Connecting the Dots between Water, Energy, Food, and Ecosystems Issues for Integrated Water Management in a Changing Climate

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Executive Summary

Global climate change creates critical challenges through increasing temperature, reducing snowpack, and changing precipitation for water, energy, and food, as well as for ecosystem processes at a regional scale. The water, energy, and food (WEF) nexus and related ecosystems have complex linkages with climate change implications. The overall objectives of this white paper are to provide background on this important subject, and help local water managers and the public better understand:

- The ecosystem services for water, energy, and food in a changing climate.
- The water-energy nexus and related climate change mitigation actions in California.
- The energy used in California's water sector and estimates of the energy intensity of regional water supplies.

Particularly, this paper largely consolidates the water-energy content originally published in *California Water Plan Update 2013* (Volumes I, II, and III), which included:

- A framework for the energy intensity of California water systems.
- An estimate of the regional energy intensity of water supplies.
- Water-energy related climate change mitigation policies and actions.
- Climate change mitigation benefits and tradeoffs associated with each of the 30 Resource Management Strategies found in Volume III.

Furthermore, this paper will explore how water, energy, food, and climate change are interconnected with ecosystems, and why we need to understand these connections and identify the information gaps and related challenges and opportunities for ecosystem services in multiple sectors. Ecosystem services provide life support, goods, and natural resources in water, energy, and food, as well as environments. These are knowledge gaps for lack of conceptual framework and practices to interlink major climate change drivers of water resources with water-energy-food nexus and related ecosystem processes. This white paper provides information review and a conceptual framework to bridge these knowledge gaps.

The case studies summarized in this paper indicate there is a large variation in energy intensities for groundwater and federal, state, and local water supplies, both within each hydrological region and among the 10 hydrological regions in California. Regional decisions were critically important in addressing water-energy conflicts and meeting local climate change challenges. These examples can be applicable for the United States and other countries with similar climate change challenges that use diversity of regional water resources for energy and food production. Future interdisciplinary research and support could bridge information and data gaps that are important for using best management practices to obtain efficiency of water, energy, and food systems related to climate change.

The increased regional temperature, changes in snowpack and precipitation, and increased water stresses from drought can reduce ecosystem services and affect the water and energy nexus, agricultural food production, and fish and wildlife habitats in California. Regional decisions and practices in integrated management of water, energy, food, and related ecosystem processes are

essential to adapting to and mitigating global climate change effects. Science and policy support for interdisciplinary research are critical in developing databases and tools for comprehensive analysis to fill knowledge gaps and address ecosystem service complexity, related natural resource investment, and integrated planning needs.

There are significant challenges and opportunities in California to use integrated water management for water, energy, food, and the environment related to climate change. The California Water Action Plan and California Water Plan Update provide a road map and resource management strategies to use integrated water resource management for the multiple benefits of these sectors. The examples and case studies in this white paper have been used to identify information gaps and address related complexity and challenges. Questions posed in this paper regarding water and energy related to the food production cycle need further research and discussion. Overall, we should identify opportunities for innovation and technologies with multiple benefits, evaluate tradeoffs, and address integrated challenges in water, energy, food, and the environment to adapt and mitigate climate change.

TABLE OF CONTENTS

PART I. INTRODUCTION

i. Objectives

Water, energy, and food are critical beneficiaries of ecosystem services for supporting life. Climate change creates significant challenges for these ecosystem services. There are complex relationships and dynamic interactions among these life supporting elements. For example, water and energy have a complex relationship with multiple interdependencies, often called the "water-energy nexus." Understanding these complex relationships can help to provide more effective ecosystem services to adapt to and mitigate climate change impacts in multiple sectors. The objective of this paper is to provide background on this important subject and to help local water managers and the public better understand:

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Furthermore, this paper will explore how water, energy, food, and climate change are interconnected with ecosystems, and why we need to understand these connections. This paper will also identify the information gaps and related challenges and opportunities for ecosystem services in multiple sectors.

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An additional dimension of the water-energy nexus related to food and the environment is also explored, including biofuel production activities. The final sections of this paper provide a conceptual information framework to connect water, energy, food, and the environment (as related to climate change) for better ecosystem services using integrated water management. Major information gaps, challenges, and opportunities are also identified using this conceptual information framework.

ii. Ecosystem Services for Water, Energy, and Food related to Environments with Climate Change Implications

The ecosystem services are attributes of ecological systems that serve people by providing water, energy, food, and healthy environments (Jansson et al. 2000; Barnosky et al. 2013).

Ecosystem services can include:

- Regulating the water cycle.
- Providing and stabilizing water supplies.
- Filtering drinking water.
- Generating renewable energy.
- Protecting agricultural soils and replenishing their nutrients.
- Providing food.
- Helping to protect species and environments as well as reduce greenhouse gases in the atmosphere.

Climate change effects on ecosystems lead to loss or reduction of these ecosystem services. Ecosystem services are widely recognized as the most critical as a result of the pressures of climate change, which affects the quantity, quality, and timing of ecosystem services, such as:

- Water uses for energy.
- Irrigation for agricultural food production.
- Water uses for urban, industrial, and environmental sectors.

Climate change creates critical challenges for managing California's water, energy, food, and environment (California Energy Commission 2012; California Department of Water Resources 2013) because of its significant effects on water, energy, food, and species and habitats. The effects of these climate changes related to California water resources include: (1) Warmer air temperatures; California climate change projections show a temperature increase of up to 4 to 9 ºF by 2100; (2) Diminishing snowpack, 48–65 percent snow-water content loss by the end of this century, limiting the amount of water that can be supplied during the summer and fall months; (3) Increased evapotranspiration and precipitation uncertainty, leading to longer, more frequent droughts and flooding; (4) Prolonged droughts with changes in precipitation and runoff patterns; (5) More frequent wildfires affecting water quality and watershed health; (6) Sea level rise, which puts facilities at low elevations at risk; (7) Increased water and energy demand, (8) Changes in species and habitats (The Third Assessment of California Climate Change Report 2012; Intergovernmental Panel on Climate Change 2014).

The vulnerability of the water sector to climate change stems from a modified hydrology that affects the frequency, magnitude, and duration of extreme events, which, in turn, affect water quantity, quality, and infrastructure. Warmer temperatures drive the snow line higher and reduce snowpack, resulting in less water storage. Intense rainfall events will continue to affect the state, possibly leading to more frequent and/or more extensive flooding. Droughts are likely to become more frequent and persistent during this century and will likely affect communities that rely on surface water deliveries, making them more dependent on groundwater (GW) sources. These changes increase the volume of runoff that arrives at reservoirs during the flood protection season, and reduce the stored water available to meet summer peaks in water demand. At the same time, higher temperatures, resulting from climate change, increase peak summer water demands beyond historical levels. Climate change impacts will put additional stress on aging freshwater collection, storage, and conveyance infrastructure, thereby reducing the capacity to provide a stable source of drinking water. Existing and future infrastructure (including green infrastructure, such as wetlands) will need to be adapted to the new timing of runoff, as well as accommodate higher flows from more powerful individual storm events in a warmer atmosphere.

These climate change effects on the water sector could increase water stress and reduce ecosystem services for energy and food. Vulnerability assessments and adaptation to climate change should be managed at local, regional, and watershed levels for the water, energy, and food sectors to address these challenges efficiently.

The energy sector is also vulnerable to many of the same climate change impacts. Loss of snowpack and changes in runoff timing will reduce hydropower generation, and higher temperatures will result in increased energy demand for cooling. This vulnerability was highlighted by a modeling study simulating hydropower generation under regional climate warming in the Sierra Nevada (Rheinheimer et al. 2012). This study findings indicate: (1) system wide hydropower generation is reduced by 9 percent when air temperature increasing 6 °C; (2) Most reductions in hydropower generation occur in the northern Sierra Nevada watersheds as a result of declining runoff, the central Sierra Nevada has less reduction in annual runoff, and southern watersheds are expected to decrease the generation. Increased temperatures could increase peak electricity demands. The energy distribution systems are also affected by increased wildfire risks. Reduced energy generation and increasing energy demands can affect water supply and use as well as agricultural food production.

Recent reporting from the U.S. Department of Energy (DOE) provided an overview of the increasing urgency to address this climate change effect on the water-energy nexus. For example, limited water availability constrained the operation of some power plants and other energy production activities when severe drought affected more than a third of the United States in 2012. Vital water infrastructure was impaired when it lost power during Hurricane Sandy. Hydraulic fracturing and horizontal drilling, the methods leading to the recent boom in domestic oil and gas development, have also added to the complex relationship between energy and water (United States Department of Energy 2014).

Climate change has significant effects on species and environment quality, including habitat loss and species extinctions that are leading to a global loss of biodiversity (Barnosky et al. 2013). Research models predict many species living in the current climate will disappear from 10 to 48 percent of Earth's surface by the year 2100, as between 12 and 39 percent of the planet will have developed climates that no living species has ever experienced (Williams et al. 2007).

PART II. THE WATER-ENERGY INFORMATION FRAMEWORK AND ITS RELATIONSHIP TO CLIMATE CHANGE

i. Water, Energy, and Climate Change

California's water sector has an important role to play in reducing greenhouse gas (GHG) emissions while meeting significant challenges, including population growth; power generation; and industrial, residential, and agricultural water uses in a changing climate. Most energy use, including electricity generation, results in GHG emissions, which are a driving force behind the current changes in climate. Improvements in water use efficiency and conservation of water can often yield energy savings and thus reduce (mitigate) GHG emissions. In order to achieve the aggressive GHG reduction targets established by former Governor Schwarzenegger and

Governor Brown, all sectors of California's economy will need to play an active role in reducing carbon emissions.

Understanding energy usage associated with water supplies has additional benefits for water agencies beyond GHG mitigation, as energy consumption is often a significant expense for water utilities. Reducing energy consumption can save money for customers. Water conservation that reduces energy consumption may open additional funding mechanisms for water projects.

This paper adds to the growing body of literature aimed at understanding the relationship of water and energy. This relationship is of growing importance for decision-making — because resource managers must increasingly improve the efficiency with which limited water and energy supplies are used to meet demands. Reducing energy intensity and energy uses can reduce GHG emissions in the water sector and mitigate climate change. Major water and energy actions related to GHG mitigation are summarized in Table 3 in the Appendix.

ii. The Water-Energy Information Framework

1. Water-Energy Connection and Diagram

Understanding the relationship between water and energy is crucial for decision-making, and resource managers should improve the system efficiency with which limited water and energy supplies are used to meet increasing future demands. Understanding and reducing energy intensity in the water sector can help reduce GHG emissions. Water and energy have a complex relationship containing multiple interdependencies, the so-called "water-energy nexus." Energy is used throughout the water sector to extract, convey, treat, distribute, and heat water.

The other side of the water-energy nexus relates to the amount of water used in producing energy, including water used:

- In the energy sector for exploration and extraction of natural gas and other fuels.
- As the working fluid for hydropower.
- As the working and cooling fluid in thermal generation systems.
- In the cultivation of biofuels.

Water systems need energy in water conveyance, distribution, treatment, and end uses, just as energy generation requires water in the life cycle of energy production process. For example, supplying water, treatment of wastewater and storm water, and disposal of sewage all require energy. Drinking water may be pumped to the treatment plant, treated, and then pumped again to consumers. In areas where fresh water is scarce, drinking water may be brought in from a long distance and over a high elevation, creating an extremely high energy intensity. Conversely, all types of electrical generation consumes water to process the raw materials used in the facility or for fuel, in constructing and maintaining the plant, or to generate the electricity itself.

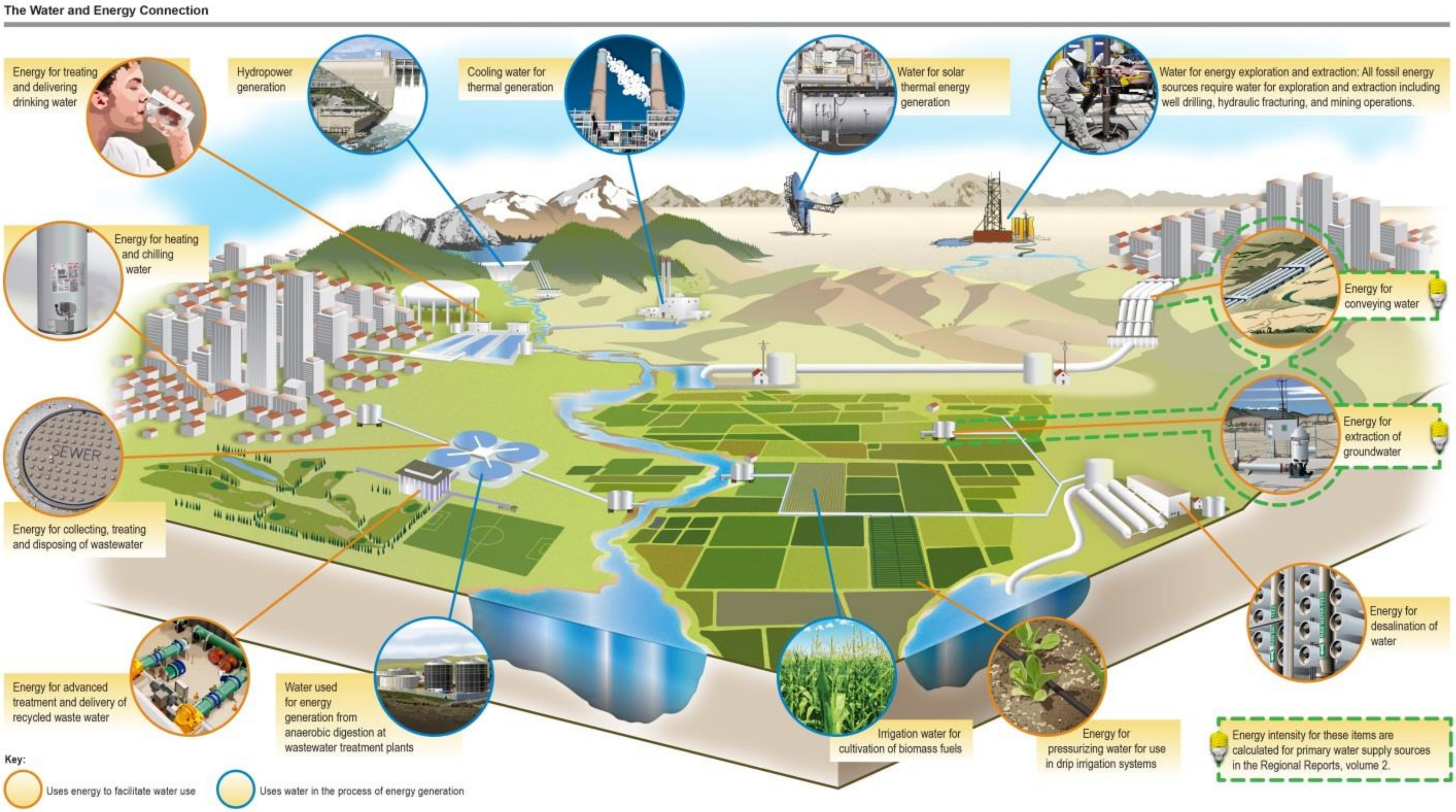
These complex connections of water and energy are explained by the visual diagram (Figure 1), including connections where water is used in the generation of hydropower, solar, biofuels and other energy, and where energy is used in the water cycle for urban and agricultural users. Connections where water is used in the generation of energy are highlighted in blue, while connections where energy is expended in the use of water are highlighted in orange.

