Arnold Schwarzenegger
Governor

STATEWIDE ASSESSMENT OF WATER-RELATED ENERGY USE

PIER PROJECT REPORT

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California Energy Commission
Public Interest Energy Research Program

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
- Energy Systems Integration Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is a report for the University of California Master Research Agreement contract, contract number __, work authorization MRA __, conducted by The Pacific Institute for Studies in Development, Environment, and Security in Oakland, California and the Water Policy Program at the Donald Bren School of Environmental Science and Management at the University of California, Santa Barbara. The report is entitled "Statewide Assessment of Water-Related Energy Use." This project contributes to the __ program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-4628.

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Abstract

The Pacific Institute's Water to Air Models allow water managers to quantify the energy and air quality impacts of their management decisions. These impacts are increasingly relevant to water decision-making, as energy intensive options like seawater desalination and inter-basin transfers are weighed against options that are usually less energy intensive, such as use-efficiency, conjunctive use, or wastewater reclamation (recycling).

This report presents the results of our preliminary application of the model to the entire state for the year 2000. The results will be refined in subsequent research. Although uncertain, the preliminary results suggest that water-related electricity, natural gas, diesel fuel, and carbon dioxide emissions amount to about 20%, 10%, 4%, and 8%, respectively, of statewide energy use or emissions in these categories in year 2000. The average energy intensity of water use was estimated at about 2,029 equivalent kWh (a measure of total, not just electric, energy use), including 1,363 actual kWh of electricity per acre-foot of water delivered to customers. Carbon dioxide emissions intensity was estimated to be about 1.03 metric tons per acre-foot delivered to customers. Water delivered to customers in year 2000 was estimated at slightly less than 38 million acre-feet. Energy and emissions intensities vary considerably depending on many factors such as geography, type of water system, and customer uses of water.

Executive Summary

Introduction

Bordered by the Pacific Ocean, and dotted with innumerable lakes, rivers, streams, reservoirs, canals, and aqueducts, California's water managers manipulate a complex array of natural and engineered systems to deliver water to where it is needed. A growing population of 36 million, as well as the State's agricultural and industrial sectors, uses more than 14 trillion gallons of water per year to maintain public health and a strong economy.

Purpose

To meet this demand, California water managers must choose from various water sources and technologies used to acquire, treat, and transport water; and then treat, recycle, or dispose of the resulting wastewater. Water supply, treatment, distribution, use, and recycle/disposal options have energy consumption and air pollution impacts, and detailed information is needed to help managers determine the implications of their decisions.

Project Objectives

The Pacific Institute's Water to Air Models – developed under a PIER grant -- allow water managers to quantify the energy and air quality impacts of their management decisions. The objectives of this project are:

- To use the models to perform a preliminary assessment of statewide water-related energy use, and
- To provide a graphic representation of statewide water-related energy use.

This project provides a basis for consideration of policy options, but it does not evaluate or prescribe policy solutions. In particular, it does not assess how much of estimated water-related energy use can be affected by public policies such as energy and water conservation programs. This project provides essential information that can be subsequently used to perform policy assessments. However, when a water-related energy use seems to have few or no policy opportunities associated with it, we spend less time quantifying and discussing it (e.g., energy used to heat swimming pools).

Project Outcomes

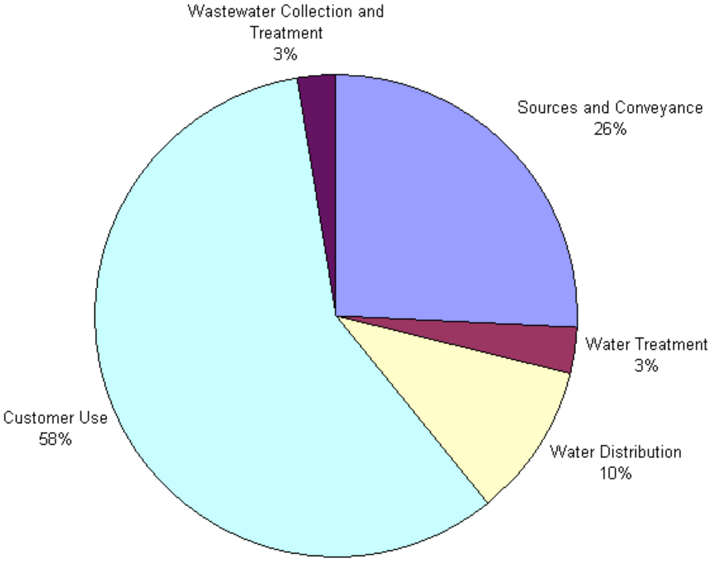
This report presents the results of our preliminary application of the Pacific Institute Water-to-Air models to the entire state for the year 2000. Our results can be summarized in two ways: total statewide water-related energy use, and statewide average energy intensity factors per unit of water managed in the state. Table ES-1 presents total statewide water-related energy use in year 2000 compared with the appropriate data from the introduction of this report. Water related electricity use comprises about 20% of statewide electricity use; water-related natural gas use is about 10% of statewide use; water-related diesel fuel use is about 4% of statewide diesel fuel consumption; and water-related carbon dioxide emissions are about 8% of statewide greenhouse gas emissions (expressed as carbon dioxide equivalents). Figures ES-1 and ES-2 present our energy intensity results.

Table ES-1: Year 2000 Water-Related Energy Use & Carbon Dioxide (CO2) Emissions

	Water-Related Totals	Statewide Totals	Water Related as a Percent of Statewide
Electricity Consumption (GWh)	51,679	263,493	20 %
Natural Gas Consumption (millions of therms)	2,375 (1)	24,446 (2)	10 % (3)
Diesel Fuel Consumption (millions of gallons)	100	2,527	4 %
CO2 Emissions (millions of metric tons)	38 (CO2)	489 (CO2 equivalents)	8 %

Notes: (1) This does not include natural gas used to produce electricity to avoid a double-count with the electricity numbers in the first row. (2) This is total natural gas consumption including gas used to produce electricity. (3) This compares with 32% of "non-generation" natural gas consumption estimated for year 2001 in CEC (2005a). The 32% converted to a percent of total statewide natural gas consumption is about 18%, based on year 2001 total natural gas consumption of 23,404 therms (see http://www.energy.ca.gov/naturalgas/statistics/natural_gas_consumption_electricity.html)

Figure ES-1: Statewide-Average Energy Intensity (2,029 equivalent kWh per af delivered to customers)



The unit intensity results summarized in Figure ES-1 should not be misinterpreted. In particular, readers need to keep in mind that:

The unit intensity results summarized in Figure 6 should not be misinterpreted. In particular, readers need to keep in mind that:

- The results are preliminary. For example, we combined energy used to collect and treat wastewater because we have no credible, separate data for collection energy at present. The zero value assumed in our analysis for wastewater collection is preliminary and needs to be improved upon.
- The results do not apply to every part of the state, service area, or customer. There is wide variation in energy intensity by service area and customer. For example, the San Diego County Water Authority case study in Wolff et.al., (2004) reported total intensity of about 7,000 kWh/af, or more than three times as high as the statewide average.1 This is because urban water use is usually more energy intensive than agricultural water use, and because San Diego County has

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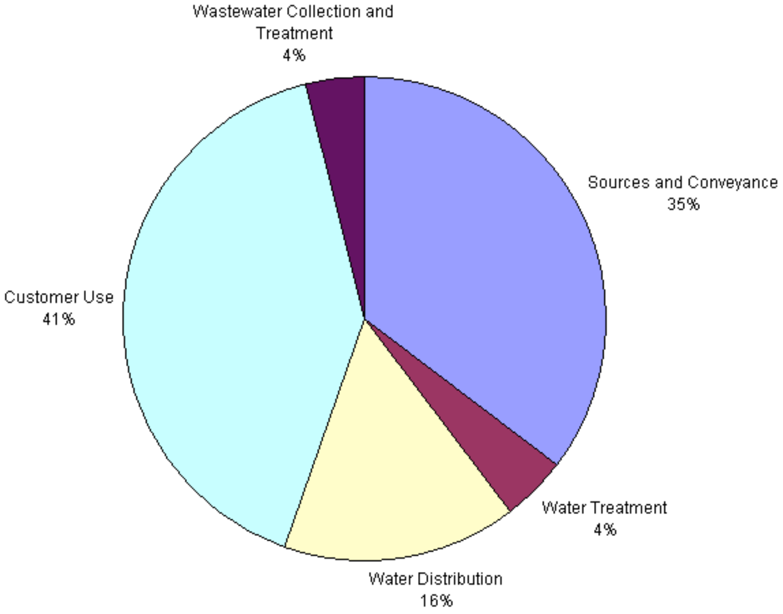
1 Although the difference would be perhaps only a factor of 2 or 2.5 if water-related cooling energy in that case study had been estimated in the same way as in this analysis.

higher energy intensity than most urban service areas due to its location at "the end of the line" for water imports from both the Colorado River and the San Francisco Bay-Delta. Similarly, intensity of use for restaurants can be 10 or more times higher than for irrigation customers like golf courses or parks.

- The equivalent kWh measure in Figure 6 includes natural gas and diesel fuel consumption, not just actual electricity. Natural gas was converted to equivalent electricity at 10.25 kWh per therm based on assumed natural gas conversion efficiency for production and delivery of 33% (about 9,750 BTUs per kWh). Similarly, diesel fuel was converted to equivalent electricity at 14.24 equivalent kWh per gallon of diesel fuel based on an assumed conversion efficiency of 30% (about 10,500 BTUs of diesel fuel per kWh).
- Statewide average *actual* electricity intensity of water use is summarized in Figure ES-2. Electricity intensity is about 1,363 actual kWh per af of water use. This implies that about 2/3 of estimated statewide water-related energy use is electricity (1,363 / 2,029 = 67%). About 31% of estimated statewide water-related energy use is natural gas, and the remaining 2% is diesel fuel.

Figure ES-2: Statewide-Average Electricity Intensity (1,363 actual kWh per af delivered to customers)



Our analysis also indicates that water-related energy use in 2000 occurred primarily in source and conveyance 2 projects (e.g., the State Water Project, the Federal Central Valley Project, groundwater pumping) and on water customer premises (e.g., homes, factories, farms). Sources and conveyance and customer use are estimated to account for 35% and 41% of actual water-related electricity use, and 26% and 58% of equivalent electricity use, respectively. The remaining 24 - 16%% of energy use is estimated to occur in water treatment and distribution and wastewater collection, treatment, and discharge. Finally, the preliminary estimate of carbon dioxide intensity is about 1.03 metric tons per acre-foot of water delivered to customers.

Recommendations

Our general recommendation for subsequent research is to fill the data gaps and clarify the data inconsistencies found in this effort. We provide a detailed, prioritized, list of gaps and inconsistencies in the final section of this report.

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2 By "sources" we mean places where water is extracted from nature. By conveyance we mean bulk transportation in pipes or canals, prior to delivery to urban utilities or agricultural irrigation districts.

It is tempting to think that the gaps that have the largest consequences for water-related energy use should be addressed first. However, that may be incorrect. For example, recreational water-related energy use and residential clothes dryer use are quite large. But there may be little opportunity to reduce water-related energy use via policies targeted at swimming pools, hot tubs, waterbeds, and clothes dryers. For that and other reasons, as explained in the report, we have excluded these categories of water-related energy use from our results. In addition to the relative size of the numbers involved, one needs to consider the policy-relevance of future data and the ease or difficulty of obtaining further information when considering which data gaps or inconsistencies to address first.

We also strongly recommend, either as part of or separately from research on the energy-water nexus, that water source and use information in California be measured or estimated with much care than is currently employed by the Department of Water Resources. In fairness to the Department, exact numbers were not critical in the past and budgetary resources for fundamental data gathering and data management have not been a high political priority. But water in California is increasingly scarce and valuable and will continue to become more so in the future. It is no longer tenable for the fifth largest economy in the world to not really know, for example, how much groundwater it is using when groundwater seems to be about 1/3 of total water supply, groundwater levels are falling in many parts of the state, and groundwater is one of the most reliable supply sources during multi-year droughts.

Benefits to California

Significant economic and environmental benefits can be achieved cost-effectively in California through efficiency improvements in both water use and in the state's water infrastructure. Electricity and natural gas ratepayers pay for these commodities directly and pay for air quality problems indirectly. When energy and water can be saved simultaneously, the economic benefits usually far exceed the economic costs. But these opportunities have not been recognized until recently, and policies to capture them are in their infancy. Consider a simple example: dual-flush toilets. These toilets use much less water than conventional toilets but their financial benefits typically exceed their financial costs only if water prices rise fairly rapidly in the future. But in tall buildings where supplemental pressurization is required to make toilets work on upper floors, these toilets may be very desirable financially because of the added energy benefit. One cannot identify and capture desirable opportunities like this without further research along the lines presented in this report.

1.0 Introduction

Bordered by the Pacific Ocean, and dotted with innumerable lakes, rivers, streams, reservoirs, canals, and aqueducts, California's water managers manipulate a complex array of natural and engineered systems to deliver water to where it is needed. A growing population of 36 million and the state's agricultural and industrial sectors directly used more than 43 million acre-feet of water in year 2000 (about 14 trillion gallons) to maintain public health and a strong economy. Direct use is water extracted from natural water bodies. In addition, indirect use (that is, environmental or "in-situ" use) of water in California was over 39 million acre-feet in year 2000; supporting economic activity such as recreation, tourism, and fishing.

The California Department of Water Resources compiles agricultural and urban applied water use3 data for selected years in the categories shown in Figure 1. The sum of the urban categories is 8.9 million acre-feet. The sum of the agricultural categories is 34.2 million acre-feet. Total direct water use in year 2000 -- the sum of urban plus agricultural categories – is 43.1 million acre-feet. About 2/3 of direct use is consumptive. That is, it is used up via evapo-transpiration through crops and urban landscapes or in other ways. The remaining 1/3 is not used consumptively; that is, it becomes wastewater or agricultural return flows that are available, at least potentially, for reuse.

