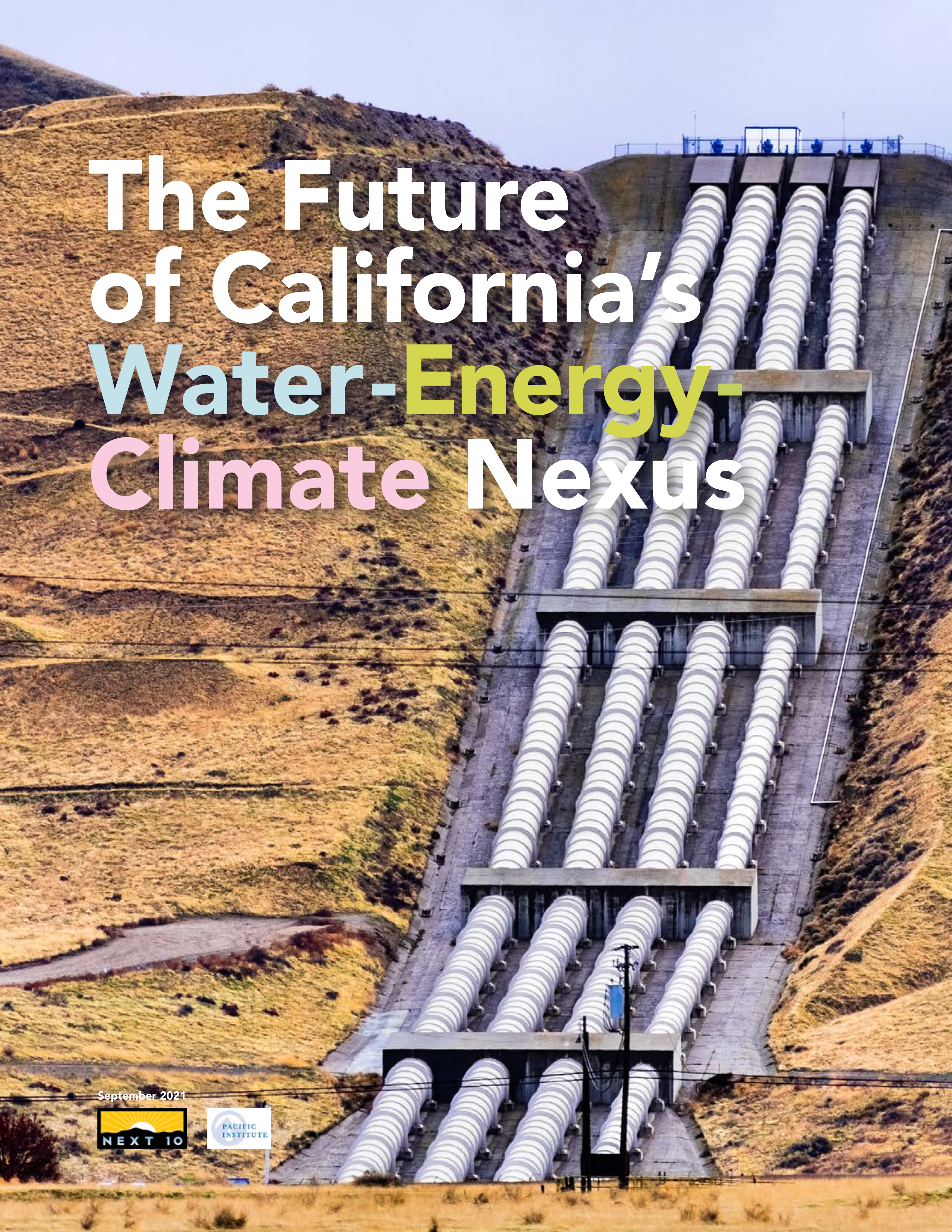
The Future of California's Water-Energy-Climate Nexus



September 2021

NEXT 10

PACIFIC INSTITUTE

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Acknowledgements:

The report authors would like to thank all those who provided their time, data, and suggestions, including staff at the California Department of Water Resources and the East Bay Municipal Water District and Darcy Bostic of the Pacific Institute. The authors would also like to thank all those who offered external reviews and comments on the report, including Dr. Bob Wilkinson (University of California at Santa Barbara), Dr. Jennifer Stokes-Draut (Lawrence Berkeley National Laboratory and University of California at Berkeley), and Dr. Kelly Sanders (University of Southern California). Finally, the authors would like to thank Next 10 for generously supporting this work. All conclusions and recommendations expressed in this report and any errors are those of the authors.

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1. EXECUTIVE SUMMARY

Water and energy are inextricably linked in California and, as one resource faces constraints or challenges, so does the other. With the state looking to both reach its climate change goals and decarbonize its economy through a transition to 100 percent clean energy, water will play an integral role. Water is a key input for energy production, and energy is integral to all aspects of water management and use in California—including collection, treatment, heating, and wastewater management. Prior studies have estimated that about 20 percent of California's total statewide electricity use, a third of non-power plant natural gas consumption, and 88 billion gallons of diesel consumption are related to water—from collection and treatment to use and wastewater management—with a large share associated with heating water. These interdependencies between water and energy supplies are commonly referred to as the water-energy nexus.

TABLE E.S.1 Estimated Urban Water-Related Energy and Greenhouse Gas (GHG) Impacts, 2015-2035

Change from 2015-2035	**Declining Per-Capita Demand Scenario (Low-Case)**	**2015 Constant Per-Capita Demand Scenario (Mid-Case)**	**Water Supplier Projections Scenario (High-Case)**
Urban Water Demand	-17%	+24%	+44%
Water-Related Electricity Use	-19%	+21%	+40%
Water-Related Natural Gas Use	-16%	+25%	+45%
GHG Emissions From Urban Water-Related Energy Use	-41%	-12%	+2%

Many factors affect California's water demand and supply portfolio, and the implications of multiple, ongoing changes to the state's water resources on future energy use are not well understood. California has experienced a dramatic decoupling between water use and growth over the last 40 years. Total urban demand has declined, particularly since 2005, despite continued population and economic growth due to end-use efficiency improvements and less water-intensive commercial and industrial activities. At the same time, urban water suppliers are pursuing local water supply options, many of which are more energy-intensive than traditional water sources but still less energy-intensive than imported water. Agricultural water use has remained relatively flat since the 1980s despite a significant increase in the economic value of crop production. Agriculture, however, is particularly dependent on unsustainable groundwater extraction, and pumping has become increasingly energy-intensive as groundwater levels have fallen around the state. Climate change, with impacts on water availability, quality, and demand, may accelerate these trends.

Water and energy trends in California also affect greenhouse gas (GHG) emissions for the state. In California, electricity generation—the main energy source for the provision and treatment of water—is undergoing structural reform to decarbonize and reduce its GHG intensity. There are also state programs and policies to incentivize switching to electric water heating, which is the most energy-intensive end-use of water and is still largely done using natural gas water heaters. While these policies and incentives help limit the energy- and carbon-intensity of the state's water sector, as droughts worsened by climate change continue to place constraints on both water supply and quality—both the energy- and carbon-intensity related to water are in danger of increasing. These complex interactions between changing water supply and demand trends, grid decarbonization, and electrification of water heaters will affect California's water-related GHG emissions.

In this analysis, the report authors evaluated the combined impact of emerging trends on California's water (including population growth, climate change, and policies to promote water efficiency and alternative water supplies) and electricity (including generation decarbonization) on the state's water-related energy and GHG footprints from 2015 to 2035. The latest available (2015) water demand and supply data from water suppliers and state water agencies were used to develop various scenarios of future water resources and to estimate associated energy and GHG emissions out to 2035. Key findings from the study, summarized in Tables ES.1 and ES.2, include:

Urban Findings:

- **If urban per-capita water demand is maintained at current (2015) levels, statewide urban water demand would increase 24 percent (1.3 million acre-feet, or MAF) between 2015 and 2035 with population growth.** This "mid-case" scenario would result in a 21 percent increase in annual water-related electricity use (from about 30,000 GWh to 36,000 GWh) and a 25 percent increase in annual natural gas use for water heating (from about 150,000,000 to 190,000,000 MMBtu).
- **If per-capita water demand increases to levels consistent with urban water suppliers' projections (a "high-case" scenario), urban water demand would increase by 44 percent (2.4 MAF) between 2015 and 2035,**

TABLE E.S.2 Estimated Central Valley Agricultural Water-Related Energy and Greenhouse Gas (GHG) Impacts, 2015-2035

Change from 2015-2035	Low Ag Water Use Scenario	Mid Ag Water Use Scenario	High Ag Water Use Scenario
Agricultural Water Supply Delivered	-3%	-2%	-5%
Water-Related Electricity Use	-5%	-4%	-6%
GHG Emissions From Agricultural Water-Related Energy Use	-62%	-62%	-62%

resulting in a 40 percent and 45 percent increase in related electricity and natural gas use, respectively. As the state replaces fossil fuel generators with more renewable resources, the GHG intensity (greenhouse gases emitted per unit of energy produced) of California's electricity is expected to decline, and consequently GHG emissions associated with urban water-related energy use (electricity and natural gas) are projected to decrease about 12 percent in the mid-case scenario. However, in the high-case scenario, GHG emissions increase two percent because growing natural gas use offsets some of the impact of decarbonization in the electricity sector.

- **The authors found that more comprehensive water conservation and efficiency efforts in urban California could reduce water-related electricity usage by 19 percent, natural gas use by 16 percent, and GHG emissions by 41 percent cumulatively between 2015 and 2035.** Because indoor residential water use is the most energy-intensive subsector (driven by high energy requirements for end-use, treatment, and wastewater treatment), water conservation and efficiency improvements for this subsector could dramatically decrease the energy use and GHG emissions that would result from the mid- and high-case scenarios.
- **While the total annual electricity use related to urban water use increases in the mid-case scenario, the average energy intensity of water—the total electricity used per unit of water used—decreases by two percent between 2015 and 2035.** This decrease is driven in part by a shift away from energy-intensive imported water toward alternative local water sources, including brackish desalination (+7,000% increase in supply between 2015 and 2035 from the current low levels), potable recycled water (+300% increase in supply between 2015 and 2035), and captured stormwater (+19,000% in supply between 2015 and 2035). The shares of these alternative sources among the statewide urban water supply portfolio remain relatively small in this scenario but have important implications for total energy use because they are less energy-intensive than imported water in most regions of California, especially in Southern California.

Agricultural Findings:

- **Central Valley agricultural water use under the mid-case scenario is projected to decline by two percent, or 0.3 MAF, between 2015 (23.4 MAF) and 2035 (23 MAF).** This decline is driven by the state's projection that urban population growth will encroach on agricultural lands. Under this scenario, the associated electricity use decreases four percent (from 14,200 to 13,600 GWh), and GHG emissions decrease about 60 percent.[1] The proportionally larger reduction in electricity usage compared to water use is due to expected reductions in supply from relatively energy-intensive water sources, such as imported water. Likewise, the proportionally larger reduction in GHG emissions is due to statewide efforts to decarbonize its electricity generation. Climate change is assumed to have minimal impacts on agricultural water use by 2035 across all of the scenarios; however, changes in temperature, precipitation, and evapotranspiration are likely to have a much larger effect on both supply availability and irrigation demand toward the end of century.

[1] These GHG emissions are entirely from electricity because natural gas agricultural use was not calculated.

- **There are also large uncertainties in the future energy use of Central Valley agriculture because of its dependence on groundwater, which the state has mandated through the Sustainable Groundwater Management Act (SGMA) to reach sustainable levels by 2040.** If pumping volumes are maintained at current levels and groundwater depths drop to the proposed minimum thresholds (levels of groundwater beyond which any reduction would cause undesirable effects in the basin), the authors estimate agricultural water system energy intensity would increase by 20 percent and six percent for the San Joaquin and Tulare regions, respectively. This would increase overall energy use for agricultural water in the San Joaquin and Tulare regions by about 16 percent by 2035. Permitting groundwater levels to rise can reduce the magnitude of the increase, as can improvements in pump efficiency. Likewise, shifting the timing of energy usage to coincide with times of renewable electricity generation could reduce the impact on GHG emissions.

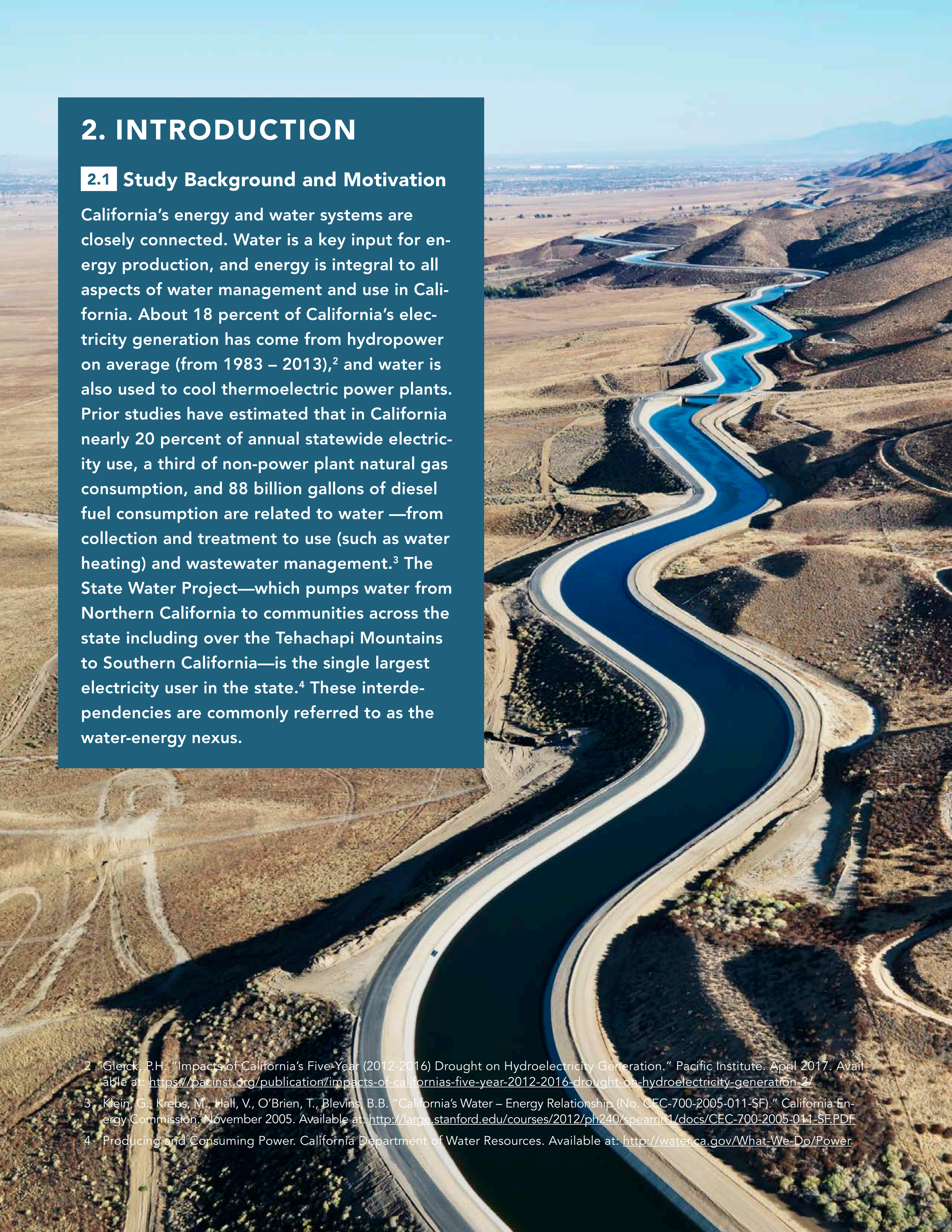
Cross-Cutting Findings:

- **Overall, urban water efficiency improvements have the largest beneficial effect on California's water-related energy use and GHG emissions because urban water is much more energy-intensive than agricultural water.** Even though Central Valley agricultural water use is projected to be almost three times that of the urban sector by 2035, agriculture's water-related electricity usage is about half, primarily because irrigation is less energy-intensive than water treatment and heating for urban end-uses. In the mid-case, the energy intensity and total GHG emissions related to urban water statewide are about 9 times that of Central Valley's agricultural water (5,400 kWh/AF and 14 million tons CO2 for urban water, compared to 600 kWh/AF and 1.4 million tons CO2 for agricultural water by 2035). GHG emissions from other aspects of the agricultural sector are not included in this assessment.
- **Water-related GHG emissions are driven by the pace of California's electricity decarbonization and end-use electrification.** The increasing share of renewables in the generation portfolio is estimated to effectively minimize the electricity component of these GHG emissions. Natural gas usage, mostly for heating water in residential and non-residential settings, is projected in the mid- and high-case scenarios to rise, which could cause GHG emissions from urban water use to increase overall. Therefore, there is an opportunity for water-energy partnerships to promote the electrification of water-end uses (water heaters) to reduce the state's GHG footprint.

Policy Recommendations:

The report authors identify specific water policies that could play an important role in helping the state meet energy and GHG goals:

- Expand urban water conservation and efficiency efforts;
- Accelerate water heater electrification;
- Maintain groundwater levels and expand flexible, high-efficiency groundwater pumps;
- Provide financial incentives and regulatory pathways for water suppliers to invest in less energy- and GHG-intensive water systems, including through existing financial incentives and programs for energy efficiency and GHG reduction;
- Expand and standardize water data reporting and energy usage tracking; and
- Formalize coordination between water and energy regulatory agencies about forecasted energy demand changes.



2. INTRODUCTION

2.1 Study Background and Motivation

California's energy and water systems are closely connected. Water is a key input for energy production, and energy is integral to all aspects of water management and use in California. About 18 percent of California's electricity generation has come from hydropower on average (from 1983 – 2013),[2] and water is also used to cool thermoelectric power plants. Prior studies have estimated that in California nearly 20 percent of annual statewide electricity use, a third of non-power plant natural gas consumption, and 88 billion gallons of diesel fuel consumption are related to water —from collection and treatment to use (such as water heating) and wastewater management.[3] The State Water Project—which pumps water from Northern California to communities across the state including over the Tehachapi Mountains to Southern California—is the single largest electricity user in the state.[4] These interdependencies are commonly referred to as the water-energy nexus.

[2] Gleick, P.H. "Impacts of California's Five-Year (2012-2016) Drought on Hydroelectricity Generation." Pacific Institute. April 2017. Available at: https://pacinst.org/publication/impacts-of-californias-five-year-2012-2016-drought-on-hydroelectricity-generation-2/

[3] Klein, G., Krebs, M., Hall, V., O'Brien, T., Blevins, B.B. "California's Water – Energy Relationship (No. CEC-700-2005-011-SF)." California Energy Commission. November 2005. Available at: http://large.stanford.edu/courses/2012/ph240/spearrin1/docs/CEC-700-2005-011-SF.PDF

[4] Producing and Consuming Power. California Department of Water Resources. Available at: http://water.ca.gov/What-We-Do/Power

Many factors affect California's water demand and supply portfolio, and the implications of multiple, ongoing changes to the state's water resources on future energy use are not well understood. California's urban water demand has been declining significantly with time, decoupling water use from population growth and economic output in the state.[5] At the same time, ongoing water-scarcity concerns and continued population growth are prompting water planners to pursue alternative, local water-supply options,[6] many of which are more energy-intensive than traditional water sources, but still less energy-intensive than imported water.[7] Similarly, declining water quality and new contaminants are leading water suppliers to adopt more energy-intensive treatment options like UV purification, ozonation, and reverse osmosis. In the agricultural sector, water use has stayed relatively flat since the 1980s while the economic value of crop production has increased significantly.[8] However, groundwater pumping, heavily relied on by the agricultural sector, is increasingly energy-intensive as groundwater levels fall in many parts of the state.[9] Climate change, with impacts on water availability, quality, and demand, is likely to accelerate these trends.[10]

Water and energy trends in California also affect greenhouse gas (GHG) emissions for the state. Shifts in water supplies and demands affect energy usage related to water and the GHG emissions associated with that energy usage. In California, electricity generation, the main energy source for the provision and treatment of water, is undergoing structural reform to decarbonize. The state has committed to reach 100 percent carbon-free electricity by 2045, including intermediate requirements of 50 percent renewable generation by 2026 and 60 percent renewable generation by 2030.[11] However, water heating is the most energy-intensive end-use of water and is still largely done using natural gas water heaters. Therefore, energy programs in the state have begun to provide incentives for switching natural gas water heaters to more efficient and less GHG-intensive electric heat pump water heaters.[12] These complex interactions between changing water supply and demand trends, grid decarbonization, and electrification of water heaters will affect California's water-related GHG emissions.

There are several options for reducing the energy and GHG footprint related to California's water. These include reducing water demand, adopting water sources with low energy requirements, and using renewable energy sources. For example, the East Bay Municipal Utility District's (EBMUD) wastewater treatment plant produces more renewable energy onsite than is needed to run the facility, selling excess energy back to the electrical grid. Some local water-supply strategies, such as Los Angeles' plans to source an increased share of water supplies from recycled water, are energy-intensive, but may offset even more energy-intensive imported water supplies. In the agricultural sector, there is an opportunity for energy savings with higher efficiency groundwater pumps, especially in Central Valley regions where the energy intensity of groundwater pumping may increase from current levels, at the proposed minimum thresholds allowed by the 2014 Sustainable Groundwater Management Act (levels of groundwater beyond which any reduction would cause undesirable effects in the basin).[13]

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[5] Cooley, H. "Urban and Agricultural Water Use in California, 1960-2015." Pacific Institute. June 2020. Available at: https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf

[6] Luthy, R.G., Wolfand, J.M., Bradshaw, J.L. "Urban Water Revolution: Sustainable Water Futures for California Cities." J. Environ. Eng. 146, 04020065. May 2020. Available at: https://doi.org/10.1061/(ASCE)EE.1943-7870.0001715

[7] Stokes-Draut, J., Taptich, M., Kavvada, O., Horvath, A. "Evaluating the electricity intensity of evolving water supply mixes: the case of California's water network." Environ. Res. Lett. 12, 114005. October 2017. Available at: https://doi.org/10.1088/1748-9326/aa8c86

[8] Cooley, H. "Urban and Agricultural Water Use in California, 1960-2015." Pacific Institute. June 2020. Available at: https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf

[9] Moran, T., Choy, J., Sanchez, C. "The Hidden Costs of Groundwater Overdraft." Water in the West | Stanford Woods Institute for the Environment. December 2014. Available at: http://waterinthewest.stanford.edu/groundwater/

[10] Anderson, J., Chung, F., Anderson, M. et al. Progress on incorporating climate change into management of California's water resources. Climatic Change 87, 91–108. March 2008. Available at: https://doi.org/10.1007/s10584-007-9353-1

[11] De Leon, K., Skinner, N. SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases. Chaptered September 2018. Available at: https://leginfo.legislature.ca.gov/faces/billHistoryClient.xhtml?bill_id=201720180SB100

[12] Gerdes, J. "California Moves to Tackle Another Big Emissions Source: Fossil Fuel Use in Buildings." Greentech Media. February 4, 2020. Available at: https://www.greentechmedia.com/articles/read/california-moves-to-tackle-another-big-emissions-source-fossil-fuel-use-in-buildings

[13] Sustainable Groundwater Management Act (SGMA). California Department of Water Resources. Available at: https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management

2.2 Scope of This Study

There is a need to update prior estimates of the water-related energy and GHG footprint of the urban and agricultural sectors in California given the complex set of trends likely to affect water and energy systems in the coming decades. This study builds on previous studies to address this need.[14,15,16,17,18,19]

First, report authors developed a comprehensive assessment of the energy and GHG footprint related to water in California. Statewide and regional trends in water supply and demand for the urban and agricultural sectors were examined, and associated energy use and GHG emissions under various future water scenarios were calculated.

Second, case studies were developed highlighting risks and opportunities associated with water-related energy use and GHG emissions, such as the adoption of biogas recovery and other renewable energy strategies implemented at EBMUD's wastewater treatment facility.

Third, a set of policy recommendations for reducing California's water-related GHG and energy footprint are offered. These policy recommendations are drawn from the scenario analysis as well as the case studies in the report.

Section 3 of this report outlines the energy, GHG, and water data and analysis methodology. Section 4 presents results of the energy and GHG emissions associated with California's urban and agricultural water. Section 5 provides three case studies highlighting examples of technical and policy innovations related to California's water-energy-GHG nexus, and Sections 6 and 7 provide conclusions and recommendations.

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[14] GEI Consultants/Navigant Consulting. "Embedded Energy in Water Studies Study 1: Statewide and Regional Water-Energy Relationship." Prepared for California Public Utilities Commission. August 2010. Available at: https://waterenergyinnovations.com/wp-content/uploads/2020/03/Embedded-Energy-in-Water-Studies-Study-1-FINAL.pdf

[15] GEI Consultants/Navigant Consulting. "Embedded Energy in Water Studies Study 2: Water Agency and Function Component Study and Embedded Energy-Water Load Profiles." Prepared for California Public Utilities Commission. August 2010. Available at: https://waterenergyinnovations.com/wp-content/uploads/2020/03/Embedded-Energy-in-Water-Studies-Study-2-FINAL.pdf

[16] Klein, G., Krebs, M., Hall, V., O'Brien, T., Blevins, B.B. "California's Water – Energy Relationship (No. CEC-700-2005-011-SF)." California Energy Commission. November 2005. Available at: http://large.stanford.edu/courses/2012/ph240/spearrin1/docs/CEC-700-2005-011-SF.PDF

[17] Porse, E., Mika, K.B., Escriva-Bou, A., Fournier, E.D., Sanders, K.T., Spang, E., Stokes-Draut, J., Federico, F., Gold, M., Pincetl, S. "Energy use for urban water management by utilities and households in Los Angeles." Environ. Res. Commun. 2, 015003. January 10, 2020. Available at: https://doi.org/10.1088/2515-7620/ab5e20

[18] Tidwell, V.C., Moreland, B., Zemlick, K. "Geographic Footprint of Electricity Use for Water Services in the Western U.S." Environ. Sci. Technol. 48, 8897–8904. June 25, 2014. Available at: https://doi.org/10.1021/es5016845

[19] Zohrabian, A., Sanders, K.T. "The Energy Trade-Offs of Transitioning to a Locally Sourced Water Supply Portfolio in the City of Los Angeles." Energies 13, 5589. October 2020. Available at: https://doi.org/10.3390/en13215589

3. ANALYSIS METHODOLOGY AND DATA

Energy is required for all stages of the managed water cycle, from extraction or generation to conveyance, treatment, distribution, end-use, wastewater collection, and wastewater treatment (Figure 1). The report authors' analysis of the energy and GHG emissions related to this managed water cycle is comprised of four steps: 1) identification of the energy intensities associated with each stage of this water management cycle, 2) calculation of the GHG intensity of each energy source related to water, 3) development of scenarios of future water supplies and demands for the urban and agricultural sectors, and 4) application of the energy and GHG intensities to historical water volumes and each scenario of future water volumes. Given data availability, the urban and agricultural water sectors were evaluated separately, and 2015 historical data was analyzed and utilized to project future scenarios in five-year intervals for 2020, 2025, 2030, and 2035. Each step of the analysis is described in detail in Figure 1.

