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Main Report

Embedded Energy in Water Studies
Study 1: Statewide and Regional Water-Energy Relationship

Prepared by
GEI Consultants, Inc./Navigant Consulting, Inc.

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Energy Division

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California Institute for Energy and Environment

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DISCLAIMER

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Study 1 Agencies:

- Central Valley Project (US Bureau of Reclamation)
- Los Angeles Department of Water and Power
- Metropolitan Water District of Southern California
- Modesto Irrigation District
- San Diego County Water Authority
- San Francisco Public Utilities Commission
- Santa Clara Valley Water District
- State Water Project (Department of Water Resources)

Study 2 Agencies:

- Beaumont Cherry Valley Water District
- Cal-Am Water Company - Monterey
- Coachella Valley Water District
- Contra Costa Water District
- East Bay Municipal Utility District
- Glenn Colusa Irrigation District
- Inland Empire Utilities Agency
- Los Angeles County Sanitation District
- Marin Municipal Water District
- Monterey Regional Water Pollution Control Agency
- Natomas Mutual Water Company
- Orange County Sanitation District
- Orange County Water District
- Rancho California Water District
- San Gabriel Water Company
- San Jose Water Company
- Semitropic Water Storage District
- Sonoma County Water Agency
- Suburban Water Systems
- The City of Calexico
- The City of Oceanside
- Valley Center Water District
- Westlands Water District

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Abbreviations and Acronyms

ACWA	Association of California Water Agencies
AF	Acre-foot
ATT	Advanced Treatment Technologies
CASA	California Association of Sanitation Agencies
CEC	California Energy Commission
CIEE	California Institute for Energy and Environment
CPUC	California Public Utilities Commission
CRA	Colorado River Aqueduct
CVP	Central Valley Project
CVWD	Coachella Valley Water District
CWA	California Water Association
DWR	California Department of Water Resources
EC	Energy consumption
EDR	Electrodialysis Reversal
EPRI	Electric Power Research Institute
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GUI	Graphical User Interface
IID	Imperial Irrigation District
IOU	Investor-Owned Utility
kWh	Kilowatt hour

kWh/AF	Kilowatt hour per acre-foot
LADWP	Los Angeles Department of Water and Power
MBR	Membrane bio-reactor
MID	Modesto Irrigation District
MMBTU	Million British Thermal Units
MWD	Metropolitan Water District of Southern California
NAICS	North American Industry Classification System
PWRPA	Power and Water Resources Pooling Authority
RFP	Request for Proposals
RO	Reverse Osmosis
SCVWD	Santa Clara Valley Water District
SDCWA	San Diego County Water Authority
SFPUC	San Francisco Public Utilities Commission
SIC	Standard Industrial Code
SWRCB	State Water Resources Control Board
SWP	State Water Project
TDS	Total dissolved solids
USBR	United States Bureau of Reclamation
UV	Ultra-violet
UWMP	Urban Water Management Plans

Executive Summary

Background and Context

Following the California Energy Commission's landmark finding – that water-related energy uses account for nearly 20 percent of the state's total energy requirements - the California Public Utilities Commission (CPUC) initiated a formal proceeding investigating California's water-energy relationships on January 19, 2007 (Application 07-01-024). Although water-energy relationships are interdependent – water systems and operations impact energy resources and infrastructure, and vice versa - the focus of this investigation is on the former; i.e., water sector impacts on the energy sector.

There are two distinctly different types of water impacts on the energy sector:

- ***Energy Use by the Water Sector*** - the amount, timing, and location of energy needed to support water sector operations.
- ***Energy Use by Water Customers*** - the amount of energy used by water customers during the consumption of water, whether for pumping, heating or other purposes.

California's investor-owned energy utilities already have many programs designed to help the water sector and their customers (water users) reduce their direct energy use. The CPUC is currently considering the following policy issues:

In 2005, the California Energy Commission estimated that water-related energy accounts for about 19.2% of the state's electricity requirements and 30% of non-power plant related natural gas consumption. These conservative estimates (that, per these studies, we recommend adjusting, see Table ES-2) included both direct electricity use by water and wastewater systems (4.9%) and operations, and electricity used in the consumption of water (for heating and pumping water during end use 14.3%). Natural gas consumption occurred principally in the water end use segment – very little natural gas is used in the transport or treatment of water by water agencies.

1. Whether energy embedded in water can be quantified and relied upon as an energy efficiency resource, and
2. Whether it is worthwhile for the CPUC to pursue energy efficiency through water conservation programs.

The CPUC's energy efficiency policies do not presently recognize energy embedded in water. Since this is a new area of study, there is no established methodology for computing water-related embedded energy. In addition, as the Study Team observed, data is not presently captured at the level and type needed to support these computations. While it is clear that measurement of embedded energy will not be a simple task, the potential for significant energy savings and associated greenhouse gases (GHGs) and other resource and environmental benefits is compelling.

Scope of this Study

In its Decision 12-07-050 on December 20, 2007, the CPUC authorized water-energy pilot projects and three studies designed to (a) validate claims that saving water can save energy, and (b) to explore whether embedded energy savings associated with water use efficiency are measurable and verifiable. The CPUC engaged the California Institute for Energy and Environment (CIEE) to manage the conduct of the three studies. The team of GEI Consultants, Inc. and Navigant Consulting, Inc. (the Study Team) was engaged to conduct two studies:

- Study 1 - Statewide and Regional Water Energy Relationship Study
- Study 2 - Water Agency and Function Component Study and Embedded Energy -Water Load Profiles

Another firm, Aquacraft, Inc., was selected to conduct Study 3 - End-Use Water Demand Profile Study. A Technical Working Group comprised of staff and consultants from CIEE and the CPUC was formed to provide guidance in the conduct of these studies.

This report presents the detailed findings of Study 1 that involved collection of detailed water and energy data from nine large or wholesale water agencies, estimation of the total amount of energy used in the Supply and Conveyance segment of the water use cycle, and development of a predictive model for estimating the range of energy impacts under a variety of scenarios of water supply portfolios and water demand for five types of hydrology years.

Study Goals and Objectives

CPUC Decision 07-12-050 stipulated the following goals for Study 1:

> “Develop a model of the functional relationship between water use in California and energy used in the water sector that can be used in a predictive mode: Given a specific water delivery requirement(s) developed from precipitation pattern information, what is the expected energy use.”[1]

To achieve this goal, the CPUC requested collection of historical water and energy data for the three largest wholesale water supply and conveyance systems in California: the State Water Project (SWP), the Central Valley Project (CVP) and the Colorado River Aqueduct (CRA). The intent was to use these data in a regression or other type of model that would enable estimating

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[1] CPUC Decision 07-12-050, Appendix B, p.2.

energy impacts under a variety of supply and demand conditions including variations in annual and seasonal hydrology.

The Study Team recommended modifications to the scope of work. In particular, the Study Team felt that the largest three water purveyors were not sufficiently representative of the energy characteristics of the state's water systems to support a predictive water-energy model. Consequently, the scope was increased to include:

- Collection of monthly water and energy data from nine large wholesale water agencies
- Comparison of the amount of water provided by these nine wholesale water agencies to the state's total water requirements during each of five types of hydrology years
- Estimates of the amount of energy needed to support the amount of groundwater pumping that exceeds the amount of groundwater provided by the nine water agencies

For these purposes as well as for development of the predictive water-energy model, the Study Team relied upon the annual regional water balances prepared by the California Department of Water Resources (DWR) as the only authoritative data source presently available that documents the portfolio of water resources that were developed and used within each of the state's ten hydrologic regions during any particular year. The regional water balances also provide annual demand by sector (agricultural vs. urban; and within urban, by residential and non-residential) for each hydrological region. This is the only place in the state where data is collected and compiled from multiple water agencies to provide a snapshot of the state's overall water supply and demand profile at the level needed to evaluate the scenarios requested by the CPUC.

Scenario Development

The Study Team relied upon input from a wide range of water-energy stakeholders to develop the scenarios of future supply and demand that would be evaluated with the predictive model. The one consensus was that there was no consensus about the "likely" mix of water resources and infrastructure in future years (2020 and 2030 were the selected forecast periods). As a result, the stakeholders suggested establishing upper and lower bounds of potential energy use by the state's water supply and conveyance segment for these forecasted water years, with the recognition that the actual outcome will likely be somewhere in the middle.

With this advice, the Study Team developed two future scenarios to evaluate against a base case ("Today" = water year 2010) for each of the five primary types of hydrology years that are used by the DWR for statewide water planning: "Wet," "Dry," "Above Normal," "Below Normal," and "Critical."

Table ES-1. Scenarios Evaluated Through Study 1

Scenario	Time Period	Assumptions
Base Case	**"Today" = 2010**	• Current year hydrology (used "Above Normal") • Current year water demand • Current year water supply portfolio • Current water policies
Low Energy Scenario	**2020 & 2030**	For each of 5 types of hydrology years: • Low water demand projections • Portfolio of future water policies that are expected to reduce the energy intensity of the Supply & Conveyance segment of the water use cycle (e.g., aggressive urban water conservation, increased use of recycled water, and new surface water storage)
High Energy Scenario	**2020 & 2030**	For each of 5 types of hydrology years: • High water demand projections • Portfolio of future water policies that are expected to increase the energy intensity of the Supply & Conveyance segment of the water use cycle (e.g., minimal urban water conservation, aggressive growth in seawater and brackish water desalination, minimal construction of new recycled water supply, new surface water storage, and infrastructure changes allowing increased Delta withdrawals)

Key Findings

Study 1 represents the first effort to collect and compile detailed water-energy data from the state's largest wholesale water systems for the purpose of validating the amount of energy used by the Supply and Conveyance segment of the water use cycle. In addition, Study 1 computed the approximate amount of electricity used for groundwater pumping which accounts for 30 percent [2] of the state's water uses. There were several major findings in Study 1:

- Groundwater energy accounts for a significant portion of the additional energy in the Supply and Conveyance segment.

- The primary driver of electricity use by the Supply and Conveyance segment of the water use cycle is water demand in relation to the types and location of water resources used to meet that demand.

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[2] Groundwater use varies by region, year and whether net or applied (DWR Bulletin 118, 2003 findings: http://www.water.ca.gov/pubs/groundwater/bulletin_118/california's_groundwater__bulletin_118_-_update_2003_/bulletin118-findings.pdf

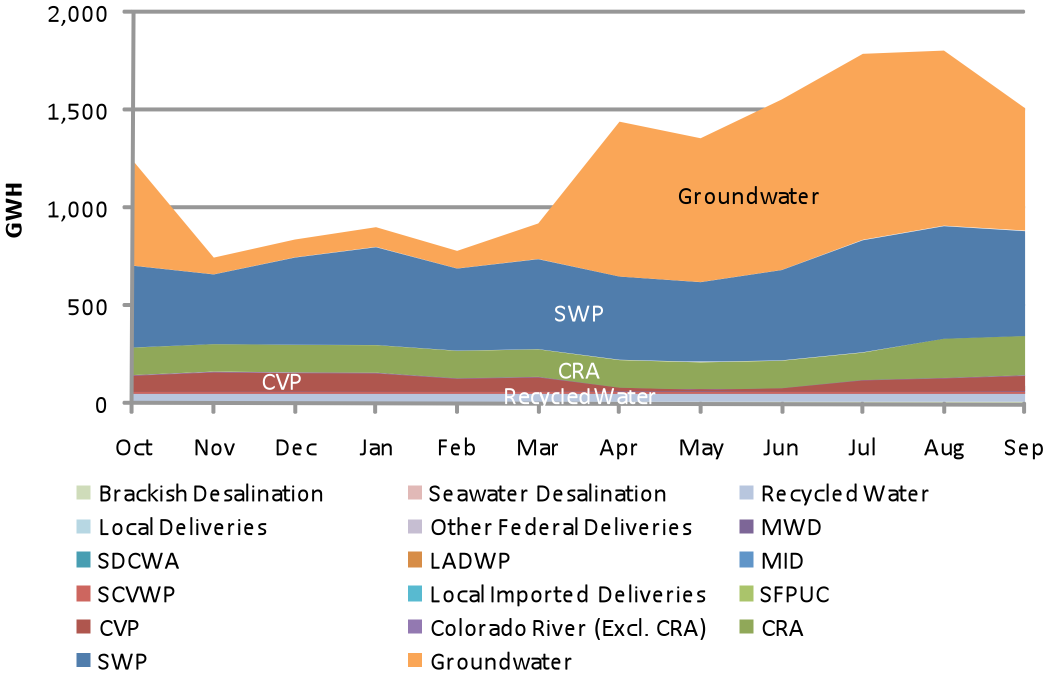
- The amount of energy previously attributed to the Supply and Conveyance segment of the water use cycle is likely understated.

These findings are described below.

Groundwater energy accounts for a significant portion of the additional energy in the Supply and Conveyance segment. One of the primary data gaps encountered by the Study Team was the lack of information about the amount of energy used to pump groundwater. Since on average, groundwater supplies about 30 percent of all water used in California, this was a significant gap that could not be overlooked. The Study Team's estimates indicate that groundwater pumping accounts for more electricity use during summer months than pumping for the state's three largest water conveyance systems – State Water Project (SWP), Central Valley Project (CVP) and Colorado River Aqueduct (CRA) - combined.

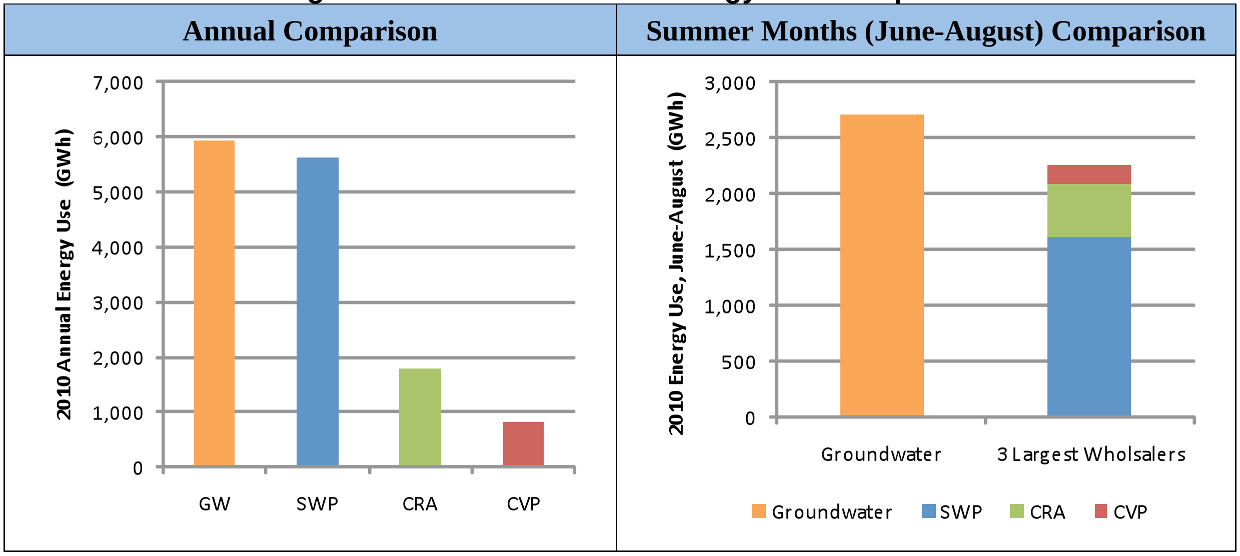
Figure ES-1 illustrates the amount of electricity expected to be consumed on a monthly basis during Water Year 2010 (October 2009 to September 2010) by groundwater vs. other water sources in the Supply and Conveyance segment of the water use cycle. Figure ES-2 shows the quantity of groundwater energy projected in Water Year 2010 vs. the amount of electricity expected to be used by the state's three largest wholesale water purveyors. The method and assumptions used to compute these estimates are documented in Appendix G, Groundwater Energy Use.

Figure ES-1. Monthly Energy Consumption in 2010 by California Water Supplies



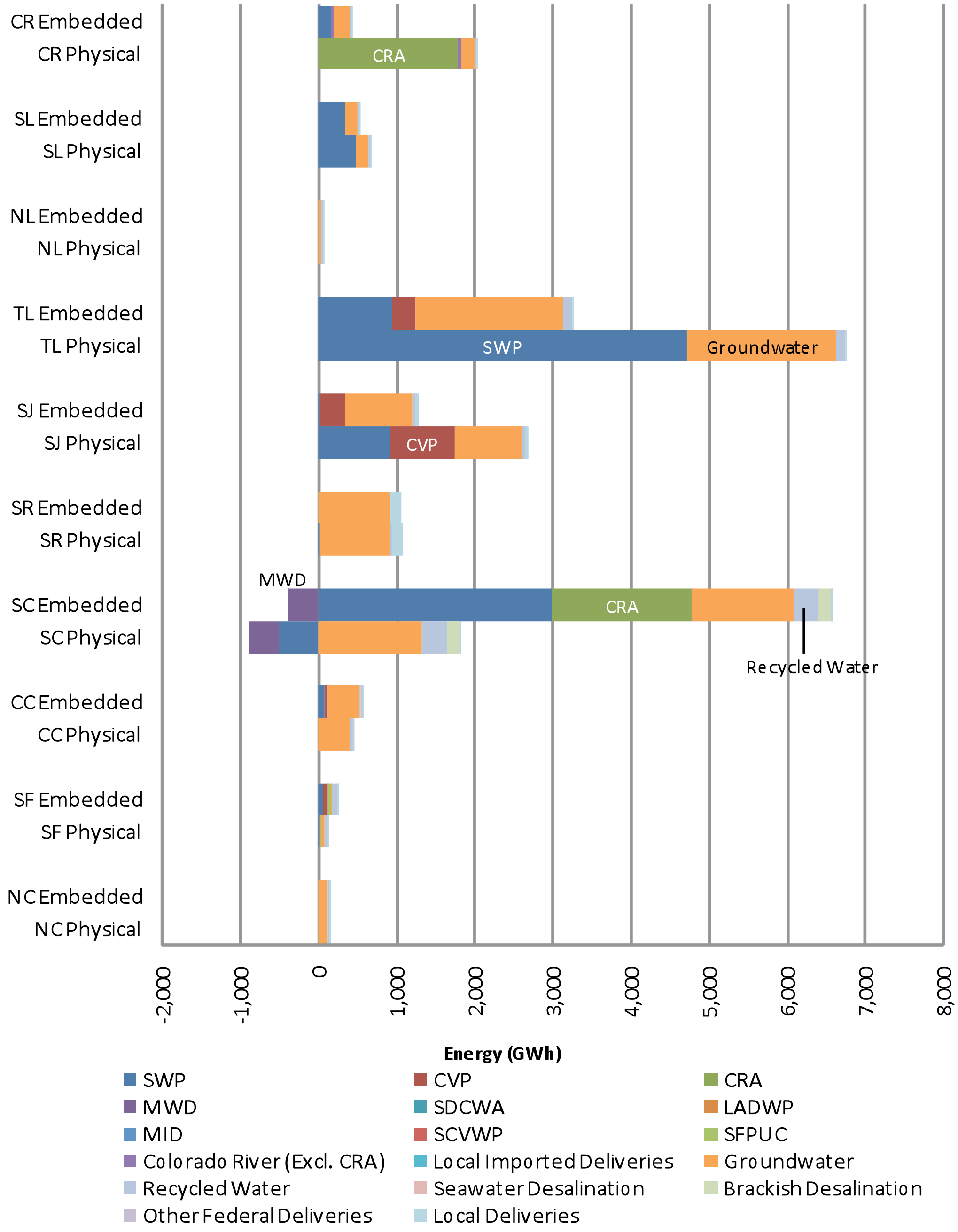
Note: The methodology used to estimate energy used for groundwater pumping did not account for pumps that may use natural gas. Although the Study Team designed its data collection to identify natural gas usage by the Supply and Conveyance sector for pumping water, very little was identified through Studies 1 and 2. Consequently, to the extent water supply pumps are actually powered by natural gas, the groundwater electricity estimate would need to be adjusted.

Figure ES-2. Groundwater Energy Use Comparison



The primary driver of electricity use by the Supply & Conveyance segment of the water use cycle is water demand in relation to the location and types of water resources used to meet that demand. California transports some water supplies hundreds of miles across the state to deliver water to where it is needed. The following diagram illustrates that this results in is a distinct difference between the amount of electricity applied to produce and transport water supplies to meet demand within each hydrologic region (i.e., "physical energy") vs. the actual amount of electricity needed in other regions to produce and deliver water that is consumed within that region (i.e., "embedded energy"). Those differences are particularly notable in the South Coast (SC) region that imports a significant quantity of its water from northern California and from Colorado.

Figure ES-3. 2010 Physical and Embedded Energy by Supply and Region[3]



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[3] The amounts shown in Figure ES-3 for embedded energy only include energy embedded in the Supply and Conveyance segment of the water use cycle. These numbers would need to be adjusted to include water treatment and distribution, and wastewater treatment, in order to represent the full value of energy embedded in a unit of water.

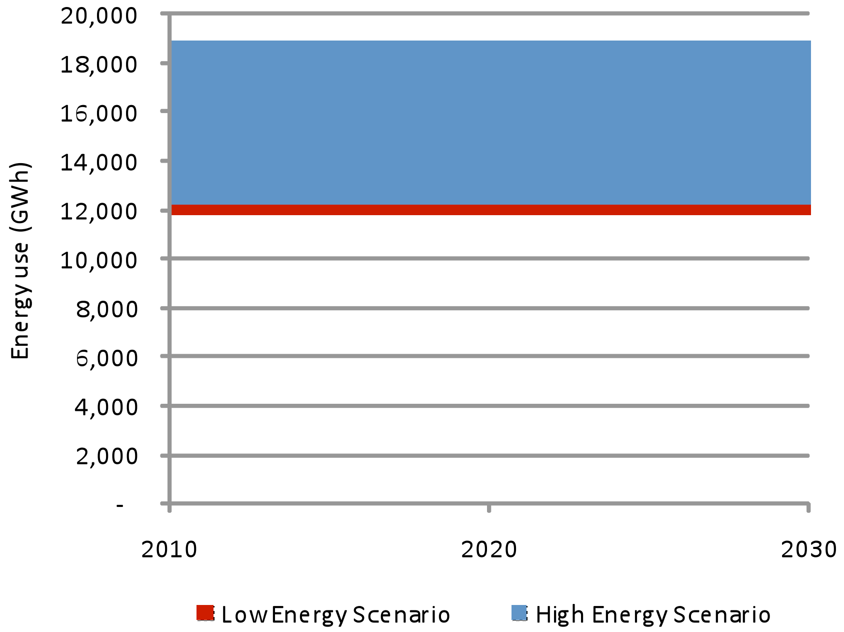
The amount of energy previously attributed to the Supply and Conveyance segment of the water use cycle is likely understated. During the course of Study 1, the Study Team found that electricity use by the water sector is higher than the CEC's conservative 2005 estimate of 5 percent of statewide electricity requirements. By combining data from both Studies 1 and 2 and comparing them with the CEC's prior estimates, the Study Team believes that water sector electricity use is at least 7.7 percent of statewide electricity requirements, and could be higher. The significance of this finding is that the amount of energy deemed embedded in water is likely understated. The updated analysis results are compared below to the CEC's conservative estimates. The bases for the Study Team's recommended adjustments are described in detail in Appendix N, Comparison of Study 1 and Study 2 Findings with Prior Studies.

Table ES-2. Comparison of Calendar Year 2001 Statewide Water Sector Electricity Use (GWh)

Segment of the Water Use Cycle	CEC Study (2005)	CEC Study (2006)	Study 1	Study 2
Supply	10,742	10,371	15,786	172
Conveyance				
Water Treatment				312
Water Distribution				1,000
Wastewater Treatment	2,012	2,012		2,012
Total Water Sector Electricity Use	12,754	12,383	18,282	
% of Total Statewide Electricity Requirements	***5.1%***	***4.9%***	***7.7%***	
Note: Excludes estimates of electricity consumption for water end uses.				