The energy required for extraction and conveyance of water are indicated with green dashed outlines. Energy used in the water system includes:

- Conveyance of water.
- Extraction of ground water.
- Desalination and recycling of water.
- Pressurization of water for drip irrigation.
- Waste water collection and treatment.
- Heating and chilling water.
- Treating and delivery of drinking water.

While not explicitly depicted in Figure 1, energy is often used to protect public health and implement environmental protection and restoration projects (e.g., increasingly stringent treatment requirements for drinking water quality and wastewater discharges, river restoration, etc.).

Figure 1. The Water-Energy Connection Diagram



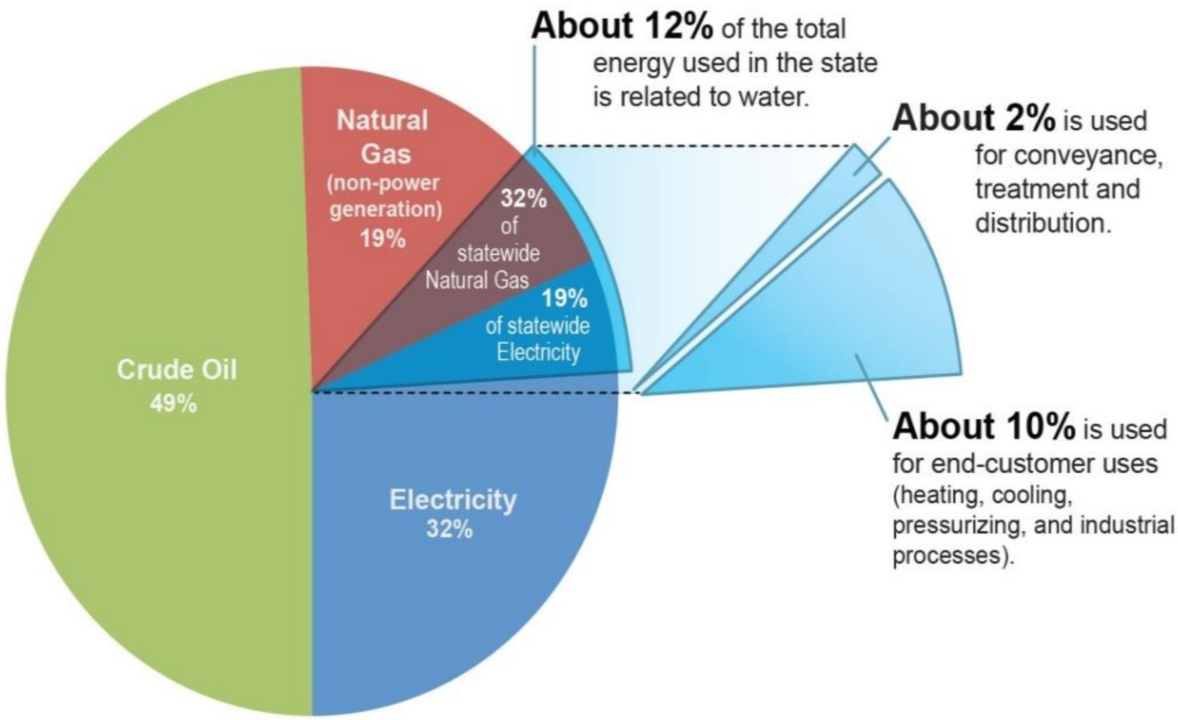
iii. Energy Intensity of Water in California Water System

1. The distribution of estimated energy use in California's water sector

The extraction, conveyance, treatment, distribution, and use of water, followed by the collection, treatment, and discharge of wastewater all require energy. The energy required to heat water is even higher, as it includes the cost of the fuel oil, propane, electricity, or natural gas used to heat the water. According to the California Energy Commission, this water-related energy consumes 19 percent of the state's electricity and 32 percent of statewide natural gas (non-power generation). Approximately 75 percent of water sector electricity consumption is by end-users, including water heating and cooling, advanced treatment by industrial customers, and on-site pumping and pressurization for irrigation and other purposes. The other 25 percent (approximately) of electricity consumption within the water sector occurs in drinking water and wastewater system operations, including water extraction and conveyance, drinking water treatment and distribution, and wastewater collection and treatment. The water-energy pie chart (Figure 2) depicts this water-related energy use in California (California Department of Water Resources 2013), including electricity, natural gas, and crude oil consumption (California Energy Commission 2005, 2013; California Public Utilities Commission 2010).

The methodology used to evaluate energy uses in this water-energy pie chart includes estimates of distribution of energy used in California according to *California Energy Balance Update and Decomposition Analysis for Industry and Building Sectors* (California Energy Commission 2013). About half of all energy use is derived from burning crude oil and crude oil derivatives, such as gasoline. The other half is divided between natural gas and electricity. The detail section, pulled out of the statewide energy usage, shows the percentage of each type of energy expended in uses related to water. This information comes from the 2005 Integrated Energy Policy Report (California Energy Commission 2005). A negligible quantity of crude oil-based energy is expended in water-related uses, such as diesel driven groundwater pumps, and the quantity is so small in relation to the overall use of crude oil-based fuels in California that it does not appear on the graph. The detailed information on this methodology is discussed in Table 4 of the Appendix section.

Figure 2. **Energy Use Related to Water in California Water System**



2. Whole water system energy intensity in California

The energy intensity (EI) [1] of water is defined as the total amount of energy required for the use of a given amount of water in a specific location, calculated on a whole-system basis (e.g., kilowatt hours per acre-foot of water, kWh/AF). The Energy Intensity Range (in kilowatt hours [kWh] per million gallons [MG]) in California's water use cycle has been evaluated by DWR and others (California Energy Commission 2005, California Public Utilities Commission 2011), as shown in Table 1 below.

Water pumping and treatment processes require energy use. Different water quality needs may imply different energy requirements for treatment. Different water sources also require different treatment intensities. Generally, treatment of water that is either high in salinity — such as brackish groundwater and seawater — or produced water from some oil and gas operations, or contains large amounts of organic material — such as municipal wastewater — has relatively high energy requirements. Pumping has a range of possible energy intensities, depending on the

[1] EI: Energy Intensity
Energy used for water transport, distribution or treatment or end uses on a per unit basis - A measure of energy efficiency in water systems.
EI: kilowatt hours per acre-foot of water (kWh/AF).
Energy Embedded in Water: The amount of energy used in water cycles including: conveyance, treatment, and distribution, and wastewater collection, treatment, and end use activities.
Useful in quantifying energy savings as a result of water savings: embedded energy saved = water saved x EI.

circumstance. The quantity of energy required for pumping primarily relates to elevation change, and some energy used could be related to distance transported without gravity flow. Table 1 shows the energy intensity of water treatment and pumping in California. The summary of Energy Intensity Range (kWh/MG) in California's water system provides general energy intensity estimates related to water treatment and distribution that are not regionally specific. As shown in Table 1, inter-basin transfer could be an order of magnitude higher in energy intensity than local distribution or groundwater pumping, and a very high amount of treatment energy is used for desalination. Evaluation of the energy required for water pumping and treatment processes in the California water system is useful for any decision-making regarding saving water and energy, and reducing GHG emissions.

Table 1. Summary of Energy Intensity Range (kWh/MG) in CA Water System

Water cycle	Energy Intensity Range (Low to High)	Reference	Notes
Treatment/drinking water	100 to 16000*	CEC 2005	See Note 1
Collection and Treatment /Wastewater	1100 to 4600	CEC 2005	
Pumping/water conveyance	0* to 14000*	CEC 2005	See Note 2
Pumping/drinking water distribution	700 to 1200	CEC 2005	
Pumping/recycled water distribution	400 to 1200	CEC 2005	
Pumping/ groundwater extraction	500* to 1500*	CPUC 2011	See Note 3

Notes:

1. Treatment energy used for drinking water: high for desalination.
2. Pumping energy used for water conveyance: 0 for gravity fed and high for State Water Project.
3. Pumping energy used for ground water extraction: low for North Coast and high for Colorado River Basin.

3. Regional Energy Intensity

Energy savings through water conservation and water use efficiency could reduce the total energy use of a water system, which could then reduce energy demand and GHG emissions in the water sector. A portfolio approach for water supplies includes utilizing water from various sources — such as the State Water Project (SWP), groundwater, local water projects, and transfers or exchange agreements. When making water management choices, the energy intensity of individual supplies should be part of the decision-making process in portfolio management. However, for each water source in the portfolio, there are water quality considerations, environmental impacts, energy requirements, reliability concerns, costs, climate change impacts, and other considerations. This section provides a useful input for water resource portfolio management, by estimating the energy intensity of different types of water supplies based on the different hydrological regions in California.

A. Description of California's Water Systems

Climate change impacts on water systems in California must be considered in the context of the interconnectivity of those water systems (shown in Figure 3). Water in California is managed at the federal, State, and local levels. These systems manage over 40,000,000 acre-feet of water per year, serving nearly 40 million people and irrigating nearly 9 million acres of farmland (California Department of Water Resources 2013). Because of California's seasonal and geographical precipitation patterns, large inter-annual precipitation variability, and geographical distribution of population, storage and conveyance of water play a major role in California water management. Several inter-basin water transfer projects have been built in California by the federal government, state government, and local water agencies. These systems capture and store winter precipitation and spring runoff from the Sierra Nevada Mountains and convey it through natural river channels, aqueducts, and pipelines to cities and farms throughout the state. Hundreds of smaller projects owned and operated by local water agencies and irrigation districts capture, store, and convey water from local streams, rivers, and lakes to customers.

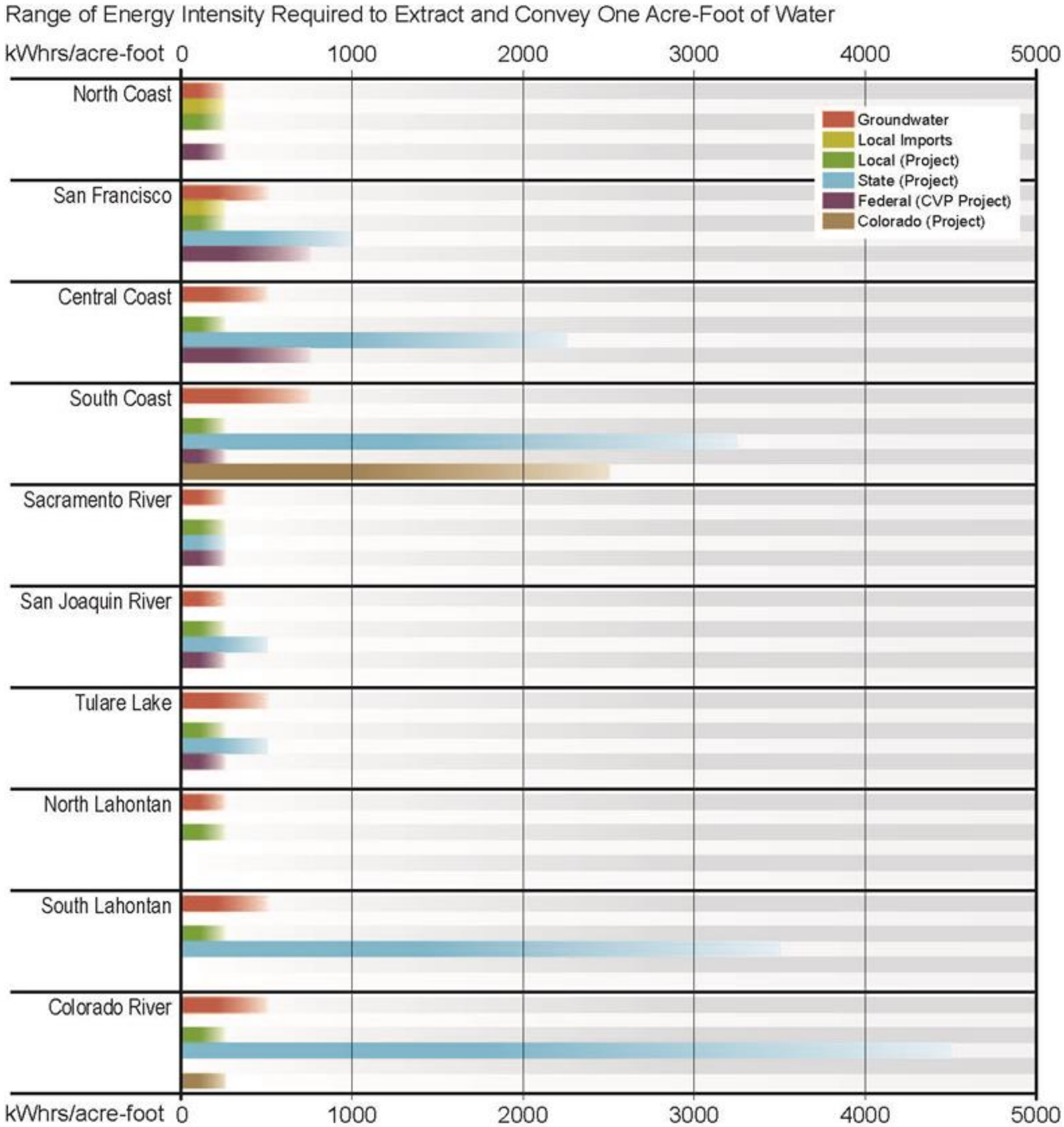
Along with California's large inter-basin transfer projects and small local surface water projects, millions of acre-feet of groundwater are also used to meet the water demands of California's people and agriculture. For example, 12 to 20 million acre-feet of groundwater was pumped to meet California's total water use in 2005 and 2009. Approximately 30 million people (80 percent of Californians) live in areas overlying alluvial groundwater basins. Some communities in California use very little groundwater, while many communities are 100-percent reliant upon groundwater (State of California Natural Resources Agency, Department of Water Resources 2015). Groundwater makes up between 30 and 60 percent of annual water supplies and serves as a critical source of water in dry years when surface water resources are scarce. Figure 3 shows California's diverse set of local, State, and federal water projects superimposed over the state's hydrologic regions, providing context for the regional energy intensity figures in the following section.

B. Estimates of the Energy Intensity of Regional Water Supplies, and the Data Sources and Methods Used

Figure 4 indicates the estimated regional Energy Intensity Range (estimated from the 10 hydrological regions shown in Figure 3). The detailed energy intensity value of the various types of water supply from each hydrological region is presented in Figure 9 in the Appendix. The data for the various water types were obtained from the water balances for the energy intensity studies of California's 10 hydrological regions, and has been documented in *California Water Plan Update 2013* in Volume 5 (Technical Guide) as the Energy Intensity of Regional Water Supplies (http://www.waterplan.water.ca.gov/technical/cwpu2013/index.cfm#climate).