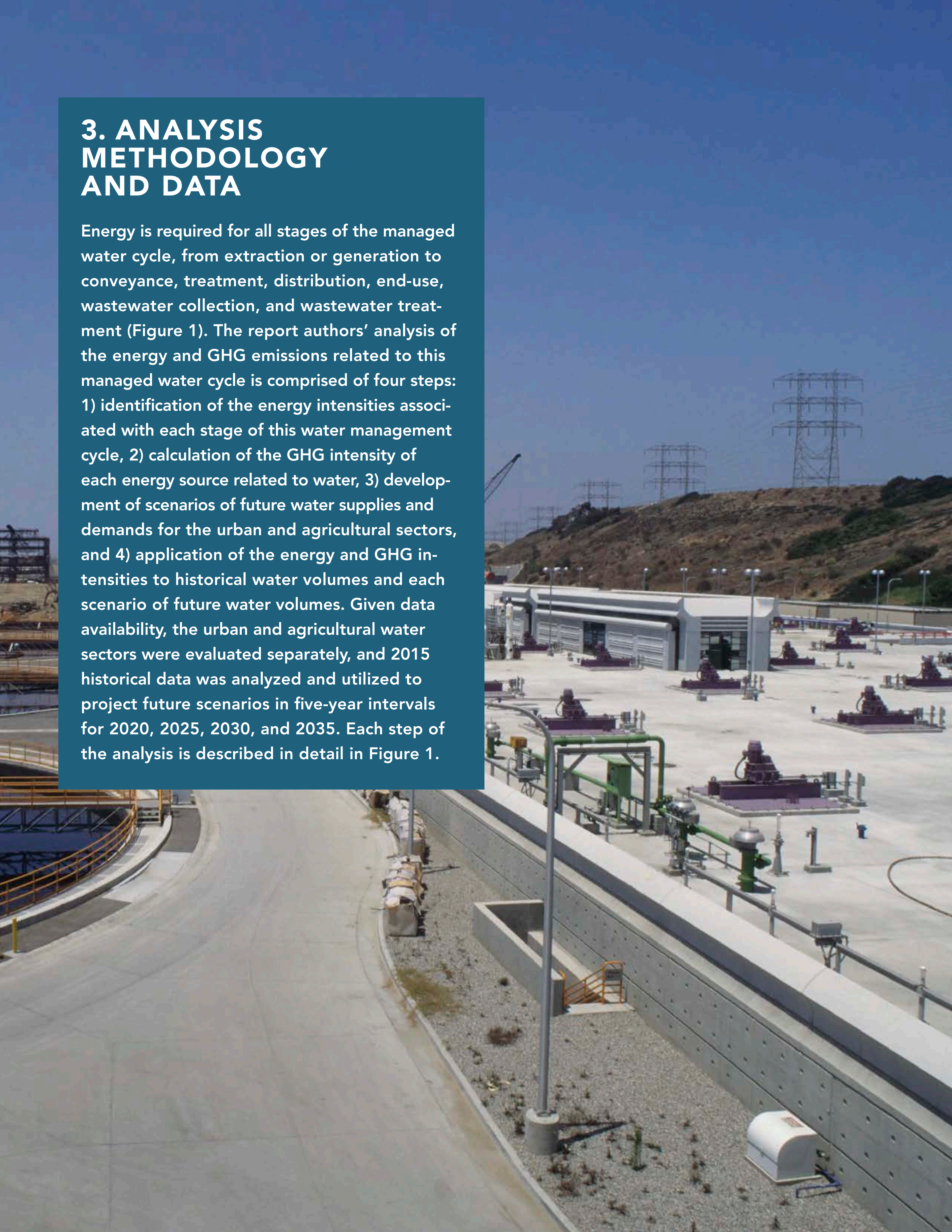
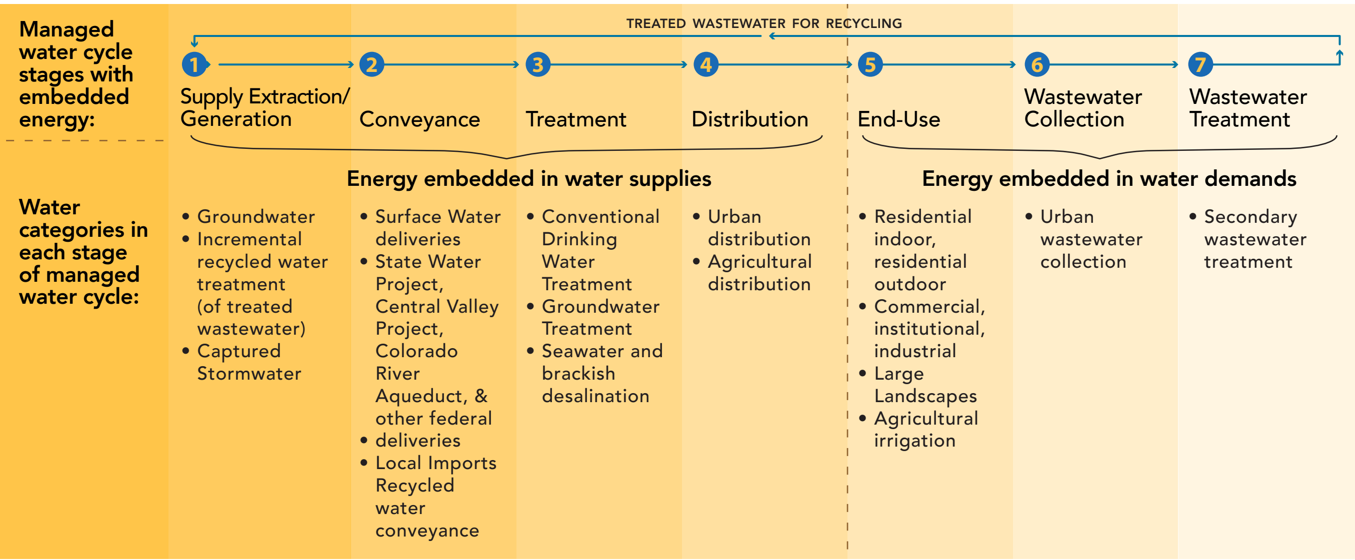


Figure 1 Stages of the Water Cycle with Embedded Energy



3.1 Energy Intensity of California's Water

Following a similar approach to Cooley et al. (2012)[20] and Diringer et al. (2019)[21] to track the total embedded energy of the managed water system (Figure 1), energy intensity values (energy use per unit volume of water in units of kWh/acre-foot (AF) for electricity and MMBtu/AF for natural gas) are assigned for the extraction, conveyance, and treatment of historical and projected water sources, and for the distribution, end-use, wastewater collection, and wastewater treatment based on end-use sector (urban and agriculture) for each of California's 10 hydrologic regions.[22] These energy intensities are summed to calculate the total embedded energy in a particular water source and water demand category and for the system as a whole. Data from Urban Water Management Plans (UWMP) and from the Department of Water Resources (DWR) were used to identify water source and demand categories for the urban and agricultural sectors, respectively (details in Section 3.3).[23]

3.1.1 Mapping Water Categories to Energy Use

First, the authors mapped the urban and agricultural water supply and demand data to the relevant stages of the managed water cycle (Figure 1), starting with categories of water sources (Table 1) and then water demands (Table 2). The water-related energy analysis focuses on electricity usage throughout each of the stages, and natural gas usage is only evaluated for water-heating—the largest natural gas user related to California water.[24] The energy intensity of recycled water, which does not fit easily in this framework, is detailed at the end of Section 3.1.1.

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[20] Cooley, Heather, et al. The Water-Energy Simulator (WESim): User Manual. WateReuse Foundation, Pacific Institute, UC Santa Barbara for California Energy Commission, 2012. Available at: https://pacinst.org/wp-content/uploads/2013/02/user_manual3.pdf.

[21] Diringer, Sarah, et al. Moving Toward a Multi-Benefit Approach for Water Management. Pacific Institute and Bren School of Environmental Science and Management, University of California, Santa Barbara, Apr. 2019. Available at: https://pacinst.org/wp-content/uploads/2019/04/moving-toward-multi-benefit-approach.pdf.

[22] The 10 hydrologic regions are North Coast, San Francisco, Central Coast, South Coast, North Lahontan, Sacramento River, San Joaquin Valley, Tulare Lake, South Lahontan, and Colorado River.

[23] We are constrained by the "water supply" and "water demand" categories included in these urban and agricultural water datasets. In cases where supply categories cannot be attributed to a specific water source, we make assumptions as noted below.

[24] Klein, G., Krebs, M., Hall, V., O'Brien, T., Blevins, B.B. "California's Water – Energy Relationship (No. CEC-700-2005-011-SF)." California Energy Commission. November 2005. Available at: http://large.stanford.edu/courses/2012/ph240/spearrin1/docs/CEC-700-2005-011-SF.PDF

TABLE 1 Energy Intensity Categories Applied to Water Sources

	WATER CYCLE STAGES RELATED TO WATER SOURCES		
	1. Extraction or Generation	**2. Conveyance**	**3. Treatment***
Water Sources			
Desalinated Water (Seawater)		Seawater Desalination Conveyance	Seawater Desalination Treatment
Desalinated Water (Brackish)	Groundwater pumping		Brackish Desalination Treatment
Exchanges		Local Imported Deliveries	Conventional Drinking Water Treatment
Groundwater	Groundwater pumping		Conventional Drinking Water Treatment
Other		Local Surface Water Deliveries	Conventional Drinking Water Treatment
Central Valley Project Deliveries		Central Valley Project Deliveries	Conventional Drinking Water Treatment
Colorado River Deliveries		Colorado River Deliveries	Conventional Drinking Water Treatment
Other Federal Deliveries		Local Imported Deliveries	Conventional Drinking Water Treatment
State Water Project Deliveries		State Water Project Deliveries	Conventional Drinking Water Treatment
Recycled Water (Indirect Potable Reuse)	Recycled Water (Potable) Treatment	Recycled Water Conveyance	Conventional Drinking Water Treatment
Recycled Water (Non- Potable)	Recycled Water (Non-potable) Treatment		
Captured Stormwater	Groundwater pumping		Conventional Drinking Water Treatment
Supply from Storage		Local Surface Water Deliveries	Conventional Drinking Water Treatment
Surface Water		Local Surface Water Deliveries	Conventional Drinking Water Treatment
Local Imports		Local Imported Deliveries	Conventional Drinking Water Treatment
Transfers		Local Imported Deliveries	Conventional Drinking Water Treatment

*Energy intensity values for treatment of water supplies to drinking water standards are only applied to water supplies for the urban sector. It is also assumed that water used in the agricultural sector does not receive potable treatment.

1. Water Extraction or Generation: Following the framework of Cooley et al. (2012),[25] water supply extraction includes the energy required to pump groundwater from its source to Earth's surface. Energy intensities depend on the depth of groundwater relative to the surface and on the pump efficiency. The energy intensity for groundwater pumping is also applied to captured stormwater because in some cities, such as Los Angeles, stormwater is used to recharge aquifers and requires pumping for extraction.[26] Groundwater energy intensities were also added for desalinated brackish water, which is typically pumped from aquifers before it is conveyed to a desalination treatment plant. Because of limited availability of detailed data, the authors assume that all groundwater pumps are electric. However, the researchers do note that this may slightly overestimate electricity use, and underestimate GHG emissions because a small portion of groundwater pumps in Cali-

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[25] Cooley, Heather, et al. The Water-Energy Simulator (WESim): User Manual. WateReuse Foundation, Pacific Institute, UC Santa Barbara for California Energy Commission, 2012. Available at: https://pacinst.org/wp-content/uploads/2013/02/user_manual3.pdf.

[26] Geosyntec Consultants, Cordoba Corp, Council for Watershed Health, CWE, DakeLuna, EW Consulting, FlowScience, HDR, Kleinfelder, Kris Helm, MWH, Murakawa Communications, M2 Resource Consulting, Ron Gastelum, "Los Angeles Stormwater Capture Master Plan." Los Angeles Department of Water and Power. August 2015. Available at: https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-w-stormwatercapturemp;jsessionid=ZqtygZTQqnmTxP2v1yrZBb6RfMWCcL9vCfKJFpYy6hDzmy2v-LKhv!-1647871916?_afrLoop=917808504540909&_afrWindowMode=0&_afrWindowId=null#%40%3F_afrWindowId%3Dnull%26_afrLoop%3D917808504540909%26_afrWindowMode%3D0%26_adf.ctrl-state%3D9wujqmer0_4

fornia use diesel or natural gas—which are both more GHG-intensive than California's current and projected electricity mix.[27,28]

This category also includes the energy to "generate" water supplies, namely the incremental treatment of wastewater to recycle it for either potable or non-potable reuse, which is described in more detail at the end of Section 3.1.1.

2. Water Conveyance: Energy for water conveyance includes the energy for pumping, lifting, and transporting raw or partially-treated water that is at the Earth's surface from its source to the drinking water treatment plant (for the urban sector) or directly to the distribution system (for the agricultural sector). The energy for water conveyance primarily depends on the lift (elevation) of the water pumped and on the pump efficiency. Conveyance energy is included for deliveries from the state's major inter-basin water transfers including the State Water Project (SWP), Central Valley Project (CVP), and Colorado River Aqueduct (CRA); local imports (water transferred by local water suppliers from other regions of California); and local surface water deliveries. For inter-basin conveyance projects (SWP, CVP, CRA) the energy intensity values for the furthest delivery point within a given hydrologic region are used. If there are multiple branches of a project within the same region, a volume-weighted average energy intensity is calculated across the delivery points in the region. In addition, average hydropower generation per unit of water volume on any conveyance project is subtracted from the energy intensity to represent a net value of energy required.[29,30] Supplies labeled as 'Other Federal Deliveries,' 'transfers' or 'exchanges' are assigned the same energy intensity as local imports, because the UWMP data do not typically include more detailed information about these categories. Supplies labeled as 'Other,' 'Supply from Storage,' or 'Return Flows' are similarly assigned the same energy intensity as local surface water. For potable recycled water, an energy-intensity for conveyance (pumping) from the wastewater treatment plant to the drinking water treatment plant is assigned[31] via an environmental buffer as detailed at the end of Section 3.1.1.[32] Finally, for desalinated seawater, the energy requirements for conveyance of ocean feedwater to the desalination plant are included.

3. Water Treatment: Water used in the urban sector is assumed to be treated to drinking water standards and is assigned a drinking water treatment energy. For all water sources (including deliveries from inter-basin water projects, local imports, and stormwater), an average energy intensity for conventional water treatment is assigned.[33]

Desalination of seawater and brackish water is included under the Treatment category. It is assumed that the desalination technology used is reverse osmosis, which is most common worldwide and for existing and proposed plants in California.[34] The energy requirements for desali-

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[27] The report authors believe the simplification is appropriate given that the 2018 Irrigation and Water Management Survey by the U.S. Department of Agriculture found that 90% of on-farm well pumps and other irrigation pumps are electric, and only 8% of on-farm well and other irrigation pumps are diesel in California. The remaining 2% of pumps are powered by natural gas or other fuels (*2018 Irrigation and Water Management Survey*. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/index.php. Accessed 3 May 2021.).

[28] Burt, C., Howes, D., Wilson, G. "California Agricultural Water Electrical Energy Requirements (No. ITRC Report No. R 03-006)." Prepared by Irrigation Training and Research Center for the California Energy Commission. December 2003. Available at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=www.google.com/&httpsredir=1&article=1056&context=bae_fac

[29] GEI Consultants/Navigant Consulting. Embedded Energy in Water Studies Study 1: Statewide and Regional Water-Energy Relationship. Prepared for California Public Utilities Commission, 31 Aug. 2010. Available at: ftp://ftp.cpuc.ca.gov/gopher-data/energy%20efficiency/Water%20Studies%201/Study%201%20-%20FINAL.pdf.

[30] Electricity generated from hydropower plants on SWP and CVP conveyance projects is also included in the calculation of the GHG intensity of California's total electricity generation, however, the contribution by conveyance project hydropower to statewide GHG intensity is nominal relative to the total emissions from all electricity in the state.

[31] Sanders, K.T., Webber, M.E. "Evaluating the energy consumed for water use in the United States." Environ. Res. Lett. 7, 034034. September 2012. Available at: https://doi.org/10.1088/1748-9326/7/3/034034

[32] We use a simplifying assumption of a uniform energy intensity for conveyance of treated potable water from the wastewater to the treatment plant across all hydrologic regions. However, the energy intensity may vary widely according to the terrain and decisions regarding buildout, which will affect the total energy requirements of recycled water.

[33] This assumption may overestimate the water treatment for groundwater sources, which in some cases may use a lower level of treatment (typically just disinfection, such as with chlorine) (*Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment - The Next Half Century*. 1006787, 2002, https://www.circleofblue.org/wp-content/uploads/2010/08/EPRI-Volume-4.pdf.).

[34] Rao, P., Kostecki, R., Dale, L., Gadgil, A. "Technology and Engineering of the Water-Energy Nexus." Annu. Rev. Environ. Resour. 42, 407–437. September 2017. Available at: https://doi.org/10.1146/annurev-environ-102016-060959

TABLE 2 Energy Intensity Categories Applied to Water Demand Sectors

	Water Cycle Stages Related to Demand Sectors			
	4. Demand Distribution	**5. Demand End-Use**	**6. Demand Wastewater Collection**	**7. Demand Wastewater Treatment**
Demand Sectors				
Commercial	Urban Water Distribution	Urban Commercial Water Heating	Wastewater Collection	Wastewater Treatment (secondary)
Industrial	Urban Water Distribution	Urban Industrial Water Heating	Wastewater Collection	Wastewater Treatment (secondary)
Institutional/ Governmental	Urban Water Distribution	Urban Institutional Water Heating	Water Treatment Wastewater Collection	Wastewater Treatment (secondary)
Large Landscape	Urban Water Distribution			
Losses	Urban Water Distribution			
Other	Urban Water Distribution		Wastewater Collection	Wastewater Treatment (secondary)
Residential- Indoor	Urban Water Distribution	Urban Residential Indoor Water Heating	Wastewater Collection	Wastewater Treatment (secondary)
Residential- Outdoor	Urban Water Distribution			
Agricultural	Agricultural Water Distribution	Agricultural Irrigation		

nation to drinking water quality (<500 ppm salinity) are much higher with seawater (35,000 – 45,000 ppm salinity) than with brackish water (1,500 – 15,000). All desalted water in coastal hydrologic regions is assumed to come from seawater, and desalted water in inland hydrologic regions is assumed to come from brackish groundwater.

Supplies for the agricultural sector are assumed to not receive treatment to potable standards and therefore have no treatment energy intensities assigned.[35]

4. Distribution: Urban water demand volumes are assigned a distribution system energy intensity to represent the energy required to pump and pressurize the water for delivery from the treatment plant to the end-user. This value varies by the distance and steepness of the terrain over which water is pumped (hilly areas require more energy to pump water).[36]

Agricultural water is assigned an energy intensity for pumping and distributing raw water from the primary conveyance or groundwater source to on-farm end-users.

5. End-Use: Energy for water heating is modeled in the residential, commercial, institutional, and industrial sectors as the primary urban end-use, and for irrigation as the primary agricultural sector end-use.

Residential indoor water is assigned electric and natural gas energy intensities for water heating calculated (Section 3.1.2.1) based on the water temperatures used by different appliances and state average saturation of electric or gas water heaters.[37,38,39] Residential outdoor

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[35] Sanders, K.T., Webber, M.E. "Evaluating the energy consumed for water use in the United States." Environ. Res. Lett. 7, 034034. September 2012. Available at: https://doi.org/10.1088/1748-9326/7/3/034034

[36] McDonald, C., Sathe, A., Zarumba, R., Landry, K., Porter, L., Merkt, E., White, L., Ramirez, I. "Water/Energy Cost-Effectiveness Analysis (No. Navigant Reference No.: 169145)." Prepared for California Public Utilities Commission. April 2015. Available at: https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5356

[37] Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing, K.K., Mann, A. "Waste Not, Want Not: The Potential for Urban Water Conservation in California." Pacific Institute. November 2003. Available at: https://pacinst.org/publication/waste-not-want-not/

[38] KEMA, Inc. "2009 California Residential Appliance Saturation Study Volume 2 (No. CEC-200-2010-004)." California Energy Commission. 2010. Available at: https://www.energy.ca.gov/data-reports/surveys/2019-residental-appliance-saturation-study/2009-and-2003-residential-appliance

[39] William B. DeOreo, Peter Mayer, Benedykt Dziegielewski, Jack Kiefer. "Residential End Uses of Water, Version 2 (No. PDF Report #4309b), Subject Area: Water Resources and Environmental Sustainability." Water Research Foundation. 2016. Available at: https://www.redwoodenergy.tech/wp-content/uploads/2017/07/4309B-June-16-2016.pdf

water use is not assigned an energy intensity for the end-use category. The estimated indoor share of commercial, institutional, and industrial (CII) water volumes are also assigned electric and natural gas energy intensities based on the estimated water temperatures of CII end-use processes. Landscape water is not assigned an energy intensity.

Agricultural end-uses are assigned an average energy intensity for irrigation, which often requires pumping and pressurization. The energy intensity is calculated (Section 3.1.2.2) based on the average share of applied water by crop, the typical energy intensity by irrigation technology, and the average irrigation technology for each crop type.

6. Wastewater Collection: Energy is required to collect and move untreated wastewater from end-users to the wastewater treatment plant.[40] As with water distribution, wastewater collection energy requirements depend on the terrain steepness and distance for pumping wastewater to the treatment facility. This energy intensity is assigned to all indoor residential, commercial, and industrial water volumes. Agricultural water is assumed to not require wastewater treatment, and therefore has no energy for wastewater collection.

7. Wastewater Treatment: Urban wastewater is assumed to be treated to secondary levels.[41] The energy intensity assigned is an average of requirements across wastewater treatment plant capacities, technologies, and efficiencies for secondary treatment. Wastewater treatment energy intensities are applied to all indoor residential, commercial, and industrial water volumes. Agricultural water is assumed to not require wastewater treatment.

Recycled Water: Recycled water does not fit neatly in the linear progression of the managed water cycle steps (Figure 1), because the "source" water for recycled water is treated wastewater. Therefore, the energy for incremental levels of treatment beyond standard, secondary wastewater treatment for recycled water for potable and non-potable reuse is included in the "extraction/generation" category.

Potable recycled water is assumed to be for indirect reuse, which is currently the only permitted form of potable recycled water in the state.[42] With indirect potable reuse, treated recycled water is stored temporarily in either a reservoir (surface water augmentation) or in a groundwater aquifer, which serves as an environmental buffer before the water is conveyed to a conventional drinking water treatment plant and distributed to the end-user.[43] For potable recycled water, a treatment train following the Orange County Water District Groundwater Replenishment System is assumed—i.e., after secondary treatment at a wastewater treatment plant, water is treated with microfiltration, reverse osmosis, and UV/Advanced Oxidation Processes (AOP). Therefore, for potable recycled water conveyance energy to represent water transport to the environmental buffer and to the drinking water treatment plant from the environmental buffer in the "conveyance" category is included, as well as conventional water treatment in the "treatment" category (Table 1).[44]

Non-potable recycled water is typically reused for irrigation of food crops, non-food crops, and parks or golf courses; cooling; and other industrial uses.[45] The treatment level for non-potable recycled water depends on the use. For example, irrigation of food crops that have an edible part in contact with the recycled water require at least disinfected tertiary treatment, whereas irrigation of food crops with the edible portion not in contact with the recycled water (or other uses such as freeway landscape, cemeteries, certain golf-courses) can use disinfected secondary treatment or undisinfected secondary treatment (including vineyards, orchards,

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[40] Cooley, H., Wilkinson, R. "Implications of Future Water Supply Sources on Energy Demands." WateReuse Foundation, Pacific Institute, UC Santa Barbara for California Energy Commission. July 2012. Available at: https://pacinst.org/publication/wesim/

[41] This energy intensity of wastewater treatment may be an underestimate because there are some treatment plants in the state which use more energy-intensive tertiary treatment.

[42] Direct potable reuse is explored further in the Los Angeles case study in Section 5.2.

[43] Environmental Protection Agency and CDM Smith. "2017 Potable Reuse Compendium." Environmental Protection Agency. 2017. Available at: https://www.epa.gov/sites/production/files/2018-01/documents/potablereusecompendium_3.pdf

[44] Note that the energy for pumping water from the groundwater environmental buffer to the surface is not captured in the calculation of the energy intensity of indirect potable recycled water.

[45] State Water Resources Control Board Regulations Related to Recycled Water. *California Code of Regulations: Title 22*. October 1, 2018. Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20181001.pdf

not-fruit bearing trees).[46] For this analysis, non-potable recycled water is assumed to receive disinfected tertiary treatment, and the incremental energy requirements for tertiary treatment plus disinfection for its energy intensity value are aggregated. Distribution energy to pump the non-potable recycled water to the end-user is also included, using the same energy intensity as for potable water distribution.

3.1.2 Literature Review and Estimation of Energy Intensities of California Water Cycle

The report authors reviewed academic literature and technical reports related to the energy usage of California's water system[47] and collected the range of low-, mid-, and high-energy intensity values from each study for each process involved in the water cycle stages described in Section 3.1.1. Data for each hydrologic region are used, if available; otherwise, a statewide value was used. For all water cycle stages except for end-use, the energy intensity values across the studies for each hydrologic region and water cycle process are averaged. In this analysis, the averages of the "mid" energy intensity values are used. For both the urban and agricultural sectors, the energy intensity values for water end-uses are calculated as described below, because these data are not available directly from the literature. The final electricity and natural gas energy intensity values used in this analysis, based on the literature and report authors calculations, are summarized by hydrologic region and water cycle stage in Table 4.

3.1.2.1 Urban End-Use Energy Intensities

End-use energy intensity for water heating is calculated for residential indoor water use as the product of several parameters. First, the average fuel share of residential water heaters is estimated (approximately 32% electric, 64% natural gas based on Energy Information Administration surveys of the Pacific region.[48]) Next, the energy intensity for water heating is calculated based on the specific heat formula, which estimates the thermal energy required to heat a unit of water a certain number of degrees. The degrees of heating for each end-use is calculated as the difference between the average water heater inlet temperature (58 °F) across California cities from a prior analysis,[49] and outlet temperatures specific to each water end-use, listed in Appendix Table 29.[50]

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[46] ibid

[47] California Water Plan Update 2013, Volume 3 - Resource Management Strategies. California Department of Water Resources. 2013. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Water-Plan-Updates/Files/Update-2013/Water-Plan-Update-2013-Volume-3.pdf; Cooley, Heather, and Robert Wilkinson. Implications of Future Water Supply Sources on Energy Demands. WateReuse Foundation, Pacific Institute, UC Santa Barbara for California Energy Commission, 2012. Available at: https://pacinst.org/wp-content/uploads/2012/07/report19.pdf; EPRI. Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment - The Next Half Century. 1006787, 2002. Available at: https://www.circleofblue.org/wp-content/uploads/2010/08/EPRI-Volume-4.pdf; GEI Consultants/Navigant Consulting. Embedded Energy in Water Studies Study 1: Statewide and Regional Water-Energy Relationship. Prepared for California Public Utilities Commission, 31 Aug. 2010. Available at: ftp://ftp.cpuc.ca.gov/gopher-data/energy%20efficiency/Water%20Studies%201/Study%201%20-%20FINAL.pdf; GEI Consultants/Navigant Consulting and GEI Consultants/Navigant Consulting. Embedded Energy in Water Studies Study 2: Water Agency and Function Component Study and Embedded Energy-Water Load Profiles. Prepared for California Public Utilities Commission, 31 Aug. 2010. Available at: ftp://ftp.cpuc.ca.gov/gopher-data/energy%20efficiency/Water%20Studies%202/Study%202%20-%20FINAL.pdf; Klein, Gary, et al. California's Water – Energy Relationship. CEC-700-2005-011-SF, California Energy Commission, Nov. 2005, http://large.stanford.edu/courses/2012/ph240/spearrin1/docs/CEC-700-2005-011-SF.PDF; Liu, Qinqin, et al. Connecting the Dots between Water, Energy, Food, and Ecosystems Issues for Integrated Water Management in a Changing Climate. Climate Change Program, California Department of Water Resources, Feb. 2017. Available at: https://cawaterlibrary.net/wp-content/uploads/2017/10/QLf2017FinalWhite-Paper_jta_edits_fk_format_2.pdf; McDonald, Craig, et al. Water/Energy Cost-Effectiveness Analysis. Navigant Reference No.: 169145, Prepared for California Public Utilities Commission, Oct. 2014. Available at: https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5360; Stokes-Draut, Jennifer, et al. "Evaluating the Electricity Intensity of Evolving Water Supply Mixes: The Case of California's Water Network." Environmental Research Letters, vol. 12, no. 11, Oct. 2017, p. 114005. Institute of Physics. Available at: https://doi.org/10.1088/1748-9326/aa8c86; Tarroja, Brian, et al. "Evaluating Options for Balancing the Water-Electricity Nexus in California: Part 1 – Securing Water Availability." Science of The Total Environment, vol. 497–498, Nov. 2014, pp. 697–710. ScienceDirect. Available at: https://doi.org/10.1016/j.scitotenv.2014.06.060; Tidwell, Vincent C., et al. "Geographic Footprint of Electricity Use for Water Services in the Western U.S." Environmental Science & Technology, vol. 48, no. 15, Aug. 2014, pp. 8897–904. ACS Publications, https://doi.org/10.1021/es5016845.

[48] Residential Energy Consumption Survey (RECS). Table HC1.1 Fuels used and end uses in U.S. homes by housing unit type. Energy Inf. Adm. EIA. 2015. Available at: https://www.eia.gov/consumption/residential/data/2015/hc/php/hc8.8.php

[49] WeCalc: Your Home Water-Energy-Climate Calculator. WeCalc Your Home Water-Energy-Clim. Calc. Available at: http://www.wecalc.org/

[50] Cooley, H., Wilkinson, R. "Implications of Future Water Supply Sources on Energy Demands." WateReuse Foundation, Pacific Institute, UC Santa Barbara for California Energy Commission. July 2012. Available at: https://pacinst.org/publication/wesim/

For gas water heaters, a typical water heater efficiency of 63 percent is applied to the thermal energy required, and for electric water heaters an efficiency of 90 percent is applied to the thermal energy required.[51] Next, data on the average share of residential indoor water for each end-use, summarized in the Appendix Table 29.[52] Finally, the fuel share, energy intensity of the water heater for each end-use, and indoor water share for each end-use are multiplied to estimate a total weighted average energy intensity that is applied to total residential indoor water use (6,800 kWh/AF for electric and 67 MMBtu/AF for natural gas water heaters).[53] The same value is used for residential indoor water volumes in all hydrologic regions. Residential outdoor water use is not assigned an energy intensity for the end-use category.

