QUANTIFIED SCENARIOS OF 2030 CALIFORNIA WATER DEMAND

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David G. Groves
Pardee RAND Graduate School

Scott Matyac and Tom Hawkins
California Department of Water Resources

Acronyms

BMPs	Best Management Practices
CC	Central Coast
CF	Consumed Fraction
CR	Colorado River
CT	Current Trends
CUWA	California Urban Water Agencies
CVPIA	Central Valley Project Improvement Act
CWP	California Water Plan (DWR bulletin B-160)
DOF	California Department of Finance
DWR	California Department of Water Resources
ET	Evapotranspiration
ETAW	Evapotranspiration of Applied Water
HH	Household
HR	Hydrologic Region
ICA	Irrigated Crop Area
ILA	Irrigated Land Area
LRI	Less Resource Intensive
LWU	Low Water Use
ma	Million Acres
MA	Multi-cropped Area
MAF	Million Acre-feet
MF	Multi-family (as in houses)
MOU	Memorandum of Understanding
MRI	More Resource Intensive
NC	North Coast
NL	North Lahontan
NOC	Naturally Occurring Conservation
PCMR	Potential Multi-cropping Ratio
SC	South Coast
SF	San Francisco Bay and Single family (as in houses)
SJ	San Joaquin River
SL	South Lahontan
ta	Thousand Acres
TAF	Thousand Acre-feet
TL	Tulare Lake

Preface

This article presents collaborative work between David Groves, a doctoral fellow at the Pardee RAND Graduate School, and Scott Matyac and Tom Hawkins of the Department of Water Resources Division of Planning and Local Assistance. This work is also part of David Groves' forthcoming doctoral thesis and was funded by a grant from the Pardee RAND Graduate School (www.prgs.edu).

1 Introduction

Assuring sufficient, high-quality water supplies for California over the next several decades will be a great challenge for water resource managers. As described in Volume 1 of the 2005 California Water Plan (CWP), the demand for water is expected to increase in response to population and economic growth and to meet current and future ecosystem restoration objectives. Meeting increasing demand will be particularly challenging as additional new supplies will be costly and the vital agricultural sector will continue to require most of the State's water supply for food and fiber production.

California water resource planners base their management strategies and investments, in part, on forecasts of future water demand. Past California Water Plans have sought to estimate the "gap," or difference between anticipated supply and projected demand, and to develop strategies to reduce this gap. Critics have argued, however, that a single forecast of the difference between supply and demand is likely to be too inaccurate to successfully guide long-term planning. Forecasting water supply is difficult due to the influence of many uncertain and poorly understood factors (such as the effects of climate change upon surface water supplies and the degradation of the State's aquifers due to pollution – see Chapter 4, Volume 1). Forecasting the demand for water is also problematic due to uncertainty about population and economic growth; changes in water used by households, businesses, and public facilities; agricultural land use and production; the needs for irrigation; and future requirements and public desire for increased water supply dedication to the environment.

The consequences of incorrectly forecasting the demand for water may become severe in coming years. As California's developed water supply is fully allocated in all but the wettest years, societal and environmental costs could be large if future water demand exceeds planners' expectations. At the same time, due to the large economic, social, and environmental costs of securing new water supplies, over-preparing for future water needs is equally problematic.

1.1 Scenarios for Water Resources Management and Planning

Analysts and decisionmakers often construct scenarios to better understand how decisions or policies may fare under a wide range of plausible future conditions. This is particularly useful when there is deep uncertainty[1] about how the future may evolve. Sometimes these scenarios are purely descriptive and are

[1] The term deep uncertainty refers to both parametric and structural uncertainty. Uncertainty about a parameter of a governing equation, such as population growth rate, is an example of parametric uncertainty. Uncertainty about the

designed to stimulate analysts and decisionmakers to consider outcomes that had previously not been considered due to limited resources for analysis or because they are viewed as unlikely or believed to be incongruent with current decisions and policies. Sometimes the scenarios are quantitative and represent discrete outcomes drawn from a range of possible outcomes. When such scenarios are generated using a probabilistic forecast model, probabilities of the scenarios can be easily reported. Assigning them probabilities may be inappropriate, however, if the scenarios describe outcomes of highly uncertain processes.

Collectively, a set of scenarios provides a broad look at how the future may evolve in response to (1) driving forces largely outside the control of policymakers (exogenous factors) and (2) policy-induced forces designed to shape future conditions (policy levers). Recognizing that a single forecast of water demand is unlikely to characterize the actual future water demand, decisionmakers often tailor their policies to be less sensitive to the key uncertainties about the future (that is, they make the policies more robust). Such a "scenario analysis" approach can help water resource managers and interested stakeholders better understand the inherent uncertainties about future water management and, in turn, help reveal more innovative and successful management strategies. Scenario analysis can also help guide more detailed assessments of particularly interesting cases using complex models.

The 2005 California Water Plan, in contrast to earlier Water Plans, introduces a long-term analytic effort to develop several scenarios of water supply and demand and to evaluate how various water management strategies (or response packages) would perform in each. To initiate this effort, the 2005 Water Plan staff and Advisory Committee developed three narrative scenarios of future water demand in California (see Volume 1, Chapter 4). These scenarios of water demand are strictly narrative, do not reflect any new water management strategies (such as new water efficiency programs), and do not address water supplies. For the 2010 Water Plan, DWR expects to build the necessary analytic tools to develop several quantitative scenarios of demand and supply and to evaluate how different response packages might perform across them.

1.2 Objective of Article

This article reports on the preliminary results of a collaborative project to:

(1) build a simple model to estimate scenarios of future water demand in California, and

(2) use this model to produce quantitative estimates of four water demand scenarios, three of which are designed to reflect the narrative scenarios developed for the 2005 California Water Plan.

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relationships among two or more of the parameters, such as the effect of climate change upon water resources, is an example of structural uncertainty.

The model provides estimates of the quantity of water demanded out to the year 2030 under specified demographic, economic, agricultural, and water management conditions. Some of these conditions are under the influence of water managers, such as the price for water, the behavior of water users, and the technical efficiency of water processing and distribution equipment. These scenarios of future water demand, therefore, should not be used solely to estimate future supply needs. Instead these scenarios should provide a starting point from which to evaluate various management options including (1) moderating water demand through demand management programs, changes in water prices, and efficiency programs or (2) increasing effective water supplies through reuse programs, new imports, more water storage and conveyance, and desalinization.

2 A Scenario Generator for Future California Water Demand

We created a simulator that estimates plausible scenarios of urban, agricultural, and environmental water demand for each of California's ten hydrologic regions (Figure 1). Urban water demand includes the demand by households, the commercial and industrial sectors, and public institutions. Environmental water demand reflects the amount of water that the water management system would allocate to environmental purposes. It does not necessarily reflect all environmental needs. Each scenario is based upon average current conditions that evolve over time according to scenario-specific parameters representing the major factors that are believed to influence future water demand. Scenarios are distinguished from one another by the specification of a unique set of factors representing various trends and parameters in the model.

Urban water demand is estimated by quantifying plausible trends of households, employees, persons (as a proxy for institutional water use), and the per unit demand for each from the year 2000 (an average year climatically for most of California) to 2030. Future urban water demand is then computed by multiplying these future demand units and their average water use. Agricultural water demand is estimated by specifying future state-wide changes in irrigated land area and multi-cropping, and trends in parameters that define how much water is needed per area of crop. Changes in crop-mix are estimated through a set of rules that apportion the statewide changes to the hydrologic regions. Future environmental water demand is based upon current environmental water use (which currently is insufficient to meet all environmental needs) and a scenario-specific percentage of year 2000 unmet environmental water need. This rudimentary method is only a placeholder for a more thorough treatment of future environmental water needs and allocations. Such a treatment would need to also consider water supplies and variability (seasonal and interannual).

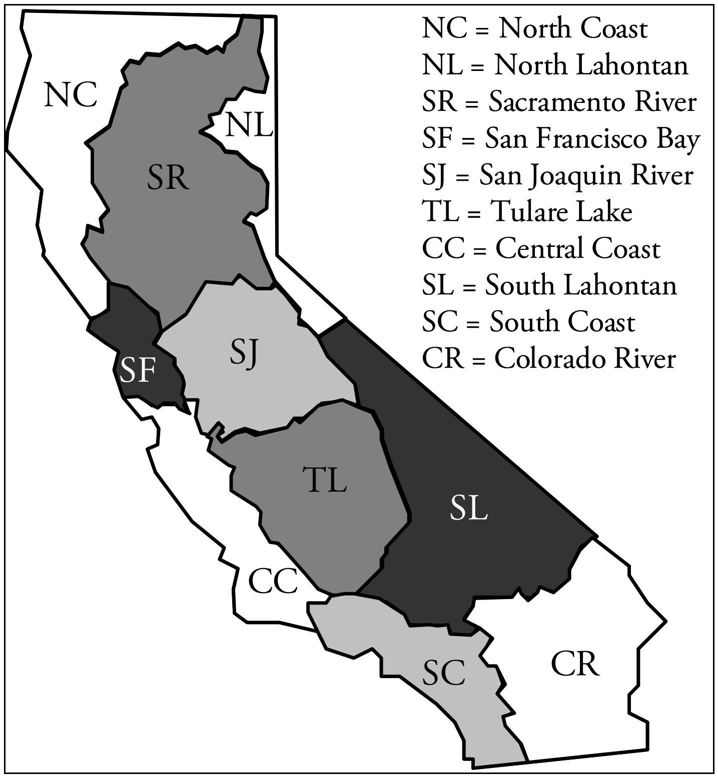

Figure 1: California's ten hydrologic regions.

This approach for estimating demand is often referred to as a "top-down" modeling approach, as individual uses of water are aggregated by end-user (e.g. persons of a household, employees of a business, and users of public institutions). This method is well suited for considering how changes in the number of water users and changes in their average water use will impact future demand. Alternative "bottom-up" approaches estimate future water use by multiplying the numbers of water-using devices, such as toilets, by their technical water requirements. This approach, used recently by Glick et al. (2003) to assess California water conservation potential in the urban sector, is particularly useful for evaluating the impact of specific technologies or water use practices and thus can establish state or region-wide water use targets.

We believe that these two approaches are complementary. Although our method does not explicitly evaluate specific water use technologies or practices, our top-down method uses aggregate water use coefficients that can reflect different levels of technical efficiency, as estimated by bottom-up studies. By varying these parameters across scenarios, our model can represent futures in which adoption of the most efficient technologies is slow and futures in which newer more-efficient technologies come on the market and are quickly adopted.

This scenario generator is purposefully simple to be transparent, easily modifiable, and readily interpretable. Although not all relevant processes are explicitly modeled, their effects are captured in aggregation. Moreover, the simplicity of design allows the generator to be informed by higher resolution models. Specifically, the California water demand scenario generator mimics the general results of detailed probabilistic water demand forecasting tools, such as IWR-MAIN and CALAG, and enables the user to quickly and interactively generate variations of the most probable forecast to visualize and understand alternative plausible outcomes. Finally, transparency and interpretation of the generator approach are enhanced through the use of a graphical modeling environment, and the overall design encourages collaboration by fostering communication among analysts, decisionmakers, and stakeholders.[2] Figure 2 shows an example of the graphical modeling environment used in this analysis.

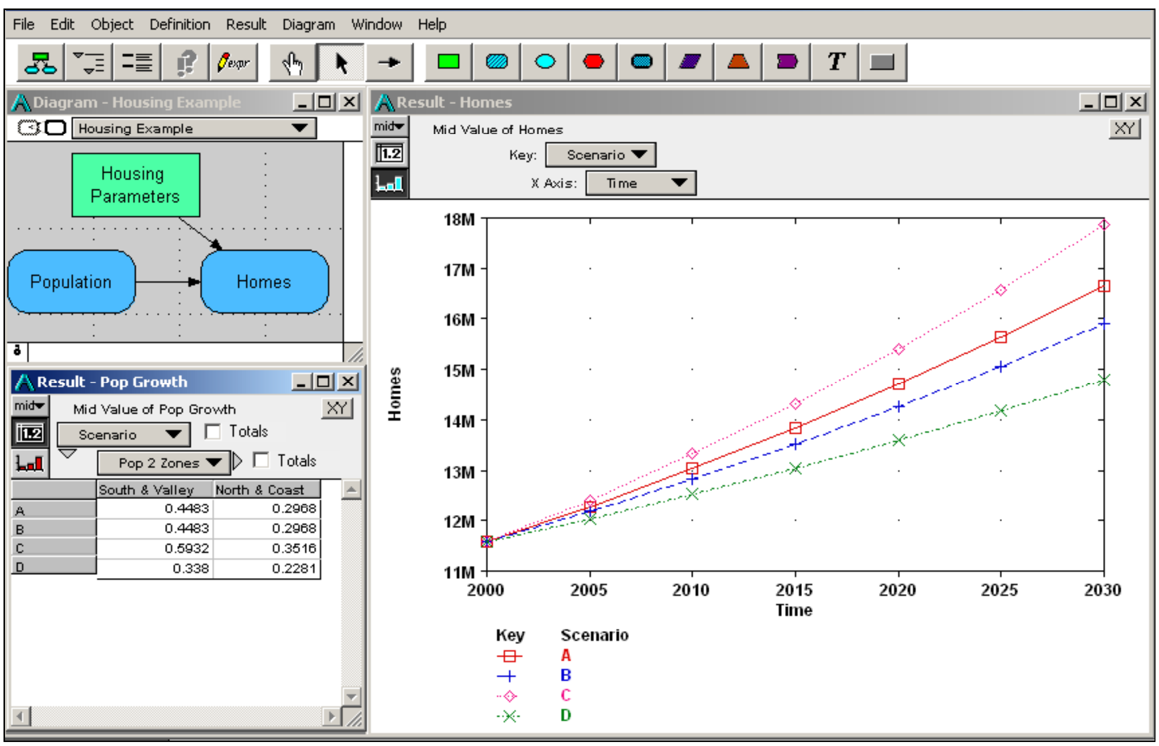

Figure 2: Screen-shot of the graphical interface of the water demand scenario generator. The upper left shows a portion of the influence diagram defining the relationships between population, other parameters, and the number of homes. In the lower left is a table defining the population growth rates for two regions of the state underlying the four scenarios. The graph on the right shows the statewide housing estimates for the four different scenarios. Changes to the table will lead to alternative estimates of the number of homes.

[2] The California water demand scenario generator was implemented in a graphically-based computer modeling environment called Analytica™, available from Lumina Decision Systems (www.lumina.com).

2.1 Urban Demand Module

2.1.1 Overview

Scenarios of urban water demand are quantified by estimating demand independently for each hydrologic region and following end-use: residential, commercial, industrial, and public/institutional. The total urban demand (*UrbanDemand*) for each hydrologic region (*HR*) and year (*y*) is the product of the number of demand units (*DemandUnit*) and their water use coefficients[3] (*UseCoefficient*) summed over each demand unit-type (*U*), plus other uses (*Other*) which includes losses and intentional groundwater recharge:[4]

$$UrbanDemand_{HR,y} = \sum_{U=unit} \left(DemandUnit_{U,HR,y} \cdot UseCoefficient_{U,HR,y} \right) + Other_{HR,y} \quad (1)$$

Table 1 lists the demand units and factors that influence the time evolution of the demand units for each end-use category

Table 1: Urban end-use demand categories and their demand units.

Urban end-use category	Demand unit	Factors influencing future demand units
Residential	Single and multi-family houses	Population, percentage of housed population, share of house type
Commercial	Commercial employees	Population, employed fraction, share of commercial employment
Industrial	Industrial employees[5]	Population, employed fraction, share of industrial employment
Public/institutional	People	Independent estimate

2.1.2 Population

Population is a primary driver of urban water demand – housing growth, employment growth, and public sector water use are all correlated with population growth.[6] We model population to increase according

[3] A use coefficient is the water used by an individual demand unit per time period in units of water volume over demand unit.

[4] Intentional groundwater recharge is classified as a demand in this model to conform to DWR water balance accounting. For applications in which this model is coupled to supply-based models, one should assure that groundwater recharge is not double counted.