Figure 3. **California Water System Map**

Figure 4. **Estimated Regional Energy Intensity by Water Type for the 10 Hydrological Regions in California**



Energy intensity in this figure is the estimated range of energy required to move one acre foot of water from the supply source to a centralized delivery point. Several water sources are color faded to indicate a range of intensity, rather than exact amounts, as a result of the limited data availability or other estimated information. All water sources are presumed to have a minimum energy intensity greater than zero, but not all water sources in a region could be listed. The goal of this figure is to provide a general idea of the energy required to deliver water to a particular region to aid water managers who wish to include energy intensity as a factor in their management decisions. The regional energy intensity compiled in this figure is provided in the *California Water Plan Update 2013, Volume 2: Regional Reports*, and in the Water-Energy Nexus. For detailed descriptions of the methodology used to calculate the energy intensity in this figure, see the *California Water Plan Update 2013, Volume 5: Technical Guide, Energy Intensity of Regional Water Supplies*.

Figure 4 shows that there was a large variation in energy intensity values estimated for groundwater and federal, State, and local water supplies, both within each hydrological region and among the 10 hydrological regions in California. For example, the South Coast region has a relatively high energy intensity from State Water Project supply compared with other regions; the energy intensity from local water projects was relatively low compared with other water supplies in this region.

C. Implications, Caveats, and Limitations

Understanding the energy intensity of the water supply at a regional scale will enable local planners to make decisions on energy savings related to each type of water supply. It may also help evaluate how much energy may be saved by water conservation and water use efficiency, showing the possible benefits of reducing water demand and greenhouse gas emissions. The energy intensity comparisons provide local planners with an estimate of the energy required to extract and convey water of various types. The regional energy intensity of water varies greatly depending on the water source, conveyance method and efficiency, regional topography, and delivery location. Water in Northern California tends to have lower energy requirements as a result of using less pumped and imported water when compared with the drier southern portion of the state. Generally, the further water travels from Northern to Southern California through high elevation, the more energy is needed (with the exception of groundwater, which could require large amounts of energy to travel only a few hundred feet to the surface).

This framework can help inform better public decision-making on water, energy, and food issues so that limited natural resources are used efficiently with regard for meeting future demands. Also, it could help address water-energy conflicts happening in places with similar climate change effects, like the American West. However, the regional energy intensity estimates do not include the energy used for water supply in the water cycle for water treatment and distribution. Furthermore, regional energy intensity estimates do not have sufficient detail for actual project-level analysis. Although there are limited tools for project-level analysis in energy intensity for the water cycle, detailed evaluations of project-level energy intensity can be gained by using tools such as WeSim, which allows water managers to model their water systems and simulate outcomes for energy, GHGs, and other metrics of water supply information (Cooley et al. 2012).

4. Energy Intensity Issues with Hydropower, Desalination, and Recycled Water

A. Desalination and Energy Use

Desalination provides a water supply that remains robust even during extreme drought periods; desalination capacity may not be affected by rising sea levels, decreased exports from the Sacramento-San Joaquin Delta, or changes in snowpack runoff. Desalination is an adaptive strategy to improve the resiliency and reliability of a region's water supply, even in the face of uncertain future climate conditions. However, as a reliable water source, all municipal drinking water facilities, especially coastal desalination facilities, need to be located away from or protected from rising sea levels and other events that could increase their vulnerability to flooding and erosion. In addition, environmental impacts related to fish, wildlife, and aquatic habitats in water desalination projects have to be assessed and mitigated to meet the requirements of environmental laws and regulations.

Energy use is a significant factor in water desalination projects because of the cost and the environmental impacts of energy generation. Each of the elements in a desalination system entails energy use, but the most significant energy use is in the treatment process in which the salt ions are removed. Generally, the energy requirement of reverse osmosis (RO) desalination is a direct function of the salinity level and the temperature of the water source. Given similar operating conditions and treatment plant parameters, brackish water desalination is usually less energy intensive, and thus less costly than seawater desalination. Several summary reports on desalination and the energy intensity of water supply and treatment systems have been published (Wilkinson 2000; Klein 2005; GEI Consultants/Navigant Consulting 2010; Water Reuse Desalination Committee 2011; Elimelech 2011; Cooley and Wilkinson 2012; Cooley and Heberger 2013).

The energy intensity of desalination for seawater ranges between 3,300 kilowatt hour per acre-foot (kWh/AF) and 5,900 kWh/AF, and desalination for brackish water ranges between 1,000 kWh/AF and 2,700 kWh/AF. To compare the energy intensity of desalinated water supplies with the energy intensity of other water supplies delineated in each regional report, a factor for water treatment would have to be added to the energy intensities of the "raw water" provided (see Volume 2 of California Water Plan Update 2013). The energy intensity of conventional water treatment is typically between 50 kWh/AF and 650 kWh/AF, depending on the capacity of the treatment plant and the quality of incoming raw water (Water Reuse Desalination Committee 2011; Cooley and Wilkinson 2012). For a seawater desalination RO facility, 28 to 50 percent of the total annual costs, including annual capital recovery costs, are devoted to energy consumption (Water Reuse Desalination Committee 2011). However, improvements in RO membranes and the incorporation of energy recovery devices in treatment facilities have resulted in reduced energy needs in new facilities. Because of the high energy requirements for desalination, it is especially important to look at the sources of power used to operate plants.

While research continues, it is not expected that further major reductions will occur in the near term. Aside from drawing electricity from a power grid to operate desalination facilities, it has been proposed that renewable energy generation could be incorporated directly into such facilities. In some proposals, seawater desalination would take advantage of its proximity to the natural energy within the ocean environment. A commercial-scale wave energy project is being constructed by Carnegie Wave Energy Ltd. in Western Australia, to provide hydroelectric power to a naval base. The project is also designed to provide water pressure to a desalination pilot plant (Australian Renewable Energy Agency 2014, https://arena.gov.au/projects/). In addition, research is being conducted on two concepts funded by the EPA: the microbial desalination fuel cell and desalination with a solar evaporation array.

B. Recycled Water and Energy Use

Municipal recycled water can support climate change adaptation, particularly where local water supplies are limited. Recycled water can be used as a source of water for groundwater recharge, surface reservoir augmentation, and salinity barriers for coastal aquifers. Although recycled water supplies can be affected by drought and increased conservation, its fluctuation is usually lower than other resources and is considered to be less sensitive to temperature and precipitation variation.

The energy intensity for pumping recycled water and distribution ranges from 400 to 1200 kWh/MG; energy intensity ranges for wastewater treatment and distribution (1100 to 4600 kWh/MG) are much higher (California Energy Commission 2005). Analyzing the energy intensity provided by recycled water in general is complex because wastewater treatment can be different at specific project sites. Wastewater treatment is necessary for discharge to the environment and can also make water suitable for beneficial reuse. Some level of treatment must be performed on all wastewater before it can be discharged to the environment, but most recycled water processes will require additional treatment to bring the quality of the water up to acceptable standards for use. Therefore, only the additional treatment and distribution energy beyond what is required for discharge is counted toward the energy intensity in recycled water. In other (rare) circumstances, the water treatment required to discharge wastewater to a waterway may actually be higher than the level of treatment required for irrigation or industrial uses. For example, nutrient removal, an energy-intensive process, might be required for wastewater discharge but not for agricultural or landscape reuse (Cooley and Wilkinson 2012). Thus, recycled water allows treated wastewater to be used at a lower level of treatment than required for discharge, resulting in energy savings or negative (beneficial) energy intensity.

Implementing municipal water recycling could reduce or increase energy consumption, which may have implications for California's climate change mitigation efforts. The water sector uses a significant amount of energy to convey water from its source to end users. Additional energy use is minimized when recycled water is used in close proximity to wastewater treatment sources and when additional treatment is not required beyond that needed for wastewater disposal.

Research is also ongoing to develop lower-energy recycling methods, which could in turn reduce the associated GHG emissions. Overall, it is assumed that implementing recycled water would provide an energy use benefit by developing local resources as opposed to importing fresh water; however, such a benefit is obviously not realized if water imports continue while at the same time recycled water is developed and used, as an additional — rather than replacement — water supply. This energy use benefit could also be realized by considering "fit for purpose" in recycled water use planning, and by avoiding treating water to a higher level than is necessary for its planned reuse.

C. The Role of Hydropower in Calculating Energy Intensity

Generation of hydroelectricity is an integral part of many of the State's large water projects. On a long-term basis, hydroelectric generation provides about 15 percent of all electricity generation in California. The State Water Project, Central Valley Project, Los Angeles Aqueduct, Mokelumne Aqueduct, and Hetch Hetchy Aqueduct all generate large amounts of hydroelectricity at large multi-purpose reservoirs at the heads of each water system. In addition to hydroelectricity generation at head reservoirs, several of these systems also generate hydroelectric energy by capturing the power of water falling through pipelines at in-conduit generating facilities. Hydroelectricity is also generated at numerous smaller reservoirs and run-of-the-river turbine facilities.

Hydroelectric generation facilities at reservoirs provide unique benefits. Water in reservoirs is potential energy. Reservoirs, like the State Water Project's Oroville Reservoir, are operated to build up water storage at night when demand for electricity is low, and release the water during the daytime hours when demand for electricity is high. This operation, common to many of the state's hydropower reservoirs, helps improve energy grid stabilization and reliability, and reduces GHG emissions by displacing the least-efficient electricity-generating facilities. Hydroelectric facilities are also extremely effective at providing back-up power supplies for intermittent renewable resources like solar and wind power. Because clouds may obscure the sun or the wind die down, intermittent renewables need backup power sources that can quickly ramp up or ramp down depending on grid demands.

Despite these unique benefits and the fact that hydroelectric generation was a key component in the formulation and approval of many of California's water systems, accounting for hydroelectric generation in energy intensity calculations is complex. In some systems, like the SWP and CVP, water generates electricity and then returns to the natural river channel after passing through the turbines. In other systems, like the Mokelumne Aqueduct, water can leave the reservoir by two distinct outflows, one that generates electricity and flows back into the natural river channel and one that does not generate electricity and enters a pipeline flowing to the East Bay Municipal Utility District service area. In both these situations, researchers have argued that hydroelectricity should be excluded from energy intensity calculations because the energy generation system and the water delivery system are in essence separate (Wilkinson 2000). In other words, it is assumed that some amount of energy would continue to be generated, even if no water were being delivered.

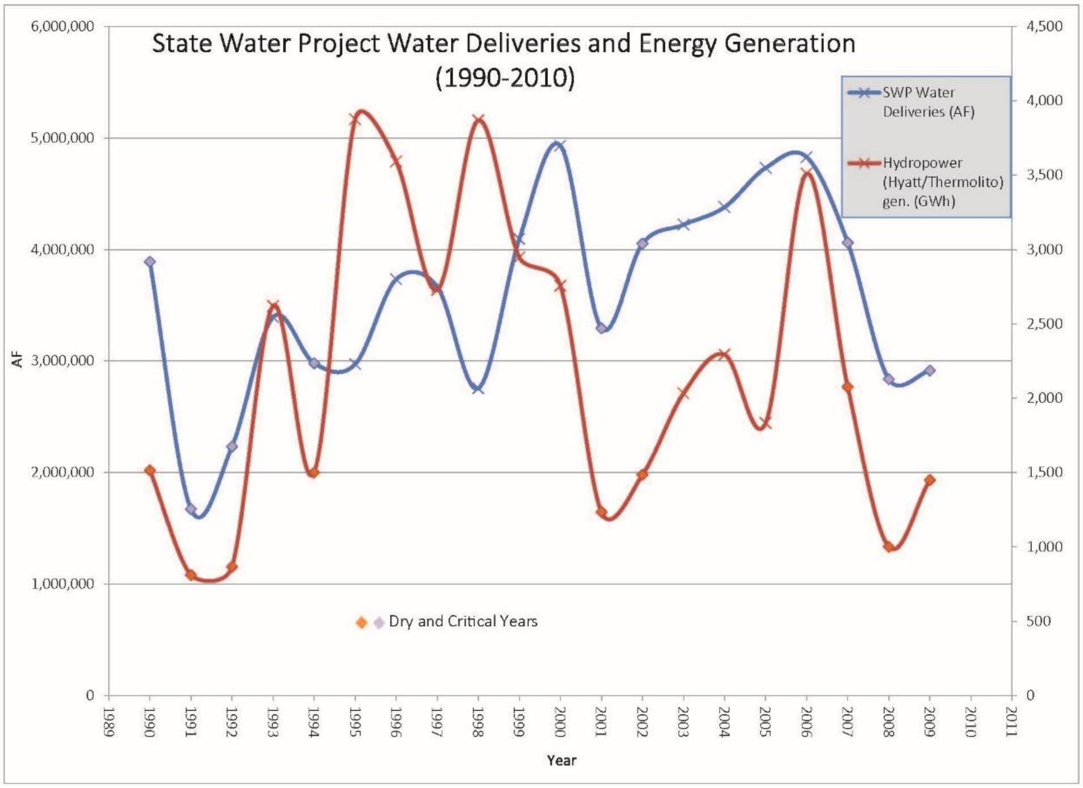
With some reservations, DWR has adopted this convention for calculating the energy intensity of water supplies in a region, as shown in each of the regional reports. All hydroelectric generation at head reservoirs has thus been excluded. Consistent with Wilkinson (2000) and others, DWR has included in-conduit and other hydroelectric generation that occurs as a consequence of water deliveries, such as the Los Angeles Aqueduct's hydroelectric generation at San Francisquito, San Fernando, Foothill, and other power plants on the system (downstream of the Owens River Diversion Gates). DWR has made one modification to this methodology to simplify the display of results: energy intensity has been calculated for each main delivery point in each system, if the hydroelectric generation in the conveyance system exceeds the energy needed for extraction and conveyance, the energy intensity is reported as zero (0). That is, no water system is reported as a net producer of electricity, even though several systems do produce more electricity in the conveyance system than is used (e.g., the Los Angeles and Hetch Hetchy aqueducts).

5. Water-Energy Nexus and Drought in California

Californians are very familiar with lower water deliveries from surface water projects like the SWP and CVP in dry and critical years, but hydroelectric generation from these projects falls even more severely in dry and critical years. Figure 5 shows how water deliveries and hydropower generation from the SWP have varied over the last 20 years. It is clear that both react similarly in response to changes in hydrology; however, hydropower generation is even more volatile than water deliveries. The year 1998 is the only one in this graph where water deliveries and energy generation are out of phase, showing an interesting aspect of this relationship. That year was the fourth wet year in a row and generated very large snow packs. The large snowpack and heavy rainfall generated lots of hydroelectricity, but water contractors did not need large deliveries because of the prolonged wet conditions.