The water end-uses within the CII sectors vary significantly. Here, the authors focus on the energy requirements for water heating on average across all CII water uses. An average share of total CII water use in California among different types of processes (i.e., landscaping, laundry, kitchen, industrial process, restroom, cooling, other) is assumed based on Gleick et al. (2003),54 as shown in Table 3. Within each of these processes, the report authors estimate the average share of water to different end-uses based on Gleick et al. (2003) as shown in Appendix Table 30. Next, temperatures are assigned to each end-use in the various process categories (Appendix Table 30), and the specific heat formula is used to calculate the energy intensity of heating to that temperature from the California average inlet temperature (as described for residential heating). Fuel shares between electric and gas water heaters are used, based on the electric and gas proportions of total commercial floor space that uses heating.55 Finally, the process shares, end-use shares within each process, energy intensity of water heating for each process, and the fuel ratios are multiplied. For electric water heaters, the same water heater efficiency value is used as for residential water heaters, and for natural gas water heaters, the energy requirements with higher efficiencies (68%) typical of average commercial water heaters were calculated.56 The resulting average energy intensities used for CII water are about 5,200 kWh/AF for electric and 30 MMBtu/AF for natural gas water heating. The same value is used for CII indoor water volumes in all hydrologic regions.

TABLE 3 Estimated CII Water Use by Process

CII Sub-Sector	Percentage of CII Total Water Use
Landscaping	35%
Laundry	2%
Kitchen	6%
Process	17%
Other	9%
Cooling	15%
Restroom	16%

Source: Data from Gleick, et.al. Waste Not, Want Not: The Potential for Urban Conservation in California. Pacific Institute, 2003.

3.1.2.2 Agricultural End-Use Energy Intensities

Irrigation is the primary agricultural end-use requiring energy. The average energy intensity for irrigation is estimated for each hydrologic region based the regional crop mix and typical irrigation technology by crop. First, the weighted average energy intensity of irrigation for

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[51] The energy required to heat one 1 kg of water by 1 °C is calculated based on the specific heat formula: $Q=mc\Delta T$, where Q = thermal energy, m= mass of water, c = specific heat capacity of water (4200 Joules/kg/°C), ΔT = change in temperature, calculated as the difference between the California average inlet temperature (58 °F) and the typical temperature for each water end-use in degrees Celsius. The formula is multiplied by 1/efficiency of the water heater.

[52] William B. DeOreo, Peter Mayer, Benedykt Dziegielewski, Jack Kiefer. "Residential End Uses of Water, Version 2 (No. PDF Report #4309b), Subject Area: Water Resources and Environmental Sustainability." Water Research Foundation. 2016. Available at: https://www.redwoodenergy.tech/wp-content/uploads/2017/07/4309B-June-16-2016.pdf

[53] We note that the energy requirements for natural gas water heaters are in "primary energy" terms, and therefore not directly comparable to electric water heaters which use "secondary energy" that is generated from primary fuel sources and is subject to generation and transmission efficiency losses.

[54] Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing, K.K., Mann, A., 2003. "Waste Not, Want Not: The Potential for Urban Water Conservation in California." Pacific Institute.

[55] Itron, Inc. "California Commercial End-Use Survey (CEUS) (No. CEC-400-2006-005)." California Energy Commission. 2006. Available at: https://www.energy.ca.gov/data-reports/surveys/california-commercial-end-use-survey/2006-california-commercial-end-use-survey

[56] Sanders, K.T., Webber, M.E. "Evaluating the energy consumed for water use in the United States." Environ. Res. Lett. 7, 034034. September 2012. Available at: https://doi.org/10.1088/1748-9326/7/3/034034

TABLE 4 California Electricity (kWh/AF) and Natural Gas (MMBtu/AF) Energy Intensities by Hydrologic Region, by Water Cycle Stage

	North Coast	San Francisco Bay	Central Coast	South Coast	Sacramento River	San Joaquin River	Tulare Lake	North Lahontan	South Lahontan	Colorado River
Electricity Energy Intensity (kWh/AF)										
1. Water Generation/Extraction										
Groundwater Pumping	343	453	479	647	350	365	450	320	433	494
Recycled (Indirect Potable) Treatment	1,218	1,218	1,218	1,218	1,218	1,218	1,218	1,218	1,218	1,218
Recycled (Non-potable) Treatment	543	543	543	419	508	508	508	508	508	508
2. Water Conveyance										
Local Surface Water Deliveries	110	110	118	128	118	118	118	110	118	128
Local Imported Deliveries	116	137	44	44	44	44	44	44	44	44
Central Valley Project Deliveries	225	650	726	225	225	334	196	NA	NA	NA
Colorado River Deliveries	NA	NA	NA	2,115	NA	NA	NA	NA	NA	225
State Water Project Deliveries	NA	1,031	2,043	3,280	238	501	2,158	NA	3,505	4,000
Seawater Desalination Conveyance	100	100	100	100	100	100	100	100	100	100
Recycled Water Conveyance	364	364	364	364	364	364	364	364	364	364
3. Water Treatment										
Conventional Drinking Water Treatment	237	237	237	227	235	235	235	235	235	235
Seawater Desalination Treatment	4,503	4,503	4,503	4,503	4,503	4,503	4,503	4,503	4,503	4,503
Brackish Desalination Treatment	1,593	1,593	1,593	1,593	1,707	1,707	1,707	1,593	1,593	1,593
4. Distribution										
Urban Water Distribution	501	977	501	501	54	54	54	54	501	54
Agricultural Water Distribution	144	144	144	488	19	19	389	144	389	488

TABLE 4 California Electricity (kWh/AF) and Natural Gas (MMBtu/AF) Energy Intensities by Hydrologic Region, by Water Cycle Stage, Continued

	North Coast	San Francisco Bay	Central Coast	South Coast	Sacramento River	San Joaquin River	Tulare Lake	North Lahontan	South Lahontan	Colorado River
5. End-Use										
Urban Residential Indoor Water Heating	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830	6,830
Urban Commercial Water Heating	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245
Urban Industrial Water Heating	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245
Urban Institutional Water Heating	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245	5,245
Agricultural Irrigation	98	154	175	181	78	116	121	84	91	98
6. Wastewater Collection										
Wastewater Collection	104	104	104	111	111	111	111	111	111	111
7. Wastewater Treatment										
Wastewater Treatment (Secondary)	716	716	716	687	697	697	697	697	697	697
Natural Gas Energy Intensity (MMBtu/AF)										
5. End-Use										
Urban Commercial Water Heating	30	30	30	30	30	30	30	30	30	30
Urban Industrial Water Heating	30	30	30	30	30	30	30	30	30	30
Urban Institutional Water Heating	30	30	30	30	30	30	30	30	30	30
Urban Residential Indoor Water Heating	67	67	67	67	67	67	67	67	67	67

each crop type is estimated, based on irrigation surveys about the typical irrigation technology used for each crop as shown in Appendix Table 31,[57] and the average energy intensity for each irrigation technology (15 kWh/AF for gravity or flood irrigation, 284 kWh/AF for standard sprinklers, and 206 kWh/AF for drip/micro-irrigation.[58] The authors find the average applied water for each hydrologic region to each crop type between 1998 and 2002 based on available data on applied crop water from DWR's Agricultural Land and Water Use Estimates.[59]

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[57] Statewide Irrigation Systems Methods Surveys. Available at: http://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Statewide-Irrigation-Systems-Methods-Surveys

[58] Burt, C., Howes, D., Wilson, G. "California Agricultural Water Electrical Energy Requirements (No. ITRC Report No. R 03-006)." Prepared by Irrigation Training and Research Center for the California Energy Commission. December 2003. Available at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=www.google.com/&httpsredir=1&article=1056&context=bae_fac

[59] Agricultural Land & Water Use Estimates. Available at: http://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates

Finally, the weighted average energy intensity of irrigation by crop is multiplied with the average applied water volumes by crop for each region to estimate an average energy intensity of irrigation by hydrologic region.

3.2 GHG Intensity of California's Water Cycle

To calculate the total GHG emissions associated with California's water system, the authors first calculated the GHG intensity (emissions of carbon dioxide (CO_2) equivalent per unit of energy) of the energy sources powering the water system: electricity (metric tons CO_2 equivalent/MWh) and natural gas (metric tons CO_2 equivalent/MMBtu).

The GHG intensity of electricity depends primarily on the regional fuel mix of generation. Because of policy targets in California like the Renewable Portfolio Standard (RPS), which requires a certain percentage of electricity be generated from renewable sources like solar and wind, electricity generation in California has a relatively low GHG intensity compared to neighboring states. The state passed Senate Bill 100 (SB 100) in 2017, which accelerated existing RPS targets for electricity and now requires 60 percent of electricity generation from renewable sources by 2030, and 100 percent of electricity from zero-emissions sources by 2045.[60] California does import electricity from outside the state to meet demands, however, because future GHG intensity projections for imported electricity were not available, this analysis assumes that the electricity demand of California's water system is met entirely by in-state generation compliant with the SB 100 renewable targets.[61]

The GHG intensity of electricity also varies temporally. For example, during times of high electricity demand, electricity may be generated from "peaking" fossil generators that have high emissions, while for other times of day, electricity demand may be met primarily from renewable generators that produce no GHG emissions. For simplicity, the California annual average GHG intensity of electricity was calculated based on the total GHG emissions from in-state electric generators divided by the total annual electricity produced.

Because state policy would drive such substantial changes to the GHG emissions from electricity over the time horizon of this analysis, the historical and projected GHG intensities are tracked in the authors' calculations. Data from the California Air Resources Board on in-state emissions and annual electricity generation were used to calculate the historical annual average GHG intensity of electricity generation.[62] For future years, the GHG intensities projected in electricity system simulations prepared for policy discussions on pathways for California's 100 percent zero-emissions electricity by 2045 were utilized.[63] The GHG intensities for the intervening years between historical data and projections are linearly interpolated. The annual GHG intensity values used are summarized in Table 5, and decrease from 0.26 tons CO_2/MWh in 2015 to 0.10 tons CO_2/MWh by 2035. The GHG emissions from natural gas are assumed to be a constant 0.053 tons of CO_2/MMBtu.[64]

3.3 Historical and Future Scenarios of Water Supply and Demande

The third step of the analysis is to collect historical data and develop future scenarios of water supply and demand volumes for the urban and agricultural water sectors in California. The analysis is conducted separately for the urban and agricultural sectors.

3.3.1 Urban Water Sector

For this analysis, historical and projected water demand and supply data were obtained from Urban Water Management Plans (UWMPs) submitted by urban water suppliers. In California, water suppliers that provide more than 3,000 AF of water annually or serve more than 3,000 customers (referred to as urban water suppliers) are required to prepare a UWMP every five years and submit those plans to the California Department of Water Resources (DWR). Together, the population served

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[60] De Leon, K., Skinner, N. SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases. Chaptered September 2018. Available at: https://leginfo.legislature.ca.gov/faces/billHistoryClient.xhtml?bill_id=201720180SB100

[61] In-state generation includes utilities within the California Independent System Operator (CAISO) region, as well as other municipal and irrigation district utilities such as Los Angeles Department of Water and Power and the Imperial Irrigation District.

[62] California Greenhouse Gas Inventory for 2000-2018 — by Sector and Activity. California Air Resources Board. 2020.

[63] California Energy Commission, California Public Utilities Commission, California Air Resources Board. "Draft 2021 SB 100 Joint Agency Report." 2020. Available at: https://www.energy.ca.gov/sb100

[64] Carbon Dioxide Emissions Coefficients. US Energy Inf. Adm. EIA. Available at: https://www.eia.gov/environment/emissions/co2_vol_mass.php

TABLE 5 GHG Intensity of California Electricity Generation 2015–2035 (Tons of CO_2 equivalent/MWh)

	Historical Observed					Interpolated					Projected From Simulations				
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2030	2035
In-State Generation	0.26	0.21	0.18	0.20	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.13	0.10

The low GHG intensity value in 2017 was due to an overall increase renewable generation on the grid as well as to the large increase in hydroelectricity production that year, the wettest year on record.

by the UWMPs is about 90 percent of California's total population; the urban water demands not included in the UWMP data are not analyzed.[65] The first UWMPs were published in 1990, and the most recent plans as of 2020 are the 2015 UWMPs.[66] Actual and projected demand and supply and current population data were extracted from the 2015 UWMPs from DWR's public data portal, WUEdata.[67] Suppliers report their data in five-year increments. Therefore, this analysis is performed using actual data for 2015, and projected data for 2020, 2025, 2030, 2035.

UWMP data are available for a total of 401 water suppliers. Only data related to retail operations for all water suppliers are used. However, data for eight suppliers were removed—which account for 0.4 percent of the total population reported in the UWMPs—from the analysis as their reported numbers are outliers and appear to be reporting errors.[68] Data for demand, supply, and population were joined with another dataset[69] to match each supplier to its respective hydrologic region. Each of these compiled datasets is then grouped and aggregated by hydrologic region for further analysis.

3.3.1.1 Urban Water Demand Data

Water demand data were extracted from "Table 4-1 Retail: Demands for Potable and Raw Water – Actual" and "Table 4-2 Retail: Demands for Potable and Raw Water – Projected." Population data were extracted from "Table 3-1 Retail: Population - Current and Projected." These data were joined with another dataset[70] to assign each supplier to a hydrologic region. Population and each demand category were then respectively summed to give totals for each hydrologic region. The UWMP data categorize residential end-use as "multifamily" and "single family." The authors separated the residential categories into "indoor" and "outdoor" using a ratio for each hydrologic region based on a six-year (2011-2016) annual average on indoor and outdoor demand from DWR's Water Balances data.[71] This ratio was then applied to the UWMP data and the respective categories were summed to get total "indoor residential" and "outdoor residential" water demand for each hydrologic region. The final set of demand categories were residential indoor, residential outdoor, commercial, industrial, institutional/governmental, landscape, losses, and other. Per-capita demand is calculated based on population for the respective year.

3.3.1.2 Urban Water Supply Data

Water supply data were extracted from "Table 6-8 Retail: Water Supplies – Actual" and "Table 6-9 Retail: Water Supplies – Projected." These data were joined with another dataset, as referred to above, to assign each supplier to a hydrologic region. Each supply category was then summed to give totals for each hydrologic region. The UWMPs combine all imported water sources into one category. For this study, this category was disaggregated into various imported sources of water, e.g., the Colorado River and the State Water Project, based on a six-year (2011-2016) average using data from DWR's Water Balances. The UWMPs combine all recycled water into one category, regardless of quality. Because of

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[65] WUEdata - Water Use Efficiency Data. Calif. Dep. Water Resources. WUEdata - Public Portal. Available at: https://wuedata.water.ca.gov/

[66] UWMPs for 2020 are under development and will be submitted to DWR in 2021.

[67] WUEdata - Water Use Efficiency Data. Calif. Dep. Water Resources. WUEdata - Public Portal. Available at: https://wuedata.water.ca.gov/

[68] These suppliers are Calaveras County Water District, City of Corcoran, City of Exeter, Fruitridge Vista Water Company, City of Greenfield, City of Lemoore, South Feather Water and Power, and Truckee - Donner Public Utilities District.

[69] Based on data from the California Department of Public Health via Pacific Institute's California Urban Water Map.

[70] California Urban Water Use Map. Pacific Institute. Available at: URL https://pacinst.org/gpcd/map/

[71] Water Portfolios. Calif. Dep. Water Resources. Available at: http://water.ca.gov/Programs/California-Water-Plan/Water-Portfolios

differences in the energy-intensity of recycled water for potable and non-potable applications, the authors split this category into potable and non-potable sources using Title 22 recycled water standards[72] and data from the 2015 UWMP "Table 6-4 Retail: Current and Projected Recycled Water Direct Beneficial Uses Within Service Area." The percentage split between potable and non-potable categories by hydrologic region was then applied to the supply volumes labeled as "recycled water" in the UWMP data.[73]

3.3.1.3 Urban Water Demand Scenarios

California's urban water demand has declined significantly over the last two decades (Cooley, 2020). A recent analysis of the state's 10 largest urban water suppliers, serving 25 percent of the population, finds that per-capita water demands declined by an average of 25 percent between 2000 and 2015.[74] Further, the study shows that many water suppliers did not adequately account for these trends in their Urban Water Management Plans, and overestimated total demand in 98 percent of the cases examined (Figure 2). Such overestimates of future water demands can result in investment in unneeded infrastructure and new sources of supply.[75]

In this analysis, three scenarios of future water demand were developed to study potential changes to California's water-related energy and GHG footprint:

i. **Water Supplier Projections Scenario (High-Case):** Assumes that total demand is maintained as reported in the 2015 UWMPs for 2020, 2025, and 2030. Given that future water supplies reported in the UWMP exceed future demand, water supplies were proportionally scaled down to match projected demand. This scenario represents the highest future water demands as envisioned by water suppliers and includes planned facilities (such as for desalination or water recycling), assumed future changes in per capita water demand, and water suppliers' projections of population growth.

ii. **2015 Constant Per-Capita Demand Scenario (Mid-Case):** Assumes system-wide per-capita water demand (i.e., for all urban end-use sectors) from the 2015 UWMPs is held constant for every future year. Total demand is then estimated by multiplying 2015 per-capita demand by projected population for each hydrologic region from the UWMP data. Supplies are then adjusted proportionally from UWMP projections to match demand by year and hydrologic region. The authors note that 2015 was not a "historically typical" year because of a statewide drought from 2012 to 2016—during which there was a mandate to reduce urban water use by 25 percent. However, monthly water use data from the State Water Resources Control Board suggest that urban water use increased slightly after the drought but remains lower than pre-drought levels.[76,77]

iii. **Declining Per-Capita Demand Scenario (Low-Case):** Assumes system per-capita demand is decreased by 2 percent annually, based on a 2020 Pacific Institute study which found a trend of such decreases among the 10 largest suppliers between the years 2000 to 2015.[78] This percentage decline is calculated using 2015 per-capita demand as the base year. Total demand is then estimated by multiplying future per-capita demand by projected population for each hydrologic region. Supplies are adjusted proportionally to match the demand volumes. This scenario represents

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[72] State Water Resources Control Board Regulations Related to Recycled Water. California Code of Regulations: Title 22. October 1, 2018. Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20181001.pdf

[73] The final list of water source categories includes desalinated water (seawater and brackish), exchanges, groundwater, other, Central Valley Project deliveries, Colorado River Aqueduct deliveries, local imports, other federal deliveries, State Water Project deliveries, recycled water (potable), recycled water (non-potable), stormwater use, supply from storage, surface water, and transfers.

[74] Abraham, S., Diringer, S., Cooley, H. "An Assessment of Urban Water Demand Forecasts in California." Pacific Institute. August 2020. Available at: https://pacinst.org/publication/urban-water-demand-forecasts-california/

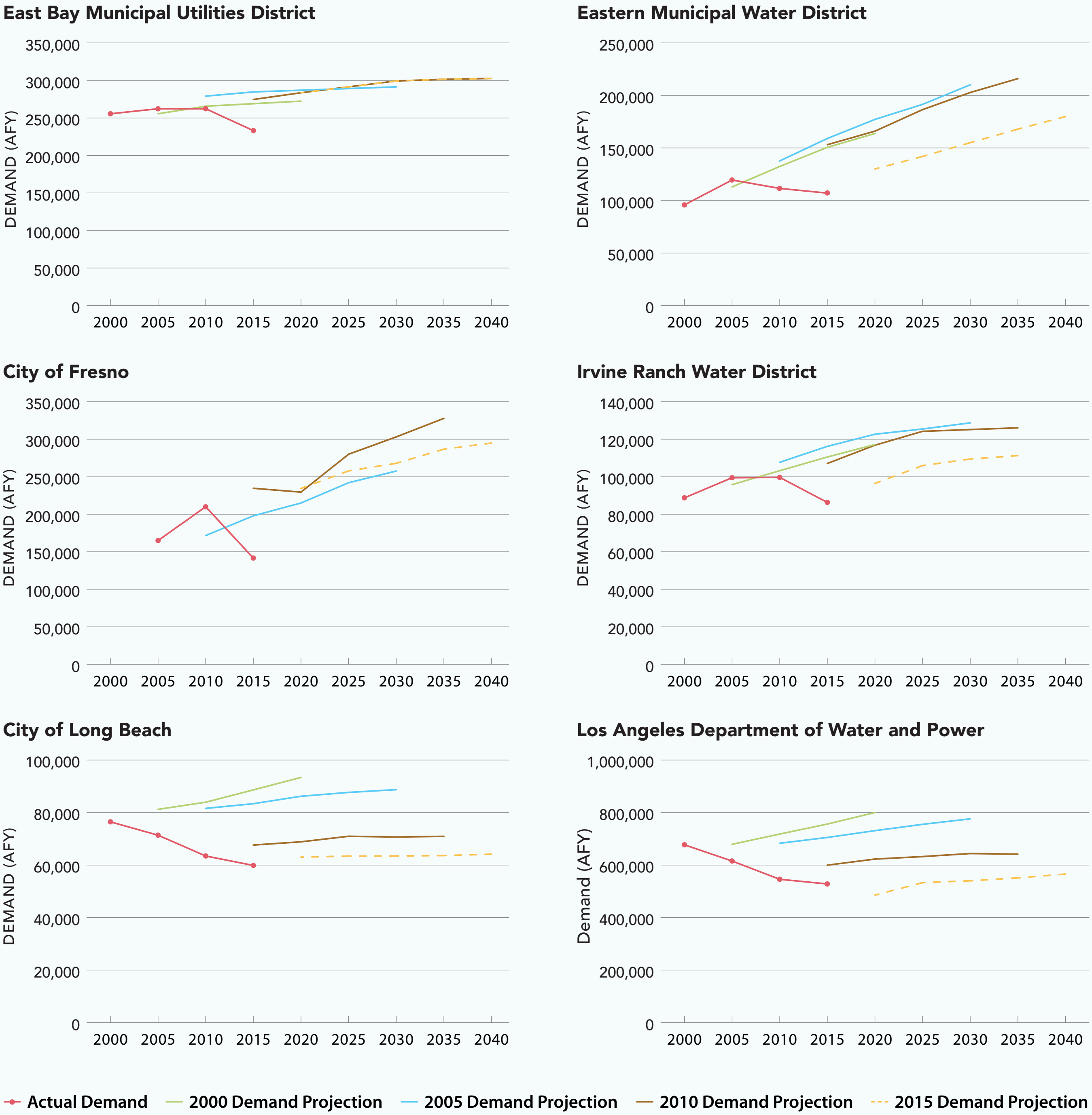
[75] ibid.

[76] ibid.

[77] Cooley, H. "Urban and Agricultural Water Use in California, 1960-2015." Pacific Institute. June 2020. Available at: https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf

[78] Abraham, S., Diringer, S., Cooley, H. "An Assessment of Urban Water Demand Forecasts in California." Pacific Institute. August 2020. Available at: https://pacinst.org/publication/urban-water-demand-forecasts-california/

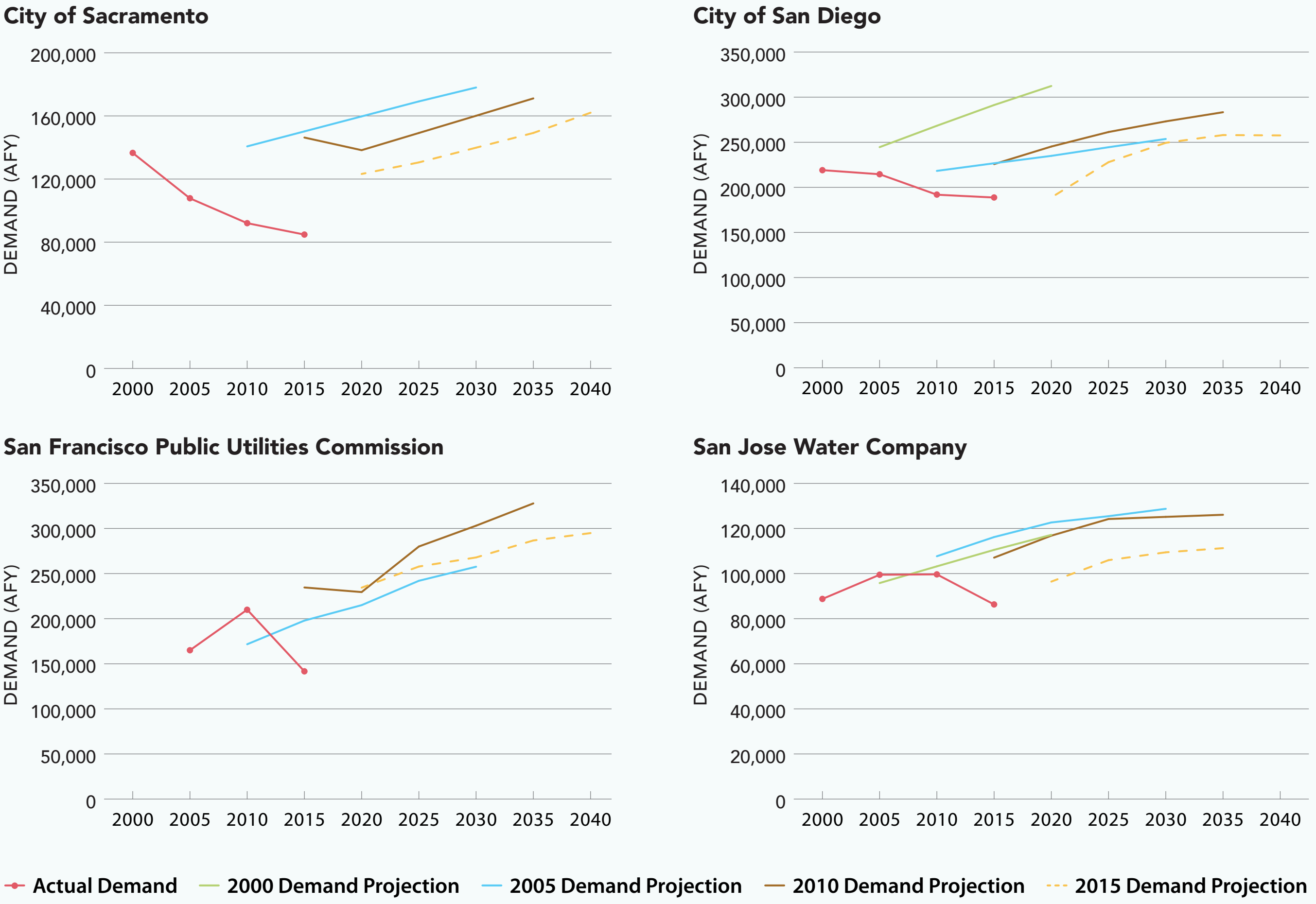
FIGURE 2 Actual and Projected Total Water Demands for Ten Selected Urban Water Suppliers (Acre-feet)



Source: Data from Abraham, S. Diringer S., Cooley, H. An Assessment of Urban Water Demand Forecasts in California. Pacific Institute, 2020.

Note: The 2000 UWMP was not avilable for the City of Fresno; the 2000 UWMPs for the City of Sacramento and San Jose Water Company dd not ontain total demand projections.

FIGURE 2 Actual and Projected Total Water Demands for Ten Selected Urban Water Suppliers (Acre-feet), Continued



City of Sacramento

City of San Diego

San Francisco Public Utilities Commission

San Jose Water Company

Source: Data from Abraham, S. Diringer S., Cooley, H. An Assessment of Urban Water Demand Forecasts in California. Pacific Institute, 2020.

Note: The 2000 UWMP was not available for the City of Fresno; the 2000 UWMPs for the City of Sacramento and San Jose Water Company did not contain total demand projections.

a future pathway with more aggressive conservation and efficiency efforts to reduce urban water usage, and therefore the lowest total water demand.

