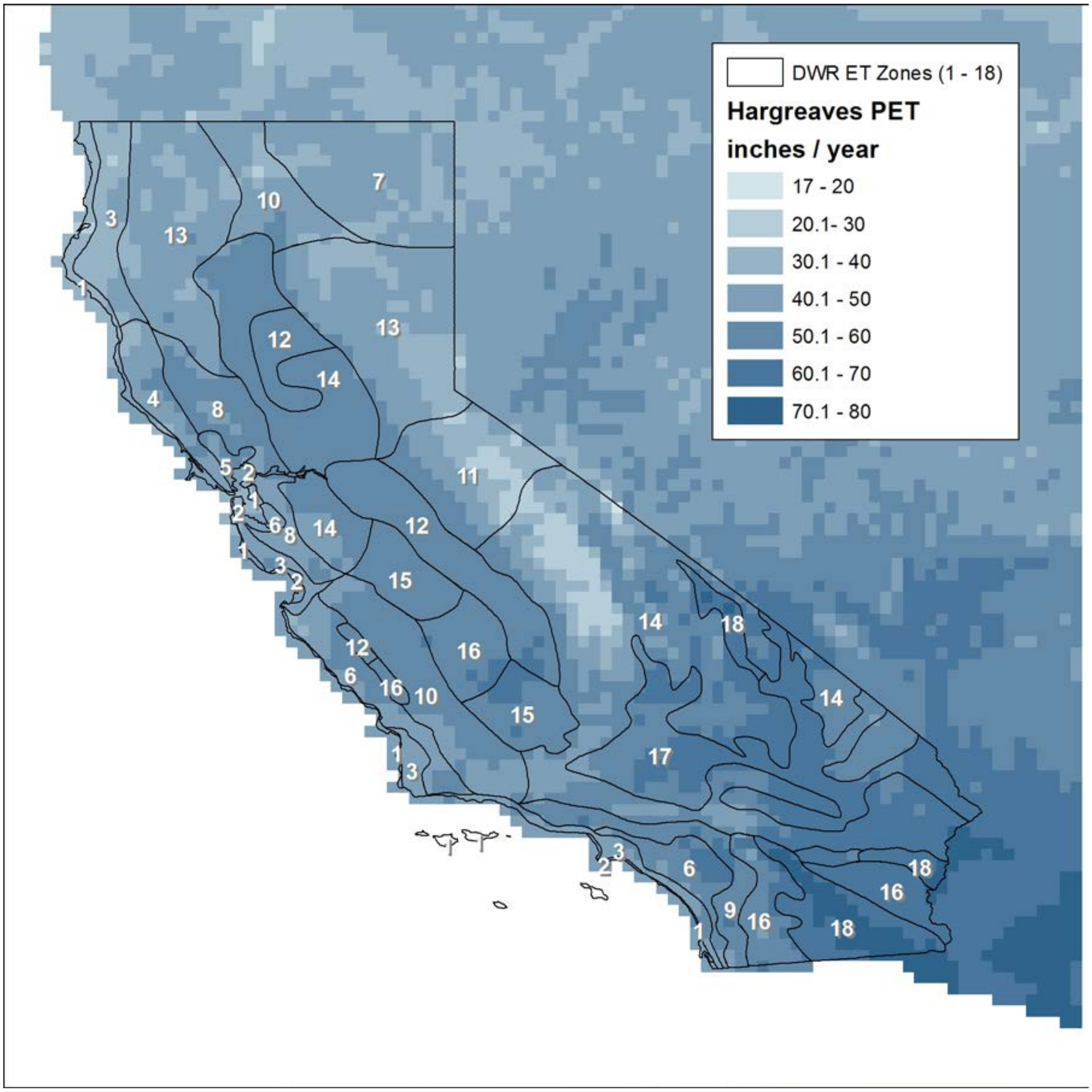


Figure 8. Map of potential evapotranspiration in the western United States calculated by the authors

In addition, we averaged calculated PET for the period 1960-1990 in each of California's 18 hydrologic regions using both the Hamon and Hargreaves method, and compared it to average observed PET published by DWR (Jones 1999) in Figure 9. In the figure, points show the average PET in the region, with error bars showing one standard deviation. We found the Hargreaves method to better match observed PET in California and, therefore, it is set as the default PET method in the model.

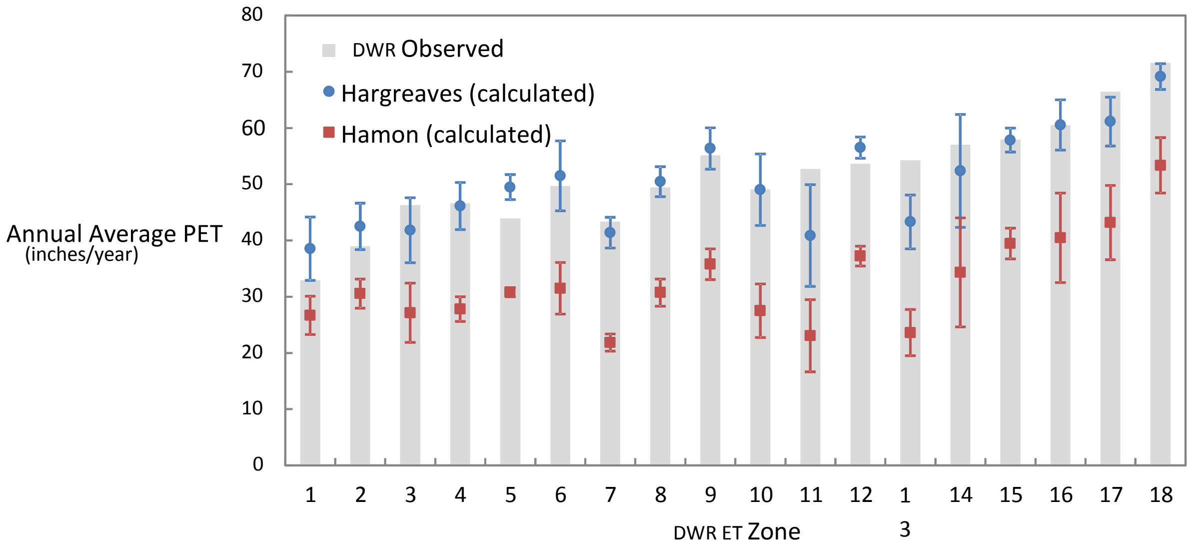


Figure 9. Comparison of observed and simulated potential evapotranspiration

We estimated monthly crop irrigation water requirement using a water balance model that has only two inputs: the long-term average monthly potential evapotranspiration (PET) and precipitation (P) for areas in California. For each month, we calculated the net irrigation requirement using the following equation (Maidment 1993):

$$I = ET_{crop} - (P + G + W) \qquad (1)$$

where *I* is the monthly irrigation requirement, *P* is the monthly precipitation, *G* is the groundwater contribution, and *W* is the stored water contribution (e.g., soil moisture) at the beginning of the month. In the agricultural sector, changes in soil moisture and groundwater use can play an important role in meeting a plant's water requirements, but in urban areas, these terms are negligible for household landscapes, and we set these terms to zero. On an annual basis, total irrigation requirements are therefore the sum over 12 months of Equation 1 (see equation 2).

$$\text{12-month estimate: } I_{Annual} = \sum_{t=1}^{12} \max\left(PET_t - P_t\right), 0) \qquad (2)$$

The application of equation 2 is shown in Figure 10 below. The plot shows natural moisture demand, and is patterned after the "water balance charts" that were shown in the California Water Atlas (Kahrl 1979). In months where precipitation exceeds evapotranspiration, the plant's water needs are fully met without irrigation. Thus, the plant's water deficit, or irrigation requirement, is zero when $PET_t - P_t < 0$. The location (Los Angeles County in southern California) is marked by hot, dry summers where the potential evapotranspiration 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 met to meet the water needs of a reference grass crop.

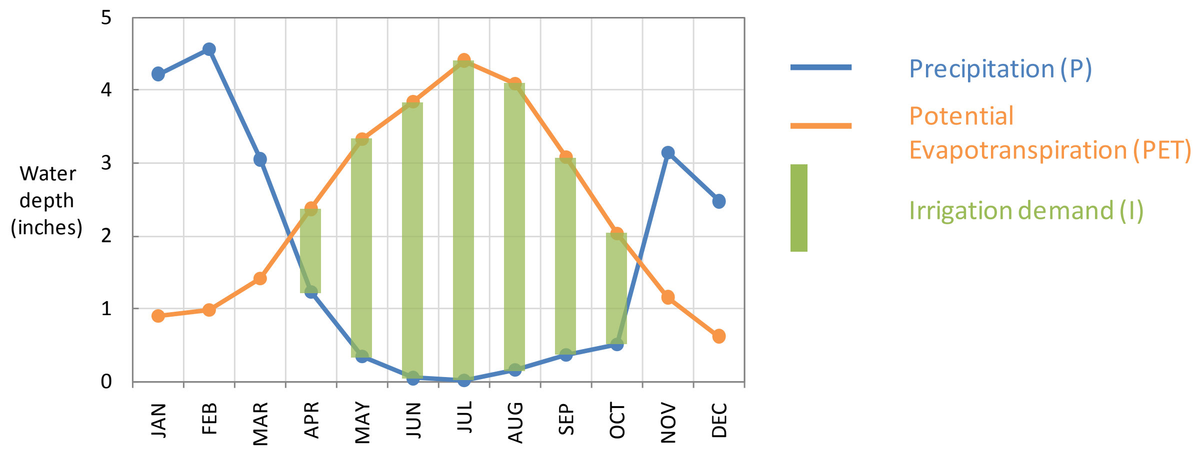


Figure 10. Monthly water deficit as a proxy for irrigation demand

In this simplified model, we assume that for vegetated areas, all of the precipitation infiltrates into the soil and there is no runoff. We also assume that none of the surplus water during winter/wet months percolates deep underground or is captured locally for use during the hotter seasons, though interest in local rainwater harvesting seeks to make use of at least some of this water. In reality, runoff and percolation can be significant fluxes of water. Ignoring these components of the hydrologic cycle could normally introduce significant error. In practice, ignoring the runoff and percolation for smaller individual urban landscapes means that our model may slightly overestimate the quantity of rainfall that is available to fulfill plant water demand and underestimate actual 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. Under some circumstances this can either over- or under-estimate total water availability, or shift the timing of that availability. The calculations were repeated on thousands of grid cells for each month over a 150-year period. To facilitate these calculations, we wrote a set of programs in Excel, Access, and Python (these programs are available upon request).

The following figures show an example of the theoretical annual average reference crop irrigation demand for Los Angeles County. Figure 11 shows the time series of the calculated irrigation demand, along with the time series created to simulate a static climate. This was done by randomly selecting a value from the years 1960-1990 for each year in the time series, a method often referred to as “bootstrap resampling.” In this and the following figures, the irrigation demand was calculated using the Hargreaves method and averaged the results for four climate models under the higher A2 scenario.