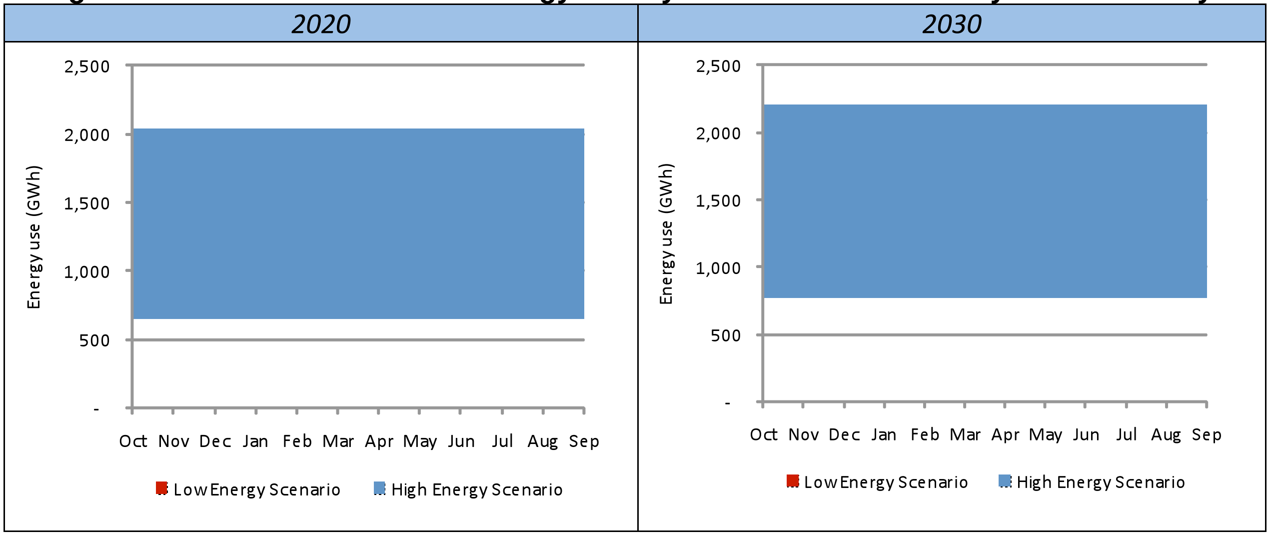
The results of the Study Team's scenario analyses produced the following range of Supply and Conveyance electricity use in the years 2010 and 2020:

Figure ES-4. Future Statewide Energy Use by the California Water System



The range created within each scenario is driven primarily by assumptions as to the types and location of water supplies that will be used to meet changes in demand. These assumptions affect water operations decisions and their electricity impacts. The monthly energy profiles for both scenarios in 2020 and 2030 illustrate the seasonal effect of hydrology on water operations (Figure ES-5).

Figure ES-5. Future Statewide Energy Use by the California Water System - Monthly



The scenario assumptions and results are described in more detail in Appendix K, Scenarios Memo.

Recognizing that various water-energy stakeholders will want to evaluate their own scenarios, the Study Team created a model that allows users to test a wide variety of water supply portfolios and water demand at the regional level for each of the forecast years, 2020 and 2030. Appendix D documents the model assumptions and structure. A Model User's Manual has been provided as Appendix M.

Recommendations

The body of work conducted through Studies 1 and 2 represents the most significant effort to-date to collect and analyze data about energy use by the state's water sector. By compiling detailed data from nine (9) very large or wholesale water agencies that participated in Study 1 and twenty-two (22) retail water and wastewater agencies that participated in Study 2, the Study Team was able to characterize a significant portion of the water sector's energy use. The nine agencies that participated in Study 1 account for approximately 70 percent of all wholesale surface water conveyance in California. Study 2 accounts for approximately 4 percent of treated water deliveries (340,000 AF) and approximately 18 percent of wastewater treatment (940,000 AF) in California.

The key recommendations indicated by Studies 1 and 2 entail improving the body of water-energy data, methods, and tools to enable more accurate measurement of the state's water-energy relationships. In particular, the Study Team recommends the following actions:

- Collect more water-energy data, and with more granularity

- Develop and adopt a methodology for computing the energy embedded in a unit of water
- Quantify water losses throughout the water use cycle

These recommendations are discussed in more detail in Chapter 7 Recommendations that also provides a proposed framework for integrating the findings of Studies 1 and 2 to compute the amount of energy embedded in water.

The model is available at: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/Embedded+Energy+in+Water+Studies1_and_2.htm .

1 Introduction

1.1 Background

In 2005, the California Energy Commission (CEC) found that water-related energy consumption and demand accounted for a significant portion – nearly 20 percent – of the state's electricity requirements.[4] Of this amount, more than 12,000 GWh (26 percent, about 5 percent of the state's total electricity requirements) was deemed attributable to energy used by water and wastewater systems and their operations.[5] The balance of water-related energy was attributed to the amount of energy needed to apply and use water for agricultural, residential, commercial and industrial purposes.

"***Energy Embedded in Water***" refers to the amount of energy that is used to collect, convey, treat, and distribute a unit of water to end users, and the amount of energy that is used to collect and transport used water for treatment prior to safe discharge of the effluent in accordance with regulatory rules.

This finding launched a series of initiatives related to increasing understanding and quantifying the interdependencies of water and energy resources and infrastructure in California. In particular, the California Public Utilities Commission (CPUC) is considering whether energy embedded in water can be quantified and relied upon as an energy efficiency resource, and whether it is worthwhile for the CPUC to pursue energy efficiency through water conservation programs.

Following several informal public meetings where members of both the water and energy industries came together to explore opportunities for leveraging the joint benefits of water and energy, on January 19, 2007, the CPUC opened a proceeding to consider applications from the state's investor-owned utilities (IOUs) to conduct water-energy pilot projects. These applications were consolidated into a single proceeding, Application 07-01-024 (A.07-01-024).[6]

The CPUC's December 20, 2007 Decision 12-07-050 (D.12-07-050) authorized the IOUs to conduct water-energy pilots and to evaluate the results of the pilot projects for the dual purposes of (a) validating claims that saving water can save energy, and (b) to explore whether embedded energy savings associated with water use efficiency are measurable and verifiable. In addition, the CPUC directed that three studies be conducted. Two of these studies were structured to work

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[4] "California's Water-Energy Relationship," California Energy Commission, Final Staff Report CEC-700-2005-011-SF, November 2005.

[5] This study indicates the true amount of energy used by water and wastewater agencies is higher – conservatively estimated at more than 7% of the state's total electricity requirements (see Appendix N - Comparison of Study 1 and Study 2 Findings with Prior Studies).

[6] California Public Utilities Commission website, http://docs.cpuc.ca.gov/published/proceedings/A0701024.htm.

in concert to enhance understanding of the types and quantities of water-energy interdependencies in the state’s wholesale and retail water systems and operations. The third study focused on understanding time-of-use water consumption patterns at the end user level.

- Study 1 - Statewide and Regional Water Energy Relationship Study
- Study 2 - Water Agency and Function Component Study and Embedded Energy -Water Load Profiles
- Study 3 - End-Use Water Demand Profile Study

These 3 studies were to be conducted in parallel with the water-energy pilot projects and evaluation, measurement and verification (EM&V) of the pilot projects’ results.

On April 30, 2008, the California Institute for Energy and Environment (CIEE) issued a Request for Proposals (RFP) on behalf of the CPUC. The team of GEI Consultants, Inc. and Navigant Consulting, Inc., hereafter referred to as the Study Team, was engaged to conduct Studies 1 and 2. Another firm, Aquacraft, Inc., was selected to conduct Study 3. A Technical Working Group comprised of staff and consultants from CIEE and the CPUC was formed to provide guidance in the conduct of these studies.

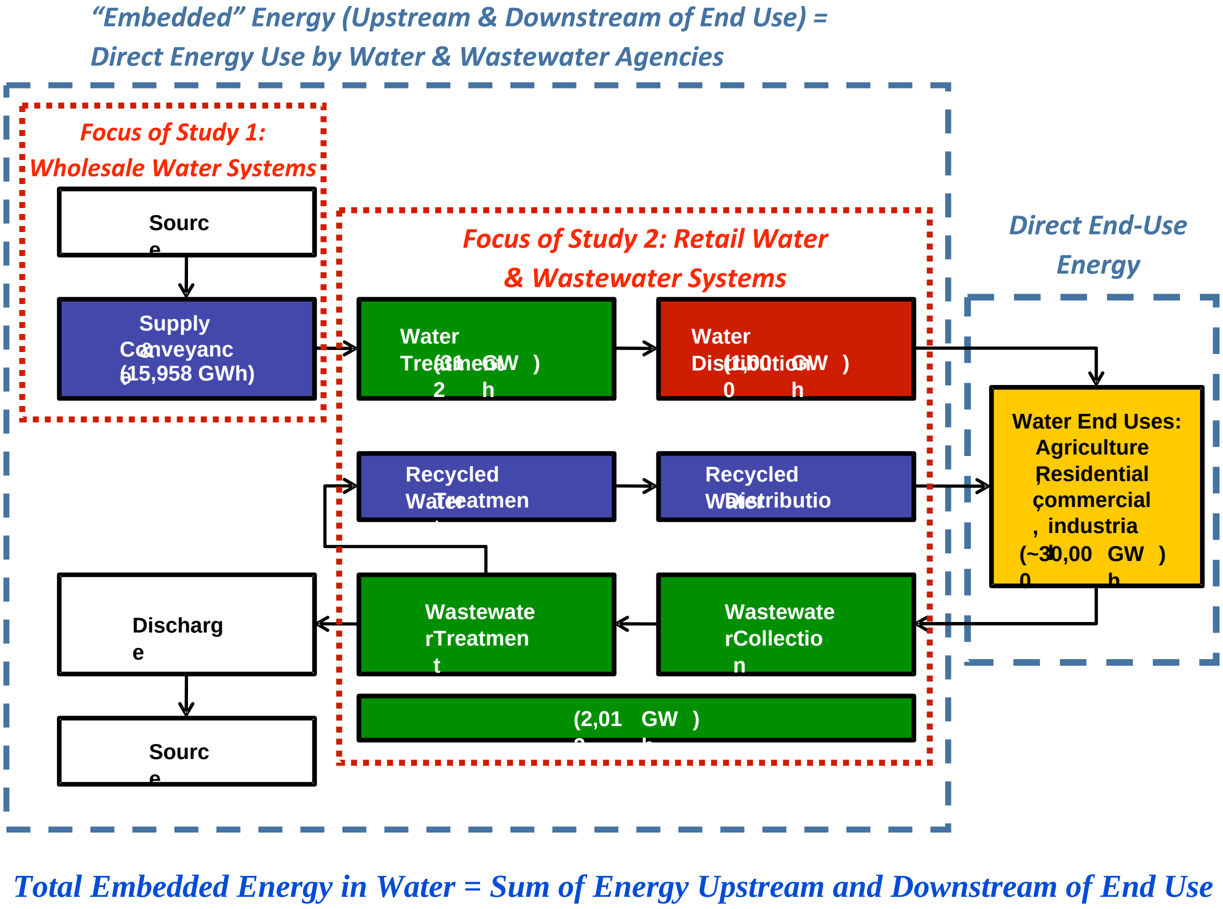
This report addresses the findings of Study 1.

1.2 Study 1 Goals and Objectives

The primary purpose of Study 1 is to increase understanding of the relationship of energy and water supplies in the Supply and Conveyance segment of the water use cycle. The desired outcome of this study is a predictive model that estimates the potential range of statewide energy impacts under a variety of future scenarios.

Figure 1-1 illustrates the key segments of the water use cycle and conservative estimates of the amount of electricity used within each. The bases for these estimates are documented in Appendix N to this report.

Figure 1-1. California's Water-Use Cycle[7]



The CPUC established the following goal for Study 1:

> "Develop a model of the functional relationship between water use in California and energy used in the water sector that can be used in a predictive mode: Given a specific water delivery requirement(s) developed from precipitation pattern information, what is the expected energy use."[8]

The types of data specified are listed in Table 1-1.

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[7] Estimated electricity use by segment of the water use cycle reflects the Study Team's recommended adjustments.
[8] CPUC Decision 07-12-050, Appendix B, p.2.

Table 1-1. Study 1 Data Contemplated in CPUC D.07-12-050

Level	Water Data	Energy Data
Statewide	Annual water deliveries: agricultural & urban sectors [1980-2005]	Annual water-related energy use (kWh & MMBTUs) [1980-2005]
IOU Service Area	Annual water deliveries: agricultural & urban sectors [1980-2005]	Annual water-related energy use (kWh & MMBTUs) [1980-2005]
State Water Project	Annual water deliveries [1980-2005]	Annual energy use, net of generation
Federal Water Project	Annual water deliveries [1980-2005]	Annual energy use
Colorado River Project	Annual water deliveries [1980-2005]	Annual energy use

In addition, D.07-12-050 required collection of data "relevant to water use and energy consumption in the water area." Examples of relevant data included "… weather, (evapotranspiration, and heating and cooling degree days, precipitation, etc.), population, energy costs, and others." These data were to be developed for each of the above levels: statewide, utility service area, and for each of the three large inter-basin water transfer systems.

The CPUC required that the predictive model use the above data to assess the change in the energy intensity of the state's large water systems under a wide variety of potential future conditions including changes in hydrology due to climate change, changes in demand due to population growth, and potential changes in water policies, rules, and regulations.

"Energy Intensity" (EI) refers to the average amount of energy needed to transport or treat water or wastewater on a per unit basis. For Study 1, energy intensity is the amount of energy used to collect or produce water, and then to transport water. "Supply and Conveyance" energy intensity is reported net of any in-conduit hydropower generated during the process of delivering the water through that conduit. For Study 2, energy intensity is defined as the amount of energy needed to treat or distribute agricultural or urban water, to treat wastewater effluent, and/or to treat and deliver recycled water, expressed in kilowatt hours per acre-foot of water [kWh/AF] or in kilowatt hours per million gallons [kWh/MG], depending on the unit appropriate to the type of system or operation.

1.3 Approach

The scope of work contemplated by D.07-12-050 for Study 1 was challenging for the following reasons:

Reliable water-energy data is not readily available. The study of the relationship between energy and water in California's wholesale water resources and infrastructure is very new. While most water agencies collect and maintain some historical water and energy data, they vary significantly with respect to the types of data collected and methods for collecting, compiling and reporting these data. The CEC requires energy providers to report energy sales by Standard Industrial Code (SIC) or North American Industry Classification System (NAICS) code on an annual basis. During the conduct of its 2005 white paper "California's Water-Energy Relationship," the CEC found that there were many inconsistencies in how the reporting agencies classify energy sales. Consequently, many estimates were applied to try to adapt reported energy data to the study for a single year, 2001. Since this is a new area of study, no one has yet collected, compiled, and reconciled all of these disparate data sets for the state's wholesale water systems.

Storage creates the ability to manage water supplies on a multi-year basis. One of the most significant differences between water and energy resource management is that water can be, and is, stored; often for multiple years. The usual drivers of energy demand thus do not apply equally to water. Whether water is in short or long supply, the energy intensity of water operations in any particular year will depend on the cumulative impact of each water purveyor seeking to optimize its water resource mix. Consequently, annual energy data cannot be directly related to water use and delivery, and need to be adjusted for other factors, such as changes in policies, rules, regulations, contract commitments, and extraordinary events.

Non-hydrology and non-water factors significantly impact water operations. While hydrology is an important predictor of the energy intensity of the state's water systems, it is only one of several factors that ultimately determine the amount and timing of wholesale water deliveries, and the resultant energy intensity of the state's large inter-regional and wholesale water systems. In fact, non-hydrology factors - infrastructure capacity; water rights, contracts and transfers; water policies, rules, and regulations - are much more important in determining how much water is delivered at any point in time along any particular path. Non-water factors, such as energy prices and extraordinary events such as the California power crisis, also affect water operations decisions.

The state's wholesale water systems and resources are very diverse. D.07-12-050 specified that wholesale water-energy data be collected and analyzed at five levels: (1) statewide, (2) IOU service area, (3) State Water Project (SWP), (4) Federal Water Project (Central Valley Project, CVP), and (5) Colorado River Project (Colorado River Aqueduct, CRA).[9] While the three agencies are the largest inter-basin transfer systems in California, there are many other wholesale water agencies with very different resources and infrastructure, and thus very different energy profiles. In particular, groundwater pumping should be included in any assessment of the energy intensity of the state's water supplies. In addition, some wholesale water agencies have systems that are primarily gravity fed and thus have very low energy intensities.

To address these challenges, the Study Team suggested the following adjustments to the Study 1 approach.

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[9] Ibid.

Table 1-2. Adjusted Approach

D.07-12-050 Appendix B Scope of Work	Data Issues & Challenges	Adjusted Approach
Annual water & energy data statewide, by utility service area and for each of the 3 large inter-basin transfer systems for years 1980-2005	Water-energy data of the types described are not available for the period 1980-2005. The specified data set omits groundwater which accounts for 30% of all water used in California. The data set also omits other types of wholesale water agencies with very different energy profiles.	Shift the study focus to more recent years where data are more likely to be available. The period 1998-2005 was recommended because the California Department of Water Resources (DWR) uses this period for statewide water planning purposes and more reliable data are available. However, since water operations are the primary determinant of wholesale water systems' energy consumption, it was more important to document the key energy drivers for the current system resources & infrastructure than for historical periods whose operations protocols are no longer relevant. Approach: Expand the data set to include other wholesale water agencies that represent the range of energy intensities in the state's wholesale water systems.
Compile independent variables relevant to water use and energy consumption	The initial scope of work presumed that the primary driver of energy consumption by wholesale water systems is hydrology. In fact, non-hydrology and non-water factors play a more significant role in the quantity & timing of water deliveries.	Shift the focus of Study 1 to documenting the primary drivers of water operations decisions for the wholesale water agencies being studied.

The recommended approach was approved by the Technical Working Group and the study plan was vetted through a public workshop on December 10, 2008. Additional refinements to the study plan were made during the course of the study, as data issues were encountered and resolved.

The Study Team interviewed key water stakeholders involved in planning and management of the state's wholesale water systems to identify the types of data available to support this study.

- The water agencies included in this study were the first stop for water and energy data about their own agencies.
- For all other types of data about the state's water systems, resources, operations, and energy impacts, DWR was deemed the most authoritative source, since DWR directs water resource planning for the state and provides most of the data upon which the California Water Plan relies.

Data were not always available in the form needed to support this study. For example, the scope of the study required estimating the total amount of energy used by the state's wholesale water systems to meet all water demand, both agricultural and urban. On an average year, groundwater currently meets about 30 percent of the urban and agricultural water demand in the state. However, most groundwater pumping is performed by owners of wells who are not required to keep detailed records of groundwater withdrawals. Since there are thousands of groundwater wells throughout the state, many of which are privately owned, it is very difficult to estimate the amount of energy used to pump groundwater. Consequently, the Study Team applied average pump efficiencies to observed fluctuations of depth-to-groundwater by major basin to approximate the energy intensity of groundwater pumping for each hydrologic region. That computed energy intensity was then applied to the amount of groundwater withdrawn in each region as reported by DWR's regional water balances.

The methodology used to estimate energy used for groundwater pumping did not account for pumps that may use natural gas. Although the Study Team designed its data collection to identify natural gas usage by the Supply and Conveyance sector for pumping water, very little was identified through Studies 1 and 2. Consequently, to the extent water supply pumps are actually powered by natural gas, the groundwater electricity estimate would need to be adjusted.

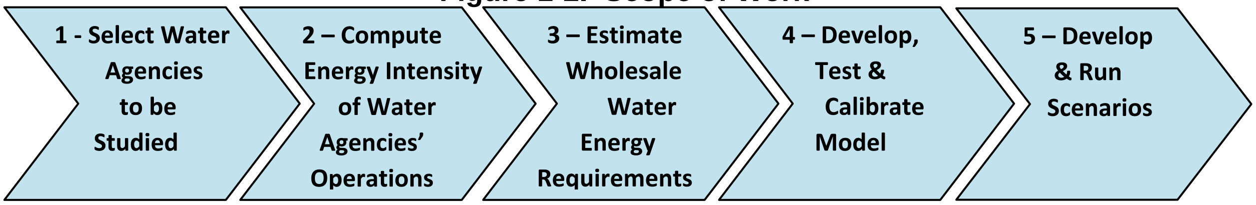
A more detailed discussion of the Study Team's approach to estimating the energy intensity and total energy requirements of the state's wholesale water systems is provided in Chapter 3, Energy Use by California's Wholesale Water Systems.

1.4 Scope of Work

Prior to commencing work, the Study Team conducted a literature search to establish a baseline understanding of the state of knowledge about the state's water-energy relationships at the wholesale water system level. As noted in Appendix L (Literature Review), since this is a new area of study, little was found that was directly relevant to this study.

Following is a description of the work that was performed, the issues encountered, and the remedies employed.

Figure 1-2. Scope of Work



1.4.1 Select Water Agencies to be Studied

The CPUC initially requested a model that assessed the energy impacts of the state's three largest inter-basin wholesale water systems: SWP, CVP and CRA. The initial scope did not address municipal water agencies, joint power authorities, and regional special districts such as the Metropolitan Water District of Southern California (MWD) and the Los Angeles Department of Water and Power (LADWP) which have significant roles in the state's wholesale water system. For example, LADWP supplies nearly 4 million people with water, much of that from the Los Angeles Aqueduct. LADWP is not, however, an "island." In drought or other years, LADWP draws upon SWP or other water supplies as its marginal supply (the next water supply source that an agency will resort to if additional water is needed). An understanding of these interrelationships among large water purveyors is essential to an understanding of the energy intensity of the state's wholesale water systems.

In fact, the state's water balance is comprised of complex storage and transfer relationships among all of these entities. In addition, the three large water purveyors identified for study are primarily surface water systems, thereby omitting inclusion of the energy requirements of groundwater.

The Study 1 scope was therefore expanded to include six additional large regional wholesale water systems with very different energy characteristics. This expanded scope enabled the development of more representative estimates of the range of energy requirements by the state's wholesale water systems. This level of understanding of key energy drivers will facilitate more informed decision making.

Table 1-3. Wholesale Water Agencies Included in Scope of Study 1

Agency	Type of Agency	Primary Function	Types of Facilities	Primary Water Resources
Statewide Water Systems Required by D.07-2-050				
State Water Project (SWP)	State (DWR)	Collect & deliver wholesale water statewide to State Water Contractors	California Aqueduct, pipelines, reservoirs, pumping plants, power generation plants	Surface water (Lake Oroville and Bay Delta)
Central Valley Project (CVP)	Federal (USBR)	Collect & deliver wholesale water statewide to CVP Contractors	Aqueducts, reservoirs, pumping plants, power generation plants	Surface water (Lake Shasta, Trinity Lake and Bay Delta)
Colorado River Aqueduct (CRA)	Local (MWD)	Deliver water from the Colorado River to the Los Angeles Area	Aqueducts, reservoirs, pumping plants	Colorado River
Regional Wholesale Water Agencies added by Study Team				
Metropolitan Water District of Southern California (MWD)	Local	Deliver wholesale water to other wholesale and retail agencies in Southern California	Pipelines, reservoirs, power plants	Imports from SWP and CRA
San Francisco Public Utilities Commission (SFPUC)	Local	Deliver water to the City of San Francisco and wholesale contractors	Aqueducts, reservoirs, pumping plants	Hetch Hetchy Reservoir
Los Angeles Dept. of Water & Power (LADWP)	Local	Deliver water to the City of Los Angeles	Aqueducts, reservoirs, power plants	Lake Crowley
Modesto Irrigation District (MID)	Local	Deliver water to agricultural customers in Stanislaus County	Aqueducts, reservoirs, power plants	Don Pedro Reservoir
San Diego County Water Authority (SDCWA)	Local	Deliver water to retail agencies in San Diego County	Aqueducts, reservoirs,	Imports from MWD (SWP and Colorado River)
Santa Clara Valley Water District (SCVWD)	Local	Deliver water to retail agencies in Santa Clara County	Aqueducts, reservoirs, pumping plants	Imports from SWP, CVP, and SFPUC
Coachella Valley Water District (CVWD)	Local	Deliver water to agricultural and urban customers	Aqueducts	Colorado River

A description of the state’s wholesale water systems and profiles of each of the above agencies is provided in Chapter 2, California’s Wholesale Water Systems.

1.4.2 Compute Energy Intensity of Water Agencies’ Operations

The Study Team spent a significant amount of time collecting, adjusting, relating and reconciling water and energy data for the nine large wholesale water systems selected for detailed study. Data collection commenced by identifying and collecting the “best” available data for each agency.

- The largest and most complex system is the State Water Project (SWP). Monthly and annual operations data are available by facility through DWR Bulletin 132.
- Other agencies provided varying levels of detail. Some data were available at the facility level, others at a more summary level; some data were available on a monthly basis, some only on an annual basis. The Santa Clara Valley Water District (SCVWD) did not provide any source data, choosing to instead provide energy intensities that it computed during the conduct of its own water-energy study, “From Watts to Water.”[10]

Ultimately, a significant amount of data investigations and adjustments were needed to “fit” all of the data for the nine agencies into the monthly delivery patterns requested by the Technical Working Group.[11]

The primary output from this effort was the range of energy intensities experienced at key points in the state’s wholesale water system for the water agencies being studied over the adjusted study period, 1998-2005. The resultant range of monthly energy intensities by facility or delivery point was analyzed to determine whether the energy intensity was fairly consistent or whether there was significant variability from one month to the next. Figure 1-3 provides an example of a facility where the energy intensities are relatively consistent.