Table 6 shows how total residential per-capita demand (R-gpcd) and indoor residential per-capita demand (indoor R-gpcd) changes between 2015 and 2035 under each of these scenarios. Under the Water Supplier Projections Scenario, both the statewide average R-gpcd and indoor R-gpcd increase 20% between 2015 (83 R-gpcd, 46 indoor R-gpcd) and 2035 (102 R-gpcd total, 56 indoor R-gpcd). However, if historical conservation trends continue as is assumed under the Declining Per-Capita Demand Scenario, statewide average residential usage drops to 59 R-gpcd and 32 indoor R-gpcd, respectively. While low, this scenario is similar to the water use already achieved in high-efficiency homes equipped with Energy Star and WaterSense appliances and fixtures[79] and in some other regions of the world, such as Israel where households on average use 36 R-gpcd.[80]

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[79] William B. DeOreo, Peter Mayer, Benedykt Dziegielewski, Jack Kiefer. “Residential End Uses of Water, Version 2 (No. PDF Report #4309b), Subject Area: Water Resources and Environmental Sustainability.” Water Research Foundation. 2016. Available at: https://www.redwoodenergy.tech/wp-content/uploads/2017/07/4309B-June-16-2016.pdf

[80] Cooley, H. “Urban and Agricultural Water Use in California, 1960-2015.” Pacific Institute. June 2020. Available at: https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf

TABLE 6 Statewide Volume-Weighted Average Residential Daily per Capita Water Demand, by Scenario (Gallons per Capita per Day, R-gpcd and Indoor R-gpcd)

Scenario	Residential Segment	2015	2020	2025	2030	2035
Water Supplier Projections Scenario (High-Case)	R-gpcd	83	101	102	102	102
	Indoor R-gpcd	46	56	56	56	56
2015 Constant Per-Capita Demand Scenario (Mid-Case)[82]	R-gpcd	83	86	87	88	88
	Indoor R-gpcd	46	48	48	48	49
Declining Per-Capita Demand Scenario (Low-Case)	R-gpcd	83	78	71	65	59
	Indoor R-gpcd	46	43	39	36	32

Residential per-capita demand increases slightly under the 2015 Constant Per-Capita Demand Scenario, because we keep the residential share of total system demand the same as that of each year's share from the Water Supplier Demand Scenario. For example, under the Water Supplier Demand Scenario, in 2015 indoor residential water use was 34% of total urban demand (1,842,682/5,432,207 AF), but in 2035 the indoor residential water use share increased to 35% of total urban demand (2,723,160/7,815,382 AF).

3.3.2 Agricultural Water Sector

For this analysis, future water demand and supply delivery data were obtained from an analysis DWR conducted for its 2018 California Water Plan Update for the three hydrologic regions in Central Valley (Sacramento River, San Joaquin Valley, and Tulare Lake) under a number of population growth and climate-change scenarios.[81] The data are publicly available to download through a WEAP Tableau workbook.[82] These data are the results of simulations conducted with the integrated water supply and demand modeling platform called Water Evaluation and Planning (WEAP), which assessed future water conditions in the Central Valley for the urban and agricultural sectors under a combination of five urban growth scenarios and 20 climate scenarios from a base year of 2006 through 2100. The data include total demand, total supply delivered, and unmet demand (the difference between water demanded and actual supply delivered) for each year, Planning Area, and sector (this study analyzed only the agricultural sector results). To be consistent with the time horizon and geographic resolution of this study's urban analysis (described in Section 3.3.1), agricultural analysis was limited to 2015, 2020, 2025, 2030, and 2035, and the data were aggregated to the hydrologic region. For each of these years, a rolling 10-year average was calculated to smooth out the inter-annual variability from the climate projections. The agricultural analysis focused only on California's Central Valley, which comprises about 80 percent of total state agricultural water use.[83]

3.3.2.1 Agricultural Water Demand Data

The "supplies delivered" variable from DWR's WEAP simulation results was utilized to represent agricultural water demand in this analysis, to be consistent with the report's urban analysis where demand and supply are balanced and because "supplies delivered" represents water use given supply availability to agricultural water users.[84]

The WEAP model simulates agricultural water conditions within the three hydrologic regions in Central Valley based on the effects of urban growth on agricultural land and climate change. The urban growth scenarios are a combination of a low-, mid-, or high-population growth rate, and a low-, central-, or high-level of population

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[81] Rayej, M., Kibrya, S., Shipman, P., Correa, M. "Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document." California Department of Water Resources. June 2019. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/SupportingDocs/Future-Scenarios-of-Water-Supply-in-the-Central-Valley.pdf

[82] WEAP Future Scenarios. Available at: https://public.tableau.com/views/WEAP_Scenarios/DemandSupplyMultiClimate?%3Aembed=y&%3AshowVizHome=no&%3Adisplay_count=y&%3Adisplay_static_image=y&%3AbootstrapWhenNotified=true&%3Alanguage=en&:embed=y&:showVizHome=n&:apiID=host0#navType=0&navSrc=Parse

[83] Water Portfolios. California Department of Water Resources. Available at: http://water.ca.gov/Programs/California-Water-Plan/Water-Portfolios

[84] We do not use the "water demand" variable from WEAP because it represents a theoretical "requested" water demand based on crop acreage and climate, which may not be met if there are insufficient supplies after the (user-specified) higher priority urban water demands are satisfied (Rayej, M., Kibrya, S., Shipman, P., Correa, M. "Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document." California Department of Water Resources. June 2019. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/SupportingDocs/Future-Scenarios-of-Water-Supply-in-the-Central-Valley.pdf).

TABLE 7 Urban Growth Scenarios from DWR Simulations, and Effect on Agricultural Water Use

DWR Scenario Abbreviation	Scenario Description
CTP_CTD	Central population growth, current trends density -> mid-level agricultural water use
CTP_HID	Central population growth, high density -> mid-level agricultural water use
CTP_LOD	Central population growth, low density -> mid-level agricultural water use
HIP_LOD	High population growth, low density -> low-level agricultural water use
LOP_HID	Low population growth, high density -> high-level agricultural water use

density.[85] In the DWR analysis, it is assumed that population growth in Central Valley urban areas will cause agricultural land to go out of production, thereby reducing agricultural water demand.[86] This effect on agricultural water increases with population growth and decreases with population density. The urban growth scenarios available in the results are listed in Table 7.

The climate scenarios include results from 10 Global Circulation Models (GCMs), and two emissions scenarios (Representative Concentration Pathways or RCP 4.5 and RCP 8.5, which represent future radiative warming of 4.5 W/m^2 and 8.5 W/m^2, respectively), as recommended to capture the range of possible climate futures in California.[87] The list of GCMs and emissions scenarios are listed in Table 8. While the water supply availability and agricultural water demands are affected by changing temperature and precipitation patterns under each climate change scenario modeled in WEAP, the variation between climate scenarios (both GCMs and emission scenarios) is minimal within this study's near-term time horizon; the overall impact of climate change is expected to be more significant, and vary between GCMs and emissions scenarios, closer to the end-century period.[88]

TABLE 8 Climate Change Scenarios Modeled in DWR Analysis

GCMs	Emissions scenarios
Access10	RCP 4.5
Access10	RCP 8.5
Canesm2	RCP 4.5
Canesm2	RCP 8.5
Ccsm4	RCP 4.5
Ccsm4	RCP 8.5
Cesm1_bgc	RCP 4.5
Cesm1_bgc	RCP 8.5
Cmcc_cms	RCP 4.5
Cmcc_cms	RCP 8.5

3.3.2.2 Agricultural Water Supply

The supply deliveries in the DWR WEAP analysis results are reported as a total volume and do not include the share of water deliveries by source. To supplement this data, a separate dataset from DWR of historical water deliveries to the agricultural sector by hydrologic region and source for 1999 to 2016 was utilized. For each hydrologic region, the historical average share of supply from each water source was calculated (Table 9) and these shares

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[85] The low, mid, and high population forecasts from the data we use for this agricultural analysis from DWR's California Water Plan are not necessarily consistent with the population forecasts that are used in the urban analysis, which are based on individual water supplier's projections for their service territories. The DWR report and individual UWMPs do not provide enough information to compare the population forecasts used.

[86] Rayej, M., Kibrya, S., Shipman, P., Correa, M., Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document. California Department of Water Resources. 2019.

[87] Lynn, E., Schwarz, A., Anderson, J., Correa, M. "Perspectives and Guidance for Climate Change Analysis." California Department of Water Resources, Climate Change Technical Advisory Group. August 2015. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Program-Activities/Files/Reports/Perspectives-Guidance-Climate-Change-Analysis.pdf

[88] We note that because all the scenarios rely on climate model data which can have small differences for the historical period, there are slight differences in the 2015 data between scenarios. We use this simulated WEAP data for 2015 despite these small differences to have a fully consistent dataset, rather than mixing data with historical data collected from another source.

were multiplied by the total projected supply deliveries from each year of the WEAP analysis to estimate water supply by source. This is a simplifying assumption given available data and implies that the historical ratio of different supply sources will stay constant in the future.[89]

3.3.2.3 Agricultural Water Scenarios

For this analysis, combinations of urban growth and climate scenarios from DWR's WEAP simulations were selected that together result in a set of (i) low, (ii) mid, and (iii) high agricultural water use scenarios. The authors first selected the three bounding scenarios among urban growth scenarios (High Population Growth + Low Density, Central Population Growth + Central Density, and Low Population Growth + High Density). For each of these urban growth scenarios, the authors found the climate scenario that produces the highest and lowest unmet demand across the study period (2015–2035) for the aggregate Central Valley region. The unmet demand is sensitive to effects of climate on both supply availability and irrigation demand and therefore captures the cumulative climate change impact on agriculture for a given urban growth scenario. For the (i) High Population Growth scenario, the authors selected the climate scenario with the maximum unmet demand (greatest climate change impact), and for the (iii) Low Population Growth scenario they select the climate scenario resulting in minimum unmet demand (smallest climate change impact). For the (ii) Central Population Growth scenario, the climate scenario with maximum unmet demand was selected. The authors note that these scenarios are largely driven by DWR's assumptions of how urban population growth will affect agricultural land and subsequently water use, and do not account for economic factors, such as crop values on domestic and international markets, federal and state agricultural policies, and other factors that may have even greater impacts on farmers' land and water use choices.[90] For example, while California's agricultural water use has remained relatively flat since the 1980s, during this time the economic value of crop production has grown significantly, by shifting to higher value crops and increased adoption of more water-efficient irrigation technologies, such as drip and micro-sprinkler systems.[91]

TABLE 9 Historical 1999–2016 Average Share of Agricultural Water Supply by Source, by Hydrologic Region

Supply Sources	Sacramento Valley	San Joaquin Valley	Tulare Lake
State Water Project Deliveries	0.2%	0.3%	8.7%
Central Valley Project Deliveries	25%	16%	15%
Other Federal Deliveries	2.8%	0.2%	0.0%
Surface Water	33%	33%	18%
Local Imports	0.4%	0.0%	0.0%
Return Flows	6.8%	11%	0.1%
Groundwater	32%	39%	58%
Colorado River Deliveries	0.0%	0.0%	0.0%

i. **Low Agricultural Water Use Scenario:** HIP_LOD (lowest agricultural demand because of urban encroachment on agricultural land) with the maximum unmet demand (highest climate change impact) based on GCM: CMCC_CMS and emissions scenario: RCP 4.5.

ii. **Mid Agricultural Water Use Scenario:** CTP_CTD (central agricultural demand) with maximum unmet demand based on GCM: CMCC_CMS and emissions scenario: RCP 4.5

iii. **High Agricultural Water Use Scenario:** LOP_HID (highest agricultural demand because of least urban encroachment on agricultural land) with the minimum unmet demand (lowest climate change impact) based on GCM: GFdl_cm3 and emissions scenario: RCP 8.5

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[89] The historical agricultural water use categories in the DWR data we use do not include recycled water; however, we recognize that there is a small share of agricultural water-supplies that comes from recycled sources ("Volumetric Annual Reporting: Recycled Water Policy I California State Water Resources Control Board," n.d.).

[90] Rayej, M., Kibrya, S., Shipman, P., Correa, M. "Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document." California Department of Water Resources. June 2019. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/SupportingDocs/Future-Scenarios-of-Water-Supply-in-the-Central-Valley.pdf

[91] Cooley, H. "Urban and Agricultural Water Use in California, 1960-2015." Pacific Institute. June 2020. Available at: https://pacinst.org/wp-content/uploads/2020/06/PI_Water_Use_Trends_June_2020.pdf

3.4 Total Energy and GHG of Urban and Agricultural Water Scenarios

In both the urban and agricultural analyses, for each future water scenario, hydrologic region, and year, the total water-related energy use and associated GHG emissions were calculated. For all the relevant stages of the water cycle described in Section 3.1.1, the corresponding energy intensities described in Section 3.1.2 were multiplied by the water supply and demand volumes of the scenarios in Sections 3.3.1.3 and 3.3.2.3, and finally summed to estimate total water-related energy usage for the urban and agricultural sectors, respectively, in each hydrologic region and scenario. For each urban and agricultural water scenario, the GHG intensity by fuel was multiplied by the total energy usage of the fuel to calculate total GHG emissions.

4. ANALYSIS RESULTS AND DISCUSSION

4.1 Urban Water Results

Here the projected demand, supply, energy, and GHG results of this report's analysis is described across scenarios for California in aggregate, by hydrologic region, by supply source and demand sector, and by water cycle stage for urban water. In each section, a high-level comparison across scenarios and detailed results for the "mid-case" 2015 Constant Per-Capita Demand Scenario are included; detailed results for the "high-case" Water Supplier Projections Scenario and the "low-case" Declining Per-Capita Demand Scenario are in the Appendix Section 9.2.

TABLE 10 State Urban Water Demand 2015–2035, by Scenario (AF)

Scenario	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Water Supplier Projections Scenario (High-Case)	5,432,207	6,778,861	7,158,608	7,485,695	7,815,382	+44%	2,383,175
2015 Constant Per-Capita Demand Scenario (Mid-Case)	5,432,207	5,751,547	6,075,776	6,396,138	6,727,985	+24%	1,295,778
Declining Per-Capita Demand Scenario (Low-Case)	5,432,207	5,198,943	4,964,351	4,723,990	4,491,656	-17%	-940,550

TABLE 11 Annual Urban Water Demand by Sector (AF)—2015 Constant Per-Capita Demand Scenario (Mid-Case)

Demand Sector	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Residential- Indoor	1,842,682	2,004,389	2,123,692	2,242,569	2,358,832	28%	516,151
Residential- Outdoor	1,448,045	1,603,035	1,709,520	1,816,070	1,922,994	33%	474,950
Commercial	682,261	720,403	753,573	785,961	821,041	20%	138,779
Industrial	216,065	217,743	223,731	227,876	240,385	11%	24,319
Institutional/ Governmental	162,886	133,502	142,866	152,689	156,521	-4%	-6,364
Large Landscape	315,900	296,957	306,808	321,261	338,634	7%	22,734
Losses	342,822	326,892	346,461	363,382	382,319	12%	39,497
Other	421,546	448,627	469,124	486,329	507,259	20%	85,713
Total	5,432,207	5,751,547	6,075,776	6,396,138	6,727,985	24%	1,295,778

4.1.1 Urban Water Demand: Historical and Future Scenarios

According to data reported by water suppliers in the UWMPs—which represent 90 percent of California's population—total urban water demand in 2015 was 5.4 million acre-feet (MAF). If per-capita water demand is held constant at 2015 levels according to the "mid-case" scenario, statewide total urban demand increases 24 percent (1.3 MAF) between 2015 and 2035 with population growth. This result is compared to water suppliers' projections ("high-case"), and the declining demand scenario ("low-case") that represents a continuation of historical conservation and efficiency trends in Table 10 and Figure 3.[92] Water suppliers project a 44 percent increase (2.4 MAF) in overall urban water demand between 2015 and 2035, about twice the rate of the 2015 Constant Per-Capita Demand Scenario. With increased conservation under the Declining Per-Capita Demand Scenario, statewide urban demand would fall by 17 percent (0.9 MAF) between 2015 and 2035.

Under the 2015 Constant Per-Capita Demand Scenario, the largest absolute and percentage change increases come from indoor residential water demand—which is also the most energy-intensive end-use sector—and from outdoor residential water demand, respectively (Table 11).[93] Across the hydrologic regions, (Figure 4), the largest absolute increases in residential water demand are in two regions with highly populated urban centers and the highest increase in overall urban demands in the state: South Coast (about +456,000 AF) and Sacramento (about +175,000 AF).

4.1.2 Urban Water Supply: Historical and Future Scenarios

To meet projected water demands under the "mid-case" 2015 Constant Per-Capita Demand Scenario, water supplies must increase by 1.3 MAF, or 24 percent, between

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[92] See the Appendix, for detailed tables of water demand results for the Water Supplier Projections Scenario and Declining Per-Capita Demand Scenario.

[93] Because we do not have data on how water suppliers projected losses, there is a simplifying assumption that losses also scale proportionally with demand in the 2015 Constant Per-Capita Demand and Declining Per-Capita Demand Scenarios.

FIGURE 3a State Urban Water Demand 2015–2035 by Scenario

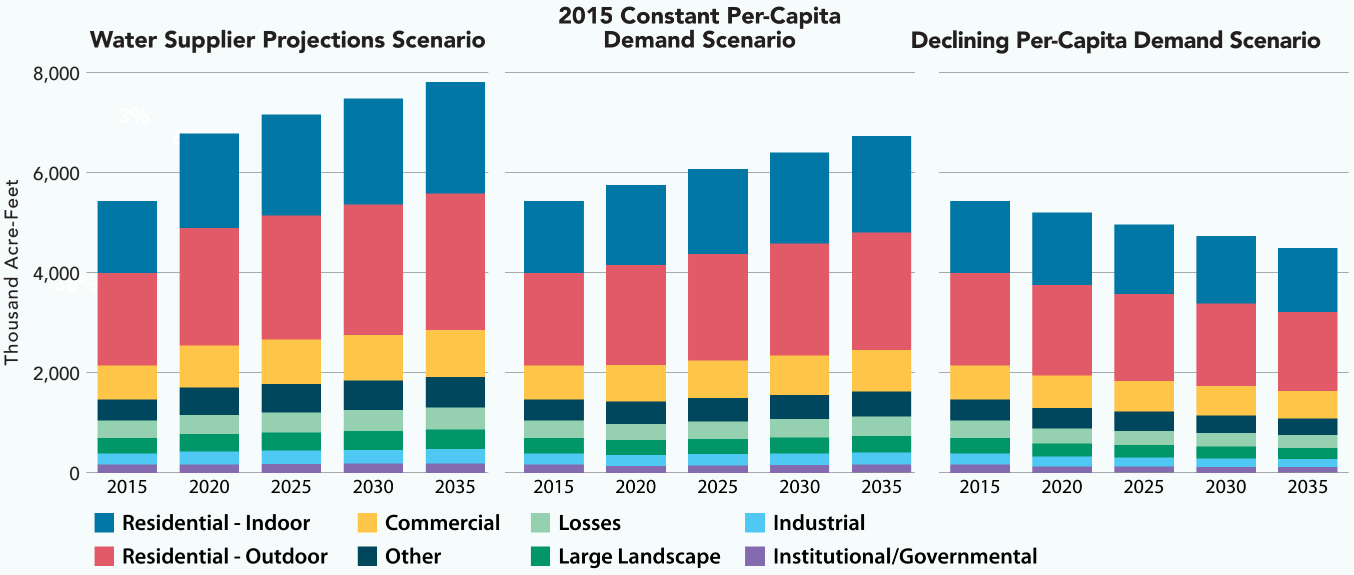
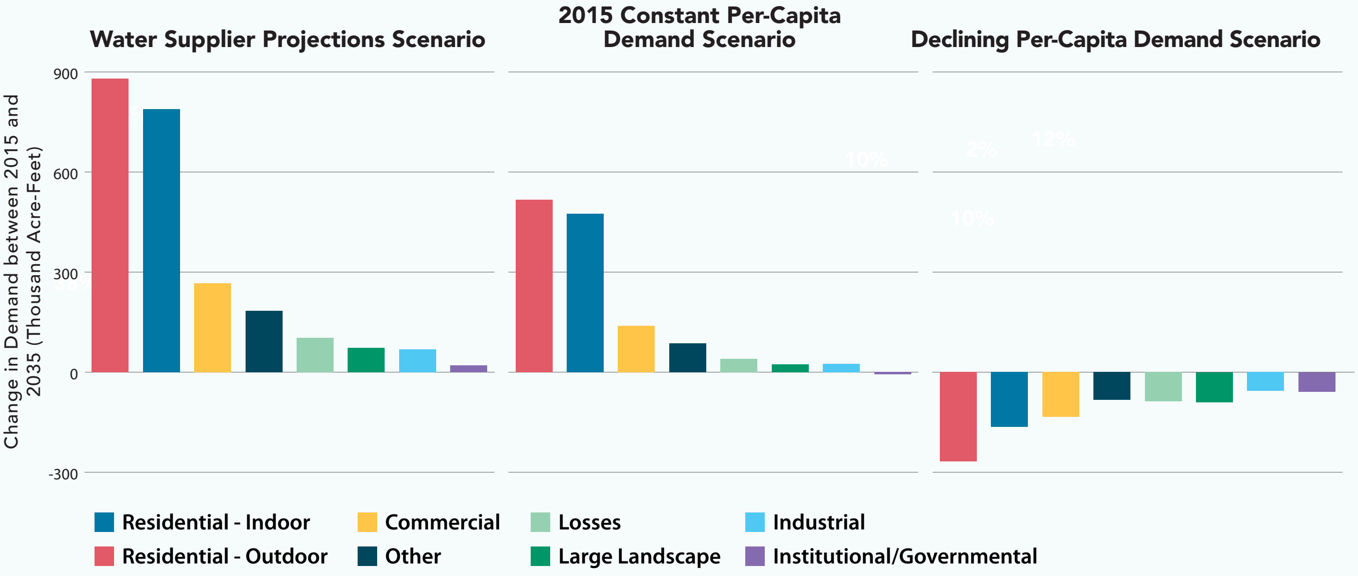


FIGURE 3b Change in State Urban Water Demand Between 2015 and 2035, by Scenario



2015 (5.4 MAF) and 2035 (6.7 MAF).[94] This supply increase is largely met using traditional water sources (groundwater and surface water)[95] (Table 12), but there are also shifts in the supply mix from imported water toward local alternative water sources , which have important energy and GHG implications. The largest percentage increases in supplies between 2015 and 2035 are from brackish desalination (+7000% increase in supply), potable recycled water (+300% increase in supply), and captured stormwater (+19,000% increase in supply). Further, there are decreases in the statewide shares of imported water from the SWP and CRA from 13 percent to 12 percent,

[94] These water supply values are water production estimates and do not include conveyance losses, such as from the SWP, CRA, or CVP.

[95] See the Appendix, for detailed tables of water supply results for the 2015 Constant Per-Capita Demand Scenario and Declining Per-Capita Demand Scenario.

FIGURE 4a 2015 Constant Per-Capita Demand Scenario (Mid-case): Change in Urban Water Demand Between 2015 and 2035, by Hydrologic Region

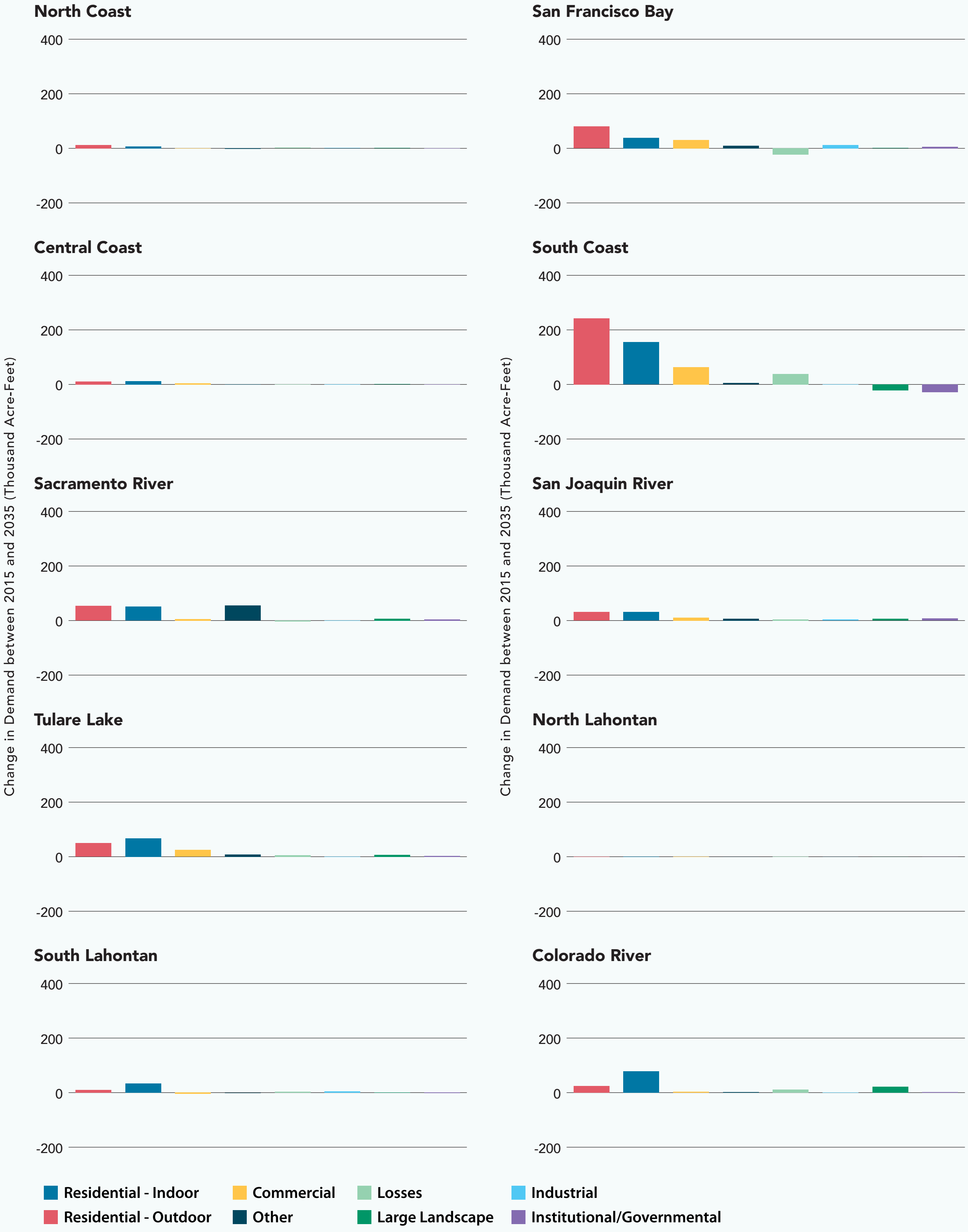
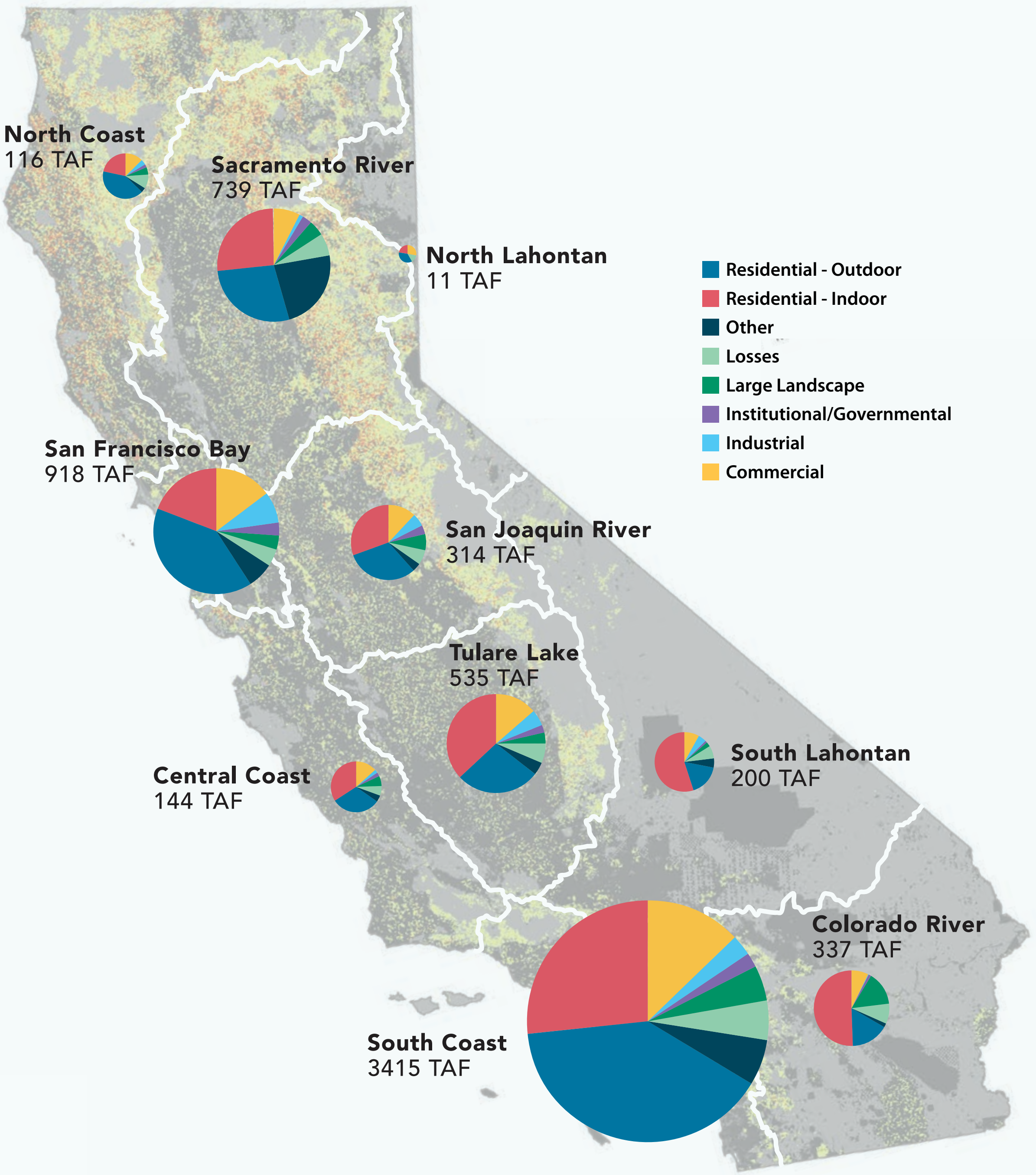


FIGURE 4b 2035 Urban Water Demand, by Hydrologic Region



and 16 percent to 13 percent respectively, between 2015 and 2035. Although many alternative water sources are energy-intensive because of the combined energy use for associated supply extraction/generation, treatment, and conveyance, in many regions, their energy needs are typically lower than for imported water (Table 4).