[5] Industrial water use is largely process-driven, and using industrial employees as a proxy for industrial water use may not always be appropriate. As state-wide industrial use is a small percentage of total urban use, we chose to use employees to simply model industrial water use. More detailed studies should use process-based method for industrial water use.

[6] We use the word correlation here because in some instances population growth leads to the construction of new homes and creation of new jobs, and in other instances, it's the other way around; i.e., the construction of new homes and the creation of new jobs attracts new population.

to a scenario-specific annual growth rate for each hydrologic region (*r*).[7] The population in region *HR* and year *y* is then:

$$Pop_{HR,y} = Pop_{HR,2000} \cdot (1 + r_{HR})^{y-2000} \tag{2}$$

2.1.3 Housing

The future stock of single-family (SF) and multi-family (MF) housing is a function of population changes, changes in the percentage of the population living in homes, the mean size of SF and MF homes, and the relative share of SF to MF homes.

The relative share of single family homes (*Sfshare*) in 2000 is computed from 2000 data of the numbers of single family homes (*SFhomes*) and multifamily homes (*MFhomes*):

$$SFshare_{HR,2000} = \frac{SFhomes_{HR,2000}}{\left(SFhomes_{HR,2000} + MFhomes_{HR,2000}\right)} \tag{3}$$

The number of people living in permanent housing (*HousedPop*) in 2000 is calculated from the number of homes in 2000 and the mean household size in 2000 (*SFhhsize* and *MFhhsize*):

$$HousedPop_{HR,2000} = SFhomes_{HR,2000} \times SFhhsize_{HR,2000} + MFhomes_{HR,2000} \times MFhhsize_{HR,2000} \tag{4}$$

The share of the population living in houses (*HousedPopShare*) is, therefore, the housed population divided by the total population. Household size, the share of single family homes, and the housed population percentage change linearly from 2000 to 2030 by scenario-specific percentages. The number of SF homes in year *y* is then calculated as:

$$SFhomes_{HR,y} = \frac{\left(HousedPopShare_{HR,y} \cdot Pop_{HR,y}\right)}{\left(SFhhsize_{HR,y} + \frac{MFhhsize_{HR,y}}{SFShare_{HR,y}} - MFhhsize_{HR,y}\right)} \tag{5}$$

and the number of MF homes in year *y* is calculated as:

$$MFhomes_{HR,y} = \frac{SFhomes_{HR,y} \cdot \left(1 - SFshare_{HR,y}\right)}{SFshare_{HR,y}} \tag{6}$$

2.1.4 Employment

The number of employees in the commercial and industrial sectors for each hydrologic region is related to the population of each hydrologic region and is represented by an employment rate. The year 2000 employment rate is:

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[7] Plausible growth rates can be informed by the results of detailed demographic models such as those used by the California Department of Finance.

$$EmployRate_{HR,2000} = \frac{\left(ComEmployees_{HR,2000} + IndustEmployees_{HR,2000}\right)}{Pop_{HR,2000}} \tag{7}$$

The employment rate changes linearly by a scenario-specific amount over the simulation period:

$$EmployRate_{HR,y} = EmployRate_{HR,2000} + \Delta EmployRate_{HR} \cdot \frac{(y-2000)}{\left(2030-2000\right)} \tag{8}$$

The number of commercial employees over the total non-farm employees (*CommFraction*) for each hydrologic region also changes linearly over the simulation period:

$$CommFraction_{HR,y} = CommFraction_{HR,2000} + \Delta CommFraction_{HR} \cdot \frac{(y-2000)}{\left(2030-2000\right)} \tag{9}$$

The number of commercial and industrial employees in year *y* and hydrologic region *HR* is thus:

$$CommEmploy_{HR,y} = Pop_{HR,y} \cdot EmployRate_{HR,y} \cdot CommFraction_{HR,y} \tag{10}$$

and

$$IndustEmploy_{HR,y} = Pop_{HR,y} \cdot EmployRate_{HR,y} \cdot \left(1 - CommFraction_{HR,y}\right) \tag{11}$$

2.1.5 Water Use Coefficients

Water use coefficients indicate the amount of water demanded by each demand unit.[8] For the year 2000, they are computed directly from the DWR year 2000 water use data and demand unit data (DWR 2005b) by hydrologic region:

$$UseCoef_{U,HR,2000} = \frac{Use_{U,HR,2000}}{DemandUnit_{U,HR,2000}} \tag{12}$$

where *U* is the particular demand unit (e.g. house type, employee, etc.).

Over time, water use coefficients may change in response to factors such as changes in the price of water and in consumer income, improvements in the efficiency of equipment related to water use (such as toilets), and active programs designed to accelerate these equipment upgrades. These effects, however, are difficult to disentangle when estimating future water demand. For example, water price may change use behavior directly and also by prompting users to purchase more efficient equipment. Rising incomes may make users less sensitive to rising water prices, but also may increase their propensity to purchase water efficient equipment. The use coefficient captures the effects of demand management programs as well as conservation that would have occurred naturally.

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[8] A use coefficient is analogous or identical with the ordinary economic concept of demand and hence is just a function of all determinants of demand, including price, and other relevant factors, some of which may be direct policy variables.

In this model water use coefficients (*UseCoef*) change in two ways. Changes in water price, income, and household size (for household coefficients) modify water use coefficients through elasticity factors (*EFactors*). All other changes are captured in a multiplicative factor (*OtherEffects*). Other effects include changes caused by the adoption of more efficient water-use technologies, conservation programs, behavioral changes not captured by the efficiency factors, etc.[9] The coefficient for water use in the interior of a single-family home at year *y* and hydrologic region *HR* ($UseCoef_{SF-\text{int},HR,y}$), for example, is estimated as:[10]

$$UseCoef_{SF\text{-}int,HR,y} = UseCoef_{SF\text{-}int,HR,2000} \cdot EFactors_{SF\text{-}int,HR,y} \cdot \left(1 + OtherEffects_{SF\text{-}int,HR,y}\right) \quad (13)$$

where

$$EFactors_{SF-\text{int},HR,y} = \left(\frac{Income_{HR,y}}{Income_{HR,2000}}\right)^{\gamma_{income}} \cdot \left(\frac{Price_{HR,y}}{Price_{HR,2000}}\right)^{\gamma_{price}} \cdot \left(\frac{SFsize_{HR,y}}{SFsize_{HR,2000}}\right)^{\gamma_{SFsize}} \quad (14)$$

and

$$OtherEffects_{SF\text{-}int,HR,y} = OtherEffects_{SF\text{-}int,HR} \cdot \frac{(y-2000)}{(2030-2000)} \quad (15)$$

In Equation 14, γ_{income}, γ_{price}, and γ_{SFsize} are elasticity factors that reflect water use changes in response to income, price, and single-family household size, respectively. In Equation 15, *OtherEffects* is the total percentage change in the use coefficient due to other effects from 2000 to 2030. Table 2 indicates which parameters affect the water use coefficients for each urban end-use category.

Table 2: Relevant elasticity factors and other effects influencing each urban end-use category.

Urban end-use category	Water price	Income	Household size	Other effects
Household interior	X	X	X	X
Household exterior	X	X		X
Commercial	X			X
Industrial	X			X
Public/Institutional				X

2.1.6 *Losses and other water demands*

The DWR includes intentional groundwater recharge and losses as two additional domestic water use categories. Our model specifies intentional groundwater recharge to remain constant at 2000 levels and for losses to remain proportional to the total use.

[9] Other effects, for example, could include the implementation of Best Management Practices as defined by the Memorandum of Understanding (CUWCC 2004) as well as other efficiency programs.

[10] The equations used to estimate the effects of income, price, and household size upon water use are based on Planning and Management Consultants (1992; 1999).

2.2 Agricultural Demand Module

2.2.1 Overview

Total agricultural water use (*AU*) can be accounted for as the sum of irrigation use (*IU*), losses, and other uses.[11] By expressing losses and other uses (*LossOther%*) as a fixed percentage of year 2000 irrigation use, the total agricultural water use for any year, *y*, and hydrologic region, *HR*, is computed as:

$$AU_{HR,y} = \frac{IU_{HR,y}}{(1 - LossOther\%)} \tag{16}$$

$$\text{where} \quad LossOther\% = \frac{AU_{HR,2000} - IU_{HR,2000}}{AU_{HR,2000}} \tag{17}$$

Irrigation water use depends upon the amount of land under irrigation, the amount of multi-cropping (planting more than one crop per year on the same land), and the water use per crop per planting. We decompose total irrigation water use (*IU*) into the product of the irrigated crop area (*ICA*) for each crop type and hydrologic region and the amount of applied water (*AW*) for each acre of crop for each region.[12] Statewide irrigation water use is therefore estimated as:

$$IU_y = \sum_{HR=1}^{R} \sum_{crop=1}^{C} \left(ICA_{crop,HR,y} \cdot AW_{crop,HR,y} \right) \tag{18}$$

Irrigation water demand changes if the mix of irrigated crops change or the applied water for crops changes. The evolution of the parameters is highly uncertain and can also be influenced by land use and water management policies.

2.2.2 Agricultural Land Use

Agricultural land use changes over time due to (1) conversion of agricultural land to urban uses, (2) new land becoming irrigated, (3) changes in the amount of multi-cropping, and (4) changes in the crops being irrigated. An important innovation of our approach is to explicitly consider the interplay between irrigated land area and multi-crop area. The irrigated crop area (*ICA*) for each hydrologic region in year *y* is the sum of the area of total irrigated land (*ILA*) and the area of land that is multi-cropped (*MA*):[13]

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[11] Water applied in the agricultural sector in California is largely used for irrigation. In the year 2000, irrigation consumed over 90% of agricultural water use.

[12] As described below, irrigated crop area (*ICA*) is the sum of irrigated land area (*ILA*) and area multi-cropped (*MA* – or area planted two or more times a year).

[13] For example, if 800 acres of farmland is used for a single crop of wheat and 200 acres is used to grow two crops of vegetables, then the total irrigated crop acreage would be 1,200 acres.

$$ICA_{HR,y} = ILA_{HR,y} + MA_{HR,y} \tag{19}$$

The irrigated crop area is also the sum of the irrigated crop area by crop type for each HR and year:

$$ICA_{HR,y} = \sum_{crop=1}^{C} ICA_{crop,HR,y} \tag{20}$$

It is difficult to project how each component of Equations 19 and 20 will evolve over time. For this model, we adopt a rules-based procedure to disaggregate scenario-specific statewide changes in irrigated land, multi-cropped, and irrigated crop area to changes at the hydrologic region and by crop type (for ICA). This procedure has three major steps:[14]

Step 1) Calculate statewide changes in irrigated land area (ILA), multi-cropped area (MA), and irrigated crop area (ICA).

Step 2) Apportion statewide changes in ILA, MA, and ICA across each hydrologic region.

Step 3) Calculate crop-mix changes (e.g. ICA by crop and HR)

Step 1: Calculate statewide changes in irrigated land

ILA is expected to change over time as land is converted from farmland to urban areas and some new lands formerly not irrigated come into production. Land use and zoning policies may also influence this base-line conversion. We model statewide ILA to change linearly by a scenario-specific amount (ΔILA) in response to these forces:

$$ILA_{state,y} = ILA_{state,2000} \cdot \left(1 + \Delta ILA_{state} \cdot \frac{(y-2000)}{(2030-2000)}\right) \tag{21}$$

The area of irrigated land area that is multi-cropped, MA, changes over time from the year 2000 by a fixed amount (ΔMA):

$$MA_{state,y} = MA_{state,2000} \cdot \left(1 + \Delta MA_{HR} \cdot \frac{(y-2000)}{(2030-2000)}\right) \tag{22}$$

Finally, statewide irrigated crop area is calculated as the sum of ILA and MA.

Step 2: Apportion statewide changes in ILA, MA, and ICA across each hydrologic region

Most of the statewide change in ILA will occur in regions of the state that (1) have significant amounts of agricultural land area under irrigation and (2) are experiencing pressures from urbanization. In other hydrologic regions, change will be modest. In the model, therefore, the state's hydrologic regions are

[14] These steps were developed initially by Tom Hawkins and Scott Matyac of DWR in spreadsheet form and then adopted into the scenario generator by David Groves of the Pardee RAND Graduate School.

classified as either high ILA-change or low ILA-change. Low ILA-change HRs are specified to change from the year 2000 to 2030 at a specified percentage of the change from 1995 to 2020 predicted in the 1998 Water Plan (DWR 1998).[15] The remaining ILA change required to satisfy the statewide change estimated in Step 1 is apportioned to all other HRs equally.

Changes in MA are also unlikely to occur uniformly throughout the state. In some hydrologic regions, multi-cropping may not increase beyond current levels. In other regions, new multi-cropping may be limited. The remaining regions have considerable flexibility to accommodate substantially new amounts of multi-cropping. In this model HRs are specified as no MA-change, low MA-change, and high MA-change HRs. As with ILA changes, low MA-change HRs are assumed to change from 2000 to 2030 at a specified percentage of the change from 1995 to 2020 predicted in the 1998 Water Plan (DWR 1998). The remaining MA change required to satisfy the statewide change estimated in Step 1 is apportioned to the high-change HRs equally.

Irrigated crop area by hydrologic region is simply computed as the sum of ILA and MA for each HR for each year.

Step 3: Calculate crop-mix changes (e.g., ICA by crop and HR)

As ILA and MA change, the area devoted to each crop type (ICA) must change as well. This model makes several key assumptions when estimating how ICA by crop type and HR will evolve over time. The first two assumptions are related to the value of the crops that are either brought into or taken out of production:

- For most regions where ICA is calculated by the model to increase, the changes occur only for high value crops.
- For regions where ICA decreases, low value crops are assumed to decrease up to a specified percentage at which point high value crops then decrease as needed.

The next two assumptions relate to the potential multi-crop ratio (*PMCR*), or the amount of crop land that could be multi-cropped (e.g., that which already is used for crops that could accommodate multiple cropping):

$$PMCR_{HR,y} = \frac{MA_{HR,y}}{\sum_{crop=1}^{C} \left(ICA_{crop,HR,y} \cdot PMC_{crop} \right)} \tag{23}$$

[15] For example, for the Current Trends scenario, the changes in ILA for low-ILA change HRs are equal to the predicted change through 2020 by the 1998 Water Plan.

where PMC_{crop} is "1" if the crop can be multi-cropped and "0" otherwise.

The rules are specified to assure that as crops are taken in and out of production due to the first two assumptions above, the potential multi-crop ratio (PCMR) remains within a plausible range:

- If the PMCR is below a minimum threshold, then potential multi-crop crops are decreased and other crops are increased until the PMCR meets the threshold.
- If the PMCR is above a maximum threshold, then potential multi-crop crops are increased and other crops are decreased until the PMCR meets the threshold.

Table 3 classifies each crop type by its value and potential for multi-cropping. In general, these assumptions will shift the crop mix towards the high value crops (2nd column) and away from the low value crops (3rd column). In regions where the PMCR is high, there will be larger increases in truck crops (top row), whereas in regions where the PMCR is low, the crop area devoted to trees and vines will increase (bottom row).

Table 3: Matrix showing the value and multi-crop potential for each crop type in California.

	High Value	Low Value
Potential multi-crops	Truck crops	Grain, corn, safflower, dry beans, other field crops
Permanent or non-multi-crops	Trees and vines	Alfalfa, rice, cotton, sugar beets, and pasture

Table 4 summarizes this three-step procedure for estimating future agricultural land use.

Table 4: Rules for estimating future agricultural land use.