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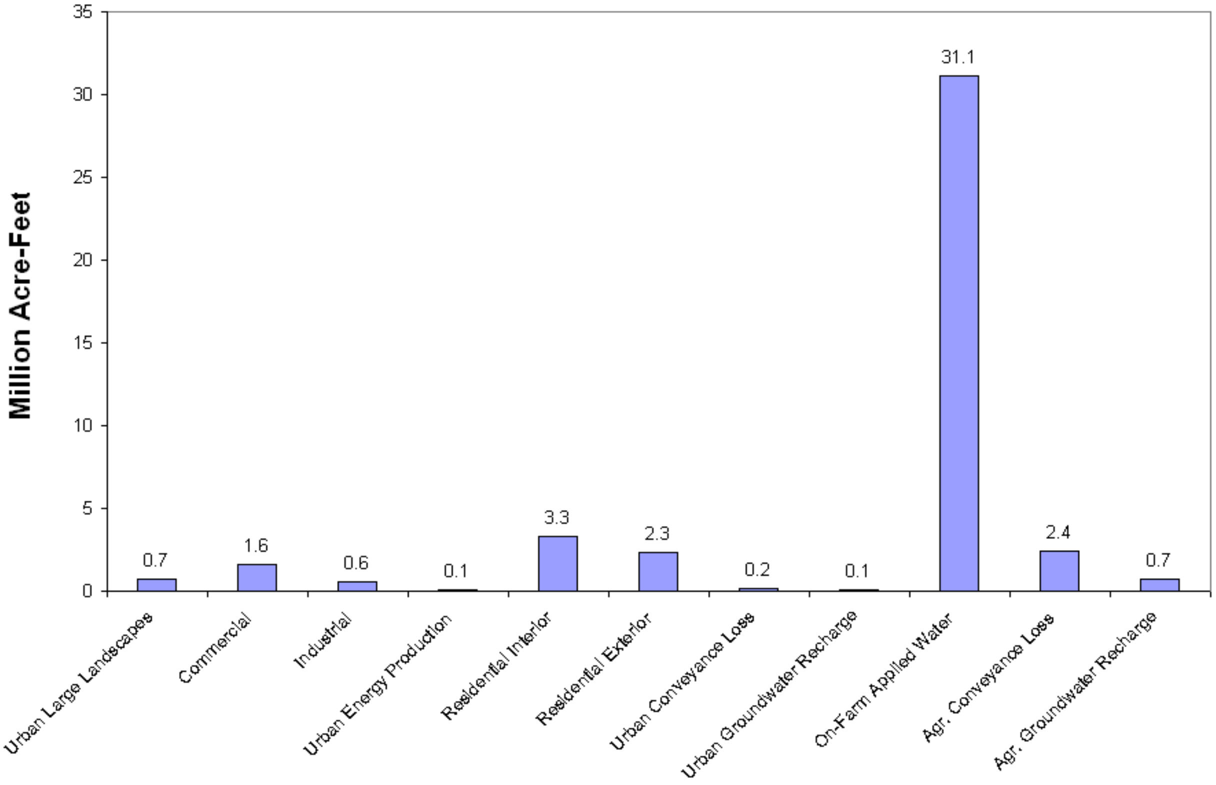
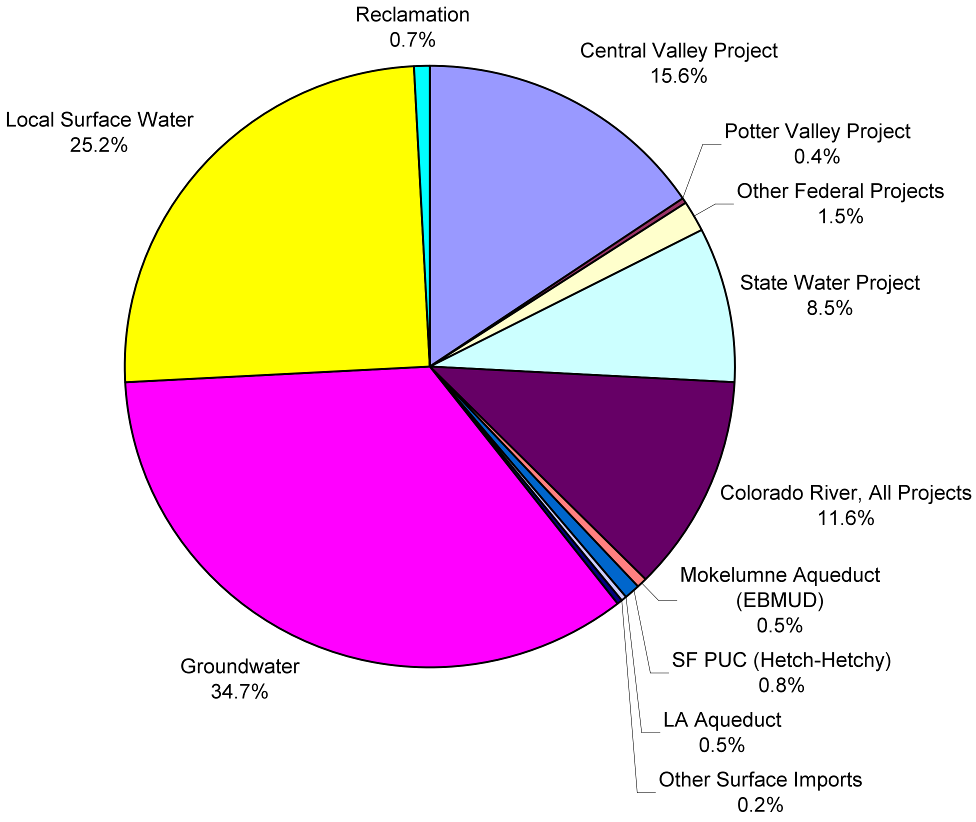
3 Although they call the data "applied water use," this phrase does not mean water delivered to and used by customers.

Figure 1: Urban and Agricultural Applied Water Use in California in Year 2000 (data from Tipton 2005)



This water is supplied from a variety of sources, such as local surface water, surface water transferred from one watershed to another ("imported water"), and groundwater. The primary sources of water for direct use in California in year 2000 are presented in Figure 2. The total of sources represented in Figure 2 is 43.1 million acre-feet, matching total use in the figure above. The source total, however, is not directly from DWR but involves data from numerous sources as described in detail later in this report.

Figure 2: Water Sources in California in Year 2000 (calculations by the authors)



To bring water through the source-use-disposal cycle, California water managers must choose from various water sources and technologies used to acquire, treat, and transport water; and then treat, recycle, or dispose of the resulting wastewater. Water supply, treatment, distribution, use, and recycle/disposal options have energy consumption and air pollution impacts, and detailed information is needed to help managers determine the implications of their decisions. Statewide data on water-related energy use will help to identify those areas (e.g., bulk water supply or industrial process heat) where new collaborations can significantly reduce water or energy use in California.

The Pacific Institute (PI) previously worked with the Natural Resources Defense Council (NRDC) to evaluate the energy used in water management (Wolff et al. 2004) based on methods pioneered by Robert Wilkinson of the University of California, Santa Barbara (Wilkinson 2000). The 2004 NRDC/PI report *Energy Down the Drain: The Hidden Costs of California's Water Supply* includes case studies of San Diego County, the Westlands Water District in Central California, and the Columbia Basin Project in the Pacific Northwest. Wilkinson (2000) and previous researchers had identified the water sector as a large user of electricity and other forms of energy in California.

Energy Down the Drain found that energy use in urban water management in California is even higher than previously recognized, primarily because energy used during customer use of water (e.g., for heating water) is often at least as large as energy used to extract, transport, treat, distribute, collect, and dispose of water and wastewater properly. For example, the San Diego County Case Study found that the equivalent [4] of about 7,000 kilowatt-hours (kWh) of electricity are used along with each acre-foot of water used there, with more than half of that energy use occurring on the customer side of the water meter but prior to wastewater discharge.

Subsequent, preliminary calculations by Energy Commission staff (CEC 2005a) suggest that 19% of electricity and 18% of natural gas use statewide5 is related to water management ("water-related"). We have re-evaluated these findings using a different method than Energy Commission staff. But before presenting our method and results, some general statistics on California's energy use are helpful. Figures 3, 4, and 5 present statewide electricity, natural gas, and diesel fuel use in recent five-year increments (1990 or 1995 through 2005). Natural gas is used to heat water, and in at least a few cases to directly drive pumps[.6] Diesel fuel is often used on farms to pump water. Another energy-related number that provides a useful context for our results – given that there is widespread interest in California in climate change issues -- is statewide greenhouse gas emissions, estimated at 489 million metric tons of carbon dioxide equivalent in 2000 (CEC 2005b).

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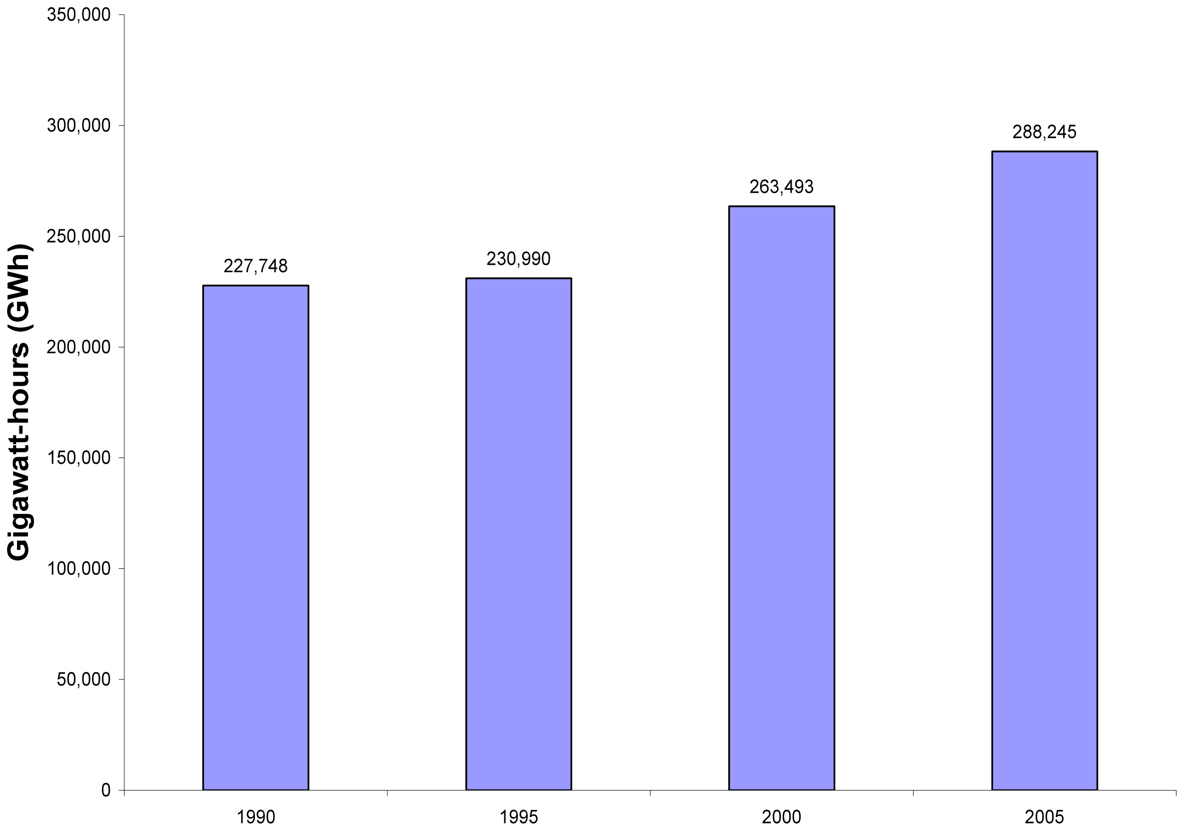
[4] All of this energy use is not electricity; hence the word "equivalent." Other types of energy use (e.g., natural gas for water heating) are converted to equivalent kWh of electricity assuming the natural gas was used to produce electricity in a central power plant.

5 The IEPR natural gas percentage is actually 32%, but this refers to the percentage of non-generation natural gas consumption in 2001 that is water-related. The lower percentage in the text is the IEPR figure restated as a percentage of statewide natural gas consumption including natural gas used to generate electricity, assuming total natural gas consumption in 2001 was about the same as in 2000.

6 Both as pure natural gas or mixed with biogas, as in wastewater treatment plants.

Figure 3: Statewide Electricity Use [7]



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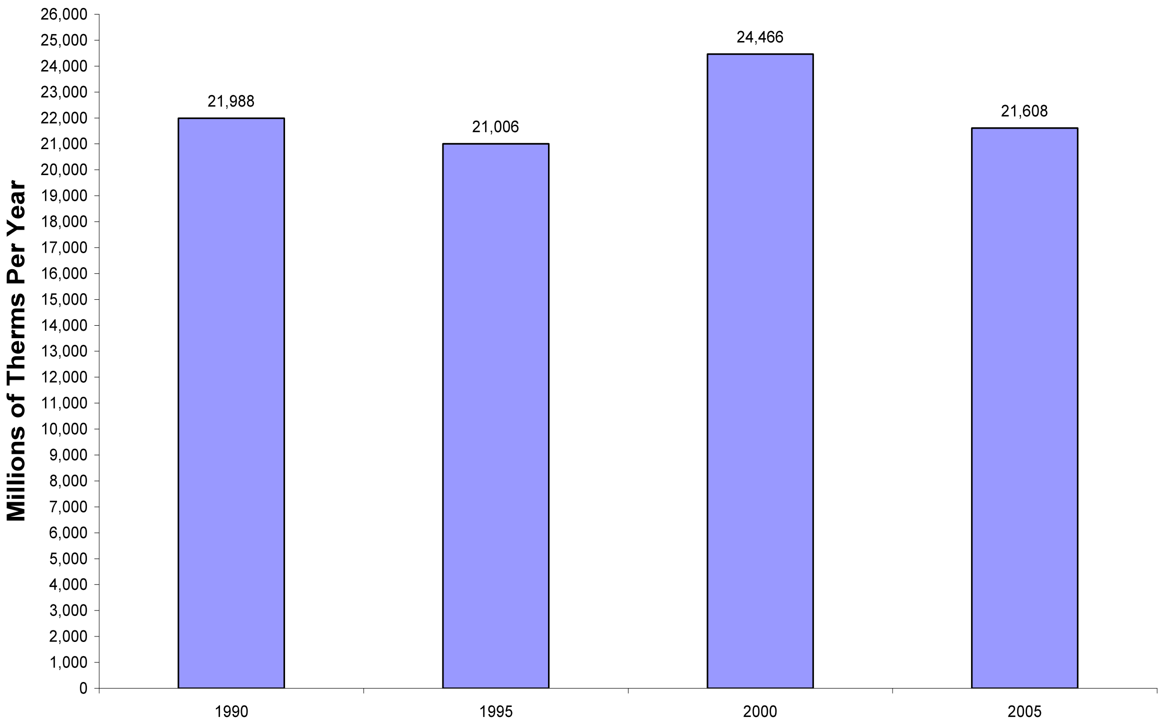
[7] Data from http://energy.ca.gov/electricity /gross_system_power.html and http://energy.ca.gov/electricity /consumption_by_sector.html

Figure 4: Statewide Natural Gas Use [8]



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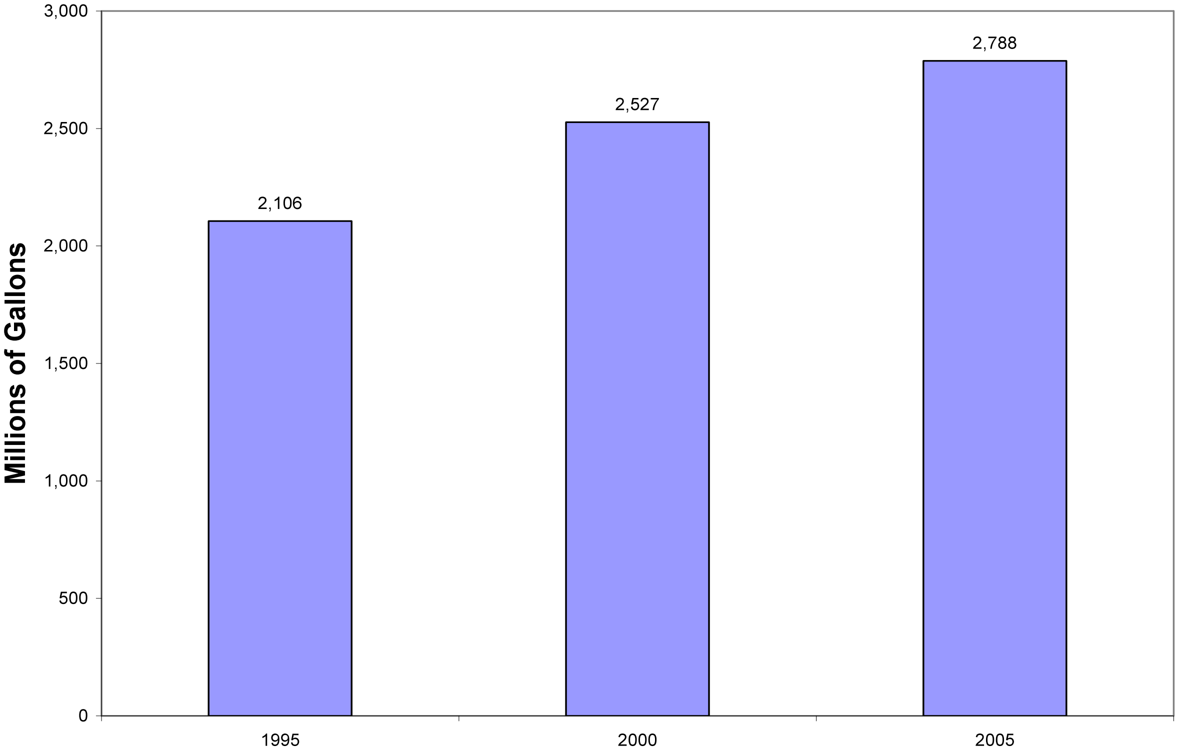
[8] Data from http://www.energy.ca.gov/naturalgas/statistics/gas_supply_by_source.html and http://www.energy.ca.gov/naturalgas/statistics/natural_gas_consumption_electricity .html

Figure 5: Statewide Diesel Fuel Use (Caltrans 2000, Caltrans 2002)9



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9 This data may exclude off-road diesel fuel use such as tractors and stationary groundwater pumps. If so, total statewide diesel fuel use is higher than shown.

2.0 Project Objectives, Approach, and Methods

2.1. Objectives

The objectives of this project are:

- Perform a preliminary assessment of statewide water and energy related use for a typical year,
- Identify data and information gaps.
- Prioritize data and information gaps that might be filled in later research.
- Provide a graphic representation of water use and water-related energy use in California.

Note that although this research has policy implications, this work does not have any policy objectives. The prioritization of additional research in the conclusions of this report is in part based on possible future policy relevance, but policy analysis is explicitly excluded from this report.