There is significant variation in how these supply changes are distributed across hydrologic regions under the 2015 Constant Per-Capita Demand Scenario (Figure 5). The absolute largest increases in groundwater and non-potable recycled water are projected to occur in the South Coast, which also sees increases in potable

TABLE 12 State Annual Water Supply by Source (AF)—2015 Constant Per-Capita Demand Scenario (Mid-Case)

Supply Source	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Central Valley Project Deliveries	259,046	270,119	292,069	310,375	325,568	26%	66,522
Colorado River Deliveries	871,975	816,885	848,783	877,729	906,259	4%	34,283
Desalinated Water (Brackish)	205	3,495	7,206	10,860	14,595	7,013%	14,390
Desalinated Water (Seawater)	27,888	29,882	32,332	32,783	33,238	19%	5,350
Exchanges	2,216	3,858	1,162	1,083	1,169	-47%	-1,047
Groundwater	2,063,977	2,006,160	2,075,120	2,175,610	2,291,486	11%	227,509
Local Imports	365,972	350,455	367,474	383,598	400,499	9%	34,527
Other	98,094	196,039	200,210	212,057	219,965	124%	121,870
Other Federal Deliveries	28,565	26,593	29,107	31,143	32,428	14%	3,863
Recycled Water- Non Potable	287,519	346,256	403,475	454,109	495,238	72%	207,719
Recycled Water- Potable	17,010	29,555	61,305	63,599	68,653	304%	51,643
State Water Project Deliveries	716,384	687,402	723,632	754,014	784,892	10%	68,508
Stormwater Use	72	2,242	5,003	8,354	13,642	18,834%	13,569
Supply from Storage	14,329	24,266	24,801	25,456	26,155	83%	11,827
Surface Water	648,056	943,758	988,764	1,036,668	1,094,451	69%	446,396
Transfers	30,898	14,583	15,333	18,699	19,748	-36%	-11,150
Total	5,432,207	5,751,547	6,075,776	6,396,138	6,727,985	+24%	1,295,778

recycled water. Although there are also large absolute increases in SWP and Colorado River imports to the South Coast, these sources decrease in their shares of the region's total supply (21% to 18% SWP, 29% to 25% Colorado River) between 2015 to 2035. Increases in surface water are dominant in the San Francisco Bay, Sacramento River, and Tulare Lake hydrologic regions.

Under the 'high-case' Water Supplier Projections Scenario, the increase in supply needed to meet the 44 percent projected demand between 2015 and 2035 primarily comes from surface water, groundwater, and non-potable recycled water (Figure 6). In the Declining Per-Capita Demand Scenario, which requires 17 percent less water by 2035 compared to 2015, the largest absolute reductions in supply deliveries come from groundwater, Colorado River water, and SWP, all of which are relatively energy-intensive water sources.

TABLE 13 State Urban Water Supply Portfolio in 2015 and 2035—2015 Constant Per-Capita Demand Scenario (Mid-Case)

Supply Source	% of 2035 Total Supply	% of 2015 Total Supply
Central Valley Project Deliveries	5%	5%
Colorado River Deliveries	16%	13%
Desalinated Water (Brackish)	0.004%	0.2%
Desalinated Water (Seawater)	1%	0.5%
Exchanges	0.04%	0.02%
Groundwater	38%	34%
Local Imports	7%	6%
Other	2%	3%
Other Federal Deliveries	1%	0.5%
Recycled Water- Non Potable	5%	7%
Recycled Water- Potable	0.3%	1%
State Water Project Deliveries	13%	12%
Stormwater Use	0.001%	0.2%
Supply from Storage	0.3%	0.4%
Surface water	12%	16%
Transfers	1%	0.3%
Total	100%	100%

FIGURE 5a Change in Urban Water Supplies Between 2015 and 2035, by Hydrologic Region

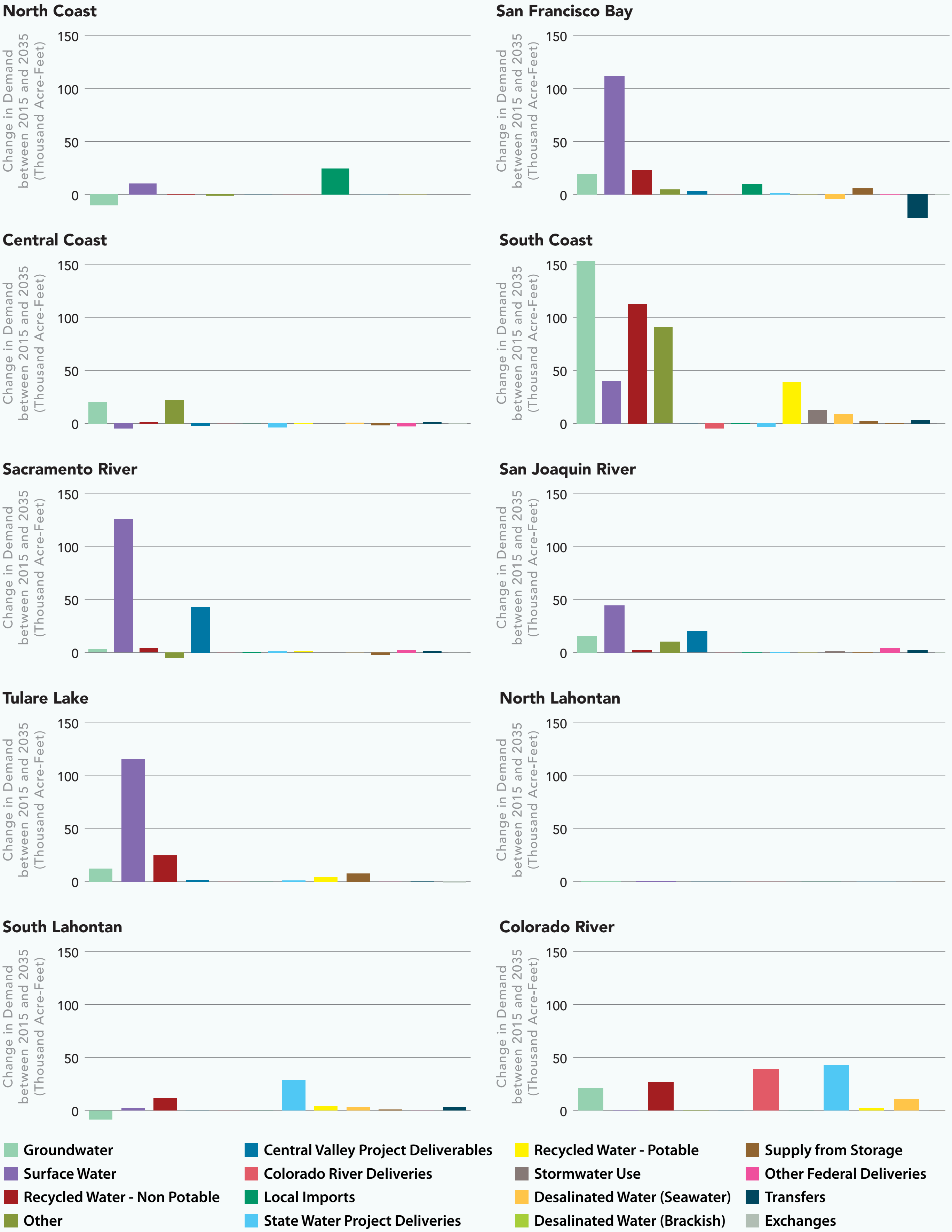


FIGURE 5b 2035 Urban Water Supplies, by Hydrologic Region

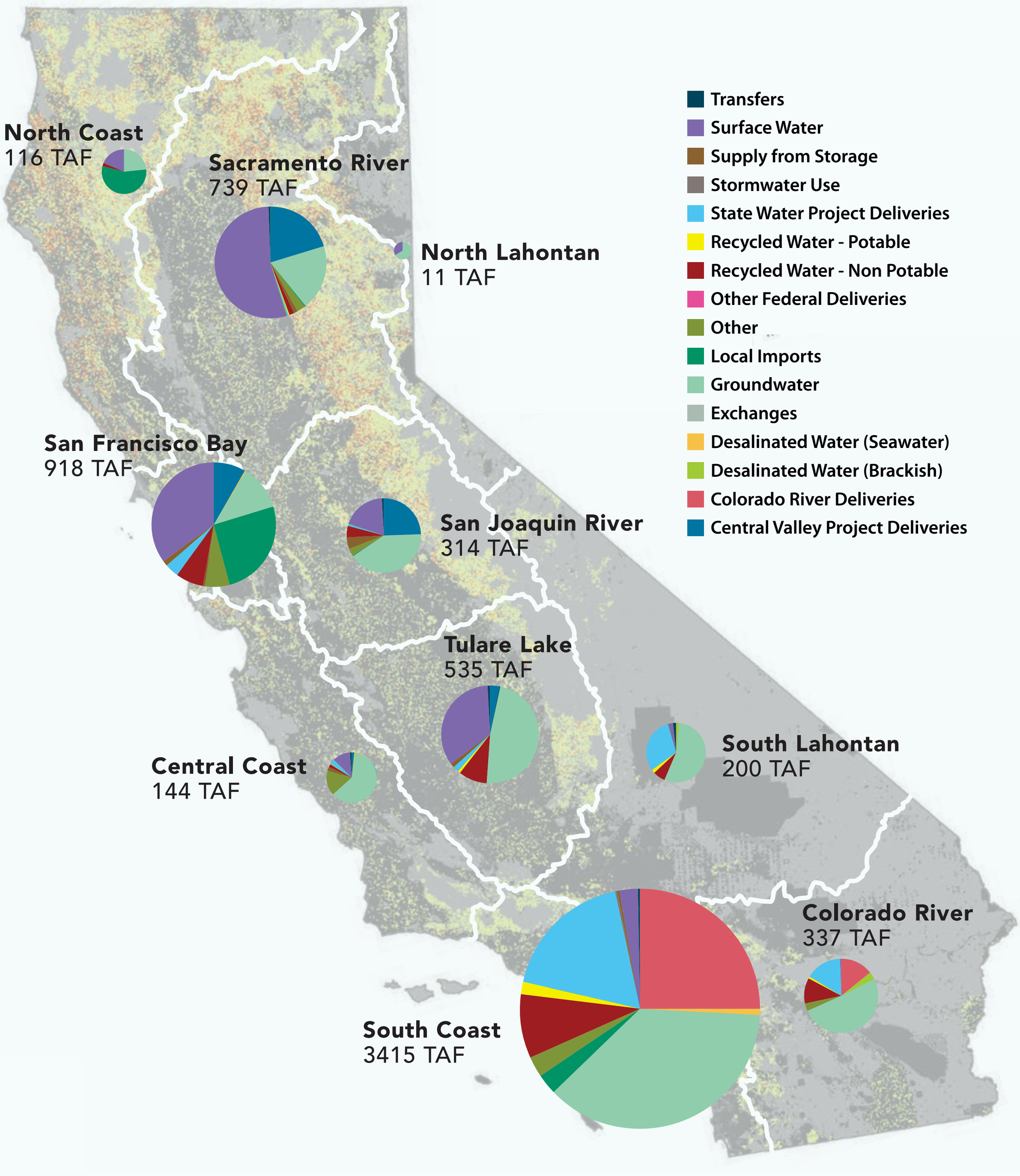


FIGURE 6a Annual Urban Water Supply by Source, California Total

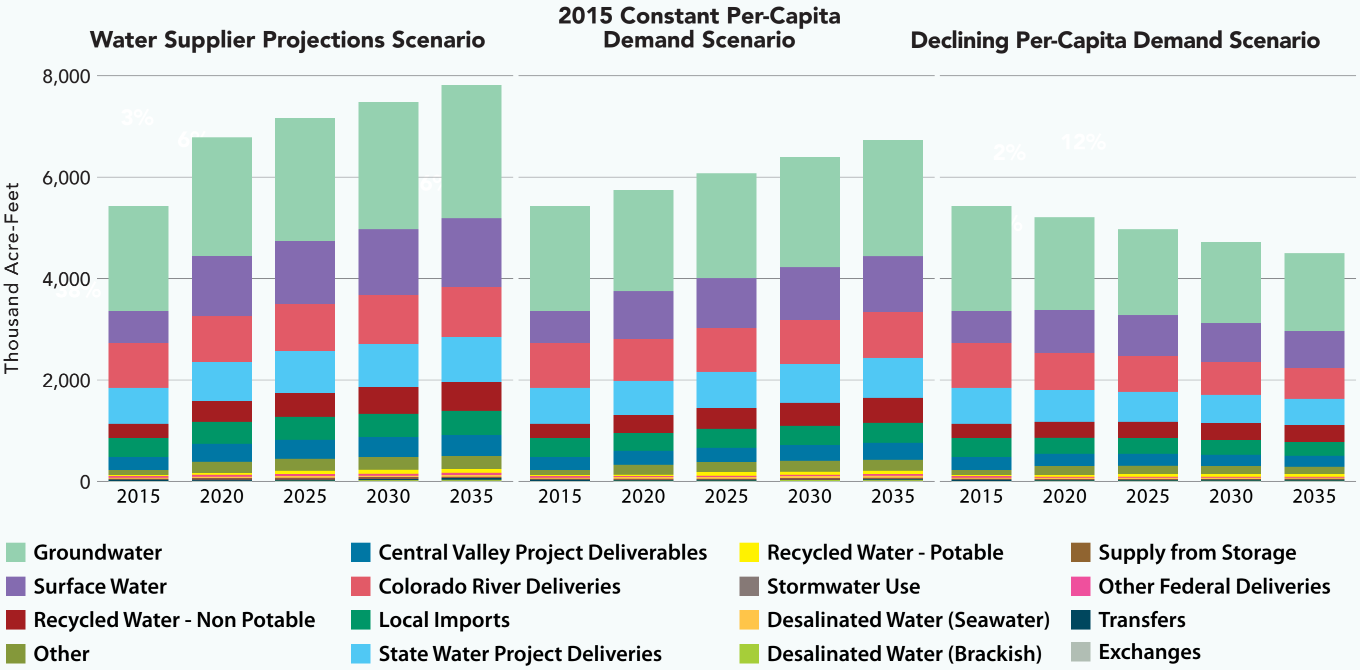


FIGURE 6b 2015-2035 Change in California Total Annual Urban Supply by Source

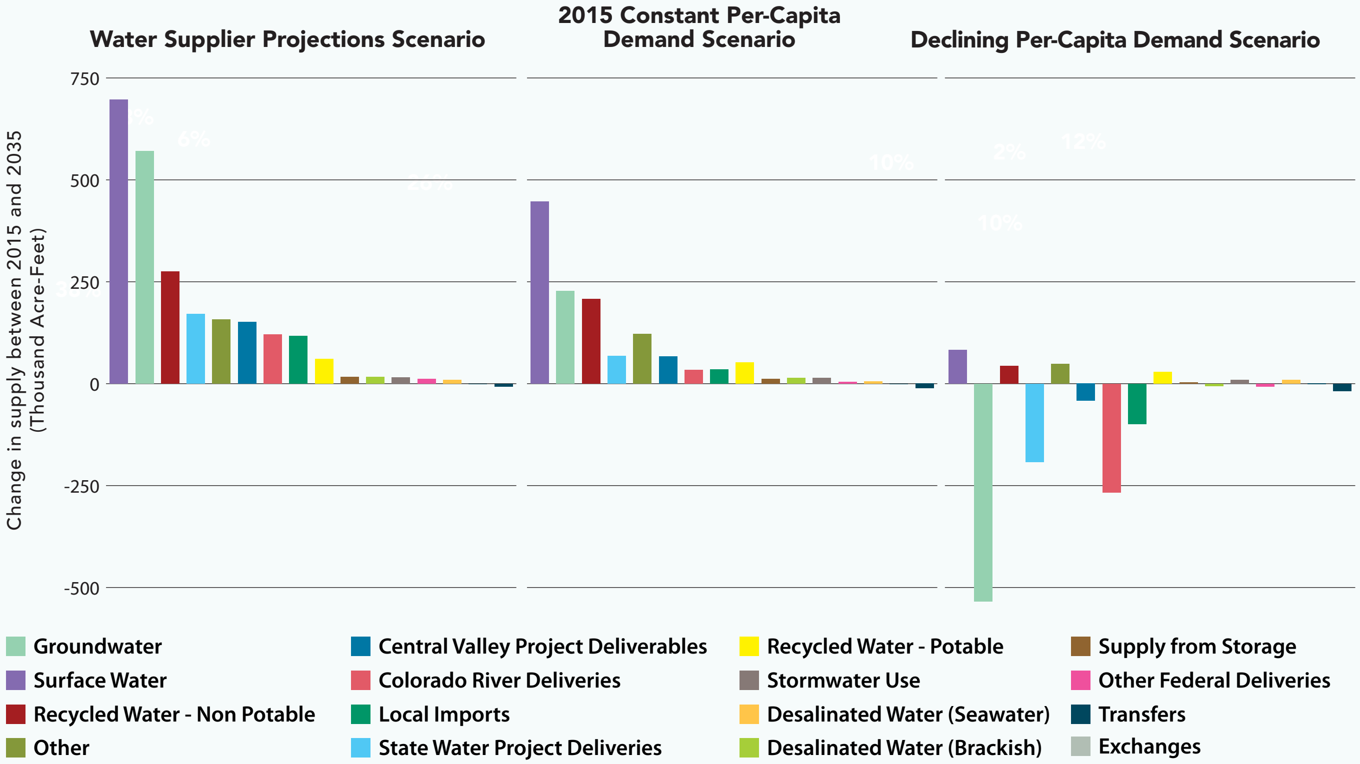


TABLE 14 State Annual Electricity Use Related to Urban Water, by Scenario (GWh)

Scenario	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Water Supplier Projections Scenario (High-Case)	29,917	36,516	38,536	40,173	41,781	40%	11,864
2015 Constant Per-Capita Demand Scenario (Mid-Case)	29,917	31,287	32,994	34,610	36,259	21%	6,342
Declining Per-Capita Demand Scenario (Low-Case)	29,917	28,281	26,958	25,562	24,207	-19%	-5,710

The authors note several limitations of these results. These results are driven in part by the simplifying assumption that increases or decreases in supply deliveries for each year under the 2015 Constant Per-Capita Demand Scenario and Declining Per-Capita Demand Scenario are divided among water sources in the same proportion as water sources for each year in the Water Supplier Projections Scenario. As discussed in Section 3.3.1.3, it is unclear whether urban water supplier projections of these supply source changes are physically, economically, ecologically, or legally possible; these estimates are taken as given and the authors make no assessment or adjustment of supplies for feasibility, but do note there are already serious constraints on existing supply options. In the two alternative demand scenarios, it is also not assumed that water agencies would change how they prioritize which supply sources to increase or conserve, such as based on energy intensity or cost. The authors also note that projections of groundwater usage to 2035 are from the 2015 UWMP and do not account for the Sustainable Groundwater Management Act (SGMA), which was passed in 2014 and seeks to limit groundwater pumping by 2040.[96] Additionally, what appears to be a statewide increase in CVP and SWP volumes from 2015 to 2035 may be a consequence of below-average deliveries from those sources in 2015 due to the 2012 to 2016 statewide drought.

4.1.3 Energy Use for Urban Water: Historical and Future Scenarios

The changing water demands and shifts in supply sources described in the previous sections can have significant effects on the urban water-related electricity footprint. Between 2015 and 2035, the report authors found the total annual water-related electricity usage increases by about 21 percent, about 6,300 GWh annually, under the "mid-case" 2015 Constant Demand Scenario (Table 14). For context, California's total economy-wide annual electricity consumption (not only related to water) is currently about 300,000 GWh, suggesting that under this scenario projected increases in urban water demand could increase the state's overall annual electricity consumption by about 2 percent by 2035. If per-capita demand increases according to water supplier projections ("high-case"), annual electricity usage for urban water increases by about twice that amount (40% or 12,000 GWh) between 2015 and 2035 (Table 14, Figure 7).

In contrast, water conservation and efficiency improvements can lead to significant energy savings along the entire managed water cycle (Figure 1) from avoided water supply, conveyance, treatment, distribution, heating, and wastewater collection and treatment energy. The Declining Per-Capita Demand Scenario ("low-case") leads to a reduction in total electricity usage for urban water by 19 percent between 2015 to 2035, corresponding with an annual savings of 5,700 GWh (Table 14, Figure 7).

In all scenarios, the largest share of statewide electricity use is from end-uses, followed by conveyance, distribution, and wastewater treatment energy (Figure 7). Under the 2015 Constant Per-Capita Demand Scenario (Table 15), between 2015 and 2035, the increase in electricity usage in absolute terms is also dominated by growing end-use electricity.[97]

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[96] Implications of SGMA on groundwater use in California's agricultural sector are explored in the case study in Section 5.3.

[97] See the Appendix, for detailed tables of energy results for the Water Supplier Projections Scenario and Declining Per-Capita Demand Scenario.

TABLE 15 State Annual Electricity Use Related to Urban Water, by Water Cycle Category (GWh) —2015 Constant Per-Capita Demand Scenario (Mid-Case)

Water Cycle Category	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Extraction or Generation	1,277	1,309	1,416	1,495	1,585	24%	308
Conveyance	4,321	4,155	4,352	4,518	4,684	8.4%	363
Treatment	1,308	1,382	1,459	1,529	1,604	23%	296
Distribution	2,483	2,596	2,714	2,825	2,942	19%	459
End-Use	18,152	19,312	20,381	21,436	22,500	24%	4,348
Wastewater Collection	323	345	364	382	400	24%	77
Wastewater Treatment	2,053	2,189	2,309	2,425	2,544	24%	491

While the total urban water-related electricity use increases in the "mid-case" scenario (and the "high-case" scenario), the statewide average energy intensity—the total electricity use divided by total water use—decreases by two percent between 2015 and 2035 (Table 16).[98] This appears to be driven primarily by a reduced energy intensity of urban water in the South Coast region, which has California's highest total water-related electricity usage (Figure 8), due to its relatively high residential water demand (Figure 3) and energy-intensive water supply mix (Figure 5).[99] By 2035, under the 2015 Constant-Per Capita Demand Scenario, the South Coast has a reduced share of energy-intensive imported resources (21% to 18% of South Coast supplies from SWP, 29% to 25% of South Coast supplies from Colorado River, from 2015 to 2035) and an increase in local water sources (such as 1% to 2% potable recycled water, 6% to 9% non-potable recycled water, and 0 to 0.4% captured stormwater, between 2015 and 2035).

Local, alternative water sources have relatively high treatment energy requirements compared to traditional water sources; however, in regions like the South Coast, they are still typically lower than the energy requirements for conveyance of imported water (except for the most energy-intensive source, seawater desalination). For example, extraction, conveyance, and drinking water treatment requires about 350 kWh/AF for local surface water and 400 kWh/AF to 700 kWh/AF, depending on the region, for groundwater (Table 4). By comparison, extraction/generation, conveyance, and drinking water treatment requires 500 kWh/AF for non-potable recycled water, 700 kWh/AF for captured stormwater, 1,800 kWh/AF for indirect potable recycled water, 2,100 kWh/AF for brackish groundwater desalination, and 4,600 kWh/AF for seawater desalination. Energy requirements for SWP and Colorado River conveyance and treatment can reach up to 4,200 kWh/AF and 2,300 kWh/AF, respectively, depending on the region.

TABLE 16 Urban Water System Energy Intensity (Electricity) by Hydrologic Region (kWh/AF)

Hydrologic Region	2015	2035	% Change 2015-2035
Central Coast	4,639	4,638	0.0%
Colorado River	2,824	3,056	8.2%
North Coast	5,169	5,170	0.0%
North Lahontan	4,771	4,887	2.4%
Sacramento River	3,485	3,466	-0.5%
San Francisco Bay	5,886	6,104	3.7%
San Joaquin River	4,241	4,215	-0.6%
South Coast	6,356	6,274	-1.3%
South Lahontan	4,102	4,262	3.9%
Tulare Lake	4,101	4,011	-2.2%
State Volume-Weighted Average Urban Energy Intensity	5,507	5,389	-2%

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[98] The energy intensity for each hydrologic region for a given year is the same across scenarios because we use the Water Supplier Projections Scenario proportions of energy supplies and demands per year and per hydrologic region for all scenarios.

[99] The San Francisco Bay and Sacramento hydrologic regions are the second and third highest overall electricity users, driven by high residential water demand. The San Francisco Bay, North Lahontan, South Lahontan, and Colorado River regions also all see an increase in energy intensity by 2035, and Tulare Lake has a decrease in energy intensity. The remaining regions (North Coast, Central Coast, Sacramento, and San Joaquin Valley) have negligible changes (+ or - < 1%) between 2015 and 2035.