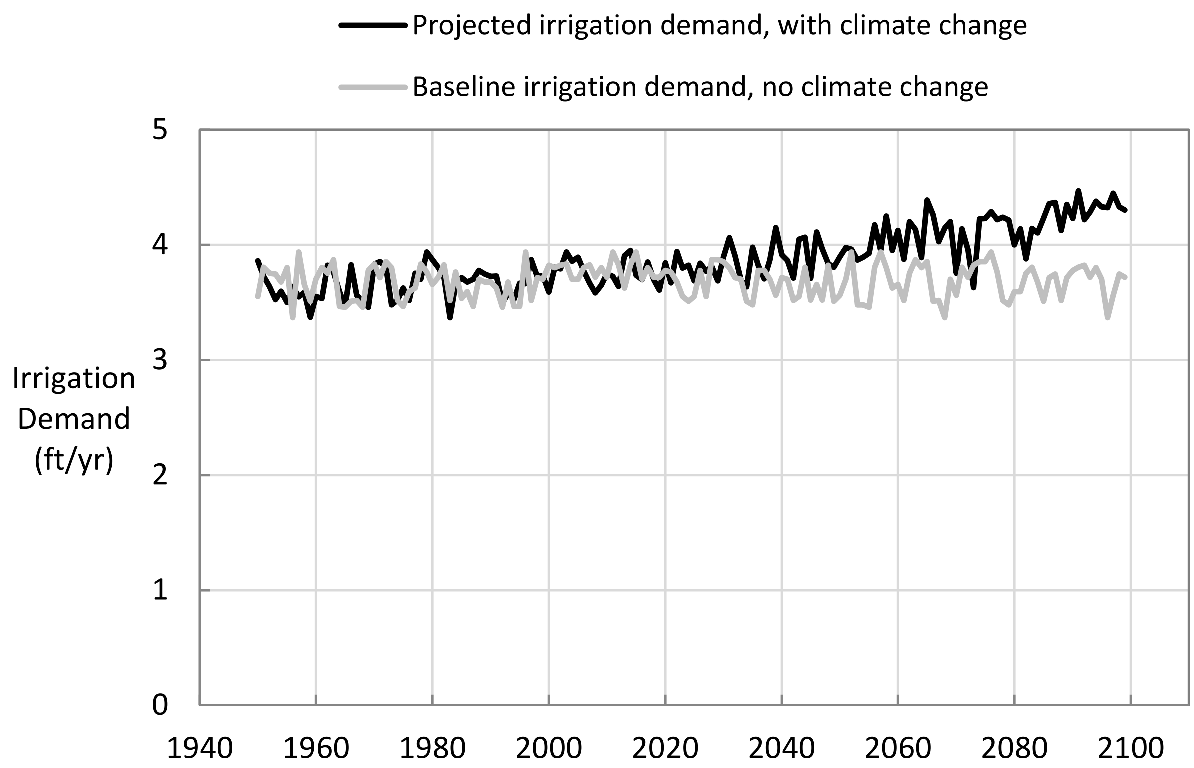
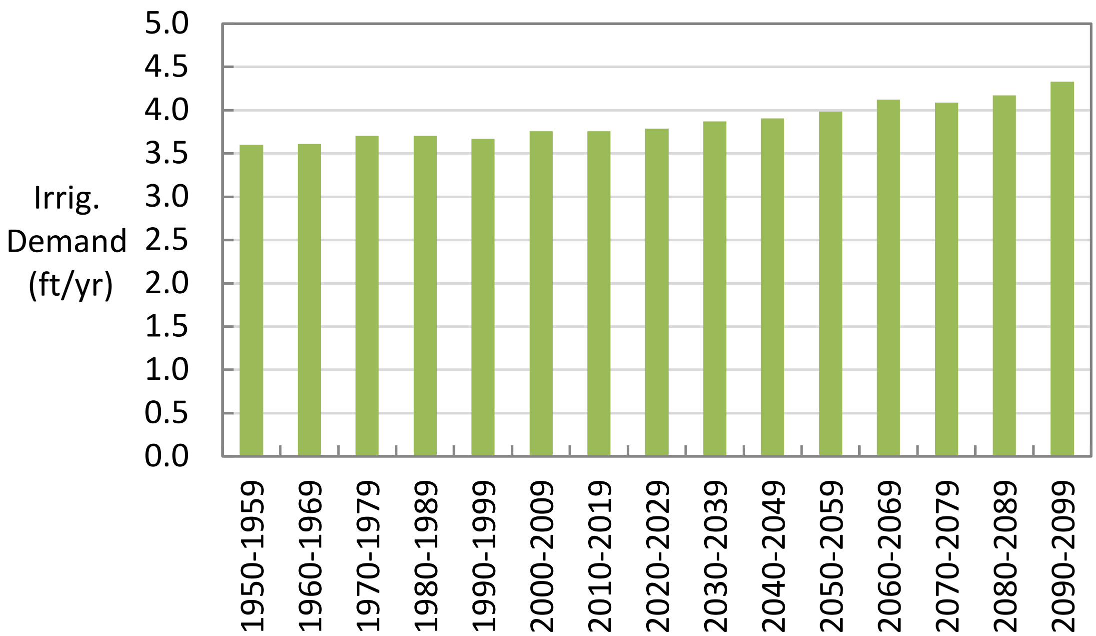


Figure 11. Time series of calculated theoretical annual average reference crop irrigation demand for Los Angeles County

Figure 11 shows the increase in the decadal average irrigation demand in Los Angeles County (black line), and departure from the historic 1960-1990 average (grey line) under a climate change scenario. This upward trend is visible in all California counties, although the percent increase appears to be higher in Southern California. Figure 12 shows the decadal average irrigation demand calculated by the Hargreaves method for the A2 scenario and averaged from four climate models (first chart). While there is variance from one year to the next, the decadal average steadily increases from the historical average, up to 18% by century's end (second chart).



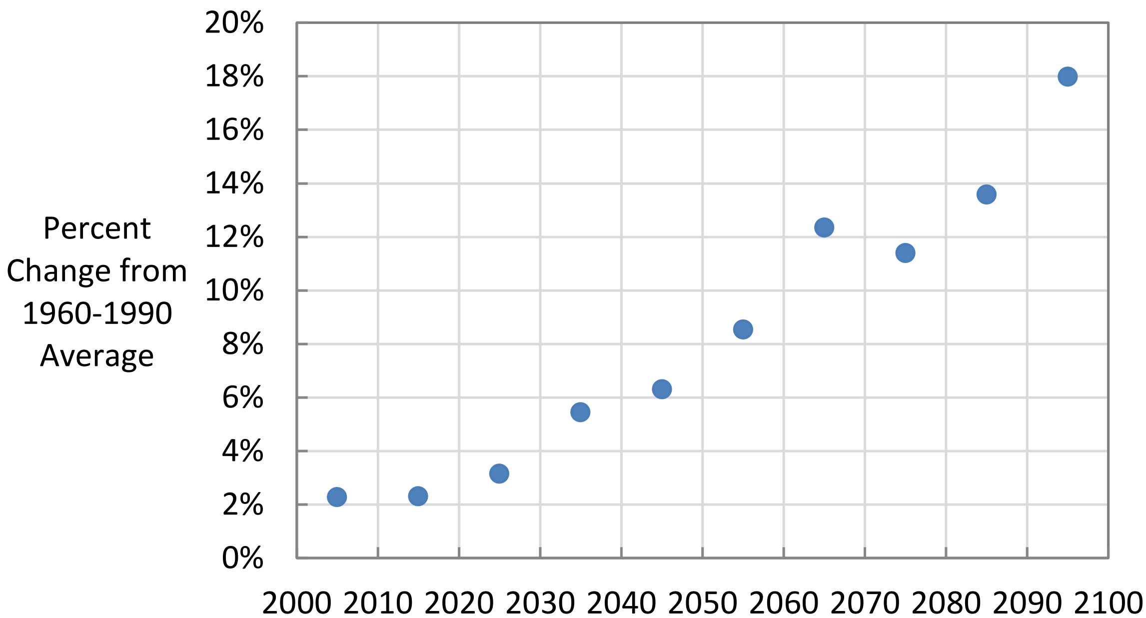


Figure 12. Decadal average irrigation demand for Los Angeles County (first chart), and departure from the historic 1960-1990 average (second chart)

We averaged the data in the grid cells to develop an irrigation demand time series for all counties and hydrologic regions. This was done by assigning each cell in the 96 x 92 grid to a county or region, and averaging values in the grid cells using a set of queries in Microsoft Access (the database and queries are available on request from the authors).

Population Scenarios

The size of the population is an important forcing function in the model. According to different scenarios, the rate of population growth may either increase or decline. We included eight population time series from three sources in the model. These are listed below, and several are shown in Figure 13.

California Department of Finance (DOF): DOF released new interim population projections in May 2012 (Schwarm 2012), which are set as the default population projections in the model, though the previous set of projections from 2007 are also included. The most recent DOF projections were revised downward to reflect the results of the 2010 Census and other factors.

US Environmental Protection Agency (USEPA): The EPA has released a set of tools and datasets for modeling housing density growth in the U.S., called Integrated Climate and Land-Use Scenarios (ICLUS) (EPA 2010). These data include four population growth scenarios reported at the county level to the year 2100. The population scenarios are based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) social, economic, and demographic storylines (Nakicenovic et al. 2000).

Public Policy Institute of California (PPIC): Three population projections to 2100 (low, middle, high) were developed by PPIC for the 2009 Water Plan Update (Johnson 2008). A brief description follows: "In the low series, population growth slows as birth rates decline, migration out of the state accelerates, and mortality rates show little improvement. In the high series, population growth accelerates as birth rates increase, migration increases, and mortality declines. The middle series, consistent with California Department of Finance projections which extend to 2050, assumes future growth in California will be similar to patterns observed over the state's recent history… A number of storylines could be developed that are consistent with each of these projections series. These storylines do not necessarily involve climate change, but could be consistent with different climate change scenarios."

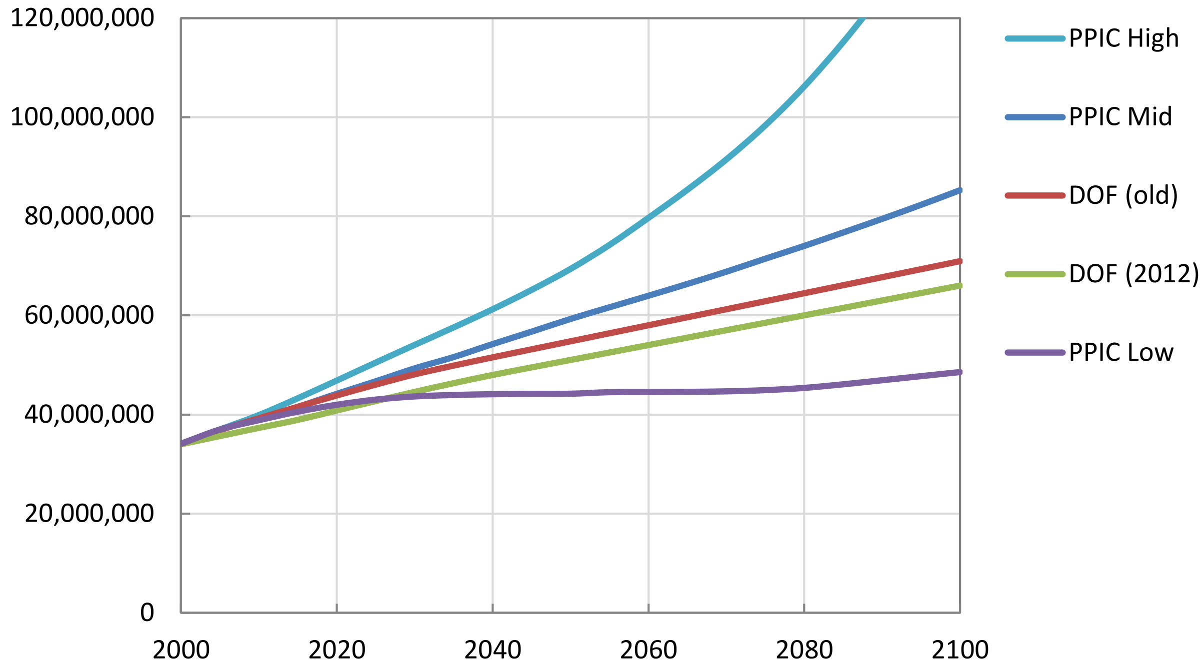


Figure 13. Comparison of several of the population projections included in the model

Estimating Residential Water Use in California

We divide water use in residences into indoor and outdoor use, and separately model two classes of residences: single-family residences or detached homes, and multi-family residences, including condominiums and apartment buildings. We make the simplifying assumption that average residential *indoor* water use is the same for all households everywhere in the state. We used a value of 175 gallons per household per day (gphd) for indoor residential water use, following recent observations by DeOreo et al. (2011).