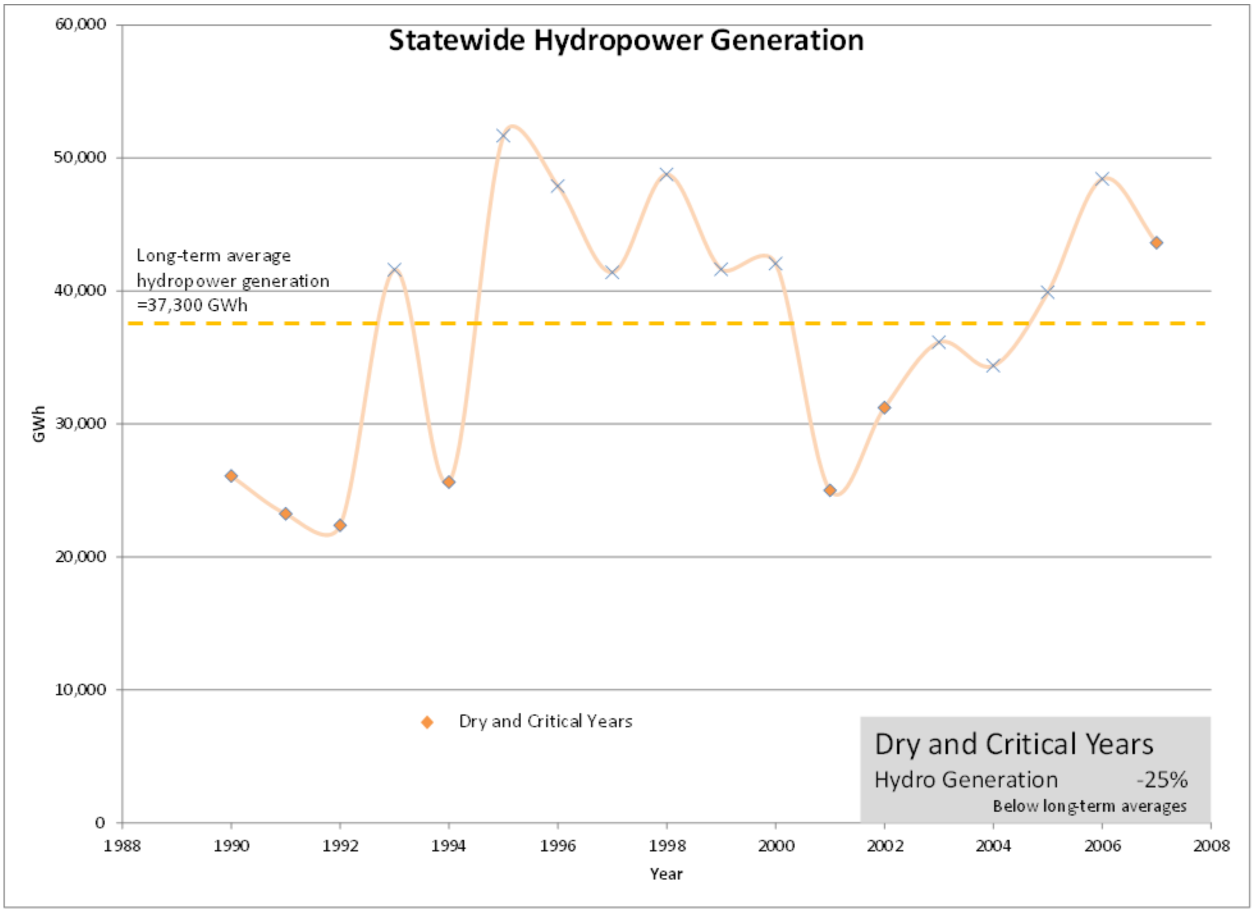
Statewide, hydropower generation is also very strongly correlated to water year type. As indicated in Figure 6, California's hydropower generation declines from the long-term average by about 9,000 GWh in dry and critical years, a 25 percent drop. California also imports hydropower from Oregon and Washington, but those imports may actually run counter to this trend, as when it is dry in California it is often wet further north, so this effect may act as a buffer against hydropower declines during dry years in California.

Figure 5. Relationship of Water Deliveries and Hydropower Generation in Dry and Critical Years



The continuous four-year drought has had a pronounced effect on the groundwater aquifers across the state. From 1998 to 2010, there were five years of either Dry (4) or Critical (1) water year (WY) types, and eight years of Wet (3), Above Normal (3), or Below Normal (2) WY types (California Department of Water Resources 2013). Our analysis indicated increased energy used by groundwater pumping that closely correlated with dry and critical years (Figure 7). We estimate that about 2.6 Million Acre Feet (MAF) of additional GW is pumped in Dry and Critical years. About 1,300 GWh of additional energy is expended in these years to pump this additional water (about 18 percent more than the long-term average). In particular, during the single Critical water year (2008), the state pumped as much as 20 MAF of groundwater, nearly 41 percent more than in a Wet or Normal water year.

Figure 6. California's Hydropower Generation Related to Water Year Type

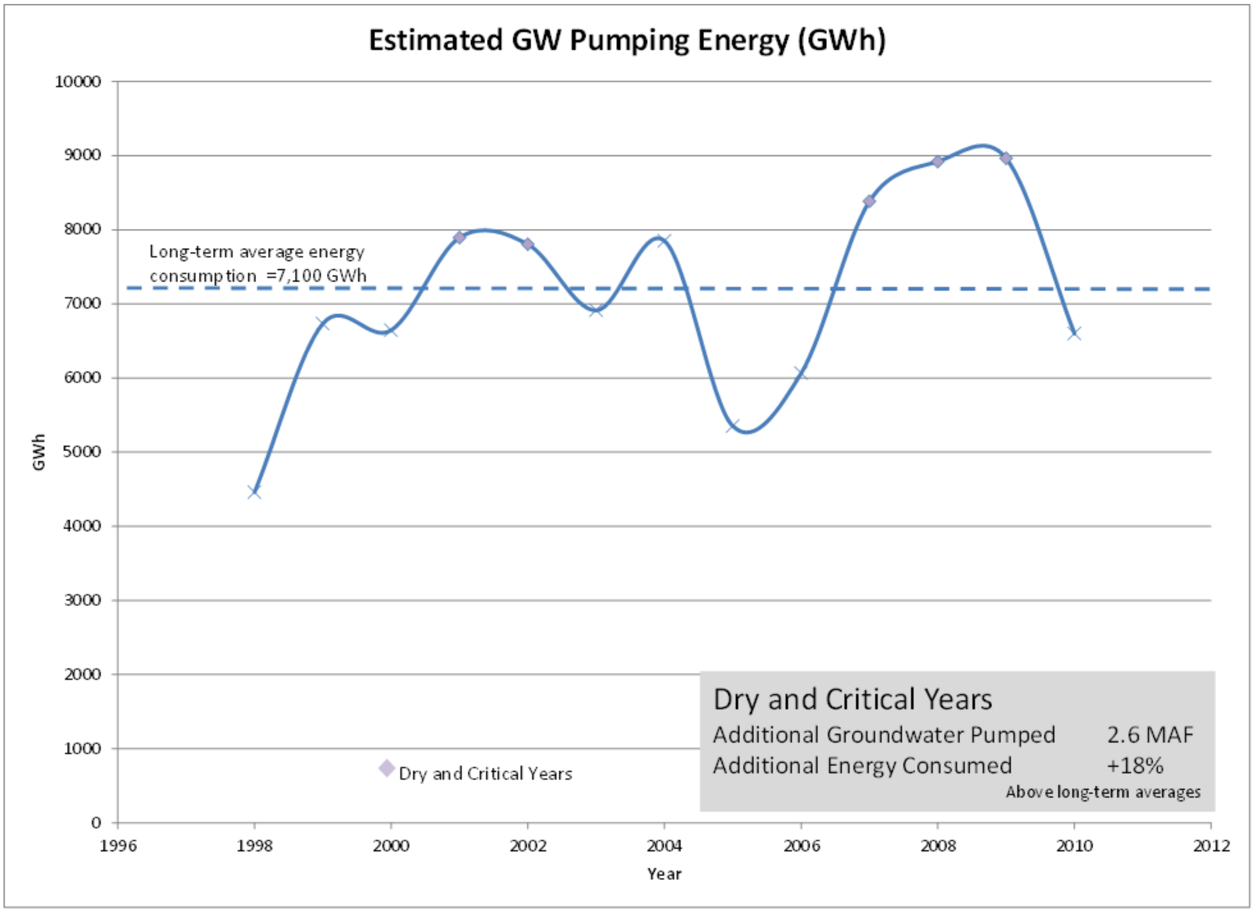


Many groundwater basins in the state have been over drafted over the last few decades. This not only threatens our water supply resources in the future but has also brought many other negative impacts, such as ground subsidence; groundwater level decrease and water quality deterioration; irreversible aquifer capacity reduction; and foundation damage to houses, buildings, streets, highways, aqueducts, and other infrastructure. Another often overlooked result of overdraft is the increased energy consumption as well as increased GHG emissions because of increased groundwater pumping and depth to the water table during drought years.

California's current multi-year drought is taking its toll on the agricultural industry. In 2014, California agriculture pumped 5 million acre feet of groundwater to make up for 6 million acre-feet in surface water reductions. More than 400,000 acres of farmland were fallowed in response to the drought and other factors. Crop, dairy, and livestock revenue losses, plus the additional costs of groundwater pumping, have a total direct cost to agriculture of approximately $1.5 billion, with the majority of these losses occurring in the San Joaquin Valley. Potentially, even greater economic losses may be incurred at the regional and state levels if the drought continues.

If groundwater pumping continues at its present rate or increases, water tables will continue to drop, increasing pumping costs and land subsidence. While droughts are a natural part of California's environment, climate change exacerbates drought conditions as increasing temperatures drive up water demand. Current drought conditions also underscore California's reliance on groundwater and serve to highlight the importance of sustainable groundwater management.

Figure 7. Estimated Groundwater Pumping Energy Related to Water Year Type



6. Resource Management Strategies with GHG Implications

The Resource Management Strategies (RMS) in *California Water Plan Update 2013* reduce water demand, increase supply, and/or improve water quality and resource stewardship as well as flood management. There are 30 RMS for which climate change implications have been evaluated, including the potential impacts on energy use and GHG emission reduction efforts (see Table 2 in the Appendix). RMS can help in meeting state and regional water-related resource needs, and developing integrated regional water management and flood management plans. RMS examples include urban water use efficiency, watershed management, ecosystem restoration, land use planning and management, sediment management, and pollution prevention. Some strategies have complex water-energy relationships related to GHG emissions. For example, for agricultural water use efficiency, drip irrigation can reduce the use of water but may increase the use of energy. In other RMSs, the benefits to the water-energy relationship are clear, such as in urban water use efficiency, as reducing water use in urban settings results in direct energy savings.

Consideration of the energy intensity and GHG emissions associated with water resources planning and management is becoming a more common practice. In 2008, the California Water Code was amended to require consideration of GHG emissions for programs and projects identified in integrated regional water management plans (IRWMP). Passage of Assembly Bill 1036 in 2014 amended the California Water Code to include voluntary reporting of water supply energy intensity for urban water management plans (UWMP).

For a complete description of each RMS, please visit *California Water Plan Update 2013* online at http://www.waterplan.water.ca.gov/cwpu2013/.

7. Water Footprint in the Energy Sector

The other side of the water-energy nexus is the water footprint of the energy sector, and it relates to the amount of water used in producing energy, including water used for extraction of fuels, used as the working fluid for hydropower or cooling in thermal generation systems, and used for irrigating biofuels. The water used in energy production is included in the "water footprint," or as it is known in the energy sector, "water intensity."

Electrical power generation is typically produced through thermoelectric processes by combustion or fission, in which the heat energy or radioactive energy is converted to electrical energy. Water withdrawals in California for thermoelectric power generation accounted for 17 percent of the statewide water withdrawals (almost exclusively from saline water) in 2010 (United States Geological Survey 2014). The power industry has engaged in conserving water by using the following technologies and approaches: (1) dry/hybrid cooling; (2) use of nontraditional water sources; and (3) recycle and reuse of water within plants.

Increasing temperatures, shifting precipitation patterns, increasing variability, and more extreme weather could lead to more regional variation in water availability for hydropower, bio-fuel production, thermoelectric generation, and other energy needs. Higher temperatures can increase the electricity demand for cooling and decrease the efficiency of thermoelectric generation (United States Department of Energy 2014).

The water used for energy for future transportation has been evaluated under California's climate goals (Teter et al. 2014). Transportation accounts for the largest share of California's GHG emissions, with 93 percent of its total emissions from petroleum products. Alternative fuel sources, including biofuels, natural gas, electricity, and hydrogen, require different types and amounts of water per unit of delivered energy than gasoline and other petroleum-derived fuels. Understanding these differences will be key for developing California's policies connecting water, energy, and climate change. For instance, increased water uses for oil production and electricity generation can be effectively managed by shifting water use from higher quality freshwater to lower quality water types, such as degraded and recycled water.

The nexus of water and other renewable resources also plays an important role in the choice of transportation fuels. Biofuel production is a critical part of renewable energy, which can have considerably larger water footprints than other energy forms, on a per unit-of-energy basis (Dominguez-Faus 2014). Water scarcity exacerbated by climate change could affect our ability to produce biofuels. One opportunity for California is in the production of forest biomass (integrated forest operations and thinning). This includes developing forest feed stocks for electricity generation, which can also reduce wildfire danger and improve watershed health. The California Water Plan Update recognizes this approach has multiple land-water benefits, including improving water supply reliability, protecting water quality, increasing flood protection, and promoting environmental stewardship (California Department of Water Resources 2013). However, technical feasibility, and cost and benefits should be assessed for the future project application of forest biofuels.

Although there has been an overall emphasis on expanding reliance on sustainable/renewable energy sources within California, fossil fuel-based power plants continue to be a major source of energy. Significant improvements in energy generation technology have reduced the environmental impacts associated with energy generation; nonetheless, energy generation (including exploration, extraction, and conversion to electricity) continues to result in significant environmental impacts. Air pollution, including GHGs, groundwater pollution, water use, and despoiling of scenic views and wildlife habitat are major concerns associated with new and existing energy generation. Many of these concerns apply not only to fossil energy sources, but also to renewable power.

The future water needs for energy production should be evaluated to identify potential conflicts with water availability, specifically in California. Recent studies of water for energy in the American West assessed water uses in fossil fuels that included coal, oil shale, and water-intensive renewables, such as concentrated thermal solar power and bioenergy (Kenney and Wilkinson 2011). In addition, a future risk of conflicts between electricity production and water availability has been evaluated for the Intermountain West (Cooley et al. 2011). The water footprint associated with energy use has been evaluated in California (Kenney and Wilkinson 2011; Fulton et al. 2012). Energy-related water use has increased since 2001, especially in ethanol production. The Pacific Institute's water footprint assessments provided valuable insight on water use trends from geographic areas where water-related decision making occurs (Fulton et al. 2014). Recent study of the water requirements of energy products consumed in California between 1990 and 2012 indicated the amount of water required to produce the energy grew by 260 percent, while California’s total annual energy consumption increased by just 2.6 percent in this period. However, most of these energy-related water footprints were related to water use in locations outside of California (Fulton et al. 2015). Less water-intensive renewable energy sources could be selected to address limited water supply for energy production. The increased vulnerability of the future water supply to climate change affecting the energy sector, such as in renewable energy, should also be addressed in State policies and water management actions.