FIGURE 7a State Urban Water-Related Electricity Use 2015 – 2035, by Scenario

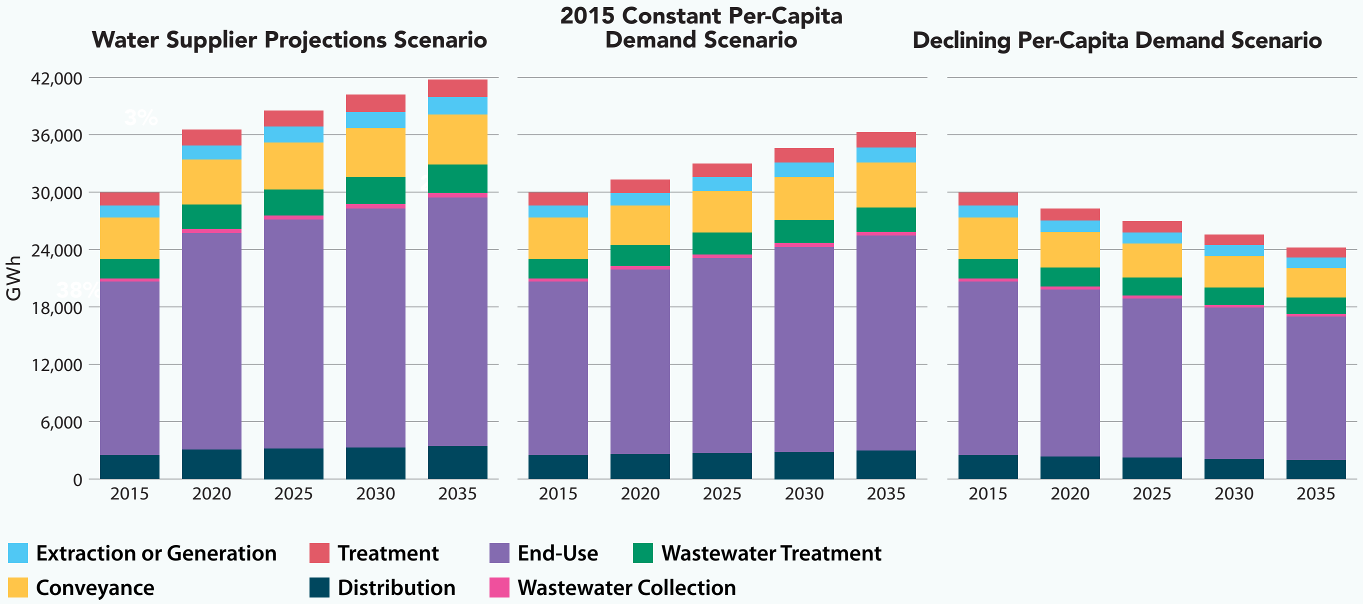

FIGURE 7b Change in State Urban Water-Related Electricity Use Between 2015 and 2035, by Scenario

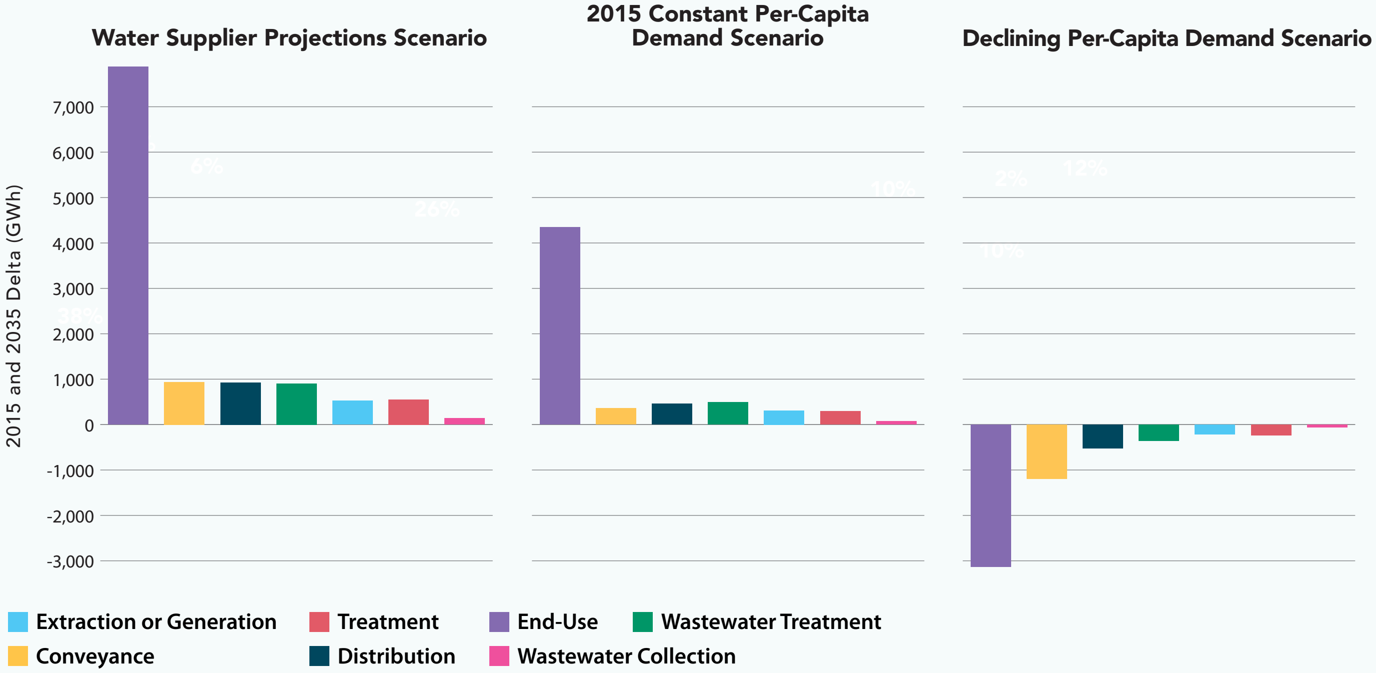

FIGURE 8a 2015 Constant Per-Capita Demand Scenario (Mid-Case): Change in Urban Water-Related Electricity Use

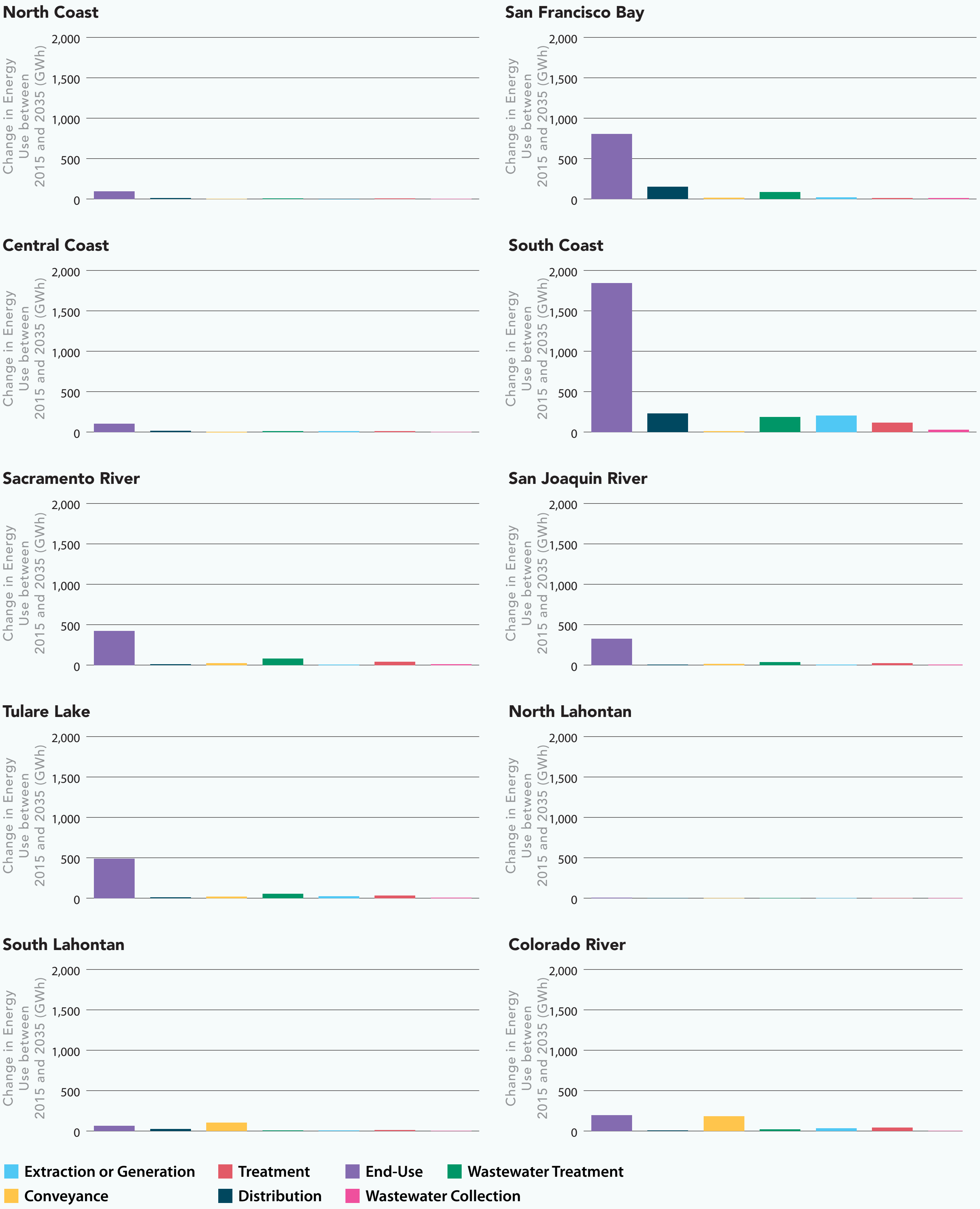

FIGURE 8b 2035 Urban Water-Related Electricity Use, by Hydrologic Region

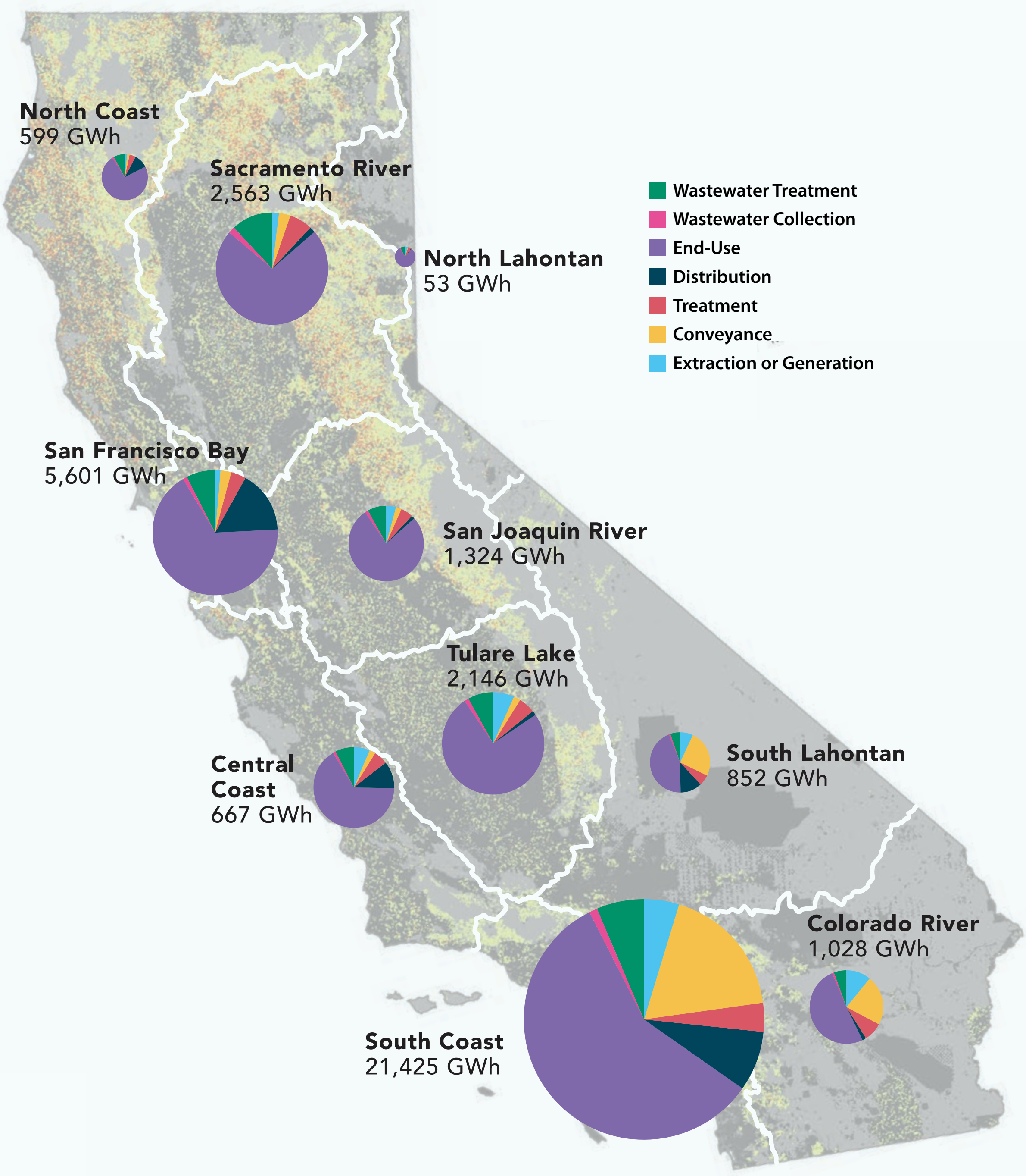

TABLE 17 State Annual Natural Gas Use by Urban Water Heating End-Uses, by Scenario (MMBtu)

Scenario	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Water Supplier Projections Scenario (High-Case)	154,350,857	194,004,931	205,011,788	214,461,995	223,580,559	45%	69,229,701
2015 Constant Per-Capita Demand Scenario (Mid-Case)	154,350,857	165,430,605	174,822,102	184,120,659	193,396,108	25%	39,045,251
Declining Per-Capita Demand Scenario (Low-Case)	154,350,857	149,536,164	142,842,381	135,985,823	129,112,787	-16%	-25,238,070

As noted in Section 3.1.1, California currently does not allow for direct potable reuse because state regulators have not yet developed water quality and public health standards.[100] As a result, for potable applications, water suppliers are currently required to pump treated recycled water to an environmental buffer and then treat it a second time at a conventional drinking water treatment plant before distribution and use.[101] The authors estimate that this increases energy usage for indirect potable recycled water by approximately 580 kWh/AF. This would be higher in regions with hilly terrain where energy requirements for pumping between the wastewater treatment plant to the buffer and drinking water treatment plant are higher. While the regulatory requirements for direct potable reuse have not yet been established, this suggests that the energy footprint of potable recycled water could be substantially lower than indirect potable reuse because it avoids these additional steps.[102] Additionally, some energy-water research suggests that there are opportunities to lower the energy usage and/or shift the timing of energy demands to avoid peak times of some certain parts of the managed water cycle, such as at wastewater treatment plants, through demand response programs and the installation of variable speed drives.[103] It is unclear however, if typical treatment plants have the water storage capacity available to implement such programs.

Increased water demand, especially for indoor residential uses, is expected to also raise natural gas usage. The authors found that between 2015 and 2035, natural gas usage for water heating in the residential and CII sectors increases 25 percent in the 2015 Constant Per-Capita Demand Scenario (from about 150,000,000 to 190,000,000 MMBtu), and 45 percent in the Water Supplier Projections Scenario (Table 17). As with electricity, the Declining Per-Capita Demand Scenario shows that water efficiency improvements save natural gas; annual water heating natural gas usage in 2035 is 16 percent lower (or about 25,000,000 MMBtu) than in 2015.

4.1.4 GHG Emissions Related to Urban Water: Historical and Future Scenarios

The results of this study show that the decarbonization of California's electricity generation to meet SB 100 goals will reduce the GHG emissions associated with urban water-related electricity usage. Despite an overall

[100] Regulating Direct Potable Reuse in California. California State Water Resources Control Board. Available at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/direct_potable_reuse.html

[101] Environmental Protection Agency and CDM Smith. "2017 Potable Reuse Compendium." Environmental Protection Agency. 2017. Available at: https://www.epa.gov/sites/production/files/2018-01/documents/potablereusecompendium_3.pdf

[102] In this analysis we assume that proportion of non-potable to potable recycled water is as projected by water suppliers in the future which does not take possible change in legislation into account; the energy usage would be higher if a higher share of recycled water is treated to potable quality.

[103] Zohrabian, A., Sanders, K.T. "The Energy Trade-Offs of Transitioning to a Locally Sourced Water Supply Portfolio in the City of Los Angeles." Energies 13, 5589. 2020. Available at: https://doi.org/10.3390/en13215589

TABLE 18 Urban Water-Related GHG Emissions from In-State Electricity, by Scenario (Million Tons CO_2-Equivalent)

Scenario	Fuel	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Water Supplier Projections Scenario (High-Case)	Electricity	7.7	7.0	6.8	5.3	4.3	-44%	-3
	Natural Gas	8.2	10.3	10.9	11.4	11.9	45%	4
	Total	15.9	17.3	17.7	16.7	16.2	2%	0.3
2015 Constant Per-Capita Demand Scenario (Mid-Case)	Electricity	7.7	6.0	5.8	4.6	3.7	-52%	-4
	Natural Gas	8.2	8.8	9.3	9.8	10.3	25%	2
	Total	15.9	14.8	15.1	14.3	14.0	-12%	-2
Declining Per-Capita Demand Scenario (Low-Case)	Electricity	7.7	5.4	4.7	3.4	2.5	-68%	-5
	Natural Gas	8.2	7.9	7.6	7.2	6.9	-16%	-1
	Total	15.9	13.4	12.3	10.6	9.3	-41%	-7

increase in electricity use, GHG emissions decline by more than half (-52%) between 2015 and 2035 in the 2015 Constant Per-Capita Demand Scenario (Table 18) because of large reductions in in-state electricity GHG intensity (Table 5). The decrease in GHG emissions is more dramatic in the Declining Demand Scenario (-68%), but still substantial under Water Supplier Projections Scenario (-44%). This analysis assumes that water-related electricity demand is met by in-state generation; if California meets water-related electricity demand by importing electricity from neighboring regions that have more GHG-intensive (fossil fuel) generating portfolios, overall GHG emissions will be higher.

However, when GHG emissions from natural gas water heating end-uses are accounted for, the authors find total GHG emissions (from electricity plus natural gas) increase two percent in the Water Supplier Projections Scenario between 2015 and 2035 (Table 18). GHG emissions still decline under the 2015 Constant Per-Capita Demand Scenario and Declining Per-Capita Demand Scenario, but at more modest rates (-12% and -41%, respectively). In this analysis, the electric share of water heaters in the residential and CII sectors is held constant at current levels (about 30% and 44%, respectively). However, with the state's energy policy moving in favor of electrification across the building sector, a greater share of water heaters may shift to electric from natural gas, which would have the effect of driving down overall GHG emissions from the water system.

TABLE 19 Central Valley Agricultural Water Supply Delivered, by Scenario (AF)

Level of Ag Use	Urban Growth, Climate Scenarios	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Low Ag Water use	HIP_LOD, Cmcc_cms, RCP 4.5	23,342,447	23,863,569	23,775,521	23,223,430	22,618,405	-3%	-724,043
Mid Ag Water use	CTP_CTD, Cmcc_ cms,RCP 4.5	23,448,421	24,050,344	24,034,625	23,554,631	23,071,053	-2%	-377,368
High Ag Water use	LOP_HID, GFdl_cm3, RCP 8.5	25,084,130	24,300,280	23,479,049	24,275,013	23,877,242	-5%	-1,206,889

4.2 Agricultural Water Results

Here, the projected agricultural demand, supply, energy, and GHG results of the analysis across scenarios are provided for Central Valley in aggregate, by hydrologic region, and by supply source and demand sector.

4.2.1 Agricultural Water Demand: Historical and Future Water Scenarios

Under all three scenarios of future agricultural water (Table 19), total Central Valley water supply deliveries[104] decline between 2015 and 2035, decreasing by three percent (0.7 MAF) under the Low Ag Water Use Scenario, by two percent (0.3 MAF) under the Mid Ag Water Use Scenario, and by five percent (1.2 MAF) under the High Ag Water Use Scenario.[105] As noted in Section 3.3.2.3, these overall declining trends are largely driven by DWR's assumptions that urban population growth will reduce agricultural land and subsequently water use. However, these scenarios do not account for economic factors, such as crop values on domestic and international markets, federal and state agricultural policies, and other factors that affect farmers' land use choices.[106] Even with decadal averaging, differences in agricultural water deliveries between years are also affected by natural inter-annual variations in climatic conditions (temperature, precipitation, and evapotranspiration drive irrigation demands).[107] The overall effect of climate change across the scenarios appears to be minimal in this near-term time horizon.

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[104] The report authors use the "supplies delivered" variable from DWR's WEAP simulation results to represent agricultural water demand to be consistent with the urban analysis where we balance demand to equal supply, and because "supplies delivered" represents the actual water use given supply availability to agricultural water users in Central Valley. We do not use the "water demand" variable from WEAP because it represents a theoretical "requested" water demand based on crop acreage and climate, which may not be met if there are insufficient supplies after the (user-specified) higher priority urban water demands are satisfied (Rayej, M., Kibrya, S., Shipman, P., Correa, M. "Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document." California Department of Water Resources. June 2019. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/SupportingDocs/Future-Scenarios-of-Water-Supply-in-the-Central-Valley.pdf).

[105] The 2015 values differ by scenario because they are all simulated data, even for the historical period, using simulated historical climate data from each GCM (climate model) which differ slightly. 2006 is the base year for DWR's WEAP simulations. We use this simulated data for all years to maintain a consistent dataset across all scenarios, rather than mixing with historical observed data for 2015. For reference, observed data for 2015 from DWR Water Balance Data shows that the total Applied Crop Water across the three Central Valley Hydrologic regions was 24.3 MAF, about equivalent to the average between the "Low Ag water use" and "High Ag water use" scenarios (24.2 MAF) ("Water Portfolios." *California Department of Water Resources Water Portfolios*, http://water.ca.gov/Programs/California-Water-Plan/Water-Portfolios. Accessed 13 May 2019.).

[106] Rayej, M., Kibrya, S., Shipman, P., Correa, M. "Future Scenarios of Water Supply and Demand in Central Valley, California through 2100: Impacts of Climate Change and Urban Growth, California Water Plan Update 2018 Supporting Document." California Department of Water Resources. June 2019. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2018/Final/SupportingDocs/Future-Scenarios-of-Water-Supply-in-the-Central-Valley.pdf

[107] The Low Ag water use and High Ag water use scenarios are based on DWR WEAP simulations with two different climate models, which may have different climate data for particular years and different patterns of underlying inter-annual variability. This results in the 2025 water supply deliveries in the High Ag water use scenario to be lower than in the Low Ag water use scenario, even though the trend is for the High Ag water use scenario to be higher in the remaining years of this analysis.

TABLE 20 Agricultural Water Supply Deliveries by Hydrologic Region, by Scenario (AF)

Hydrologic Region	Level of Ag Use	Urban Growth, Climate Scenarios	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
Sacramento River	Low Ag Water Use	HIP_LOD, Cmcc_ cms, RCP 4.5	7,791,897	8,124,773	8,281,018	8,054,964	7,926,691	2%	134,794
San Joaquin River			6,407,804	6,547,874	6,548,395	6,478,338	6,209,435	-3%	-198,369
Tulare Lake			9,142,747	9,190,922	8,946,108	8,690,128	8,482,279	-7%	-660,468
Sacramento River	Mid Ag Water Use	CTP_ CTD, Cmcc_ cms, RCP 4.5	7,827,603	8,188,157	8,372,529	8,170,778	8,084,196	3%	256,593
San Joaquin River			6,445,920	6,615,489	6,644,809	6,602,755	6,374,638	-1%	-71,282
Tulare Lake			9,174,898	9,246,698	9,017,288	8,781,097	8,612,219	-6%	-562,679
Sacramento River	High Ag Water Use	LOP_HID, GFdl_ cm3, RCP 8.5	8,291,290	8,140,020	7,859,446	8,118,026	8,169,114	-1%	-122,177
San Joaquin River			6,912,865	6,640,439	6,403,358	6,671,952	6,501,189	-6%	-411,677
Tulare Lake			9,879,975	9,519,821	9,216,245	9,485,035	9,206,939	-7%	-673,036

TABLE 21 Central Valley Annual Agricultural Water Supply by Source (AF)—Mid Ag Water Use Scenario

Supply Source	2015	2020	2025	2030	2035	% Change 2015-2035	Change 2015-2035
State Water Project Deliveries	827,354	834,614	815,022	794,036	778,624	-6%	-48,730
Central Valley Project Deliveries	4,384,778	4,513,291	4,529,638	4,436,782	4,352,714	-1%	-32,064
Other Federal Deliveries	233,993	244,505	249,760	243,989	241,072	3%	7,079
Surface water	6,386,804	6,575,142	6,604,000	6,480,093	6,345,748	-1%	-41,056
Local Imports	29,808	31,165	31,852	31,099	30,750	3%	942
Return Flows	1,261,943	1,305,528	1,321,200	1,302,645	1,270,991	1%	9,048
Groundwater	10,323,741	10,546,099	10,483,153	10,265,987	10,051,153	-3%	-272,588
Total	23,448,421	24,050,344	24,034,625	23,554,631	23,071,053	-2%	-377,368

FIGURE 9a Central Valley Agricultural Water Supply 2015–2035, by Scenario

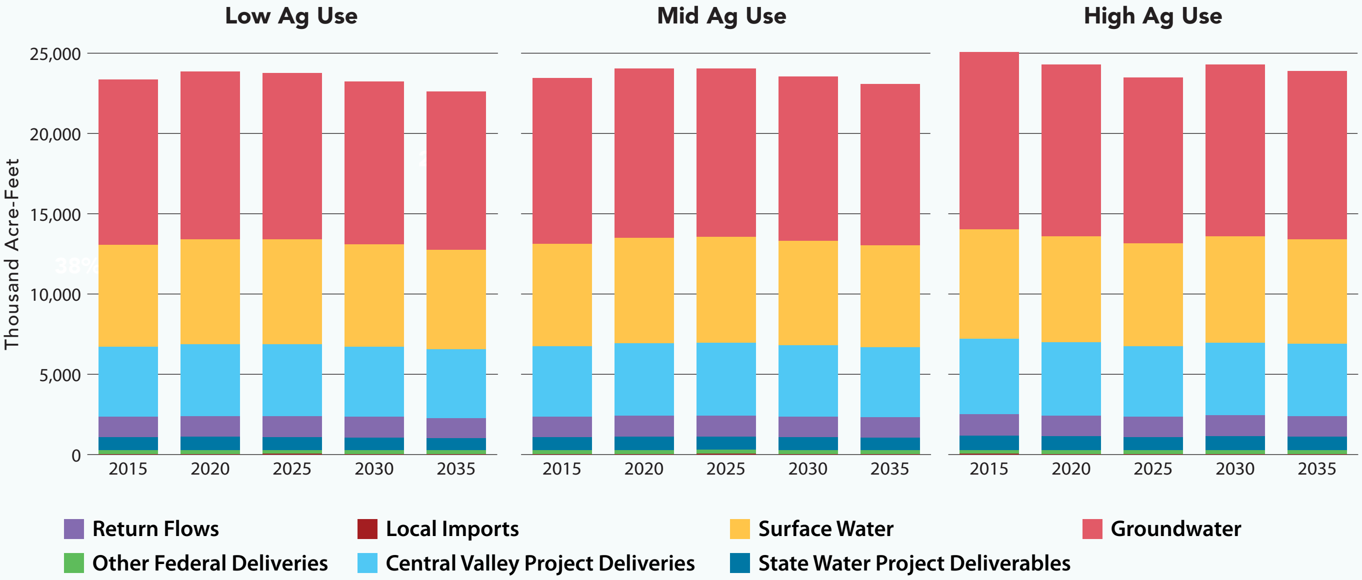
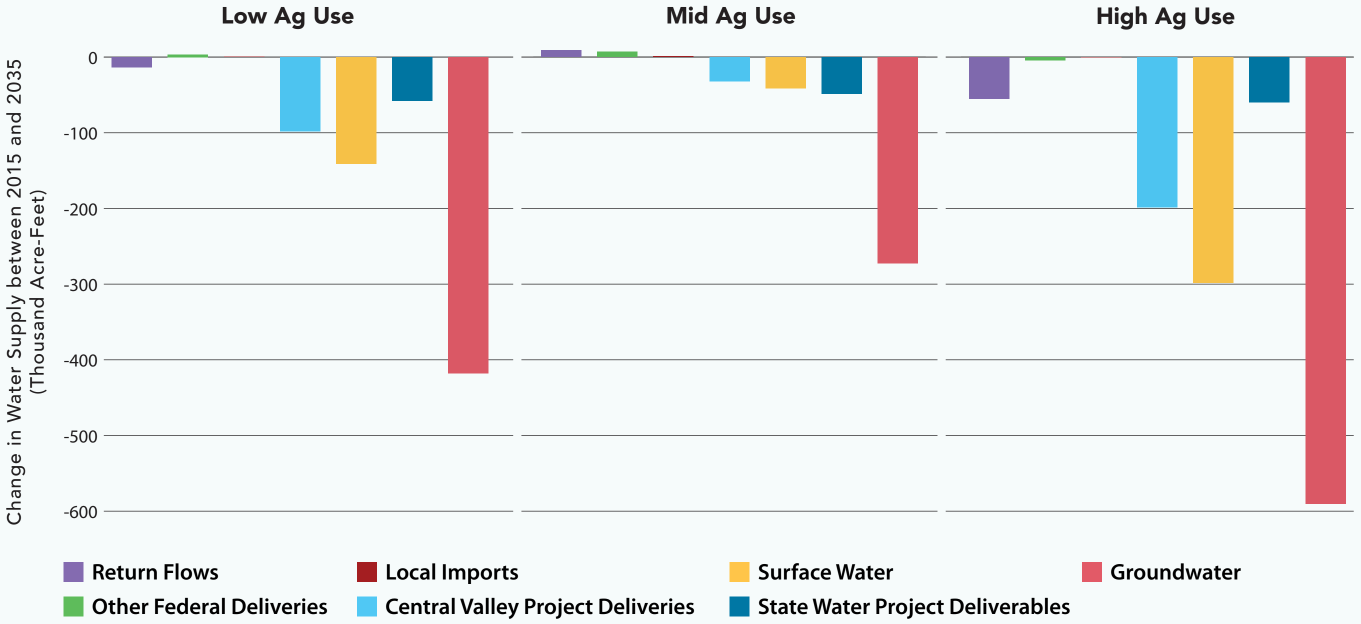


FIGURE 9b Change in Total Central Valley Agricultural Water Supply Between 2015 and 2035, by Scenario



Across all three scenarios (Table 20), the Tulare Lake hydrologic region, which has the highest agricultural water demand among the Central Valley regions, experiences the largest percentage declines (up to -7%) in supply deliveries between 2015 and 2035. In contrast, the Sacramento River hydrologic region sees an increase in supply deliveries in all but the High Ag Water Use Scenario.