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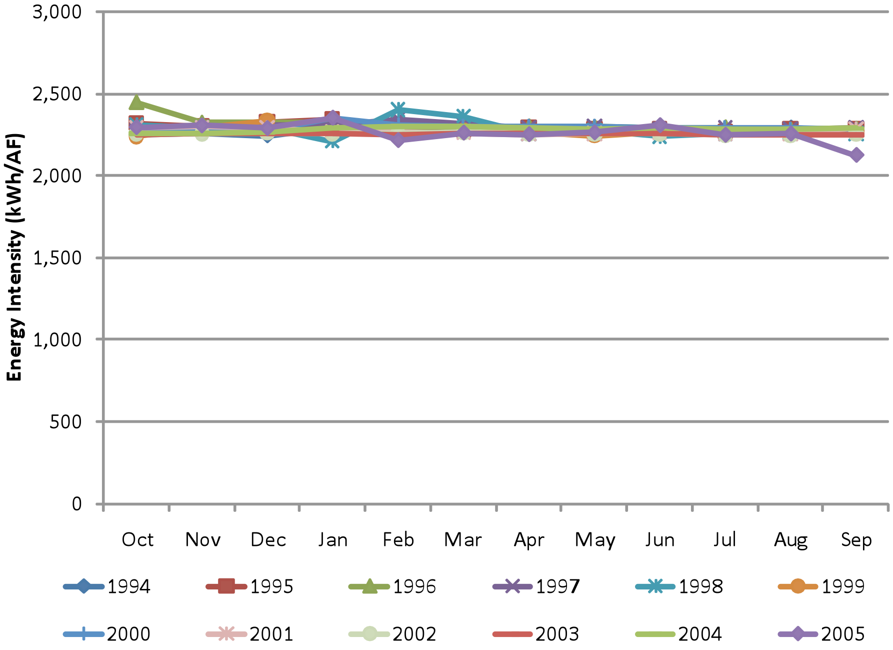
[10] SCVWD. *From Watts to Water* (2007) available at http://www.valleywater.org/programs/waterconservation.aspx.

[11] The Technical Working group requested that the scope be modified to include monthly water deliveries and associated energy requirements in order to assess the coincidence of wholesale water energy requirements with summer electrical peak demand.

Figure 1-3. Edmonston Pumping Plant Energy Intensity Analysis

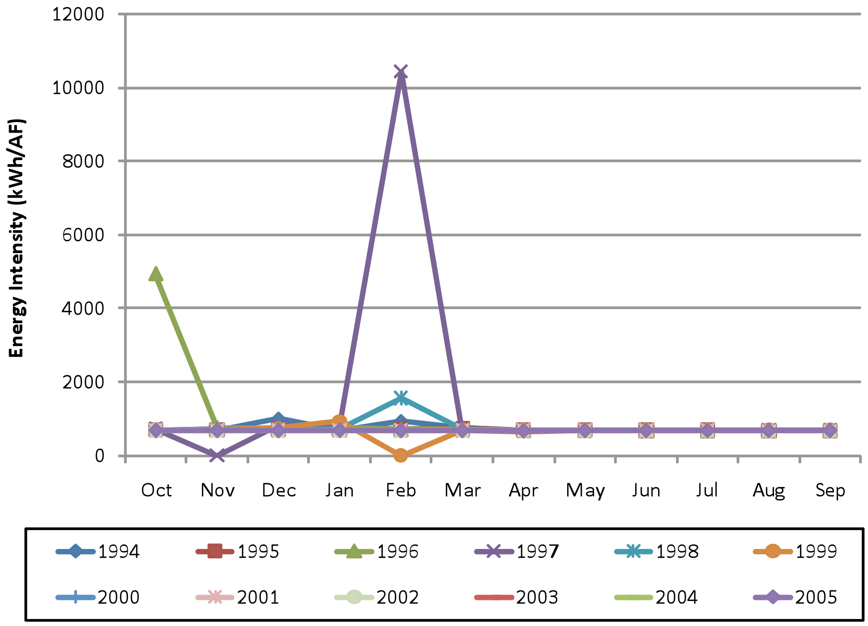


If the energy intensity was fairly consistent, the average was adopted for use in the model. If the energy intensity at any facility was highly variable, the Study Team conducted additional investigations including interviews of knowledgeable agency operations and engineering staff to determine the likely sources of the variances. The draft agency profiles and energy intensity computations were provided to each agency for review, correction, and approval. The Study Team relied heavily upon the knowledge of water agency operations and engineering staff to document the primary energy drivers at each major facility and to explain the causes of significant variances. Where identifiable, the primary drivers were documented and integrated into the model. If the underlying causes of the variability were not readily determinable, a value or a range of values was selected with the assistance of agency staff.

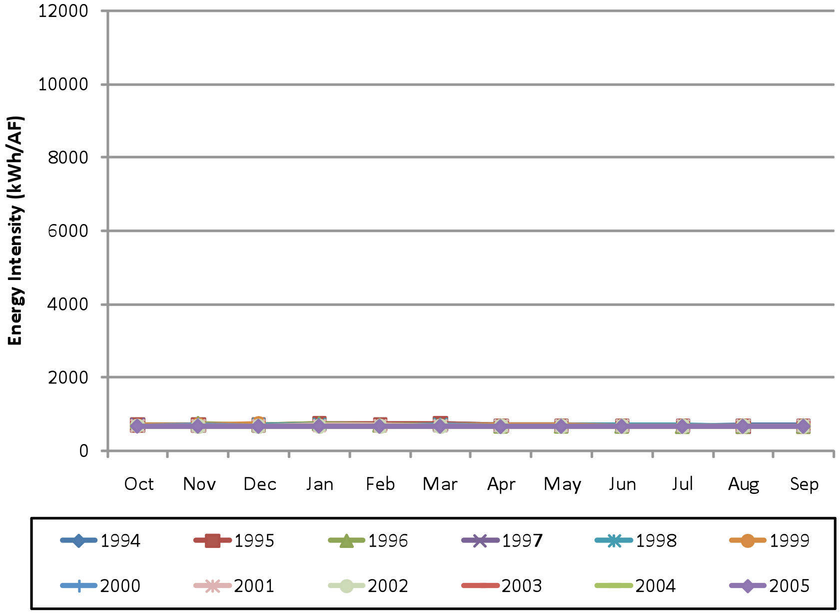
Figure 1-4 is an example of a State Water Project pump station where energy intensity exhibited some variation. Upon reviewing State Water Project documentation and the data, several data points were removed from consideration (such as November and February of 1997 and October of 1996). These data points represented times during which the plant was not operating or was pumping very small amounts of water. When plants are not pumping water, energy intensity cannot be calculated (such is the case in November 1997). When plants are pumping, very small amounts of water energy intensity values can vary widely as the calculation is more prone to errors in energy and water flow data.

Figure 1-4. Pearblossom Pumping Plant, Before and After Data Correction

Before



After



The primary energy drivers of the state's wholesale water systems are described in Chapter 3, Energy Use by California's Wholesale Water Systems. The energy intensities at each facility or point of water delivery that were used as inputs to the model are also documented.

1.4.3 Estimate Wholesale Water Energy Requirements

The nine wholesale water agencies are a subset of the state's wholesale water systems. Figure 1-5 indicates the regions to which these wholesalers make deliveries and the regions in which their infrastructure are located. The detailed data from the nine agencies were compared to annual water balances prepared by DWR for each hydrologic region by water year to identify the quantity of additional water by type (surface water, groundwater, recycled water, and desalinated water) for which energy requirements needed to be estimated.

Figure 1-5. Location of Wholesale Water Suppliers' Infrastructure and Deliveries

		Hydrologic Region									
		NC	SF	CC	SC	SR	SJ	TL	NL	SL	CR
Wholesale Water Agency	SWP		●	◐	●	●	●	●		●	◐
	CVP		◐	◐		◐	●	◐			
	CRA				◐						◑
	MWD				●						
	SDCWA				◐						
	LADWP				◐						
	MID						◐				
	SCVWP		●				◑				
	SFPUC		●								

Legend		
	◐	Water Agency delivers water to this region
	◑	Water Agency has facilities that consume (pump stations) or produce (power plants) energy in this region
	●	Water agency delivers water to this region and has facilities that consume or produce energy in this region

A number of data inconsistencies complicated the computations:

Water Supplies

- ***Regional Water Balances Do Not Necessarily Match Individual Agency Data.*** There are ten hydrologic regions in the state of California (Figure 2-4). DWR assigns the responsibility for preparing the water balances to four planning regions. Each planning region has its own data sources and methodology for preparing the regional water balances for which it is responsible. The regional inputs are then provided to a DWR staff person who compiles the regional balances for the year into a statewide water balance and adjusts data as needed to reconcile imbalances. Most of the individual agency inputs cannot be directly tracked to the regional balances because their numbers are consolidated with other water sources by type. SWP, however, is separately identified, which enabled the Study Team to identify variances between quantities of water reported in Bulletin 132 and SWP numbers reported in the regional water balances. Interviews with DWR planning staff indicated that adjustments are sometimes made by DWR planning regions. The reasons for these adjustments were typically not well documented, and a pattern could not be identified by the Study Team or DWR. The Study Team's approach to addressing these types of imbalances and data imperfections is discussed in Chapter 3, Energy Use by California's Wholesale Water Systems.

- ***Some of the Values in the Regional Water Balance Were Not Appropriate for Use in the Model.*** The Regional Water Balances use some direct inputs; other values are computed. Demand met through surface water supplies is an input. Since many groundwater pumps are privately owned or not subject to reporting, demand met through groundwater supplies is estimated (see Appendix G – Groundwater Energy Use). Environmental water includes all water resources that are deemed not captured for purposes of water supplies, including outflows of surplus water into natural waterways and the ocean. In order to allow repurposing in-region surplus water to meet growth in demand for scenario analyses, the Study Team decided to use only the quantity of environmental water required by regulation: instream applied water, managed wetlands, and required delta outflow. All other surplus water, especially that shown in the regional water balances as "applied" to "wild and scenic" purposes, was left out of the model as these uses vary drastically each year and do not consume energy. For more details, see Chapter 4, Model Development.

Energy Requirements

Energy requirements were computed for each agency by hydrologic region in two ways: Physical Energy Use and Embedded Energy Use.

- Physical Energy Use refers to the actual amount of energy used by the Supply & Conveyance segment of the water use cycle within a given hydrologic region regardless of the destination of the water from each facility.

- Embedded Energy Use accounts for the total energy required by the Supply & Conveyance segment of the water use cycle to produce and deliver water to a given hydrologic region regardless of where that energy was consumed.

Physical and embedded energy requirements are computed for the balance of supplies in each region using estimated energy intensities for each type of water resource. See Table 1-4.

Table 1-4. Illustrative Calculation of Non-wholesale Supply Energy Use

Supply	Deliveries (TAF)	Energy Intensity (kWh/AF)	Calculated Energy Use (MWh)
Groundwater	1,866	541	1,010,506
Recycled Water	368	1,129	313,168
Seawater Desalination	100	4000	400,000

Energy intensity of the nine water agencies varies widely, depending on system design, pump efficiency, and a variety of other factors.[12] Estimates were employed to approximate the energy requirements for the remaining water supplies. The annual energy requirements were then spread over 12 month periods in accordance with the delivery pattern applicable to that particular agency, facility, or delivery point. The bases for these estimates and the values applied in each region are documented in Chapter 3, Energy Use by California's Wholesale Water Systems.

1.4.4 Develop, Test, and Calibrate Model

The Embedded Energy in Water Model was developed in an Excel workbook. A user-friendly graphical user interface (GUI) was developed in ArcGIS to enable users to better visualize the relationships of the water systems to the regions, and the regions to the statewide wholesale water systems. Significant flexibility has been provided for advanced users to test a wide variety of scenarios. The full capabilities of the model and the types of access available for different levels of users are described in Appendix M, Model User's Manual.

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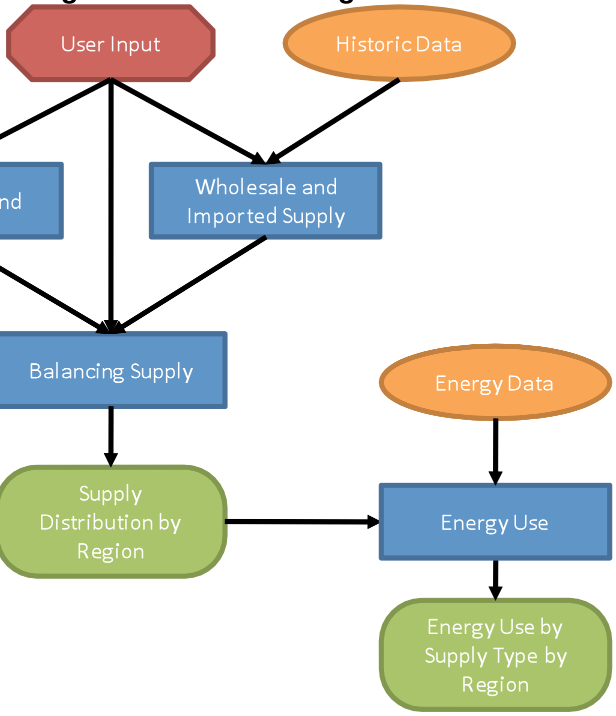
[12] See Appendix C

Figure 1-6. Model Diagram



A description of the model design, key inputs, and operations is provided in Chapter 4, Model Development. The detailed model documentation, including a description of the data issues, estimates employed, algorithms, and model structure is provided in Appendix D, Model Documentation. A Model User's Manual with detailed information about how to use the model is provided in Appendix M, Model User's Manual.

1.4.5   Develop and Run Scenarios

The Study Team conferred with key water and energy stakeholders to develop a range of assumptions that bound the high and low energy cases and compare those cases to the "base case" (i.e., "today"). These high and low energy cases include packages of potential policies that have the ability to increase (high energy case) or decrease (low energy case) energy use by wholesale water systems. Along with the policy packages, the Study Team input low and high water demand scenarios for the future. The combination of Low Demand and Low Energy Case policies creates an optimistic scenario (Low Energy Scenario) while the combination of High Demand and High Energy Case policies creates a pessimistic scenario (High Energy Scenario), see Table 1-5. The scenarios were run for two different forecast years: 2020 and 2030.

Table 1-5. Future Scenarios to Model

			Projected Period		
Scenario	**Water Demand**	**Policies**	**2010**	**2020**	**2030**
Baseline	Baseline	None	X		
Low Energy Scenario	Low Demand	Low Energy Case		X	X
High Energy Scenario	High Demand	High Energy Case		X	X

The assumptions embedded in the scenarios and the results of these analyses are presented in Chapter 5, Scenario Development.

The model is available at:
http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/Embedded+Energy+in+Water+Studies1_and_2.htm .

2 California's Wholesale Water Systems

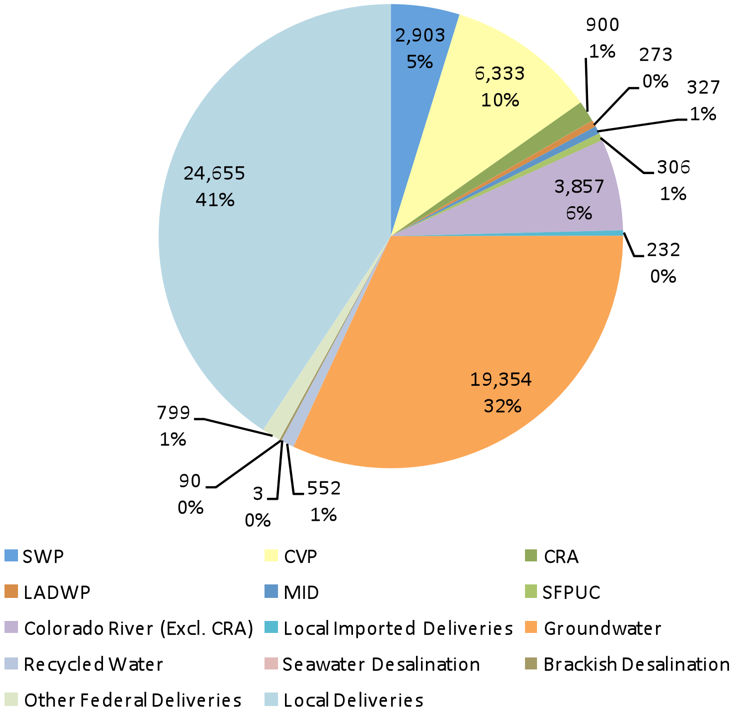
To understand the energy characteristics of the state's Supply & Conveyance systems, we first need to understand the state's water resource portfolio, the distribution and types of water demands, and the configuration of the statewide and regional systems that deliver these resources to meet water demand throughout the state.

2.1 California's Water Resource Portfolio

Surface water supplies are comprised principally of runoff from precipitation and snowmelt that are captured and stored in either natural or manmade reservoirs. Groundwater aquifers also store runoff from precipitation or are recharged by deliveries of surface water supplies.

Presently, a very small percentage (<2%) of water demand is met by other resources such as recycled water and desalination.

Figure 2-1. California's 2010 Water Resource Portfolio (TAF)



2.2 California’s Wholesale Water System

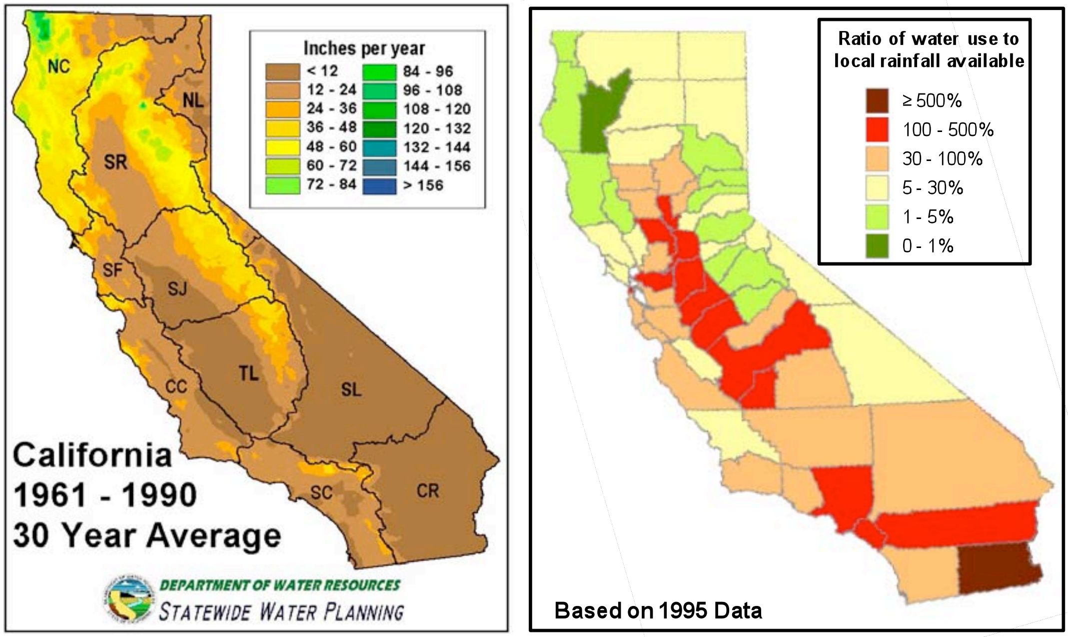
The configuration of California’s wholesale water system is determined principally by two factors: (1) most of the state’s water supplies are produced in northern California, while most of the water demand occurs in the southern part of the state; and (2) precipitation occurs in winter/spring months and demand peaks in the summer. Reallocation of water supplies throughout the state to meet demand causes large quantities of water to be stored in reservoirs and aquifers and pumped hundreds of miles over varying topology: at its highest point, water is pushed more than 2,000 feet over the Tehachapi range to reach users in southern California.

Water supplies played (and continue to play) a pivotal role in the development of the state’s communities and economies. Substantial investments in labor and capital were made to construct large reservoirs and water conveyance systems spanning hundreds of miles to transport water supplies to water-challenged areas to support development. This legacy has left California with an extensive system of pipelines and canals that use considerable amounts of energy to transport water across the state.

The three largest statewide conveyance systems – the state owned and operated SWP, the federally owned and operated CVP, and the CRA owned by the Metropolitan Water District of southern California (MWD) are designed as inter-basin transfer systems: their primary purpose is to redistribute water from areas in which there is plenty to areas in which there is not enough. The SWP and CVP redistribute California water supplies; CRA brings vital water supplies from the Colorado River to supplement supplies in the desert regions of southern California.

Figure 2-2 illustrates the dramatic inverse geographical relationship of California’s water supplies.

Figure 2-2. Precipitation Distribution Across the State



Left – Precipitation in inches per year. Source: DWR 2005.[13]
Right – Ratio of water use to local rainfall. A value of 100% or greater indicates water is imported to a county to meet its demand. Source: EPRI 2003.[14]

California's wholesale water system is complicated, comprised of federal, state, and regional water agencies, and special districts. Some are single purpose (agricultural or urban) while others deliver water to both types of users. Figure 2-3 illustrates the extensive network of water conveyance systems that are managed by these entities.

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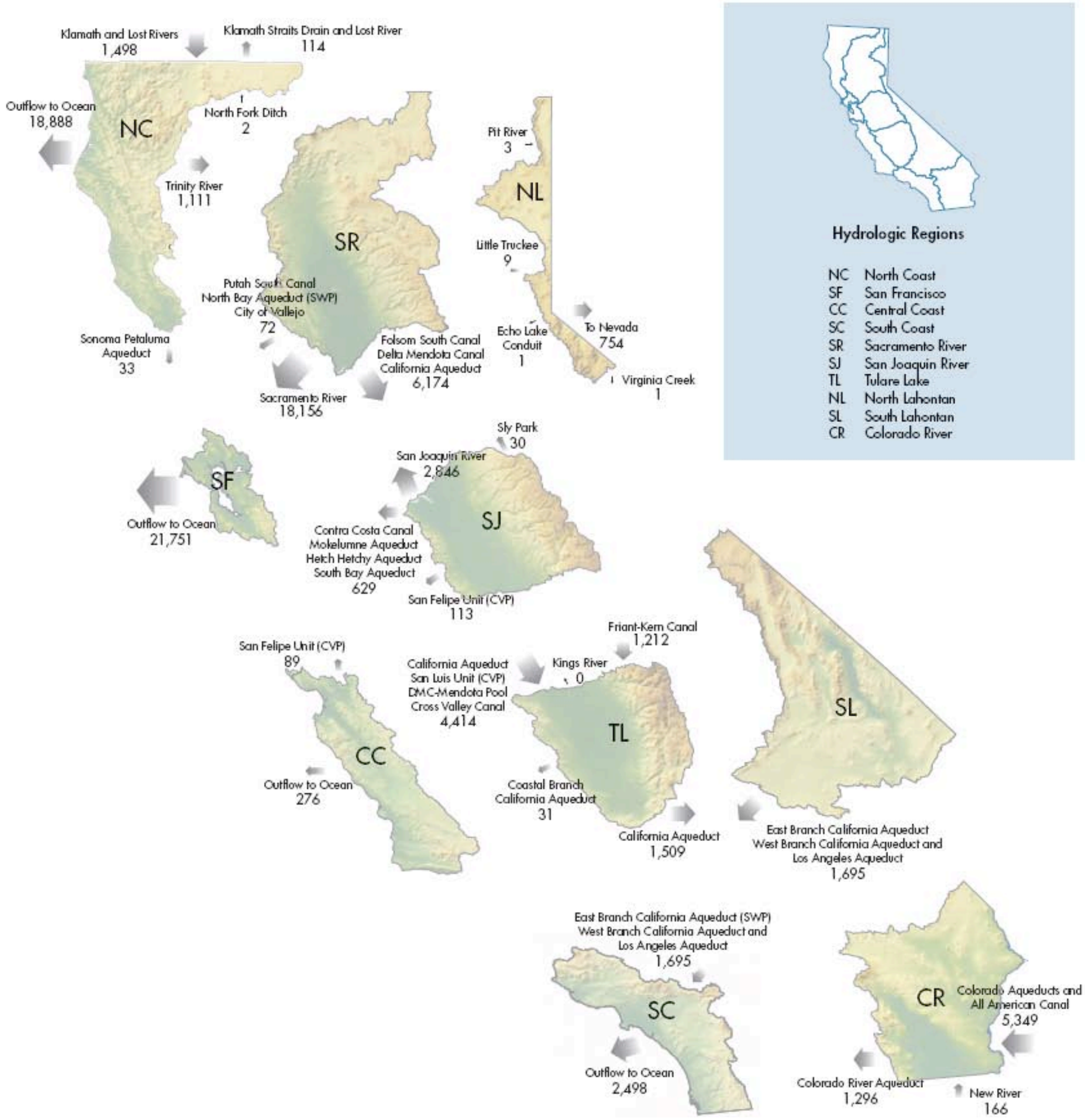
[13] *California Water Plan Update 2005*, Department of Water Resources Bulletin 160-05, Volume 3, p.1-5.