2.2. Approach and Limitations

Our approach involved two elements. First, identify annual water volumes that flow through a series of steps in the human water use cycle, commencing with extraction from nature and ending with either discharge of wastewater back to nature or consumptive use of water (e.g., evaporation and transpiration in landscapes and on farms). Second, estimate energy used to either move water through the human use cycle, or used along with water use (e.g., heating or supplemental pressurization on customer premises).

Wolff (2004) previously created the Pacific Institute *Water-to-Air Models* under a PIER Environmental Assessment grant, specifically in order to automate this approach. There are separate urban and agricultural models. The models run in Excel. They automate the calculations described above and performed in case studies in *Energy Down the Drain* and add an air quality 'layer.' The models allow water or irrigation district staff to compare the energy use and air emissions associated with pairs of water management scenarios that they create. The models and user manual are available for free download from www.pacinst.org

In this analysis, we initially attempted to apply the Water-to-Air models to statewide urban and agricultural sectors, respectively. However, some of the data on water sources is not linked to data on water end-uses, so separate analysis of urban and agricultural sectors would introduce potentially large errors in the analysis we felt it was best to avoid in this first preliminary analysis (see further discussion below on this data gap). Consequently, we modified the urban model to analyze statewide water-related energy use in urban and agricultural settings. We also added graphic outputs to the model in pursuit of the 'visual' objective mentioned above. These outputs update automatically when model inputs are changed.

Although the model allows one to compare two statewide scenarios, we only prepared a baseline scenario that reflects actual water and energy use in year 2000 (an average water year per DWR 2005). Scenario comparisons with other years or 'what if futures' were beyond the scope of this study. Our approach, however, allows such comparisons to be made easily in future studies or evaluations.

Finally, this project provides a basis for consideration of policy options, but it does not evaluate or prescribe policy solutions. In particular, it does not identify or assess how much of estimated water-related energy use can be affected by public policies such as energy and water conservation programs. This is an important dimension of future work. High water-related energy intensity does not necessarily imply that an opportunity to reduce energy or water use exists. Nonetheless, this project provides information that will be essential as policy opportunity assessments are performed, later.

2.3. Method and Limitations

The statewide Water-to-Air model provides a consistent accounting framework for water-related energy use. It requires users to list the facilities at which energy is used in the water source-use-disposal chain. For example, potable water treatment plants, distribution booster stations, end-use appliances (e.g., clothes washers), and wastewater treatment plants are facilities. The model also requires users to list the amount of water that flows through each facility in acre-feet per year. It is important to recognize that the value of the model is its consistent and transparent accounting framework, not necessarily the default values embedded in the model. We present the basis for all default or entered values used in our analysis in the detailed discussion below.

The model is limited to 20 facilities within each type (e.g., water treatment plants). When more facilities exist, one can list and sum them outside the model, or otherwise estimate water and energy use for that category of facilities. For example, one inputs all clothes washer water and energy use in the state as a single facility rather than listing individual makes and models of clothes washers and their water and energy use data. In most applications, 19 categories offer enough detail to capture water and related energy use with reasonable accuracy. But in some cases, an explicit list of facilities outside the model is useful. This is how we handled industrial process water and energy use, an area with high energy-intensity per unit of water used, and large variability in energy intensity between process categories that we felt were important to report separately.

The model allows users to specify the amount of energy used at each facility (see Box 1) in total over a year, or to use a default energy intensity factor per acre-foot in some cases. When total energy data is entered, energy intensity per unit of water use is calculated. When a default factor is used, total energy use is calculated. This means that the model is linear in structure: energy use does not vary per acre-foot of water that passes through each facility. This assumption is inaccurate for many individual facilities; but is appropriate for obtaining averages over many facilities.

Box 1: What is energy use "at" each facility? What facilities should be included?

Energy used by facilities is not as simple a concept as it might appear. For example, although energy used in clothes dryers is physically 'outside' the clothes washer whose use precedes the clothes dryer; some would argue that the washer-dryer pair is a single facility since the sole purpose of the dryer is to remove water. For this reason, clothes dryer energy was included in the analysis presented in CEC (2005a). However, we excluded clothes dryer energy because it depends on choices independent of the choice of clothes washer. One could dry clothes on a line. One could purchase a washer that uses large quantities of water but spins the clothes rapidly, reducing dryer energy use but not washer water use.

Another example of the difficulty of determining facility boundaries is cooling towers, where we have excluded the large amount of energy used in the low-molecular weight compression cycle and included only our estimate of the energy used in the water recirculation function of the tower itself, although one could argue that the former should be included as it was in Wolff et. al. (2004) and Wolff (2004). Another example of the difficulty of determining which facilities to include relates to devices that use water to transfer energy. We excluded residential hot tubs, swimming pools, and waterbeds and commercial and industrial boilers used for building heat (we included boiler energy for process water). Our rule was to exclude energy associated with facilities whose water use is *de minimis*, but our judgment about which facilities have *de minimis* water use may be incorrect.

Our 'boundary decisions' are somewhat arbitrary, although consistent. Future research may use other 'boundary decisions.' It is important to explicitly identify these decisions, evaluate and discuss their impacts, and avoid arguments about which definition of 'water-related' is 'right.'

All energy intensity numbers are per acre-foot of water that is delivered to customers. This is an important accounting convention. If instead, energy intensity were calculated for each step in the water source-use-disposal cycle, separately, then added, the sum of the intensity numbers would not be accurate because water is lost through the cycle. For example, intensity of 2,000 kWh per acre-foot of water delivered to customers should not be added to intensity of 1,000 kWh per acre-foot of water entering a wastewater treatment plant since a large percentage of the original acre-foot does not become wastewater (e.g., it evaporates). The delivery plus wastewater treatment intensity is either 2,500 kWh per acre-foot delivered to customers, or 5,000 kWh per acre-foot entering the wastewater plant, if only 50% of water use becomes wastewater. Either number is accurate. But 3,000 kWh per acre-foot is not accurate, since it is unclear what acre-foot the 3,000 kWh per acre-foot number would refer to. For this analysis, we chose to use acre-feet delivered to customers as the denominator in our energy intensity calculations because it seemed the most useful and easiest to understand. But from a method perspective, water flow at any point in the source-use-disposal cycle could be specified in the intensity denominators.

The model also requires users to specify a mix of energy for every facility. This is relevant to both our estimates of air emissions from water-related energy use and possible consequences of water-related energy use for different energy markets (e.g., electricity, natural gas, diesel fuel). Some examples of energy mixes are:

- 100% electricity from the California Grid, or
- A combination of electricity from the grid and direct use of natural gas, as is the case for the energy used in clothes- and dishwashers.

Up to nine sources of energy can be combined to make a mix, and the model allows users to specify as many as eight mixes. If users know their electricity comes from a particular utility, they can contact the utility and find out the percentages to use (e.g., of natural gas, coal, and nuclear) to create a local grid mix. Energy sources in the model also include some non-electricity options like direct drive diesel pumps, which are widely used in agriculture. Air pollution emissions factors are embedded in the model for each of the nine types of energy sources. The model does not allow emissions factors to be easily changed at present. This is an important limitation since the grid mix of energy sources may have changed significantly from the year (2002) data embedded in the model.10

The model calculates energy use using two units: actual kilowatt-hours (kWh) and equivalent kWh. The equivalent number is the sum of actual kWh and the kWh that would have been generated if natural gas, diesel fuel, or other energy sources used directly to manage water had instead been used to generate electricity in a central power plant. The model outputs therefore do not distinguish between forms of energy other than electricity and non-electric. In the results reported below, however, we have manually calculated the natural gas and diesel fuel components.

The number of facilities and energy sources permitted by the model limited our application of the model. For example, we were not able to specify all mixes of electricity sources that probably exist. This does not affect our water-related energy results, but it does affect the air emissions outputs since changes in the mix of sources of electricity will affect emissions. Consequently, the air emissions outputs should be considered less reliable than the energy use outputs. If air emissions information is considered critical, this problem could be addressed by programming additional capacity into the energy source input matrix during subsequent research efforts.

2.4. Primary Data Sources

The most extensive or important sources of data used in this report are described in this section. Other sources from which we obtained less critical data points are referenced as appropriate in later sections of this report. The original source data is extensive and contains not only gaps but also contradictions. For this reason, we have not included

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10 PG&E reports a large decrease in coal-sourced electricity in recent years, but we have not reviewed statewide changes since air emissions are not the focus of this report.

summaries of the source data in this report, other than the tables and figures in the introduction, above.

Year 2000 was a typical water year according to the State Water Plan (DWR 2005). Consequently, we focused on year 2000 data. Statewide water use has not increased over the last few decades (Wolff and Gleick, 2002), although there has been variation from year to year and a shift from agricultural toward urban use. However, as figures 3 and 5 show, electricity and diesel fuel use have been rising steadily over time. Figure 4 shows that year 2000 natural gas use was unusually high in the 1990-2005 time span. It is possible that water-related electricity and diesel fuel intensity have been or are increasing over time, but we have not evaluated that possibility in this report because it was outside our objectives.

Our most extensive source of data for water data for all planning units and hydrologic regions of California for 1998, 2000, and 2001 was a spreadsheet provided by Tipton (2005). DWR staff advised us that there might be errors in the spreadsheet because it is very large, has been updated numerous times by various staff members, and is not a carefully reviewed, published document. Consequently, we used this reference only for comparison with data from other references, or when it provided data not available from any other reference.

For example, Tipton (2005) reports total urban water use as 8.9 million acre-feet. Gleick et. al. (2003), in contrast, report year 2000 urban water use of 7.0 million acre-feet plus or minus 10%. These sources use different methods, which were not comparable because DWR staff could not explain precisely how their numbers were obtained other than to say that DWR staff responsible for each planning unit provides data from a variety of local sources such as utility staff. DWR staff, however, was able to provide numerous other clarifications of the data (primarily Hillaire 2005). Consequently, our total urban water use number reflects the upper end of the range reported by Gleick, et. al., in order to give as much credence to DWR data as possible. It also incorporates some of the details provided by DWR that are not present in Gleick et. al.

For water source data, we relied heavily on Hutson et.al. (2004) and Burt et. al., (2003), and to a lesser extent on Tipton (2005) and DWR (1995). Hutson is a published peer reviewed document that reviewed and included as appropriate data from DWR, while Tipton (2005), as noted above, is unpublished and not peer reviewed. We felt that Hutson was more reliable for that reason. However, Burt et. al. (2003), Tipton (2005), and DWR (1994) provide details that are not present in Hutson, so we again used those details as appropriate.

Data on water for agriculture is critically important since agricultural water use is such as large portion of total water use in California (around 80%). However, none of the data sources report actual measures of groundwater used in agriculture, although groundwater constitutes more than 1/3 of total estimated agricultural use.11 The

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11 DWR (2003) acknowledges this limitation and others concerning groundwater

method commonly employed to estimate agricultural groundwater use is to infer total water use from crop production and weather data. Surface water deliveries to farms are measured in most cases, so groundwater use is estimated as the difference between total estimated use and delivered surface water. This method is reasonable, but clearly contains significant potential for error as discussed further below.

Water-related energy use data were obtained from a wide range of sources, including phone conversations with water agency and district staff. Specific references are provided later in this report.

We used data from Gleick et. al. (2003) and DOE (1998 and 2002) to evaluate industrial process water-related energy use. The raw data on process water use that was evaluated in Gleick et. al. is from a 1995 DWR survey of California commercial, institutional, and industrial (CII) water use. The data on manufacturing energy use in DOE is from a periodic national survey of manufacturers. We used 1998 and 2002 data since the survey was not performed in year 2000. As discussed below, we found that industrial process water-related energy use is the largest category of water-related energy use in California, but it is also highly uncertain.

Finally, we used a number of sources to crosscheck data from these primary sources, including: CEC (2005a), CEC (2005c), EIA (2001), House (2006), Wolff et.al. (2004), Wilkinson (2003), PG&E (2002), and Klein (2005). In particular, energy utility reports to the CEC on sales by SIC or NAICS code were of special interest. We discuss how data from various sources compares in the discussion of results section later in this report.

3.0 Results and Discussion

3.1. Summary of Statewide Water-Related Energy Use

Our results can be summarized in two ways: total statewide water-related energy use, and statewide average energy intensity factors per unit of water managed in the state. Table 1 presents total statewide water-related energy use in year 2000 compared with the appropriate data from the introduction of this report. Water related electricity use comprises about 20% of statewide electricity use; water-related natural gas use is about 10% of statewide use; water-related diesel fuel use is about 4% of statewide diesel fuel consumption; and water-related carbon dioxide emissions are about 8% of statewide greenhouse gas emissions (expressed as carbon dioxide equivalents). The water-related emissions estimates are the least accurate of the estimates developed in this analysis because the energy source mixes for each facility were not researched in detail and the

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management in California.

emissions factors are from years prior to our recent energy crisis; which has led to significant changes in the composition of energy supply in California.

Table 1: Year 2000 Water-Related Energy Use & Carbon Dioxide (CO2) Emissions

	Water-Related Totals	Statewide Totals	Water Related as a Percent of Statewide
Electricity Consumption (GWh)	51,679	263,493	20 %
Natural Gas Consumption (millions of therms)	2,375 (1)	24,446 (2)	10 % (3)
Diesel Fuel Consumption (millions of gallons)	100	2,527	4 %
CO2 Emissions (millions of metric tons)	38 (CO2)	489 (CO2 equivalents)	8 %
Notes: (1) This does not include natural gas used to produce electricity to avoid a double-count with the electricity numbers in the first row. (2) This is total natural gas consumption including gas used to produce electricity. (3) This compares with 32% of "non-generation" natural gas consumption estimated for year 2001 in CEC (2005a). The 32% converted to a percent of total statewide natural gas consumption is about 18%, based on year 2001 total natural gas consumption of 23,404 therms (see http://www.energy.ca.gov/naturalgas/statistics/natural_gas_consumption_electricity.html)			

These totals for electricity and natural gas differ from those in the 2005 Integrated Energy Policy Report (CEC 2005a). Table 2 provides a summary comparison. *Both estimates are preliminary and depend heavily on differences in the data sources, especially with regard to industrial process energy use and residential hot water use, and assumptions used to estimate the fraction of energy use by industrial customers that is water-related. Neither estimate is necessarily more accurate than the other.* 12

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12 Although our estimate, with the exception of industrial process energy use, is based on 'bottom-up,' facility-by-facility assessments of energy use while CEC (2005c) is entirely based on 'top-down' aggregate data provided by investor owned energy utilities. Neither approach is necessarily better, but the bottom-up approach is more transparent and potentially more accurate if sufficient disaggregate data were to exist.

Table 2: This Study and CEC 2005a (IEPR) Estimates Compared

	Electricity (Annual GWh)	**Non-Power-Generation Natural Gas (1)** (Millions of Therms)	**Diesel Fuel (1)** (Millions of Gallons
2005 IEPR	48,012	4,284	88
This Report	51,679	2,375	100
Percent Difference	+8% (2)	-45%	+14%
Notes: (1) Natural gas and diesel fuel use presented in this table exclude natural gas or diesel used to generate electricity. If we had not excluded gas or diesel used to generate electricity from the noted columns, a double-count would have existed with energy use in the electricity column. (2) If clothes dryers had been included in our analysis, as they were in CEC (2005a and 2005c), this difference would be 20%, and the natural gas difference would be about –42%.			

It is not surprising that our natural gas results differ. Natural gas used to heat water is around 750 million therms higher in the IEPR than in our analysis. Natural gas use for oil and gas extraction estimated to be 'water-related' in the IEPR accounts for another 1,388 million therm difference in the estimates. These differences alone account for more than the total difference in the natural gas estimates. However, the apparently close match after these adjustments, and the close match of the electricity numbers should not be taken too seriously. Including clothes dryer data used in CEC (2005c) and presented in CEC (2005a), which we excluded, would increase the gap between our and the IEPR results from 8% to 20%. And there are numerous differences in the natural gas estimates that would move the numbers apart rather than closer.

Nonetheless, the two estimates are well within the factor-of-two accuracy range specified by the American Society of Cost Engineers for "order of magnitude" estimates. This increases the credibility of both estimates, since they used *entirely different* 13 data sources and years of data (discussed later in this report).

We found that reasonable variation in the assumptions made about how much of industrial energy use is water-related do not change the broad results of our analysis since industrial energy use which is plausibly water-related is so large. Wolff, et. al.