<table>
<tr><th>Step</th><th>Parameter</th><th colspan="2">Initial data / condition</th><th>Calculation</th><th>Final result</th></tr>
<tr><td rowspan="3">1</td><td>ILA (statewide)</td><td colspan="2">2000 data</td><td>Linear trend (1)</td><td>2000 – 2030 estimate</td></tr>
<tr><td>MA (statewide)</td><td colspan="2">2000 data</td><td>Linear trend (2)</td><td>2000 – 2030 estimate</td></tr>
<tr><td>ICA (statewide)</td><td colspan="2">2000 data</td><td>ILA + MA</td><td>2000 – 2030 estimate</td></tr>
<tr><td rowspan="6">2</td><td rowspan="2">ILA (HR)</td><td colspan="2">Low change HRs (3)</td><td>% 2020 ILA trend for current trends</td><td rowspan="2">2000 – 2030 estimate</td></tr>
<tr><td colspan="2">High change HRs (4)</td><td>Remaining proportional change</td></tr>
<tr><td rowspan="3">MA (HR)</td><td colspan="2">No change HRs (5)</td><td>2000 data</td><td rowspan="3">2000 – 2030 estimate</td></tr>
<tr><td colspan="2">Low change HRs (6)</td><td>% 2020 MA change for current trends</td></tr>
<tr><td colspan="2">High change HRs (7)</td><td>Remaining proportional change</td></tr>
<tr><td>ICA (HR)</td><td colspan="2"></td><td>ILA + MA</td><td>2000 – 2030 estimate</td></tr>
<tr><td rowspan="6">3</td><td rowspan="3">ICA (crop and HR)
[meeting high value crop ratio requirements]</td><td rowspan="2">Positive ICA change</td><td>HRs w/ low value crop increases (8)</td><td>Increase all crops by same %</td><td rowspan="3">Interim estimate</td></tr>
<tr><td>HRs w/ only high value crop increases (8)</td><td>Increase high value crops only</td></tr>
<tr><td colspan="2">Negative ICA change</td><td>Reduce low value crops equally up to threshold (9). Additional reduction from high value crops</td></tr>
<tr><td rowspan="3">ICA (crop and HR)
[meeting multi-crop ratio requirements]</td><td colspan="2">Potential multi-crop ratio < lower threshold (10)</td><td>Decrease potential multi-crops and increase other crops to meet lower multi-crop ratio threshold</td><td rowspan="3">2000 – 2030 estimate</td></tr>
<tr><td colspan="2">Potential multi-crop ratio > upper threshold (11)</td><td>Increase potential multi-crops and decrease other non-permanent crops to meet upper multi-crop ratio threshold</td></tr>
<tr><td colspan="2">Others</td><td>No adjustment</td></tr>
</table>

() indicates factor that can vary across scenarios.

2.2.3 Applied Water

Applied water meets the evapotranspiration requirements[16] of the crop (*ETAW*) and other beneficial needs such as salt leaching and frost control. Some applied water is also non-beneficial. Applied water (*AW*) is decomposed into evapotranspiration of applied water (*ETAW*) and the fraction of applied water consumed by the plant (*CF*):[17]

$$AW_{crop,HR} = \frac{ETAW_{crop,HR}}{CF_{crop,HR}} \tag{24}$$

A *CF* of 1 implies that all applied water satisfied *ETAW* and that no other beneficial or non-beneficial uses existed. Under actual conditions, however, *CF* varies between about 55% (rice grown in the Sacramento River region) to a bit over 80% (processed tomatoes). The consumed fraction of many crops can increase by reducing the non-beneficial portion of applied water through the deployment of more sophisticated irrigation technology and use of more advanced irrigation management practices.[18]

ETAW is the difference between the plant's natural evapotranspiration (*ET*) and effective precipitation (*EP*):

$$ETAW_{crop,HR} = ET_{crop,HR} - EP_{crop,HR} \tag{25}$$

Effective precipitation is the amount of precipitation that is stored in the soil and is available to satisfy crop needs and is largely a function of the region's rainfall, soil conditions, and plant rooting depth. Evapotranspiration varies by crop and growing condition and may be reduced by improving irrigation methods (by decreasing non-productive evaporation) and may be increased when yields are increased.

Until recently, it was assumed that evapotranspiration for a specific crop under specific growing conditions could not be changed. Some evidence suggests that evapotranspiration may increase, within limits, if new cultural practices or higher-yield crop varieties are used (Hsiao and Xu 2000). Evapotranspiration may also decrease as more efficient irrigation practices are used. These yield effects are modeled by an elasticity

---

[16] Evapotranspiration of applied water (*ETAW*) is the amount of applied water that transpires from plant leaves and that evaporates from the soil surface.

[17] Note that consumed fraction is the portion of applied irrigation water that satisfies crop evapotranspiration, as used in the 2005 Water Plan.

[18] For regions where non-consumed water flows back to usable aquifers and surface rivers or streams, improvements in the consumed fraction does not actually increase the water supply, although this saved water could be reapplied to other non-consumptive uses without needing to expand the water supply.

factor (γ_{yield}), and the practice effects are modeled by a factor (*ΔETpractice*) that changes linearly over the simulation period:[19]

$$ET_{crop,HR,y} = ET_{crop,HR,2000} \cdot \left(\frac{Yield_{crop,HR,y}}{Yield_{crop,HR,2000}} \right)^{\gamma_{yield}} \cdot \left(1 + \Delta ETpractice_{crop,HR} \cdot \frac{(y-2000)}{(2030-2000)} \right) \quad (26)$$

Yield changes linearly by a scenario-specific percentage from 2000 to 2030.

Effective precipitation can vary linearly from 2000 to 2030 by a scenario-specific percentage to simulate long-term variability caused, for example, by climate change.

The consumed fraction of a particular crop is influenced primarily by irrigation practices and technology. We assume that increasing water price will provide incentives to farmers to use irrigation practices that increase the consumed fraction and decrease the required applied water. This effect is captured by a water price elasticity factor (γ_{price}). Investments in irrigation technology also affect the consumed fraction linearly by a scenario-specific percentage (*ΔCFtech*). Consumed fraction by crop, HR, and year therefore is:

$$CF_{crop,HR,y} = CF_{crop,HR,2000} \cdot \left(\frac{WaterPrice_{crop,HR,y}}{WaterPrice_{crop,HR,2000}} \right)^{\gamma_{price}} \cdot \left(1 + \Delta CFtech_{crop,HR} \cdot \frac{(y-2000)}{(2030-2000)} \right) \quad (27)$$

2.2.4 Irrigation Water Use

All together, we estimate future water use for irrigation (*IU*) in year y using the following formula:

$$IU_y = \sum_{HR=1}^{R} \sum_{crop=1}^{C} ICA_{crop,HR,y} \cdot \left(\frac{\left(ET_{crop,HR,y} - EP_{crop,HR,y} \right)}{CF_{crop,HR,y}} \right) \quad (28)$$

2.3 Environmental Demand Module

Environmental water use is classified by the Department of Water Resources as the amount of water purposefully permitted to flow through natural river channels and wetlands, instead of being diverted and used for urban or agricultural purposes. As described extensively in Volumes 1 and 3 of the 2005 Water Plan, these allocations are not always sufficient to meet the ecological objectives of the state's aquatic ecosystems. An important objective of future California water management is to improve the health of such ecosystems, in part, by meeting legal mandates and effectively increasing environmental flow allocations.

The amount of water needed for such environmental use varies considerably with the level of precipitation and runoff in the state. It is difficult, therefore, to evaluate independently water source and

[19] The equation used to estimate the effect of yield upon crop evapotranspiration is based on Planning and Management Consultants (1992; 1999).

supply estimates. For purposes of quantifying scenarios of total water demand independently of source and supply estimates, the model specifies future environmental water demand to be the quantity used in the year 2000 (an average year) plus a scenario-specific additional amount by region. Scenarios in which water managers' commitment to meet environmental needs are high are specified to have greater environmental water demand.

3 Quantified Scenarios of 2030 Water Demand

In this section we describe the model parameter values used to quantify a set of water demand scenarios for California. The first three scenarios are intended to represent those described in Volume 1 of the 2005 California Water Plan. The fourth scenario was developed by the authors. The model parameter values that specify each scenario were selected by the authors with consultation for other DWR staff.

These water demand scenarios indicate the amount of water that would be demanded at the scenario-specific water price (for the urban and agricultural sectors). Therefore, they technically are scenarios of water quantity demand (water demand implies the relationship between use and price). Finally, these demand scenarios all assume that water management practices will stay as they are now and that none of the 17 response packages described in Volume 2 of the Water Plan are implemented.

The first three demand scenarios are designed to represent the three 2005 Water Plan narrative water demand scenarios developed using a consensus-based approach (after Schwarz (1996), described in Volume 1, Chapter 4 of the Water Plan. These scenarios are briefly described as:

> **Current Trends**: Water demand based on "current trends with no big surprises."
>
> **Less Resource Intensive**: "California is more efficient in 2030 water use than today while growing its economy within much more environmentally protective policies."
>
> **More Resource Intensive**: "California is highly productive in its economic sector. Its environment, while still important, is not the state's first priority for water management decisions. Water use in this scenario is less efficient in 2030 than it is in [the other] scenarios…." (DWR 2005a)

As shown in the results section below, future water demand for agriculture in the Less Resource Intensive scenario is greater than the demand in the Current Trends scenario. The population growth rates are also the same for the Current Trends and Less Resource Intensive scenarios. Therefore, we include an additional scenario to represent the lower-range of plausible future water demand:

> **Low Water Demand**: Water demand is lower in the urban and agricultural sectors due to slower population growth coupled with increasing conservation and low-water use economic development. The agricultural sector becomes more water efficient than expected, the conversion of land away from agriculture slows, and the shift towards more intensive agriculture is more moderate than in the other scenarios. Finally, lower demand in the urban and agricultural sectors leads to more public pressure for greater allocations to the environment.

Table 5, adapted by a table developed by DWR staff, describes how factors impacting water supply and demand might evolve from 2000 to 2030 in each scenario. In the Current Trends scenario, population is specified to evolve according to California State Department of Finance (DOF) forecasts, whereas trends in economic activity, agricultural use, and ecosystem maintenance (environmental factors) are not explicitly defined. Many factors for the other three scenarios are described as modifications to the Current Trends factors.

The urban demand factors specified in Table 5 suggest that urban water demand will be greatest for the More Resource Intensive scenario and lowest for the Low Water Demand scenario. Agricultural demand changes are less clear. Under the Current Trends scenario, the total crop area in California would decrease the most, whereas in the Less Resource Intensive scenario, crop area is specified to remain constant. This alone would lead to greater agricultural water demand in the Less Resource Intensive scenario than in the Current Trends scenario. However, total crop water use is specified to be greater in the More Resource Intensive scenario than the Current Trends scenario. As a result, the direction of agricultural water demand changes under the More Resource Intensive and Less Resource Intensive scenarios are ambiguous in the narrative. Agricultural water demand changes under the Low Water Use scenario will be lower, as in the Current Trends scenario. Finally, 2030 environmental water demand will be greater for the Less Resource Intensive and Low Water Use scenarios (high environmental protection) and lowest for the More Resource Intensive scenario (year 2000 level of use). Table 14 shows how the demand factors for the Water Plan scenarios listed in Table 5 are quantified in the model to produce numerical scenarios of water demand.

To help understand the components of each scenario, Table 6 characterizes each scenario by sector and major influencing factor. For example, scenarios of urban water demand are distinguished by their demographic trends and water use efficiency trends. The table also presents symbolic representations of these factors for use in the results section.

Table 5: Notional descriptions of factors affecting regional and statewide water demand and for the three 2005 California Water Plan scenarios (Current Trends, Less Resource Intensive, and More Resource Intensive) and a fourth scenario (Low Water Demand). Adapted from DWR (2005a).

FACTOR	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4
	Current Trends	**Less Resource Intensive**	**More Resource Intensive**	**Low Water Demand**
Total population	DOF	DOF	Higher than DOF	Lower than DOF
Population density	DOF	Higher than DOF	Lower than DOF	Higher than DOF
Population distribution	DOF	DOF	Higher inland and southern	DOF
			Lower coastal and northern	DOF
Commercial activity	Current trend	Increase in trend	Increase in trend (as in 2)	Increase in trend (as in 2)
Commercial activity mix	Current trend	Decrease in high water use activities	Increase in high water use activities	Decrease in high water use activities
Total industrial activity	Current trend	Increase in trend	Increase in trend (as in 2)	Increase in trend
Industrial activity mix	Current trend	Decrease in high water use activities	Increase in high water use activities	Decrease in high water use activities
Total crop area	Current trend	Level out at current crop area	Level out at current crop area	Current trend
Crop unit water use	Current trend	Decrease in crop unit water use	Increase in crop unit water use	Decrease in crop unit water use
Environmental water-flow	Current trend	High environmental protection	Year 2000 level of use	High environmental protection
Environmental water-land	Current trend	High environmental protection	Year 2000 level of use	High environmental protection
Naturally occurring conservation	Naturally occurring conservation (NOC) trend in MOUs	Higher than NOC trend in MOUs	Lower than NOC trend in MOUs	Higher than NOC trend in MOUs
Urban water use efficiency	All cost effective BMPs in existing MOUs implemented by current signatories			
Ag Water Use Efficiency	All cost effective EWMPs in existing MOUs implemented by current signatories			
Per capita income	Current trends			
Seasonal/permanent crop mix	Current trends			
Irrigated land retirement	Currently planned			

Table 6: General characteristics of water demand scenarios by sector and factor. Symbolic representation of each scenario is shown for reference and presentation of results.

Sector and Factors	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Urban Sector				
Demographics	Expected Growth / Expected density	Expected Growth / Higher density	Higher Growth / Lower density	Lower Growth / Higher density
Use Efficiency	Expected conservation	More Conservation	Less Conservation	Most conservation
Symbolic representation	→ growth, → density, → conservation	→ growth, ↑ density, ↑ conservation	↑ growth, ↓ density, ↓ conservation	↓ growth, ↑ density, ↑↑ conservation
Agricultural Sector				
Land Use	Decreasing ICA / Large ILA decrease	Constant ICA / Small ILA decrease	Constant ICA / Large ILA decrease	Decreasing ICA / Modest ILA decrease
Crop Water Use	Expected reduction	Greater Reduction	Lesser reduction	Greatest Reduction
Symbolic representation	↓ ICA, ↓↓ ILA, → CWU reduction	→ ICA, ↓ ILA, ↑ CWU reduction	→ ICA, ↓↓ ILA, ↓ CWU reduction	↓ ICA, ↓ ILA, ↑↑ CWU reduction
Environmental Sector				
Environ. Allocation	Expected allocation	Higher allocation	Lower allocation	Highest allocation
Symbolic representation	→ allocation	↑ allocation	↓ allocation	↑↑ allocation

3.1 Urban Sector

3.1.1 Urban Demand Drivers

For the Current Trends and Less Resource Intensive scenarios we specify annual population growth to be congruent with the latest California Department of Finance (DOF) projection of 2030 population by county (DOF 2004). For the More Resource Intensive scenario we specify the population growth rate to be 25% greater for the inland and southern HRs (South Coast, South Lahontan, Colorado River, Sacramento River, San Joaquin River, and Tulare Lake) and 16% greater for coastal and northern HRs (North Coast, San Francisco Bay, Central Coast, and North Lahontan). This roughly matches the 1998 DOF 2030 population projections (DOF 1998). For the Low Water Demand scenario, we specify total population growth to increase by 31% instead of 41% as in the DOF projections.

Housing in the Current Trends scenario is based upon DWR projections of housing (DWR 2004). The household population, share of multifamily housing, and housing size changes for the Current Trends scenario are calculated from DOF 2030 population projections (DOF 2004), Woods and Poole 2030 population projections (Woods & Poole Economics 2004), and 1980 – 2000 U. S. censuses. The housed population is nearly constant, the share of MF housing decreases from 35.5% in 2000 to 33.9% in 2030 (as a statewide average), and the household size decreases modestly for single and multifamily households under these scenarios.

For the Less Resource Intensive and Low Water Demand scenarios the share of multifamily housing is specified to increase 10% more than in the Current Trends scenario, and the household size increases by 0.2 persons by 2030. For the More Resource Intensive scenario, multifamily housing decreases by 5% below the Current Trends scenario, and the household size is the same as the Current Trends scenario.

The mean income (in constant dollars) for each hydrologic region is specified to increase according to recent projections from Woods and Poole Economics (2004) for all scenarios.[20] Urban water price (in constant dollars) is specified to increase by 20% from 2000 to 2030 in all areas for each scenario. Table 7 summarizes the parameters chosen to generate the four scenarios.

Table 7: Parameters for urban demand drivers for scenarios.

Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Total population	DOF trends 48.1 million (2030)	As current trends	DOF trends + 12%* 52.3 million (2030)	DOF trends – 10% 44.7 million (2030)
Inland and southern (SC, SL, CR, SR, SJ, TL)	DOF trends 37.3 million (2030)	As current trends	125% DOF trends 41.1 million (2030)	79% DOF trends 34.5 million (2030)
Coastal and northern (NC, SF, CC, NL)	DOF trends 10.8 million (2030)	As current trends	116% DOF trends 11.2 million (2030)	79% DOF trends 10.2 million (2030)
Housed population fraction	DOF trends** Nearly constant (~98%)	As current trends	As current trends	As current trends
MF housing share	DOF trends** 35.5% → 33.9%***	DOF trends + 10% 35.5% → 43.9%***	DOF trends - 5% 35.5% → 28.9%***	DOF trends + 10% 35.5% → 44.0%***
SF house size	DOF trends** 3.13 → 3.06***	DOF trends + 0.2 persons/household	As current trends	DOF trends + 0.2 persons/household
MF house size	DOF trends** 2.41 → 2.38***	DOF Trends + 0.2 persons/household	As current trends	DOF trends + 0.2 persons/household
Mean income (1996 dollars)	DOF trends** $87,225 → $116,269***	As current trends	As current trends	As current trends
Employment fraction	Woods and Poole trends 58% → 60%***	As current trends + 2.5%	As current trends + 2.5%	As current trends + 2.5%
Urban water price***	2000 prices + 20%	As current trends	As current trends	As current trends

* The population 1998 DOF population trend projection (2000 to 2030) is about 11% greater than the 2004 DOF projection (51.9 million people in 2030).
** Trend varies by hydrologic region.
*** Values for 2000 -> 2030.
**** Constant dollars.

[20] Income and employment data were disaggregated by hydrologic region by Marla Hambright and Richard Le of the California Department of Water Resources.

3.1.2 Urban Demand Factors

Elasticity effects for price, income, and household size vary modestly across the scenarios (Table 8). For the Current Trends scenario, the single family price elasticity factor is derived from the 1998 Water Plan Update (DWR 1998), and multi-family price, income and household size elasticity factors are derived from a range recommended for use in the IWR-MAIN urban water demand model (Planning and Management Consultants 1999).

The Water Plan scenario narratives disaggregate water use conservation that occurs without policy intervention (called naturally occurring conservation or NOC) and through efficiency due to the continued implementation of existing Best Management Practices (BMPs) in the Memorandum of Understanding (MOU) (CUWCC 2004). Efficiency that would occur from the implementation of additional water conservation programs is not included. Recall from Section 3 above that water use coefficients in the model vary due to changes in income, water price, and household size, and other water use effects. For purposes of quantifying the Water Plan narrative scenarios, we assume that the naturally occurring conservation and efficiency effects are captured in the "*OtherEffects*" multiplicative factor described in Section 3.1.5, but are disaggregated as NOC effects and Efficiency effects, in line with the Water Plan narrative.

A&N Technical Services (2004), on behalf of California Urban Water Agencies (CUWA), estimates the total domestic conservation (termed the Gross effect) and the portion of the total conservation due solely to the implementation of a subset[21] of BMPs (termed the Net effect).[22] The difference between the Gross and Net effects is naturally occurring conservation (NOC). The report presents Net and Gross savings for 7 of the 10 California hydrologic regions at years 2007, 2020, and 2030. Over time, the Net savings (and therefore the Gross savings as well) decrease from 2020 to 2030 because of fixed life spans or decay rates for the BMP programs. Naturally occurring conservation increases from 2007 to 2030 and is the same for each of the three BMP implementation scenarios.

Using the data and assumptions contained in the A&N Technical Services report along with year 2000 DWR domestic water use estimates, we find that by 2030 NOC could decrease water demand by about 10% and that the effect directly attributable to the BMP could decrease water demand by about 5% of 2000

[21] Of the 14 BMPs, only eight of them were quantified in the A&N Technical Services study.

[22] A&N Technical services (2004) estimate water savings for three different implementation scenarios: Existing Conditions, Cost-Effective Implementation, and Full Implementation.

demand. We use these estimates for the Current Trends scenario (Table 8).[23] To distinguish between the Less Resource Intensive and More Resource Intensive scenarios, we specify NOC to be -15% and -5%, respectively. We use the same NOC and Efficiency estimates for the commercial, industrial, and public sectors. In other on-going work, we derive these factors independently.

Table 8: Domestic water demand factors for Water Plan scenarios.

Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Price elasticity – SF [1]	-0.16	-0.35	-0.05	-0.35
Price elasticity – MF [2]	-0.05	-0.07	-0.03	-0.07
Income elasticity – SF [2]	0.4	0.2	0.6	0.2
Income elasticity – MF [2]	0.45	0.25	0.65	0.25
HH size elasticity – SF [2]	0.4	0.2	0.6	0.2
HH size elasticity – MF [2]	0.5	0.3	0.7	0.3
Naturally occurring conservation – interior [3]	-10%	-15%	-5%	-15%
Naturally occurring conservation – exterior [3]	-10%	-15%	-5%	-15%
Efficiency – interior [3]	-5%	-5%	-5%	-5%
Efficiency – exterior [3]	-5%	-5%	-5%	-5%

[1] Renwick, Green, and McCorkle (1998).
[2] Based on ranges of recommended values for IWR-MAIN (Planning and Management Consultants 1999).
[3] Based on analysis of CUWA report (A&N Technical Services 2004) and DWR 2000 water use data (see text).

Table 9 lists the commercial, industrial, and public water demand factors used for the three scenarios.

Table 9: Commercial, industrial, and public water demand factor parameters.

Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Price elasticity [1]	-0.085	-0.1	-0.07	-0.1
Naturally occurring conservation [2]	-10%	-15%	-5%	-15%
Efficiency [2]	-5%	-5%	-5%	-5%

[1] Price elasticity applies only to commercial and industrial water demand. Based on ranges of recommended values for IWR-MAIN (Planning and Management Consultants 1999).
[2] We use the same values as derived for domestic NOC and efficiency.

[23] For purposes of estimating NOC savings for households under the Current Trends 2004 Water Plan scenario, we consider the 2030 Cost Effective Implementation BMP savings over year 2000 household water use. This savings rate varies from 7% of year 2000 water use for Central Coast to about 14% in the San Joaquin River Region, excluding South Lahontan, which is above 70%. The average savings for the seven hydrologic regions is 9.8%. We use 10% as a rough estimate of total NOC for Current Trends by 2030. We apply this value equally across all hydrologic regions, despite the range of values calculated by the study. Total Net savings as a percentage of year 2000 use is estimated to be 4% for the Cost Effective scenario. For simplicity, we choose 5% for all three Water Plan scenarios, corresponding to the narrative description: "All cost effective BMPs in existing MOUs implemented by current signatories."

3.2 Agricultural Sector

There are three sets of parameters used to define the scenarios of agricultural water demand, as described in Section 3: statewide agricultural land use changes, rules determining agricultural land use changes by hydrologic region and crop-type, and crop-water demand changes. The paragraphs below and Table 10 - Table 12 summarize the parameters used to represent each scenario.

Following the 2005 Water Plan's narrative description of the Current Trends scenario, irrigated crop area is specified to decrease according to DWR forecasts based on historical rates of land conversion from agriculture to urban development, tempered by increases in multi-cropping and some new lands coming into production. [24] The Water Plan specifies that in the Less Resource Intensive scenario, irrigated crop area levels out at the current area. To implement this in the model, we assume that irrigated land area decreases at half the rate as in the Current Trends scenario (5.6% total reduction from 2000-2030 instead of 10.0%), and the percentage of multi-cropped area increases to 11.6% in 2030. These two adjustments lead to a constant total irrigated crop area. In the More Resource Intensive scenario, irrigated crop area also levels out at the current area as in the Less Resource Intensive scenario. We specify ICA to be the same for the Low Water Demand scenario as for the Current Trends scenarios, but with a small reduction in ILA (compensated for by lesser increase in multi-cropping). Table 10 summarizes the specified trends for each agricultural land-use parameter by scenario.

Table 10: Quantification of statewide agricultural land use changes for narrative scenarios.

Agricultural Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Irrigated crop area [1]	~4.9% reduction (9.5 ma → 9.05 ma)	Constant (2000 Value - 9.5 ma)	Constant (2000 Value - 9.5 ma)	~4.9% reduction (9.5 ma → 9.05 ma)
Irrigated land area [2,3]	10% reduction (9.0 ma → 8.1 ma)	5% reduction (9.0 ma → 8.5 ma)	10% reduction (9.0 ma → 8.1 ma)	7.5% reduction (9.0 ma → 8.5 ma)
Multi-cropped area [4]	80% increase (540 ta → 970 ta)	85% increase (540 ta → 990 ta)	165% increase (540 ta → 1,420 ta)	40% increase (540 ta → 752 ta)

[1] Changes in ICA described in narrative scenarios and computed from specified changes in ILA and MA.
[2] Changes in ILA for Current Trends and More Resource Intensive scenarios derived from off-line regression analysis.
[3] Changes in ILA for Less Resource Intensive scenario specified to be half the change expected for Current Trends.
[4] Changes in MA specified to produce the ICA changes shown.

[24] The 2030 ILA was determined using a regression equation developed using ILA data from 1990 to 2000 with time as the independent variable. The 2030 MA was determined using a regression equation developed using the MA (as a percent of ILA) from 1988 to 2000 with time as the independent variable. The 2030 ICA is the sum of 2030 ILA and MA.

Table 11 shows the parameters used to implement the rules to apportion state-water agricultural land use changes to crop changes by hydrologic region (see Section 2.2.2). The only parameters aside from the statewide trends that change across scenarios are the low value crop reduction upper limit and the potential multi-crop ration upper limit. The values shown in the table were chosen by DWR staff members as part of the development of the above mentioned rules.

Table 11: Parameters specifying agricultural land use changes by hydrologic region and crop type for each sceanrio. Parameter numbers refer to rules listed in Table 4.

#	Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
1	ILA statewide trend (as in Table 10)	-10%	-5%	-10%	-7.5%
2	MA statewide trend (as in Table 10)	+80%	+85%	+165%	+40%
3	Low ILA change HRs	NC, SF, NL, SL			
4	High ILA change HRs	CC, SC, SR, SJ, TL, CR			
5	No MA change HRs	CC			
6	Low MA change HRs	NC, SF, SC, NL, SL, CR			
7	High MA change HRs	SR, SJ, TL			
8	HR(s) with low value crop increases	NL			
9	Low value crop reduction upper limit	50%	50%	75%	50%
10	Potential Multi-crop ratio lower limit	2000 potential multi-crop ratio by HR			
11	Potential Multi-crop ratio upper limit	36%	36%	40%	36%

Table 12 shows the parameters affecting crop water demand used for each scenario. The narrative specifies that the crop unit water use to decrease the most under the Less Resource Intensive scenario and the least under the More Resource Intensive scenario. The ET Technique and Technology CF Effects factors are specified to represent these differences. The crop water demand parameters for the Low Water Demand scenario are specified to be the same as those for the Less Resource Intensive scenario.

Table 12: Crop water demand parameters for each scenario.

Agricultural Parameter	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Agricultural Yield	2000 values*	110% of 2000 values	100% of 2000 values	110% of 2000 values
Yield-ET Elasticity	0.2 [1]	As Current Trends	As Current Trends	As Current Trends
ET Technique Factor	0	-2.5%[2]	0	-2.5%[2]
Effective Precipitation	2000 values	As Current Trends	As Current Trends	As Current Trends
Agricultural Water Price	110% of 2000 values	As Current Trends	As Current Trends	As Current Trends
Price-CF Elasticity	0.28 [3]	As Current Trends	As Current Trends	As Current Trends
Technology CF Effects	2.5%	5%	0%	5%

* Value varies by crop and hydrologic region. Changes are from 2000 to 2030.
[1] This effect is not well understood.
[2] CALFED (2000)
[3] Approximately the average long-term water price elasticity for Central Valley agriculture as reported by DWR Bulletin 160-98, Table 4A-5 (DWR 1998).

3.3 Environmental Sector

Environmental Defense prepared for the California Water Plan staff a preliminary estimate of flow objectives for the year 2000 for some but not all of the major environmental objectives managed by the fisheries management agencies throughout the state (Rosekrans and Hayden 2003). These unmet objectives include the additional instream flows needed to meet the goals of CALFED's Ecosystem Restoration Program, the objectives in the Anadromous Fisheries Restoration Program, and the additional water needed to reach the "Level 4" supplemental water supplies for National Wildlife Refuges, cited in CVPIA sections 3405 and 3406(b). A more comprehensive analysis of unmet environmental objectives would include *all* water legal mandates extending from the Klamath River in the north to the Salton Sea in the south and would likely result in a number much greater than the 987 MAF concluded in the Environmental Defense analysis.

We use these estimates as a starting approximation for the amount of additional water that could be allocated to the environment under various scenarios. In Table 13, we assign these additional flow requirements to their respective hydrologic region. Environmental water demands for 2030 are then specified as the sum of the 2000 environmental water use for all scenarios (39.41 MAF) and the following percentages of these unmet needs: 50% for Current Trends, 100% for Less Resource Intensive, 0% for More Resource Intensive, and 150% for Low Water Demand. For example, in the case of the Less Resource Intensive scenarios, the 2000 water use is 39.41 MAF and 100% of the quantified demands (i.e., 0.987 MAF). Therefore, the 2030 environmental water "demand" in this case is 40.39 MAF.

Table 13: Partial additional flow requirements, and their respective hydrologic region (Adapted from Rosekrans and Hayden (2003)).

Location	Additional Flow Requirement (TAF)	Hydrologic Region
American (Nimbus)	55	Sacramento River
Stanislaus (Goodwin)	34	San Joaquin River
ERP #1 Flow Objective	0	Sacramento River
ERP #2 Flow Objective	65	Sacramento River
EFP #4 Freeport (Dayflow)	0	Sacramento River
Trinity (Lewiston)	344	North Coast
SJR at Vernalis (Dayflow)	96	San Joaquin River
SJR below Friant	268	San Joaquin River
Level 4 Refuge Water[1]	125	Sacramento and San Joaquin Rivers
TOTAL (TAF)	987	

[1] Annual water needed in addition to current deliveries to 19 Sacramento and San Joaquin refuges, evenly split between the Sacramento and San Joaquin River regions.