We calculate outdoor water use as the amount of water that is required to irrigate outdoor turf and gardens. We make use of the standard crop coefficient method, using the annual irrigation demand that we calculated as described above.

$$W = \frac{A \cdot I \cdot p}{e} \tag{3}$$

where:

W = landscape water use, ft^3/yr

I = reference crop irrigation demand, ft/yr

A = landscape area, ft^2

p = plant factor, a dimensionless ratio

e = irrigation efficiency, a dimensionless ratio

The "plant factor" or "crop coefficient" is a number that, when multiplied by reference evapotranspiration, estimates the amount of water needed by plants. For purposes of this equation, the plant factor range for low water use plants is 0 to 0.3, the plant factor range for moderate water use plants is 0.4 to 0.6, and the plant factor range for high water use plants is 0.7 to 1.0 (Table 4).

Table 4. Typical crop coefficients

Plant Type	Crop Coefficient
Turf	0.80
Non-turf Trees, Shrubs	0.65
Vegetable Gardens	0.80
Xeriscaping	0.30
Non-irrigated Areas	0.00

Source: DeOreo et al. (2011), Table 12

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. If an irrigation system is optimized and operated at theoretical 100% efficiency, this means that all water makes its way to the plant's root zone, and the exact amount of water required is applied. This is almost never true in the field, and there are a number of ways that water is wasted in irrigation, including percolation to deep groundwater, runoff, wind drift, mist evaporation, among others. The Handbook of Hydrology reports field application efficiencies range from 0.5 to 0.8 (McMahon 1993, 27.33).

Data sources for default values are reported in Appendix A. Briefly, defaults are based on empirical data from the East Bay Municipal Utility District's 1995 Water Conservation Baseline study, which found the median landscaped area for single-family residences was 2,645 ft^2 and for multi-family residences was 1,970 ft^2, and empirical data from DeOreo et al. (2011), which found the average plant factor of landscaped areas was 0.64. Finally, we assume an average irrigation efficiency of 0.6 (typical of sprinklers) for existing residences and 0.7 (as required by the Model Landscape Ordinance) for new construction. To estimate outdoor water use at commercial and industrial facilities, we use the same defaults for plant factor and irrigation efficiency, but assume an irrigated area of 7,000 ft^2.

Modeling Conservation and Efficiency Efforts

We use a physically-based approach to modeling how much water is saved by conservation practices and devices. For indoor water conservation and efficiency, we estimate the number of households that use a conserving device, given a certain rate of adoption. Table 5 shows the average annual uptake rate for three efficient devices in single-family homes in California from 1997 – 2007 (DeOreo et al. 2011). The uptake rates for conserving devices is set at a default of 3% but can be adjusted by the model user. The model tracks the number of conserving devices present in each class of household (single-family vs. multi-family residences and existing residences vs. new construction).

Table 5. Percentage of households with efficient appliances

	Percentage of Households		Annual Uptake Rate
	1997	2007	
Showers	70%	80%	1%
Clothes Washers	1%	30%	3%
Toilets	10%	30%	2%

Source: DeOreo et al. (2011), pg 36.

Each device is assumed to save a fixed amount of water. Again, this is a parameter that can be customized by the user; however we provided default values from the literature, as shown in Table 6.

Table 6. Default parameter values for water savings for conserving devices for residential indoor use.

Type	Water Savings (gal/household·day)	Source
Efficient Toilets	9.8	Public Draft Technical Memorandum,Task 4 (California 20x2020 Task Force, 2008)
Efficient Washing Machines	14.4	Cost Effectiveness Analysis Tool (California Urban Water Conservation Council)
Efficient Showerheads	12.2	Public Draft Technical Memorandum, Task 4 (California 20x2020 Task Force, 2008)
Leak Repair	25.0	California Single-Family Water Use Efficiency Study (DeOreo et al. 2011)
Faucet Aerators	35.0	California's Next Million Acre-Feet: Saving Water, Energy, and Money, Appendix A: Technical Documentation (Cooley et al. 2010).

Note: Water savings defaults can be changed in the model to account for greater or lesser savings assumptions.

We programmed the model to consider two forms of common outdoor water conservation and efficiency measures: adoption of weather-based irrigation controllers (WBICs) and conversion of "conventional" landscapes to "water-efficient" landscapes. Like the indoor conservation calculations described above, the number of annual installations or conversions is based on an annual uptake rate, which is a parameter set by the model user. Other increases in landscape water-use efficiency (for example, increased use of efficient micro-sprinklers and drip irrigation) are captured by entering a lower average plant factor for new development and higher average irrigation efficiency.

Rebates and incentives for weather-based irrigation controllers targeted at customers using large amounts of water can result in significant reductions in landscape water use. However, the literature on actual measured savings is sparse. We use an average value of 7.3% reduction, based on information in Mayer et al. (2009, Table 51).

For the second form of outdoor conservation, conversion to "efficient" landscapes, we drew on information in the Model Water Efficient Landscape Ordinance, or MWELO, California Assembly Bill 1881, passed in 2006. The law limits the percentage of the landscape that can be planted in turf grass or other high-water-use plants. While the rules are somewhat complicated, water use is tied to a theoretical irrigation requirement.

Essentially, the landscape ordinance states that all new landscapes will be subject to a water budget. In practical terms, it limits how much area is planted as grass or other high-water-use plants and requires efficient irrigation. This can be related to equation 3 above, which calculates landscape water use based on its area, plant factor, and irrigation efficiency.

Estimating Commercial, Institutional, and Industrial Water Use in California

CII water use was estimated by applying sector-specific water use intensity factors (in gallons per employee per day) to forecasts of employment by sector. The lack of data on CII water use in California presented a major challenge in forecasting CII water use – the most recent measured, statewide, data on CII water use is from the mid-1990s.

More recent data on industrial water use in Canada was found; however, due to the many differences in climate, commercial and industrial mix, and regulations, these data were not representative of California CII water use. Several local-level studies have been conducted, including studies in Santa Clara and San Francisco (Hannaford 2004). In some cases, when statewide data were unavailable or deemed inaccurate, local-level data were relied upon.

Due to this dearth of good data, our CII water use forecasts should be read and cited with caution, and the reader should take time to understand the limitations and underlying assumptions. We estimate CII water use based on a water factor with units of gallons per employee per day, with separate water factors for each of 11 sectors. Because of the uncertainty associated with the CII water factors, the model parameters can be changed or replaced if better data become available.

Water use factors used in the model are primarily from the report *Waste Not, Want Not: The Potential for Urban Water Conservation in California* (Gleick et al. 2003). This report relied on a water use survey of CII customers performed by the California Department of Water Resources in 1994, water use by sector as reported by nearly 150 water districts in 1995 and 2000, and a few studies based on surveys of water use primarily in southern California's commercial sector, including Dziegielewski (2000).

In Gleick et al. (2003), the authors used two independent approaches to estimate CII water use in California, and cross-checked these estimates against other published estimates. "The first approach consisted of compiling, reviewing, and analyzing data gathered from CII water users around the state in various surveys (CDWR 1995a, Davis et al. 1988, Dziegielewski et al. 1990, and Dziegielewski et al. 2000) to calculate water intensity factors for different economic sectors, in gallons per employee per day. These factors were then multiplied by statewide employment data, resulting in an estimate of overall CII use in California. The second method did not involve using water intensity factors, and instead relied on water-delivery data by sector, as reported by water agencies. These two methods produced total California CII water use estimates that were within 10 percent of each other" (Glieck et al. 2003.)

The water factors compiled by Gleick et al. in their first method of estimating statewide water use were used for most sectors in our model. However, for a few sectors, no data were available from Gleick et al. 2003, or newer data were deemed more reliable. For instance, we used data collected in San Francisco over the five-year period from 1993 to 1998 (Hannaford 2004) for the construction and wholesale trade sectors.

Employment data for the accommodation and food service sectors were only available in aggregate, while water factors were available separately. Therefore, we used a weighted average of the water factors for these two sectors, based on 2008 employment in the two sectors. The ratio of employees in the food services sector to those in the accommodation sector was five to one. While the ratio of employees in these two sectors may change over time, and therefore the ratio may not be accurate when applied to employment forecasts, the difference in water use between the two sectors is relatively small (240 gallons/employee·day or ged for lodging and 265 ged for food service). Therefore, we found this weighted average to be an acceptable approximation.

All CII water factors were considered to be uniform across the state, with the exception of the manufacturing sector. Because of the diversity within this sector, water use intensity varies a great deal by location. We calculated a weighted average of the water factor at the county level, using the current number of employees (ca. 2008) and separate water factors for 19 manufacturing sub-sectors (detailed in Appendix B). The map in Figure 14 shows the number of manufacturing employees in each county; the color tint for counties corresponds to the weighted average water factor we calculated for each county, in gallons per employee per day (ged). Note that the county averages vary from 341 to over 3,900 ged.

Comparisons of data across the studies were in most cases not possible, because of the differences in CII categories used, and the general lack of data. However, data on water use in offices were compared across three studies:

- Waste Not, Want Not (Gleick et al. 2003)
- Santa Clara Valley Water District Commercial, Institutional, Industrial (CII) Water Use and Conservation Baseline Study (SCVWD 2008)
- City and County of San Francisco Retail Water Demands and Conservation Potential (Hannaford 2004)

This comparison revealed that the water factor used in Gleick et al. 2003 was several times larger than that used in the other studies. Because of the large discrepancy between these data, and because of the likelihood that office water use has decreased since the data used in *Waste Not, Want Not* was collected, we decided instead to rely on newer data – the water factor for offices reported in SCVWD 2008. All of the water factors, sources, and notes related to CII water use are listed in Appendix B.