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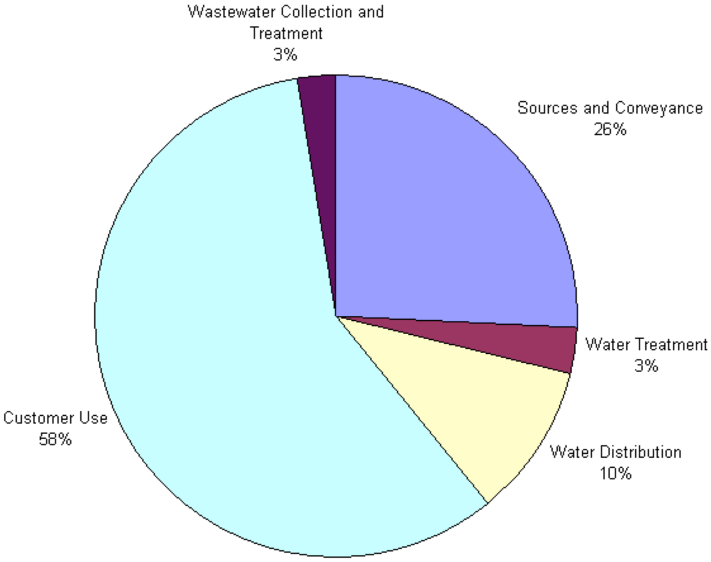
13 In a very few cases we used data from CEC (2005c) or Klein (2005). But these overlaps account for a small percentage of total energy use in our analysis.

(2004) found that energy used along with water on the customer side of the water meter dominates water-related energy use, and that finding is supported by this analysis and is robust to reasonable changes in the assumptions about water-related industrial energy use. For example, we assumed that 50% of process heat natural gas energy use was water-related, but even if only 10% were water related, our result for process water energy intensity, overall, will change by well less than a factor of 5. Further, we found that changes of a factor of 10 or more are required in the water-related process energy use numbers to significantly alter the pattern of water-related energy intensity presented in Figure 6.

Figure 6: Statewide-Average Energy Intensity (2,029 equivalent kWh per af delivered to customers)



The unit intensity results summarized in Figure 6 should not be misinterpreted. In particular, readers need to keep in mind that:

- The results are preliminary. For example, we combined energy used to collect and treat wastewater because we have no credible, separate data for collection energy at present. The zero value assumed in our analysis for wastewater collection is preliminary and needs to be improved upon.
- The results do not apply to every part of the state, service area, or customer. There is wide variation in energy intensity by service area and customer. For example, the San Diego County Water Authority case study in Wolff et.al., (2004) reported total intensity of about 7,000 kWh/af, or more than three times as high

as the statewide average.14 This is because urban water use is usually more energy intensive than agricultural water use, and because San Diego County has higher energy intensity than most urban service areas due to its location at "the end of the line" for water imports from both the Colorado River and the San Francisco Bay-Delta. Similarly, intensity of use for restaurants can be 10 or more times higher than for irrigation customers like golf courses or parks.

- The equivalent kWh measure in Figure 6 includes natural gas and diesel fuel consumption, not just actual electricity. Natural gas was converted to equivalent electricity at 10.25 kWh per therm based on assumed natural gas conversion efficiency for production and delivery of 33% (about 9,750 BTUs per kWh). Similarly, diesel fuel was converted to equivalent electricity at 14.24 equivalent kWh per gallon of diesel fuel based on an assumed conversion efficiency of 30% (about 10,500 BTUs of diesel fuel per kWh).
- Statewide average *actual* electricity intensity of water use is summarized in Figure 7. Electricity intensity is about 1,363 actual kWh per af of water use. This implies that about 2/3 of estimated statewide water-related energy use is electricity (1,363 / 2,029 = 67%). About 31% of estimated statewide water-related energy use is natural gas, and the remaining 2% is diesel fuel.
- The intensity numbers summarized in both figures are expressed per acre-foot of water *use*. That is, the numbers represent the intensity of energy use per unit of water delivered to customers; or about 37.868 million af in year 2000 (Table 3). As mentioned previously, this is a necessary but potentially confusing accounting convention. For example, wastewater treatment statewide uses far more energy per unit of water that actually flows through treatment plants than 53 kWh/af (the value that underlies the percentages shown in Figures 6 and 7).

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14 Although the difference would be perhaps only a factor of 2 or 2.5 if water-related cooling energy in that case study had been estimated in the same way as in this analysis.

Figure 7: Statewide-Average Electricity Intensity (1,363 actual kWh per af delivered to customers)

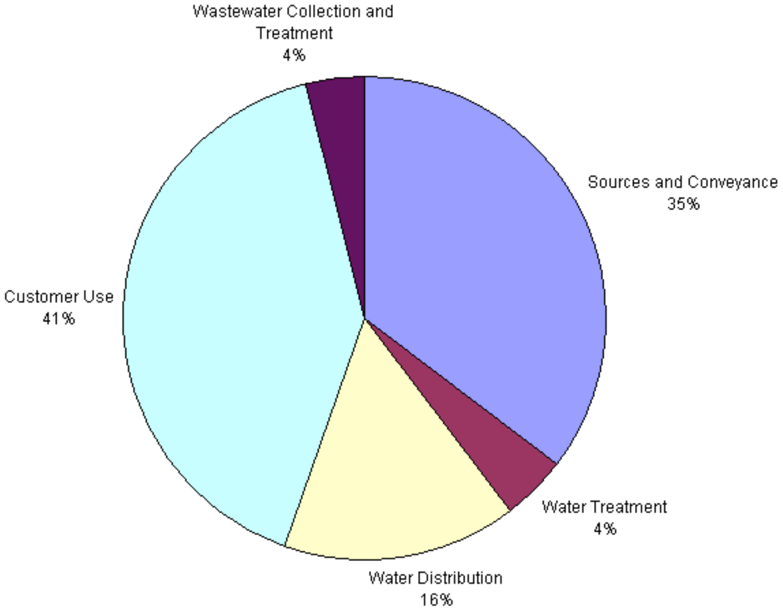

Table 3: Estimated Year 2000 Water Quantities in the Source-Use-Disposal Cycle

Step in the Cycle	**Quantity (millions of acre-feet)**
Sources and Conveyance (Subtotal)	43.405
Groundwater	17.070
Local Surface Water	9.079
Reclamation (Recycling)	0.282
Imported (Inter-Regional Transfers)	16.974
Desalination	0.000
Water Treatment	40.805 (1)
Water Distribution	40.619 (2)
Customer Use	37.868
Wastewater Collection	7.600 (3)
Wastewater Treatment and Discharge	7.600 (4)
Notes: (1) Only 7.796 million af of this water is actually treated, but all source and conveyance water is required to pass through the 'treatment step' so that water losses through the cycle can be readily identified. (2) Similarly, only 27.507 million af is actually distributed. (3) Infiltration and inflow have not been accounted for in our analysis. (4) 3.600 million af is wastewater currently treated; 4.000 million af is agricultural return flows that may be treated in the future but generally are not.	

Our analysis also indicates that water-related energy use in 2000 occurred primarily in source and conveyance 15 projects (e.g., the State Water Project, the Federal Central Valley Project, groundwater pumping) and on water customer premises (e.g., homes, factories, farms). Sources and conveyance and customer use are estimated to account for 35% and 41% of actual water-related electricity use, and 26% and 58% of equivalent electricity use, respectively. The remaining 24 - 16%% of energy use is estimated to occur in water treatment and distribution and wastewater collection, treatment, and discharge.

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15 By "sources" we mean places where water is extracted from nature. By conveyance we mean bulk transportation in pipes or canals, prior to delivery to urban utilities or agricultural irrigation districts.

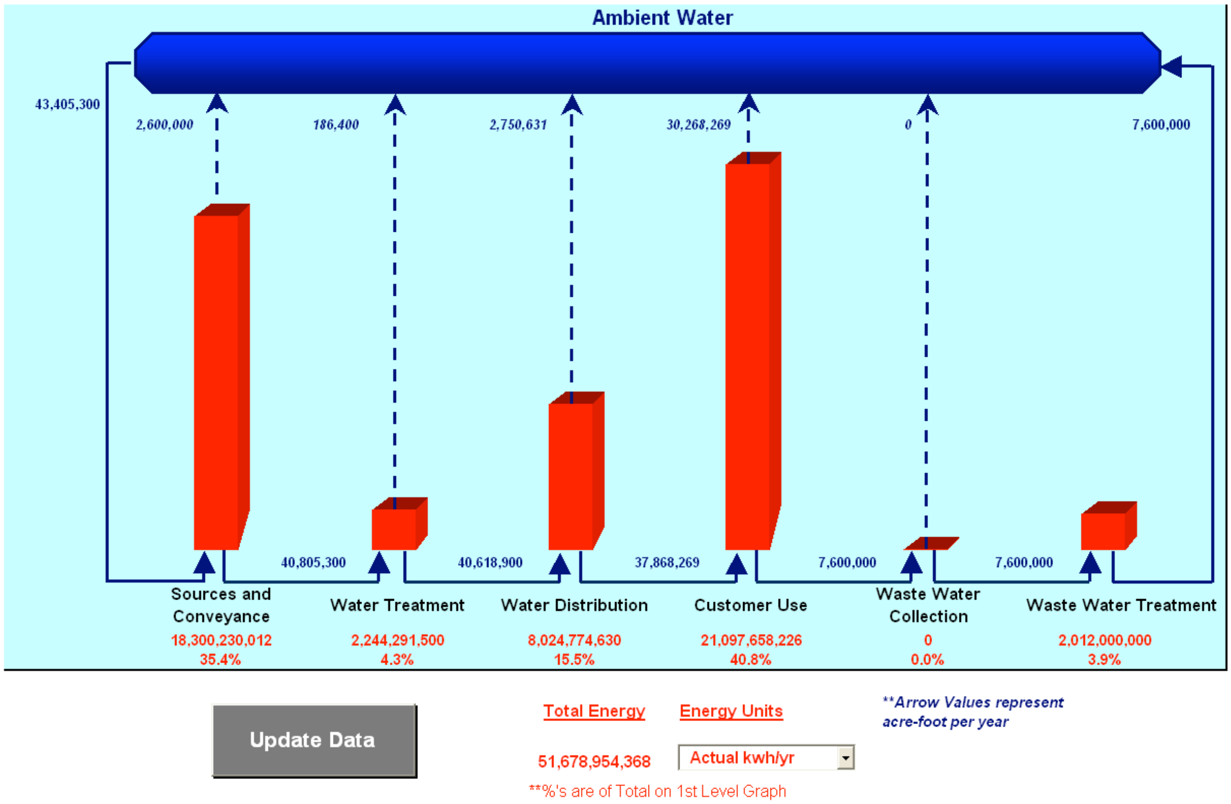
Finally, our estimate of carbon dioxide intensity is about 1.03 metric tons per acre-foot of water delivered to customers.

3.2. A Master Graph of Statewide Water and Water-Related Energy Use

*Note to reviewers – this section will be improved upon by bob wilkinson. In this draft, however, we've provided the best summary graphs available at present.*__

The statewide version of the water-to-air model created in this project includes graphic representations of water quantities and energy or electricity use for every facility input to the model. There are three levels of representation, with more detail at lower levels. Figures 8a and 8b are the uppermost level summary charts, one showing actual electricity use by step in the water cycle, the other showing equivalent electricity use.

Figure 8a: Water-Related Actual Electricity Use in Year 2000



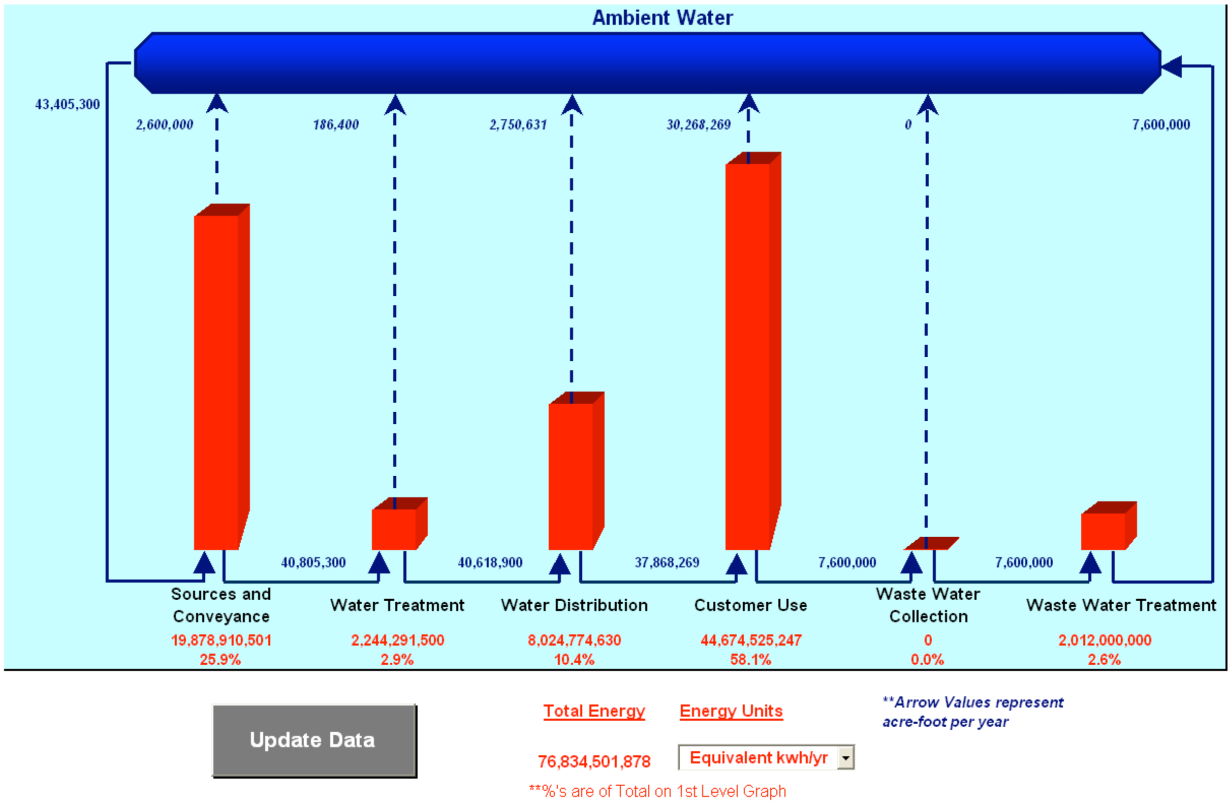
Total Energy: 51,678,954,368

Energy Units: Actual kwh/yr

**Arrow Values represent acre-foot per year

**%'s are of Total on 1st Level Graph

Figure 8b: Water-Related Equivalent Electricity Use in Year 2000



Total Energy: 76,834,501,878

Energy Units: Equivalent kwh/yr

**Arrow Values represent acre-foot per year

**%'s are of Total on 1st Level Graph

3.3. Details From the Statewide Water-to-Air Model

The preliminary statewide water-to-air model run that underlies the results presented above is contained in the file "W-to-A_statewide_revision_final.xls" . We describe and discuss the model inputs and outputs in this section. All of the figures presented in this section may be updated whenever new data is added to the model spreadsheets. Also, please note that the sizing of the figures in this report is not final, but varies as necessary to make each figure fit on at most one page with legible numbers.

3.3.1. Energy Mixes

There are eight energy mixes specified at the top of the start tab of the model. Although they reappear on other sheets within the model, energy mix inputs must be made on the start sheet. Mix one is the California grid in year 2002. We have not adjusted the composition of the mix (e.g., percent coal, percent hydro, etc.) to reflect year 2000 both because emissions are not the primary objective of this project, and only the emissions outputs will be changed if the mix is changed.

Mix 2 is pure natural gas use, such as in direct drive pumps or water heaters.

Mixes 3, 4, and 5 involve blends of grid electricity with natural gas and diesel fuel. They represent data from Burt et. al., (2003) on the composition of energy sources for groundwater pumping by farmers in California. We rounded from Burt in some cases in order to reserve energy mixes in the model for other important purposes.

Mix 6 is the blend of electricity and natural gas used along with process water in California, as estimated in detail in the way described below.

Mixes 7 and 8 represent common appliances and plumbing fixtures used in residential, commercial, and institutional settings. Mix 8 represents the composition of water heating in California reported in the Residential Energy Consumption Survey (EIA 2001). About 15% of water heating is electric, 80% natural gas, and 5% propane or butane. We have included propane and butane with natural gas for simplicity. Again, if the emissions outputs of the model were critical, one might want to modify the model to allow more energy mixes and sources such as liquid petroleum gases Mix 7 represents hot water from mix 8 passing through appliances (e.g., clothes and dish washers) whose electricity consumption for motive power is 10% of their total energy use. 16

3.3.2. Sources and Conveyance

There are five categories of water sources and conveyance in the model. Each category can contain up to 19 facilities or categories of facilities. Figures 9a and 9b represent water and actual or equivalent electricity for the five categories within sources and conveyance. Further detail within each category is provided below.