[14] *A Survey of Water Use and Sustainability in the United States with a Focus on Power Generation*. EPRI. November 2003.

Figure 2-3. California's Wholesale Water Systems

DWR breaks the state into ten hydrologic regions for water supply planning purposes (Figure 2-4). Each region has its own unique mix of water supplies, climate, and hydrology.

Figure 2-4. California's Hydrology Regions[15]



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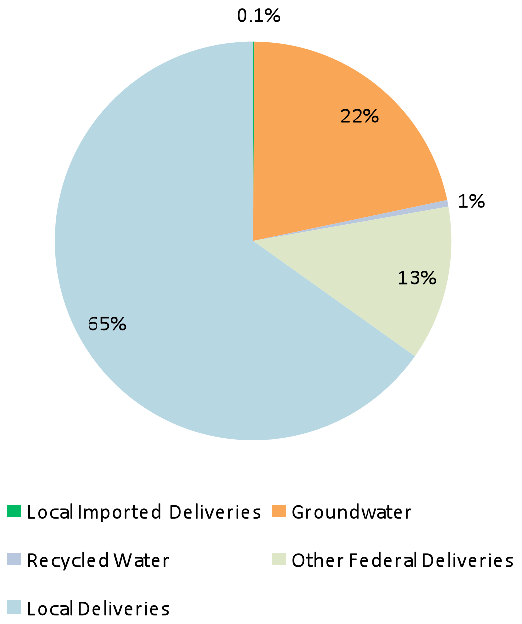
[15] DWR Bulletin 160-05, California Water Plan Update.

Tables 2-1 through 2-10 describe the ten hydrologic regions and their water supply characteristics.[16] More information about each hydrologic region is provided in Appendix B.

Table 2-1. North Coast Hydrologic Region at a Glance

<table>
<tr><th colspan="3">North Coast</th></tr>
<tr><td rowspan="4">**Total Water Supply (2010)**
3,251 TAF
 </td><td>**Size:**</td><td>19,476 square miles
(12.3% of State)</td></tr>
<tr><td>**Population Growth (2005-2030):**</td><td>39%</td></tr>
<tr><td>**Water Use:**</td><td>Urban: 17%
Agriculture: 83%</td></tr>
<tr><td colspan="2">**Snapshot:** Heavy rainfall in the coastal mountain ranges makes the North Coast region the most water-abundant area of California, producing about 41 percent of the state's total natural runoff. As a result of the abundant rainfall, local surface deliveries and groundwater make up the bulk of the region's water supply. With population growth, urban demand will increase in the region, but local water supplies are expected to be sufficient to meet projected growth in demand through 2030.</td></tr>
</table>

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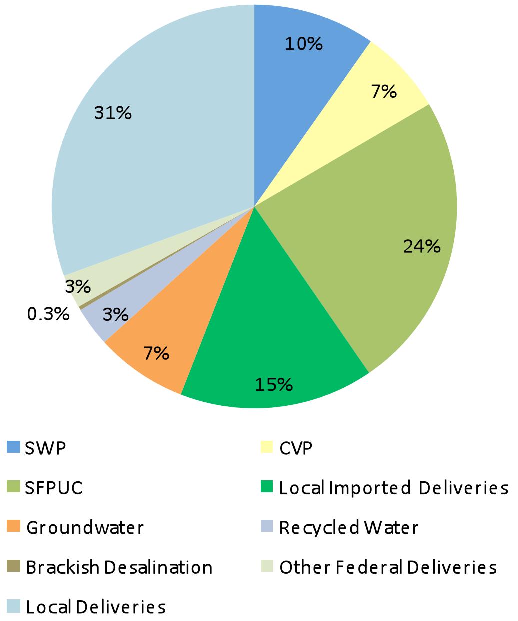
[16] Much of the data presented in the regional descriptions is taken from the California Water Plan 2005 Update, found at http://www.waterplan.water.ca.gov/

Table 2-2. San Francisco Bay Hydrologic Region at a Glance

<table>
<tr><th colspan="3">San Francisco Bay</th></tr>
<tr><td rowspan="4">

Total Water Supply (2010)
1,277 TAF



</td><td>Size:</td><td>4,506 square feet (2.85% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>29%</td></tr>
<tr><td>Water Use:</td><td>Urban: 90%
Agriculture: 10%</td></tr>
<tr><td colspan="2">Snapshot: Portions of the region are highly urbanized and include the San Francisco, Oakland, and San Jose metropolitan areas. Water imported from other regions comprises up to 40% of the region’s water supply. Population growth is most likely to occur in urban areas, increasing the urban demand in future years. Major wholesalers in the region are the SFPUC and the SCVWD, which purchase water from the SWP and the CVP.</td></tr>
</table>

Table 2-3. Central Coast Hydrologic Region at a Glance

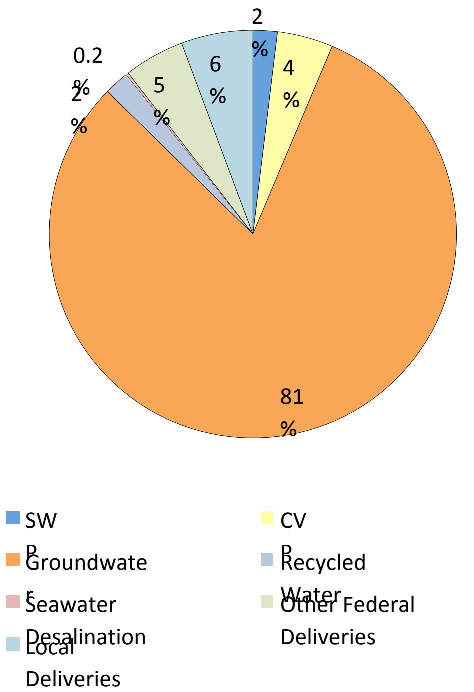
<table>
<tr><th colspan="3">Central Coast</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
1,219 TAF
 </td><td>Size:</td><td>11,326 square miles
(7.1% of the state)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>30%</td></tr>
<tr><td>Water Use:</td><td>Urban: 23%
Agriculture: 77%</td></tr>
<tr><td colspan="2">Snapshot: The Central Coast Hydrologic Region extends from southern San Mateo County in the north to Santa Barbara County in the south. The region's landscape is primarily pastoral and agricultural. Groundwater is the region's primary source of water. A significant amount of groundwater recharge is provided by the Pajaro, Salinas, and Carmel Rivers, and by the Arroyo Seco which flows into the Salinas River. As population increases, urban demand will increase in the metropolitan areas of the Central Coast region, but agriculture will still remain the region's primary end-use.</td></tr>
</table>

Table 2-4. South Coast Hydrologic Region at a Glance

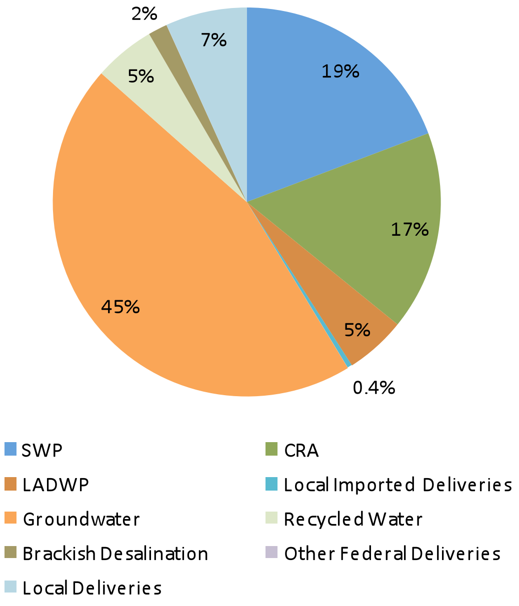
<table>
<tr><th colspan="3">South Coast</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
5,408 TAF
 </td><td>Size:</td><td>10,925 square miles (6.9% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>24%</td></tr>
<tr><td>Water Use:</td><td>Urban: 83%
Agriculture: 17%</td></tr>
<tr><td colspan="2">Snapshot: The South Coast Hydrologic Region comprises the southwest portion of the state and is California's most urbanized and populous region. The region has developed a diverse mix of both local and imported water supply sources. Local water resources development since 1995 has included water recycling, groundwater storage and conjunctive use, brackish water desalination, and water transfer and storage. The region imports water through the SWP, the CRA, and the Los Angeles Aqueduct through LADWP. This diverse mix of sources provides flexibility in managing supplies and resources in wet and dry years; but with huge water supply demand and heavy reliance on imports that have declined significantly in recent years due to legal and regulatory issues, the region remains in a tenuous water supply shortage situation.</td></tr>
</table>

Table 2-5. Sacramento River Hydrologic Region at a Glance

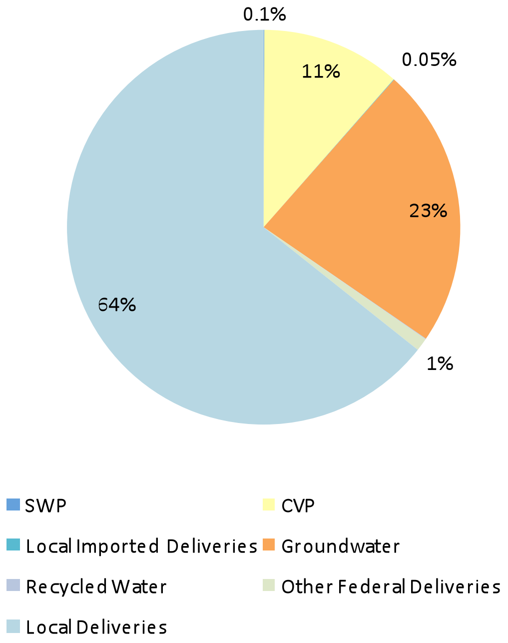
<table>
<tr><th colspan="3">Sacramento River</th></tr>
<tr><td rowspan="4">**Total Water Supply (2010)**
21,545 TAF
 </td><td>**Size:**</td><td>27,246 square miles
(17.2% of State)</td></tr>
<tr><td>**Population Growth (2005-2030):**</td><td>76%</td></tr>
<tr><td>**Water Use:**</td><td>Urban: 9%
Agriculture: 91%</td></tr>
<tr><td colspan="2">**Snapshot:** The Sacramento River Hydrologic Region includes the entire drainage area of the state’s largest river and its tributaries, extending from the Oregon border downstream to the Sacramento – San Joaquin Delta. Because of the weather patterns that produce a high level of precipitation in the region, major water supplies from the region are provided through deliveries from local surface storage and from groundwater pumping. Population in this region is forecasted to grow significantly, shifting the present agriculture-dominated demand to more urban demand. The CVP is a major wholesaler in this region.</td></tr>
</table>

Table 2-6. San Joaquin River Hydrologic Region at a Glance

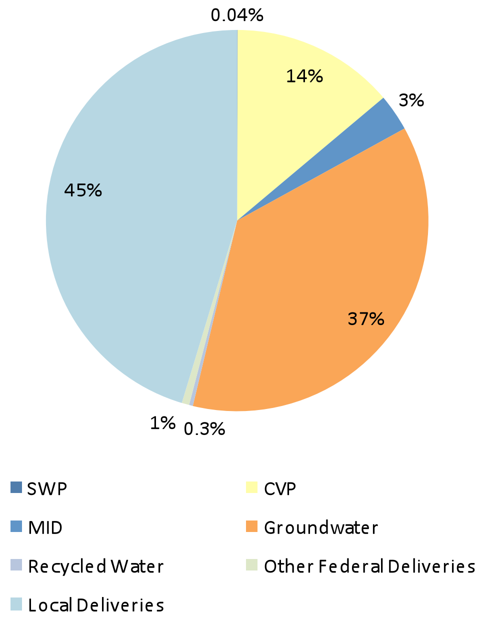
<table>
<tr><th colspan="3">San Joaquin River</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
10,448 TAF
 </td><td>Size:</td><td>15,214 square miles (9.6% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>93%</td></tr>
<tr><td>Water Use:</td><td>Urban: 6%
Agriculture: 94%</td></tr>
<tr><td colspan="2">Snapshot: The San Joaquin River hydrologic region is in the heart of California and includes the northern portion of the San Joaquin Valley. The valley portion of the San Joaquin River region consists primarily of highly productive farmland and the rapidly growing urban areas of Stockton, Tracy, Modesto, Manteca, and Merced. The primary sources of surface water in the San Joaquin River region are the rivers that drain the western slope of the Sierra Nevada. CVP is a major wholesaler in the region, with many of its facilities located throughout the San Joaquin Valley. Agricultural demand dominates the region’s water requirements.</td></tr>
</table>

Table 2-7. Tulare Lake Hydrologic Region at a Glance

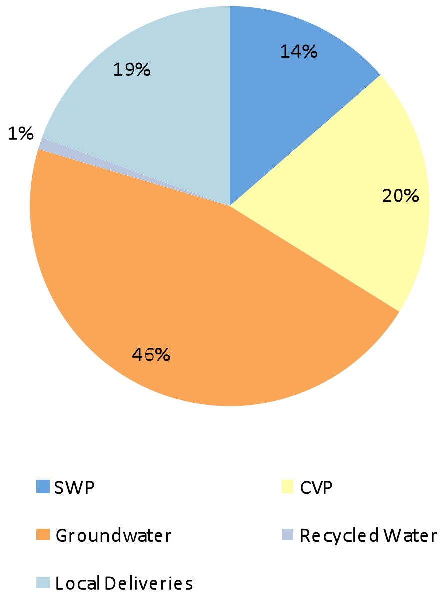
<table>
<tr><th colspan="3">Tulare Lake</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
11,258
 </td><td>Size:</td><td>17,033 square miles (10.7% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>66%</td></tr>
<tr><td>Water Use:</td><td>Urban: 3%
Agriculture: 97%</td></tr>
<tr><td colspan="2">Snapshot: The Tulare Lake Hydrologic Region is in the southern end of the San Joaquin Valley. Major water conveyance facilities in the region include the California Aqueduct, the Friant-Kern Canal, and the Cross Valley Canal, all part of the CVP and SWP. Local deliveries from water diversions from the San Joaquin River at Friant Dam are also a significant supply source for all uses in the Tulare Lake region, along with groundwater. The region is almost entirely agricultural, and despite high forecasted population growth, this balance is unlikely to shift.</td></tr>
</table>

Table 2-8. North Lahontan Hydrologic Region at a Glance

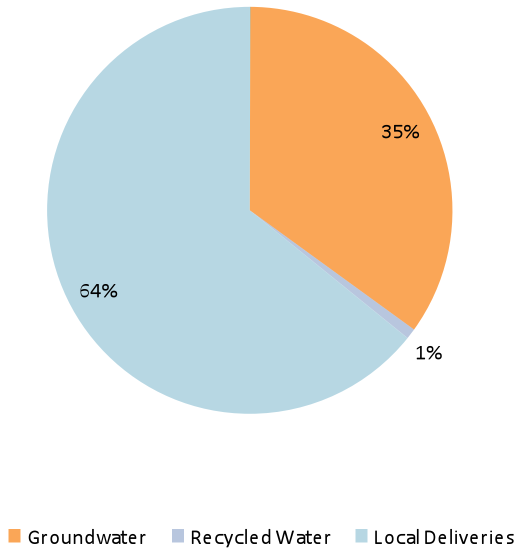
<table>
<tr><th colspan="3">North Lahontan</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
691 TAF
 </td><td>Size:</td><td>6,122 square miles (3.9% of the state)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>32%</td></tr>
<tr><td>Water Use:</td><td>Urban: 6%
Agriculture: 94%</td></tr>
<tr><td colspan="2">Snapshot: The North Lahontan Hydrologic Region forms part of the western edge of the Great Basin, a large landlocked area that includes most of Nevada and northern Utah. All surface water in the region drains eastward toward Nevada. There are no major wholesalers in this region, so most locally developed water supplies are from groundwater or small surface water diversions, with storage provided by outlet dams constructed on natural lakes.</td></tr>
</table>

Table 2-9. South Lahontan Hydrologic Region at a Glance

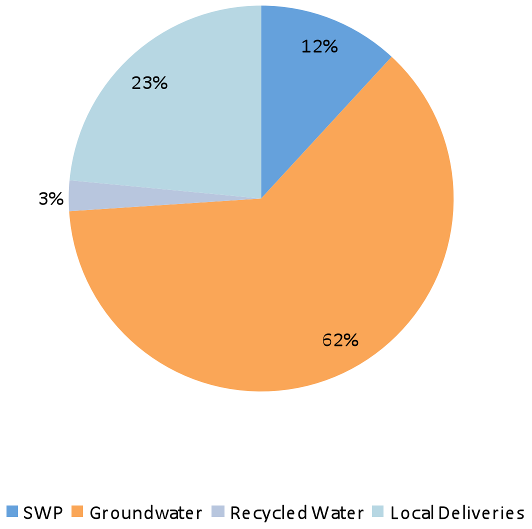
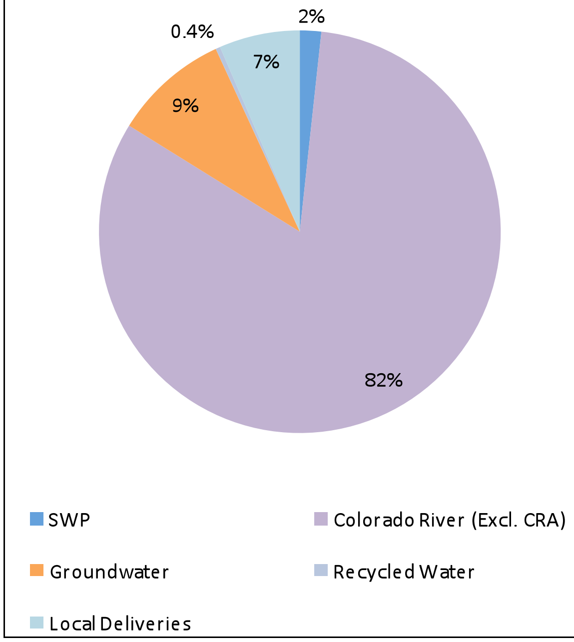
<table>
<tr><th colspan="3">South Lahontan</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
730 TAF
 </td><td>Size:</td><td>26,732 square miles (16.9% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>76%</td></tr>
<tr><td>Water Use:</td><td>Urban: 37%
Agriculture: 63%</td></tr>
<tr><td colspan="2">Snapshot: The South Lahontan Hydrologic Region contains the Eastern Sierra and the Mojave Desert and includes both the highest point (Mount Whitney) and lowest point (Death Valley) in the lower 48 states. The region supports a variety of urban and agricultural uses, including a moderate amount of agricultural acreage and several growing cities. The Los Angeles Aqueduct is the region's major water development feature, operated by LADWP. There are eight small reservoirs in the Los Angeles Aqueduct system with a combined storage capacity of about 323,000 acre-feet. Groundwater is also a significant source of water for this region, contributing to over half of the water supply.</td></tr>
</table>

Table 2-10. Colorado River Hydrologic Region at a Glance

<table>
<tr><th colspan="3">Colorado River</th></tr>
<tr><td rowspan="4">Total Water Supply (2010)
4,697 TAF
 </td><td>Size:</td><td>19,962 square miles (12.6% of State)</td></tr>
<tr><td>Population Growth (2005-2030):</td><td>92%</td></tr>
<tr><td>Water Use:</td><td>Urban: 10%
Agriculture: 90%</td></tr>
<tr><td colspan="2">Snapshot: The Colorado River Hydrologic Region is in the southeastern corner of California. The region includes all of Imperial County, about the eastern one-fourth of San Diego County, the eastern two-thirds of Riverside County, and the southeastern one-third of San Bernardino County. About 85 percent of the region's urban and agricultural water supply comes from surface water deliveries from the Colorado River. Water from the river is delivered into the region through the All-American and Coachella canals, local diversions, and the Colorado River Aqueduct by means of an exchange for SWP water. The remaining water is provided by local surface water and groundwater.</td></tr>
</table>

2.3 The Principal Determinant of Energy Intensity is Water Operations

Energy consumption by California's Supply & Conveyance systems is determined primarily by water operations:

- The quantity of water that is transported throughout the state and the distance and elevations over which it must be pumped to reach end users, and
- The amount of water that is pumped from aquifers.

In addition to the quantity of energy used, there is a significant time component to water that is very different than energy: while energy cannot yet be effectively stored and needs to be used as it is produced, water can be and is stored in reservoirs or in aquifers for future use – sometimes for hours, days, weeks, or months; and often for multiple years.

The ability to store water creates tremendous opportunities to optimize water supplies. Supplies collected during wet seasons can be held to meet water demand during periods of low to zero precipitation (e.g., summer); supplies collected during one year can be held for use in future years. Water held for use in future years, known as "carryover storage," is an essential drought hedge and a major component of every water agency's water resource portfolio.

The overarching goal of every major water purveyor in California is to effectively manage its system to comply with the law and to ensure long-term water supply reliability for its customers and constituents.

- In addition to meeting minimum flow requirements, California's water agencies are governed by flood control requirements (contracts) that are designed to minimize risks to public health and safety.

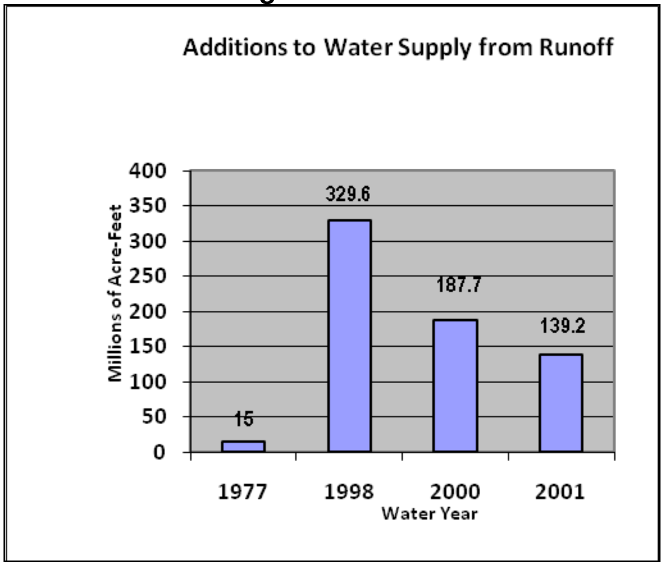
- Once all contractual requirements have been met, California's water agencies make choices as to how best to meet current and future demands from existing and planned future resources. Fluctuations in annual hydrology and imperfect long-range forecasting tools and techniques require California's water managers to plan within an environment that is inherently uncertain.

Both of the above factors significantly affect the timing, quantity and location of water releases and deliveries throughout California.

The Role of Hydrology

Over the past 100 or so years of recorded hydrology, water planners have observed years with very little precipitation, such that existing reservoirs were not filled, and years with very high precipitation and runoff in which there was significant flooding. See Figure 2-5, Variations in California's Annual Hydrology.

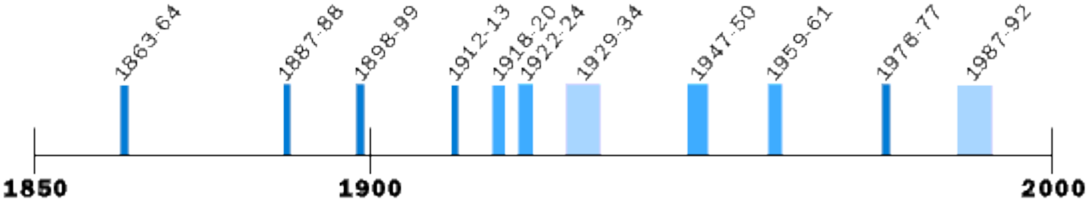
Figure 2-5. Variations in California's Annual Hydrology[17]



Water year 2000 was just about "normal" at 97% of average precipitation. The following year was dry, about 72% of normal. The difference in contributions to California's water supply was 48.5 million acre-feet, about 16 trillion gallons. In 1998, a 171% water year, precipitation added 107 trillion gallons to California's water supply. The driest year on record within the past 100 years was 1977, a 21% water year, which contributed a scant 15 million acre-feet, about 5 trillion gallons.

Given the goal of long-term water supply reliability, these substantial variations in annual hydrology cause water managers to operate their systems conservatively. No one can yet predict whether a year will be wet, dry or "normal." They also do not know whether a dry year will be followed by a wet one, or whether there may be multiple consecutive dry years (drought). Figure 2-6 shows the frequency of historical dry periods in California from 1850 to 2000. Consequently, California's water managers typically plan water supplies for multiple years anticipating the worst, never knowing whether the current year will be the first year of an extended drought.