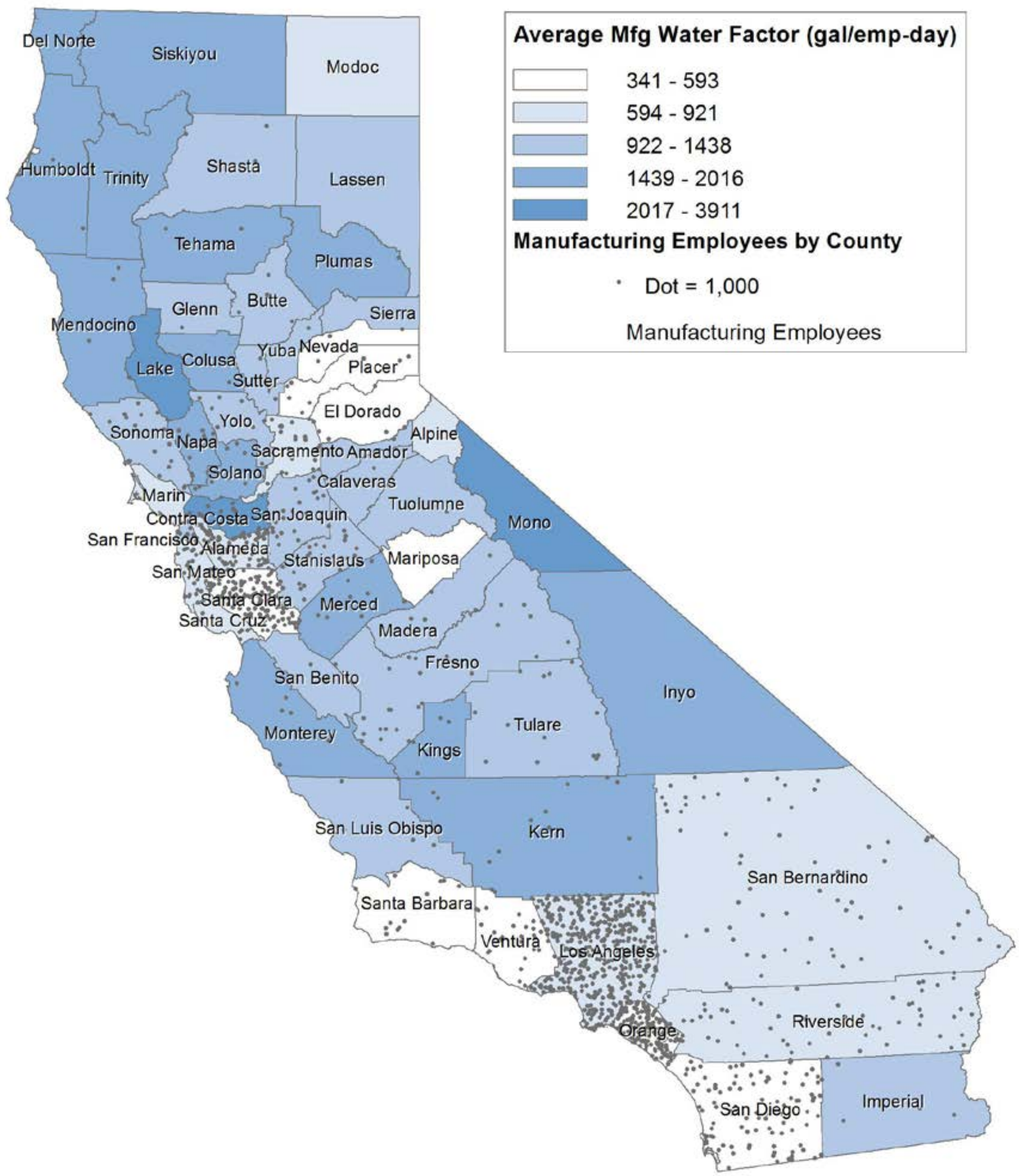


Figure 14. Map of water factors for the manufacturing sector by county.

Estimating Energy Intensity of Water in California

We have included a simple set of calculations to provide rough estimates of future water-related energy consumption and carbon emissions. These calculations are not detailed, but are included to help give an indication of the effects of changing urban water demand on future energy use and emissions. More detailed estimates can be developed and used in the model, if users would like them, from separate tools/models such as WeSim (available online at: http://www.pacinst.org/resources/wesim/). It is important to keep in mind that future energy requirements will likely be much different than past energy requirements and the results of detailed forecasting of future energy demands can be used to replace the model's default values to increase accuracy. All of the default values used in the model, data sources, and notes related to energy intensity of water use are listed in Appendix C.

Energy Intensity (or "Embedded Energy") refers to the energy needed to collect, treat, and distribute water. It is usually expressed in units of energy per volume of water, for example kilowatt-hours per million gallons (kWh/MG). Below are some recent published estimates for energy intensity (Klein et al. 2005, 11), used as the model's defaults:

Northern California: 4,000 kWh/MG
Southern California: 12,700 kWh/MG

Emissions factors represent the amount of greenhouse gas emissions released per unit of fuel or energy consumption. For example, burning one barrel of diesel fuel (which is about 86% carbon) liberates 400 kg of carbon dioxide gas, along with small amounts of other gases. Note that methane is 25 times more potent than CO_2, in terms of global warming potential. Nitrous oxides are 298 times more potent than CO_2. The potency of the various greenhouse gases are taken into account when calculating the total global warming potential, which is typically expressed in units of CO_2-equivalents.

The EPA produces the Emissions and Generation Resource Integrated Database (eGRID), a comprehensive data source for electricity emissions factors for 26 sub-regions across the United States. These data are updated periodically to better reflect changes in emissions from the U.S. electricity grid. The newest version, released in February 2011, provides data for the year 2007. Again, it is important to emphasize that these estimates are for current energy uses and sources and can be modified by the user to more accurately represent their area and to incorporate projections from any future forecasting efforts.

Interaction between Price Policies and Consumption

The link between water prices and consumption has been understood for decades. Water demand is not, as was once believed, inelastic: many studies have shown that people consume less at higher prices (Campbell, Johnson, and Larson 2004; Olmstead and Stavins 2007). There are, however, difficulties in incorporating pricing policy and demand elasticity in a simulation model. Water users usually respond to higher prices with a mix of behavioral and technological changes. On the one hand, they may take shorter showers or irrigate their lawn less often. They may also invest in a low-flow showerhead or remove their grass and replace it with less water-intensive plants.

Estimates of water demand elasticity in the literature are likely to include both behavioral and technological forms of conservation. Our model already includes the spread of technological water conservation practices. If the conservation and pricing policy options are simulated at the same time, it could result in double-counting of water savings. Thus, we recommend that users check either one of the following options on the input page, but not both:

- Include simulation of improved water conservation and efficiency
- Include simulation of price increases and demand elasticity

Limitations

The statistician George E. Box famously mused that "all models are wrong; some are useful." All models are simplified representations of the real world. As such, inaccuracies come from two sources. First, the form of the model may be wrong. Perhaps the modeler did not include some important dynamic that occurs in the real world. In our case, we have not attempted to simulate how changes in people's behaviors and attitudes toward water may affect consumption in the future. There is evidence that marketing campaigns can be effective at lowering water use (Aisbett and Steinhauser 2011), but it is unclear how this can be quantified or included in a computer model. Another example is our use of "water factors" to simulate water demand in the commercial and industrial sector. To wit, we estimate water use in the "Leisure and Hospitality" sector using a water factor of 261 gallons per employee per day. This single factor obscures a tremendous amount of variety, as it includes everything from video arcades to luxury hotels.

The second source of error can come from the data and numeric quantities used in the model. Here, we can distinguish between forcing functions and parameters. Forcing functions are external time series that are inputs to the model, such as the annual irrigation demand or scenarios of population growth. Parameters are the values for internal model variables, for example, the average baseline indoor water use, in gallons per day. We made an effort to locate reliable sources of many parameter values from the literature, or by performing our own calculations using public datasets, for example from the U.S. Census Bureau or the DWR. Many of our parameter values are estimations or are not based on detailed measurements. We offer the user the option of changing many of the parameters to reflect regional difference or preferences, or to test the sensitivity and importance of specific parameters.

Thus, errors and inaccuracies can come from either the methods or data employed in modeling complex, messy real-world phenomena. Below, we highlight some of the main areas of concern for each of these. We do this for two reasons. First, this can help future researchers to improve upon our model by using more accurate or up-to-date data and methods. Second, users of the model and its results should clearly understand its limitations. The model incorporates ranges of results and provides reports on uncertainty.

Model Domain and Geographic Scope

The model simulates urban water use for the state of California for the years 2000 to 2100. Thus, the model domain is all of the urban and suburban land and households in the state. Because the climate varies widely within the state, we felt it was important to develop a "distributed" rather than a "lumped" parameter model. This means that the model domain is divided into smaller geographic units, and each can have its own unique set of parameters and inputs.

We considered running the simulation based on grid cells, census blocks, or some other convenient way of carving up the land into discrete units. Dividing the state into thousands of units would have been computationally complex, and there is also the question of where to find data to populate these sub-units. We decided to use both counties and hydrologic regions as the sub-domains. There are 58 counties in the state and 10 hydrologic regions. When the model is run, it simulates one area at a time, and looks up the appropriate values for this area. For example, each county has different forcing functions (time series of population and irrigation demand) and parameters (such as the number of persons per household).

We did not have sufficient data to spatially disaggregate many parameters, nor is it always desirable to do so. Consider for example the average size of a residential landscape. We suspect that landscapes vary in size across the state, and are perhaps larger in Orange County than in San Francisco. However, in the absence of reliable data to populate this parameter for each county, we set landscape size as a *global* parameter. The same parameter value is applied to each region. In general, the principle of parsimony holds that the simplest model that explains a phenomenon is usually the best. In our case, this meant using many global parameters for quantities that we suspect vary geographically. This is one more potential source of error in the model. Future data collection and GIS analysis may enable the development of more spatially explicit models of urban water use in California and we urge the collection of such data.

Lack of Reliable Measurements for Model Parameters

Lack of real-world measurements made it difficult to estimate model parameters and to accurately calibrate our model. For example, water use projections for the CII sector should be considered to be rough approximations. Most of the water factors that we use are based on data that is over 15 years old. In the past 15 years, water-use efficiency in the CII sector is likely to have increased, and therefore the water factors used are likely to overestimate actual use. On the other hand, the structure of the California economy has also changed, and this can also affect overall water requirements. There is a need to collect updated, comprehensive CII water use data at the state level so that we can better understand trends over time and better estimate future CII water needs.

The water-factor based approach where water use is estimated based on the number of employees is likely to be more accurate for some sectors than in others. In offices, for example, there is likely to be a strong relationship between the number of employees and the amount of water used, because water use is primarily from toilet flushing, hand washing, etc. In other sectors, such as manufacturing, the water use may be more closely tied to the amount or kind of a product produced than to the number of employees.

Additionally, the sector categorizations for the water factors in Gleick et al. 2003 and the other CII water use studies did not always match exactly with the sectors for which we have employment forecasts. This is due in part to the switch from the Standard Industrial Classification system to the North American Industry Classification System (see Gleick et al. 2003 for a full discussion). Finally, there is significant heterogeneity in water use between different sub-sectors within many of the CII sectors used in this report.