8. Climate Adaptation and Mitigation — Water-Energy Coordination and Tradeoffs

Both adaptation and mitigation are needed to manage climate change risks for ecosystem services in water and energy, which are often overlapping, complementary, or conflicting (Liu 2016). Coordinating these actions presents a significant challenge for water and energy, since there may be unintended consequences without proper planning. For example, increased groundwater pumping as a result of prolonged droughts and increased heat days can lead to saltwater intrusion in freshwater aquifers, leading to the adaptation response of fresh water injection. Fresh water injection can be high in water and energy use, which can conflict with climate change mitigation goals. A coordinated effort may be one that uses recycled water injected by using renewable energy, along with a sustainable groundwater pumping plan. Thus, a strategy of infrastructure upgrades could be based on coordination between adaptation and mitigation that can also reduce conflict on the water-energy nexus.

PART III. FUTURE CHALLENGES AND OPPORTUNITIES

i. Connecting Water, Energy, Food and in the Environment in a Changing Climate Using a Conceptual Framework

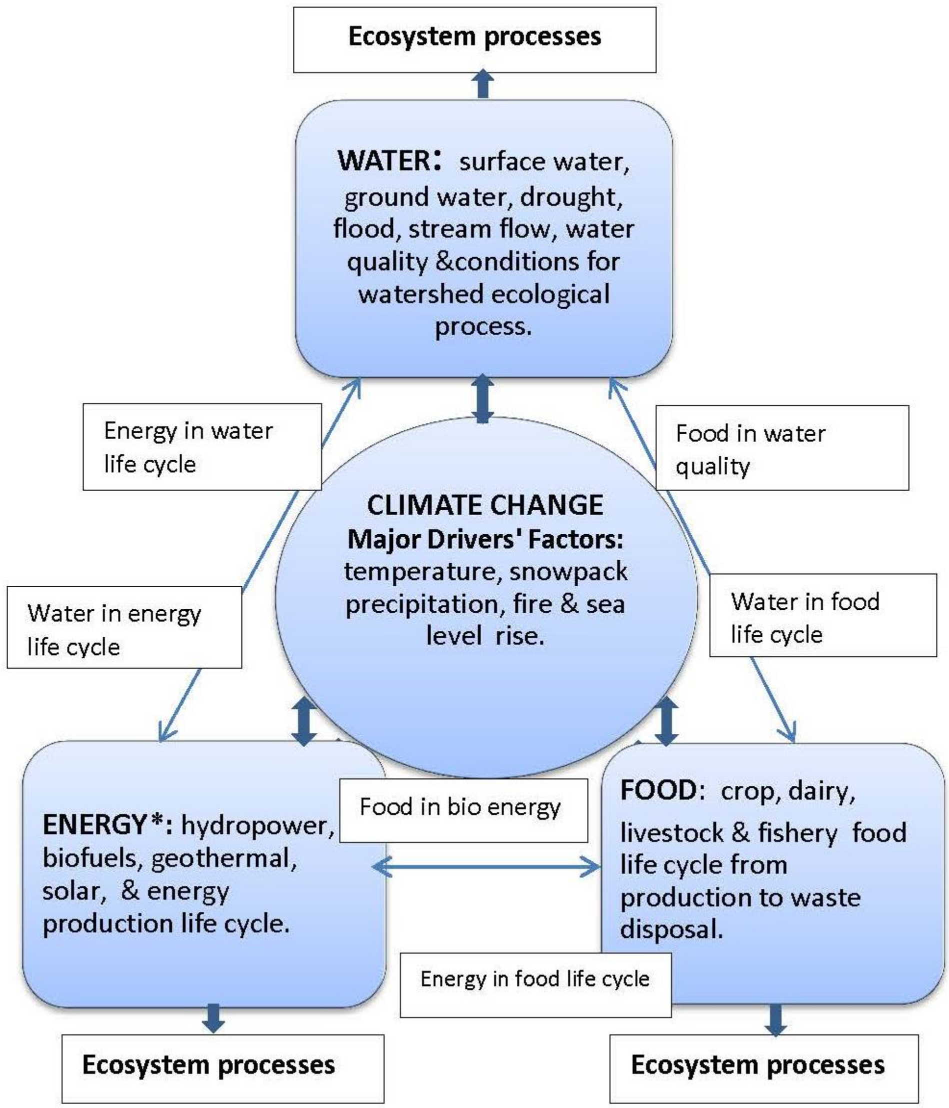
1. Overview of Conceptual Information Framework and Key Elements

Climate change, water, energy, food, and ecosystems are inextricably linked; actions in one area have impacts on the others. Better understanding of these complex and dynamic interrelationships are critical in addressing the increasing demand for freshwater, energy, and food under the pressures of future population growth, climate change, and compromised ecosystem health. Understanding the complex interrelationships between these elements helps us in using integrated water management strategies to evaluate tradeoffs and balance different goals and interests to adapt to and mitigate climate change.

A conceptual framework (Figure 8) has also been proposed to connect climate change, water, energy, food, and ecosystems (Liu 2014 and Liu 2016). This framework has also been evaluated for the public outreach and education (Jablonski et al. 2015). The proposed conceptual framework describes the complex and interrelated structure of water, energy, food, and climate change in ecosystems, including the major climate change impacts on temperature, snowpack, and precipitation. In the center of the framework, climate change impacts of temperature, snowpack, and precipitation affect the quantity, quality, and timing of water supply and its related uses in the life cycles for energy and food production, as well as urban, agricultural, and environmental water uses. These impacts may lead to increased trade-offs and conflicts among these natural resources sectors. Related ecosystem processes include forest, wetlands, watershed and streamflow, and water quality for fish and wildlife species. Fossil energy production and use increase GHG emissions and alters ecosystem processes with decreased water quality and increased air pollution.

The ecosystem provides services for water, energy, and food related to physical, chemical, and biological environments. These services are a natural source of capital that provides multiple benefits, such as production of goods (crops, timber, etc.), and providing life-support systems (clean air, water, energy, flood control, wildlife and habitats, forestry, recreational opportunities, etc.). Related ecosystem services in this conceptual framework include critical elements of water, energy, food, and ecosystem environments affected by climate change (Liu 2016). Appendix Table 5 lists specific connections between these critical elements. Increasing competition for ecosystem services between water, energy, food and biomass, and fish and wildlife could have global impacts for ecosystem health in a changing climate. Better understanding of the complex and dynamic interrelationships between these elements in decision-making processes allows us to manage our limited resources sustainably to adapt to and mitigate climate change.

Figure 8. **Conceptual Framework to Connect Climate Change, Water, Energy, and Food Related to Ecosystems**



Water and food, as well as biomass, are also closely connected. For example, the largest user of water is the agricultural sector for food production, including 70 percent of total global freshwater withdrawals (World Economic Form 2011). Agriculture uses about 40 percent of California's available water, compared with 10 percent for urban uses; the other 50 percent is used as environmental water (California Water Resources 2013). Water is not only used for agricultural, fishery, livestock, food production, food supply chain and food processing, but also for forestry, fiber, and biomass. On the other hand, the agricultural runoff from fertilizers, herbicides, and pesticides, as well as food waste as a result of food production, affects water also. Furthermore, environmental water is critical for ecosystem integrity and function, promoting healthy fish and wildlife habitats. Healthy fish and wildlife habitats improve water quality for related ecosystem services. Energy, food, and biomass are also interrelated. Energy is required to produce, transport, and distribute food; crops and biomass are used to produce biofuels.

The proposed conceptual model is the first step toward helping us better understand the complex and dynamic interactions of climate change, water, energy, and food in ecosystems. This provides the framework to sustainably manage natural resources and preserve ecosystem function and services. This conceptual framework could be used to:

- Systematically analyze these interactions for coordinated ecosystem services and sustainable use of natural resources across sectors.
- Build synergies, and identify and manage trade-offs.
- Identify knowledge and information gaps.
- Conduct case studies for integrated and cost-effective planning through cross-sectorial actions.

The conceptual framework is used in this white paper to identify information gaps, challenges, and opportunities across sectors in the following sections. Added value and multiple benefits might be obtained, as well as the ability to evaluate a decision that affects one sector for use on other sectors, and anticipate potential tradeoffs and synergies to maximize overall benefits. Integrated water management can be used as a strategy to enhance water, energy, and food security by improving efficiency and coordination across sectors.

ii. Identify Information Gaps

1. Missing Information and Gaps in Water-Energy Nexus

A. Water-Energy Data and Current UWMP Data Efforts

Water-energy data from the California water sector, consisting of thousands of water and wastewater systems, are not readily available from different parts of the water use cycle (e.g., treatment and distribution) at the project level. A comprehensive database of California water and wastewater agencies, containing detailed information about their energy characteristics, does not exist. Data collected for the energy intensity range in the California water system from the 2005 CEC report should be updated to keep up with changes in the use of water and energy in California. Water-energy studies and data are not adequate on a statewide basis to adequately describe differences between utilities. As a result of this, it is currently difficult to make estimates of EI for different parts of the water use cycle, or to describe the EI differences between utilities.

CPUC has initiated a Water Agency and Function Component Study, and have created Embedded Energy-Water Load profiles. CPUC has also collected data from limited water agencies in California (California Public Utilities Commission 2010), including a diverse group of water and wastewater agencies, irrigation districts, and other types of providers of water supplies and services. Not all of the targeted agencies were able to provide the requested water and energy data prior to completion of this CPUC study.

As directed by Senate Bill 1036, DWR has developed guidance to standardize voluntary reporting of the energy intensity of water supplies in Urban Water Management Plans (UWMPs). This guidance is intended to disclose the amount of energy required to extract and divert, place into storage, convey, treat, and distribute water supplies within an urban water supplier's operational control. The guidance also provides the opportunity for reporting the energy intensity of wastewater and recycled water collection, treatment, and distribution/discharge processes. The data collected through UWMP reporting may be useful for developing a better understanding of how energy consumption for water management operations varies throughout the state. UWMP and CPUC proceedings could eventually provide more detailed information at the service area level, and can help to fill gaps in information about water-energy intensity information.

B. Groundwater Data Uncertainty

The energy consumption and GHG emissions related to the groundwater pumping have drawn increasing attention recently. To estimate the total energy consumption and GHG emissions, we need to obtain the groundwater volumes produced, the total dynamic heads (TDH) in wells, and the pump efficiency. These are daunting tasks to be completed.

2. Water-Energy Information Gaps in Food Systems

Understanding the connections between water, energy, and food and their relationship to ecosystem health and changing climate is vital to informed decision-making, and resource management strategies need to be developed to use limited water and energy supplies efficiently to meet increasing future demands. The connections between these sectors should be kept in mind when making resource and planning decisions. Understanding the water-energy use in our food systems also warrants study. Every step in the system requires tapping into the water-energy nexus, such as the water needed to grow, process, and transport any of the hundreds of specialty or commodity crops in California. More than 90 percent of California's water footprint is associated with agricultural products. Meat and dairy products account for more than 40 percent of California's water footprint mostly from growing feed (Fulton et al. 2012). Dairy and livestock industries face similar energy needs during milking, cooling, feeding, watering, and cleaning animals.

Often it is difficult to get a clear picture of the true cost of energy and water in our food systems because the process is broken up categorically with water, energy, and transportation all being considered separate and unassociated with each other. To determine water and energy needs in our food, every associated cost within the food production cycle needs to be considered. Beginning with the following questions:

- How much water and energy were used in the irrigation of crops (conveyance, treatment, pumping, pressurizing)?
- How much energy was used in growing crops (e.g., tractor passes, spraying, harvesting)?
- How much water and energy were used in food harvesting and processing (e.g., cooling, washing, sorting, packaging)?
- How much water and energy were used in generating crop inputs (e.g., fertilizers, herbicides, pesticides)?
- How much energy was used in transportation (field to processing, processing to distribution, distribution to market)?
- How much water and energy were used at the market?

Most critical to this process, and where a large portion of water and energy is consumed, is with end users. The consumer will use energy and water to wash and cook food in-home. Finally, one of the most forgotten portions in this cycle is the energy and water used in waste and disposal of food. Food waste must be collected and processed for disposal. Understanding the true costs of water-energy in our food should also make us acknowledge that the wasting of food is also the wasting of all the other resources used to produce those items.

3. Information Gaps in Models, Data, and Tools for Integrated Assessment

Data and model systems can improve our understanding of the interactions between water, energy, food, and ecosystems, leading to better-informed decision making. There is limited assessment with integrated research to study complex dynamics and the connection of climate change, water, energy, and land related to agriculture (Skaggs et al. 2012; United States Department of Energy 2014).

Research is also lacking in the data collection, model system development, and integration assessment fields, making it difficult to understand the complex dynamics and interactions between water, energy, food, ecosystems, and climate change necessary for integrated water management to adapt and mitigate climate change. Application of models could help to quantify the relationships and tradeoffs among a comprehensive set of water-energy constituents. For example, two California water-energy modeling platforms are interlinked in order to quantify these tradeoffs and relationships by using the Water Evaluation and Planning (WEAP) and the Long-range Energy Alternatives Planning (LEAP) software (Stockholm Environment Institute 2012). Water and electricity elements are represented and analyzed within the WEAP-LEAP integrated model. Hydropower generation is evaluated by LEAP, while its water availability is simulated in WEAP at the same time. Thermal cooling requirements are based on electricity demand from LEAP, but the amount of water available is estimated by WEAP.

Regional data and research to assess the relative effects and risks of water use in energy production and the energy intensity of water use in California are still limited. Future research and data collection on water intensity for energy production and the energy intensity in the water cycle and end uses, based on hydrological regions of California, could support the integrated water and energy decision-making process. Using this regional data for integrated water-energy analysis and planning are critical when coordinating strategies in climate adaptation and mitigation.

Bridging information gaps and assessing the water-food-energy-ecosystem nexus related to climate change by improving data collection and developing integrated models and tools, as well as data systems, is vital. Indeed, lack of data systems and integrated models is a critical problem when quantifying the tradeoffs and linking the relationships between water, energy, food, and ecosystems related to climate change. The conceptual framework presented (Liu 2014, Liu 2016) provides the first step and open discussion toward developing integrated model applications, identifying pilot projects, and evaluating the tradeoffs and multiple benefits across sectors. Pilot projects should be identified with multiple benefits of energy and water efficiency, food production efficiency, conservation and best management of water, energy, and food as well as watersheds and ecosystems for integrated water management.

iii. Complexity, Challenges, and Opportunities of Connecting the Dots

1. Complexity and Challenges in Connecting Water, Energy, Food, and Ecosystems in a Changing Climate

Research evaluating the water-energy impacts from the food production cycle is still in an early stage. Case study has evaluated the technical potential to recover and conserve hot water resources, achieve energy conservation, and recover excess heat from the research conducted by the California Institute of Food and Agricultural Research (CIFAR) at the University of California, Davis. This research provided evidence about the potential to achieve hot water and energy conservation for environmental sustainability benefits at a tomato processing facility by reducing energy intensity and conserving water resources. For example, a water-energy nexus assessment has identified opportunities for improvements in energy efficiency, operational efficiency, and sustainability opportunities for combined heat and power, as well as hot water conservation. Related benefits also include reduced energy costs, conserved groundwater resources, and reduced GHG emissions and wastewater discharge (Amónet al. 2013). Older facilities, however, face significant challenges getting an economic return on investment. Long-term physical capital sustainability investment to upgrade older facilities can cost much more than the return on the investment. For California-based companies and businesses, there are challenges as well as opportunities for innovation and investment when adopting industrial best management practices to further reduce GHG emissions. These opportunities will be especially important to companies required by AB 32 to participate in the California Air Resources Board (CARB) Cap and Trade program.