Figure 2-6. California's Multi-Year Historical Dry Periods, 1850-Present[18]



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[17] California Water Plan Update 2005, Department of Water Resources Bulletin 160-05, Volume 3, p.1-12 and California Department of Water Resources Website, Drought Preparedness Frequently Asked Questions, viewed February 21, 2008. http://watersupplyconditions.water.ca.gov/questions.cfm

[18] California Department of Water Resources Website, Defining Drought, viewed February 21, 2008. http://watersupplyconditions.water.ca.gov/background.cfm

The Role of Storage

With such high variability and uncertainty from one year to the next, storage is an essential tool for water supply management, enabling excess water supplies to be stored for use in future years. From a modeling perspective, the role of storage increases the complexity of predicting the amount of energy used in any year by Supply & Conveyance systems.

Since water can be stored for multiple years, the usual drivers of energy demand do not apply equally to water. Whether water is in short or long supply, the energy intensity of wholesale water operations in any particular year depends on the cumulative impact of each water purveyor seeking to optimize its water resource portfolio and carryover storage.

In addition, each facility's operations are guided by its own unique set of operating protocols. Many reservoirs are not large enough to capture all of the available precipitation and runoff within their watersheds. Consequently, reservoirs may "turn over" several times in any water year – that is, a reservoir may capture and transport more water in any water year than its actual capacity. What is "typical" for any particular facility depends on many factors:

- The decisions about how to manage reservoir operations are made by individual water agencies on the basis of requirements (flood control and environmental flows) and water supply.
- Other types of issues, such as reservoir and pipeline maintenance and outages, can change the pattern of "typical" operations at any particular location.
- Water quality issues can affect the amount and timing of reservoir releases.
- Other types of facility-specific operating decisions include capacity constraints and delivery commitments.

Figures 2-7 and 2-8 illustrate monthly operations patterns at two SWP facilities: Banks and Dos Amigos pumping plants. Banks is shown to have two "peaks" in deliveries with significant pumping in the winter to draw surplus water from the Delta and put it into storage in San Luis Reservoir, followed by more pumping in the summer coinciding with higher real-time demand by agricultural and urban customers. Dos Amigos has only one "peak," in the summer season, to satisfy agricultural and urban demands.

Figure 2-7. Banks Pumping Plant Historic Water Deliveries

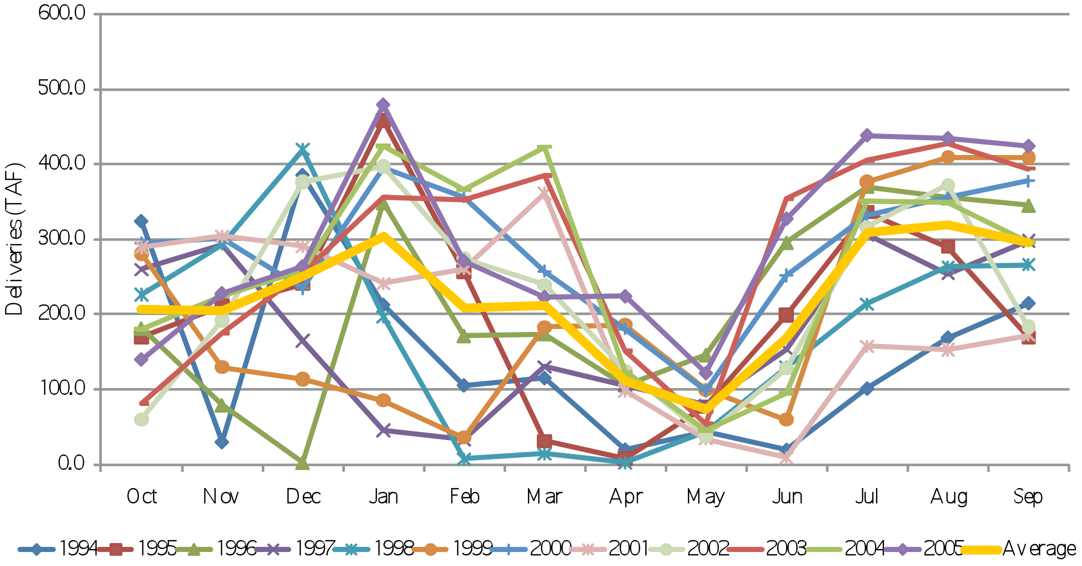
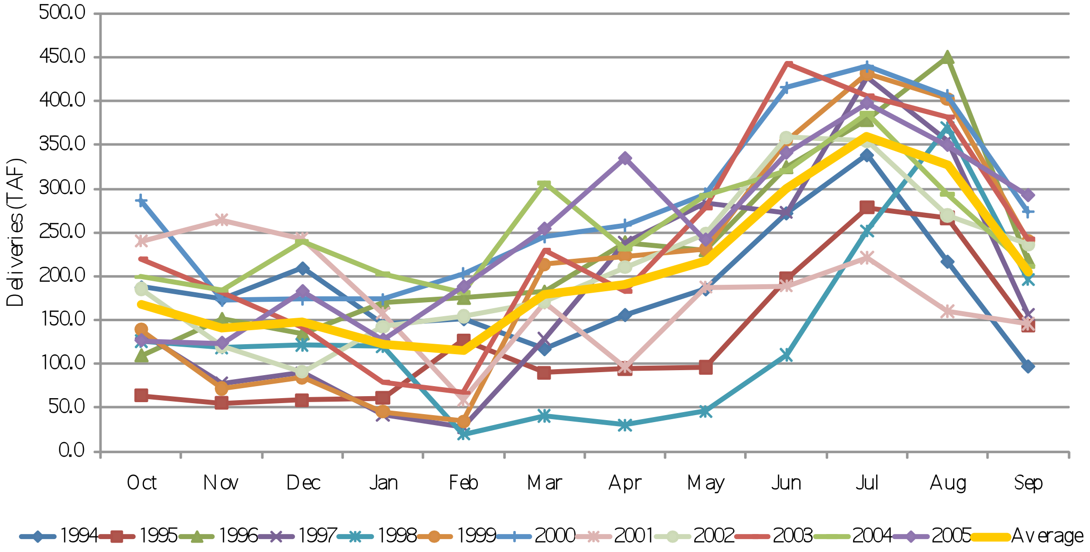


Figure 2-8. Dos Amigos Pumping Plant Historic Water Deliveries



The pattern of Supply & Conveyance energy use in any particular year is determined by a complex system of resources, infrastructure, storage, water rights, transfers, groundwater pumping, and banking – all related to efficiently and economically meeting current demand while maximizing carryover storage to mitigate drought risks.

In order to develop a predictive model capable of modeling the state's wholesale water systems so that we can understand how much, where and when energy is used, we first needed to understand and document the primary determinants of water deliveries in California.

2.4 Primary Determinants of Wholesale Water Delivery Decisions

In designing this study and the predictive model, the Study Team was guided by the following important factors:

- Water deliveries are not directly or exclusively related to annual hydrology
- Water deliveries and water consumption are not necessarily equivalent
- Water demand is not static

Each of these factors is described below.

Water deliveries are not directly or exclusively related to annual hydrology. Contrary to popular thought, water delivery decisions depend only in part on annual hydrology. In fact, water operations are impacted by a wide variety of non-hydrology factors that ultimately determine the magnitude, pattern and timing of production,[19] storage and transport of wholesale water in California.

- It does not matter how much precipitation occurs in a particular area – if storage is insufficient to capture it, it will be lost for purposes of water supply; if there is storage but no conveyance system to move it, it cannot be used outside of the local area.
- The ability to divert water from a water storage facility or from a natural or manmade waterway does not, in itself, convey rights to effect that diversion – one must also have rights to that water.
- The role of hydrology is most significant in seasonal water operations: during fall and winter, to manage precipitation events; during late spring to late summer, to meet agricultural irrigation and peak summer urban demands caused in large part by high volumes of outdoor water use (urban landscape irrigation).

Water use can also be conveyed by transactions – i.e., parties can buy or sell water. Add to the mix policies, rules, and regulations – the determinants of water operations decisions are very complex. Again, with the overarching goal of ensuring long-term water supply reliability, water operations decisions can be significantly impacted by temporary conditions and opportunistic events, as shown in the following example.

> *In its constant search for additional water supplies to make up for recent reductions in historical CRA and SWP water supplies upon which MWD’s 26 members depended*

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[19] E.g., groundwater pumping.

> *heavily, MWD is proactively seeking to purchase and store surplus water supplies. Many of the agencies with priority rights to CRA supplies determine surpluses available for sale at the end of each calendar year, which is the planning period for CRA. Consequently, in recent years, MWD has modified its CRA operating pattern with the objective of moving as much CRA water as it can during January through September to allow conveyance capacity for capturing as much surplus CRA water as possible during the last 2-3 months of each calendar year.*[20]

These types of operational decisions make it difficult to infer a relationship between water supplies and conveyance energy without extensive analyses.

Non-hydrology factors include: demand, water rights, and/or contractual obligations that impact the allocations and timing of water deliveries to various regions and customers; infrastructure changes such as storage additions or deletions, pipeline changes, major (extended) outages, and other major system changes that affect the pattern and timing of water deliveries; and policies and/or regulations that determine the amounts and/or timing of water allowed to be stored or released. Non-water factors include economic factors, such as energy costs, that affect near-term water operations decisions, and extraordinary events that are impossible to predict but can have significant data impacts that will need to be adjusted. An example of an extraordinary event was the 2001 California power crisis which caused some wholesale water agencies to operate their systems differently to mitigate the exorbitant costs created by short-term power market price volatility.

Water deliveries and water consumption are not necessarily equivalent. Water deliveries are often made, for example, for the purpose of replenishing surface, groundwater and other types of water storage facilities. Annual water deliveries thus often exceed annual water consumption by end users, except in the driest years when excess water may not be available to replenish storage. Energy cannot be simply related to current year water demand – adjustments are needed to allocate energy to that needed to meet water uses, and that which occurred for other reasons (usually to replenish storage).

Water demand is not static. Many factors can change the pattern of water use in any particular year. For example: crop changes in response to changed market and economic conditions can significantly change agricultural water demand, and water conservation measures and initiatives can change water use amounts and patterns over both short and long-term periods. Changes in state and federal water policies, rules and regulations and water agencies' water supply risk management policies and procedures can also change water demand. An example is Senate Bill 7, which seeks funding to support a 20 percent reduction in urban per capita water use by the

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[20] Interview with MWD, Jon Lambeck and Keith Nobriga on February 2, 2010.

year 2020. Another is the federal district court decision issued by Judge Wanger that restricts withdrawals from the Delta for protection of the Delta smelt.[21,22]

2.5 Selection of Water Agencies and Systems

The three largest inter-basin transfer systems - SWP, CVP and CRA - form the backbone for the conveyance energy potion of this study. In order to provide a more complete picture of the state's wholesale water systems, the Study Team added six wholesale water agencies: San Francisco Public Utilities Commission, Santa Clara Valley Water District, Modesto Irrigation District, Los Angeles Department of Water and Power, Metropolitan Water District of Southern California, and San Diego County Water Authority. The inclusion of these additional agencies increased the amount of water deliveries represented by studied agencies to 73 percent of the state's wholesale surface water supplies.[23] The balance of water supplied by other agencies was estimated using annual water balances prepared by DWR.

However, these large water purveyors are primarily surface water systems, thereby omitting the energy impacts associated with groundwater, recycled water and desalination. In order to estimate the total amount of energy used within the state's Supply and Conveyance segment of the water use cycle, this study also includes these types of water resources which are not necessarily provided by wholesale agencies. Groundwater can be pumped directly by end users such as farmers and by retail water agencies. Recycled and desalted water are typically provided by retail water agencies or by small wholesalers.

Following is a description of the water agencies studied in detail, followed by a description of how the regional water balances were used to estimate the amount of water provided by other water purveyors. More detailed descriptions of the water-energy characteristics of each water agency can be found in Appendix C.

2.5.1 State Water Project (SWP)

The SWP is the largest state built, multi-purpose water project in the country. It was designed and built to deliver water, control floods, generate power, provide recreational opportunities, and enhance habitat for fish and wildlife. SWP water irrigates about 750,000 acres of farmland, mainly in the south San Joaquin Valley. About 24 million of California's estimated 36 million

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[21] California's Water, A Crisis We Can't Ignore. *Water Supply Cutbacks.* http://www.calwatercrisis.org/ACWA.WS.SupplyCutbacks%202007.pdf

[22] New York Times, *California Judge Helps Declining Fish*. September 2, 2007. http://www.nytimes.com/2007/09/02/us/02delta.html?_r=1

[23] Does not include groundwater or local surface water. If including all surface water, the Study 1 agencies represent 29% of statewide water supply; if including all surface and groundwater, the Study 1 agencies represent 21% of statewide water supply.

residents benefit from SWP water. The SWP depends on a complex system of dams, reservoirs, power plants, pumping plants, canals, and aqueducts to deliver water. Although initial transportation facilities were essentially completed in 1973, other facilities have since been built, and still others are either under construction or are planned to be built. The SWP facilities include 25 dams and reservoirs, 29 pumping and generating plants, and approximately 700 miles of aqueducts. The SWP delivered 3,292 TAF of water to long-term contractors in Water Year (WY) 2000 (a "normal" year).

The SWP was constructed from 1957 to 1973 pursuant to passage of the Burns-Porter Act. It is owned and operated by DWR, which has contracts with 29 wholesale and retail water agencies. Deliveries to all 29 contractors are made pursuant to long-term contracts in which the contractors receiving the benefit of water delivered though SWP pay for allocated shares of capital and operating costs. Operating costs include the cost of energy used to transport water.

2.5.2 Central Valley Project (CVP)

The CVP delivers water to farms, homes, and industry in California's Central Valley and to urban centers in the San Francisco Bay Area. It is also a source of water for California's wetlands. In addition to delivering water for farms, homes, factories, and the environment, the CVP produces electric power and provides flood protection, navigation, recreation, and water quality benefits. It irrigates about 3 million acres of farmland (approximately one-third of the agricultural land in California) and supplies close to 1 million households. While the facilities are spread out over hundreds of miles, the project is financially and operationally integrated as a single large water project. The CVP reaches from the Cascade Mountains near Redding in the north to the Tehachapi Mountains near Bakersfield in the south, approximately 500 miles away. It is comprised of 20 dams and reservoirs, 11 power plants, and 500 miles of major canals as well as conduits, tunnels, and related facilities. The CVP delivered 6,227 TAF of water to long-term contractors in Water Year (WY) 2000 (a "normal" year). It provides about 600 TAF for municipal and industrial uses. The CVP also dedicates 800 TAF per year to fish and wildlife and their habitat and 410 TAF to State and Federal wildlife refuges and wetlands pursuant to the Central Valley Project Improvement Act (CVPIA).

The CVP began construction in the late 1930s pursuant to the Emergency Relief Appropriation Act and Rivers and Harbors Act of 1937 for the purpose of addressing increasing salinity in the Delta. The CVP is owned and operated by the U.S. Bureau of Reclamation on behalf of its contractors. Deliveries are made to more than 250 contractors pursuant to long-term contracts in which the contractors receiving the benefit of water delivered though CVP pay for allocated shares of capital and operating costs. Operating costs include the cost of energy used to transport water.

2.5.3 Colorado River Aqueduct (CRA)

The Colorado River Compact of 1922 allocated 7.5 million acre-feet (MAF) to the states of the lower Colorado River, and shortly after, the Boulder Canyon Project Act of 1928 allocated 4.4 MAF to California. MWD was formed in 1928 through state legislation for the purpose of obtaining water from the Colorado River though the Colorado River Aqueduct. In 1931, $220 million in bonds were passed to fund the Colorado River Aqueduct; and in 1941, the aqueduct began delivering water from Lake Havasu near the Parker Dam to MWD's service area. The CRA now serves as one of the two main sources of water for MWD.

2.5.4 Metropolitan Water District of Southern California (MWD)

MWD is the nation's largest provider of treated water. It was established in 1928 through state legislation for the purpose of increasing water reliability in southern California through construction of the CRA.

MWD has approximately 750 miles of raw and treated water distribution pipelines spanning six counties in the southern California area. Additionally, MWD manages hundreds of miles of power transmission lines, five water treatment plants, nine reservoirs, and sixteen hydroelectric plants.

Today, MWD moves more than 1.5 billion gallons of water on a daily basis through its distribution system, delivering supplies to 26 member agencies. Those agencies, in turn, sell that water to more than 300 sub-agencies or directly to consumers. In all, 19 million southern Californians live within MWD's six-county service area, which encompasses 5,200 square miles in Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties.

MWD imports its water from two sources—the Colorado River and SWP. SWP brings supplies south from the Sacramento-San Joaquin Delta, while the CRA moves water from the east from the Colorado River along the California-Arizona border. MWD built and owns the CRA and is responsible for system operations and maintenance. A series of canals, siphons, pipelines, and pumping plants moves the water west to MWD's service area.

MWD's regional distribution system connects to Lake Perris and Castaic Lake, which are terminal reservoirs for the East and West Branches of the state-owned and operated SWP as well as the SWP-operated Devil Canyon Afterbay and the Santa Ana Pipeline.

2.5.5 San Francisco Public Utilities Commission (SFPUC)

The SFPUC provides water to both retail and wholesale water customers. A population of over 2.5 million people within the counties of San Francisco, San Mateo, Santa Clara, Alameda and Tuolumne rely entirely or in part on the water supplied by the SFPUC. The SFPUC's retail water customers include the residents, business and industries located within the corporate boundaries of the City and County of San Francisco. In addition to these customers, retail water service is provided to other customers located outside of the city, such as Treasure Island, the Town of Sunol, San Francisco International Airport, Lawrence Livermore Laboratory, Castlewood, and Groveland Community Services District. The SFPUC currently sells water to 27 wholesale water customers.

Approximately 96 percent of San Francisco’s demand is provided by the SFPUC Retail Water System (RWS), which is made up of a combination of runoff into local Bay Area reservoirs and diversions from the Tuolumne River through the Hetch Hetchy Water and Power Project (HHWP). The RWS supplies are distributed within San Francisco through SFPUC’s in-city distribution system. A small portion of San Francisco’s water demand is met through locally-produced groundwater and secondary-treated recycled water. The SFPUC currently serves an average of approximately 265 million gallons per day (mgd) to 2.5 million users in Tuolumne, Alameda, Santa Clara, San Mateo and San Francisco counties. In 2001-2002, the SFPUC wholesale customers collectively purchased two-thirds of their total water supply (approximately 170 million gallons per day) from the SFPUC regional water system. Their remaining demands were met through a combination of groundwater, recycled water, water conservation, and other sources of supplies such as the SWP.

2.5.6 Los Angeles Department of Water and Power (LADWP)

The LADWP, a department of the City of Los Angeles, is responsible for potable water service to the second largest city in the nation with an area of 464 square miles and a population of four million. The city relies on four primary sources of water: imported water from the Los Angeles Aqueduct (LAA), the SWP, the CRA, and local groundwater. Recycled water has played a relatively small role in the overall water supply, meeting only 1 percent of its total water demand today. The original LAA was constructed between 1908 and 1913 to provide the City of Los Angeles with a larger and more reliable supply of water; it had a capacity of 485 CFS. The second LAA was completed in 1970 to expand the aqueduct to its current capacity of 775 CFS.

2.5.7 Modesto Irrigation District (MID)

MID was formed in 1887, shortly after the Wright Act of 1887, which allowed for the creation of irrigation districts in California. MID was formed for the purpose of expanding the agricultural base of the area. Today, MID provides irrigation water to 60,000 acres of farmland in Stanislaus County. MID’s supplies include surface water and local groundwater. MID operates the Modesto Regional Water Treatment Plant and sells treated water to the City of Modesto. Don Pedro Reservoir serves as MID’s primary water storage facility and supply. In 1893, the MID and Turlock Irrigation District (TID) built La Grange Dam along the Tuolumne River to serve as the original water supply for both districts. Canals were completed in 1903, and the first official MID irrigation season opened in 1904. The New Don Pedro Reservoir and Dam were completed in 1971 to enhance supply. MID currently owns 31.5 percent of the Don Pedro Project, while TID owns the remainder.

2.5.8 San Diego County Water Authority (SDCWA)

SDCWA was created in 1944 to administer the region's Colorado River water rights, import water, and take over the operation of an aqueduct that connects with MWD. The SDCWA provides water to the people who live and work in the San Diego region, a population of 3 million and a $171 billion economy. All but 11 percent of SDCWA’s imported water is currently obtained from MWD. MWD imports consist of a mix of water that originates from the SWP and the CRA; on average 40 percent of imported MWD water is from the SWP while the other 60 percent is from the CRA. SDCWA imports both treated and raw water from the MWD. Currently, 43 percent of the total water imported from MWD is treated; the remaining 57 percent is raw. Supplies were recently augmented by a transfer agreement with the Imperial Irrigation District (IID). SDCWA funded the lining of the All American Canal which will conserve 67.7 TAF, the majority of which will be transferred to SDCWA. SDCWA provides water to 24 member agencies that import water through pipelines with a maximum capacity of 900 mgd.

2.5.9 Santa Clara Valley Water District (SCVWD)

SCVWD is the primary water resources agency for Santa Clara County, California. SCVWD manages Santa Clara County's drinking water resources, coordinates flood protection for its 1.7 million residents, and serves as steward of the county's more than 800 miles of streams and 10 district-built reservoirs. The district’s water supply system is a complex interdependent system of storage, conveyance, treatment, and distribution facilities comprised of 10 surface reservoirs plus 393 acres of recharge ponds, 76 miles of instream recharge, 142 miles of pipelines, 3 pump stations, 3 treatment plants, and 1 recycled water treatment plant and distribution system. The District has a diverse mix of water supplies and a strong commitment to water use efficiency.

2.6 The Role of Regional Water Balances

The state’s water supply portfolio is depicted in the regional water balances prepared by DWR to support statewide water planning. The regional water balances include yearly water supply data for two major suppliers: SWP and CVP. The quantities of water provided by other water purveyors are aggregated within these balances.

The Study Team relied on the regional water balances to compute the amount of water used to meet in-region demand attributable to the balance of water supplied by agencies for which data were not separately collected. Figure 2-9 shows a statewide monthly water supply profile for the baseline (2010) amount of water supplied by each water type. Figure 2-10 shows the 2010 water supply by hydrologic region and by the five water year types. The figures show groundwater varies significantly over the year while many of the surface water supplies have little annual variance. Water supply also varies significantly by hydrologic region with the Central Valley receiving a majority of the state’s water.