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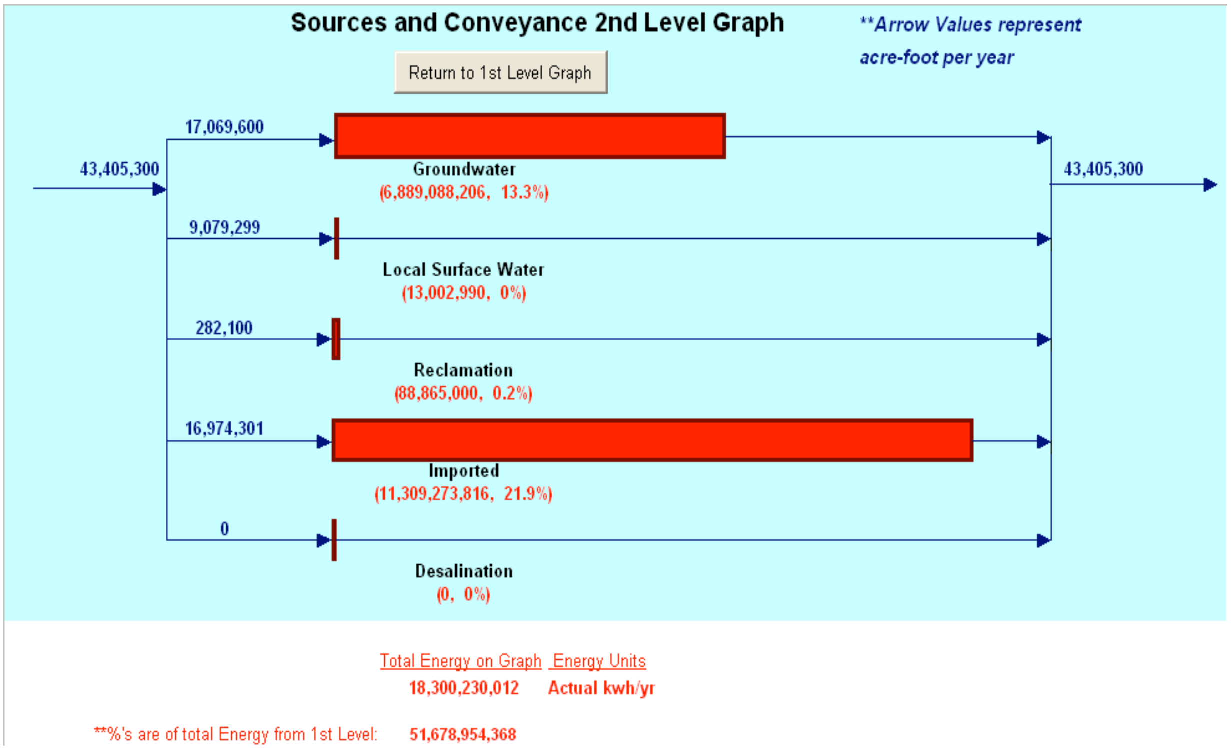
16 This 10% assumption was obtained from undocumented materials on the World Wide Web and is not considered a reliable estimate (see http://homeenergy.org/archive/hem.dis.anl.gov/eehem/96/961103.html and “energy use for clothes washers” at http://mauielectric.com). We requested fully referenced data on this point from the US Energy Star program via e-mail, but did not receive a reply.

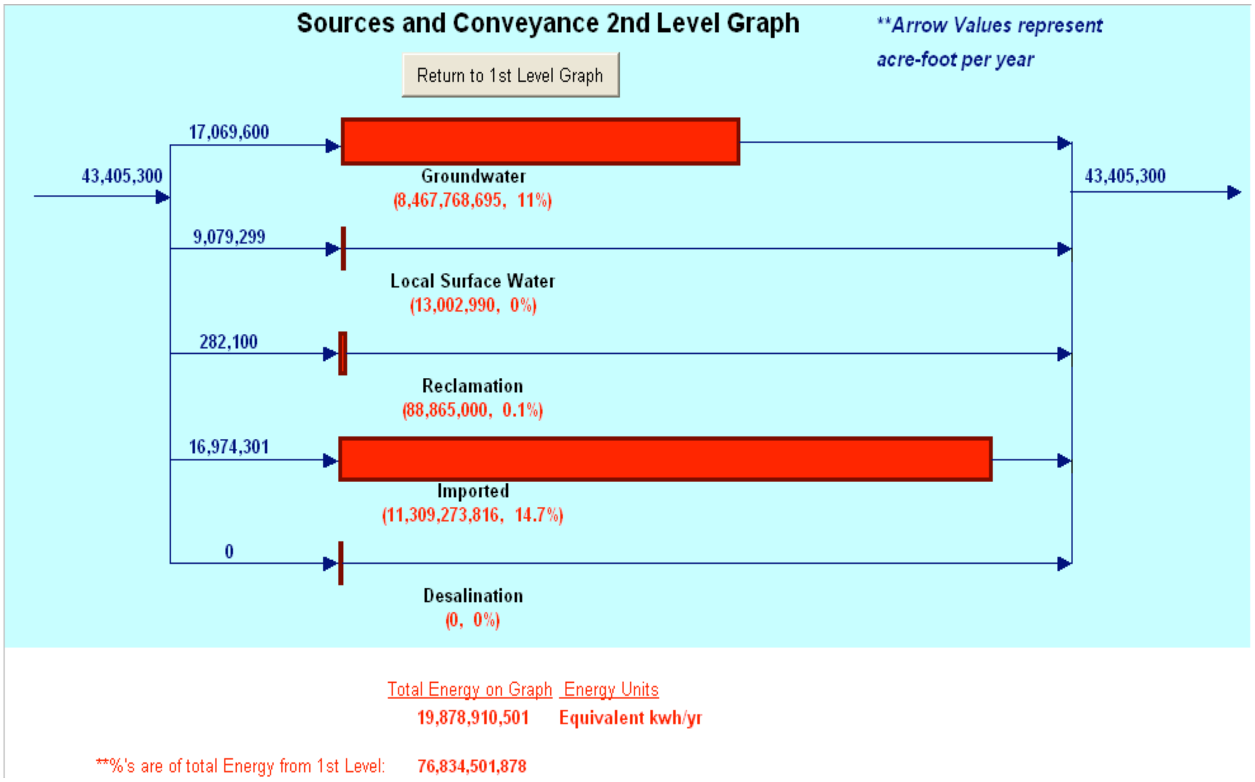
Figure 9a: Sources and Conveyance, Actual Electricity Use in Year 2000



Total Energy on Graph	Energy Units
18,300,230,012	Actual kwh/yr

**%'s are of total Energy from 1st Level: 51,678,954,368

Figure 9b: Sources and Conveyance, Equivalent Electricity Use in Year 2000



Total Energy on Graph	Energy Units
19,878,910,501	Equivalent kwh/yr

**%'s are of total Energy from 1st Level: 76,834,501,878

3.3.2.1. Groundwater

The total quantity of groundwater used in year 2000 (17.069 maf) was taken from Hutson et.al. (2004). Tipton (2005) reports a significantly lower number, 14.951 maf, but as noted above, we consider Hutson et.al. to be more reliable. Furthermore, the difference in the numbers is about 15%, a reasonable difference given that neither total water use nor groundwater use in agriculture is measured directly.

Our analysis includes 19 groups of groundwater facilities (see Figures 10a and 10b). Thirteen are farm evapo-transpiration zones evaluated by Burt et.al. (2003). Another is irrigation district groundwater pumping, also from Burt et.al. Groundwater pumped for livestock and aquaculture, industrial, mining, thermo-electric, and domestic self-supplies were taken from Hutson et.al., as was groundwater pumped by water utilities for public supply. The difference between total groundwater supply and these 19 facility categories is only 0.202 maf, or slightly more than 1% of total groundwater supply. This is a very good fit given that two unrelated data sources were used.

Figure 10a: Groundwater, Actual Electricity Use in Year 2000

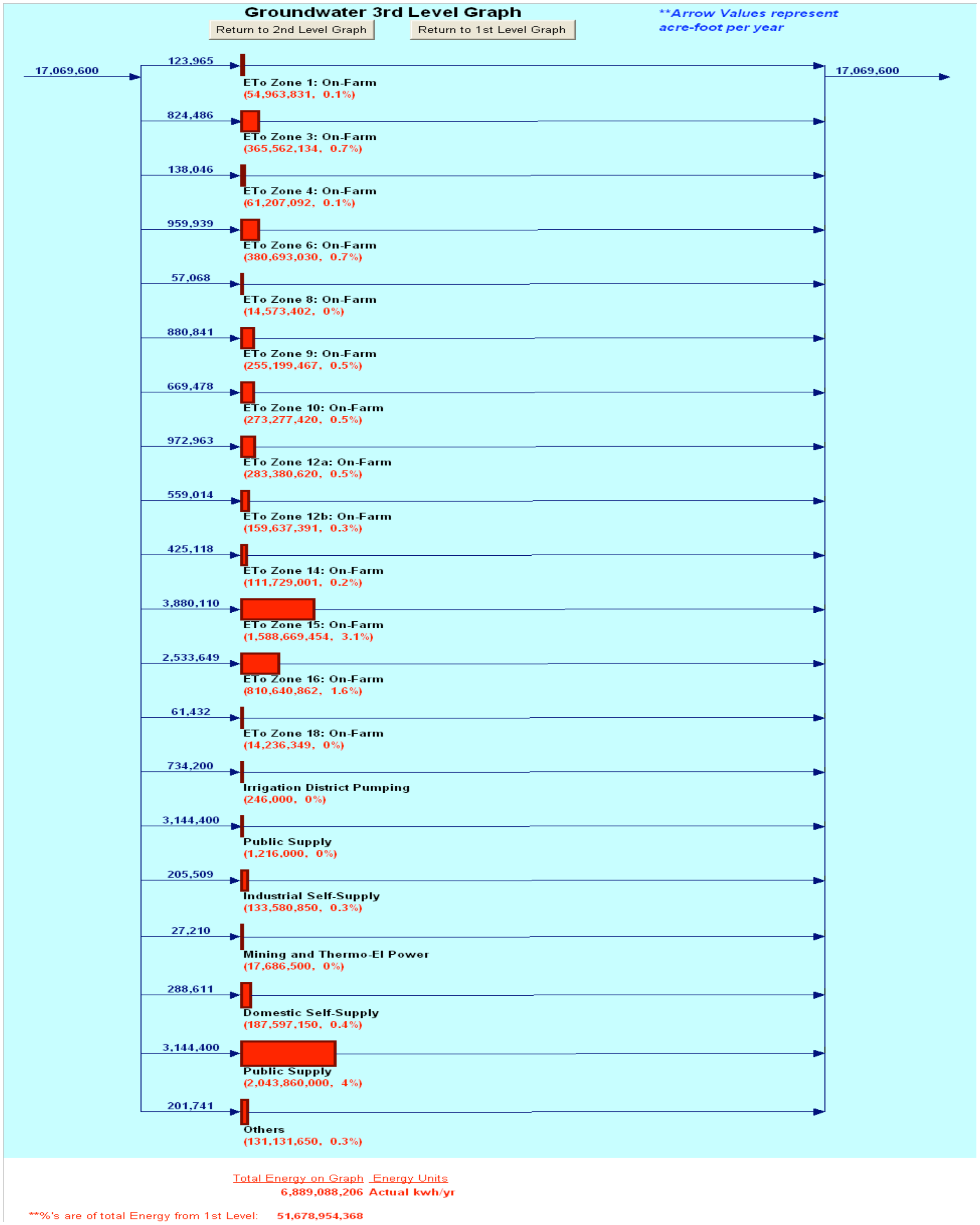
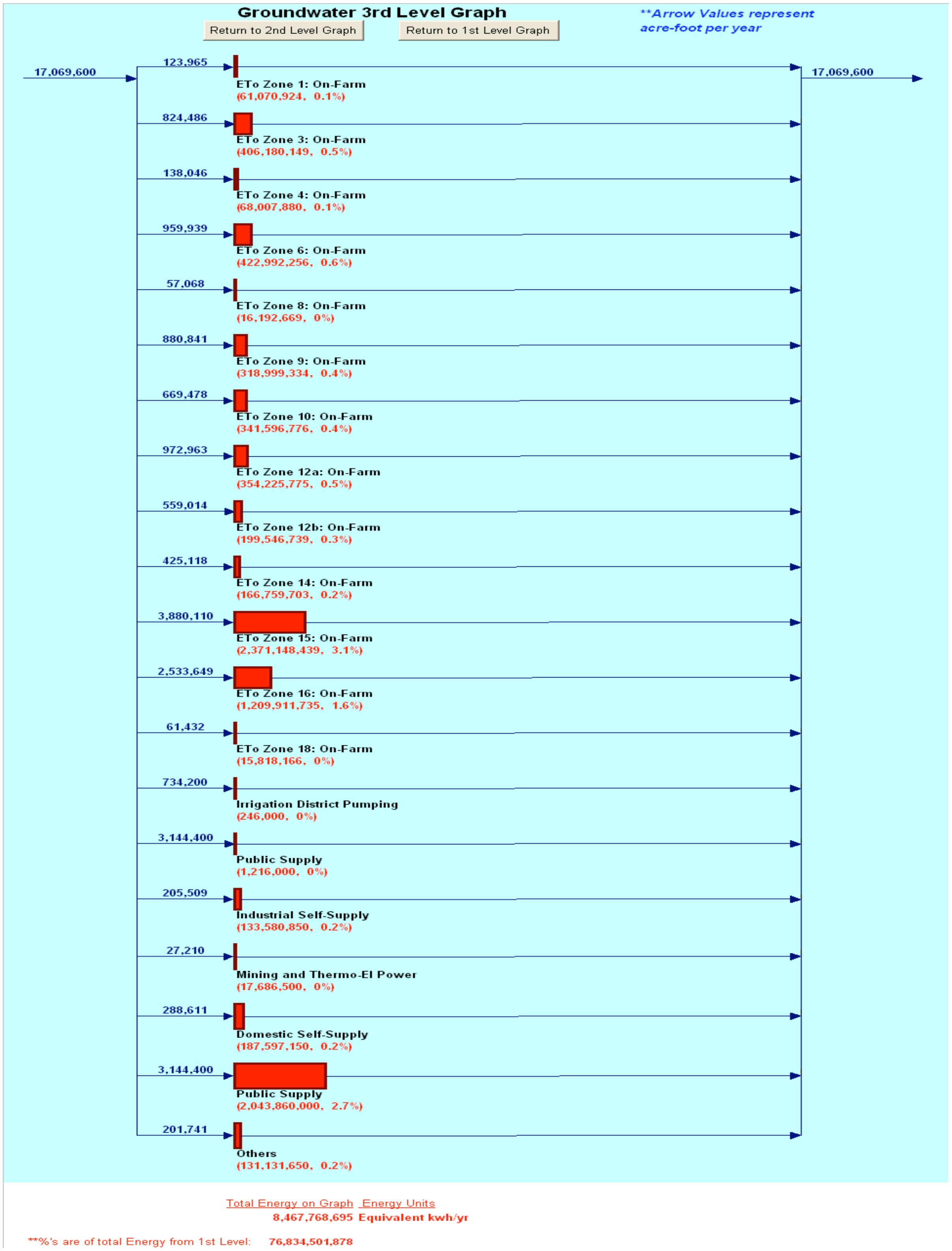


Figure 10b: Groundwater, Equivalent Electricity Use in Year 2000



3.3.2.2. Local Surface Water

Local surface water supplies include run-of-the-river systems and local reservoirs. Total year 2000 supply from these sources was estimated at 9.079 maf. This is the difference between total surface water supply reported in Hutson, et. al. (2004) and imported surface water supplies reported in Tipton (2005). It is well below the quantity of local surface water supply reported by Tipton (2005) and modified by Hillaire (2005) to remove local in-stream flows or releases of surface water for environmental purposes (12.025 maf). As stated above, we felt that Hutson et. al. were more accurate. In essence, Hutson et. al., shows more groundwater and less local surface water was utilized in year 2000 than records from DWR (Tipton and Hillaire) indicates. Since water from shallow groundwater wells adjacent to rivers or intakes buried in river bottoms might be classified as local surface water or as groundwater, depending on one's perspective, it is possible these references differ somewhat for semantic reasons. Nonetheless, Hutson et. al., report two maf more than DWR (Tipton 2005), while DWR reports three maf more local surface water than is implicit in Hutson et. al. So the difference is not entirely a semantic one.