Narrative Scenario Factors	MODEL PARAMETERS	Initial Conditions (2000)	SCENARIO 1 Current Trends	SCENARIO 2 Less Resource Intensive	SCENARIO 3 More Resource Intensive
Total Population	See Population Distribution	n/a	n/a	n/a	n/a
Population Density	Share of MF housing by HR	2000 Values	2030 DOF Forecast	2030 DOF + 10%	2030 DOF - 5%
	Persons per SF household by HR	2000 Values	2030 DOF Forecast	2030 DOF + 0.2	2030 DOF
	Persons per MF household by HR	2000 Values	2030 DOF Forecast	2030 DOF + 0.2	2030 DOF
Population Distribution	Inland & Southern Population (mil)	2000 Values	2030 DOF Forecast	2030 DOF	125% DOF
	Coastal & Northern Population (mil)	2000 Values	2030 DOF Forecast	2030 DOF	116% DOF
Commercial Activity	Employment Fraction by HR	2000 Values	Woods & Poole Forecast	W&P + 2.5%	W&P + 2.5%
	Commercial Fraction by HR	2000 Values	Woods & Poole Forecast	W&P	W&P
Commercial Activity Mix	Response to Water Price Captured by NOC and Urban Efficiency	See Naturally Occurring Conservation			
Total Industrial Activity	Employment Fraction by HR	2000 Values	Woods & Poole Forecast	W&P + 2.5%	W&P + 2.5%
	Industrial Fraction by HR	2000 Values	Woods & Poole Forecast	W&P	W&P
Industrial Activity Mix	Use response to Water Price Captured by NOC	See Naturally Occurring Conservation			
Total Crop Area*	Statewide Irrigated Crop Area	Computed from Irrigated Land Area and Multi-cropped Fraction			
	Statewide Irrigated Land Area	2000 Values	2000 Values - 10%	2000 Values - 5%	2000 Values - 10%
	Statewide Multi-cropped Area	2000 Values	2000 Values + 80%	2000 Values + 85%	2000 Values + 165%
Crop Unit Water Use	Evapotranpiration (ET) by HR and crop	2000 Estimates	Computed from 2000 estimates modified by factors below		
	Effective Precipitation (EP) by HR and crop	2000 Estimates	2000 Estimates	2000 Estimates	2000 Estimates
	Consumed Fraction (CF)	2000 Estimates	Computed from 2000 estimates modified by factors below		
	Agricultural Yield	2000 Estimates	2000 Estimates	110% of 2000 Estimates	2000 Estimates
	ET Response to Yield (ET-Yield Elasticity)	n/a	0.2	0.2	0.2
	Irrigation Technique on ET	n/a	0.0%	-2.5%	0.0%
	Relative Agricultural Water Price	2000 Prices	110% of 2000 Prices	110% of 2000 Prices	110% of 2000 Prices
	CF Response to price (Price-CF Elasticity)	n/a	0.28	0.28	0.28
	Technology on CF	n/a	2.5%	5.0%	0.0%
Environmental Water-Flow Based Environmental Water-Land Based	Unmet flow requirements as quantified by Environmental Defense	2000 Environmental Demand	2000 Env. Demand + 50% ED Unmet Flows	2000 Env. Demand + 100% ED Unmet Flows	2000 Env. Demand
Naturally Occurring Conservation (NOC)	Relative Urban Water Price	2000 Prices	120% of 2000 Prices	120% of 2000 Prices	120% of 2000 Prices
	SF Price Elasticity	n/a	-0.16	-0.35	-0.05
	MF Price Elasticity	n/a	-0.05	-0.07	-0.03
	Incomes	2000 Incomes	Woods & Poole Forecast	W&P Forecast	W&P Forecast
	SF Income Elasticity	n/a	0.4	0.2	0.6
	MF Income Elasticity	n/a	0.45	0.25	0.65
	SF HH Size Elasticity	n/a	0.4	0.2	0.6
	MF HH Size Elasticity	n/a	0.5	0.3	0.7
	NOC - Domestic (interior & exterior)	n/a	-10%	-15%	-5%
	Commercial Price Elasticity	n/a	-0.085	-0.1	-0.07
	NOC - Commercial	n/a	-10%	-15%	-5%
	Industrial Price Elasticity	n/a	-0.085	-0.1	-0.07
	NOC - Industrial	n/a	-10%	-15%	-5%
	NOC - Public	n/a	-10%	-15%	-5%
Urban Water Use Efficiency	Efficiency - Domestic (interior & exterior)	n/a	-5%	-5%	-5%
	Efficiency - Commercial	n/a	-5%	-5%	-5%
	Efficiency - Industrial	n/a	-5%	-5%	-5%
	Efficiency - Public	n/a	-5%	-5%	-5%
Ag Water Use Efficiency	Irrigation Technique on ET Technology on CF	See Crop Water Use			

Table 14: Model parameters for 2005 State Water Plan narrative scenarios.

4 Results

The water demand scenario generator computes water demand for each of the State's ten hydrologic regions. To focus attention on the main trends and challenges facing California, we divide the state into thirds (Figure 3). When necessary to reflect important differences within these large zones, the North zone is disaggregated into the Mountain North[25] and Valley North,[26] and the Central zone is disaggregated into the Coast Central[27] and Valley South.[28] The South remains the same.[29] The results shown in Appendix 1 are presented using the five regions.

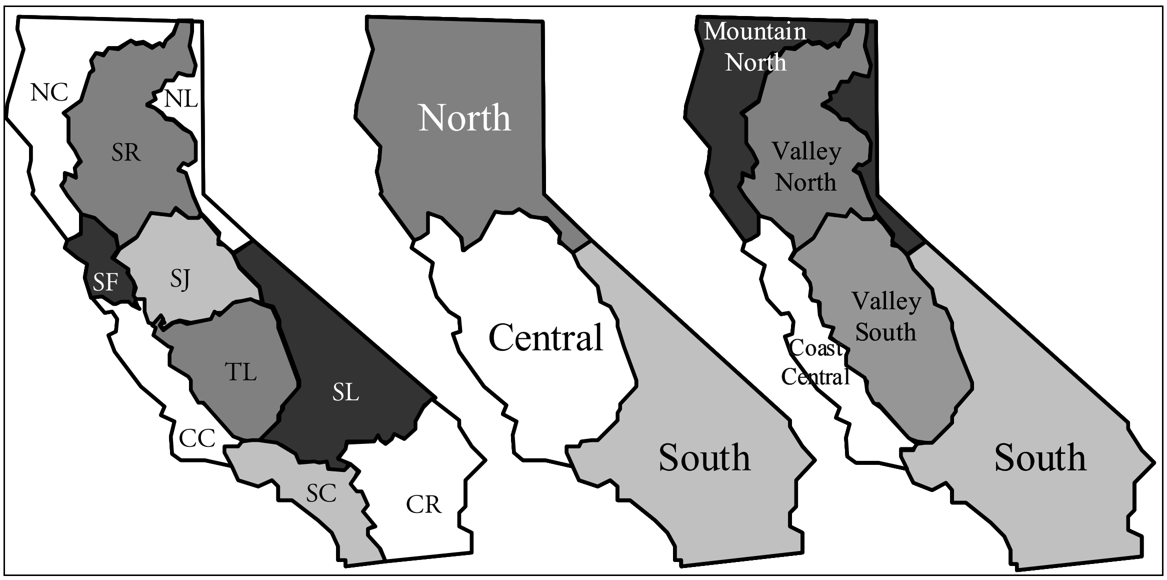

Figure 3: Three different geographic divisions of the state.

4.1 Urban Demand Drivers

In all four scenarios, statewide population growth is large as specified by the scenario input parameters (Figure 4). Population growth from 2000 to 2030 ranges from about 10.5 million people in the Low Water Demand Scenario to over 18 million people in the More Resource Intensive scenario (the State's population in 2000 was 34.1 million). Population growth is largest in the South and smallest in the North. Changes in employment (Figure 4) and housing (Figure 5) are largely proportional to population growth.

[25] The Mountain North is the combination of the North Coast and North Lahontan hydrologic regions.

[26] The Valley North is the Sacramento River hydrologic region.

[27] The Coast Central is the combination of the San Francisco and Central Coast hydrologic regions.

[28] The Valley South is the combination of the San Joaquin River and Tulare Lake hydrologic regions.

[29] The South is the combination of the South Coast, Colorado River, and South Lahontan hydrologic regions.

The state's housing stock is comprised of more multifamily housing units in the Less Resource Intensive and Low Water Demand scenarios than the others (Figure 5).

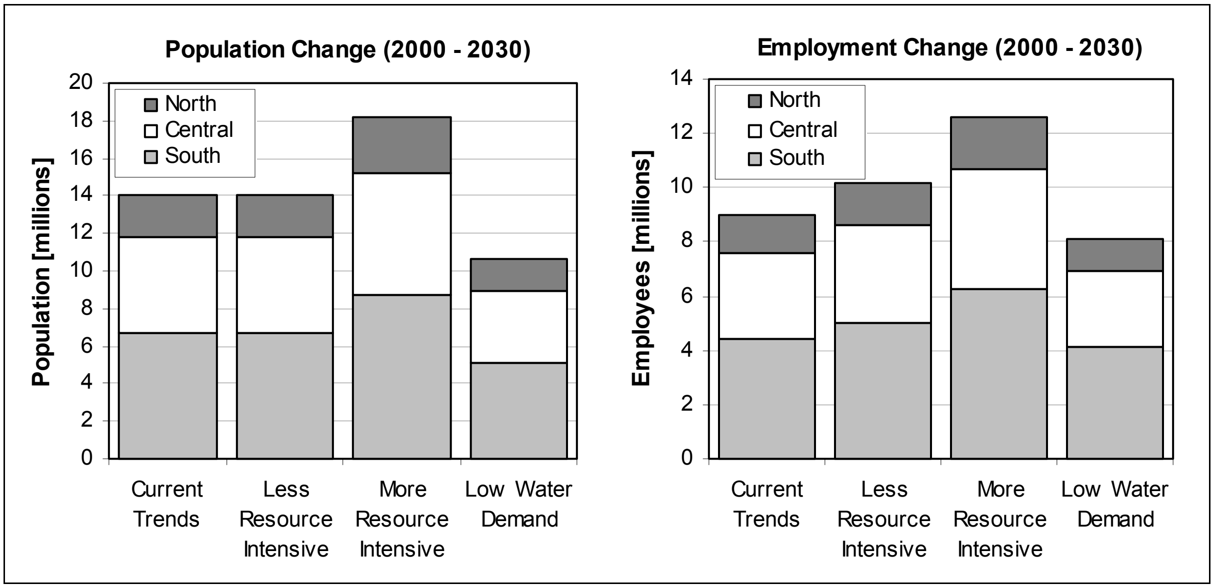

Figure 4: Projected changes in population and employment from 2000 to 2030 for each scenario. The year 2000 population was 34.1. There were 19.8 million employees in 2000.

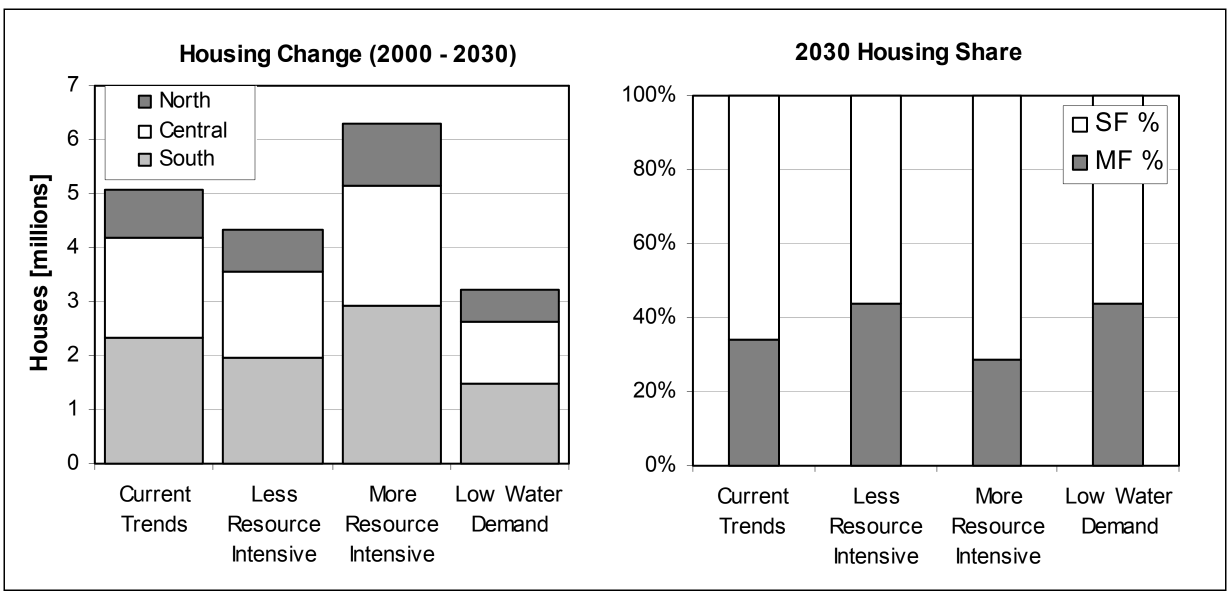

Figure 5: Projected changes in housing from 2000 to 2030 (left) and statewide housing share for each scenario (right). The housing stock in 2000 was 11.6 million units.

In the agricultural sector, the irrigated crop area (ICA) decreases about 5% from 9.5 million acres in 2000 to about 9.1 million acres in 2030 in the Current Trends and Low Water demand scenarios. ICA remains constant in the Less Resource Intensive and More Resource Intensive scenarios as specified (Figure 6). In all scenarios, ICA increases in the North regions and decreases in the Central and South regions. The

ICA increases in the North are due to both increases in irrigated land area (consistent with the 1998 Water Plan forecast) and to greater multi-cropping.

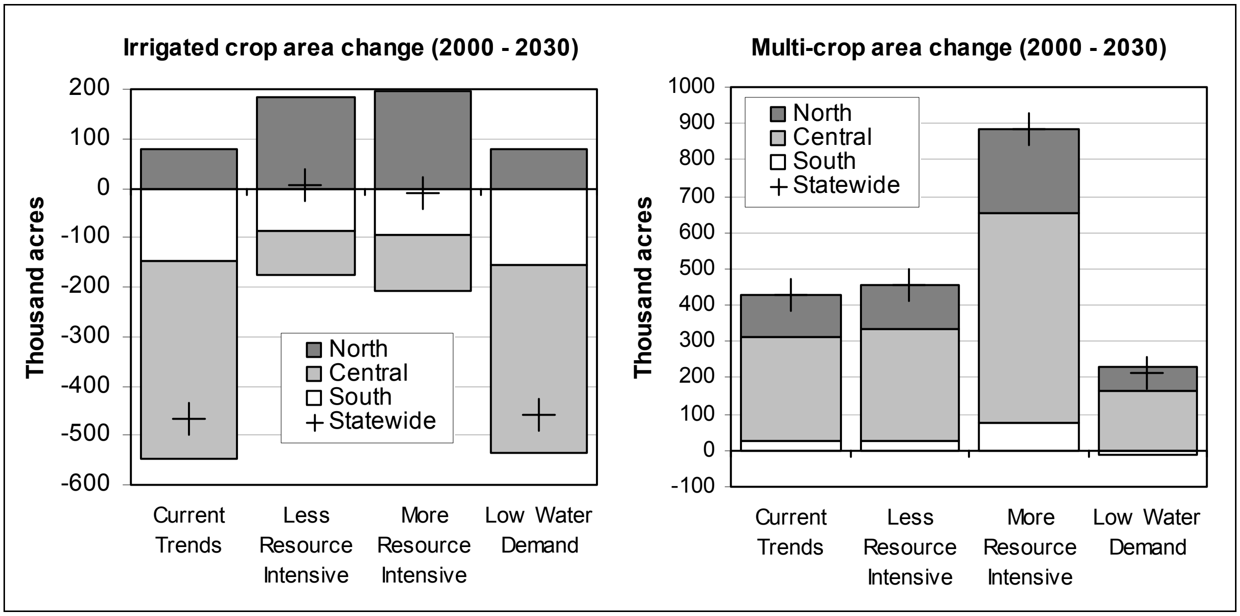

Figure 6: Projected changes in irrigated crop area and multi-crop area from 2000 to 2030 for each scenario and third of the state. Plus symbols indicate total changes.

4.2 Water Demand Changes

Care must be taken when interpreting the results of the water demand scenario generator. The four scenarios quantified, by design, reflect what water demand might be (1) under specific assumptions of future water price, (2) if no additional water management strategies were implemented, and (3) under average climatic conditions. The water demand estimates presented for these scenarios can be significantly influenced by policy actions, and thus the change in water demand is not necessarily the amount of new supply required to meet future needs.

Statewide urban water demand is projected to increase from 2000 to 2030 in all four scenarios (Figure 7). The symbols characterizing the scenarios (in the plot legend) show that urban demand is greatest for the scenario with large population growth and lower water conservation. Scenarios with lower population growth and more conservation show slower demand increases. Demand increases the most (by about 6 MAF) in the More Resource Intensive scenario and the least (less than 1 MAF) in the Low Water Demand scenario (Figure 8). In the Current Trends scenario demand increases by about 3 MAF. The urban demand changes are greatest in the South for the Current Trends and More Resource Intensive scenarios, but larger for the Central region in the Less Resource Intensive and Low Water Demand scenarios. The relatively large increases in naturally occurring conservation in the Less Resource Intensive and Low Water Demand scenarios drive large absolute water savings from existing urban development. As urban use is greater in the South than in the Central or Northern regions, the relative efficiency gains produce the greatest absolute savings in the south. These water savings offsets much of the population growth in the South.