The agricultural sector plays an important role in reducing greenhouse gas (GHG) emissions through reduced energy use, modified agricultural practices, and carbon sequestration associated with crop and grassland management. Conservation practices include utilizing renewable resources with lower non-renewable inputs of fuel, water, and/or synthetic nitrogen fertilizer, as well as implementing drip irrigation, conservation tillage, and certified organic production. However, it is uncertain how farmers may change future practices, what may influence these decisions, and what are the new roles for urban and organic agriculture in future food production.

There are enormous challenges in vulnerability and complexity for water, energy, and food related to ecosystem health and climate change. For example, the Sacramento-San Joaquin Delta (Delta) is a complex ecosystem that not only supports over 700 species of fish and wildlife, but is also used to convey water from Northern California to Southern California, which consumes large amounts of energy. In addition, Delta agricultural land is used for food production. The coequal goals of the Delta Reform Act recognize critical problems in ecosystem function and water supply reliability from a complexity of natural and human-made systems in the Delta. A multitude of stressors threaten our ability to achieve the coequal goals that provide a more reliable water supply for California, and protect, restore, and enhance Delta ecosystems. Effects of these stressors include:

- Declining water supply reliability.
- Increasing risk to Delta levees.
- Increasing winter floods.
- Sinking farmland.
- Increased vulnerability to earthquakes.

- Decreased water quality.
- Increased invasive species distributions that are harming native species.

Many of these stressors produce non-linear effects on the Delta ecosystem. The Delta systems do not respond to each stressor individually, since there are dynamic interactions of species' changes and habitat quality in this complex ecosystem. In addition, it is uncertain how Delta systems will change in response to both current and future stressors related to changing climate. Policy- and decision-makers need to plan Delta management in the context of multiple complex stressors. Complex scopes of studies are required to understand dynamic interactions and effects of many stressors presented in the Delta, and their implications for ecosystem services in water, energy, and food related to ecosystem health and climate change.

2. Innovation and Technology for Multiple Benefits

There are opportunities to innovate new technologies that provide ecosystem services with multiple benefits in water, energy, food, and environmental sectors, enabling adaptation and mitigation of climate change. For example, green infrastructure can be used to manage and improve water quality to enhance ecosystem services for environmental sustainability related to climate change (Pitman et al 2015). Natural processes can be used to restore the hydrologic function of the watershed and urban landscape, manage storm water at its source, and reduce the need to add traditional water infrastructure. Reduced storm water volume may improve water quality by reducing pollutant loads, stream bank erosion, and sedimentation. Another example of green infrastructure includes Delta wetland restoration that could reduce GHG emissions, sequester carbon, rebuild subsided agricultural lands, and provide multiple benefits for ecosystem health.

The development and application of new technology can provide new opportunities to reduce water and energy intensity and their ecosystem effects in both sectors (United States Department of Energy 2014). Future integrated challenges and opportunities include the following examples:

- Water efficiency in energy systems.
- Energy efficiency in water systems.
- Productive use of nontraditional waters.
- Identifying specific economically and environmentally preferable solutions, such as:
  - Using wasted heat for desalination and combined heat and power (CHP).
  - Using water systems for energy storage or electricity demand management.

Efficiency improvements in water- and energy-intensive industrial processes offer multiple benefits in energy and biofuels production, forest products, food processing, and refining and chemical manufacturing. These efficiency improvements include the following practices:

- More efficient and less expensive options for cooling.
- Waste heat recovery in thermoelectric power plants.
- Improving water and energy efficiency in industrial processes.
- Identifying alternatives for fresh water in energy production.
- Beneficial use of water produced from oil, gas, and geothermal operations.
- Using nontraditional waters, desalination, and brackish groundwater resources.

Municipal wastewater treatment can also recover water and energy from its processes. For example, treated water from municipal wastewater treatment (WWT) facilities could be used as cooling and processing water for energy and power production, or as irrigation water for biofuel crops. This could productively re-use the water and make dual use of the energy already expended to operate the WWT facility. Similarly, developing and implementing cooling and other industrial water use technologies to use non-treated brackish or saline water could avoid the demand to use additional energy for water treatment, since the treatment of produced water and wastewater requires more energy and water. Reduced wastewater release will reduce contaminants that have adverse ecosystem effects for human health and the environment.

New technologies to grow algae biomass provide multiple benefits by using non-potable water sources, such as wastewater from agricultural runoff, municipal or industrial waste sources, produced water, brackish water, or seawater. This technology using nutrient-laden water could reduce demand on limited freshwater sources, minimize inputs of synthetic fertilizers, and create new options for algae-based treatment of produced or impaired water sources, including possibilities for carbon capture (Razzak et al. 2013). Furthermore, using leak detection to reduce water system losses could also provide multiple benefits in water and energy efficiency and GHG reduction. It is important to continue improving best management practices, tools, technologies, and techniques to reduce water and energy losses in water systems.

Increasing water demand for application of new technologies and management practices related to energy, food, and environments presents a great challenge for California. As demands increase for limited fresh water supplies in the future, the treatment and re-use of non-fresh water and the desalination of brackish or saline water is expected to grow. These processes are also relatively energy-intensive with related environmental impacts. Using new technology for carbon capture and storage needs both water to strip CO_2 from flue gas and power to process concentrated liquefied CO_2 (United States Department of Energy 2014). Geothermal technology could also use more water to produce energy, and could affect landscape environments.

To address issues of California's limited water resources, renewable energy resources with wind, solar, geothermal, biomass, and small hydroelectric production could be coupled with policy on limited use of potable water for new electricity generation. Although expanded use of wind and solar can theoretically reduce demand for water in energy production, the amount of intermittent renewable energy generation capacity that can be added to the utility grid system is ultimately limited by stability issues and back-up power requirements.

Climate change will affect the water-energy relationship including in-state hydropower, agricultural groundwater, and urban water uses in California. Climate change is likely to make surface water scarcer, particularly in agricultural food production. Meanwhile, increasing temperatures will likely boost energy demand for cooling. Increased urban water use efficiency and development of local sources are important in offsetting these trends, reducing overall energy demand. Water prices provide fundamental incentives to encourage conservation. However, rate structures should be designed for utilities to recover costs when water sales fall or when supply costs increase.

In conclusion, there are significant challenges and opportunities in California to use integrated water management for water, energy, food, and the environment related to climate change. The California Water Action Plan (California Water Action Plan 2014) and California Water Plan Update (California Department of Water Resources 2013) provide a road map and resource management strategies to use integrated water resource management for the multiple benefits of these sectors. The examples and case studies noted here have been used to identify information gaps and to address related complexity and challenges. Questions posed here on water and energy related to the food production cycle need further research and discussion. AB32 created opportunities for innovation and investments in California to adopt best management practices and to further reduce GHG emissions. Overall, we should identify opportunities for innovation and technologies with multiple benefits, evaluate and decide tradeoffs, and address integrated challenges in water, energy, food, and the environment to adapt and mitigate climate change.

PART IV. APPENDIX AND TECHNICAL INFORMATION

i. Regional Energy Intensity Appendix Link

Figure 9. **Regional Energy Intensity — Bulb Diagrams** (energy Intensity values have not been evaluated for all types of water supply due to the data limitation in each region)

North Coast Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	21%
State (Project)	*This type of water not available*	0%
Local (Project)	<250 kWh/AF	27%
Local Imports	<250 kWh/AF	1%
Groundwater	<250 kWh/AF	28%

North Lahontan Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	*This type of water not available*	0%
State (Project)	*This type of water not available*	0%
Local (Project)	<250 kWh/AF	44%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	22%

Central Coast Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)		7%
State (Project)		3%
Local (Project)	<250 kWh/AF	3%
Local Imports	*This type of water not available*	0%
Groundwater		79%

Sacramento River Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	28%
State (Project)	<250 kWh/AF	<1%
Local (Project)	<250 kWh/AF	30%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	19%

San Francisco Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)		12%
State (Project)		12%
Local (Project)	<250 kWh/AF	15%
Local Imports	*<250 kWh/AF	38%
Groundwater		19%

* Hetch Hetchy is a net energy provider

San Joaquin River Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	16%
State (Project)		<1%
Local (Project)	<250 kWh/AF	29%
Local Imports	*This type of water not available*	0%
Groundwater	<250 kWh/AF	31%

South Coast Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)		21%
Federal (Project)	<250 kWh/AF	<1%
State (Project)		27%
Local (Project)	<250 kWh/AF	4%
Local Imports	0*	5%
Groundwater		33%

* Los Angeles Aqueduct is a net energy provider

South Lahontan Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	*This type of water not available*	0%
State (Project)		14%
Local (Project)	<250 kWh/AF	7%
Local Imports	*This type of water not available*	0%
Groundwater		64%

Colorado River Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	<250 kWh/AF	79%
Federal (Project)	*This type of water not available*	0%
State (Project)		1%
Local (Project)	<250 kWh/AF	<1%
Local Imports	*This type of water not available*	0%
Groundwater		9%

Tulare Lake Energy Intensity per Acre-Foot of Water

Type of Water	Energy Intensity (= 1-250 kWh/AF = 251-500 kWh/AF)	Percent of Regional Water Supply*
Colorado (Project)	*This type of water not available*	0%
Federal (Project)	<250 kWh/AF	15%
State (Project)		8%
Local (Project)	<250 kWh/AF	16%
Local Imports	*This type of water not available*	0%
Groundwater		50%

ii. RMS Table Related to Water-Energy and GHG Mitigation

Table 2. Resource Management Strategies with Greenhouse Gas (GHG) Implications

Resource Management Strategy	Possible GHG Emission* Reductions from Strategy	Possible GHG Emission* Increases from Strategy
Reducing Water Demand		
Agricultural Water Use Efficiency: Water management practices designed to achieve net water savings or increased crop production through Water Use Efficiency methods.	Conserving water can also result in energy savings by reducing the amount of energy needed for water conveyance, treatment, and distribution.	Converting furrow irrigation to drip or sprinkler systems (pressure irrigation) could result in an increase in the amount of energy used for irrigation.
Urban Water Use Efficiency: Practices that maximize use of available water supplies by reducing water waste and increasing efficiency.	Reducing urban water use can also reduce the amount of related energy used to treat, transport, and distribute the water.	Some water use efficiency projects may increase energy use if there is a tradeoff between water and energy, thereby increasing GHG emissions.
Improving Flood Management		
Flood Management: Employing structural and nonstructural flood management measures to maximize the benefits of floodplains, minimize loss of life and damage to property from flooding, and recognize the benefits to ecosystems from periodic flooding on a watershed scale.	Nonstructural approaches to flood management can be less energy intensive. Flood plain restoration can aid in carbon sequestration to offset GHG emissions.	Structural approaches to flood management, such as construction and maintenance of infrastructure, can be very energy intensive.
Improving Operational Efficiency and Transfers		
Conveyance — Delta: A new facility would help meet the coequal goals of the Delta Plan by providing a more reliable supply of water while simultaneously maintaining sufficient bypass flows for State and federally listed species.	Restoring the ecosystem and upgrading the conveyance systems of the Delta could increase water system efficiency and carbon sequestration, and in addition, may reduce energy use and GHG emissions.	GHG emissions may result from short term construction as well as from the indirect effects of general growth and development.
Conveyance — Regional/Local: Improvement and maintenance of regional/local water conveyance systems to improve system reliability, protect water quality, increase available water supplies, and provide operational flexibility.	Upgraded and well-maintained conveyance systems can be more energy efficient, which reduces energy consumption and thus reduces the associated GHG emissions.	Construction and maintenance of new conveyance infrastructure can have short term negative effects on energy use and the associated GHG emissions.

System Reoperation: Changing existing operation and management procedures in place for water supply, conveyance facilities, and end user demands; the goal is to increase the benefits desired from the system.	Reoperating systems to maximize hydroelectric power generation would produce clean, renewable energy. Emissions associated with system reoperation would likely be significantly less than the emissions associated from constructing an entirely new infrastructure.	There may be a tradeoff between water supply and hydroelectric power generation as related to GHG emissions.
Water Transfers: Temporary or long-term change in the point of diversion, place of use, or purpose of use as a result of a transfer, sale, lease, or exchange of water or water rights.	Water transfers could reduce GHG emissions if the transfer eliminated the need to use a water source with higher-associated GHG emissions.	Conveying transferred water can be energy intensive, depending on the source and the use location; for example, fallowing a field before water transfer can reduce carbon sequestration in the plants and soil.
Conjunctive Management and Groundwater Storage: Coordinated and planned use and management of surface water and groundwater resources to maximize the availability and reliability of water supplies.	Conjunctive management of water resources could ensure that the most easily accessible water sources are being used, thus reducing the use of pumped or conveyed water, both of which have higher energy needs and are associated with GHG emissions.	Using injection wells and conveyance systems, or building and maintaining conjunctive management facilities can be energy intensive processes associated with GHG emissions.
Desalination (Brackish and Sea Water): Removal of salts from saline waters; desalinate sea water for coastal communities, and brackish groundwater for inland water users.	Energy intensity and GHG production could be reduced by increasing operational and process efficiencies, and by using sustainable energy sources and technologies in desalination facilities.	Energy intensive desalination could increase GHG emissions, depending on the energy source.
Precipitation Enhancement: Commonly called "cloud seeding," this is the artificial stimulation of clouds to produce more rainfall or snowfall than they would produce naturally.	Precipitation enhancement can reduce GHG emissions if the rain produced replaces the need for a water source with higher associated GHG emissions. This could also result in increased hydropower production.	The common dispersal method for precipitation enhancement is via aircraft, which typically have high fuel needs and associated GHG emissions.
Municipal Recycled Water: Municipal wastewater treated to a specified quality and recycled for non-potable use.	Implementing municipal water recycling could reduce the need for water sources with higher energy intensity and potentially higher associated GHG emissions. Depending on the level of treatment required for existing wastewater discharge, the additional energy needed for recycled water use may be minimal.	Treating and recycling water could use more energy and potentially increase GHG emissions, depending on the energy source being used.