Our analysis includes five categories of facilities for local surface water. Domestic, industrial, mining, and thermo-electricity quantities of water were from Hutson et.al. (2004). Energy used for each category was assumed to required 30 kWh/af to lift the water 10 feet. That may be an inaccurate estimate, but the quantities of water involved are small, so more accurate numbers will change our overall results very little.

A fifth category – lift for local urban surface water – was input in an attempt to separate local urban supplies that flow by gravity to the treatment plant from those that require pumping. This seemed potentially a large source of water-related energy use. We know that at least some significant urban supplies are pumped from local surface waters (e.g., the area served by the Sonoma County Water Agency). However, we were unable to obtain a credible estimate for this quantity, and entered a value of "0" based on a calculation of the quantity of imported surface water supplies for urban customers (Table 4).

The calculation in Table 4 was necessary because none of the references provide separate estimates of local surface water delivered to urban versus agricultural customers.

Table 4: Estimate of Local Urban Surface Water, Year 2000

Name of Imported (Non-Local) Source	**Statewide Deliveries (maf)**	Percent Urban	**Urban Quantity (maf)**
CVP Base and Project Deliveries	6.708	10%(1)	0.671
Potter Valley Project	0.154	20%(2)	0.030
Other Federal Deliveries	0.645	0%(2)	0.000
State Water Project	3.670 (6)	37%(3)	1.358
Colorado River to MWD	1.081	93%(4)	1.006
Colorado River to IID, PVID, and Others	3.905	2%(5)	0.078
Mokelumne	0.210	100%(2)	0.210
Hetch Hetchy	0.330	100%(2)	0.330
LA Aqueduct	0.200	100%(2)	0.200
Other	0.071	0%(2)	0
Total Imported Surface Water	**16.974**	Not Applicable	**3.883**
Total Urban Surface Water Per Hutson et.al. (2004):			3.728
Estimated Local Surface Water Supply:			**-0.155**
Notes: (1) Williams 2005, (2) plausible assumptions by the authors; unless grossly incorrect, the general result will hold, (3) DWR 2002, (4) Finnely 2005, (5) Heinning 2005 and Gonezella 2005, (6) This quantity is far larger than average annual deliveries by the State Water Project and should be verified or explained in future research.			

We are not comfortable with the outcome of this calculation and recommend that it be revisited in future research. Based on the best available information to date, the data would appear to indicate that local surface water supplies for urban utilities (that is, excluding self-supplies) are zero in quantity. We know that this is strictly incorrect because local urban surface water reservoirs exist. Clarifying the total quantity and percentages of local surface water supply that go to urban and agricultural customers is an important priority for future research.

3.3.2.3. Reclamation (Recycling)

Tipton (2005) provides the best estimate of statewide water reclamation (recycling). Our analysis includes two categories of recycling: recycled domestic wastewater for urban (0.254 maf) and for agricultural (0.028 maf) purposes. Urban recycling is assumed to use about 350 actual (as opposed to equivalent) kWh/af for the additional treatment required to upgrade secondary wastewater to Title 22 standards for urban recycled water (Wolff, et. al., 2004). Typically, but not always, this involves tertiary treatment plus a final "ultra-filtration" step, often using reverse osmosis membranes. Wastewater reused in agriculture is assumed to usable without further treatment. Although both these estimates are conservative, in that urban recycled water distribution requires energy and some wastewater reuse on farms may require additional treatment, the quantities of water involved are small enough that even large differences in assumptions would not change our overall results by much.

3.3.2.4. Imported (Inter-Basin Transfers)

Imported water supply is one of the two largest source categories in California, about equal with groundwater. Each comprises nearly 40% of total sources and conveyance. Tipton (2005) identified 16.974 maf of imported water supply in year 2000, as previously detailed in Table 4.

Electricity use in inter-basin systems varies from negative (they produce energy) to very large. Several of the inter-basin transfer projects both produce and consume electricity . For example, the Central Valley Project (CVP) consumed about 1,340 GWh of electricity in year 2000 (Williams 2005). But it produces more than 4,500 GWh per year (Wolff et. al., 2004). Since production and consumption are entirely independent, we use the consumption figures in this report. Similar logic applies to energy produced in the Hetch-Hetchy water system operated by the City and County of San Francisco.

When production of electricity from in-line energy recovery systems exists, as it does in the State Water Project, net energy consumption is the appropriate data to use. Net consumption for deliveries from the State Project is documented in DWR (2002). We used total net electricity consumption for year 2000 for the SWP and for the Mokelumne system operated by the East Bay Municipal Utility District. Young (2005) provided data for EBMUD.

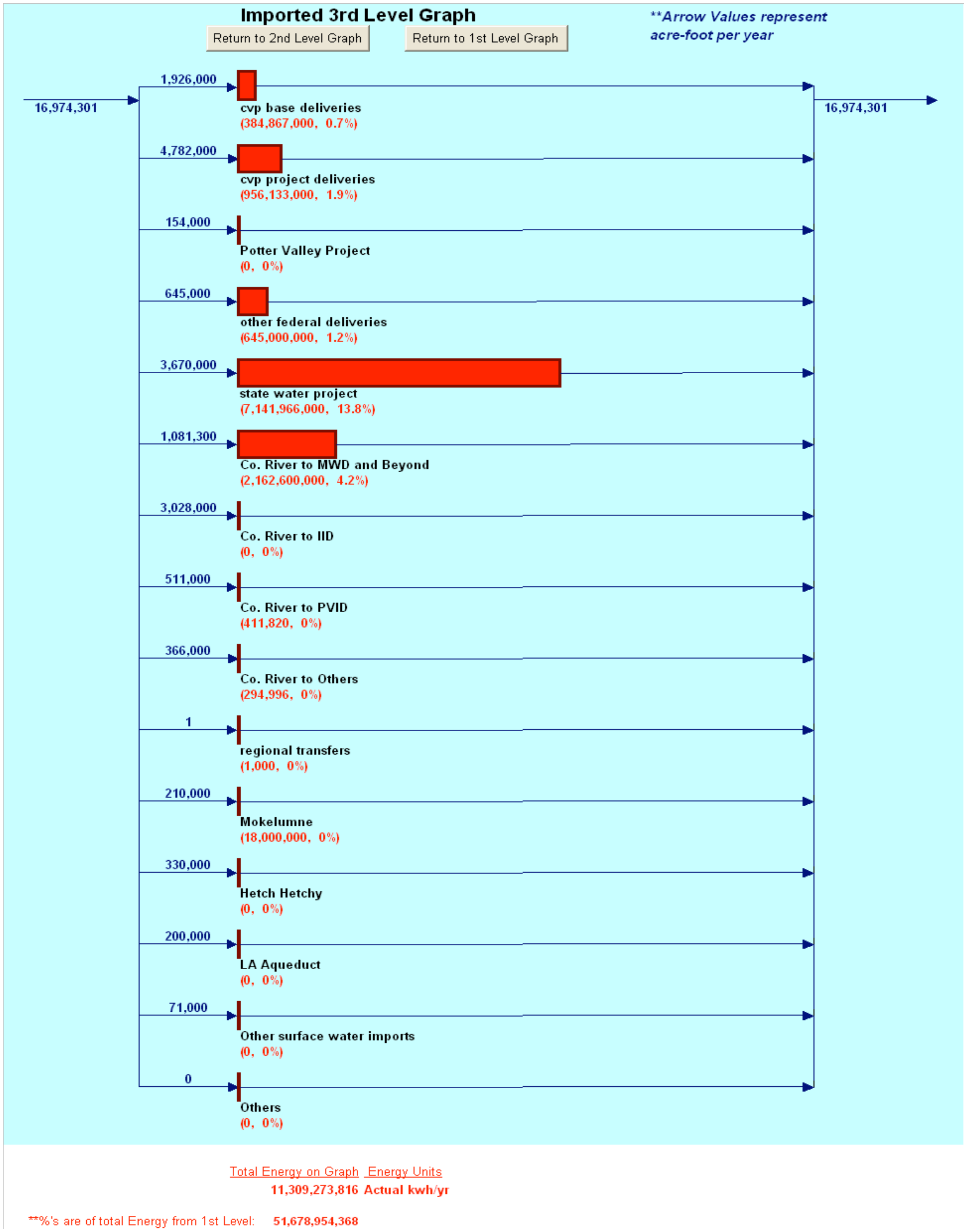
Data on the Colorado River Aqueduct is from Wilkinson (2000). Other Colorado River water-related energy numbers were obtained by phone interviews with Olstowski (Imperial Irrigation District) and Heinning (Palos Verdes Irrigation District).

Some of the in-line energy recovery systems are net producers of electricity. If water through the system were to decline (via conservation efforts for example) energy production would decline. For example, the Metropolitan Water District distribution system reportedly produced about 474 GWh in year 2000 (Finnely 2005). We neglected this energy in our analysis because the model will not accept negative energy use input values. This seemed like a reasonable action to take because the neglected amount of energy amounts to less than 1% of our total statewide estimated actual electricity use for water-related purposes.

The alternative choices were to subtract the energy from some other part of the water system (e.g., the SWP or CRA, which deliver water to Metropolitan high enough to make this energy recovery possible). However, handling the data in that way would make the energy consumption and intensity results for the SWP, CRA, and source and conveyance categories overall, inaccurately represent the net energy actually used by those facilities and within that category.

Figure 11 summarizes the flow and energy consumption data in our analysis of imported water supplies. Note that we do not provide a graph showing equivalent kWh data because all energy in our analysis of imported water supply is actual electricity.

Figure 11: Imported Surface Water, Actual Electricity Use in Year 2000



3.3.2.5. Desalination

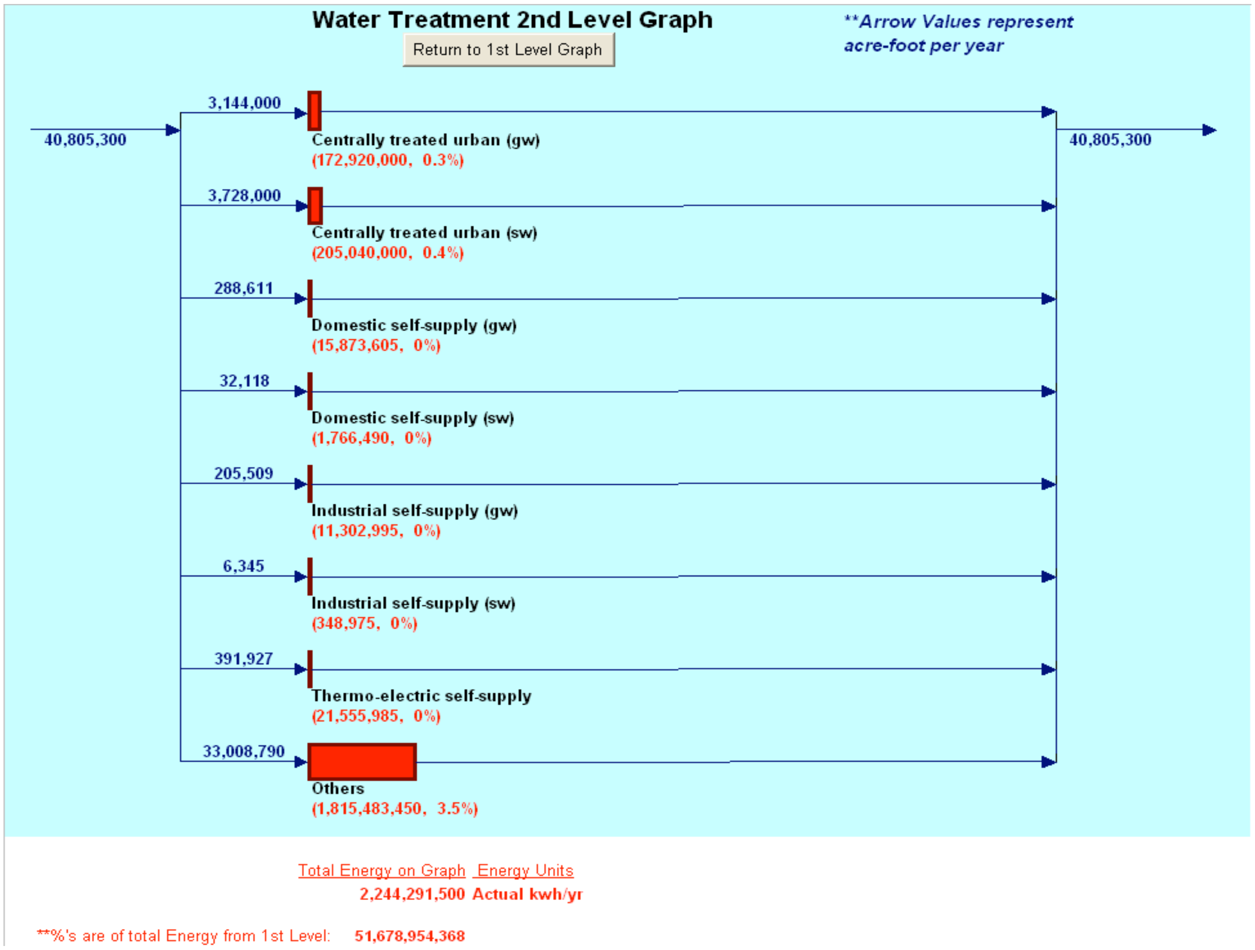
Tipton (2005) reports no desalination in California in year 2000. Even if that is strictly incorrect, the quantity of desalinated water in year 2000 is so minor that it is understandable that the 'the beast' should neglect it. Future supply from desalination could be significant and would use in the vicinity of 4,500 kWh/af of produced water (an average of 4,800 for the Ionics plant in Trinidad and 4,200 for the proposed Poseidon plant in Carlsbad, California (Wolff 2004)).

3.3.3. Water Treatment

Our analysis involves two water treatment numbers. Overall, we report water treatment as 40.805 maf in year 2000. That number reflects total sources and conveyance of 43.405 maf, less losses in conveyance reported by Tipton (2005). This 6% loss is an important number to keep track of, and it is easiest within the model structure to represent it in this way.

However, as noted previously, the quantity of water actually undergoing treatment is much less. Using data from Hutson et.al. (2004) we were able to identify seven categories of water supply that are treated, and that total 11.319 maf. Figure 12 presents the quantities in these categories and the energy used to treat it. Note that we do not provide a graph showing equivalent KWh data because all energy in our analysis of water treatment is actual electricity. We used a default value from Wolff et. al., (2004) for all types of water treatment. It would be worthwhile in future research to vary the energy inputs for treatment of these seven categories, at minimum assessing energy for treatment of groundwater at a lower level than energy for treatment of surface water.

Figure 12: Water Treatment, Actual Electricity Use in Year 2000

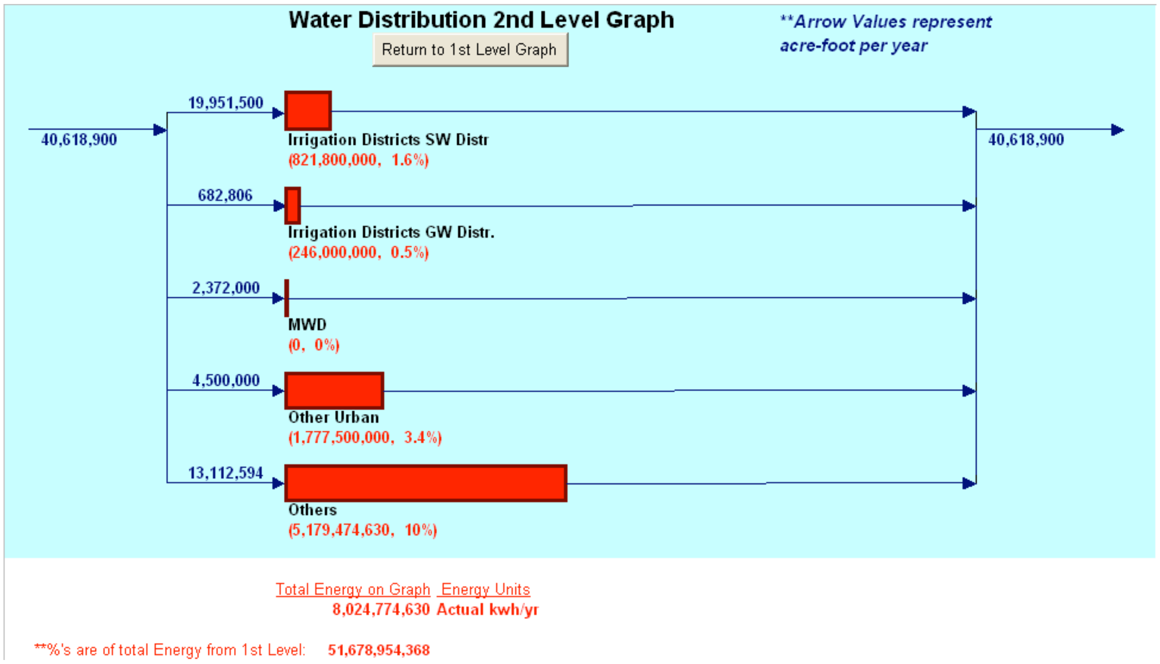


3.3.4. Distribution[17]

Distribution, like water treatment, involves two summary numbers. First, we report 40.619 maf of water distribution in year 2000 on the start sheet and summary graphic output from the model. This reflects the water treatment total less 5% of water actually treated, since water treatment occurs in outdoor facilities where water can evaporate or (in some cases) percolate downward from the treatment basins or channels.