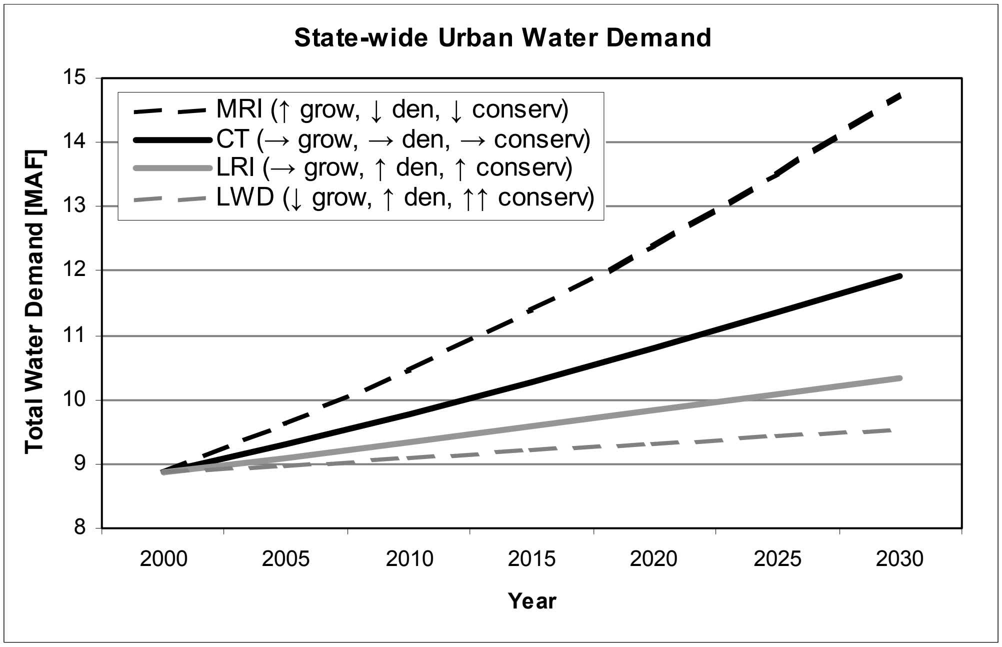

Figure 7: Average-year urban water demand from 2000 to 2030 for each scenario (see Table 6 for legend of symbols).

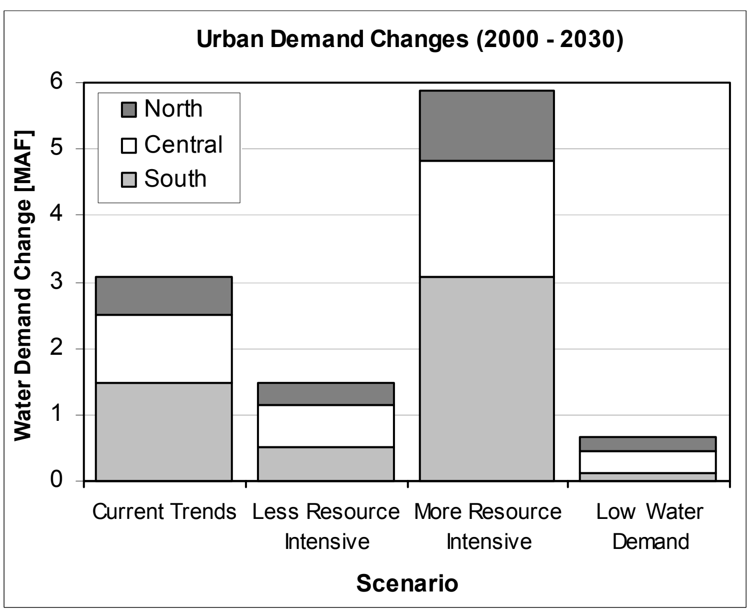

Figure 8: Urban water demand changes (2000 to 2030) by geographic region for each scenario.

Figure 9 shows the agricultural water demand from 2000 to 2030 for each scenario. Water demand is projected to decrease for all four scenarios because each scenario assumes a reduction in irrigated land area and decreased crop water use. Those scenarios with lower irrigated crop area (ICA) and greatest crop water use reductions (see legend in figure) have lower 2030 water demand. Agricultural demand reductions are largest in the Low Water Demand scenario, as it reflects a large reduction in irrigated land area (same as Current Trends) and a large decrease in effective crop water use (same as Less Resource Intensive). Agricultural water demand reduction is least in the More Resource Intensive scenario due primarily to lower efficiency gains than in the Less Resource Intensive scenario. Note that the range of changes in agricultural water demand is about equal to the demand change for the More Resource Intensive scenario, suggesting that policies aimed at influencing the scenarios can have an important effect upon water demand changes.

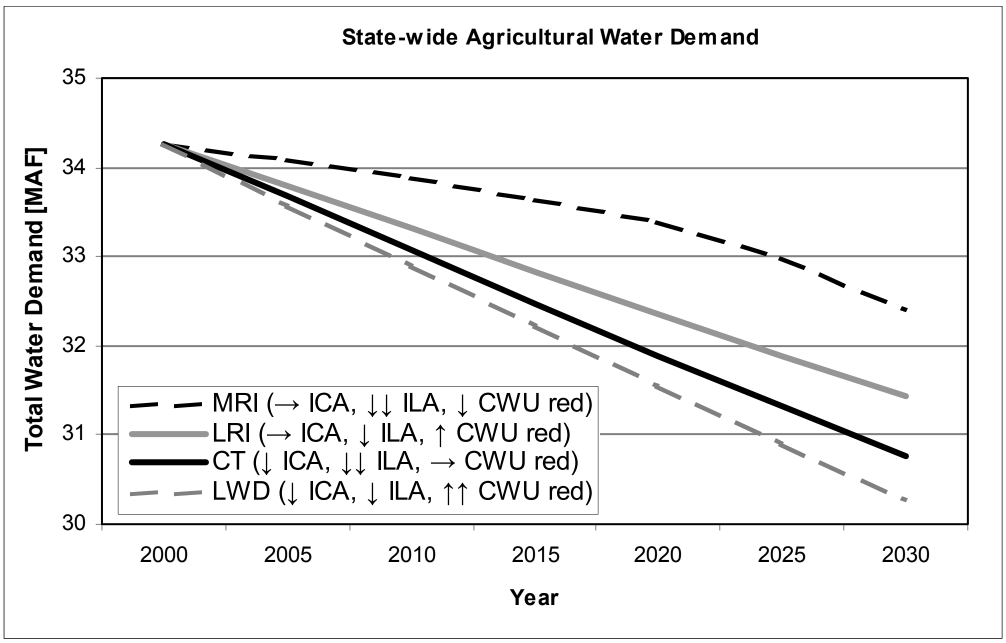

Figure 9: Average-year agricultural water demand from 2000 to 2030 for each scenario (see Table 6 for legend symbols).

Figure 10 shows the agricultural demand changes by geographic region and scenario. Agricultural demand changes in the South are similar across the scenarios, whereas demand changes vary significantly in the North and Central regions.

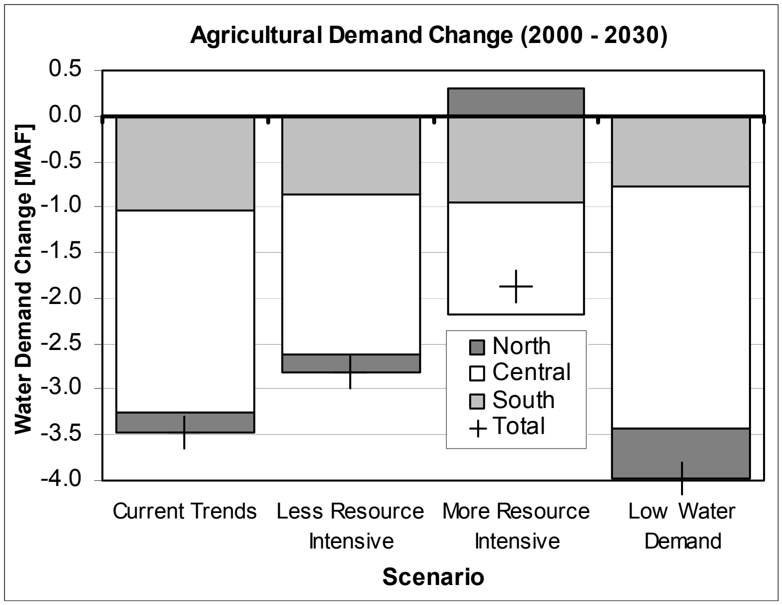

Figure 10: Agricultural water demand changes (2000 to 2030) by geographic region for each scenario.

Finally, changes in environmental water demand range from no increase for the More Resource Intensive scenario to about 1.5 MAF for the Low Water Demand scenario (150% of the Environmental Defense partial unmet demand) (Table 15). In 2030 in the Low Water Demand scenario, large environmental allocations and lower use in the urban and agricultural sectors push the statewide environmental water use to over 50% of total environmental demand. In the More Resource Intensive scenario environmental demand is only 46% of total water demand.

Table 15: Change in environmental water demand and 2030 percentage of total demand.

Scenario	Change in agricultural water demand	Percent environmental demand in 2030
Current Trends (→ allocation)	494	48%
Less Resource Intensive (↑ allocation)	987	49%
More Resource Intensive (↓ allocation)	0	46%
Low Water Demand (↑↑ allocation)	1,481	51%

Figure 11 - Figure 13 show the water demand changes by sector for the Northern, Central, and Southern regions, respectively. In the Northern regions (Figure 11) urban water demand change is large for the Current Trends and More Resource Intensive scenarios and more modest for the other scenarios. Environmental water demand change is significant for the Current Trends, Less Resource Intensive, and Low Water Demand scenarios. In the Central regions (Figure 12), urban water demand increases and agricultural demand decreases in all scenarios. For the Current Trends, Less Resource Intensive, and Low Water Demand

scenarios, the net change in water demand is negative. For the More Resource Intensive scenario it is positive. Finally, in the Southern regions (Figure 13) urban water demand increases for all scenarios (although the increase is slight for the Low Water Demand scenario). The urban demand changes, however, vary considerably across scenarios. Agricultural demand changes are slightly negative across all the scenarios. The net water demand change is positive for the Current Trends and More Resource Intensive scenario and negative for the Less Resource Intensive and Low Water Demand scenarios.

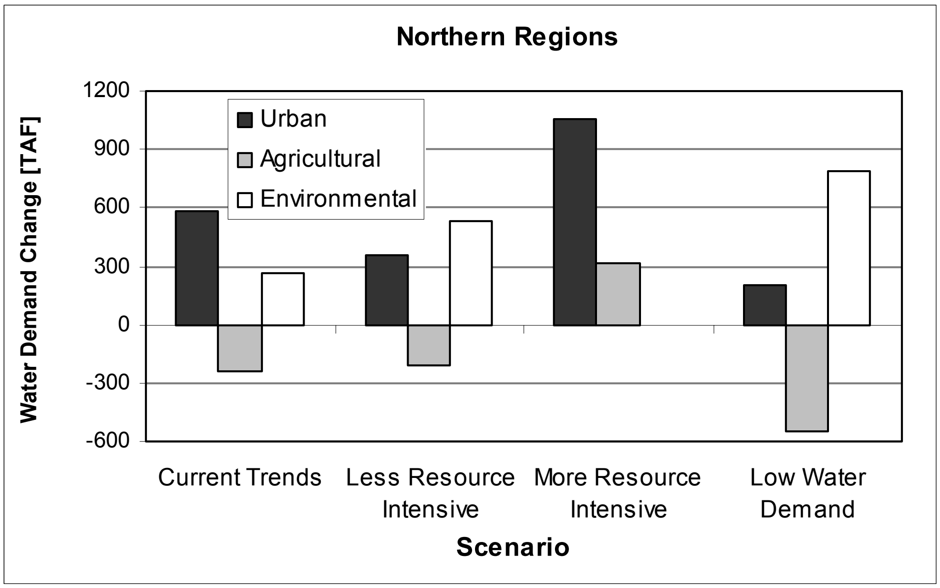

Figure 11: Scenarios of demand changes in Northern regions by sector, 2000-2030.

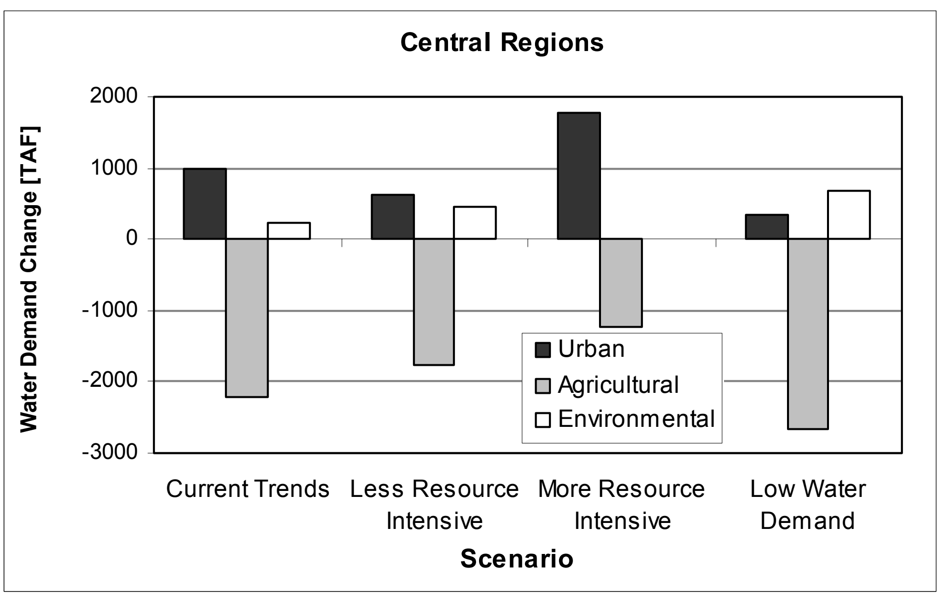

Figure 12: Scenarios of demand changes in Central regions by sector, 2000-2030.

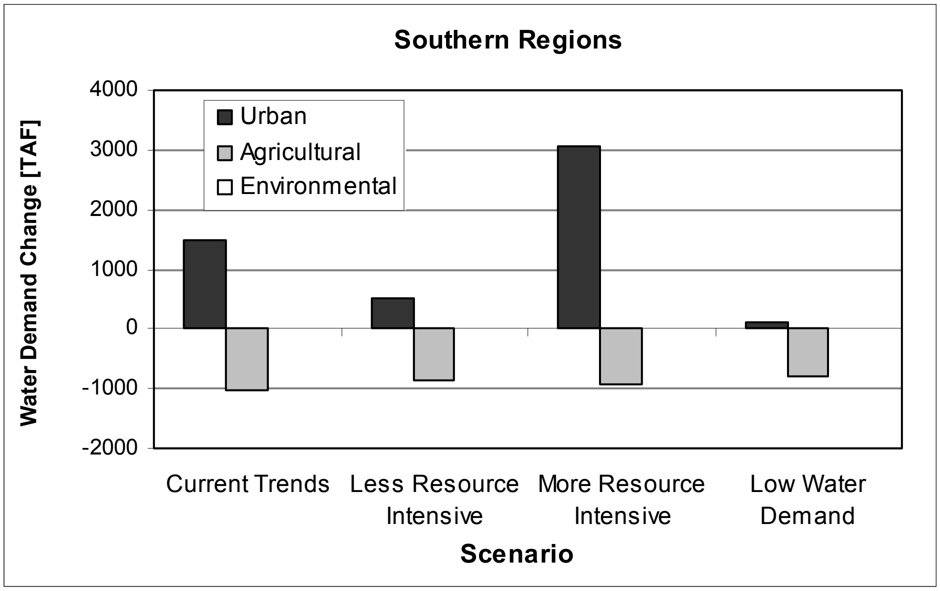

Figure 13: Scenarios of demand changes for Southern regions by sector, 2000-2030.