Surface Storage — CALFED/State: Refers to five potential surface storage reservoirs that are being investigated for construction by the California Department of Water Resources (DWR), U.S. Bureau of Reclamation (Reclamation), and local water interests.	Additional reservoirs could produce hydro power, which can reduce GHG emissions when replacing energy sources with higher associated GHG emissions. Building water storage closer to end users can reduce the energy and associated GHG emissions needed to convey water over long distances and high elevations.	Construction of new surface storage projects could increase short term energy use and related GHG emissions. Off-stream surface storage projects could require energy to pump water into the reservoir for storage, and potentially increase GHG emissions depending on the energy source being used.
Surface Storage — Regional/Local: Refers to potential surface storage reservoirs at the regional or local scale, and the management of those reservoirs.	Surface storage and on-stream reservoirs with hydroelectric generating capacity can produce substantial quantities of renewable energy, which can reduce GHG emissions when replacing energy obtained from fossil fuels.	Construction of surface storage reservoirs could increase short term energy use and related GHG emissions. Off-stream surface storage projects could require energy to pump water into the reservoir for storage. Depending on the energy source being used, these projects can potentially increase GHG emissions.
Improving Water Quality		
Drinking Water Treatment and Distribution: Development and maintenance of public water treatment and distribution facilities to achieve reliability, quality, and safety of drinking water from raw water supplies.	Promoting opportunities to use less bottled water. Managing the water and energy efficiency of a variety of facilities will save water and energy while reducing the associated GHG emissions.	Drinking water treatment and distribution systems can have a high energy intensity, resulting in related high GHG emissions.
Groundwater/Aquifer Remediation: Removal of contaminants which negatively affect the beneficial use of groundwater.	Reliable water yield from restored groundwater basins may reduce the need for higher energy intensity imported water.	Treatment technologies used for groundwater remediation may have high energy intensities and their related GHG emissions.
Matching water quality to use: Using management strategy to recognize that not all water uses require the same water quality.	Energy benefits from GHG emissions reduction can be obtained from treating less water to a higher quality than is needed for the intended use.	Construction of water recycling infrastructure and the process of municipal wastewater treatment may increase energy use and the associated GHG emissions.
Pollution Prevention: Reducing or eliminating waste at the source by modifying production processes, promoting the use of non-toxic or less toxic substances, implementation of practices or conservation techniques that reduce generation or discharge of pollutants, and application of alternative technologies to prevent pollutants from entering the environment.	The existence of fewer pollutants could reduce the energy used for water treatment, and the need for integrated pest management. Reduced fertilizer application could lower GHG emissions from fertilizer production and the treatment of nitrates.	Changing production processes at the source, or disposing of contaminants via alternative methods, may increase energy use and the associated GHG emissions.

Salt and Salinity Management: Reduces salt loads that impact a region, and is also a key component of securing, maintaining, and recovering usable water supplies.	Protecting groundwater basins can reduce demand for higher energy water supplies or remediation. Reduced fertilizer application could lower GHG emissions from fertilizer production and the treatment of nitrates.	Salinity management, development of seawater intrusion barriers, and brackish desalination are typically energy intensive processes associated with GHG emissions.
Urban Storm water Runoff Management: Activities to manage both storm water and dry-weather runoff. Dry-weather runoff occurs when, for example, excess landscape irrigation water flows to the storm drain.	Harvesting rainwater can reduce localized flooding and increase local water supply through groundwater recharge. This decreases the demand for higher energy intensive water supplies.	Capturing, treating, and conveying run-off could use energy types associated with GHG emissions.
Practicing Resource Stewardship		
Agricultural Land Stewardship: Agricultural lands that produce public environmental benefits in conjunction with the food and fiber they have historically provided, while keeping these lands in private ownership.	Conservation tillage and improved soil health on agricultural lands can aid in carbon sequestration and increase soil water retention, resulting in reduced energy demands for irrigation and soil water content.	Intensive agricultural management may use an energy type associated with GHG emissions, depending on the energy source being used.
Ecosystem Restoration: Improve the environmental condition of modified natural landscapes and biological communities; provide ecosystem sustainability so that current and future generations can enjoy their use.	Significant expansion of wetland and riparian forest acreage could provide a large carbon sink to offset carbon emissions.	Construction activities for restoration and management may need to use types of energy associated with a short term GHG emissions.
Forest Management: Management activities on public and privately-owned forest lands to improve availability and quality of water for downstream users.	Can provide GHG reduction benefit through carbon sequestration. Other benefits, such as water quality protection and energy savings from better water quality, can also be derived.	Fuel reduction projects, such as mechanical thinning, low severity prescribed fires, and management of forest roads could initially contribute to climate change, both from the energy used and black carbon effects.
Land Use Planning and Management: Collaboration between land use planners and water managers to promote more efficient and effective land-use patterns and integrated regional water management (IRWM) practices to produce safer and more resilient communities.	More efficient and effective land use can provide many water-related benefits, including water use efficiency, water quality, and efficient use of local water supplies. These benefits typically result in reduced GHG emissions.	There may be a trade-off if the construction and maintenance of water infrastructure use fossil energy associated with releases of GHG emissions.
Recharge Area Protection: Ensuring areas suitable for recharge continue to be capable of adequate recharge rather than being covered by urban infrastructure, such as buildings and roads. Preventing pollutants from entering groundwater, which avoids expensive treatment.	In many regions of the state, ground water is less energy intensive than imported or desalinated water supplies, which could have energy-related GHG reduction benefits. Adequate ground water recharge may help reduce energy use and GHG emissions.	Protecting recharge areas may require locating new urban infrastructure in less desirable areas, potentially further from city centers, resulting in increased GHG emissions from transportation of people and services.

Sediment Management: Strategies to address excessive sediment in watersheds, including sediment material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body.	Reuse of dredged sediment for wetland and vegetated habitat restoration has the potential to sequester carbon. Reduced energy needs for dredging and sediment removal maintenance activities to reduce GHG emissions.	Removing sediment for navigation, flood control, and reservoirs is a continuous process that could result in GHG emissions from fossil fuel-powered equipment.
Watershed Management: Process of creating and implementing plans, programs, projects, and activities to restore, sustain, and enhance watershed functions.	Restoring stream channel morphology and creating habitats around stream and river corridors can increase rates of carbon sequestration. Improved watershed management for water reuse, pollution control, and other ecosystem services could reduce the energy needed for the treatment, and thus the associated GHG emissions.	Active watershed management, such as project construction, could be energy intensive and associated with GHG emissions (depending on the energy source being used).
People and Water		
Economic Incentives: Financial assistance, water pricing, and water market policies intended to influence water management. Economic incentives can influence the amount and time of water use, the volume of wastewater, and the source of the water supply.	Economic incentives can encourage water and energy use efficiency, which can result in reduced energy consumption. Incentivizing the use of fewer energy intensive water sources can reduce the associated GHG emissions.	Driving up the costs of certain water sources may encourage consumers to use other sources, such as pumping groundwater from deeper depths, with the higher energy intensities associated with GHG emissions.
Outreach and Engagement: Use of tools and practices by water agencies to facilitate contributions, by public individuals and groups, toward good water management outcomes.	Educating the public and water managers about climate change and resource management will aid in reducing GHG emissions, and encourage climate change mitigation in planning.	Outreach and education campaigns could use energy in producing materials and traveling to venues. These actions are associated with GHG emissions.
Water and Culture: Linking cultural considerations to water management. Increasing the awareness of how cultural values, uses, and practices are affected by water management, as well as how they affect water management, will help inform policies and decisions.	GHGs could be mitigated by identifying opportunities for water recycling and renewable energy, increasing understanding of cultural practices associated with GHG reduction, and providing benefits and incentives for tribal water and energy efficiency projects.	There may be trade-off between water and energy uses related to cultural values, uses, and practices.

Water-Dependent Recreation: Planning for water-dependent recreation activities in water projects, water managers play a critical role in ensuring that all Californians, today and into the future, are able to enjoy such activities.	Water-dependent recreation encourages residents to use less carbon-intensive forms of transportation, reduce the amount of stormwater runoff, increase groundwater recharge rates and stormwater filtration opportunities, filter roadway pollution, and increase carbon sequestration.	More visitors could mean that more energy is used in producing materials and traveling to recreation sites. This increase in energy used could have the potential for GHG emissions.
Other		
Other Resource Management Strategies: Variety of water management strategies that can potentially generate benefits that meet one or more water management objectives, including crop idling for water transfers, fog collection, irrigated land retirement, rain-fed agriculture, snow fences, and water-bag transport/storage technology (more information on RMS can be found in *California Water Plan Update 2013*).	Mitigation can be accomplished by replacing high-GHG emissions systems with lower-GHG emissions systems that use less water or energy, or use clean energy, or create emissions sinks.	Potential GHG impacts may be based on specific strategies; for example, crop idling for water transfers and irrigated land retirement could remove a carbon sink, especially if the land is being fallowed for agricultural conservation practices.

*Note: Increasing fossil energy use leads to increased GHG emissions.

iii. Mitigation Actions for GHG Emissions in California

Table 3. List Actions Related to Water and Energy in the State for Climate Change Mitigation

1	**State Legislation, Policies, and Related Actions**
	California's Global Warming Solutions Act of 2006 (Assembly Bill 32) mandated statewide reductions in Greenhouse Gas (GHG) emissions to 1990 levels by 2020. In 2008, the California Air Resources Board adopted the Assembly Bill (AB) 32 Climate Change Scoping Plan, which describes how California will achieve these emissions reductions in all sectors. The plan requires a comprehensive set of actions designed to reduce overall GHG emissions in California, improve the environment, reduce the state's dependence on oil, diversify energy sources, save energy, create new jobs, and improve public health. The Water Energy Team of the Governor's Climate Action Team (WETCAT) coordinates State-level water and energy planning and policy. The AB-32 scoping plan update in 2014 provided policy and additional future guidance to mitigate climate change through GHG reduction and related measures in water and energy efficiency, including guidance for the water sector. In April 2015, Governor Jerry Brown issued Executive Order B-30-15 to establish a California GHG reduction target of 40 percent below 1990 levels by 2030. The executive order also calls for State agencies to take climate change into account in their planning and investment decisions, and employ full life-cycle cost accounting to evaluate and compare infrastructure investments and alternatives. Senate Bill X7-7 (SB X7-7) of 2009 mandates the reduction of per-capita urban water-use consumption statewide by 20 percent by 2020, and requires agricultural entities to apply efficient water management practices to reduce water demand. SB 1036, an update to the water code, directs DWR to develop guidance for the voluntary reporting on the energy intensity of water supply. AB 2067 revised the demand management reporting requirements in urban water management plans to provide more flexibility in water conservation implementation, with an extended submittal date in 2016. SB 1420 requires water loss reporting in urban water management plans, the use of standardized electronic data forms for urban water management plan (UWMP) data submittal, and for DWR to develop guidelines for the voluntary reporting of water savings from codes, standards, and land and transportation planning. In April of 2015, Governor Edmund G. Brown, Jr. announced actions that will save water, increase enforcement to prevent wasteful water use, streamline the State's drought response, and invest in new technologies that will make California more drought resilient. For the first time in State history, the Governor has directed the State Water Resources Control Board to implement mandatory water reductions in cities and towns across California to reduce water usage by 25 percent. The Governor's order called on local water agencies to adjust their rate structures to implement conservation pricing, recognized as an effective way to realize water reductions and discourage water waste.

	The California Water Bond (Proposition 1), passed by voters in November 2014, and the California Natural Resources Agency released a draft schedule on February 10, 2015, detailing key milestones for the first 10 years. SB 4 created a Statewide system of regulating and permitting well stimulation activities in California, which is a comprehensive system of State regulation for hydraulic fracturing, and calls for a study to evaluate the risks associated with hydraulic fracturing in California. Senate Bill 107, expanded in 2011 under Senate Bill 2, California's Renewables Portfolio Standard (RPS), is one of the nation's most ambitious renewable energy standards. The RPS program requires investor-owned utilities, electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33 percent of total procurement by 2020. California has a wide range of options to meet the RPS. Specifically, the State is pursuing a mix of roughly 30 percent wind, 35 percent solar, 20 percent geothermal, 10 percent biomass, and 5 percent small hydroelectric.
2	**Department of Water Resources Actions**
	In 2012, DWR adopted the Greenhouse Gas Emissions Reduction Plan (GGERP) as part of its Climate Action Plan. The plan dramatically curtails DWR's GHG emissions in the coming decades, and describes how the department will reduce GHG releases linked to global warming by 50 percent below 1990 levels within the next seven years. The plan also sets the stage for an 80-percent emissions reduction by 2050. DWR's GGERP will cut annual emissions from operation of the State Water Project (SWP) by more than 1 million metric tons of GHGs by 2020, and by more than 2 million tons by 2050. These GGERP actions have been honored by The Climate Registry, the U.S. Environmental Protection Agency (EPA), the Association of Climate Change Officers, and the Center for Climate and Energy Solutions with a climate leadership award for excellence in GHG management for the GHG emissions reduction goal setting. GHG reduction actions outlined in the GGERP include: • Boosting the proportion of electricity consumed by the SWP created from renewable and high-efficiency, natural-gas-fired sources. • Exploring ways to develop renewable energy on land owned by DWR, such as installing solar panels on land adjacent to pumping plants. • Terminating a contract with the Reid Gardner coal-fired power plant in Nevada that accounts for approximately 30–50 percent of DWR's operational emissions. • Increasing the efficiency of pumps and turbines throughout the SWP system with state-of-the-art design, construction, and refurbishing. • Changing construction practices to minimize fuel consumption and landfill waste. • Participating in the Sacramento Municipal Utility District's (SMUD's) Greenergy® program, to ensure that much of DWR's office space in Sacramento is powered by renewable sources. • Buying carbon offsets from SMUD for its retail natural-gas use, which will fund projects that reduce GHG emissions. • DWR has also taken the following actions in water conservation and water use efficiency related to GHG mitigation: ○ Developed a report with methodologies for reducing urban per-capita water use

and adopted a regulation for industrial process water, as required by SB X7-7.

- Developed a methodology for calculating the urban water-use target of SB X7-7.
- Developed a regulation for agricultural water measurement and a guidebook to assist agricultural water suppliers in preparing agricultural water management plans; received and reviewed agricultural water management plans to comply with SB X7-7.
- Developed a guidebook and guidance to assist urban water suppliers in preparing urban water management plans (UWMPs), including water-energy reporting; received and reviewed UWMPs; provided a report on the progress toward achieving an urban water-use reduction of 20 percent per capita.

DWR convened a task force consisting of academic experts; urban retail water suppliers; environmental organizations; and commercial, industrial, and institutional water users to develop BMPs for the commercial, institutional, and industrial (CII) water sectors. DWR's forthcoming "CII Task Force Report to the Legislature" includes recommended BMPs and their technical and financial feasibility to support water use efficiency and water supply sustainability in CII sectors.

DWR also issued Integrated Regional Water Management (IRWM) Grant Program Guidelines that require regional planning agencies and organizations throughout the state to consider the water-energy nexus, as well as climate change, in their IRWM plans (see Chapter 28, "Economic Incentives — Loans, Grants, and Water Pricing," in Volume 3, Resource Management Strategies, of *California Water Plan Update 2013*). These plans can include water management actions that reduce energy consumption and associated GHGs by changing systems, facilities, processes, and end uses of water. Furthermore, DWR has established water and energy grant programs to assist local water and energy efficiency projects in urban water systems.

3 Some Actions from Other Agencies and Organizations

The California Public Utilities Commission (CPUC) oversees a portfolio of energy efficiency programs currently administered by the investor-owned energy utilities. The CPUC completed pilot programs for embedded energy in water to assess the potential to achieve meaningful energy efficiency savings in the water sector. Some CPUC efforts include: (1) developing a water-energy calculator for tracking IOU and water agency investments, GHG reductions, and energy efficiency; (2) analyzing whether an increase in energy efficiency portfolio emphasis on measures to maximize energy savings in the water sector, and how cost effectiveness should be evaluated for water/energy nexus programs. The CPUC has also directed energy utilities, local government partners, and others to include the water-energy nexus in energy efficiency programs.