4.2.2 Agricultural Water Supply: Historical and Future Water Scenarios

The analysis found that the largest absolute and percentage decreases in Central Valley agricultural water supplies come from SWP deliveries and groundwater, both of which are relatively energy-intensive water sources. Table 21 shows results for the Mid Ag Water Use Scenario, and Figure 9

FIGURE 10a Mid Ag Use Scenario: Change in Agricultural Water Supply by Source Between 2015 and 2035, by Hydrologic Region

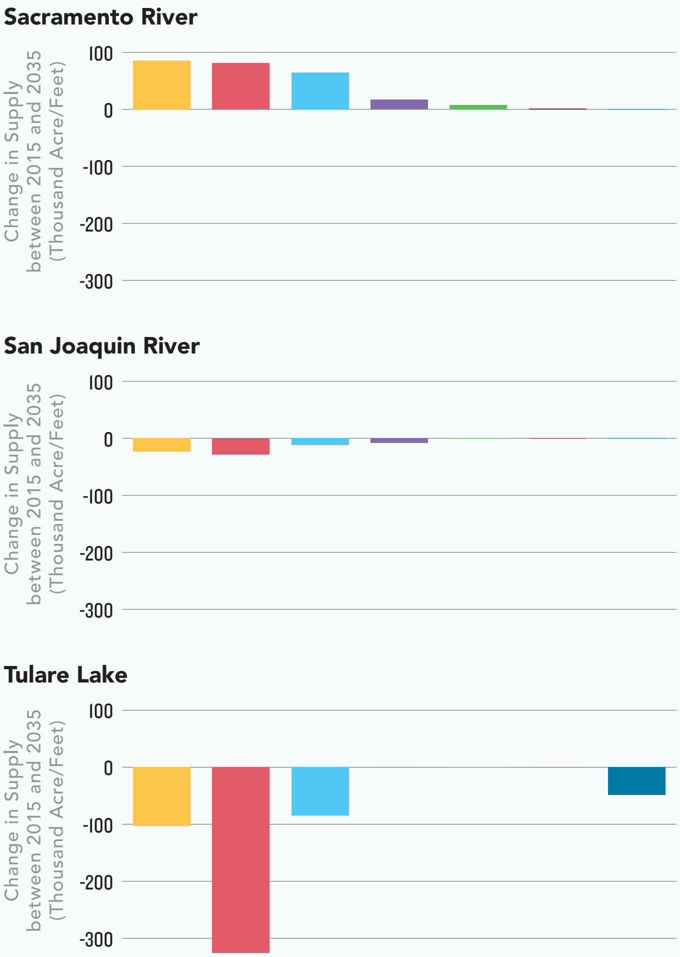
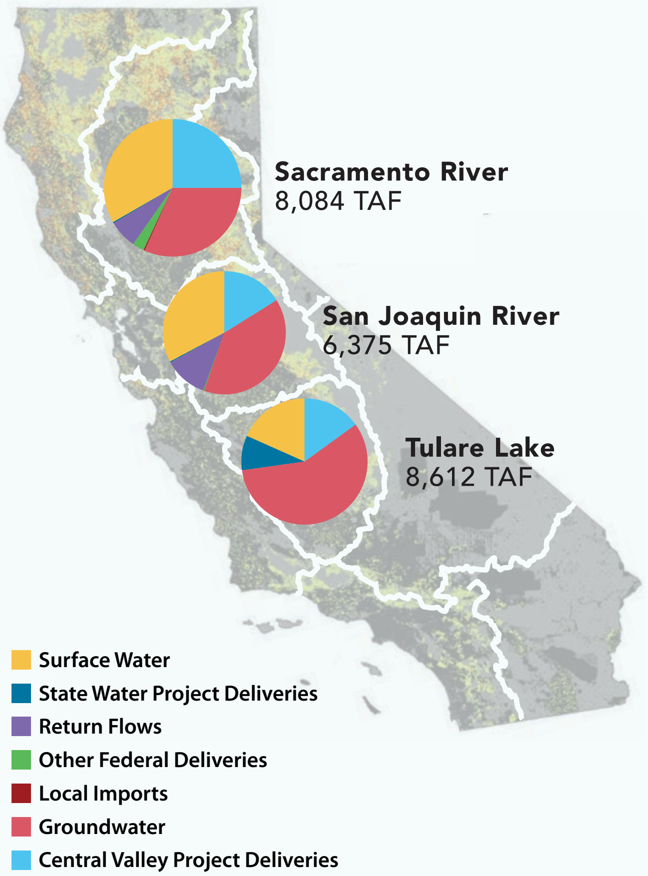


FIGURE 10b Mid Ag Use Scenario: 2035 Agricultural Water Supply Volumes by Source, by Hydrologic Region



compares differences between 2015 and 2035 supplies across scenarios. The authors note that these results would change if it was not assumed that future agricultural water supplies maintain the historical proportion of sources. However, declines in SWP deliveries may be likely in the future due to climate change impacts,[108] and decreased groundwater use is consistent with the goals of SGMA especially in regions with over-drafted basins, such as in Tulare Lake, where Figure 10 shows that supplies are dominated by groundwater use.

4.2.3 Energy Use for Agricultural Water: Historical and Future Scenarios

Despite almost double the water volumes, the authors found that water-related electricity use for agriculture in the Central Valley is about half that of California's urban areas (14,000 GWh in the Mid Ag water use scenario compared to 36,000 GWh in the urban mid-case scenario) in 2035. This relatively lower energy usage is due to much lower end-use energy use (compared to energy-intensive water heating), and the very limited, if any, energy requirements for water treatment, waste-

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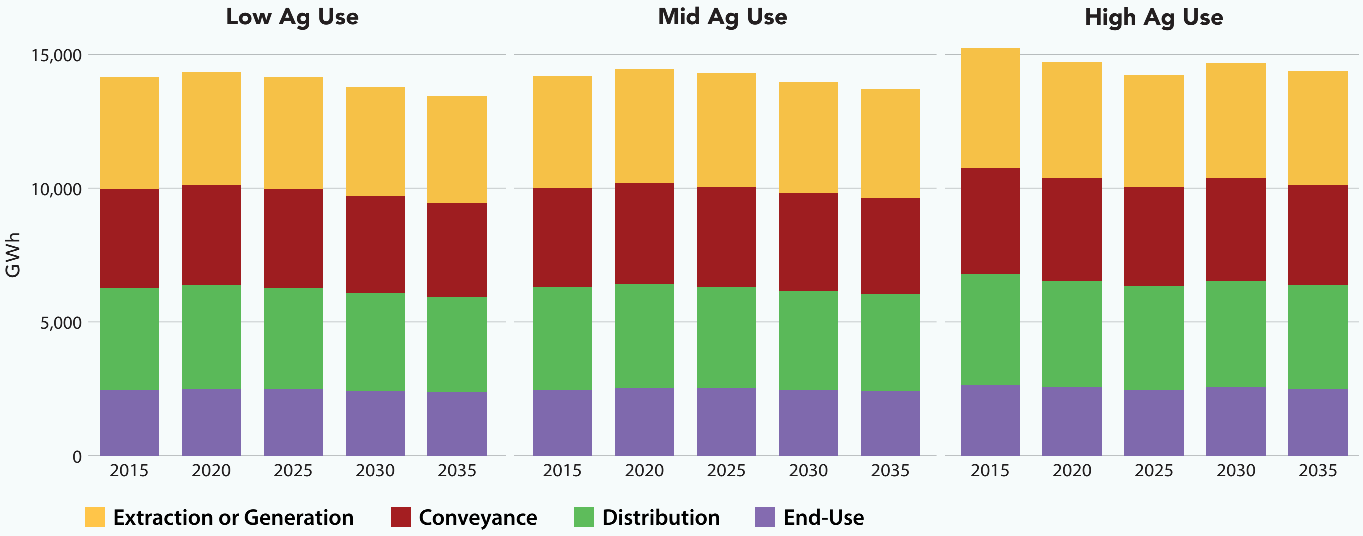
[108] Selmon, Michelle, et al. *Climate Change Action Plan, Phase 3: Climate Change Vulnerability Assessment.* California Department of Water Resources, Feb. 2019, https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAP-III-Vulnerability-Assessment.pdf?la=en&hash=7DF13A5B51C4B4FA808166C596F7EAE67ED58AC5.

TABLE 22 Central Valley Electricity Use Related to Agricultural Sector, by Scenario (GWh)

Level of Ag Use	Urban Growth, Climate Scenarios	2015	2020	2025	2030	2035	Change 2015-2035	% Change 2015-2035
Low Ag Water Use	HIP_LOD, Cmcc_cms, RCP 4.5	14,135	14,342	14,144	13,788	13,434	-701	-5%
Mid Ag Water Use	CTP_CTD, Cmcc_cms, RCP 4.5	14,193	14,444	14,282	13,964	13,678	-515	-4%
High Ag Water Use	LOP_HID, GFdl_cm3, RCP 8.5	15,230	14,714	14,228	14,684	14,354	-876	-6%

FIGURE 11 Central Valley Electricity Use by Agricultural Water, by Scenario



water collection, and wastewater treatment within the agricultural sector. Declining supply deliveries over time in the scenarios further decrease electricity use related to agricultural water in the Central Valley. Across the three scenarios of agricultural water use, electricity use decreases 5 percent (700 GWh) under the Low Ag Water Use Scenario and decreases 6 percent (876 GWh) under the High Ag Water Use Scenario (Table 22). Among the water cycle categories (Figure 11), Central Valley-wide electricity use for agricultural is much more evenly split between supply extraction/generation, conveyance, distribution, and end-use than in urban areas.

Electricity use is greatest in Tulare (Figure 12), not just because of high overall agricultural water use but also because of relatively high energy intensities for distribution (389 kWh/AF) and groundwater pumping (450 kWh/AF) compared to neighboring San Joaquin Valley (19 kWh/AF for distribution, 365 kWh/AF for groundwater pumping) and Sacramento River (19 kWh/AF for distribution, 350 kWh/AF for groundwater pumping). The 2035 energy intensity for Tulare's combined agricultural water supply and demands is 1,009 kWh/AF, about three times that in the Sacramento River (313 kWh/AF) and San Joaquin River (396 kWh/AF) (Table 23).

FIGURE 12a Change in Agricultural Water Supply by Source Between 2015 and 2035, by Hydrologic Region

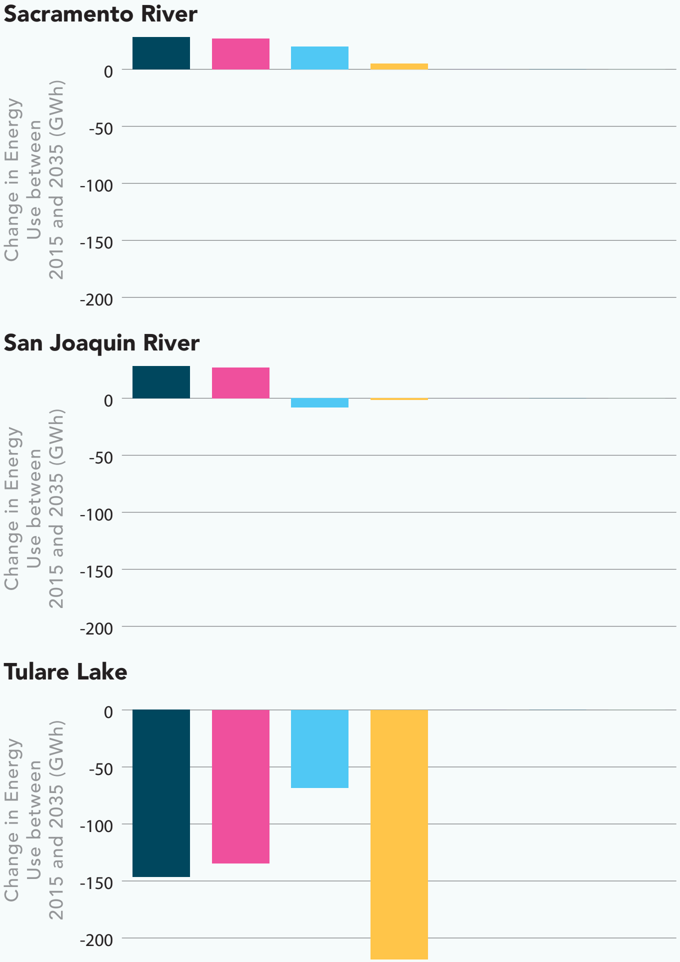


FIGURE 12b 2035 Agricultural Water Supply Volumes by Source, by Hydrologic Region

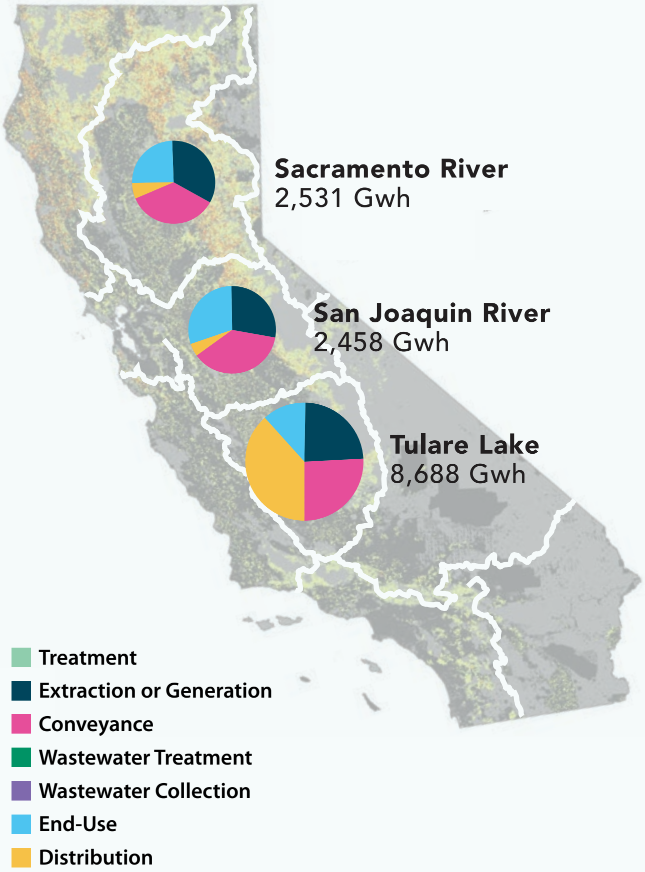


TABLE 23 2035 Agricultural Water System Energy Intensity (Electricity) by Hydrologic Region (kWh/AF)

Hydrologic Region	Energy Intensity (kWh/AF)
Sacramento River	313
San Joaquin River	386
Tulare Lake	1,009
Central Valley Volume-Weighted Average Agricultural Energy Intensity	593

TABLE 24 Central Valley Agricultural Water-Related GHG Emissions from In-State Electricity, by Scenario (Million Metric Tons CO_2-equivalent)

Level of Ag Use	Urban Growth, Climate Scenarios	2015	2020	2025	2030	2035	Change 2015-2035	% Change 2015-2035
Low Ag Water Use	HIP_LOD, Cmcc_cms, RCP 4.5	3.65	2.75	2.49	1.82	1.38	-2.3	-62%
Mid Ag Water Use	CTP_CTD, Cmcc_cms, RCP 4.5	3.67	2.77	2.51	1.84	1.41	-2.3	-62%
High Ag Water Use	LOP_HID, GFdl_cm3, RCP 8.5	3.94	2.82	2.51	1.94	1.48	-2.5	-62%

4.2.4 GHG Emissions Related to Agricultural Water: Historical and Future Scenarios

Across all scenarios, GHG emissions associated with Central Valley's agricultural water sector decrease by more than 60 percent (about two million tons) by 2035, due to the combined effect of lower electricity use and declining GHG intensity of California's electricity generating resources (Table 24). Since this analysis does not include natural gas energy use for agriculture, this result captures the full effect of the decarbonization of California's electricity generation mix. In comparison, in urban California where natural gas GHG emissions are included (and total water demand is rising), total GHG increases by one million tons in the Water Supplier Projections Scenario. Emissions from agricultural pumps that use diesel fuel are also not included in this analysis because of limited available data, but indications are that only a very small share of pumps are diesel-powered in the state.[109]

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[109] 2018 Irrigation and Water Management Survey. Available at: https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/index.php

5. CASE STUDIES

- **5.1** Energy Recovery at EBMUD's Wastewater Treatment Plant
- **5.2** Shifting Los Angeles' Water Portfolio from Imported to Local Sources
- **5.3** The Sustainable Groundwater Management Act and Energy for Groundwater

5.1 Energy Recovery at EBMUD's Wastewater Treatment Plant

5.1.1 Introduction

Wastewater treatment, as currently practiced, is an energy-intensive process. Across the United States, municipal wastewater systems use 0.8 percent of total electricity use in the country, which amounts to about $2 billion in annual electric costs.[110,111] However, wastewater holds the potential to generate far more energy than is needed for treatment, held in the form of chemical or thermal energy. By some estimates, this could be 6 to 9 times more than the energy than it consumes.[112] This means that wastewater treatment systems have the capacity to be net energy-positive or neutral, and further, have the ability to meaningfully reduce greenhouse gas emissions.

East Bay Municipal Water District (EBMUD), which provides water and wastewater service to approximately 1.3 million people in Alameda and Contra Costa counties, has been a leader in implementing energy recovery at its main wastewater treatment plant in Oakland, California, and in 2012, its treatment plant became the first in North America to be a net energy producer. This case study examines the incentives and barriers behind this achievement and how this may be a model for other wastewater treatment plants across the country.

5.1.2 Energy from Waste

EBMUD operates a wastewater treatment plant that serves 740,000 people along the eastern shore of the San Francisco Bay and treats an average of 50 million gallons of wastewater per day. Like many wastewater systems, the treatment plant utilizes anaerobic digestion as part of the process to break down organic matter in wastewater, producing methane. In 1985, EBMUD installed three 2.5 MW engines driven entirely by methane produced during anaerobic digestion to power the system. In 2002, the facility began accepting trucked waste, and now accepts food waste, industrial waste, and other organic materials from neighboring cities and counties. The facility now uses approximately 100 percent biogas, about two-thirds from high-strength waste and the remaining from municipal sludge.

Over the years, several actions have increased the amount of energy generated at the treatment plant. EBMUD received funding from the California Energy Commission in 2004 to install a solid-liquid waste receiving station, allowing high-strength wastes to be taken directly to the wastewater treatment facility for energy recovery. In 2013, they installed a 4.5 MW turbine, which increased the onsite energy production capacity of the system from 40 to 50 percent to over 80 percent of total onsite energy consumption. Since 2013, the facility has generated more energy than is needed to power the plant, selling the excess energy to the power grid through an agreement with the Port of Oakland. This agreement includes both electricity as well as Renewable Energy Credits, in compliance with California's Renewable Portfolio Standard.

By producing energy onsite, the facility improves their energy reliability, and saves approximately $2.5 million in power costs and exports electricity with a revenue of about $750,000 a year. However, in addition to generating surplus power, the facility also produces excess methane that is disposed of through flaring. This excess gas is created because of the timing of solid waste deliveries. Deliveries come in in the latter half of the week and therefore, gas must be flared off in the first half of the week and is used to produce electricity in the second half. EBMUD is exploring options on alternative uses for this excess gas, particularly in their transportation division.

While there are numerous environmental and economic benefits to utilizing onsite energy for wastewater treatment, there are also several challenges. The value of Renewable Energy Credits and electricity has been declining, driving down the value of selling energy back to the grid. Further, alternative waste disposal options, such as landfills and compost, can be cheaper.[113] Regulatory hurdles are a

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[110] Electric Power Research Institute/Water Research Foundation. Electricity Use and Management in the Municipal Water Supply and Wastewater Industries. 2013. Available at: https://www.waterrf.org/research/projects/electricity-use-and-management-municipal-water-supply-and-wastewater-industries

[111] U.S. Department of Energy. Energy Data Management Manual for the Wastewater Treatment Sector. December 18, 2017. Available at: https://www.energy.gov/eere/slsc/downloads/energy-data-management-manual-wastewater-treatment-sector

[112] Capodaglio, A.G., Olsson, G. "Energy Issues in Sustainable Urban Wastewater Management: Use, Demand Reduction and Recovery in the Urban Water Cycle." Sustainability 12. December 2019. Available at: https://doi.org/10.3390/su12010266

[113] Zulkepli, N.E., Muis, Z.A., Mahmood, N. a. N., Hashim, H., Ho, W.S. "Cost Benefit Analysis of Composting and Anaerobic Digestion in a Community: A Review." Chem. Eng. Trans. 56, 1777–1782. 2017. Available at: https://doi.org/10.3303/CET1756297

key barrier in this process. The digestion of food waste is a relatively new concept, and EBMUD, being one of the first to explore this concept, played a significant role in paving the regulatory pathway. However, the future may look different. California legislation passed in 2016 (SB 1383) to reduce methane emissions, will require diversion of organic wastes from landfills and creates a policy incentive for organic wastes to instead go to wastewater treatment facilities for co-digestion with sewage sludge.[114] Offsetting emissions that would have been produced by waste in landfill is a key benefit of the municipal wastewater treatment plant. However, as GHG reporting currently stands, EBMUD is unable to receive full credit for their GHG reductions. Requiring water suppliers to reduce GHG emissions could provide additional incentive for this energy recovery model. EBMUD might also be able to benefit from demand response programs if the treatment plant can be operated to reduce its energy use during peak periods, and/or by shifting operations to increase generation during those times.[115] Further, EBMUD may be able to reduce the flaring of excess methane and coincide power production with peak times by coordinating the timing of deliveries of waste used in the co-digestion process.

Overall, this model has the potential to be scaled. It can leverage existing wastewater infrastructure, which may have excess digestor capacity, and use the proximity of waste generators to wastewater facilities to create a system that powers itself, reduces GHG emissions, and diverts landfill waste. However, logistic, regulatory, and economic challenges remain to be addressed to make the model truly cost-effective and sustainable.

TABLE 25 Volumes of Water by Source for Each Supply Scenario

	Volume of Water (AF)				
Supply Category	**Baseline 2015**	**Projected 2035**	**Projected 2035-SW**	**Projected 2035-IPR**	**Projected 2035-DPR**
Groundwater	90,438	114,670	114,670	114,670	114,670
LA Aqueduct	57,535	288,600	288,600	288600	288,600
MWD- SWP	210,659	28,256	0	0	0
MWD- CRA	151,948	32,374	0	0	0
Recycled Water (non-potable reuse)	10,421	68,940	68,940	68940	68,940
Stormwater Use	0	16,600	77,230	16600	16,600
Indirect Potable Reuse	0	0	0	60630	0
Direct Potable Reuse	0	0	0	0	60,630
TOTAL	521,001	549,440	549,440	549,440	549,440

5.2 Shifting Los Angeles' Water Portfolio from Imported to Local Sources

5.2.1 Introduction

The Los Angeles Department of Water and Power (LADWP), established in 1902, provides water and power to more than four million residents of the City of Los Angeles (LA). LADWP built the Los Angeles Aqueduct in 1913 to import water from the Owens Valley in the Eastern Sierra Nevada and ensure a reliable water supply for the growing city. Today, the Los Angeles Aqueduct represents about 38 percent of LADWP's water supply, which also includes water imported from Northern California through the State Water Project (SWP) (41%) and from the Colorado River Aqueduct (CRA) (8%), local groundwater (11%), and recycled water (2%).[116] Water imports

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[114] Rashi Gupta (Carollo Engineers, Inc.), Sarah Deslauriers (Carollo Engineers, Inc.), Elizabeth Charbonnet (Carollo Engineers, Inc.), Chelsea Ransom (Carollo Engineers, Inc.), Robert Williams (UC Davis). "Co-Digestion Capacity Analysis Prepared for the California State Water Resources Control Board under Agreement #17-014-240." June 2019. Available at: https://www.waterboards.ca.gov/water_issues/programs/climate/docs/co_digestion/final_co_digestion_capacity_in_california_report_only.pdf

[115] Zohrabian, A., Sanders, K.T. The Energy Trade-Offs of Transitioning to a Locally Sourced Water Supply Portfolio in the City of Los Angeles. Energies 13, 5589. October 2020. Available at: https://doi.org/10.3390/en13215589

[116] LADWP Facts & Figures. Los Angeles Dept. Water Power. Available at: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-factandfigures;jsessionid=9rvGgGvQc9Gnz0GyhGh2HQqhgSkSmrWsF1Rp4hzhMqnwTldgFJ9G!1912823497?_adf.ctrl-state=jshn5ui58_21&_afrLoop=37708847717811&_afrWindowMode=0&_afrWindowId=null#%40%3F_afrWindowId%3Dnull%26_afrLoop%3D37708847717811%26_afrWindowMode%3D0%26_adf.ctrl-state%3D1cjn6i6kwb_4

from the SWP and CRA are delivered via the Metropolitan Water District of Southern California (MWD). In recent years, climate pressures, environmental regulations, and groundwater contamination have put pressure on LA's water supplies and increased reliance on imported water from MWD. To diversify water sources, ensure water security, and adapt to climate change, LA is turning to local sources of supply. This case study examines the energy effects of moving supplies away from energy-intensive imported sources to more local supplies, including stormwater capture, indirect potable reuse, and direct potable reuse.

TABLE 26 Total Energy Use Related to LADWP's Water Supply System, for Each Scenario

	Total Energy Use (GWh)			
Scenario	**Water Generation and Extraction**	**Conveyance**	**Treatment**	**TOTAL**
Baseline 2015	4.4	1,015	95	1,115
Projected 2035	103	176	91	370
Projected 2035-SW	103	23	91	217
Projected 2035-IPR	177	37	91	305
Projected 2035-DPR	177	15	77	269

5.2.2 Policy Landscape

The major drought in California from 2012–2016 was a wake-up call for the state and the city of LA that water supplies are increasingly vulnerable to climate change. In response, LA's mayor Eric Garcetti set a goal for LA to reduce per capita water use, reduce the purchase of imported water, and create an integrated water strategy to improve local water security. Following this directive, Mayor Garcetti released the first citywide Sustainable City pLAn in April 2015, with an update in 2019, as a roadmap to create a cleaner environment, stronger economy, and a commitment to equity for the city.[117] The pLAn establishes a 2050 goal for a zero-carbon grid, zero-carbon transportation, zero-carbon buildings, zero waste, and zero-wasted water. It also sets an ambition for the city to lead the nation in water conservation and source most of its water from local sources. Specifically, the 2035 goal is to source 70 percent of L.A.'s water locally—i.e., local groundwater, conservation, stormwater capture, and recycled water, and to recycle 100 percent of all wastewater for beneficial reuse.[118] Some of the near-term priority initiatives are to expand recycled water production using indirect and direct potable reuse (IPR/DPR), such as through Operation NEXT. It is noteworthy that the reduction of imported water was also part of the city's climate goals to reduce energy consumption and associated GHG emissions.

5.2.3 Energy Implications of Shifting to Local Water Sources

This study estimated the energy implications of providing water to the city of LA by shifting to local water sources under a baseline (2015) and three future water supply scenarios. The water supply portfolio for the Baseline and Projected 2035 scenarios were based on estimates provided in LADWP's 2015 Urban Water Management Plan for 2015 and 2035, respectively.[119] Three alternative scenarios for 2035 were then constructed, where water supplies imported through MWD were replaced with local stormwater (Project 2035-SW), indirect potable reuse (Project 2035-IPR), and direct potable reuse (Project 2035-DPR). The water supply portfolios for each of the scenarios are shown in Table 25. The energy requirements for water supply generation and extraction, conveyance, and treatment were then estimated under each of the five scenarios by multiplying the amount of water from each source by its energy intensity using values in Table 4 of this report. To assess the

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[117] L.A.'s Green New Deal: Sustainable City pLAn 2019. Available at: https://plan.lamayor.org

[118] The LA Aqueduct is not considered 'local supplies' in LA's water-related goals. However, it is not considered an imported source either since the Aqueduct is managed by the city and supply from the Aqueduct is expected to stay consistent in the future. Goals around reducing imported water purchases refer to MWD supplies.

[119] Los Angeles Department of Water and Power (LADWP). Urban Water Management Plan 2015. Available at: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-sourcesofsupply/a-w-sos-uwmpln?_afrLoop=923157928852772&_afrWindowMode=0&_afrWindowId=null#%40%3F_afrWindowId%3Dnull%26_afrLoop%3D923157928852772%26_afrWindowMode%3D0%26_adf.ctrl-state%3Dv1sjl5ymy_4

overall embedded energy for water used in Los Angeles, the energy use required to convey water to the LADWP service territory is also included in this analysis, even if the energy consumption occurs outside the LADWP service territory. For example, imported SWP water requires pumping at the Edmonston pumping plant, which is located outside LADWP's boundaries.[120]

In this case study, additional water conservation and efficiency opportunities are not evaluated, although these are examined in other sections of this report. If implemented, however, conservation could reduce future energy requirements for providing water to LA. Likewise, the implications of seawater desalination as an alternative to imported water are not examined, as LADWP does not have any planned desalination projects.[121] Finally, opportunities to shift from the LA Aqueduct to local water sources are not examined.