4.3 Water Demand Change Decomposition

Changes in water demand can be decomposed into the portions of change attributable to each of the factors defining water demand. For example, the change in single family water use from the year 2000 to year 2030 (ΔUse_{SF}) can be decomposed into the change due to variation in the number of single family households ($\Delta HH_{SF}\ term$) and the change due to variations in per household water use ($\Delta UseCoef_{SF}\ term$), and a residual joint change term ($Joint\ change\ term$):

$$\Delta Use_{SF} = Use_{SF,2030} - Use_{SF,2000} \tag{29}$$

where

$$Use_{SF} = \left(HH_{SF} \cdot UseCoef_{SF}\right) \tag{30}$$

Combining Equations 29 and 30 yields:

$$\Delta Use_{SF} = \left(HH_{SF,2030} \cdot UseCoef_{SF,2030}\right) - \left(HH_{SF,2000} \cdot UseCoef_{SF,2000}\right) \tag{31}$$

Since

$$HH_{SF,2030} = HH_{SF,2000} + \Delta HH_{SF} \text{ and} \tag{32}$$

$$UseCoef_{SF,2030} = UseCoef_{SF,2000} + \Delta UseCoef_{SF} \tag{33}$$

Equation 31 can be rewritten as:

$$\Delta Use_{SF} = (HH_{SF,2000} + \Delta HH_{SF}) \cdot (UseCoef_{SF,2000} + \Delta UseCoef_{SF}) - HH_{SF,2000} \cdot UseCoef_{SF,2000} \tag{34}$$

Distributing the terms and canceling yields the final decomposition:

$$\Delta Use_{SF} = \left(UseCoef_{SF,2000} \cdot \Delta HH_{SF}\right) + \left(HH_{SF,2000} \cdot \Delta UseCoef_{SF}\right) + \left(\Delta HH_{SF} \cdot \Delta UseCoef_{SF}\right) \qquad (35)$$

or

$$\Delta Use_{SF} = \left\{\Delta HH_{SF}\ term\right\} + \left\{\Delta UseCoef_{SF}\ term\right\} + \left\{Joint\ change\ term\right\} \qquad (36)$$

Note that as the factor changes approach zero in the limit, the joint change term approaches zero and Equation 34 becomes equivalent to taking the total derivative of single family water use with respect to time by applying the chain rule:

$$\frac{D}{Dt}\left(Use_{SF}\right) = \frac{D}{Dt}\left(HH_{SF} \cdot UseCoef_{SF}\right) \qquad (37)$$

$$\frac{D}{Dt}\left(Use_{SF}\right) = \left(UseCoef_{SF} \cdot \frac{\partial}{\partial t} HH_{SF}\right) + \left(HH_{SF} \cdot \frac{\partial}{\partial t} UseCoef_{SF}\right) \qquad (38)$$

Figure 14 shows these three terms and the total water demand change for households (single- and multi-family houses) for each scenario. The '+' symbols denote the total water use changes and the height of the bars indicate the magnitude and sign of each change terms. This figure shows that for all four scenarios, population changes alone (light grey bars) lead to large water demand increases (over 1.5 MAF for the Low Water Demand scenario to about 3 MAF for the More Resource Intensive scenario). For the Less Resource Intensive and Low Water Demand scenarios, however, decreases in household water use compensates for more than half of the entire increase due to the increase in the number of households. For Current Trends and More Resource Intensive, per household water use changes (the dark layers Figure 14) are either only slightly negative or are positive despite the fact that both scenarios were specified to reflect increasing water use efficiency (NOC plus Efficiency).

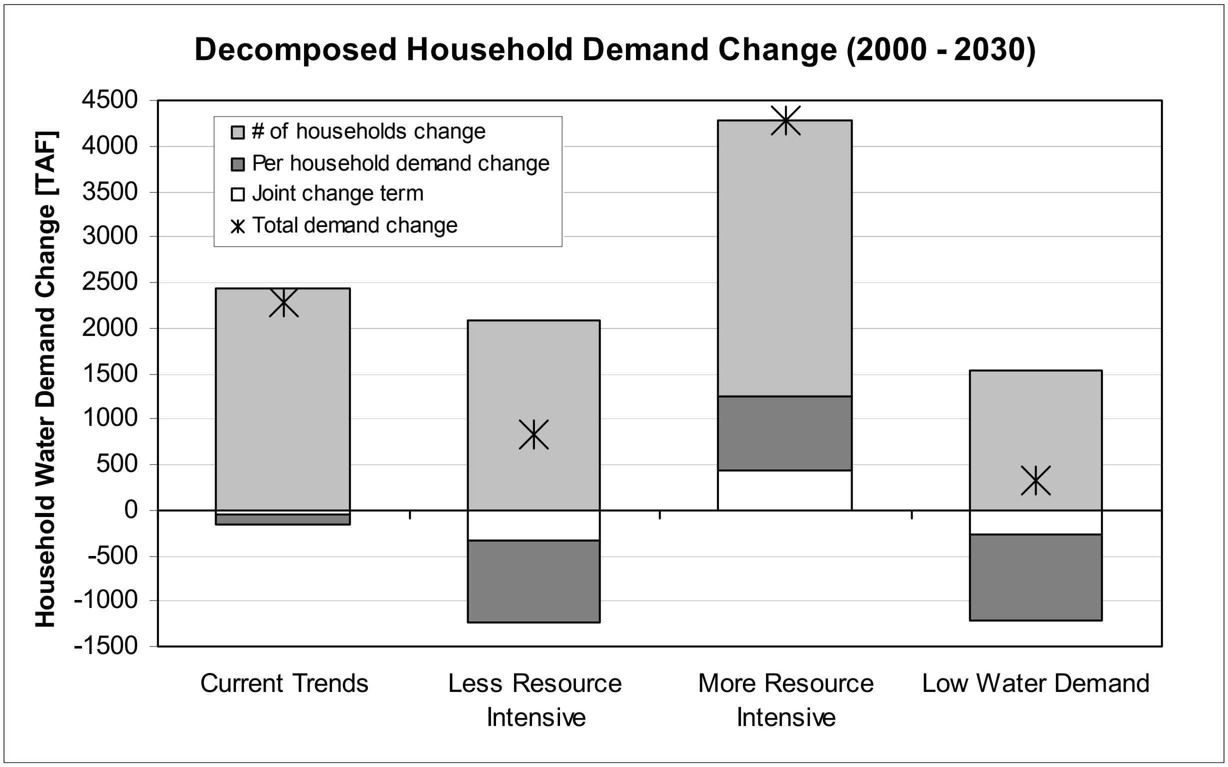

Figure 14: Decomposed single-family household water demand change from 2000 to 2030 for each scenario.

To examine the forces behind the Per Household Demand changes, Figure 15 shows how the Per Household Water Demand coefficient changes in response to changes in individual driving factors. For example, NOC and Efficiency effects alone would decrease household water use by 15%, 20%, 15%, and 20% respectively (the first vertical bar in the figure). The effect of price is not very large in all scenarios, indicating that the specified 20% price change over 30 years will have at most only a small effect on water demand. Changes in income (the middle vertical bar in the figure) are substantial (ranging between about 7% to over 20%). Demographic changes are those attributable to the location of new housing. Scenarios (such as the More Resource Intensive scenario), in which population growth is greater in high water use regions, have a greater demographic household water use effect. Notice that this effect exceeds 5% for the More Resource Intensive scenario.

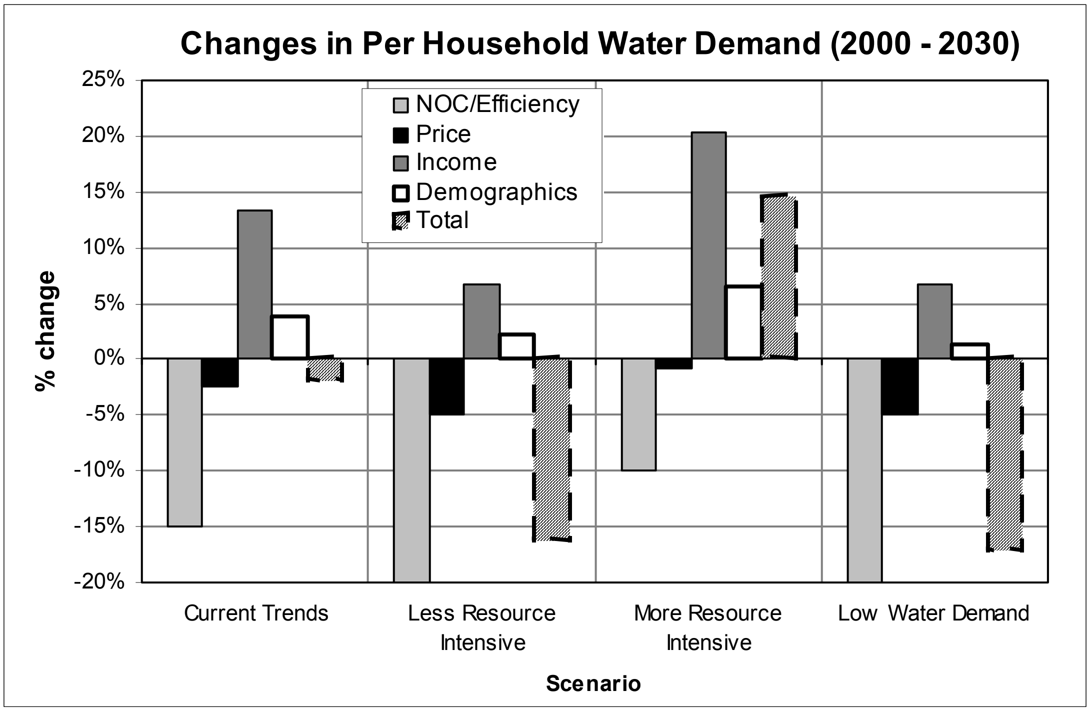

Figure 15: Changes in statewide per household water demand from 2000-2030 due to NOC/Efficiency, Water Price, Income, and Demographics. See text for explanation.

Water demand for irrigation changes over time in response to variations in the total irrigated crop area and the amount of water used for each crop. Using a methodology similar to that described for household water use, we decompose irrigation water demand changes into the following four components: low value crop water use, high value crop water use, low value ICA, and high value ICA (Figure 16). For all four scenarios, changes in crop water use reduces water demand. These changes are proportionally larger for low value crops than high value crops. In all scenarios, ICA for low value crops decreases and thus reduces water demand. In the Less Resource Intensive and More Resource Intensive scenarios, ICA increases for high value crops and thus increases demand. The change in crop mix is caused by increases in high value crops that can be multi-cropped.

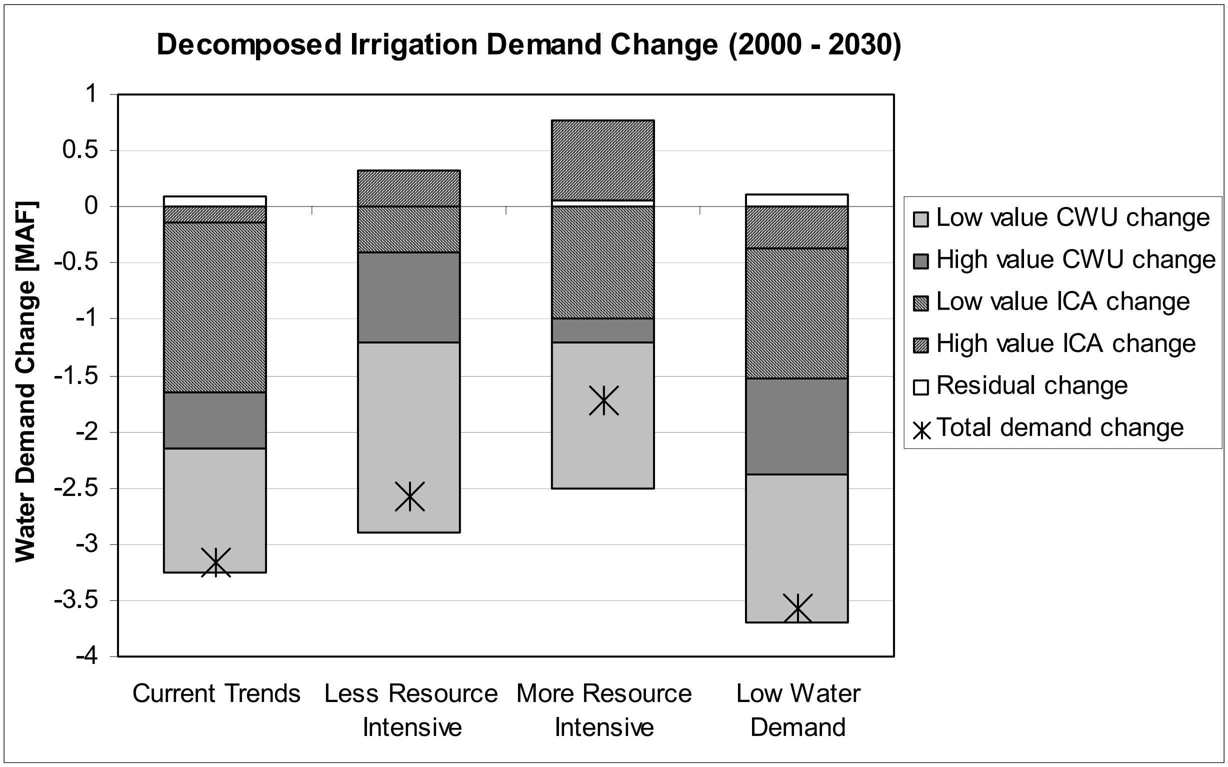

Figure 16: Decomposed irrigation water use change from 2000 to 2030 for each scenario.

4.4 Effects of Price and Policy-induced Efficiency on Urban Demand

Each scenario of water demand assumes a specific water price and no additional water use efficiency policies. Figure 17 shows how statewide urban water demand changes as a function of water price changes for each scenario. The dots indicate the water quantity demand as specified in the previous sections. For all scenarios, as price increases, demand changes from 2000 to 2030 are reduced. The changes by price are larger for the Low Water Demand and Less Resource Intensive scenarios due to greater water use price elasticity factors specified.

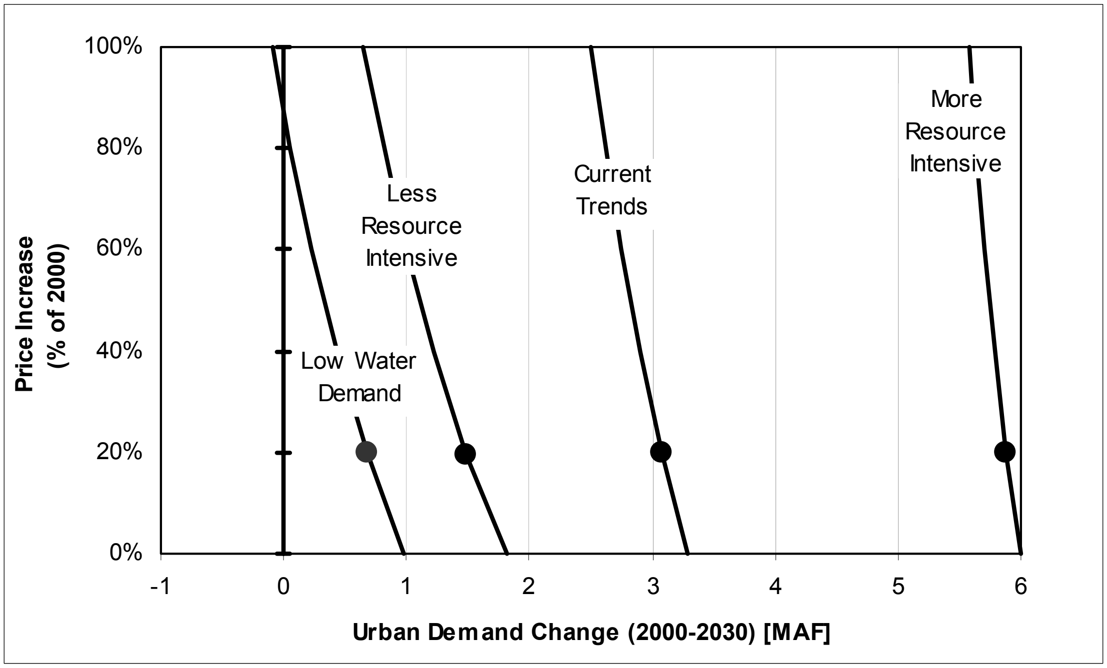

Figure 17: Statewide urban water demand changes for each scenario as a function of water price changes (as a percentage of 2000 water price).