Only One Scenario of Economic Growth

The model is constrained by having only a single input dataset representing economic growth. The forecasts prepared by Jeffrey Michaels with the Insight Model cover only a single scenario of population and economic growth. If the model user changes the population scenario to one representing higher or lower growth, this change is not reflected in the economic dataset, which consists of a table reporting the number of employees by county and by sector in future decades. Under the old Department of Finance population forecast (DOF 2007), the ratio of employees to total population stayed fairly constant at around 35%. Under the new Interim Population Projections released by DOF this year (Schwarm 2012), the percent employment increases from 37% in 2010 to 43% in 2050. (The state decreased its estimate of 2010 population from 39 million to 37 million following the release of Census 2010 results. DOF's projection of 2050 population was lowered from 55 million to 51 million.)

Use of Extrapolated Long-Term Projections

Many of the model input datasets created by demographers or economists extend only to 2050, unlike the climate datasets that end in December 2099. We sought to run a longer-term simulation to examine, among other things, the long-term impacts of climate change on water consumption in the state. This required us to extrapolate several of the datasets for the period from 2050 – 2100. In each case, we used simple linear-regression-based extrapolation to lengthen time series of employment and population.

The world's climate system is one of physical phenomena, and is perhaps more amenable to modeling than many social phenomena. One could argue that looking into the future more than two generations is the realm of futurists rather than demographers and economists. Many users of the model may not be interested in projections more than 20 or 30 years in the future. However, we feel that the long-term forecasts are a useful planning tool. Again, we are not attaching likelihood to any of the projections. Rather, they are useful tools in scenario-based planning. For example, this model can answer the question: "If California's population grows to 60 million, what does this mean for water and energy consumption?"

Calibration of the Model

We calibrated the model to information on existing current urban water use in California. Calibration consisted of adjusting model parameters in order to fit the simulation results to a set of calibration targets. Here we distinguish between well-documented values that were kept fixed, and variables with greater uncertainty or which are largely unknown, which are customizable. For example, estimates of the number of residents per household in each county were available from the U.S. Census Bureau. As this is a definitive and high-quality data source, we considered these values fixed rather than "tunable" parameters. In other words, we did not adjust these values in order to calibrate the model. Our calibration goals were as follows:

Use accurate, realistic, and defensible parameter values. We gave preference to documented studies and existing datasets that were up-to-date and based on empirical data. An example is the recent *California Single-Family Water Use Efficiency Study* (DeOreo et al. 2011). We used a number of values from this study, and it had several qualities to recommend it. First, it is based on actual water measurements, collected in California homes. Second, it is fairly recent. Third, its data and conclusions have generally been accepted by DWR and utility staff around the state, who participated in designing and reviewing the study. As one example, we used this study's average indoor water use of 175 gallons per household per day. There are several reasons why this may not be 100% accurate: sampling error, errors in the study methodology, the fact that it only covered single-family homes (and not apartments), or bias based on the areas sampled – the study only covered certain geographic areas participating in the study. In all cases, we used our best judgment from the available literature and data sets to estimate realistic ranges values.

Accurately simulate the total water use for the baseline decade (2000-2009). There is no definitive source that quantifies urban water use in California. Many water uses are not measured, instead most federal and state agencies rely on modeling, resulting in a wide range of estimates for urban water use (see Table 7). For instance, the U.S. Geological Survey estimates freshwater use in the United States every five years. According to their latest report (Kenny et al. 2009), in 2005, California withdrew 7,550 million gallons per day of freshwater for public supply, industrial, and domestic use. This is equivalent to 8.5 maf (or 212 gpcd, based on an estimated 2005 population of 35.66 million).[5] Yet, the Governor's Task Force (DWR et al. 2010) estimates that, in 2005, California's urban water use was only 7.7 maf (or 192 gpcd).[6] And Gleick et al. (2003) estimated that California's urban water use, in 2000, was approximately 7.0 maf (or 188 gpcd, based on an estimated 2000 population of 34 million). Because these are estimates rather than actual measurements, we considered them "soft" calibration targets. In other words, we calibrated the model to return results within the range of values listed above, but did not attempt to exactly match particular estimates.

Table 7. Estimates of urban water use in California

Year	Total urban water use (maf)	Per capita use (gpcd)	Source	Citation
2005	8.5	212	U.S. Geological Survey	Kenny et al. 2009
2005	7.7	192	20 x 2020 Report	DWR et al. 2010
2000	8.5	230	DWR Water Plan Update 2005	Rayej 2009
2000	7.0	188	Pacific Institute	Gleick et al. 2003

Reflect reduced per capita water use by 2020, following the stated goals of recent legislation (Senate Bill x7-7, The Water Conservation Act of 2009). We set the baseline scenario to achieve a 15% reduction in per capita water use between the first decade (2000 – 2009) and the third (2020 – 2029). This assumes that most water utilities will meet the goals of the mandate. It also

[5] All population projections are based on the most recent Department of Finance report (Schwarm 2012).
[6] The Governor's Task Force initially estimated 7.9 maf in their report, but stipulated that they calculated this based on an urban water use of 192 gpcd and out-dated Department of Finance population projections for 2005. We re-did the calculation with the updated 2005 population projections (Schwarm 2012), resulting in 7.7 maf.

acknowledges that not every agency is required to reduce per capita water use 20% by 2020 and that baselines vary.

Scenario Development

In this report, we describe six statewide scenarios. The scenarios include a set of three baseline scenarios that represent an extrapolation of current trends with different assumptions about future climate conditions:

- **Baseline with no warming –** an extrapolation of current trends given official state population projections (Schwarm 2012); the requirements of Senate Bill x7-7 for reduced per capita water use by 2020; and a static climate.
- **Baseline with slower warming –** an extrapolation of current trends with the same assumptions as above but with low greenhouse gas emissions levels (SRES B1).
- **Baseline with faster warming –** an extrapolation of current trends with the same assumptions as above, but with medium-high greenhouse gas emissions levels (SRES A2).

We also present a set of three "efficient" scenarios that are based on many of the same assumptions as the baseline scenarios; however, the efficient scenarios continue the per capita water conservation that is required by the 20x2020 legislation (Senate Bill x7-7, Water Conservation Act of 2009) out to year 2100. In other words, the "efficient" scenarios model the continuation of the same level of water conservation efforts past the 2020 deadline. This may require additional legislation.

The efficient scenarios are also modeled under varying assumptions of future climate conditions:

- **Efficient with no warming –** based on the state's population projections (Schwarm 2012); assumes that water conservation and efficiency efforts do not cease at year 2020 but continue at the same rate through to year 2100; and a static climate
- **Efficient with slower warming –** based on the same assumptions as above but with low greenhouse gas emissions levels (SRES B1).
- **Efficient with faster warming –** based on the same assumptions as above but with medium-high greenhouse gas emissions levels (SRES A2).

Results

In the following sections, we report the results of our simulation model of urban water use in California out to the year 2100, under the different sets of assumptions related to climate and efficiency as described above.

Scenario-Based Analyses

This section reports on the results of the six simulations described above. The model allows the user to run a scenario multiple times (the user sets the "number of realizations" from 1 to 1,000) and the average values are reported within error bars. The results that we describe below are an average of 10 realizations for each scenario. Thus, the reader should be aware that these results may be slightly different from the results from other model runs with the same assumptions.

The model outputs total water demand and water demand by sector (e.g., residential and CII) averaged over each decade. We chose not to display annual outputs for two reasons. First, there is significant variability from one year to the next, and this "noise" in the output can obscure the overall trend. This variability is caused by changing weather from one year to the next, as is simulated by climate models, and is reflected in our time series of irrigation demand. Second, saving annual data for large runs creates a data management problem, as it means storing 100 values for each county and for each simulation. When the model is run hundreds of times in stochastic or "Monte Carlo" mode this means storing millions of data points on an Excel spreadsheet, which causes the workbook to become unstable.

We do not attempt to deliver seasonal or monthly water demand forecasts. However, some scientists have projected that climate change is likely to increase peak demand in hot summer months, at exactly the same time that supply is most constrained.

Table 8. Summary of six simulations of urban water requirements run for Baseline (conservation to 2025) and Efficient (conservation continues to 2100).

	Scenario	Global climate model	Potential ET estimation method	Population projection	Climate Scenario	Efficiency Levels	2055 (maf)	2095 (maf)
1	Baseline with no warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	Static climate	20x2020 targets, ending in 2025*	9.6	12.3
2	Baseline with slower warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	SRES B1	20x2020 targets, ending in 2025*	9.9	12.8
3	Baseline with faster warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	SRES A2	20x2020 targets, ending in 2025*	10.6	13.9
4	Efficient with no warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	Static climate	20x2020 targets, continue to 2100**	8.9	10.8
5	Efficient with slower warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	SRES B1	20x2020 targets, continue to 2100**	9.1	11.2
6	Efficient with faster warming	Average of all 4	Hargreaves	DOF (Schwarm 2012)	SRES A2	20x2020 targets, continue to 2100**	9.2	11.5

Note: *We assume that conservation and efficiency measures will not cease completely at the end of 2020, but will continue until 2025. **Residential conservation and efficiency measures continue at the same rate until 2100. CII water factors are reduced 20% each decade between 2010 and 2029, and then remain the same from 2029-2099 in order to avoid unreasonably low CII water demand by the end of the century.

The results from the simulations show that climate changes are likely to cause modest increases in urban water use, particularly at higher greenhouse gas emissions levels. The effect is more pronounced under higher warming scenarios and the effect is greater at the end of the century than at mid-century. Both sets of scenarios – the Baseline scenarios and Efficient scenarios – follow a similar trajectory through 2029, in order to be in compliance with the 20x2020 legislation. However, after the 2019-2029 decade they diverge markedly as shown in Figure 15. After 2020, the Baseline scenarios begin to rise quickly, while the Efficient scenarios remain flat for several years and then rise more slowly.

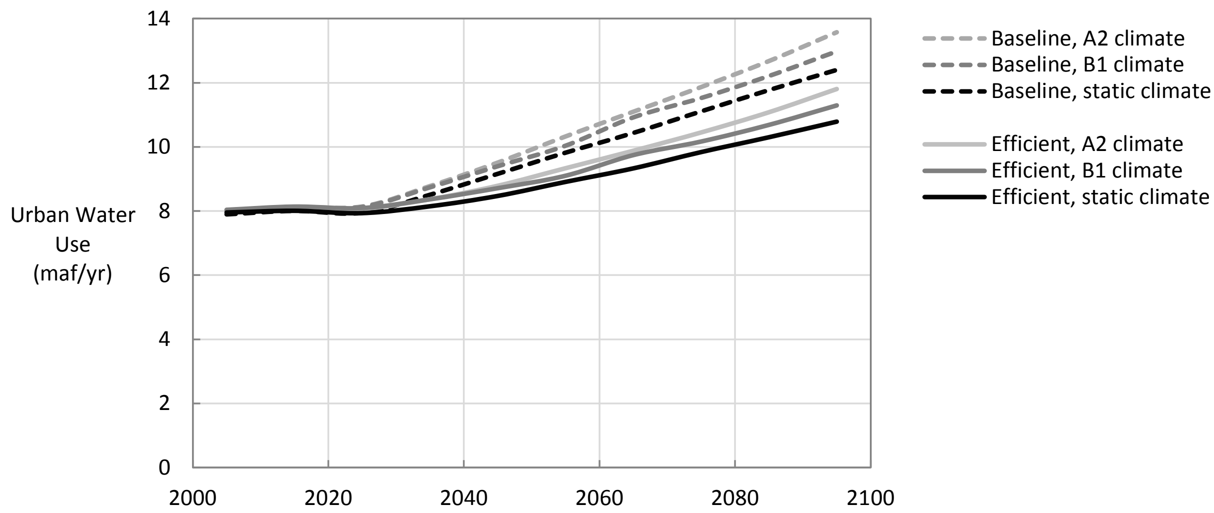


Figure 15. Time series of decadal average urban water use for the six simulations

The *Baseline with no warming* scenario begins with an average urban water demand of 198 gpcd for 2000-2009, which is close to the estimate of 192 gpcd published in the 20x2020 report (DWR et al. 2010) (see Table 7). By year 2020, per capita water use is reduced 15% to 166 gpcd, which is slightly above the 20x2020 target of 154 gpcd (DWR et al. 2010); however the model begins with a somewhat higher estimate of per capita water use. After 2020-2029, per capita use begins to rise again, to 172 gpcd by the end of the century. The increase in per capita water use is primarily due to two factors: changes in commercial and industrial water use and residential growth in warm areas where outdoor water use tends to be higher. By 2100, the *Baseline with no warming* scenario projects a total urban water demand of 12.4 maf.