The second summary number, however, reflects water actually distributed (27.506 maf). Water actually distributed falls into four categories: surface water distributed by irrigation districts, groundwater distributed by irrigation districts, urban water distributed by the Metropolitan Water Districts of Southern California (MWD), and other urban distributors of water. Figure 13 presents the water quantities and energy use associated with these categories. Again, we do not provide a graph showing equivalent kWh data because all energy in our analysis of water distribution is actual electricity.

Figure 13: Water Distribution, Actual Electricity Use in Year 2000



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[17] By distribution, we mean delivery of water either after treatment (e.g., in urban potable water systems) or delivery by a local irrigation district through a system of pipes and local canals. For untreated water, the boundaries between the source and conveyance category and the distribution category are the locations ("turn-outs") where water in large projects is turned over to local irrigation districts.

Irrigation district surface water is from Hutson et.al. (2004). The corresponding estimate in Burt et. al. (2003) was too large to be consistent with other numbers used in our analysis. It appears that the analysis in Burt et. al., is for a year in which less groundwater and more surface water was used by farmers than in year 2000. Energy use for irrigation district surface water distribution came from Burt et. al., but was scaled linearly to reflect the lower quantity we input to the model. Energy use for groundwater distributed by irrigation districts was taken directly from Burt et. al. Energy use by MWD was assumed to be zero, although MWD actually produced 474 GWh in year 2000 from energy recovery devices in their distribution system (Finnely 2005). As stated above, the model does not allow a negative energy use value to be entered, but perhaps it should be modified to allow such inputs in future research. Finally, other urban distribution was assumed to require 395 kWh per af, the default value in the model, based on nationwide information in Burton (1996) and data from San Diego County in Wolff (2004).

3.3.5. Customer Use

Total customer water use was estimated to be 37.868 maf in year 2000. Although less than suggested in both Tipton (2005) and Hutson et. al. (2004), neither of these sources accounts properly for losses in the water cycle. That is, they report sources of water – at the point water is removed from nature – equal in sum to uses of water – at the point where customers use it. This is obviously not possible. Tipton (2005) specifically lists water losses in conveyance, but does not describe losses in treatment or distribution. DWR (1995) reports 10% loss in urban distribution systems in California, and we used this figure to adjust the total distribution number (40.805 maf) downward to account for losses in distribution. We assumed 10% loss in irrigation district distribution as well, but no losses in on-farm surface and groundwater sources. Ten percent loss in irrigation district canals and pipes seems reasonably conservative given that DWR (Tipton 2005) reports 6% loss in conveyance of water in large, typically lined, canals or pipeline systems. Smaller diameter pipes and unlined canals leak more than larger diameter pipes and lined canals.

Figures 14a and 14b present our analysis of the quantities of water and water-related energy used by customers. Each row in the figures is discussed in the subsections below. Overall, our method for determining percentages of total customer use in each facility category involved three steps. First, we determined indoor and outdoor residential, indoor and outdoor CII, and agricultural categories, based on the percentage of total statewide urban plus agricultural water use in Tipton (2005), after losses explicitly listed in Tipton (2005). These percentages were consistent with those in Hutson et. al. (2004) and Gleick et. al., (2003). Second, we provided additional detail within these categories using percentages for specific customer uses (e.g., pre-rinse nozzles in commercial kitchens) in Gleick, et. al. Finally, we created a “recreation” category of water use, correspondingly reducing CII ‘leaks/miscellaneous’ to ensure the percentages still add to 100%. This final step was necessary in order to make use of energy information on residential pools, hot tubs, and waterbeds, in Klein (2005).

Figure 14a: Customer Use, Actual Electricity Use in Year 2000

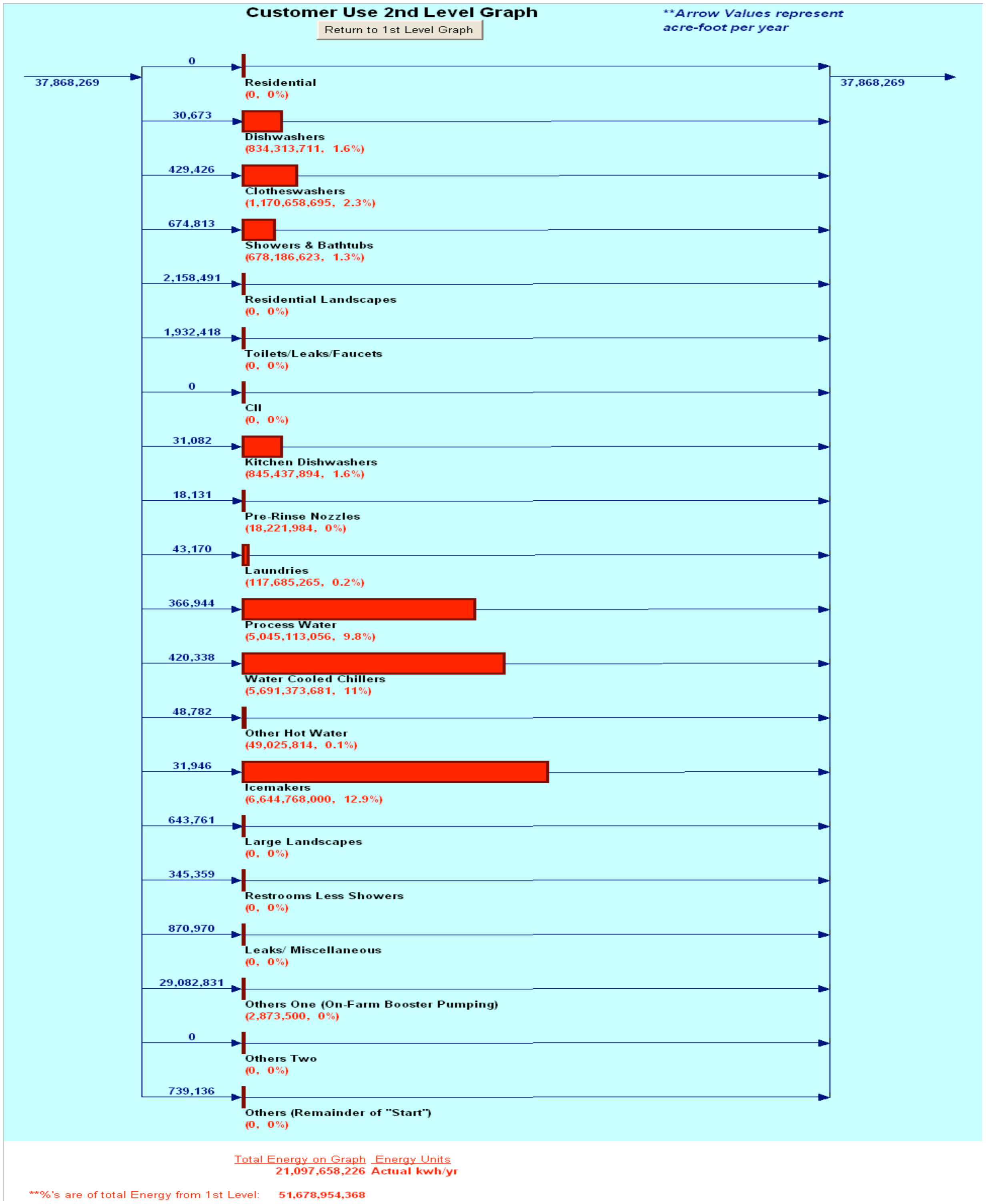
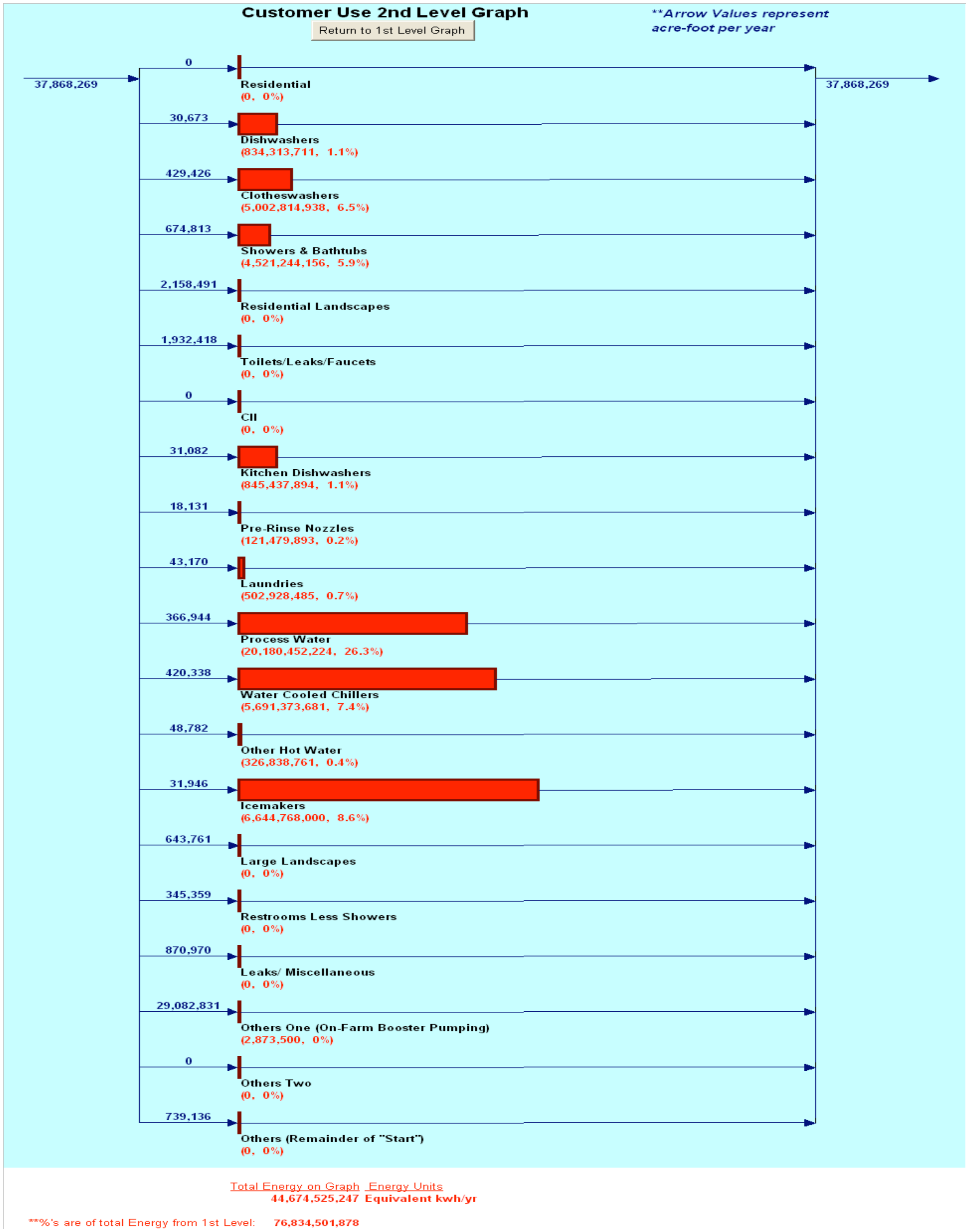


Figure 14b: Customer Use, Equivalent Electricity Use in Year 2000



3.3.5.1. Residential Uses

Our analysis presents residential use in five categories: dishwashers, clothes washers, showers and bathtubs, residential landscapes, and toilets/leaks/faucets.

Dishwashers account for 1.4% of indoor residential water use in California (Gleick et. al., 2003). Their energy use is also documented in that study and Wolff et. al., 2004. The model default factor (Wolff 2004) is based on these sources. Similarly, clothes washers account for 22.7% of indoor residential water use in California, and showers and bathtubs account for 17.8% and 1.8% of indoor residential water use in California. Data sources are the same for clothes washers, showers, and bathtubs as listed for dishwashers.

Data on energy use for clothes washers and hot water heating is presented in CEC (2005c, appendix B). Our estimate for these categories is considerably lower, and we conservatively used the lower estimate. Furthermore, our estimate is based on detailed evaluation of energy use in appliances by the Department of Energy, multiplied by credible estimates of the number of such appliances in California. The CEC data is from energy utilities, but since separate meters do not exist for clothes washers or water heaters, we felt that their disaggregation of customer bills into appliance categories could be incorrect.

We conservatively excluded include energy used in residential clothes dryers, although that analytical decision is arguable (see Box 1). We felt that the data in CEC (2005c, appendix B) was not reliable in this regard. It suggests that the vast majority of dryers in California use electric heating elements, while the vast majority of clothes washers in California use water heated in natural gas water heaters. This is inconsistent with our experience; that is, that builders nearly always run a gas line to the laundry when a home has natural gas space and water heat. The electric consumption in clothes dryer number reported in CEC (2005c) is also quite large; 5,769 GWh. This is about 10% of our estimate of statewide water-related electricity use. Reported natural gas consumption in clothes dryers was smaller; about 145 million therms, which amounts to about 1,500 equivalent GWh. Because these numbers are large, they should be revisited in subsequent research.

Landscape irrigation is assumed to use no additional energy at the customer premises. The quantity of water was obtained as described above. Finally, toilets/leaks/faucets were also assumed to use no energy on customer premises. This is a conservative assumption since at least some faucet use is hot water, and hot water valves sometimes leak (drip). We understand that there is an Energy Commission study on this topic underway (Lutz 2006), and that combined with previous CEC-sponsored research (Hiller 2005), these studies will make it possible to make credible inputs in later research.

3.3.5.2. Commercial Institutional, and Industrial (CII) Uses

Our analysis summarized CII uses in ten categories of facilities: commercial kitchen dishwashers, pre-rinse nozzles, laundries, industrial process water, water-cooled chillers, other hot water (including showers), icemakers,18 large landscapes, restrooms (less showers), and leaks/miscellaneous.

Water and energy use in kitchen dishwashers, pre-rinse nozzles, laundries, other heated water, and water-cooled chillers were obtained from the sources and in the manner described above for residential dishwashers, etc. Dishwashers use 24% of the 6% of indoor CII use that occurs in kitchens. Pre-rinse nozzles use 14% of the 6% of indoor CII use that occurs in kitchens. Laundries comprise 2% of indoor CII use. Water-cooled chillers comprise 15% of total CII use. Other heated water includes 19% of the 6% of indoor CII use that occurs in kitchens, plus 7% of the 16% of indoor CII use that occurs in restrooms. Our energy estimates in these categories are based on standard calculations of energy required to heat water and data on energy required to run appliances described in Gleick et. al., (2003), Wolff et. al. (2004) and Wolff (2004). For the most part, this data comes from appliance evaluations conducted by the Department of Energy, Energy Star program.

Energy use in cooling towers was estimated in Wolff et. al. (2004) using data on commercial cooling towers from the Department of Energy. The default value in the water-to-air models represents that calculation. For this analysis, however, we assumed that only 20% of total cooling energy was for operation of the water loop in the cooling tower. This yielded a result that is close to the cooling estimate in CEC (2005c). However, both numbers may be inaccurate. CEC (2005c) assumed that 50% of commercial cooling energy was water-related, a significantly higher assumption than ours. We believe our assumption more accurately reflects the amount of energy used in cooling towers themselves. However, CEC (2005c) presents a much lower total energy for cooling estimate than ours. The difference may be that CEC (2005c) data does not include industrial cooling, or one or the other of our total statewide cooling energy estimates may be incorrect. The estimate in Wolff et. al. (2004) was reasonable but not necessarily more reliable than utility supplied aggregate data. Since statewide cooling tower energy is large, regardless of source, this issue should be revisited in future research.