Figure 18 shows how urban water demand would change in response to additional policy-induced efficiency (at 5% improvement increments) for the entire state.[30] Such efficiency improvement could be achieved, in part, through the implementation of the urban water use efficiency resource management strategies described in Volume 2 of the 2005 California Water Plan. The larger efficiency improvements shown in Figure 18 may require efficiency measures that are more aggressive than those considered in the Water Plan. Also, any particular efficiency program is likely to have different effects across the scenarios. This analysis does not evaluate the feasibility of such improvements, but instead illustrates the effect that new urban water use efficiency management policies could have upon the presented water demand scenarios.

Additional efficiency improvements of 15% would result in a statewide water demand increase of only about 1 MAF under the Current Trends scenario, water demand decreases in the Less Resource Intensive and Low Water Demand scenarios, and water demand increases of less than 3.5 MAF in the More Resource Intensive scenario.

[30] These results are generated by decreasing in 5% increments (from -5%) the urban water use efficiency factors for each scenario (reported in Table 8 and Table 9).

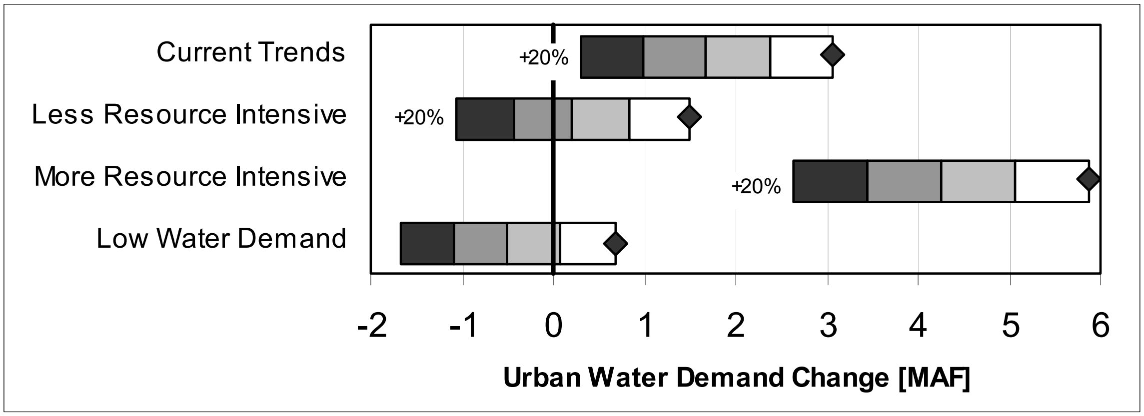

Figure 18: Statewide changes in urban water demand by scenario. The diamond symbols represent the changes for each scenario as under the default level of efficiency (5%). The shaded regions to the left represent the demand changes with additional water use efficiency programs that increase efficiency by 5% for each increment.

5 Conclusions and Recommendations for Further Research

Four scenarios of year 2030 water demand in California are quantified and reveal several important insights about future California water resource management challenges.

Findings related to urban water demand include the following:

1) If no new water management strategies are implemented, water demand for urban consumption in California is likely to increase from 2000 to 2030 in response to population and economic growth.
2) Significant uncertainties about demographic trends, water use behavior, and penetration of water efficiency technologies over the scenario period suggest a wide range of plausible urban demand increases, possibly spanning the range of 1 MAF to 6 MAF. These increases can be tempered significantly by increasing water prices or increasing water use efficiency through additional management policies.
3) Scenarios with high population growth and low naturally occurring conservation will lead to the greatest water demand increases.
4) Even if conservation were to reduce statewide water use at the same rate as population growth, urban water demand would increase as new housing and economic development will occur largely in high water using regions.
5) Variation in demand changes across regions is substantial. The Southern regions will experience the greatest demand increases under high population and low conservation scenarios.

Findings related to agricultural water demand include:

1) Demand for water in the agriculture sector decrease under all scenarios considered.

2) Scenarios in which urban growth induces conversion of farmland may also lead to large decreases in agricultural water demand.
3) Trends towards multi-cropping and lower crop water use through more efficient practices and crop varieties could enable the agriculture sector to maintain existing production (proxied in this model by irrigated crop area) while consuming substantially less water.

Finally, under the four scenarios considered, water allocations to the environment would increase environmental demand by up to 1.5 MAF.

Estimates of future statewide average-year water demands, however small or large, do not adequately characterize the challenges facing California water. Increases in water demand must be addressed at regional and local scales because available supplies in one part of the state cannot necessarily be used to meet rising demands in another part. Furthermore, the timing of demand and supply and interannual variability of supply are masked by average-year balances and represent the greatest challenges to water managers.

Greater urban water demand under all but the low water demand scenario would present significant challenges to water planners. If future factors influencing water demand resemble the Current Trends scenario, California would need to offset an additional 3.5 MAF of urban and environmental water demand per year with a combination of management strategies to reduce demand, improve system efficiency, and redistribute and augment supplies. As seen by the regional results above, most of the agricultural demand reductions occur in the Central Valley, whereas much of the additional urban demand would be in the Southern part of the state. The ability to transfer water from the Central Valley to Southern California could be constrained by existing conveyance facilities, area-of-origin issues, environmental impacts, and other third-party effects.

If future water demand changes more like the More Resource Intensive scenario, water management challenges would be even greater. Demand would increase in all areas of California, and agricultural demand would not decrease as much as it does in the other three scenarios. Consequently, the reduction in agricultural demand would only offset a portion of the increase in urban demand.

The demand changes in the Less Resource Intensive and Low Water Demand scenarios would be more manageable than the other two scenarios. If, however, future water supplies are lower due to climate change, for example, then even these scenarios could present considerable challenges for California water management.

Other challenges not captured by demand changes exist as well. As local demands increase, future droughts could result in more severe local water shortages than in recent experience. Moreover, the challenges of flood management, protecting water quality, and managing water systems to help restore the environment will all require California's water managers to develop strong water plans that go well beyond just meeting water demand increases in average years.

Several areas of promising research were revealed in the course of this study. Some of these could involve further development of the present scenario generator, while others might entail development of independent models that interact with the generator in modular fashion. Potentially fruitful avenues of development include:

- Making explicit the ability to take as input the output from various probabilistic forecasting models such as IWR-MAIN and CALAG. For example, IWR-MAIN might be used to estimate the "other effects" category of urban water use, which accounts for those changes caused by the adoption of more efficient water use technologies, conservation programs, and behavioral changes not captured by efficiency factors. Similarly, CALAG might be used to estimate the current trends scenario of irrigated crop area, with alternate scenarios keying off of the current trends estimate.
- Explicitly treating and accounting for consumptive and non-consumptive water uses to better describe the effects of change in water use on regional water supplies.
- Expanding the scope of the generator or separately modeling water supplies to account for the effects of water supply variation and distribution system limitations.
- Expanding the scope of the generator or separately modeling the effects of various water management options on water demand and supply.

6 Appendix – Detailed Results

This appendix is included for the review of the Water Plan Advisory Committee and other interested members of the public. A smaller subset of these results will be presented in the Volume 4 article. See Figure 3 for a description of the five geographic regions used below.

Table 16: Urban demand drivers for 2000 and 2030 for each scenario.

Demand Drivers (in millions)	Year 2000	Year 2030 by scenario			
		Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Population	**34.1**	**48.1**	**48.1**	**52.3**	**44.7**
Mountain North	0.7	1.0	1.0	1.1	1.0
Valley North	2.6	4.6	4.6	5.3	4.1
Valley South	3.6	6.5	6.5	7.5	5.8
Coast Central	7.6	9.7	9.7	10.2	9.2
South	19.6	26.3	26.3	28.3	24.7
Houses (SF%)*	**11.6 (64)**	**16.7 (66)**	**15.9 (56)**	**17.9 (71)**	**14.8 (56)**
Mountain North	0.3	0.4	0.4	0.4	0.4
Valley North	1.0	1.7	1.6	1.9	1.4
Valley South	1.2	2.1	2.0	2.4	1.8
Coast Central	2.7	3.6	3.4	3.7	3.2
South	6.5	8.8	8.4	9.4	7.9
Employees (C%)**	**19.8 (83)**	**28.8 (86)**	**30 (86)**	**32.5 (86)**	**28 (86)**
Mountain North	0.4	0.6	0.6	0.6	0.6
Valley North	1.4	2.7	2.8	3.2	2.5
Valley South	1.7	2.9	3.1	3.5	2.7
Coast Central	5.1	7.2	7.4	7.7	7.0
South	11.1	15.5	16.2	17.4	15.2

* Number in parentheses indicates percentage of single-family housing.

** Number in parentheses indicates percentage of commercial employees.

Table 17: Urban water use coefficients for 2000 and 2030 for each scenario.

Water Use Coefficients (AF/unit-year)	Year 2000	Year 2030 by scenario			
		Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Per Household Demand (SF/MF)*	**0.48 (0.54/0.36)**	**0.47 (0.52/0.37)**	**0.4 (0.45/0.34)**	**0.55 (0.6/0.41)**	**0.4 (0.52/0.37)**
Mountain North	0.36	0.33	0.29	0.38	0.29
Valley North	0.53	0.52	0.43	0.61	0.43
Valley South	0.80	0.73	0.68	0.80	0.68
Coast Central	0.32	0.29	0.26	0.34	0.26
South	0.49	0.47	0.39	0.56	0.39
Per Employee Demand (C/I)**	**0.11 (0.09/0.17)**	**0.09 (0.08/0.15)**	**0.08 (0.07/0.14)**	**0.1 (0.09/0.16)**	**0.08 (0.08/0.15)**
Mountain North	0.16	0.13	0.12	0.14	0.12
Valley North	0.16	0.12	0.12	0.13	0.12
Valley South	0.14	0.10	0.09	0.11	0.09
Coast Central	0.07	0.06	0.05	0.06	0.05
South	0.11	0.09	0.09	0.10	0.09
Per Person Public Demand	**0.02**	**0.02**	**0.02**	**0.03**	**0.02**
Mountain North	0.02	0.02	0.02	0.02	0.02
Valley North	0.04	0.04	0.03	0.04	0.03
Valley South	0.01	0.01	0.01	0.01	0.01
Coast Central	0.02	0.01	0.01	0.01	0.01
South	0.03	0.03	0.03	0.03	0.03

* Numbers in parentheses are SF and MF household use coefficients.

** Numbers in parentheses are commercial and industrial employees water use coefficients.

Table 18: Agricultural land use and effective crop water use for 2000 and 2030 for each scenario.

Parameter	Year 2000	Year 2030 by scenario			
		Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Irrigated Crop Area*	**9,510**	**9,050**	**9,520**	**9,500**	**9,050**
Mountain North	450	500	480	500	490
Valley North	2,040	2,070	2,200	2,190	2,080
Valley South	5,270	4,920	5,210	5,210	4,930
Coast Central	680	620	650	620	630
South	1,080	930	990	980	920
Irrigated Land Area*	**8,980**	**8,080**	**8,530**	**8,080**	**8,300**
Mountain North	450	500	480	500	490
Valley North	2,020	1,940	2,060	1,940	2,000
Valley South	5,050	4,410	4,680	4,410	4,550
Coast Central	510	460	480	460	470
South	950	780	830	780	800
Multi-cropped Area*	**540**	**970**	**990**	**1420**	**750**
Mountain North	0	0	0	0	0
Valley North	20	130	140	250	80
Valley South	220	510	530	800	390
Coast Central	170	170	170	170	170
South	130	160	160	210	120
Effective Crop Water Use**	**3.42**	**3.41**	**3.30**	**3.58**	**3.26**
Mountain North	2.72	2.63	2.53	2.70	2.54
Valley North	3.73	3.75	3.59	3.98	3.53
Valley South	3.15	3.19	3.09	3.38	3.00
Coast Central	2.11	2.02	1.93	2.06	1.98
South	5.23	5.13	4.99	5.22	5.26

* Areas in thousands of acres.

** Effective crop water use is the ratio of irrigation water use divided by the irrigated land area (acre-fee per acre).

Table 19: Statewide urban water demands by sector for 2000 and 2030 for each scenario.

Water Demand (in MAF)	Year 2000	Year 2030 by scenario			
		Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Total Urban*	**8.9**	**11.9**	**10.3**	**14.7**	**9.5**
Mountain North	0.2	0.2	0.2	0.3	0.2
Valley North	0.9	1.4	1.2	1.8	1.1
Valley South	1.3	2.0	1.8	2.5	1.6
Coast Central	1.4	1.6	1.4	1.9	1.4
South	5.2	6.7	5.7	8.3	5.3
Household	**5.5**	**7.8**	**6.4**	**9.8**	**5.9**
Mountain North	0.1	0.1	0.1	0.2	0.1
Valley North	0.5	0.9	0.7	1.2	0.6
Valley South	0.9	1.6	1.4	1.9	1.2
Coast Central	0.9	1.1	0.9	1.2	0.8
South	3.1	4.2	3.3	5.3	3.1
Economic	**2.1**	**2.6**	**2.5**	**3.1**	**2.3**
Mountain North	0.1	0.1	0.1	0.1	0.1
Valley North	0.2	0.3	0.3	0.4	0.3
Valley South	0.2	0.3	0.3	0.4	0.3
Coast Central	0.4	0.4	0.4	0.5	0.4
South	1.2	1.5	1.4	1.8	1.3
Public	**0.84**	**1.15**	**1.08**	**1.36**	**0.98**
Mountain North	0.01	0.02	0.02	0.02	0.02
Valley North	0.11	0.17	0.16	0.20	0.14
Valley South	0.05	0.08	0.08	0.10	0.07
Coast Central	0.12	0.13	0.12	0.14	0.11
South	0.55	0.75	0.71	0.90	0.64

* Total urban demand includes losses and groundwater recharge (0.12 MAF).

Table 20: Statewide agricultural and environmental water demands by sector for 2000 and 2030.

Water Demand (in MAF)	Year 2000	Year 2030 by scenario			
		Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Agricultural Sector	**34.3**	**30.8**	**31.4**	**32.4**	**30.3**
Mountain North	1.3	1.4	1.3	1.4	1.3
Valley North	8.7	8.4	8.5	8.9	8.2
Valley South	17.8	15.8	16.2	16.8	15.3
Coast Central	1.1	1.0	1.0	1.0	1.0
South	5.3	4.2	4.4	4.3	4.5
Environmental Sector	**39.41**	**39.90**	**40.39**	**39.41**	**40.89**
Mountain North	19.53	19.71	19.88	19.53	20.05
Valley North	13.49	13.58	13.67	13.49	13.76
Valley South	6.04	6.27	6.50	6.04	6.73
Coast Central	0.15	0.15	0.15	0.15	0.15
South	0.19	0.19	0.19	0.19	0.19

Table 21: Water demand changes from 2000 to 2030 by scenario and hydrologic region.

Water Demand (in TAF)	Change from 2000 to 2030			
	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
Statewide	**57**	**-360**	**3,999**	**-1,846**
North Coast	178	296	58	460
San Francisco	207	59	389	23
Central Coast	-104	-139	-10	-173
South Coast	637	-120	1,712	-233
Sacramento River	299	337	1,157	-86
San Joaquin River	-150	178	421	-76
Tulare Lake	-947	-764	-274	-1,392
North Lahontan	126	36	148	68
South Lahontan	59	24	185	-6
Colorado River	-249	-266	212	-432

Table 22: Statewide water demand changes from 2000 to 2030 by sector.

Water Demand (in TAF)	Change from 2000 to 2030			
	Current Trends	Less Resource Intensive	More Resource Intensive	Low Water Demand
All Sectors	**57**	**-360**	**3,999**	**-1,846**
Urban	3,045	1,467	5,859	657
Agricultural	-3,482	-2,815	-1,860	-3,984
Environmental	494	987	0	1,481

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