In comparison, under the *Baseline with faster warming* scenario total urban water demand rises to 13.9 maf (Table 8), or 188 gpcd (Table 9), by the end of the century. The difference between the total urban water demand of these two scenarios, representing over 1 million acre-feet, is solely attributable to climate change. One million acre-feet is roughly enough water to satisfy the needs of an additional 6.7 million Californians (more than the growth expected by demographers in the next 10 years) or the amount of water that would be produced annually by 18 large desalination plants (the size of the proposed Carlsbad desalination plant, which would be the largest in the northern hemisphere) (Cooley et al. 2010).

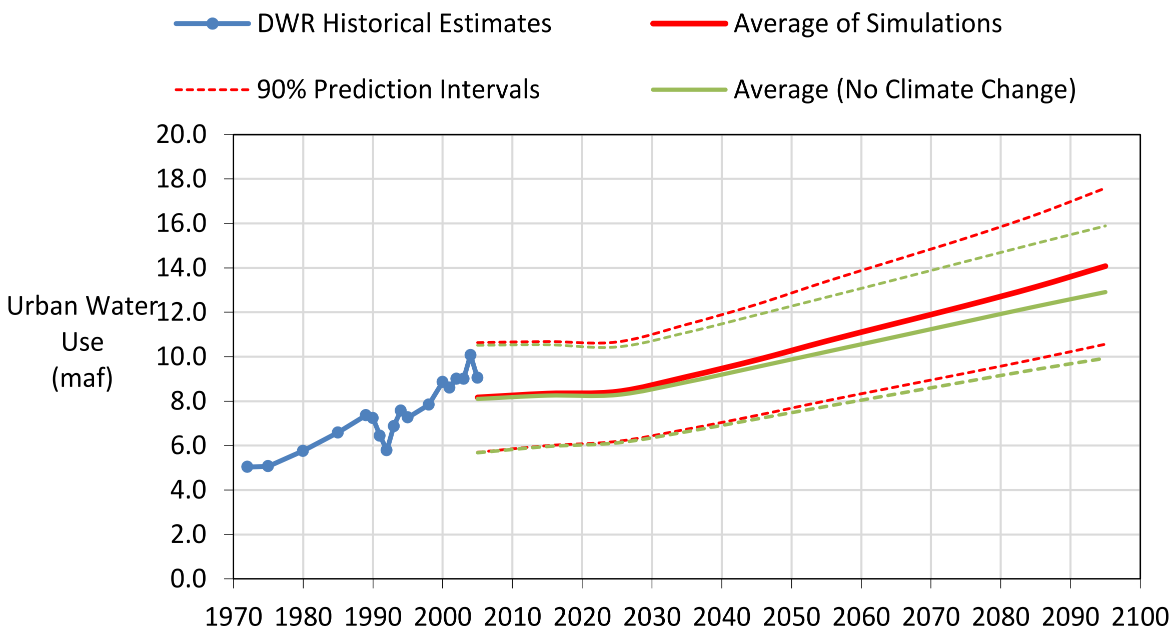


Figure 16. Simulated total water use with 90% prediction intervals for the *Baseline with faster warming* scenario, and the same scenario without the effects of climate change

The results can be visualized in a number of ways. Each scenario can be viewed as a time series graph (see Figure 16), which allows the user to view the trend in total urban water use over time in comparison to DWR historic estimates, with 90% prediction intervals. Results are also provided in a table format, which displays information about how urban demand is changing by sector (see Table 9). For example, in the *Baseline with faster warming* scenario, hotter temperatures drive higher levels of evapotranspiration, which in turn leads to increased residential outdoor water demand and large landscape water demand (see Table 9 for a breakdown of urban water demand by sector for the *Baseline with faster warming* scenario).

Table 9. Simulated water use by sector and by decade for the *Baseline with faster warming* scenario (maf/year)

Decade	Residential-Indoor	Residential-Outdoor	CII	Large Landscape	Total (maf/yr)	Total (maf/yr) without climate change
2000 - 2009	2.38	2.46	2.23	0.97	8.04	7.96
2010 - 2019	2.45	2.55	2.06	1.08	8.15	8.05
2020 - 2029	2.49	2.65	1.85	1.16	8.16	8.04
2030 - 2039	2.70	2.90	1.89	1.31	8.79	8.59
2040 - 2049	2.91	3.13	2.03	1.46	9.53	9.27
2050 - 2059	3.10	3.41	2.18	1.65	10.34	9.89
2060 - 2069	3.30	3.66	2.34	1.82	11.11	10.53
2070 - 2079	3.50	3.90	2.50	1.99	11.88	11.23
2080 - 2089	3.69	4.17	2.65	2.18	12.69	11.85
2090 - 2099	3.88	4.51	2.80	2.40	13.59	12.47

However, in the *Efficient with no warming* scenario, water conservation efforts continue past the 20x2020 deadline, leading to a total water demand of only 10.8 maf by the end of the century (Table 8). Yet, even in the *Efficient with faster warming* scenario, the gains made by continued conservation and efficiency improvements are eventually overcome by the impact of warmer climate conditions. In particular, after decreasing steadily to 158 gpcd, urban demand begins to creep up over the last two decades of the century, reaching 162 gpcd by 2100 (Table 10) despite continued expansion of conservation and efficiency improvements.

Policymakers and others may ask which emissions and climate change scenario is the most likely. Recent data collected and published by the International Energy Agency (IEA) shows that global emissions of CO_2 and other greenhouse gases continues to grow. In 2010, emissions were higher than even the highest scenario imagined by scientists at the IPCC (Raupach and Canadell, 2010). Despite a small slowdown in emissions following the 2008 economic crisis, emissions have rebounded strongly. Emissions are tracking well above the highest scenario (A1), which represents higher CO_2 levels and warming than the scenarios that have been used by water planners in California for the last several years (B1 and A2). If this trend continues, model users will want to pay more attention to the "faster warming" scenarios. Future efforts should incorporate higher emissions scenarios into water planning.

Table 10. Simulated water use by decade and by sector for the *Efficient with faster warming* scenario (gpcd)

Decade	Residential-Indoor	Residential-Outdoor	CII	Large Landscape	Total (gpcd)	GPCD change from 2000-2009	Total (gpcd) without climate change
2000 - 2009	59	72	55	25	211	-	209
2010 - 2019	55	67	47	25	194	-8%	192
2020 - 2029	51	61	37	24	173	-18%	170
2030 - 2039	48	58	33	24	163	-23%	159
2040 - 2049	46	56	34	24	159	-24%	154
2050 - 2059	44	55	34	25	159	-25%	152
2060 - 2069	43	54	35	26	158	-25%	150
2070 - 2079	42	54	35	27	158	-25%	149
2080 - 2089	42	54	36	27	159	-24%	149
2090 - 2099	41	56	36	29	162	-23%	149

Sensitivity Analysis

In the following sections, we report results of several sensitivity analysis runs. We conducted a simple analysis by varying a single input or parameter, while holding all other inputs and variables constant. This allows us to test the changes in the output of the model that are due to one factor at a time. This is one of the greatest advantages of computerized simulation modeling. In the real world, it would be very difficult to isolate the "signal" that climate change has had or will have on water consumption. There are simply too many other changes happening at the same time: the population is growing, industries shift, conservation efforts are expanded, etc. In the model, we can "turn off" all of these other changes, and examine climate in isolation, holding all other factors constant.

Effect of Climate Change

We created a "static" simulation that deactivates all of the factors that may change urban water consumption, varying the only input that is influenced by climate: the theoretical annual irrigation demand. In these simulations, all other factors are held constant, including population after 2010. The results show the potential magnitude of the warming trend and the increase in evapotranspiration on future urban water use in California. The differences in urban water use are reported below and shown in Figure 17.

	2050	2100
B1:	+0.33 maf	+0.53 maf
A2:	+0.53 maf	+0.85 maf

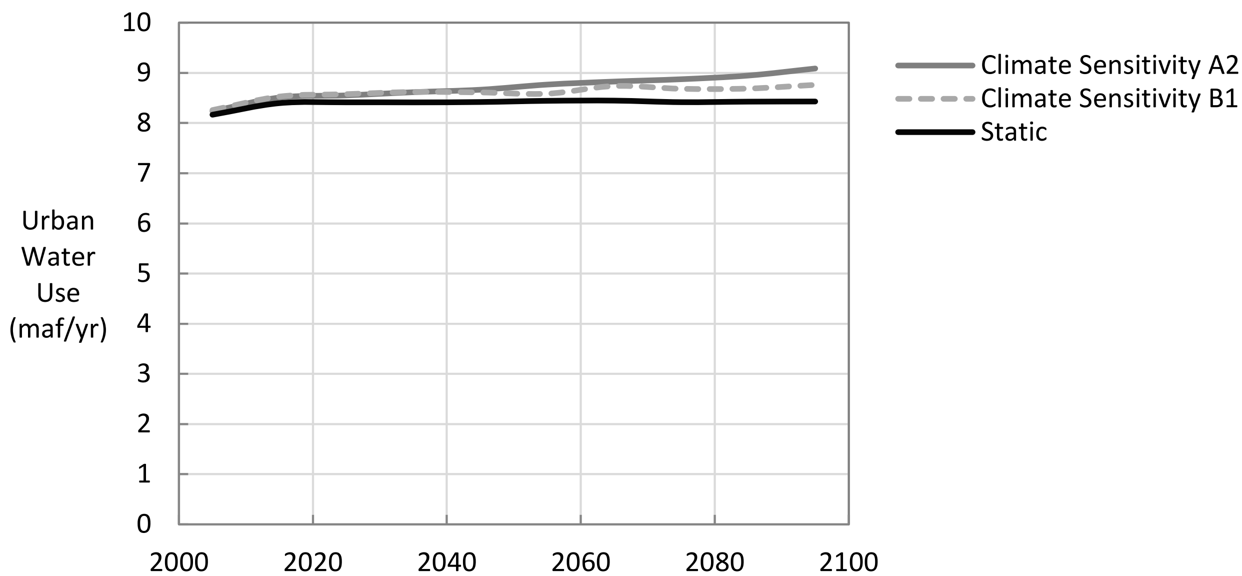
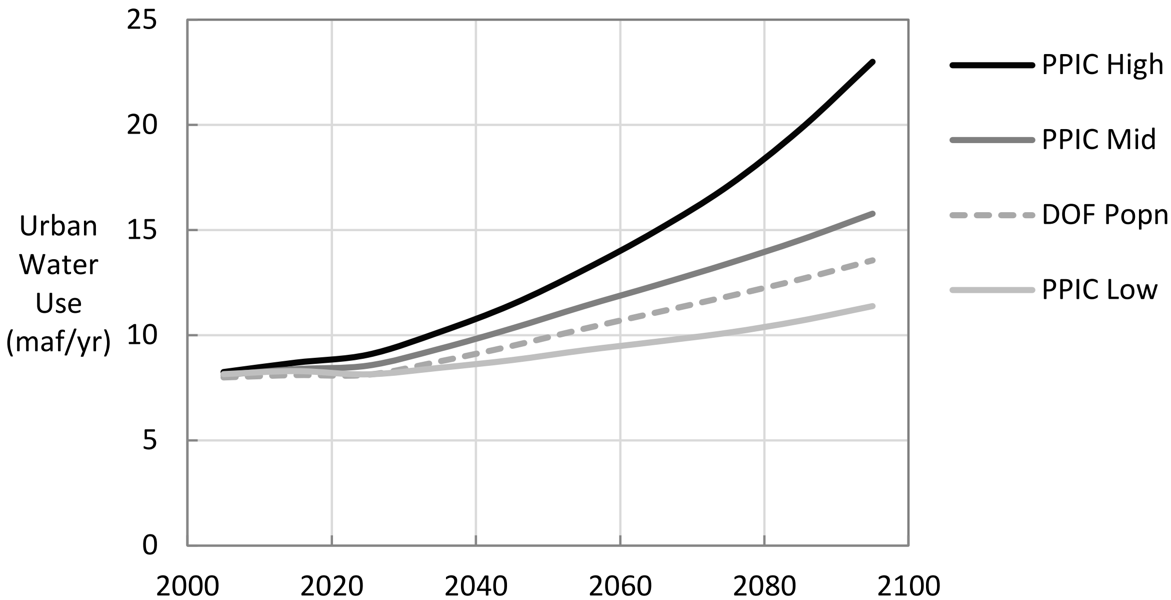