Figure 2-9. 2010 Monthly Water Supply by Type

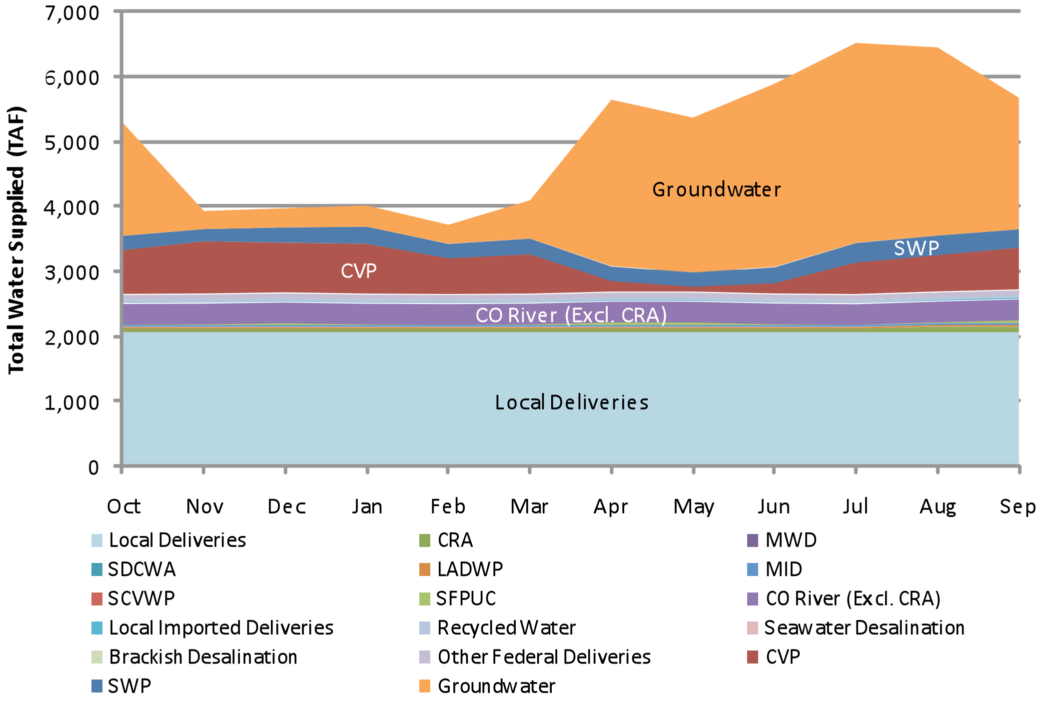
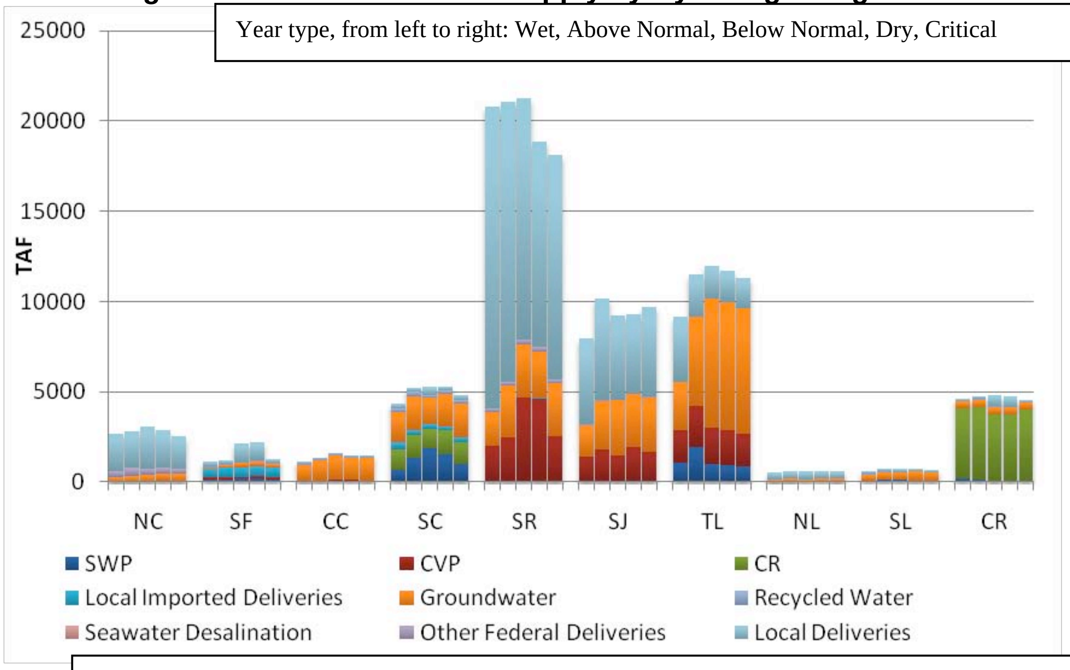


Figure 2-10. Historic Water Supply by Hydrologic Region and Water Year


Year type, from left to right: Wet, Above Normal, Below Normal, Dry, Critical

Notes: CR = All Colorado River Diversions; Data in this graph is from 1998, 2000, 2001, 2002 and 2004

In the next chapter, we describe the energy characteristics of the state’s wholesale water systems.

3 Energy Use by California's Wholesale Water Systems

As discussed in Chapter 2, the primary determinant of energy use by wholesale water systems is water operations decisions that are unique to each agency as it seeks to meet its own short-term water commitments while concurrently maximizing long-term water supply reliability for its customers and constituents. As a consequence, there is no single algorithm that can effectively represent the decisions made by water operators. While each is guided by a set of goals, operations plans and protocols, many of their decisions are reactive and opportunistic as they proactively manage risks to public health and safety while concurrently protecting ecosystems and leveraging short-term opportunities for long-term water reliability benefits. Water releases for flood control; increasing water conveyances to take advantage of surplus water supplies made available by other water agencies; and other types of water operations decisions can be anticipated, but not accurately predicted.

Recognizing that there is no perfect answer, the Study Team focused on documenting the pattern of monthly energy and water deliveries by the nine agencies Although D.07-12-050 specified developing a model based on data from 1980-2005, the Study Team recommended focusing on water years 1998-2005 for the following reasons:

- Current periods are more representative of the current state of water resources and infrastructure, and thus will more fairly represent the types of water operations decisions being made by California's wholesale water agencies.
- Water years 1998-2005 provide sufficient diversity of hydrology types to identify the range of variations in water operations that may be attributable to hydrology.
- Best available data about the types of water supply resources that were used to meet demand in specific years are DWR's regional water balances that are presently only available for these years.

To represent projected future energy intensity, the Study Team relied upon scenario analyses that considered composites of planned future policies, rules, regulations, programs, resources, infrastructure, etc., and their potential impacts on wholesale water operations. Two composite cases were developed to represent the potential impacts of changes in water resources, demand and policies: a high energy intensity case and a low one. In this manner, the potential range of energy impacts could be estimated to support policy deliberations.

The high and low energy scenarios developed by the Study Team are discussed in more detail in Chapter 5. In this Chapter, we discuss the base case: current energy usage by California's

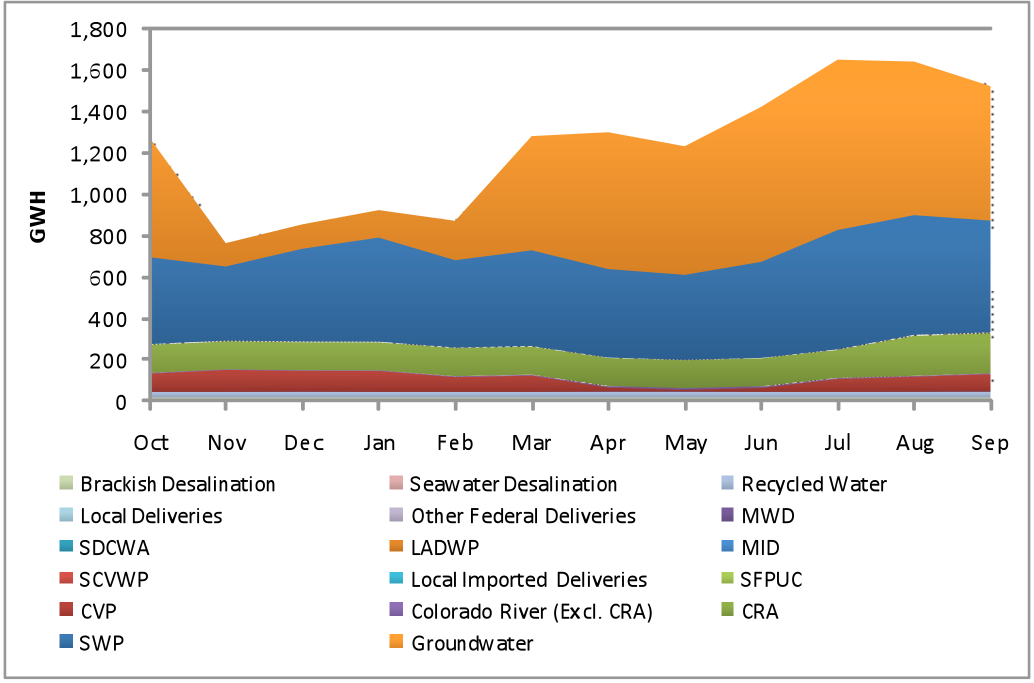
Supply & Conveyance systems. Although water year 2010 is not yet over, precipitation to-date has been reported as “above normal.” Consequently, “Base Case” is water year 2010 with above normal hydrology, current water demand, and current policies.

3.1 Energy Use by Wholesale Water Systems

California’s wholesale water systems use energy in the following ways:

Water Pumping. Most of the energy used by wholesale water systems is for pumping water. As noted in Chapter 2, substantial quantities of energy are used to move large volumes of water hundreds of miles throughout the expanse of California and over highly variable topography. The highest energy intensity incurred to transport water occurs in SWP’s system at Edmonston Pumping Plant where water is pushed 2,000 feet uphill over the Tehachapi Mountains for delivery to users in southern California. Despite the high energy intensity of SWP, more energy is used every year to pump groundwater. Furthermore, energy use for groundwater pumping during summer months exceeds all pumping energy by the three largest inter-basin transfer systems combined (see Figure 3-1).

Figure 3-1. 2010 Baseline Monthly Energy Profiles of Statewide Water Delivery Operations



The primary drivers of energy use for wholesale water pumping differ according to the water resource.

- Energy used to transport surface water supplies depends on the quantity of water being moved, the distance over which it is being moved, and the elevation over which it is being pumped.

- Energy is also used to extract groundwater from subsurface aquifers. For groundwater, the primary driver is the depth from which the pump must pull the groundwater – referred to as "depth to groundwater."

Other factors such as pump head and efficiency, pipeline friction and conveyance losses also affect the energy intensity of water operations. Urban groundwater pumps often pump at higher pressures to accommodate distribution where agricultural well pumps are at lower pressures.

Water Production. Energy is also used to create new water supplies. The primary types of "produced" water are recycled and desalinated.

- ***Recycled water*** adds to water supply by recovering wastewater effluent. Although state law allows wastewater treated to secondary standards to be used for certain types of beneficial uses, most uses require treatment to tertiary standards. For purposes of Study 1, we are only considering tertiary treated water as additional water supply. The energy intensity of recycled water is measured as the incremental amount of energy needed to treat water to tertiary standards, thereby creating water of a quality that is approved by the state for reuse. The amount of incremental energy is determined by the effluent discharge rules applied by the State Water Resources Control Board (SWRCB):
    - In some cases, wastewater must be treated to secondary standards. For these cases, the incremental energy needed to create recycled water is deemed to be that needed to treat the recycled water to tertiary standards.
    - In some areas, effluent discharge rules already require that wastewater be treated to tertiary standards. For these areas, the incremental energy to create recycled water is deemed to be zero.

  Examples of approved uses of recycled water include a wide variety of water uses that do not need potable water. These include outdoor landscape irrigation, power plant cooling and other industrial uses, and recharge of groundwater (and in some areas, recharge of some surface reservoirs).[24] In all such cases, substituting recycled water for non-potable uses frees up precious potable water supplies for potable uses.[25]

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[24] The City of San Diego is proceeding with an indirect potable reuse pilot that would mix recycled water with surface supplies.

[25] Advanced water treatment technologies such as ozonation and UV light arrays can be used to purify tertiary treated water to levels that can be directly ingested. The energy intensity associated with purifying tertiary water to create directly potable water supplies is addressed in Study 2.

- ***Desalination.*** Energy is also used in the Supply & Conveyance segment to create usable water supplies from water resources that are otherwise not usable for either agricultural or urban purposes. These consist primarily of brackish groundwater that is contaminated with heavy concentrations of salts and minerals, and ocean seawater. Desalination plants typically use reverse osmosis technologies requiring water to be highly pressurized to pass through semi-permeable membranes removing salts. The energy intensity requirements of desalination depend on the salinity of the source water. Seawater desalination requires significantly more energy than brackish water desalination as the source water contains higher concentrations of salt.

3.2 Quantity of Energy Used in the Supply & Conveyance Segment

In 2005, to estimate the amount of water-related energy consumed in California, staff of the California Energy Commission (CEC) relied primarily on available data that included:

- Energy consumption data reported by electricity sellers required to report annual sales by Standard Industrial Code (SIC) or North American Industry Classification System (NAICS) building codes (hereafter referred to as "SIC/NAICS");

- Anecdotal information from water and wastewater treatment plant operators; and

- Input from other staff agencies.

These data, although illustrative, were not definitive for the purpose of quantifying electricity use by the water sector. CEC staff then attempted to organize that data in a manner that facilitated allocating water-related energy to the various segments of the water use cycle. All end uses of energy were included in that process - i.e.:

- Energy used by water and wastewater agencies themselves in the conduct of their respective missions. Water and wastewater operations include (a) production, collection, conveyance, treatment and delivery of potable water; (b) collection, transport, treatment and disposal of wastewater; and (c) additional treatment and delivery of recycled water.

- Other end uses were comprised of both agricultural and urban pumping, heating and other energy uses needed to support end uses of water, including residential, commercial and industrial indoor and outdoor water uses. Agricultural uses of water (irrigation pumping and potentially other uses) were also included.

The fundamental problem in comparing these data to Studies 1 and 2 is that the CEC's database contains information about electricity sales, while Studies 1 and 2 focus on electricity requirements by California water and wastewater agencies. (Natural gas was included in the scope of the studies but most water-related natural gas is used for heating; little natural gas consumption is used by the water sector itself.) While it seems logical that there should be a reasonable correlation between these two data sets, the amount of electricity sales reported by SIC/NAICS does not accurately report the nature of the energy end use for the following reasons related to how data are categorized:[26]

- ***Inconsistent application of SIC/NAICS codes***. Organizations assign these codes differently. Even within any particular organization, individuals assign these codes differently.

- ***A single energy meter may serve multiple end uses***. Meters that serve multiple purposes may be coded to any one of the purposes or to a very broad generic category. Further, there are inconsistencies as to which codes are used for ancillary systems that support primary functions.

- ***Loads connected to energy meters can change over time***. SIC/NAICS codes may not be updated to reflect these changes.

CEC staff that manage the state's database of energy consumption by SIC/NAICS observed that electricity sellers vary as to how they report water-related energy consumption. There were too many inconsistencies and unknowns to enable reclassifying these data to segments of the water use cycle.

Despite all of these data imperfections, the CEC's database of statewide energy consumption was the best source of data available in 2005, and it probably still is.[27] So, what is the total amount of energy used in California by the water sector itself? The best answer as of 2006 (CEC 2006) was 12,383 GWh - the sum of urban and agricultural water supply and treatment plus wastewater treatment - about 4.9 percent of total electricity consumption in California during calendar year 2001. During the course of Study 1, however, the Study Team became aware that the electricity data collected from the nine wholesale water agencies were not exactly the same as that reported in the CEC's energy consumption database that was used to support its estimates of water-related electricity. In addition, it appeared that groundwater energy was significantly understated.

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[26] Interview with Lorraine White, Senior Energy Specialist and Advisor to Commissioner Anthony Eggert, California Energy Commission, May 19, 2010.

[27] California Energy Consumption Database, California Energy Commission's website: http://www.ecdms.energy.ca.gov/

After comparing the sources of differences in the data, the Study Team recommended adjusting the allocation between energy used by the water sector itself and water-related end uses. The results of the Study Team's comparisons are reflected in Table 3-1.

Table 3-1: Comparison of Calendar Year 2001 Statewide Water Sector Electricity Use (GWh)

Segment of the Water Use Cycle	CEC Study (2005)	CEC Study (2006)	Study 1	Study 2
Supply	10,742	10,371	15,786	172
Conveyance				
Water Treatment				312
Water Distribution				1,000
Wastewater Treatment	2,012	2,012		2,012
Total Water Sector Electricity Use	12,754	12,383	19,282	
% of Total Statewide Electricity Requirements	5.1%	4.9%	7.7%	
Note: Excludes estimates of electricity consumption for water end uses.				

The potential adjustments identified by the Study Team are very conservative. A detailed discussion of the bases for these adjustments is provided in Appendix N, Comparison of Study 1 and Study 2 Findings with Prior Studies.

3.3 Water Agencies' Energy Profiles

While most wholesalers move water in similar ways, pumping water in canals and aqueducts, the distinguishing characteristics of each cause a wide range of energy use and energy intensity. The following sections describe each wholesaler, its energy use, and the energy intensity of its water supplies. Additional water supplies beyond the nine wholesalers included in Study 1 are also discussed.

3.3.1 State Water Project

The SWP is a major user of energy. During Water Year (WY) 2000, a "normal" water year, the SWP delivered 3,553 TAF of water to State Water Contractors (SWCs) and an additional 1,378 TAF of non-SWP water to other contractors. The total annual amount of energy needed to convey all water in the SWP was 8,418 GWh. Of this energy, 28 percent (2,380 GWh) was needed during summer months (June, July, August); the balance of energy consumption (72 percent, 6,038 GWh) occurs during the other nine months of the year. Deliveries and total energy use in other water year types can be seen in Table 3-2. Historic deliveries and energy use are not representative of future deliveries and energy use because the Wanger Decision has reduced pumping out of the Delta. Multiple stakeholders are seeking remedies to the loss of water supplies from the Delta.

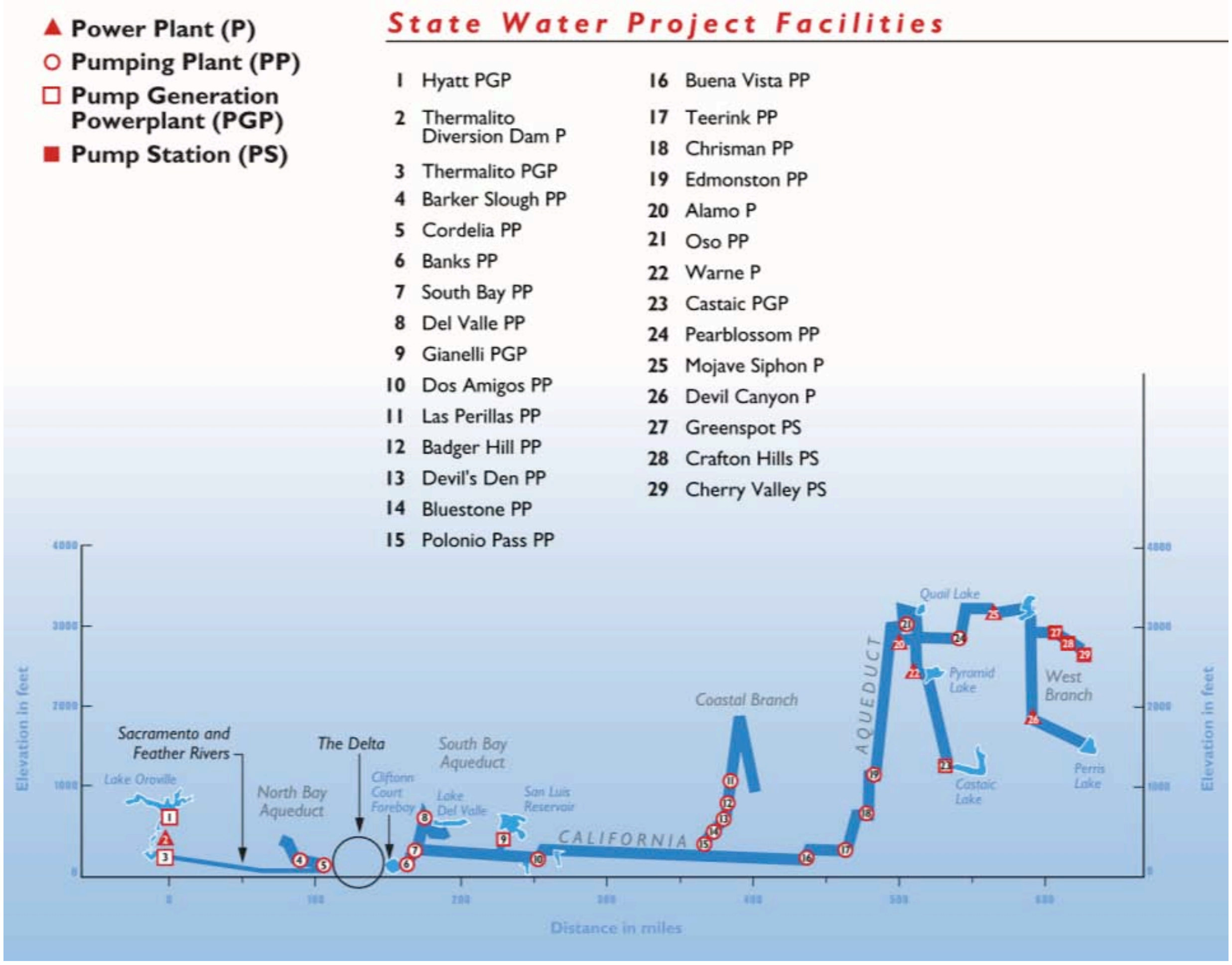
Table 3-2. Water Deliveries and Energy Use by the SWP

Water Year	Data Year	SWP Water Delivered via SWP (TAF)	Total Water Delivered via SWP (TAF)	Energy Used for Water Deliveries (GWh)
Wet	1998	1,734	2,779	4,179
Above Normal	2000	3,553	4,932	8,418
Below Normal	2004	3,204	4,487	9,895
Dry	2002	2,545	3,927	8,233
Critical	2001	1,986	3,492	7,548

Of the energy needed to support SWP deliveries during a "normal" year, 38 percent (3,227 GWh) is met through in-conduit hydropower generated during the process of delivering the water. An additional 35 percent (2,958 GWh) is met through other sources of self generation, and the balance (27 percent, 2,233 GWh) is purchased under long term wholesale power contracts or through short-term power purchases.

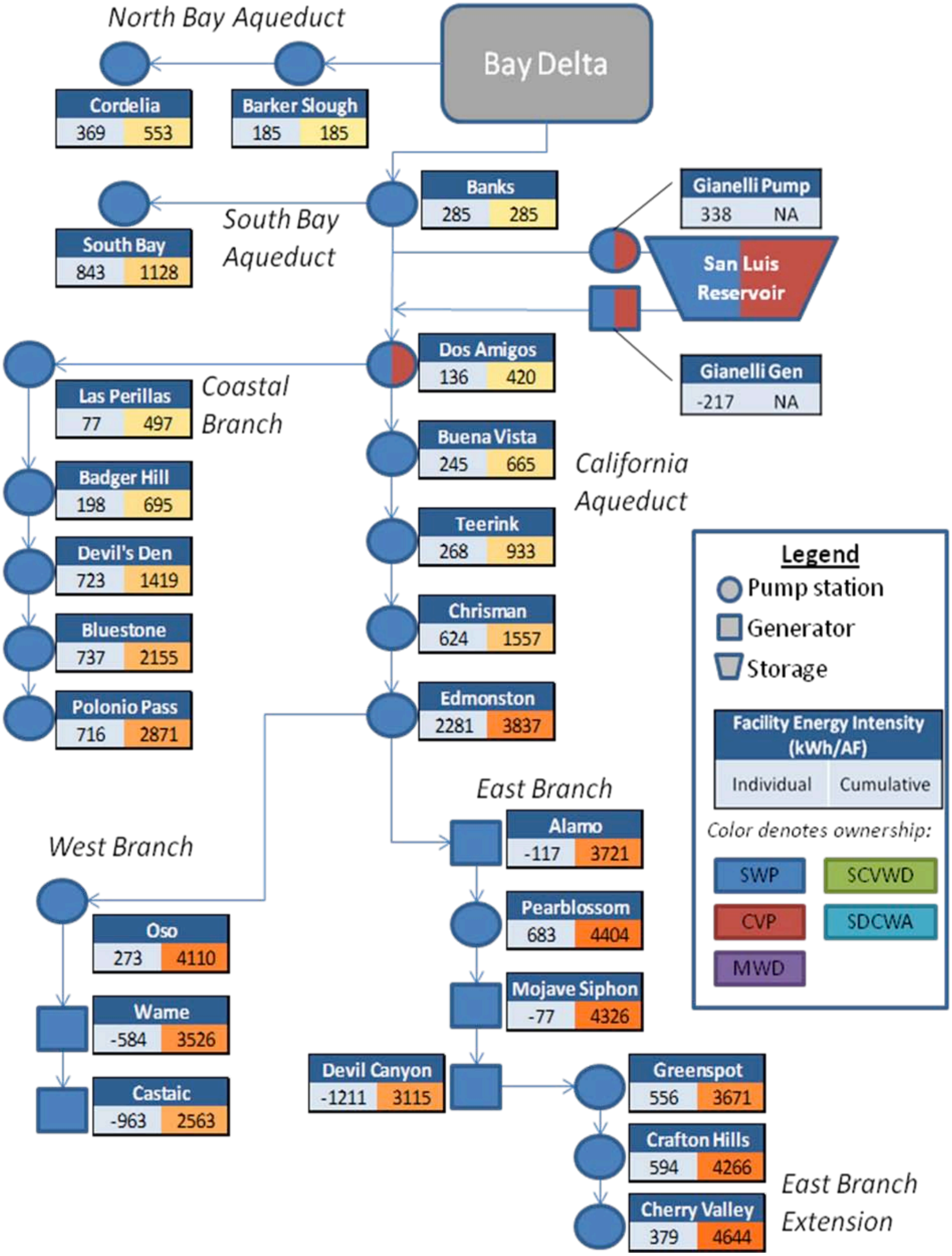
Significant energy use is required by SWP's 21 pumping stations. These pump stations must overcome significant elevation differences (see Figure 3-2, elevation profile of SWP). Edmonston Pumping Plant alone must pump to an elevation of approximately 2,000 feet, accounting for approximately 45 percent of the SWP's energy use. Water traveling from the Delta to southern California must overcome an elevation difference of approximately 3,000 feet. As water passes through each pump station, it incrementally raises the energy intensity of the water flow, ultimately reaching more than 2,500-4,600 kWh/AF for deliveries to various locations in southern California. Figure 3-3 shows the energy intensity of the SWP facilities as well as the cumulative intensity that results as water is transported along the system from north to south. A negative energy intensity for a facility indicates a generating plant while a positive energy intensity denotes a pumping plant.