Table 26 shows the energy implications of each scenario. The actual 2015 water supply is the most energy-intensive scenario, using more than 1,100 GWh of electricity. The highest energy use in this case is for conveyance due to large volumes of imported water from MWD. In 2035, LADWP's water-related energy use would decline 67 percent to 370 GWh due to reduced imports from MWD and more water from stormwater and the LA Aqueduct. Shifting to stormwater has the lowest overall energy use at nearly 220 GWh, followed by direct potable reuse, and indirect potable reuse. Indirect potable reuse is the most energy-intensive due to multiple levels of treatment required. As described in Section 3.1.1, the authors assume indirect potable reuse involves a treatment train following the Orange County Water District Groundwater Replenishment System (i.e., after secondary treatment at a wastewater treatment plant, water is treated with microfiltration, reverse osmosis, and UV/Advanced Oxidation Processes (AOP)), and water is stored in an environmental buffer before receiving conventional drinking water treatment. Shifting imported supplies to direct potable reuse instead of indirect potable reuse would save 36 GWh of electricity. These results are consistent with a recent study, which found that LA city's water supply including imported water, groundwater pumping, treatment, and distribution used a total of 348 GWh, comparable to the 2035 projection in Table 26.[122]

These results suggest that shifting towards local water sources, especially stormwater and direct potable reuse, can be an effective way to cut the overall energy requirements related to providing water to LA. However, these shifts in supply will affect the spatial distribution of energy use within the broader South Coast region.[123] For example, energy use that currently occurs outside LADWP's territory for pumping imported water will likely decrease, while an increase in local supplies will raise treatment energy within the LADWP area.

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[120] If we were to analyze energy use where it occurred, shifts to local water and away from imported water will likely change local energy use for LADWP because new treatment loads for IPR or DPR will be inside of LADWP's territory and decreases in SWP pumping will be outside LADWP's territory.

[121] Los Angeles Department of Water and Power (LADWP). Urban Water Management Plan 2015. Available at: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-sourcesofsupply/a-w-sos-uwmpln?_afrLoop=923157928852772&_afrWindowMode=0&_afrWindowId=null#%40%3F_afrWindowId%3Dnull%26_afrLoop%3D923157928852772%26_afrWindowMode%3D0%26_adf.ctrl-state%3Dv1sjl5ymy_4

[122] Porse, E., Mika, K.B., Escriva-Bou, A., Fournier, E.D., Sanders, K.T., Spang, E., Stokes-Draut, J., Federico, F., Gold, M., Pincetl, S. Energy use for urban water management by utilities and households in Los Angeles. Environ. Res. Commun. 2, 015003. January 2020. Available at: https://doi.org/10.1088/2515-7620/ab5e20

[123] Zohrabian, A., Sanders, K.T. "The Energy Trade-Offs of Transitioning to a Locally Sourced Water Supply Portfolio in the City of Los Angeles." Energies 13, 5589. 2020. Available at: https://doi.org/10.3390/en13215589

5.3 The Sustainable Groundwater Management Act and Energy for Groundwater

5.3.1 Introduction

In 2014, in the middle of the historic 2012 to 2016 drought, California signed into law the Sustainable Groundwater Management Act (SGMA), the state's first framework for regulating groundwater.[124] SGMA applies to all high- and medium-priority unadjudicated alluvial basins in the state. It mandates that local stakeholders in these basins form groundwater sustainability agencies (GSAs) which are then required to develop groundwater sustainability plans (GSPs) that detail how the basin will ensure groundwater levels are maintained at sustainable levels through measurable objectives and minimum thresholds (MT). The main indicators of sustainability that must be considered are: groundwater-level declines, groundwater-storage reductions, land subsidence, interconnected surface-water depletions, seawater intrusion, and water-quality degradation. GSAs in critically overdrafted basins were required to submit GSPs by 2020, and the remaining are required to submit by January 2022. The intent of the GSP is to plan for long-term sustainable groundwater management; however, they only come into effect 20 years after plan submission, in 2040. In the interim period, GSAs will create infrastructure to support maintaining sustainable groundwater levels, such as increased groundwater storage.

According to SGMA, the GSPs are required to set a minimum threshold for groundwater levels in their basin. This is a quantified level of groundwater beyond which any reduction would cause an undesirable effect in the basin. The minimum thresholds, however, only come into effect in 2040. In several Central Valley basins, where the agricultural sector relies heavily on groundwater, these GSP minimum thresholds are actually set at lower depths than current levels, implying that energy use for pumping may increase from current rates as conditions are allowed to worsen.[125] Because the energy consumption for groundwater pumping increases with depth, declining groundwater levels increase the energy required to pump water and contribute to higher GHG emissions. This case study examines the energy implications of declining groundwater levels in the San Joaquin Valley and Tulare Lake regions, as put forth in GSPs submitted in high-priority basins.

5.3.2 Implications for Groundwater Pumping Energy

In this section, the authors calculated the expected change in energy use for groundwater pumping in the San Joaquin Valley and Tulare Lake regions if groundwater depths decreased about 100 feet from 2019 levels (average of 168 feet) to the minimum threshold levels (average of 273 feet).[126] This estimate evaluates the additional energy use, if pumping continued to withdraw historical volumes (2020) of groundwater for agriculture, but depths declined to the minimum threshold levels prescribed by the GSP plans submitted for high-priority basins. The analysis was performed for 2020, the most recent year of available data. Further, the authors also recognize this is an aggregate estimate, and depths and volumes vary across the region. Based on literature estimates, pump efficiency is assumed to be 30 percent (low efficiency), 50 percent (medium efficiency), and 70 percent (high efficiency).[127,128]

The authors estimate that pumping one acre-foot of water from 2019 depths using a medium efficiency (50%) pump, which is an average pump efficiency in

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[124] SGMA Groundwater Management. Available at: http://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management

[125] Bostic, D., Dobbin, K., Pauloo, R., Mendoza, J., Kuo, M., London, J. "Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells." UC Davis Center for Regional Change. September 2020. Available at: https://pacinst.org/publication/sustainable-for-whom/

[126] Pauloo, R., Bostic, D., Monaco, A., Hammond, K. "GSA Well Failure: forecasting domestic well failure in critical priority basins." 2021. Available at: https://www.gspdrywells.com

[127] Burt, C., Howes, D., Wilson, G. "California Agricultural Water Electrical Energy Requirements (No. ITRC Report No. R 03-006)." Prepared by Irrigation Training and Research Center for the California Energy Commission. December 2003. Available at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=www.google.com/&httpsredir=1&article=1056&context=bae_fac

[128] Green, W., Allen, G. Irrigation pump efficiency – the evolving essentials. REDtrac LLC and the Center for Irrigation Technology at California State University, Fresno. 2018. Available at: https://ucanr.edu/sites/calasa/files/287377.pdf

TABLE 27 Averaged Calculated Energy Intensity for Groundwater Pumping in San Joaquin and Tulare Regions

	At 2019 Groundwater Depths	At Minimum Threshold (MT) Groundwater Depths	Difference
	kWh/AF		
Using a High Efficiency Pump (70%)	244	399	155
Using a Medium Efficiency Pump (50%)	342	559	217
Using a Low Efficiency Pump (30%)	569	932	362

Sources: Groundwater levels from (Pauloo et al., 2021). GW levels are as calculated for the valley floors of the San Joaquin Valley and Tulare Lake hydrologic regions. The authors assume that there is minimal agricultural groundwater use in the mountainous regions. Groundwater pumping coefficient from (Peacock, n.d. Energy and Cost Required to Lift or Pressurize Water). Pump efficiency is based on information found in (Burt et al., 2003; Green and Allen, n.d. irrigation pump efficiency the evolving essentials)

TABLE 28 Total Energy Use for Groundwater Withdrawal in the San Joaquin and Tulare Region, if Groundwater Use Stays Constant at 2015 Levels

	At 2019 Groundwater Depths	At Minimum Threshold (MT) Groundwater Depths	Difference between 2019 and MT Depths	Total 2035 San Joaquin and Tulare Ag Energy Use (Mid Ag Use Scenario)	% Change in Total Ag Energy Use From 2019 to MT Groundwater Depths
	GWh/year				
Using a High Efficiency Pump (70%)	1,941	3,176	1,236	11,147	+11%
Using a Medium Efficiency Pump (50%)	2,717	4,447	1,730	11,147	+16%
Using a Low Efficiency Pump (30%)	4,528	7,412	2,883	11,147	+26%

Sources: Groundwater levels from (Pauloo et al., 2021). GW levels are as calculated for the valley floors of the San Joaquin Valley and Tulare Lake hydrologic regions. The authors assume that there is minimal agricultural groundwater use in the mountainous regions. Groundwater pumping coefficient from (Peacock, n.d.). Pump efficiency is based on information found in (Burt et al., 2003; Green and Allen, n.d.) Groundwater volumes for agriculture in 2015 were summed across San Joaquin Valley and Tulare Lake hydrologic regions. Volumes were calculated in this report for the 'mid-ag use' scenario, from total supply delivery volumes found in DWR's Central Valley simulations (Rayej et al., 2019) and historical shares of groundwater from DWR's water balance data for the agricultural sector as described in the Agricultural water results section of this report.

California,[129] requires 342 kWh of electricity.[130] This increases by two-thirds to 559 kWh per acre-foot when groundwater is pumped from minimum threshold depths. This analysis found that pumping 7.9 million acre-feet of groundwater, equivalent to 2020 groundwater use, from minimum threshold depths increases energy use by 1,200 to 2,800 GWh per year, or by 64 percent. For the San Joaquin and Tulare regions, if groundwater pumping uses 559 kWh/AF at minimum threshold levels, the systemwide energy intensity is estimated to increase to 462 kWh/AF and 1,072 kWh/AF, representing a 20 percent and 6 percent increase for each region, respectively.

Declining groundwater levels make energy efficiency improvements more financially attractive. This analysis

[129] Burt, C., Howes, D., Wilson, G. "California Agricultural Water Electrical Energy Requirements (No. ITRC Report No. R 03-006)." Prepared by Irrigation Training and Research Center for the California Energy Commission. December 2003. Available at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=www.google.com/&httpsredir=1&article=1056&context=bae_fac

[130] The calculated energy intensity (342 kWh/AF) of groundwater pumping with a medium efficiency pump for this case study is very similar to the average energy intensity from across the literature (365 kWh/AF) for the San Joaquin Valley, which we use for the main urban and agricultural analysis in this report. The average energy intensity from the literature that we use for the Tulare Lake region, which generally has lower depths, is 450 kWh/AF.

assumed an electricity rate of $0.40 per kWh during peak times (5pm to 8pm), during summer months.[131] For a grower using a medium efficient pump during the peak hours of summer months, the energy cost per AF to pump groundwater increases by about $90 for a 100-foot decline in groundwater levels. Switching from a low- to high- efficiency pump to extract groundwater from current levels during the peak summer months would save $130 per AF in electricity costs. These cost savings increase to over $200 per AF when groundwater has declined 100 feet and is at the minimum threshold levels. At these minimum threshold groundwater depths, switching from a low to a high efficiency pump can produce energy savings of about 4000 GWh per year across the San Joaquin and Tulare Lake regions (Table 28).

In addition to higher efficiency pumps, growers may consider the benefits of installing variable frequency drives, which adjust the motor speed of the pump to match operating conditions.[132] These pumps can also be controlled in a more flexible way through demand response programs to coincide with the timing of renewable generation on the electric grid, thereby further reducing the GHG footprint and cost of agricultural water.[133,134]

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[131] The agricultural electricity rate varies based on the size of the pump, season, and hours of use. $0.40/kWh is the rate during peak hours (5pm-8pm) during the summer months for farms with single-motor installations smaller than 35 kilowatts (kW) ("Electric Schedule Ag: Time-of-use Agricultural Power," 2021). For farms of this size, the rate is $0.24/kWh during off-peak hours during the summer, suggesting that there are also opportunities for saving money on pumping by shifting to off-peak hours. Farms with larger motors (pumps) pay $0.18 to $0.34/kWh for peak summer hours, and $0.14 to $0.18/kWh for off-peak summer hours.

[132] Hanson, B., Weigand, C., Orloff, S. Variable-frequency drives for electric irrigation pumping plants save energy. Calif. Agric. 50, 36–39. January 1996. Available at: http://calag.ucanr.edu/Archive/?article=ca.v050n01p36

[133] Aghajanzadeh, A., Sohn, M., Berger, M. Water-Energy Considerations in California's Agricultural Sector and Opportunities to Provide Flexibility to California's Grid. 2019. Available at: https://escholarship.org/uc/item/2qx647xg

[134] Alstone, P., Potter, J., Piette, M.A., Schwartz, P., Berger, M.A., Dunn, L.N., Smith, S.J., Sohn, M.D., Aghajanzadeh, A., Stensson, S., Szinai, J., Walter, T., McKenzie, L., Lavin, L., Schneiderman, B., Mileva, A., Cutter, E., Olson, A., Bode, J., Ciccone, A., Jain, A. "Final Report on Phase 2 Results, 2025 California Demand Response Potential Study: Charting California's Demand Response Future." Lawrence Berkeley National Laboratory, Energy and Environmental Economics, and Nexant. March 2017. Available at: https://buildings.lbl.gov/publications/2025-california-demand-response

6. CONCLUSIONS

This analysis evaluated the combined impact of emerging pressures on California's water—including population growth, climate change, and policies to shift to water efficiency and alternative water supplies—and of electricity generation decarbonization on the energy and GHG footprints for urban and agricultural water from 2015 to 2035.

6.1 Urban

Report authors find that if urban per-capita water demand is maintained at current (2015) levels, statewide urban water demand increases 24 percent (1.3 million acre-feet, or MAF) between 2015 and 2035 with population growth. This "mid-case" scenario would result in a 21 percent increase in water-related electricity use (from about 30,000 GWh to 36,000 GWh) and a 25 percent increase in natural gas use (from about 150,000,000 to 190,000,000 MMBtu). In contrast, if per-capita water demand increases to levels consistent with urban water suppliers' projections (a "high-case" scenario), urban water demand increases by 44 percent increase (2.4 MAF) between 2015 and 2035, resulting in a 40 percent and 45 percent increase in related electricity and natural gas use, respectively. As the state replaces fossil-fuel generators with more renewable resources, the GHG intensity of California's electricity is expected to decline, and consequently GHG emissions associated with urban water-related energy use (electricity and natural gas) is projected to decrease about 12 percent in the mid-case scenario. However, in the high-case scenario, GHG emissions increase two percent because growing natural gas use dampens the effect of decarbonization in the electricity sector.

More comprehensive water conservation and efficiency efforts in urban California can reduce water-related electricity usage by 19 percent, natural gas use by 16 percent, and GHG emissions by 41 percent between 2015 and 2035. Because indoor residential water use is the most energy-intensive subsector (driven by high energy requirements for end-use, treatment, and wastewater treatment), water conservation and efficiency improvements for this subsector could dramatically decrease the energy use and GHG emissions that would result from the mid- and high-case scenarios.

While the total annual electricity use related to urban water increases in the mid-case scenario, the average energy intensity of California's urban water—the total electricity used per unit of water used—decreases by two percent between 2015 and 2035. This decrease is driven in part by a shift in water supplies away from energy-intensive imports towards alternative sources, including brackish desalination, potable recycled water, and captured stormwater. While the shares of these alternative sources among the statewide urban water supply portfolio are still relatively very small, they have important implications for total energy use because, they are less energy-intensive than imported water in most regions of California, especially in the largest urban water region of South Coast. For example, Los Angeles' move to more local water with increased water recycling, and stormwater recharge, has reduced the overall increase in energy use compared to imported water. In 2035, the city plans to significantly reduce imported water and shift towards local sources, reducing energy use by 64 percent compared to 2015 values. Further, if the city shifted all imported sources to stormwater or direct potable reuse, energy use is estimated to further decrease between 27 percent and 40 percent.

6.2 Agricultural

Central Valley agricultural water use under the mid-case scenario (assuming central urban growth and density scenario) is projected to decline by two percent, or 0.3 MAF, between 2015 (23.4 MAF) and 2035 (23 MAF). This decline is driven only by DWR's projection that urban population growth will encroach on agricultural lands, not including any changes from crop prices, changes in agricultural markets, or other external factors that would also affect agricultural water use. Under this scenario, the associated electricity use decreases four percent (from 14,000 GWh to 13,600 GWh), and GHG emissions decrease about 60 percent (from 3.7 to 1.4 million tons CO_2).[135] The proportionally larger reduction in electricity usage compared to water use is due to expected reductions in supply from relatively energy-intensive water sources, i.e., groundwater (350 kWh/AF in Sacramento, 365 kWh/AF in San Joaquin, 450 kWh/AF in Tulare) and SWP deliveries (240 kWh/AF in Sacramento, 500 kWh/AF in San Joaquin, 2100 kWh/AF in Tulare). Likewise, the proportionally larger reduction in GHG emissions is due to statewide efforts to decarbonize its electricity generation. Climate change has minimal impacts on agricultural water use by 2035 in all three scenarios; however, changes in temperature, precipitation, and evapotranspiration are likely to have a much larger effect on both supply availability and irrigation water demand toward the end of century.

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[135] GHG emissions are entirely from electricity because we do not calculate natural gas agricultural use.

There are also large uncertainties in the future energy use of Central Valley agriculture because of its dependence on groundwater, which the state has mandated through SGMA to reach sustainable levels by 2040. The agricultural case study featured in this report evaluated the sensitivity of agricultural energy use in the San Joaquin Valley and Tulare regions to changing groundwater depths. If pumping volumes are maintained at current levels and groundwater depths drop to the minimum thresholds, overall agricultural water system energy intensity are projected to increase by 20 percent and 6 percent for the San Joaquin and Tulare regions, respectively. This would increase energy use in the San Joaquin and Tulare regions by about 16 percent in 2035. Permitting groundwater levels to rise can reduce the magnitude of the increase, as can improvements in pump efficiency. Likewise, shifting the timing of energy usage to coincide with times of renewable electricity generation could reduce the impact on GHG emissions.

6.3 Cross-Cutting Findings

Urban water efficiency improvements can have the largest statewide effect on California's water-related energy use and GHG emissions because urban water is much more energy-intensive than agricultural water. Even though Central Valley agricultural water use (~23 MAF) is projected to be about three times that of the urban sector (~7 MAF) by 2035, agriculture's water-related electricity usage is about half, primarily because irrigation end-uses are less energy-intensive than water heating for urban end-uses. By 2035 in the mid-case, the energy intensity and total GHG emissions related to urban water statewide are about 9 times that of Central Valley's agricultural water (5,400 kWh/AF and 14 million tons CO2 for urban water, compared to 600 kWh/AF and 1.4 million tons CO2 for agricultural water by 2035).

Water-related GHG emissions are driven by the pace of California's electricity decarbonization and end-use electrification. With increased renewable resources on the grid, the GHG intensity of electricity generation is projected to decrease from 0.26 to 0.1 tons of CO2-equivalent/MWh between 2015 and 2035. This decrease is estimated to effectively minimize the electricity component of the GHG emissions related to urban water. Natural gas usage, mostly for heating water in residential and non-residential settings, is projected to rise, causing urban GHG emissions to still increase overall. Therefore, there is an opportunity for water-energy partnerships to promote the electrification of water-end uses (water heaters) to reduce the state's GHG footprint.

7. RECOMMENDATIONS

This analysis identifies specific water policies that can play an important role in helping the state meet energy and GHG goals. The authors provide the following recommendations for energy- and GHG-conscious water policies for (1) reducing energy and GHG emissions associated with end-uses of water, (2) reducing energy and GHG emissions associated with the provision of water and wastewater services; and (3) supporting cross-sectoral collaborations.

7.1 Reducing Water, Energy, and GHG Emissions Associated with End-Uses

Expand urban water conservation and efficiency efforts.

Urban water efficiency, for both indoor and outdoor uses of water and within the water distribution system, can save energy and avoid the associated GHG emissions for water extraction and generation, conveyance, treatment, and distribution. Indoor efficiency can further reduce end-use energy requirements and GHG emissions by avoiding, for example, water heating, as well as wastewater collection and treatment. Prior studies have shown there is significant urban conservation and efficiency potential in California—between 2.9 to 5.2 MAF per year[136]—through programs that cut water losses, encourage uptake of efficient devices and landscapes, and promote behavioral change through social norming.[137] One analysis found that water-efficiency programs during the most recent California drought saved as much energy as, and were cost-competitive with, the state's electric investor-owned utility efficiency programs during the same period.[138] Coordinating water and efficiency programs between water and energy suppliers can help both sectors meet water and energy goals and make these programs more cost-effective.

Accelerate water heater electrification.

Within the water management cycle, natural gas water heaters are the single largest emitters of GHGs. Electric heat pump water heaters are up to five times more thermally efficient than natural gas heaters[139] and can also provide significant GHG savings as the electricity system is decarbonized. However, the initial cost of electric heat pump water heaters is typically higher than natural gas heaters. Customer incentives that reduce the upfront cost of electric heaters can encourage more fuel-switching, reducing the state's overall GHG emissions. There is momentum at the state and local level to accelerate this transition. In 2020, the California Public Utilities Commission revised a previous policy preventing utilities from offering fuel-switching incentives and subsequently approved $45 million of the state's Self-Generation Investment Program budget to fund electric heat pump water heater rebates.[140] Further, several cities around California have passed regulations prohibiting natural gas in new housing developments.[141,142] Together with water efficiency programs that reduce hot water usage, incentives for electrification of water heaters can help lower the energy and GHG emissions from residential and non-residential water use.

Maintain groundwater levels and expand flexible, high-efficiency groundwater pumps.

Maintaining groundwater levels above the minimum thresholds identified in GSPs can reduce energy use, energy costs, and GHG emissions. More efficient pumps and variable frequency drives can provide additional reductions, and rebates can lower the upfront cost of these upgrades.[143] Through demand-response programs, farmers can also be compensated for operating their groundwater pumps to coincide with the timing of lower electricity

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[136] Gleick, P., Cooley, H., Poole, K., Osann, E. Issue Brief: The Untapped Potential of California's Water Supply: Efficiency, Reuse, and Stormwater (Issue Brief No. IB:14-05-C), California Drought Capstone. Pacific Institute and Natural Resources Defense Council. June 2014. Available at: https://pacinst.org/wp-content/uploads/2014/06/ca-water-capstone.pdf

[137] Lede, E., Meleady, R., Seger, C.R. Optimizing the influence of social norms interventions: Applying social identity insights to motivate residential water conservation. J. Environ. Psychol. 62, 105–114. April 2019. Available at: https://doi.org/10.1016/j.jenvp.2019.02.011

[138] Spang, E.S., Holguin, A.J., Loge, F.J. The estimated impact of California's urban water conservation mandate on electricity consumption and greenhouse gas emissions. Environ. Res. Lett. 13, 014016. January 2018. Available at: https://doi.org/10.1088/1748-9326/aa9b89

[139] Product Finder — ENERGY STAR Certified Water Heaters. Available at: https://www.energystar.gov/productfinder/product/certified-water-heaters/results?page_number=0

[140] Gerdes, J. "California Moves to Tackle Another Big Emissions Source: Fossil Fuel Use in Buildings." Greentech Media. February 4, 2020. Available at: https://www.greentechmedia.com/articles/read/california-moves-to-tackle-another-big-emissions-source-fossil-fuel-use-in-buildings

[141] Ivanova, I. "Cities are banning natural gas in new homes, citing climate change." CBS News. December 6, 2019. Available at: https://www.cbsnews.com/news/cities-are-banning-natural-gas-in-new-homes-because-of-climate-change/

[142] Mulkern, A.C. California Is Closing the Door to Gas in New Homes. Scientific American. January 4, 2021. Available at: https://www.scientificamerican.com/article/california-is-closing-the-door-to-gas-in-new-homes/

[143] Get Big Rebates For Small Agricultural Pumps. PGE. Available at: https://www.pge.com/en/mybusiness/save/smbblog/article/get_big_rebates_for_small_agricultural_pumps.page?redirect=yes

prices and renewable electricity generation on the grid,[144] and variable frequency drives can further be automated to adjust to grid needs.[145] This can help integrate renewable electricity and lower overall GHG emissions from electricity generation.

7.2 Reducing Water, Energy, and GHG Emissions Associated with the Provision of Water and Wastewater Services

Provide financial incentives and regulatory pathways for water suppliers to reduce the energy- and GHG-intensity of water systems.

California should make existing financial incentives and programs for energy efficiency and GHG reduction available to water suppliers for shifting to less energy-intensive water supplies. Energy- and GHG-related programs, such as the state's cap-and-trade funds,[146] or state bond money, such as a Climate Resilience Bond,[147] are potential funding sources that could be provided to water suppliers for developing alternative local sources that save energy and reduce GHG emissions. It may also be possible to stack incentives across sectors, such as from electric investor-owned utility efficiency programs to account for the range of co-benefits of energy and GHG savings.

California should also prioritize creating regulatory pathways that enable water and wastewater services to reduce energy and GHG emissions. Guidance on direct potable reuse standards is expected to be issued from the State Water Resources Control Board by December 2023. Clear state guidelines and regulations allowing direct potable reuse may offer energy and GHG benefits over indirect potable reuse, as it could avoid energy, GHG emissions, and costs, from the additional conveyance and treatment that is currently required for indirect potable reuse. In addition, regulations that address challenges of co-digestion and resource recovery at wastewater treatment plants can lower GHG emissions, generate renewable energy, and divert organic waste from landfills with existing wastewater infrastructure. Coordination between electric and water utilities may provide opportunities to implement demand response programs at urban water and wastewater treatment plants to reduce or shift the timing of energy use. This could help alleviate stress on the electric grid from additional water-related energy use and allow energy demand to coincide with renewable generation to reduce the overall GHG intensity related to water.

7.3 Water and Energy Data Reporting and Planning

Expand and standardize water data reporting and energy usage tracking.

A unified set of projections of future water supply and demand portfolios for both urban and agricultural water suppliers is not publicly available, therefore the authors used different urban and agricultural datasets for this analysis. Such data—reported in a standardized way across water suppliers with harmonized assumptions (such as for population growth and climate change impacts) between urban and agricultural suppliers is essential to understand future water system conditions. These data should also include mandatory reporting of energy usage and energy intensity of the water cycle stages for each water supplier. Ultimately the energy intensity of the water system must be tracked alongside other state environmental indicators to help California meet its energy and GHG goals.

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[144] Aghajanzadeh, A., Sohn, M., Berger, M. Water-Energy Considerations in California's Agricultural Sector and Opportunities to Provide Flexibility to California's Grid. 2019. Available at: https://escholarship.org/uc/item/2qx647xg

[145] Alstone, P., Potter, J., Piette, M.A., Schwartz, P., Berger, M.A., Dunn, L.N., Smith, S.J., Sohn, M.D., Aghajanzadeh, A., Stensson, S., Szinai, J., Walter, T., McKenzie, L., Lavin, L., Schneiderman, B., Mileva, A., Cutter, E., Olson, A., Bode, J., Ciccone, A., Jain, A. "Final Report on Phase 2 Results, 2025 California Demand Response Potential Study: Charting California's Demand Response Future." Lawrence Berkeley National Laboratory, Energy and Environmental Economics, and Nexant. March 2017. Available at: https://buildings.lbl.gov/publications/2025-california-demand-response

[146] California Climate Investments. California Air Resources Board. Available at: https://ww2.arb.ca.gov/our-work/programs/california-climate-investments

[147] Cart, J. "Bonds on the ballot: Will billions of dollars help California cope with climate change?" CalMatters. January 22, 2020. Available at: https://calmatters.org/environment/2020/01/bonds-on-the-ballot-will-billions-of-dollars-help-california-cope-with-climate-change/

Formalize coordination between water and energy regulatory agencies about forecasted energy demand changes

If water system energy demands grow as projected, California's electricity and natural gas systems will need to incorporate changes in their infrastructure planning to ensure that energy supply will reliably meet energy demand. Formal regulatory proceedings and reporting between water suppliers, state water agencies, electric and natural gas utilities, state energy regulators, and planning agencies can help facilitate coordinated cross-sectoral planning. For example, currently there is no explicit reporting of expected changes in water-related energy demand in California's Integrated Energy Policy Report and associated energy demand forecast.[148] As a result, it is unclear if the energy use growth anticipated based on water supplier projections has been factored into electricity and natural gas planning and procurement decisions. Improvements in coordination between agencies should lead to better integrated energy and water planning, reduced costs to consumers, and faster decarbonization of California's water system.

Addressing California's Water-Energy Nexus

To adequately address California's joint water and climate challenges, coordinated policy and planning are necessary to ensure that sustainable and safe water supplies can be delivered reliably and cost-effectively, without increasing the greenhouse gas emissions from the state's water sector. This report provides an in-depth analysis of how the state can do just that – and actually reduce GHG emissions in the process. Through comprehensive policy solutions like those suggested here, California can strengthen its commitment to climate goals while ensuring a sustainable path forward for water resource management in the state.

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[148] California Energy Commission. "Integrated Energy Policy Report - IEPR." *California Energy Commission*, California Energy Commission, current-date, https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report.