Figure 17. Simulated urban water use in California with varying climate scenarios only

Effect of Population Growth or Decline

As expected, the choice of population scenario has a large effect on the state's total future urban water use. The effect of population growth is somewhat offset by the fact that new homes tend to use less water indoors, because they are fitted with modern, more efficient appliances and fixtures. The plots in Figure 18 show the effect of various population scenarios on water use. These simulations are based on Scenario 3, Baseline with Faster Warming, and hold all inputs equal other than the population. The highest population scenario considered, PPIC's High Growth scenario, projects water use to more than double to 23 maf. All the scenarios include some level of increased urban water demand; in other words, none of them forecast a net decline.



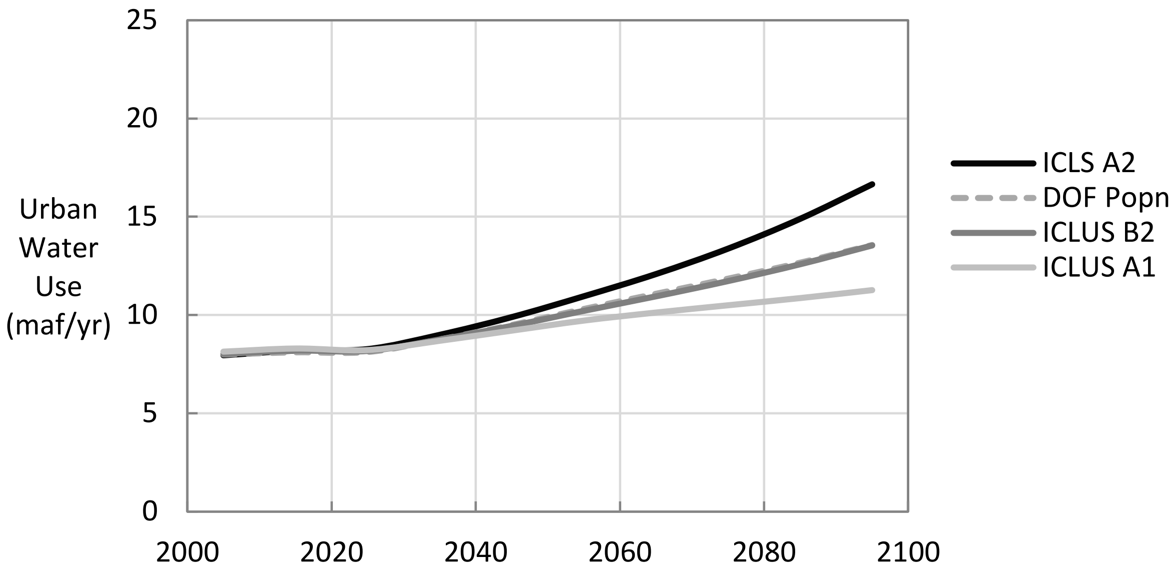


Figure 18. Simulated urban water use in California under various population forecasts by the state Dept. of Finance, EPA's ICLUS modeling group (first chart), and the PPIC (second chart)

Effect of Conservation and Efficiency

The rates at which conservation and efficiency improvements are put in place, and the degree to which they are continued in the future, has a major effect on future urban water use. As shown in Figure 19, when all conservation is turned off, per capita rates of water use remain steady, and water use continues to grow linearly, in proportion with population, reaching 16.5 maf by the end of the century. For our baseline scenario, we programmed the model to include the 20x2020 conservation targets. If conservation efforts end in 2025, per capita use rates cease to decline and begin to creep upward slightly. This is a result of the climate signal and growth in inland valleys, both of which cause higher outdoor water use. We should note that our model only includes five indoor and two outdoor conservation technologies. We have not imagined any innovative technologies to conserve water that may be invented in the future. Further, under the simulations shown here, we have not attempted to capture conservation resulting from behavior change or higher water prices.

If conservation programs continue at the same rate necessary to achieve the 20x2020 targets, there are diminishing returns, because there are fewer households in the state still using old, inefficient fixtures to target. However, aggressive and ongoing conservation can cause water use to decline slightly, despite a growing population and a hotter climate. If additional conservation is combined with a lower population scenario, it result in very slow increases in urban water use over the long term, with future water use only 20% higher in 2100 than today, despite a population that is 30% larger. Below, we used EPA's ICLUS A1, which forecasts 47 million Californians in 2100 as opposed to 66 million when DOF's projections are extrapolated to 2100.

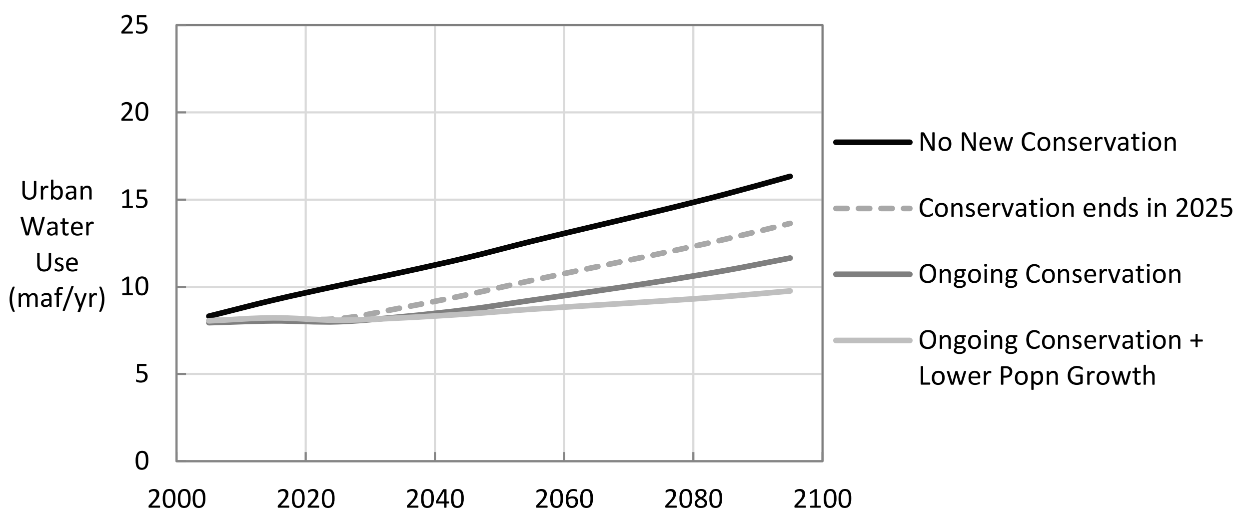


Figure 19. Simulated urban water use under four scenarios of conservation and population

Conclusions

It is impractical to ignore climate change in water demand forecasting. As the AWWA noted as long ago as 1997:

> "Although water management systems are often flexible, adaptation to new hydrologic conditions may come at substantial cost. Water professionals should consider reexamining engineering design assumptions, operating rules, system optimization, and contingency planning for existing and planned water management systems under a wider range of climate conditions" (AWWA 1997).

For this study, we have applied a simulation modeling approach to forecast future urban water use in California with climate change. Demand forecasting is both an art and a science. Future water use depends on a range of factors—technological, societal, political, and economic—many of which are uncertain. Rather than develop a single estimate, we have created a flexible modeling tool that allows users to conduct scenario analysis, comparing how a range of factors is likely to affect future patterns of water use in California.

There are several major conclusions of this scenario-analysis:

- Climate change is likely to contribute to an increase in future urban water demand in California. Under the highest climate change scenario modeled (SRES A2), warming may cause an increase in urban water use of more than 1 maf by 2100.
- The rate of temperature changes are reflected in water demand; demand increases more quickly under higher greenhouse gas emissions scenarios than under more moderate scenarios.
- The effects of climate change are likely already being felt. Temperature, evapotranspiration, and irrigation demand are higher in our model for the period 2000-2009 than for the period from 1960-1990. This resulted in small, but observable, differences of up to 0.1 maf for contemporary water demand under the current climate compared to 20th century climate.
- California's stated target of reducing per capita urban water demand by 20% by the year 2020 is likely to keep overall urban water use at or near current levels over the next decade. However, if efforts at improving water conservation and efficiency end in 2020, per capita use begins to quickly rise again, driven largely by rising population growth in some of the driest parts of the state where outdoor water demand is high.
- Continued implementation of new water conservation and efficiency efforts can offset population growth. When we simulated a continuation of conservation and efficiency programs at the levels necessary to meet the 20x2020 goals indefinitely, water use increased; with ongoing and aggressive conservation, urban water use increases by 40% despite a doubling of the state's population.
- The commercial and industrial sector can continue to grow while remaining "water-neutral" (i.e. not consuming more water) if it continues to improve its water use efficiency. Although it is difficult to simulate conservation in the commercial and industrial sectors due to the diversity of water uses, the literature abounds with descriptions of successful water-saving practices and technologies.