Figure 3-2. State Water Project Facility Elevations



Source: Department of Water Resources Bulletin 132

Figure 3-3. Energy Intensity of State Water Project Facilities



3.3.2 Central Valley Project

CVP's water delivery system is comprised of 500 miles of major canal as well as conduits, tunnels, and related facilities. The majority of energy used by CVP is to deliver water to customers along the Delta-Mendota Canal and San Luis Canal (shared with CVP). Deliveries to these customers require significant energy use by pump stations. Flows in other CVP canals are mostly gravity fed or use little energy for diversion pumps (with the exception of the Contra Costa Canal, which is operated by CCWD). For this reason, the Study Team focused on operations and energy consumption associated with making deliveries along the Delta Mendota Canal and San Luis Canal.

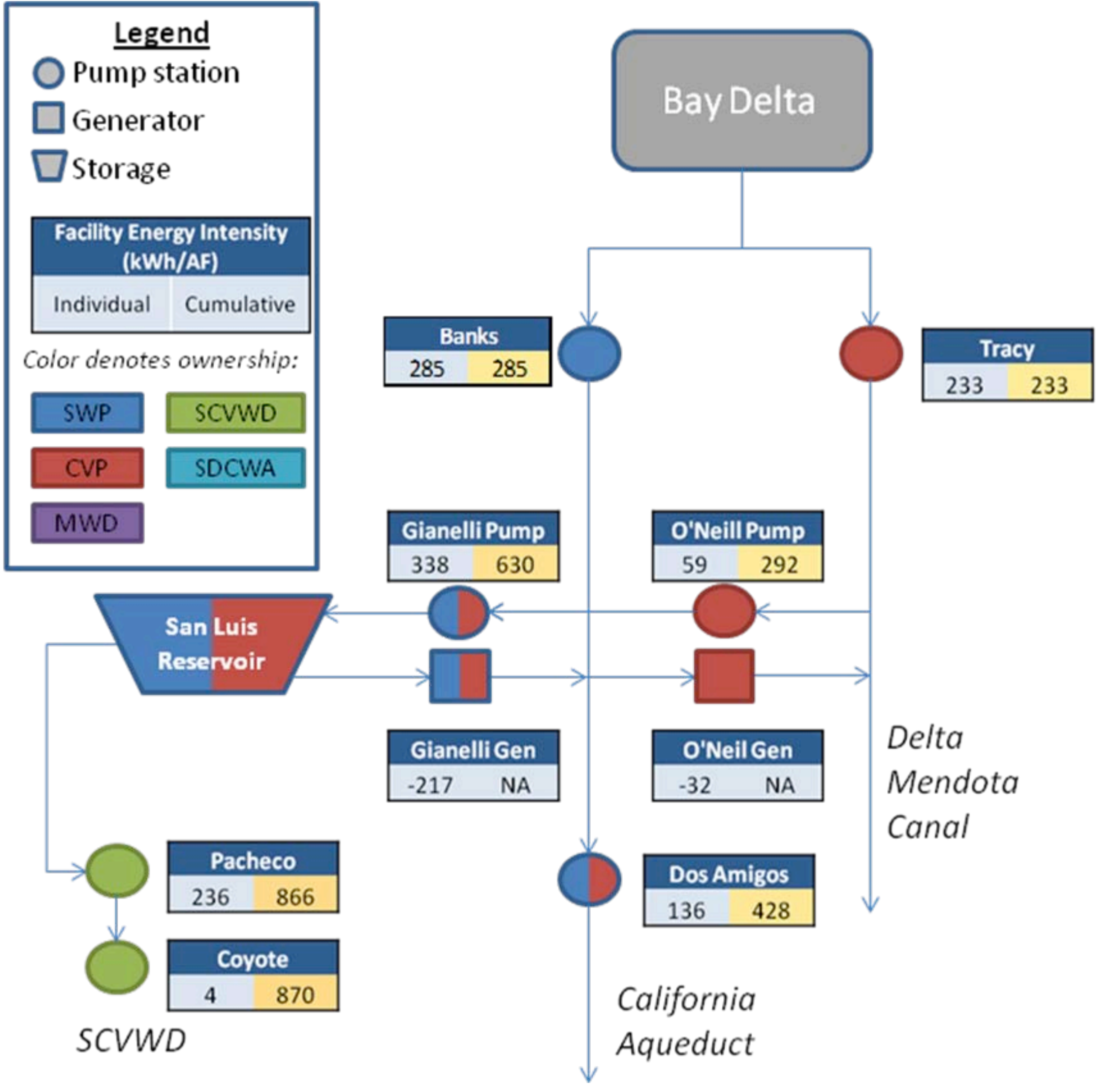
During WY 2000, a "normal" water year, the CVP delivered 6,227 TAF of water to contractors: 3,293 TAF of these deliveries were made via the Delta Mendota and San Luis Canal. The total annual amount of energy needed to convey all Delta Mendota and San Luis Canal water was 1,148 GWh. Of this energy, 21 percent (241 GWh) is needed during summer months (June, July, August); the balance of energy consumption (79 percent, 907 GWh) occurs during the other nine months of the year. See Table 3-3 for water deliveries and energy consumption in other year types. Historic deliveries and energy use are not representative of the future because the Wanger Decision has reduced pumping out of the Bay Delta.

Table 3-3. Water Deliveries and Energy Use by the CVP

Water Year	Data Year	Total Water Delivered via CVP (TAF)	Delivered via Delta Mendota and San Luis Canals (TAF)	Energy Used by Delta Mendota and San Luis Canal Facilities (GWh)
Wet	1998	5,539	3,314	1,155
Above Normal	2000	6,227	3,293	1,148
Below Normal	2004	6,073	3,903	1,173
Dry	2002	5,888	3,502	1,089
Critical	2001	5,532	3,438	1,026

Substantial quantities of energy are required by CVP's four pumping stations. These pump stations move large amounts of water over long distances and significant changes in elevation. As water passes through each pump station, it incrementally raises the energy intensity of the water flow, ultimately reaching 428 kWh/AF for deliveries to Central California via the California Aqueduct (see Figure 3-4).

Figure 3-4. Energy Intensity CVP and SCVWD Facilities



3.3.3 Colorado River Aqueduct

The CRA is a major user of energy, pumping water from five large pump stations over 330 miles of aqueduct and pipeline. The main aqueduct is nearly 240 miles and ranges from the Parker Dam on the Colorado River in the east to Lake Mathews in the West.

During WY 2000, a “normal” water year, the CRA delivered 1,299 TAF. The total annual amount of energy needed to convey that water in the CRA was 2,557 GWh. Of this energy, 25.6 percent (353 GWh) was needed during summer months (June, July, August); the balance of energy consumption (74.4 percent, 1904GWh) occurred during the other nine months of the year. Table 3-4 shows water deliveries and energy consumption data for other historic water year types. Historic deliveries and energy use are not representative of the future because the

Quantification Settlement Agreement (agreement of the future water allocation between Colorado water users) in 2003 has reduced deliveries to MWD via the CRA.

Table 3-4. Water Deliveries and Energy Use by the CRA

Water Year	Data Year	Water Delivered via CRA (TAF)	Energy Used for Water Deliveries (GWh)
Wet	1998	1,085	2,136
Above Normal	2000	1,299	2,557
Below Normal	2004	720	1,416
Dry	2002	1,277	2,543
Critical	2001	1,264	2,506

Significant energy use is required by CRA's five pumping stations. These pumping stations must move large amounts of water over a total elevation difference of 1617 feet. As water passes through each station, it incrementally raises the energy intensity of the water flow, ultimately reaching 1,976 kWh/AF for deliveries to MWD (see Figure 3-5).[28]

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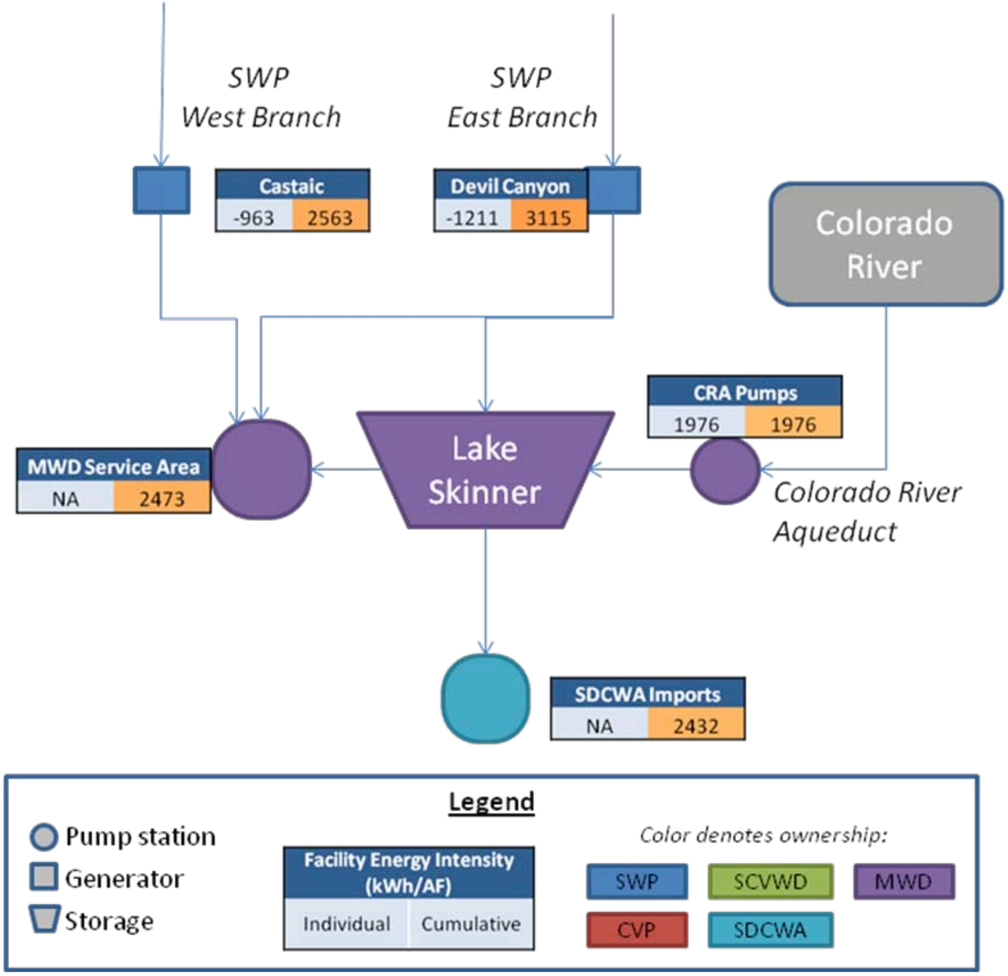
[28] MWD aggregated energy data for major stretches along CRA where water was being pumped without any deliveries being made along the way.

Figure 3-5. Energy Intensity CRA, MWD, and SDCWA Facilities



3.3.4 Metropolitan Water District of Southern California

Relatively little energy is used to move water imported by MWD since SWP water is primarily delivered by gravity once it gets over the Tehachapis. A further benefit is that MWD is able to recover portions of the energy through its 16 hydropower plants.

The energy data below summarizes only conveyance energy and hydropower production. In order to facilitate comparisons of energy intensities of different types of wholesale water conveyance systems on an equivalent basis, all treatment energy is separately covered in Study 2.

During WY 2000, a “normal” water year, MWD delivered 2,622 TAF of water to member agencies. Relatively little energy is used to distribute this water; significant amounts of energy are generated through deliveries. MWD’s imports arrive at high elevations, and deliveries are made to member agencies at lower elevations allowing energy generation. During WY 2000, 41.6 GWh was generated through in-conduit hydropower facilities as a process of delivering the water. Power is mostly sold under long-term power contracts. Table 3-5 shows water deliveries and power generation for other water year types.

Table 3-5. Water Deliveries and Energy Use by the MWD

Water Year	Data Year	Water Delivered via MWD (TAF)	Energy Generated from Water Deliveries (GWh)
Wet	1998	1,565	25.7
Above Normal	2000	2,622	41.6
Below Normal	2004	2,222	46.5
Dry	2002	2,617	42.8
Critical	2001	2,458	31.5

While relatively little energy is used by MWD to deliver water, its embedded energy is high. This is because the majority of MWD's water supplies originate from SWP or CRA. The average energy intensity of water delivered by the MWD to its customers is 2,473 kWh/AF (see Figures 3-3 and 3-5). Power production is treated separately – i.e., not netted from the energy intensity of water deliveries – because its hydropower facilities do not meet the test of "in-conduit hydropower generated as a byproduct of water deliveries."

3.3.5 San Diego County Water Authority

The San Diego County Water Authority (SDCWA) operates an aqueduct that connects with MWD. All but 11 percent of the SDCWA's imported water is currently obtained from MWD. MWD imports consist of a mix of water that originates from SWP and the Colorado River Aqueduct; on average 40 percent of imported MWD water is from SWP while the other 60 percent is from the CRA.

No energy is used by SDCWA to import water from MWD as the system is mostly gravity fed. Several pumps are located throughout SDCWA's conveyance system; however, these are mostly used to move local surface water and to provide integrated connection between pipelines for supply reliability. Water can be pumped from San Diego's local reservoirs to its entire service area should MWD's supplies be interrupted. Additionally, pumps are capable of reversing the flow in the First and Second Aqueducts to deliver SDCWA water to Skinner Lake should MWD need it in an emergency.

While little energy is used by SDCWA to make its deliveries, the energy intensity of water delivered is still quite high. This is because the majority of water it delivers originates from the SWP or CRA which embed significant energy in water delivered to MWD and subsequently to SDCWA. The Study Team estimates the average energy intensity of water delivered by SDCWA to its customers is 2,432 kWh/AF (see Figure 3-5). This does not account for power generation or treatment activities by MWD, and also assumes that SDCWA's SWP water arrives via the East Branch.

3.3.6 *San Francisco Public Utilities Commission*

The SFPUC Regional Water System (RWS) consists of approximately 160 miles of pipelines and tunnels spanning from Yosemite National Park to Crystal Springs Reservoir. The majority of conveyance operations are gravity fed; however, the use of some pumping is required.

During WY 2000, a "normal" water year, the SFPUC delivered 306 TAF of water to customers. The total annual amount of energy needed to convey all water in the SFPUC RWS was 28 GWh. Of this energy, 26.7 percent (7.5 GWh) was needed during summer months (June, July, August); the balance of energy consumption (73.3 percent, 20.5 GWh) occurred during the other 9 months of the year. During WY 2000, the SFPUC produced 449.5 GWh from water that is used for water deliveries. It exceeds the energy needed to support all SFPUC/Water Enterprise activities, and the balance (421.5 GWh) supports the City and County of San Francisco's municipal load requirements, or is sold to Modesto Irrigation District, Turlock Irrigation District, and several other public utility or government customers. Table 3-6 shows the total water delivered by the SFPUC in five water year types and the associated energy used for the conveyance of that water.

Table 3-6. Water Deliveries and Energy Use by the SFPUC

Water Year	Data Year	Water Delivered via SFPUC RWS (TAF)	Energy Used for Water Deliveries (GWh)
Wet	1998	253.8	24.7
Above Normal	2000	305.6	28.0
Below Normal	2004	294.8	29.9
Dry	2002	317.2	28.3
Critical	2001	309.5	28.0

SFPUC's operations have low energy use resulting in low energy intensities. The Study Team estimated average energy intensity of deliveries by the SFPUC for three service areas, illustrated in Table 3-6a.

Table 3-6a. Energy Intensity of Water Deliveries by the SFPUC

Service Area	Energy Intensity of Deliveries (kWh/AF)
SFPUC South Bay	0.7
SFPUC Peninsula	114.6
SFPUC SF City	235.9

3.3.7 Santa Clara Valley Water District

The Santa Clara Valley Water District (SCVWD) is the primary water resources agency for Santa Clara County, California. The district's water supply system is a complex interdependent system comprised 10 surface reservoirs, 393 acres of recharge ponds, 76 miles of instream recharge, 142 miles of pipelines, 3 pump stations, 3 treatment plants, and 1 recycled water treatment plant and distribution system.

During WY 2000, a "normal" water year, SCVWD delivered 235 TAF of water to contractors (from all sources; CVP, SWP, and SFPUC). The majority of energy consumption required by the SCVWD's conveyance system is used to transport imported water from CVP. Additional imports are available from SWP and SFPUC, though energy use associated with these deliveries is minimal. The annual amount of energy needed to import and convey the CVP water in SCVWD was 28.2 GWh. All energy use associated with the conveyance of water is attributed to Pacheco and Coyote pumping plants. Table 3-7 summarizes imports and energy use in other water year types. SCVWD purchases power to operate its CVP import pump stations. It does not use any power generated through in-conduit hydropower or other means of self generation for CVP imports. The majority of energy used for these pump stations is obtained from CVP via the Western Area Power Administration (WAPA); however, some energy is purchased from Pacific Gas & Electric (PG&E, approximately 15 percent).

Table 3-7. Water Deliveries and Energy Use by the SCVWD

Water Year	Data Year	CVP Imports to SCVWD (TAF)	SWP Imports to SCVWD (TAF)	SFPUC Imports to SCVWD (TAF)	Energy Used for CVP Imports (GWh)
Wet	1998	66	45	43	27.3
Above Normal	2000	89	84	62	28.2
Below Normal	2004	135	63	61	26.1
Dry	2002	127	60	59	34.7
Critical	2001	141	55	63	21.2

While little energy is used by SCVWD to make its deliveries, the energy intensity of water delivered contains embedded energy from the CVP and the SWP operations. The average energy intensity of the CVP water delivered by the SCVWD to its customers is 870 kWh/AF (see Figure 3-4). Imports from the SWP arrive via the South Bay Aqueduct with an energy intensity of 1128 kWh/AF (see Figure 3-3). This does not account for treatment activities by the SCVWD.

3.3.8 Los Angeles Department of Water and Power

The LADWP, a department of the City of Los Angeles, is responsible for potable water service to the second largest city in the nation: with an area of 464 square miles, it serves a population of nearly four million. The City relies on four primary sources of water: imported water from the Los Angeles Aqueduct (LAA), the State Water Project (SWP), the Colorado River Aqueduct (CRA), and local groundwater. LAA consists of approximately 223 miles of canals and pipelines (including 53 miles of tunnels) and is the only part of LADWP included in this study.

Little energy is required to make deliveries via LAA as the entire aqueduct is gravity fed. LADWP operates several hydroelectric generation facilities powered by water flow from the aqueduct.

3.3.9 Modesto Irrigation District

MID was formed for the purpose of expanding the agricultural base of Stanislaus County. Don Pedro Reservoir serves as MID's primary water storage facility and supply. MID's distribution system consists of 208 miles of canals.

During WY 2000, a "normal" water year, MID delivered 327 TAF of surface water to customers and contractors. No energy was used for MID's surface water deliveries from New Don Pedro Reservoir, since the system is entirely gravity fed. MID does operate a hydroelectric generation facility to generate power at the reservoir; however, this is not an in-conduit hydropower facility and thus has not been included in this study.

3.4 Energy Intensity of Groundwater and "Produced" Water Supplies

Groundwater energy use was estimated by the Study Team by applying estimates for energy intensity based on well depth and pump efficiency. The Study Team developed groundwater energy intensities for each year type in each hydrologic region. As noted earlier, the amount of groundwater pumping energy that is met by natural gas pumping is unknown. Consequently, all estimates were converted to electricity (kWh). See Appendix G for a detailed discussion of these computations.

3.4.1 Desalination (Brackish and Seawater)

Desalination technologies consume significant amounts of energy to remove dissolved salts from water. Plants typically use reverse osmosis technology requiring water to be highly pressurized to pass through semi-permeable membranes. The amount of energy required depends on the salinity of the source water. For example, seawater desalination requires significantly more energy than brackish water desalination as the source water contains more salt. The Study Team estimated the energy intensity of these supplies using literature reviews and data collected for Study 2. For purposes of Study 1, the energy intensity of seawater desalination was estimated at

4,000 kWh/AF[29] while brackish water desalination was estimated at 1,301 kWh/AF.[30] Brackish water is normally found in groundwater. To capture the total energy intensity of brackish water desalination, average groundwater pumping energy intensity in an Above Normal water year type is added. See Table 3-8 for the estimated desalination energy intensity by water region.

Table 3-8. Desalination Energy Intensity

Region	Seawater (kWh/AF)	Brackish (kWh/AF)
NC	4,000	1,470
SF	4,000	1,643
CC	4,000	1,689
SC	4,000	1,842
SR	4,000	1,485
SJ	4,000	1,524
TL	4,000	1,670
NL	4,000	1,464
SL	4,000	1,657
CR	4,000	1,736

3.4.2 Recycled Water

The energy intensity of recycled water is measured as the incremental amount of energy needed to treat wastewater effluent to California recycled water standards. Standard plants utilize primary, secondary and tertiary wastewater treatment along with other disinfection technologies. Newer plants using more advanced technologies are emerging across the state. These plants utilize microfiltration, reverse osmosis and ultraviolet light, which are all energy intensive processes. For purposes of Study 1, the Study Team assumed that continued increases in water quality standards will require future recycled water plants to utilize all of these technologies. The resultant estimated energy intensity of recycled water on a statewide average basis is 1,129 kWh/AF.[31]

3.5 Energy Intensity of Other Water Supplies

DWR's regional water balances provided quantities of local surface water, other local imported water deliveries and other federal deliveries. These types of supplies are highly diverse and

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[29] Source: *The Role of Recycled Water in Energy Efficiency and Greenhouse Gas Reduction,* California Sustainability Alliance, 2008.

[30] Source: Study 2 data from the Chino Basin Desalter provided by the Inland Empire Utilities Agency.

[31] Source: Study 2 data of recycled water production at Orange County Water District's Advanced Water Purification Facility.

account for a very small portion of the state's wholesale water supplies. Consequently, they were not evaluated in this report. Most of these deliveries are assumed to occur via gravity flow. The Study Team assigned a de minimis energy intensity of 10 kWh/AF to these supplies.

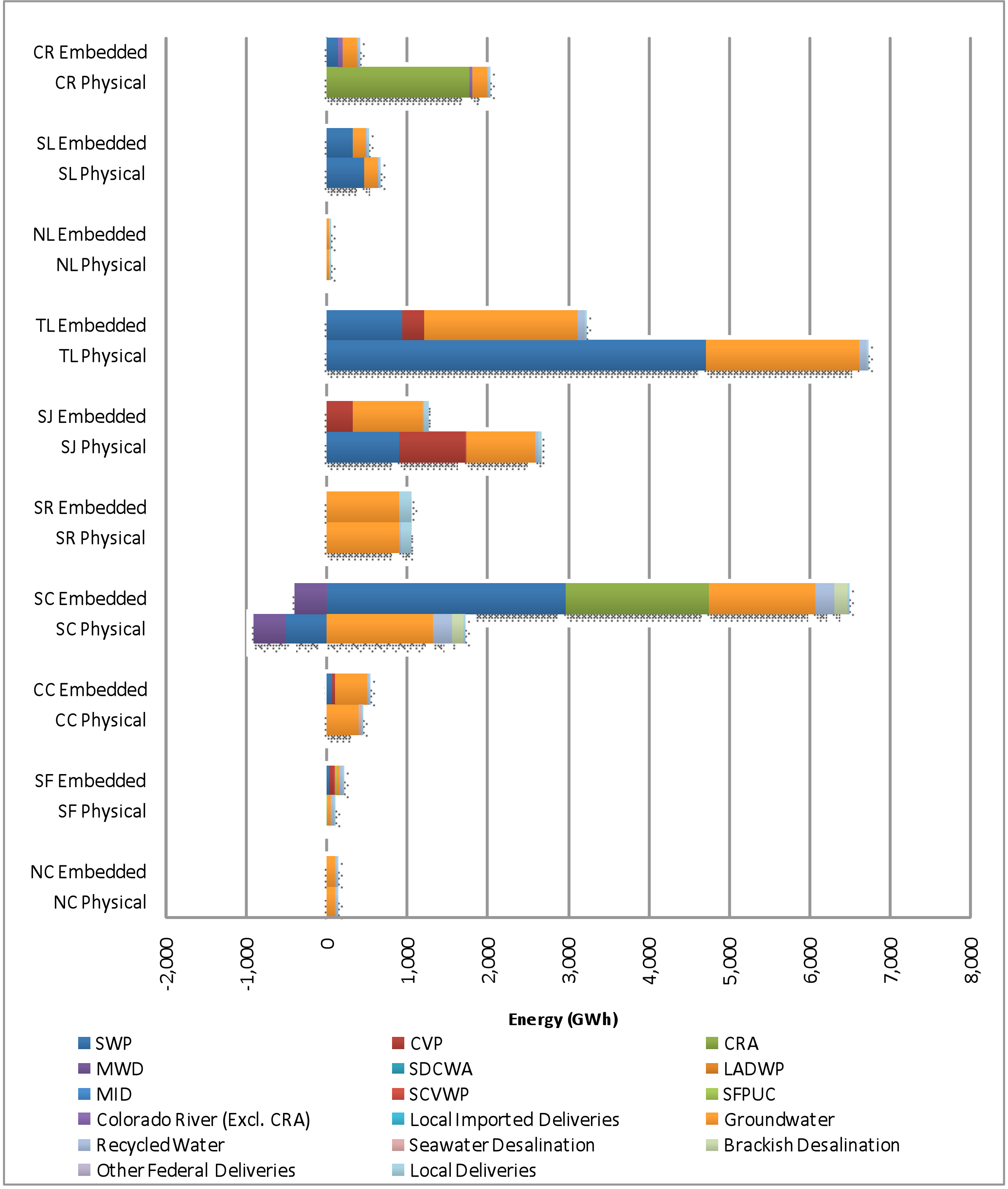
3.6 Statewide Energy Use by Wholesale Water Systems

Most of the energy consumed by the Supply and Conveyance segment of the water use cycle is used for groundwater pumping (see Figure 3-1). The next largest energy consumers are the three largest inter-basin transfer systems: SWP, CVP and CRA.