The California Energy Commission (CEC) administered the Public Interest Energy Research Program (PIER), which has a broad mandate to research the environmental effects of energy technology, production, delivery, and use. The 2014–2015 Investment Plan Update guides the allocation of program funding for this fiscal year for Alternative and Renewable Fuel and Vehicle Technology. It also covers the sixth year of the program and reflects laws, executive orders, and policies to reduce greenhouse gas emissions, petroleum dependence, and criteria emissions.

The State Water Resources Control Board (SWRCB) has established a team to work on water-climate issues, using grant and loan funds to support sustainable infrastructure. The State Water Quality Control Board's legal actions update related to drought and water use, and includes an emergency regulation to increase conservation practices for all Californians. The new conservation regulation targets outdoor urban water use. This regulation establishes the minimum level of activity that residents, businesses, and water suppliers must meet as the drought deepens, and will be in effect for 270 days unless extended or repealed.

Some actions from the California Air Resources Control Board (ARB) include: (1) developing AB-32, the scoping plan update, to reduce water-related energy consumption and increase production and use of clean, environmentally responsible energy supplies for GHG reduction. Cap-and-Trade Auction Proceeds Investment Plan has been developed for fiscal years 2013–14 through 2015–16. Projects eligible for funding include the areas in reducing GHG emissions associated with water use and supply; reducing energy used for water supply, conveyance, and treatment; water conservation, capture, and storage; water system and use efficiency (such as energy efficiency in water pumping/conveyance, and use of biogas from wastewater treatment plants to generate energy or fuels); advanced renewable energy and energy efficiency technologies, including water efficiency.

The California Department of Food and Agriculture (CDFA) programs and actions are related to agricultural water efficiency, drought resources for farmers, ranchers, and farmworkers, as well as financial assistance.

The California Independent System Operator (CAISO — a nonprofit public benefit corporation) is responsible for both managing the flow of power across California's high-voltage transmission system and operating to maintain system electric reliability. Water management strategies are important in supporting statewide electric reliability for CAISO system operation.

The EPA regional office established the California Water and Energy Program (CalWEP) to assist water and wastewater utilities in identifying and developing energy and water efficiency, as well as renewable energy projects. Water and energy audits have been conducted for many water and wastewater agencies with assistance from this program.

The Department of Energy (DOE) initiated a department-wide Water-Energy Tech Team (WETT) to achieve objectives of increasing cohesion within DOE and providing outreach to other agencies and stakeholders. These objectives have been addressed in WETT's Water-Energy nexus report highlighting the following key issues: (1) Optimize the freshwater efficiency of energy production, electricity generation, and end-use systems; (2) Optimize the energy efficiency of water management, treatment, distribution, and end-use systems; (3) Enhance the reliability and resilience of energy and water systems; (4) Increase safe and productive use of nontraditional water sources; (5) Promote responsible energy operations

	with respect to water quality, ecosystem, and seismic impacts; (6) Exploit productive synergies among water and energy systems. The U.S. Geological Survey (USGS) has reported on the Water-Energy Nexus. Studies from an Earth science perspective have indicated water availability and use are closely connected with energy development and use. This report reviews the complex ways in which water and energy are interconnected and describes the Earth science data collection and research that can help the nation address these important challenges (United States Geological Survey 2015). The California Water and Energy Coalition (CalWEC) was established by local water agencies and energy utilities to develop collaborative approaches for providing a sustainable and cost-effective supply of water and energy. Other organizations, universities, and NGOs also have their water-energy and climate change initiatives, such as the Pacific Institute; Water in the West at Stanford University; Center for the Water-Energy Efficiency at University of California, Davis; the Alliance for Water Efficiency; and the California Sustainability Alliance.

iv. Method Used to Estimate Distribution of Energy Use in the State of California

Table 4. Method Used to Estimate Distribution of Energy Use in the State of California

Distribution of energy use estimated in California	**References**
The distribution of energy use in California was estimated from *California Energy Balance Update and Decomposition Analysis for Industry and Building Sectors* (California Energy Commission 2013). About half of all energy use is derived from burning crude oil and crude oil derivatives, such as gasoline. The other half is divided between natural gas and electricity. Overlaid on top of statewide energy usage is the percentage of each type of energy expended in uses related to water. This information comes from the *2005 Integrated Energy Policy Report* (California Energy Commission 2005). A negligible quantity of crude-oil-based energy is expended in water related uses, such as diesel-driven groundwater pumps, but the quantity is so small in relation to the overall use of crude-oil-based fuels in California that it doesn't even show up on the graph. About 32 percent of natural gas use (non-power generation) is related to water, and 19 percent of electricity use is related to water. Put together, these two components equal about 12 percent of all California statewide energy usage. In 2005, the California Energy Commission also showed that over 99 percent of natural gas usage and 61 percent of electricity usage related to water were expended by end users (e.g., retail or industrial customers heating and cooling water, supplemental pressurization, advanced	*California Energy Balance Update and Decomposition Analysis for Industry and Building Sectors* (California Energy Commission 2013). 2005 Integrated Energy Policy Report (California Energy Commission 2005)

treatment for industrial use). Based on these percentages, about 10 percent of the 12 percent of statewide energy usage related to water is expended by end users. The remaining 2 percent is expended by water utilities to extract, convey, treat, distribute, collect, and dispose of water. The State Water Project, which delivers water that originates in Northern California to the Central Valley and Central and South Coast areas, expends nearly 8,000 gigawatt-hours of electricity each year to move water around, representing over 3 percent of the total electricity consumption of the state.	

v. Conceptual Framework Key Elements

Table 5. Key Elements in Conceptual Framework for Interactions of Climate Change, Water, Energy, Food, and Related Ecosystems

Ecosystems & services	Provide ecological function and ecosystem service for water, energy, food, and biomass, as well as environments; interconnect natural resources for ecological function; provide physical, chemical, and biological connections for the environment, including climate and hydrology.
Climate change	1. Changing climate affects ecosystems and related services for water, energy, and food security; long-term global warming affects physical, chemical, and biological environments with significant impacts on ecosystems and related services for water, energy, food, biomass, and fish and wildlife. 2. Ecosystem services affect changing climate (e.g., increase or reduce GHG from water, energy, and food uses and productions).
Water and Energy	1. Water: Hydrology, snow pack, precipitation, surface and ground water. a. Water in energy (water used for energy production, including cooling, extraction of fuels, hydropower, biofuels, and renewable). 2. Energy: Electricity, gas and oil fuels, bio-fuels, renewable. a. Energy in water (energy used for water-pumping, desalination, conveyance, distribution and treatment, as well as urban and agricultural end water use).
Water and food	Food: Agricultural, fishery, and industry production of food, including crops, fish, livestock, poultry, dairy, and industry food products; agricultural and forestry for biomass. 1. Water in food and biomass (water used for food and biomass production). 2. Food and biomass in water (water quality effects from food waste, fertilizers, herbicides, and pesticides from agricultural runoff).

Food and energy	1. Food in energy for biofuels production. 2. Energy in food: Energy used for food and biomass production, including energy for water pumping, fertilizers, herbicides, pesticides, food supply chain, food transport and process.

PART V. REFERENCES

AB32 Climate Change Scoping Plan 2014. http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf.

Amón R, Maulhardt M., Wong T, Kazama D, 2013. *Industrial Water Energy Nexus Assessment, Campbell Soup California Tomato Processing Facility, University of California Davis*. Viewed online at: http://www.cifar.ucdavis.edu/projects/media/Campbell_Soup_Water_Energy_Nexus_Assessment_final1.pdf.

Australian Renewable Energy Agency 2014, https://arena.gov.au/projects/.

Barnosky AD, Brown JH, Daily GC, Dirzo R, Ehrlich AH, Ehrlich PR, Eronen JT, Fortelius M, Hadly EA, Leopold EB, Mooney HA, Myers JP, Naylor RL, Palumbi S, Stenseth NC, Wake MH. 2013. *Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century*.

California Department of Water Resources. 2015. California climate science and data for water resources management. Viewed online at: http://www.water.ca.gov/climatechange/docs/CA_Climate_Science_and_Data_Final_Release_June_2015.pdf.

California Water Action Plan 2014. Viewed online at: http://resources.ca.gov/docs/california_water_action_plan/Final_California_Water_Action_Plan.pdf.

California Department of Water Resources. 2013. *California Water Plan Update*. Viewed online at: http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm.

California Department of Water Resources. 2013. *California Water Plan Update*. Regional Report, Volume 2. Viewed online at: http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm.

California Energy Commission. 2012. Our Changing Climate- Vulnerability & Adaptation to the Increasing Risks from Climate Change in California. Viewed online at: http://www.energy.ca.gov/2012publications/CEC-500-2012-007/CEC-500-2012-007.pdf.

California Energy Commission. 2005. Integrated Energy Policy Report.

California Energy Commission. 2013. *California Energy Balance Update and Decomposition Analysis for Industry and Building Sectors.* (2008 year data) Table 6 and Figure 1.

California Public Utilities Commission. 2010. *Embedded Energy in Water Studies. Study 1: Statewide and Regional Water-Energy Relationship*.

California Public Utilities Commission. 2010. *Embedded Energy in Water Studies. Study 2: Water Agency and Function Component Study and Embedded Energy-Water Load Profiles*.

California Public Utilities Commission. 2011. *Embedded Energy in Water Studies. Study 3: End-Use Water Demand Profiles.*

Cooley H and Heberger M. 2013. *Key Issues for Seawater, Desalination in California: Energy and Greenhouse Gas Emissions*. 37 pp. Oakland (CA). Pacific Institute.

Cooley H, Wilkinson R. 2012. *Implication of Future Water Supply Sources for Energy Demands*. 82 pp. Alexandria (VA). WateReuse Research Foundation.

Cooley H, Heberger M, Allen L, Wilkinson, R. 2012. *Water-Energy simulator (WESim) User Manual*.

Cooley H, Fulton J, Gleick PH. 2011. Water for Energy: Future Water Needs for Electricity in the Intermountain West. http://pacinst.org/app/uploads/2013/02/water_for_energy3.pdf.

Elimelech M, Phillip WA. 2011. "The Future of Seawater, Desalination: Energy, Technology, and the Environment." *Science* **333**, 712 (2011).

Fulton J, Cooley H, Gleick PH. 2014, Water Footprint Outcomes and Policy Relevance Change with Scale Considered: Evidence from California. Springer Science and Business Media Dordrecht. Viewed online at: http://pacinst.org/publication/water-footprint-outcomes-and-policy-relevance-change-with-scale-considered-evidence-from-california/.

Fulton J, Cooley H, Gleick PH. 2012. *California's Water Footprint*. Nancy Ross and Paula Luu, editors. Pacific Institute. http://pacinst.org/app/uploads/2013/02/ca_ftprint_full_report3.pdf.

Fulton J, Cooley H. 2015 "The Water Footprint of California's Energy System, 1990-2012." Environmental Science & Technology, February 26, 2015.

GEI Consultants/Navigant Consulting, Inc. 2010. *Embedded Energy in Water Studies, Study 1: Statewide and Regional Water-Energy Relationship*. Prepared for California Public Utilities Commission, Energy Division.

IPCC (2014) Synthesis Report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Pachauri RK and Meyer LA, editors. IPCC, Geneva, Switzerland, 151 pp.

Jablonski LM, Klemow K, Puttick G. 2015. *Achieving Energy and Ecological Literacies for All: Linking Ecology and Energy Education*. Perspectives from Sessions at Ecological Society of America (ESA) 2014 Annual Meeting. Journal of Sustainability Education Vol 8.

Jansson NK, Levin S, Lubchenco J, Mäler KG, Simpson D, Starrett D, Tilman D,Walker B (2000). "The value of nature and the nature of value." Science 289(5478):395–396

Kenney DS, Wilkinson R, Eds. 2011. *The Water-Energy Nexus in the American West*. Northampton, MA.

Klein G. 2005. *California's Water-Energy Relationship: Final Staff Report*. Report No. CEC-700-2005-011-SF. California Energy Commission.

Liu Q. 2014. Connecting the Dots Between Energy, Water, Food, Ecosystems, and Climate Change. Ecological Society of America Annual Meeting. Abstract viewed online at: http://eco.confex.com/eco/2014/webprogram/Paper46698.html.

Liu Q. 2016 WEF Nexus Cases from California with Climate Change Implication, In press for publication. in Water-Energy-Food Nexus: Theories and Practices (Salam et al. Eds.), AGU Books, ScholarOne, Wiley-Blackwell.

Liu Q. 2016. Interlinking Climate Change with Water-Energy-Food Nexus and Related Ecosystem Processes in California Case Studies. Ecological Processes, 5(1), 1-14.

Pitman SD, Daniels CB, Ely ME. 2015. "Green infrastructure as life support: urban nature and climate change." Transactions of the Royal Society of South Australia. 139: 97-112.

Razzak SA, Hossain MM, Lucky RA, Bassi AS, de Lasa H. 2013. "Integrated CO_2 capture, wastewater treatment and biofuel production by microalgae culturing—A review." Renewable and Sustainable Energy Reviews, 27, 622–653. Viewed online at: http://doi.org/10.1016/j.rser.2013.05.063.

Rheinheimer DR, Ligare ST, and Viers JH (Center for Watershed Sciences, University of California, Davis). 2012. Water-Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Simulating the Regulated Rivers of California's West Slope Sierra Nevada. California Energy Commission. Publication number: CEC-500-2012-016.

Skaggs R, Janetos TC, Hibbard KA, Rice JS. 2012. *Climate and Energy-Water-Land System Interactions, Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment*.

State of California Natural Resources Agency- Department of Water Resources, 2015. California's Groundwater Update 2013- A Compilation of Enhanced Content for California Water Plan Update 2013.

Stockholm Environment Institute. 2012. Software. Viewed online at: http://www.sei-us.org/weap.

Teter J, Tiedeman K, Mishra GS, and Yeh S. 2014. UC report.

The Third Assessment of California Climate Change Report. 2012.

United States Department of Energy. 2014. *The Water-Energy Nexus: Challenges and Opportunities*.

United States Geological Survey. 2014. *Estimated Use of Water in the United States in 2010*. Viewed online at: http://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf.

United States Geological Survey Report on Water-Energy Nexus. Healy RW, Alley WM, Engle MA, McMahon PB, and Bales JD. 2015. "The water-energy nexus — An earth science perspective." U.S. Geological Survey Circular 1407. 107 p. Digital object identifier: http://dx.doi.org/10.3133/cir1407. Viewed online at: http://pubs.usgs.gov/circ/1407/.

WateReuse Desalination Committee. 2011. *Seawater Desalination Power Consumption*. Alexandria (VA). WateReuse Association. 16 pp.

Wilkinson R. 2000. *Methodology for Analysis of Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integral Water-Energy Efficiency Measures*. Berkeley (CA). Ernest Orlando Lawrence Berkeley Laboratories, California Institute for Energy Efficiency. 90 pp.

Williams JW, Jackson ST, Kutzbach JE. 2007. "Projected distributions of novel and disappearing climates by 2100 AD." Proceedings of the National Academy of Sciences 104, 5738-5742.

World Economic Forum. 2011. *Water Security: The Water–Food–Energy– Climate Nexus*. World Economic Forum, Washington, DC.