Water use in industrial processes was estimated as 17% of indoor CII water use (Gleick, et. al., 2003). Energy use related to industrial process water use involved such complex calculations that they are explained in a separate section immediately following this one.

Icemakers comprise 19% of water use in CII kitchens (Gleick, et. al., 2003). We conservatively estimated their energy use at 208,000 kWh/af (7.6 kWh/hundred pounds of ice). We say "conservatively" since this level of electricity use for ice making is "recommended" by the Department of Energy, which indicates that actual machines in use (some of which are documented at

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18 There are other food service appliances that may have significant water-related energy use, such as steam tables. This is a topic that should be investigated in future research.

http://www.eere.energy.gov/femp/procurement/eep_ice_makers.cfm) use much more energy per hundred pounds of ice produced.

Large CII landscapes, restroom water use other than showers, and leaks/ miscellaneous were assumed to use no supplemental energy on customer premises. Again, that is a conservative assumption. Hot water recirculation loops, and supplemental pressurization in high-rise buildings, are possibly significant users of on-site energy that should be researched in future efforts.19

3.3.5.3. Industrial Process Energy Use

We evaluated water-related energy use for industrial process water via the 1998 and 2002 US Manufacturing Energy Consumptions Surveys (US Department of Energy, 1998 and 2002). We compared this data with California water use data by industrial process category (Gleick et.al., 2003). There were seven categories of industry for which US-wide process electricity and natural gas data were available, and for which California water use data were also available. We estimated California electricity and natural gas use in these seven categories by comparing the California value of shipments in each category with the US value of shipments in each category (US Census Bureau, 2003). Together, these allow one to calculate total process-related electricity and natural gas use per unit of process water in these seven categories.

But our interest is in water-related energy use. Some of the process-related energy use in these categories was clearly not water-related. For example, motive force is the largest user of process electricity in these categories. Although motive force includes motor drives for pumps that pump either water or water-based fluids, it also includes motor drives for non-water based fluids (e.g., hydraulic fluids) and motor drives for fans, conveyor belts, and other non-water-related uses. We estimated water-related energy use in each category from a variety of sources (US Department of Energy 2004 and 2000); US Environmental Protection Agency (1995), and the assumptions in Table 5.

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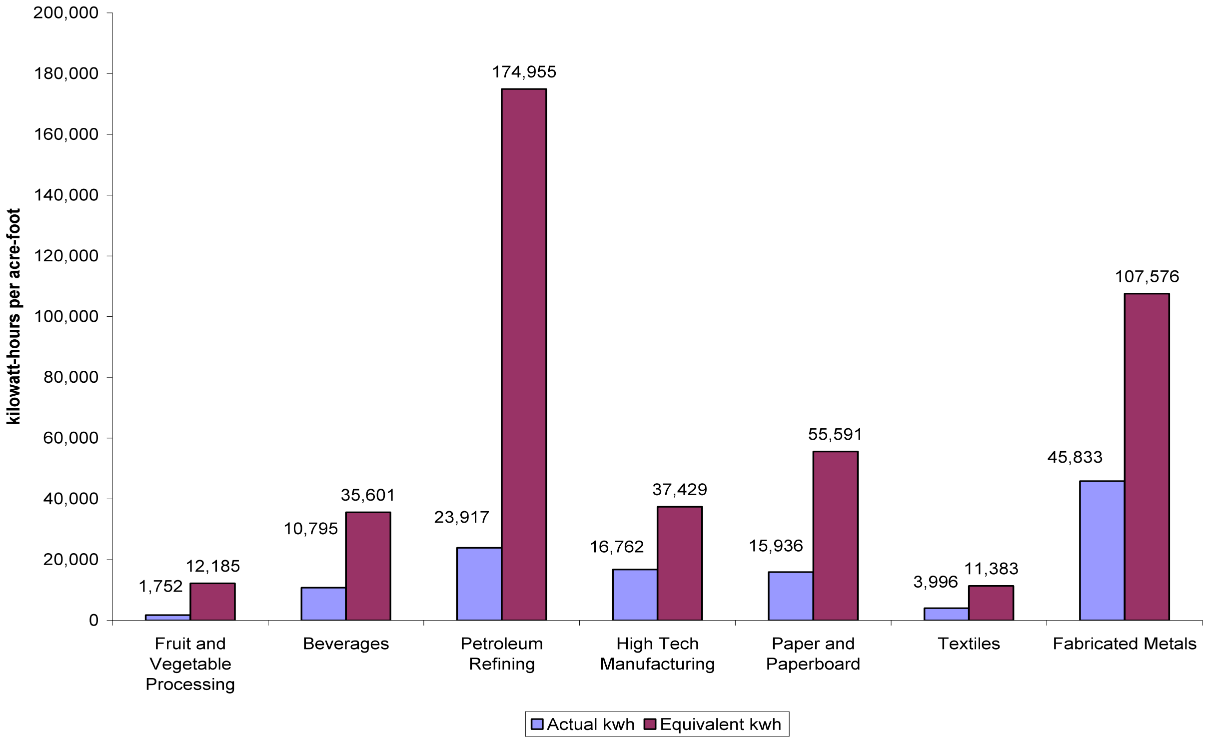
19 Klein (2006) reported that a reasonable first approximation of energy use in hot water recirculation systems is 40% of the total for water heating. However, we were not able to include this information in our numerical results for scheduling reasons.

Table 5: Percent of Industrial Process Energy Use Assumed to be Water-Related

Type of Process Energy Use	Electricity	Natural Gas
Boiler	100%	100%
Process Heat	0%	50%
Process Cool	50%	0%
Machine Drive	20%	20%
Electro Chemical	10%	10%
Other	10%	10%

Figure 15 presents the water-related electricity and equivalent electricity intensities found in our analysis. The California water-consumption weighted average of these uses is 54,996 equivalent kWh/ af.

Figure 15: Water-Related Energy Intensity of Industrial Process Categories in CA



Based on this analysis, we entered the product of the weighted average equivalent intensity and year 2000 industrial process water use (that is, we input 2.02 x 10^{10}) into the "actual estimates" column of the customer use facility list. We also created energy mix 6 to reflect the percentage of this energy use that is actual electricity (25%) versus natural gas (75%).

This method assumes that the weighted-average energy intensity of the seven categories of process use we were able to analyze accurately represents the full range of industrial process uses in California. That should be revisited in future efforts if additional data on industrial process energy and/or water use is found.

3.3.5.4. On-Farm Booster Pumping

On-farm booster pumping is significant in California. Farmers who use drip or spray systems either pressurize water delivered to their farm, or use additional energy in groundwater pumps to distribute the water in drip or spray apparatus rather than by gravity, once brought to ground surface. The energy number used in our analysis is from Burt et. al., for on-farm booster pumping. It is NOT a conservative number, 20 and the calculation behind it is not entirely clear. Nonetheless we used it because the source is credible and well –documented in general.

3.3.5.5. "Recreational" Uses

Finally, we categorized residential swimming pool heaters and pumps, hot tub heaters and pumps, and waterbed heating, as "recreational" uses of water. Klein (2005) provided a spreadsheet that contains energy use data from the investor-owned energy utilities in California, categorized by SIC code. The data are not entirely reliable, at least for agricultural use, as discussed in Burt et.al. (2005). Consequently, we used this data source as a means of comparison with other data when other data existed. But for these recreational uses, we found no other credible references. Recreational use may be much more significant – consider that CII pools and tubs, and pumped water features in both residential and CII landscapes, are not included in our analysis.

Despite the availability of data, we chose to conservatively exclude these and other uses of water (e.g., boilers used for building heat) that involve *de minimis* levels of water use, as mentioned in Box 1. This was consistent with CEC (2005c). However, this analytical choice should be revisited in future research.

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20 A back-of-the-envelope calculation of energy required for on-farm boosting, using 205 kWh/af pressurized (Wolff 2004) and the percentage of agricultural water that is drip or spray irrigated (about 20%) per the DWR website, yields energy use about half that reported by Burt et.al. (2003). This discrepancy is worth investigating further in later research.

3.3.6. Wastewater Collection

Statewide wastewater collection data were available only from Tipton (2005). That reference estimates urban wastewater at 3.600 maf in year 2000 and agricultural return flows at 4.000 maf in year 2000.

In the absence of a credible source on lift stations within sanitary sewer systems statewide, we conservatively used zero as the energy intensity for urban wastewater collection systems. Furthermore, our analysis neglects infiltration and inflow to sanitary sewers, which is factually non-zero and probably significant based on the attention paid to this issue by the Water Boards, sanitation utilities, and stakeholders affected by sewer overflows. Clearly, both of these assumptions should be improved upon in later research.

We also assumed zero energy intensity for agricultural return flow, since such flows are usually by gravity to a river, lake, or groundwater aquifer. The quantity of return flows is worth revisiting in future research, given their potential for treatment and reuse, and the consequent new energy consumption that would occur should recycled return flows become a significant source of water supply in the future.

3.3.7. Wastewater Treatment and Discharge

Our analysis uses the same flow assumptions for wastewater and discharge as are provided for wastewater collection. Energy use for agricultural return flows is again assumed to be zero. Energy used to treat urban wastewater is from data reported by the investor-owned energy utilities for a category described as "sanitary service" (Klein 2005).21 This reported use (2,012 GWh) exceeds by more than a factor of three energy use for wastewater treatment that would be estimated by the model if the default factor documented by Wolff (2004) were used (0.584 GWh). The higher number from Klein (2005) is plausible, however, since Wolff's default figure is only for secondary treatment of wastewater.22 It excludes tertiary or advanced treatment and energy required to pump treated wastewater to or into the receiving water. Discharge pipeline energy use can be significant, sometimes exceeding total energy used to treat wastewater. Finally, it is possible that the sanitary services number reported in Klein includes wastewater collection lift stations. This point should be investigated further in subsequent analysis.

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[21] Information pertinent to sanitary service customers of investor-owned energy utilities in California is presented in House (2006). We were not able to verify, however, whether annual electricity use for sanitary services in his report – which is incidental to the peak demand focus of his report – is actual data or is the result of a simulation. This point should be clarified in future research.

[22] From a case study in San Diego County, but consistent with PG&E (2002).

4.0 Preliminary Conclusions and Recommendations

4.1. Preliminary Conclusions

The patterns found in this analysis confirm that expanded understanding of water-related energy use by customers will be critical to future efforts to improve the efficiency of energy and water use in California. Customer use of water-related energy dominates total water-related energy use in California, and that is very unlikely to change as this analysis is improved upon. Electricity use accounts for 2/3 of total water-related energy use statewide,23 once disparate forms of energy are converted to a common metric of "equivalent kWh."

The patterns imply that decisions about future water supply[24] will probably have larger statewide energy and air quality implications than decisions about, for example, drinking water or wastewater quality standards.[25] Managing energy use in new supply – and under drought conditions when hydropower is scarce and more groundwater is being pumped than in average years -- will be an important task for future water/ energy planning.

Water conservation is a clear winner in this regard WHEN water savings also save energy on the customer premises. In that case, energy will be saved throughout the water use cycle. Recycled water also looks more attractive relative to imported water and seawater desalination. It uses approximately 10% the energy of desalination. This energy benefit may help to offset the sometimes-excessive concern over public health associated with recycled water. On the other hand, seawater desalination is not much more energy intensive than shipping water through the State Water Project to Southern California. It may be attractive in the overall mix of statewide supplies, depending on the other sources in the mix.

4.2. Recommendations

A number of data gaps and inconsistencies have been identified in this report. Resource limitations may prevent all of them from being resolved in future research. It is tempting to think that the gaps that have the largest consequences for water-related energy use should be addressed first. However, that may be incorrect. For example, recreational water-related energy use is reportedly quite large (over 6, 000 equivalent GWh, or nearly 8% of statewide water-related energy use). Residential clothes dryer energy use is also reported to be large (over 7,000 equivalent GWh, or nearly 9% of our estimate of statewide water related energy use). But there may be little opportunity to reduce

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23 Comparing the total intensity in Figures 6 and 7 reveals 2,363 / 2,029 = 67%.

24 Including water conservation, which is now typically listed among potential supplies.

25 A possible exception would be a state water quality policy to subsidize research and installation of advanced water treatment technologies as part of a process of tighter standards, which might have large, beneficial energy impacts due to technological or economy of scale spillovers into desalination and reclamation water supply decisions.

water-related energy use via policies targeted at swimming pools, hot tubs, waterbeds, and clothes dryers. In addition to the relative size of the numbers involved, one needs to consider the policy-relevance of future data and the ease or difficulty of obtaining further information when considering which data gaps or inconsistencies to address first.

The list below both summarizes and prioritizes, based on the three criteria above, the gaps and inconsistencies noted in the body of this report. The list is from highest to lowest priority.

1. Verify or modify the estimate of local surface water for urban use presented in Table 4. If a sufficient estimate can be obtained, urban and agricultural water use should be separately modeled in future research, allowing explicit energy intensity estimates for each step of the water cycle for urban and agricultural sectors.
2. Disaggregate, if possible, the groundwater pumping energy input for urban use to reflect quantities and depths of water in the hydrologic regions of the state.
3. Estimate the quantity of energy use to lift sewage in sanitary sewers in California at locations other than wastewater treatment plants (e.g., pump stations, individual home lift pumps, etc.). This estimate should be integrated with data on “sanitary services” energy use in Klein (2005) to ensure that double counting does not occur, and should verify the original sources of data in House (2006).
4. Estimate the quantity of infiltration and inflow to sanitary sewers in California.
5. Quantify energy used in CII and residential hot water recirculation loops. This energy is not included in our “other heated water” category of CII facilities.
6. Quantify supplemental pressurization in high-rise buildings.
7. Quantify the potential energy savings in clothes dryers if more water-efficient clothes washers are used. If clothes dryer energy is saved almost automatically when efficient washers are installed, credible statewide estimates of energy used in clothes dryers should be developed.
8. Verify and modify if appropriate Burt et. al.’s (2004) estimate of on-farm booster pumping energy.
9. Verify, if possible, that the weighted-average energy intensity numbers estimated across seven categories of industrial process water use in California are representative of the full range of industrial process water uses in California.
10. Obtain more detailed, category-specific energy inputs for the seven types of water treatment in this analysis. At minimum, differentiate between treatment of ground and surface waters.
11. Quantify energy used to heat water for residential and CII faucet use. We conservatively entered a value of zero for this category in our analysis because

credible estimates do not yet exist but several studies are underway that will provide credible estimates.

12. Verify or modify the assumption that 10% of water-related clothes washer and dishwasher energy use is, on average, for motive power and that the remaining 90% is for water heating.
13. Clarify the difference in DWR and USGS (Tipton 2005 and Hutson et. al. 2004) total groundwater and surface water numbers for year 2000. Is it possible that water extracted from wells near rivers or from intakes buried in river bottoms is classified by one as groundwater and by the other as surface water? Or does some other difference in method explain the discrepancy?
14. Modify the model to allow negative energy use inputs for those situations in which hydroelectricity power would not be produced if water were not consumed (e.g., the Potter Valley project, the All-American Canal, and the MWD distribution network).
15. Update the emissions factors for the California grid mix to reflect the current composition of energy sources. This would allow more realistic assessment of current or future greenhouse gas emissions impacts of water management decisions.
16. Modify the model to allow more energy mixes and sources, so that the emissions results will more accurately reflect actual or "what-if" patterns of water-related energy use.
17. Expand the recreational use estimate to include CII pools and hot tubs, and fountains or other powered water features in residential and CII landscapes.

We also strongly recommend, either as part of or separately from research on the energy-water nexus, that water source and use information in California be measured or estimated with much care than is currently employed by the Department of Water Resources. In fairness to the Department, exact numbers were not critical in the past and budgetary resources for fundamental data gathering and data management have not been a high political priority. But water in California is increasingly scarce and valuable and will continue to become more so in the future. It is no longer tenable for the fifth largest economy in the world, for example, to not know how much groundwater it is using when groundwater comprises nearly 1/3 of total water supply, groundwater levels are falling in many parts of the state, and groundwater is one of the most reliable supply sources during multi-year droughts.

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6.0 Glossary

AF	Acre-feet
CIEE	California Institute for Energy Efficiency
CUWCC	California Urban Water Conservation Council
GWh	Gigawatt-hours, that is, 1 billion watt-hours
KWh	Kilowatt hours; that is, 1,000 watt-hours
MAF	Million acre-feet
NRDC	Natural Resources Defense Council
PI	Pacific Institute
PIER	Public Interest Energy Research
USGS	United States Geologic Survey