- There is significant year-to-year variation in water use, largely driven by plant watering needs for outdoor landscaping. In hot, dry years, evapotranspiration increases, and fewer of the plants' water needs are fulfilled by rain and soil moisture, driving up overall water demand.
- New "greenfield" development can cause large increases in water use, even with consistent implementation of local Water-Efficient Landscape Ordinances. Better approaches to limiting demand may be to promote water-neutral development, encourage the planting of natives that require less water, and minimize new irrigated areas in urban and suburban settings by promoting urban infill or "brownfield" development.
- Population declines do not necessarily result in linear decreases in water use, due to the spatial patterns of growth and decline inside the state. In other words, it not only matters how much we grow, but where we grow. Shifts in population to hotter, drier areas in the Great Central Valley and in Southern California (present in several of the population scenarios we considered) can increase overall water use.

Recommendations for Future Study

The framework presented above helps incorporate information from climate models into urban water demand forecasting. More theoretical work should be done to explore the links between climate change and evapotranspiration demands, as well as other links to urban water use.

More work could also help to disentangle the degree to which customers respond to increased prices or water scarcity with behavioral versus technological means, and how long these effects last. For example, urban water consumption was cut dramatically in Australia during its 9-year drought. To the surprise of many analysts, consumption has not rebounded as much as expected after a return to normal conditions, even when controlling for the increased number of efficient toilets, rain barrels, etc. In other words, a permanent behavioral shift seems to have occurred. We are not aware of any studies of the "rebound" in water use following the lifting of California's 2007-2009 drought, but a better understanding of this phenomenon may aid future drought management and conservation efforts.

Effort to collect more accurate and high resolution water use data for the state would assist greatly at refining estimates of water use, and developing more accurate models of future water use. In particular, California is long overdue for a comprehensive assessment of current commercial, industrial, and institutional water use, by sector. Improved understanding of residential landscape areas and water applications would also help urban water planners more accurately assess future supply and demand challenges.

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Appendix A: Default Values for Residential Water Use in California

Option/Parameter	Value	Source	Notes
Baseline indoor water use, gphd	175 gphd	California Single Family Water Use Efficiency Study (DeOreo et al. 2011, 136)	This parameter is indoor water use in households (not per capita). We assume that indoor water use is similar across geographic regions, unlike outdoor use, which varies as a function of climate. A recent study found average indoor water use in single-family homes of 175 gphd (DeOreo et al. 2011, p. 136).
Median landscaped area (single-family residence)	2,645 ft^2	East Bay Municipal Utility District's 1995 Water Conservation Baseline study	The study collected empirical data on median landscaped area for both single- and multi-family residences.
Median landscaped area (multi-family residence)	1,970 ft^2	East Bay Municipal Utility District's 1995 Water Conservation Baseline study	The study collected empirical data on median landscaped area for both single- and multi-family residences.
Average plant factor of landscape (existing landscapes)	0.64	California Single Family Water Use Efficiency study (DeOreo et al 2011, 92)	Calculated based on data provided in Table 16: Statistics extracted from outdoor summary table and plant factors provided in Table 12: Annual Crop Coefficients.
Average irrigation efficiency (existing landscapes)	0.6		Typical efficiency of sprinklers.
Average irrigation efficiency (new landscapes)	0.7	Model Water-Efficient Landscape Ordinance (WELO), California Code of Regulations, Title 23, Division 2, Chapter 2.7	More information available at the Department of Water Resources website: http://www.water.ca.gov/wateruseefficiency/landscapeordinance/
Savings associated with efficient toilets (1.6 gpf)	9.8 gphd	California 20x2020 Task Force, Public Draft Technical Memorandum Task 4 – Potential Conservation Savings from Current Actions, November 8, 2008	
Savings associated with efficient washing machines	14.4 gphd	California Urban Water Conservation Council's Cost Effectiveness Analysis Tool	This is an Excel-based tool that incorporates a series of spreadsheets.
Savings associated with efficient showerheads (1.5 gpm)	12.2 gphd	California 20x2020 Task Force, Public Draft Technical Memorandum Task 4 – Potential Conservation Savings from Current Actions, November 8, 2008	4.5 gpcd multiplied by 2.7 people per household = 12.2 gphd
Savings associated with leak repair	25 gphd	California Single Family Water Use Efficiency Study (DeOreo et al. 2011)	DeOreo et al. (2011) reports an average leak of 31 gpd. We assume that there will always be some amount of leakage and use a default value of 25 gphd.

Option/Parameter	Value	Source	Notes
Savings associated with weather-based irrigation controllers	7.3%	Evaluation of California Weather-Based "Smart" Irrigation Controller Programs (Mayer et al. 2009).	We chose to use the average, weather-normalized change in outdoor use for residential sites (Table 51, page 103).
Savings associated with faucet aerators (1.5 gpm)	35 gphd	California's Next Million Acre-Feet: Saving Water, Energy, and Money Appendix A: Technical Documentation (Cooley et al. 2010).	

Appendix B: Water Factors for CII Water Use in California

Sector	Subsector	Water Factor (GED)[1]	Source	Name of sector in source	Notes
Construction, Natural Resources, & Mining	Natural Resources & Mining	N/A			Not an urban use.
	Construction	31	Hannaford 2004		Converted from a 365 to a 225 day year.
Manufacturing	Wood Products	2,144	Gleick et al. 2003	Lumber and Wood Products	
	Nonmetallic Mineral Products	1,304	Gleick et al. 2003	Stone, clay, glass, and concrete	Category in Gleick 2003 is SIC system, "nonmetallic mineral products" is corresponding NAICS code, but category may not match up exactly.
	Primary Metals	1,318	Gleick et al. 2003	Primary metal industries	
	Fabricated Metal Products	738	Gleick et al. 2003	Fabricated metal products	
	Machinery	110	Gleick et al. 2003	Industrial machinery and equipment	
	Computer and Electronic Products	203	Gleick et al. 2003	"High Tech"	Category in Gleick 2003 groups the following sub-industries: semiconductor devices, PCB manufacture and assembly, computer and office equipment, rest of high tech.
	Electrical Equipment and Appliances	284	Gleick et al. 2003	Electrical and electronic equipment	
	Transportation Equipment	228	Gleick et al. 2003	Transportation equipment	
	Furniture and Related Products	53	Gleick et al. 2003	Furniture and fixtures	
	Miscellaneous Manufacturing	86	Gleick et al. 2003	Misc. manufacturing industries	
	Food Manufacturing	1,967	Gleick et al. 2003	Food and kindred products	
	Beverages and Tobacco Products	2,169	Gleick et al. 2003	Total Beverage Industry	There are no tobacco manufacturers in California.
	Textile Mills	1,660	Gleick et al. 2003	Textile industry	
	Textile Product Mills				
	Apparel				
	Leather and Allied Products	32	Gleick et al. 2003	Leather and leather products	
	Paper and Paper Products	1,000	Gleick et al. 2003	Paper and allied products	

	Printing and Related Support Activities	98	Gleick et al. 2003	Printing and publishing	
	Petroleum and Coal Products	11,399	Gleick et al. 2003	Petroleum and coal products	
	Chemicals	833	Gleick et al. 2003	Chemicals and allied products	
	Plastics and Rubber Products	120	Gleick et al. 2003	Rubber and misc. plastics products	
Transp., Trade, & Utilities	Wholesale Trade	95	Hannaford 2004	Wholesale Trade	Converted from a 365 to a 225 day year.
	Retail Trade	152	Gleick et al. 2003	Misc. retail	Does not include grocery
	Transportation and Warehousing	None found	None found	None found	Gleick et al 2003 (Appendix C, Table C-2, page 12) break this category down into several sub-sectors (local and interurban passenger transit, U.S. postal service, air transport, etc.). WNWN categorizes them all as "offices," but the widely varying water use suggests that they shouldn't be lumped into an "offices" category. I can't find current sector employment at this level to do a weighted average.
	Utilities	52	Gleick et al. 2003	Electric, gas, and sanitary services	From Dziegielewski et al. 1990
Information		47	SCVWD 2008	Offices[2]	Office water use likely does not encompass all water uses (e.g. for print publishers). However, we do not have data on publishing water use.
Financial Activities		47	SCVWD 2008	Offices[2]	Converted from a 365 to a 225 day year.
Professional & Business Services		47	SCVWD 2008	Offices[2]	Converted from a 365 to a 225 day year.
Educational and Health Services	Educational Services	237	Gleick et al. 2003	Educational services	
	Health Care and Social Assistance	155	Gleick et al. 2003	Health services	
Leisure and hospitality	Arts, Entertainment, and Recreation	733	Gleick et al. 2003	Amusement and recreational services	
	Accommodation and Food Services	261			Weighted average of water factor for accommodation and water factor for food services, based on statewide mix of these two sectors in California in the year 2008. Ratio of employees

					in food services vs. accommodation is approximately 5:1 (see spreadsheet "Industries by county"). The water factor for accommodation ("hotel industry" in Gleick 2003) is 240 GED. The water factor for food service ("restaurants" in Gleick 2003) is 265. While the ratio of employees in the accommodation and food services sectors will be less accurate for forecasted data, because their water factors are relatively similar, it is not likely to significantly affect the results.
Government		47	SCVWD 2008	Offices[2]	Converted from a 365 to a 225 day year.
Military		None found	None found	None found	
Other Services		N/A			Too broad of a category to estimate water use.
[1] Based on a 225-day year					
[2] The water factor for offices that was used in Waste Not, Want Not of 127 gallons per employee per day (GED) was found to be several times that of measured office water use in two more recent California studies - Hannaford 2004, which reports office water use at 18.3 GED; and SCVWD 2008 (which reports office water use at 29 GED -both based on a 365 day year). Because of the large discrepancy, and the likelihood that office water use has decreased since the data used in Waste Not, Want Not was collected, we decided not to use that number. Instead, the water factor reported in SCVWD 2008 was used; data from SCVWD was used instead of data from Hannaford 2004, which collected water use data in San Francisco, because water use in San Francisco is generally lower than average for the state, particularly due to its low cooling requirements, and therefore would likely underestimate statewide office water use.					

Appendix C: Default Values for Energy and Emissions

Option/Parameter	Value	Source	Notes
Energy intensity of water – Northern California	1,500 kWh/MG	California's Water–Energy Relationship: Final Staff Report (Klein et al. 2005)	The sum of the electricity use associated with "Water Supply and Conveyance", "Water Treatment," and " Water Distribution" (Table 1-3 on page 11).
Energy intensity of water – Southern California	10,250 kWh/MG	California's Water–Energy Relationship: Final Staff Report (Klein et al. 2005)	The sum of the electricity use associated with "Water Supply and Conveyance", "Water Treatment," and " Water Distribution" (Table 1-3 on page 11).
Energy intensity of wastewater – Northern California	2,500 kWh/MG	California's Water–Energy Relationship: Final Staff Report (Klein et al. 2005)	The electricity use associated with "Wastewater Treatment" (Table 1-3, page 11).
Energy intensity of wastewater – Southern California	2,500 kWh/MG	California's Water–Energy Relationship: Final Staff Report (Klein et al. 2005)	The electricity use associated with "Wastewater Treatment" (Table 1-3, page 11).
Emissions factor	0.20 kg CO_2-eq/kWh		The EPA produces the Emissions and Generation Resource Integrated Database (eGRID), a comprehensive data source for electricity emissions factors for 26 subregions across the United States. These data are updated periodically to better reflect changes in emissions from the U.S. electricity grid. The newest version, released in February 2011, provides data for the year 2007.