Figure 3-6 shows physical and embedded energy for each of DWR water regions. Note that for purposes of this analysis, the amounts shown for embedded energy only include energy embedded in the Supply and Conveyance segment of the water use cycle. These numbers would need to be adjusted to include water treatment and distribution, and wastewater treatment, in order to represent the full energy value embedded in a unit of consumed water.

As seen in this figure, the majority of energy consumption by California water systems occurs in the Tulare Lake Region (see Figure 3-6). Much of this energy is attributed to the State Water Project as several large pump stations are physically located in the region to pump water over the Tehachapi Mountains to southern California. While little energy is used in the South Coast, it is the region with the largest embedded energy associated with water deliveries to the region. This is because water transported to the South Coast via the SWP and the CRA require significant amounts of pumping.

Figure 3-6. 2010 Physical and Embedded Energy by Supply and Region



In Chapter 4, we describe how these energy intensities by water agency, by water resource type and by hydrologic region are employed in the model.

4 Model Development

As shown in Chapter 2, the energy intensity of the state's wholesale water systems is driven principally by water operations decisions made by individual water agencies, each seeking to optimize its own water supply portfolio given its unique mix of policies, goals, resources, infrastructure, contracts, relationships and transactions. Both short- and long-term planning decisions have an energy impact: short-term water supply needs cause water to be pumped from surface and groundwater sources to meet current demand, and long-term water supply needs cause water to move in ways that may not seem intuitive as water agencies seek to concurrently maximize carryover storage to meet future demands and to serve as a hedge against drought.

Water delivery decisions are made at various intervals: monthly when planning seasonal deliveries; weekly and daily as needed to manage inflows due to rainfall, snow melt and other types of flow events; and sometimes, even hourly, during storm events that drop very large volumes of precipitation within a short period of time.

Recognizing that energy requirements of wholesale water systems depend on many factors, many of which are not easily predictable, the Study Team decided that it was important to focus on the operations decisions made by the nine major wholesale water system operators that account for 73 percent of all wholesale surface water consumed in California.[32] Their operations under different types of hydrology and given different mixes of water supply resources were documented. Maximum flexibility was integrated into the model to allow users to test the energy impacts of changes to future water supplies, demand, and policies.

4.1 Model Design Approach

The Study Team interviewed key stakeholders, including DWR’s lead water modeler, and reviewed several existing water models to evaluate their ability to perform the tasks necessary to satisfy the goals of Study 1. Through this work, the Study Team concluded that no existing model can cost-effectively meet the Study 1 goals. Consequently, the Study Team embarked upon development of a customized water-energy model designed specifically to meet the goals of Study 1; i.e., to predict the energy impacts of the state’s wholesale water systems under a variety of potential future conditions.

In designing the model, the following data issues were considered:

- Water years are effective in depicting seasonal variations in water operations.

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[32] Local surface water and groundwater were excluded from this calculation.

- Facility level energy analyses help to identify energy drivers.

- The balance of water supplies can be estimated from regional water balances.

- Physical energy and embedded energy are measured differently.

The significance of these data issues is discussed below.

- ***Water Years.*** The Technical Working Group requested that the Study Team document and predict monthly variations in water and energy patterns in California's wholesale water systems. For this purpose, water years (October to September) are informative in depicting the distinct inverse patterns of hydrology and demand in California.

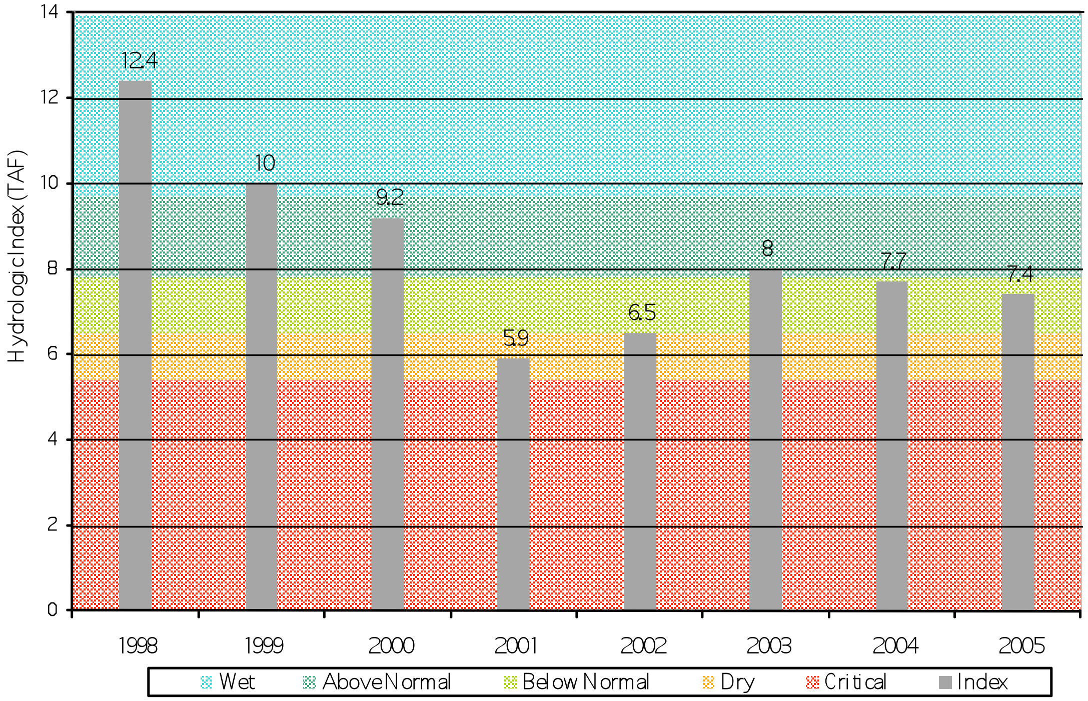
    1. ***Hydrology.*** California's precipitation typically starts in the fall, between October and November, ramping up through winter, and tapering off in spring. Precipitation received at high elevations during winter months when temperatures are low is stored temporarily as snow. The timing of runoff from snowmelt depends on many factors, including temperature and humidity, but typically occurs between May and June. In years with very heavy snowpack and moderate temperatures, runoff from snowmelt can extend into late summer.

    2. ***Water Demand.*** The agricultural irrigation season starts when precipitation drops off, typically between April and May, and extends through late summer (August to September), depending on the crops being grown. Urban demand reflects some seasonality, primarily due to seasonal industries plus additional outdoor landscape irrigation during hot summer months, but does not vary as much as agricultural water demand.

The primary departure from this pattern is operation of CRA which delivers water to southern California from Lake Mead. MWD operates CRA in a manner that maximizes its delivery capabilities during the last quarter of each calendar year, enabling MWD to take as much surplus water as is made available by other CRA users. Declarations of surplus water are typically made at the end of each contract delivery year which is based on calendar years. Further, the Colorado River watershed has a different climate and hydrology patterns than California. Consequently, California's seasonal hydrology has little impact on the pattern of CRA deliveries.

To capture the potential magnitude of seasonal variations in wholesale water delivery operations, the Study Team analyzed water delivery patterns for the five primary water year types used by DWR in statewide water planning: Wet, Dry, Critical, Above Normal and Below Normal. All water year types except "Critical" are represented in the study time period: 1998-2005.[33] Figure 4-1 shows the water year classifications according to the Sacramento Valley Hydrologic Index that is used by DWR to determine water year type. For purposes of this Study, the year producing the least amount of water, 2001 (a Dry year), was deemed to represent a "Critical" year and used to approximate water operations during a very dry year.

Figure 4-1. Water Year Classification by River Indices



- ***Facility Level Energy Intensities*** were computed where available for the nine water agencies to illustrate the variability in energy intensity by each major wholesale water facility, primarily either a pump station delivering surface water or an in-conduit hydropower facility that generates hydropower as a by-product of those water deliveries. Each facility was mapped to the hydrologic regions in which it resides and to the energy supplier(s) that provided the energy that was used by those facilities to deliver water.

Not all agencies provided facility level data:

  - MWD provided the combined amount of energy between primary delivery points in their system (i.e., the sum of energy from multiple pump stations that were operated in serial to deliver water to a particular point).

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[33] The last "Critical" year to occur in California was water year 1994. Limited data were available on wholesale and other water operations in 1994.

  - SCVWD provided its own estimates of energy intensities.

Energy used by each facility was reduced by the amount of in-conduit hydropower generated as a by-product of water delivery operations at that point. That is, had water not been delivered via that water conduit, power could not have been produced. In this manner, both the total and net energy requirements of the wholesale water system are identifiable.

- ***Balance of Water Supplies***. The Study 1 scope of work specified computing the quantity of energy associated with all water consumed in California by both the agricultural and urban sectors. As noted earlier, the nine water agencies studied account for 73 percent of all wholesale inter-basin surface water consumed in California. In order to compute the balance of water not provided by the nine water agencies, the Study Team relied on DWR's regional water balances. In each region, the amount of water delivered by the nine agencies was deducted from total in-region and imported water supplies to compute the amount of other water used to meet regional demand.

- ***Physical vs. Embedded Energy***. Energy intensities by facility, agency and/or water supply resource were computed and used in two ways: (1) to compute the amount of energy used for wholesale water operations in each hydrologic region (i.e., the physical energy used in-region), and (2) to compute the amount of energy embedded in water used in each hydrologic region (i.e., upstream Supply and Conveyance energy).

  Definitions of energy intensity, physical energy and embedded energy are provided below.

Energy Intensity (kWh/AF)

For Study 1, energy intensity is defined as the amount of energy needed to produce and transport a unit of wholesale water. ***Individual energy intensity*** refers to the energy requirements of a single pump or power station. ***Cumulative energy intensity*** refers to the sum of the energy intensities of all facilities upstream of a given facility and including that facility. A positive value for energy intensity indicates a facility uses energy to move water (pumping). A negative value indicates a facility generates energy from water flow.

Physical Energy (kWh)

Physical energy is calculated at the facility level. It represents the total energy that needs to be supplied to a pump station or is generated by a power plant. It can be calculated at the facility level by multiplying the individual energy intensity of a facility by the water that flows through it. The physical energy use for a hydrologic region is the sum of the physical energy use of all facilities located in that region.

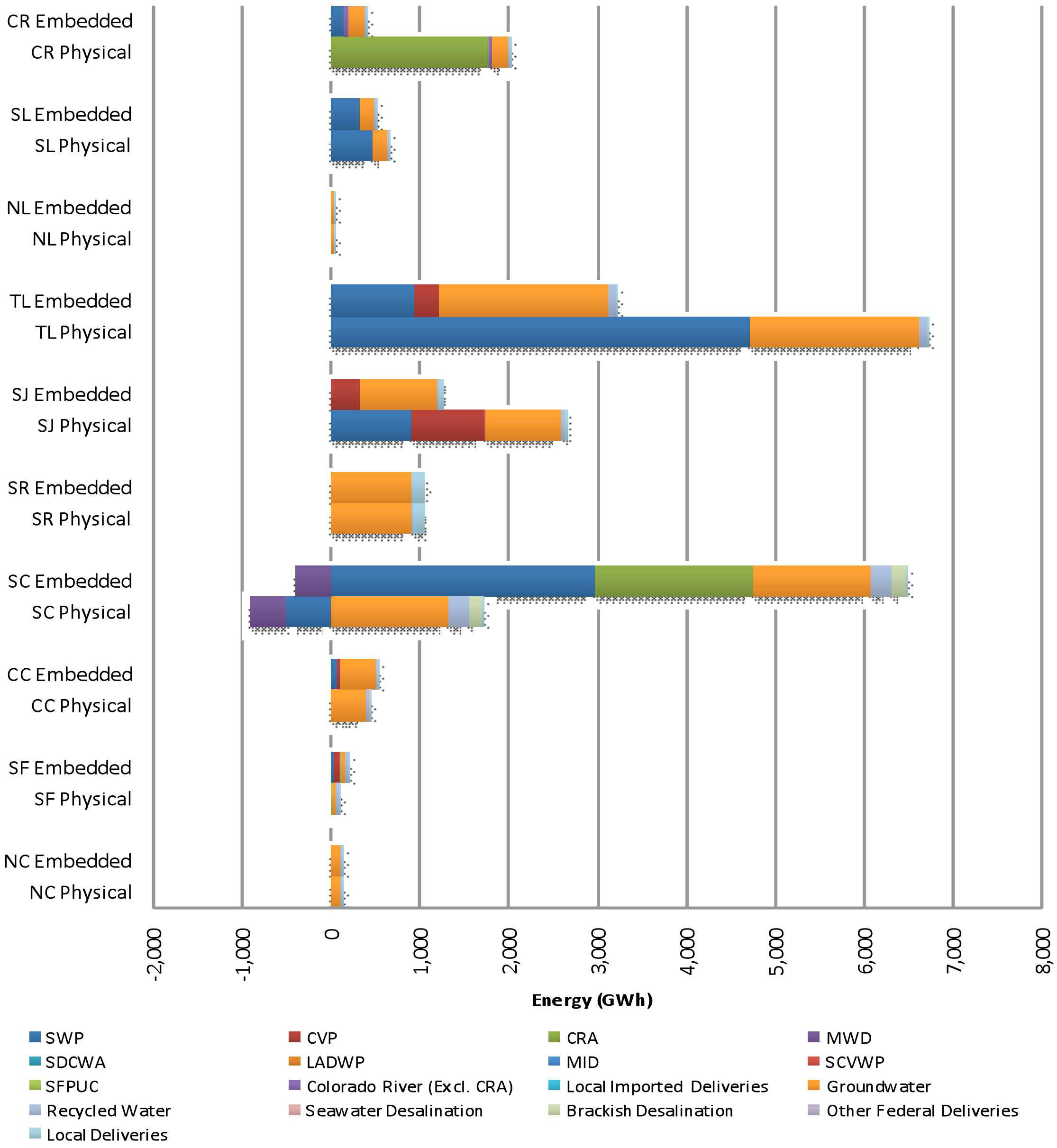
Embedded Energy (kWh)

Embedded energy is reported at the regional level. It represents all the energy that is required to make water deliveries to that region, regardless of where the energy consumption actually occurred. It can be calculated by multiplying the water deliveries made to a region by the cumulative energy intensity of the last facility through which the water passed. The embedded energy associated with a hydrologic region is not necessarily consumed by facilities in the region.

Physical energy was computed by region for water supplies attributable to the nine agencies for which we were able to obtain energy data. Groundwater energy was estimated using average beginning and ending depth-to-groundwater measurements by groundwater basin for each water year type. Embedded energy was computed by summing the upstream energy deemed embedded in wholesale water operations for each water supply resource, and then mapping it to the hydrologic regions in which the water was used.

Figure 4-2 illustrates physical vs. embedded energy by water supply resource in each of the hydrologic regions for base water year 2010. As discussed earlier, the amounts shown for embedded energy only include energy embedded in the Supply and Conveyance segment of the water use cycle. These numbers would need to be adjusted to include water treatment and distribution, and wastewater treatment, in order to represent the full embedded energy value of a unit of water.

Figure 4-2. 2010 Physical vs. Embedded Energy by Region



4.2 Model Structure

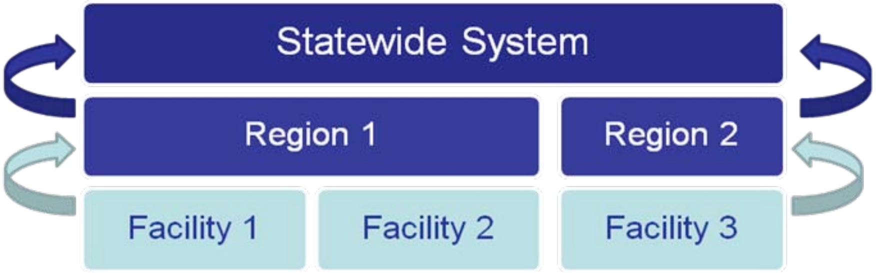
California's water agencies have collectively spent hundreds of millions of dollars on a wide variety of models to help them plan and manage their water supplies. There is no 'perfect' model and there is no 'one size fits all.'

In designing this model, the Study Team’s overarching goal was to enable estimating the energy impacts of a wide variety of potential changes to water resources and infrastructure. The granularity of inputs was determined primarily by the types of policies that are being considered by California policymakers and stakeholders that can significantly affect the timing and quantity of wholesale water supplies that are being moved at any particular point or at any particular time. The data selected for use in the model was determined on the basis of "best available" for this purpose.

For the nine water agencies being studied in detail, the water agencies themselves were considered the most authoritative source. As the state's water resource planning organization, DWR was deemed the authoritative source for all other types of water data. The Study Team looked to individual agencies for policies – for example, the State Water Resources Control Board (SWRCB) is the state's authority on recycled water policies. With respect to statewide water supply and demand, the only reliable source of information is DWR's regional water balance in which water supplies and demand are balanced for specific water years by hydrologic region.

With those primary sources of data identified, the Study Team created a model that relies first on individual agency level data, then reconciles the agencies' data to the regional water balances. The model then computes the energy requirements of water delivered by the nine agencies. Figure 4-3 depicts the model structure.

Figure 4-3. Model Calculation Structure



Separately, energy attributable to other water resources (surface, groundwater, recycled and desalinated water) is computed using other in-region resources as a proxy. Where an appropriate proxy was not available within the region, other estimation bases were selected.

Ultimately, the model calculates water and energy use by hydrologic region. Agency-specific facility data are mapped to the hydrologic regions in which they are located to identify their separate contributions to water deliveries within that region and the associated quantity of energy used at that site.

Within the model, both demand and supplies are modifiable by the user within certain parameters. An overview of the structure and operations of the model is provided in this chapter. More detailed documentation including the calculation methodology and input parameter constraints is provided in Appendix D.

4.3 Primary Data Sources

The model relies upon three primary data sources:

- Agency-specific monthly water and energy data, collected at the facility level where available and at specific delivery points where facility level data are not available
- DWR regional water balances
- Detailed water demand projections from DWR

These data form the crux of Study 1. From these data, energy intensity of wholesale water supplies by water resource and by region is computed. These data are then rolled up to the statewide level to compute total energy requirements of the wholesale water system and the embedded energy of various water resources.

Although the Study Team selected these sources as "best available" for purposes of Study 1, there were some challenges:

1. Water-energy data are not presently readily available in the form needed for this study and the model. Collecting, compiling, and analyzing the data to develop model inputs required an extensive effort.

2. In order to develop the capability to predict energy impacts under future conditions, the Study Team needed to identify a rational basis for extrapolating water-energy relationships observed in prior years to future scenarios. Energy intensity at the facility level or delivery point – i.e., the amount of energy needed to pump water at any particular location measured in kWh/AF - was selected with the intent of ratcheting total energy requirements up or down with the assumed future quantities of water by agency and/or type and location of water resource. During the analyses of energy intensities, data adjustments were made to eliminate obvious outliers. For facilities at which significant variations in energy intensities were observed, knowledgeable agency managers were interviewed to identify the sources of such variances. In general, the recommendations of the agency operations managers as to how to treat these variations were accepted. As noted earlier in this report, in order to facilitate an understanding of the true energy requirements of wholesale water systems, energy intensities for water pumping were computed separately from in-conduit hydropower. The model employs energy intensities net of in-conduit hydropower.

3. Regional water balances were selected as the authoritative source of data about the state's total water supplies and demand. DWR is divided into four planning regions that share responsibility for compiling the water balances for the ten hydrologic regions. Each of DWR's planning regions prepares its hydrologic regional balances separately. A DWR

staff person then adjusts and compiles the statewide water balance. Upon close inspection, the Study Team found inconsistencies in the types of adjustments made by DWR planning regions that complicated the mapping of agency specific data to the hydrologic regions. For example, SWP deliveries recorded in the hydrologic region water balances do not necessarily tie to the amounts reported in Bulletin 132. In addition, several variables are computed. Upon conferring with DWR, the Study Team decided to discard computed variables that primarily dealt with water flows that were deemed "lost" (unavailable) from a water supply perspective. More information about the types of data provided by the regional water balances is provided in Appendix E, Water Balance Definitions.

4.4 Agency-Specific Data

The Study Team collected monthly water flows and energy used to move that water by each of the nine large wholesalers for water years 1998-2005.

For the nine large water agencies, data were collected by facility (i.e., pump station or power generation station).[34] Each wholesale agency has a unique mix of facilities, with different designs and constraints. Detailed profiles of each agency and their corresponding facilities are presented in Appendix C.

Most water and energy data collected for this study were provided directly by the wholesale agencies themselves, with the exception of the SWP data which were taken from DWR Bulletin 132. Energy intensity at each facility was calculated from monthly water delivery and energy use data. Generally, the energy intensity at each facility was fairly consistent, but the Study Team did observe significant variances at several facilities. To better understand the drivers of significant variations in energy intensity, the Study Team interviewed experienced water planners and operators. These interviews are documented in Appendix C, along with the documented energy intensity by agency and facility.

4.5 Regional Water Balances

Water supply and use by hydrologic region were compiled from historical regional water balances contained in DWR Bulletin 160. The regional water balances show the total water use within each region and the water supplies that were applied in a particular water year to meet that water use. "Balance" implies that supply equals use. In fact, there are significant data gaps that require estimating certain line items in the water balances. A description of the key variables documented in the regional water balances and the sources of the data shown – i.e., whether

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[34] Some wholesale water agencies also provide treatment. Treatment energy was not included in Study 1 to facilitate comparison of the energy intensity of wholesale water deliveries on a comparable basis.

collected and compiled vs. estimated – are shown in Table 4-1. For a detailed description of the water balance items, see Appendix E.

Table 4-1. Illustrative Regional Water Balance for a Single Hydrologic Region

WATER USE		
End Use	**Annual Volume of Water (TAF)**	**Primary Data Source(s)**
Agricultural		Data are computed through use of DWR's agricultural water model
Applied Water – Crop Production	691.9	
Conveyance Applied Water	0.0	
Groundwater Recharge Applied Water	0.0	
Total Agricultural Use	**691.9**	
Urban		Data are compiled from UWMP's when available, missing information is estimated by local planning areas
Large Landscape	165.7	
Commercial	699.5	
Industrial	186.0	
Energy Production	39.8	
Residential-Interior	1593.9	
Residential-Exterior	776.1	
Conveyance Applied Water	160.0	
Groundwater Recharge Applied Water		
Total Urban Use	**3,621.0**	
Environmental		Data are taken from stream measurements and modeled for managed wetlands
Instream Applied Water	3.5	
Wild and Scenic Applied Water	284.2	
Required Delta Outflow Applied Water	0.0	
Managed Wetlands Applied Water	31.2	
Total Environmental Use	**318.9**	
Total Use	**4631.8**	
SUPPLY		
Resource	**Annual Volume of Water (TAF)**	
Surface Water		Data are taken from delivery records, from Bulletin 132, from USBR, data from water agencies, and from estimates/adjustments made by planning areas.
Local Deliveries	292.1	
Local Imported Deliveries	442.0	
CR	1,081.3	
CVP	0	
Other Federal Deliveries	4.2	
SWP	687.7	
Total Groundwater	1,632.3	Generally computed as the balancing supply
Reuse/Recycle		Data are taken from local water agencies and estimated by planning areas
Reuse of Surface Water	287.7	
Recycled Water	204.5	
Desalination	0	
Total Supplies	**4631.8**	
Note: Data taken from the South Coast Regional Water Balance for water year 1998		

DWR matches water supplies and use by water year and by hydrologic region, and then compiles these data on a statewide level. In accordance with the Technical Working Group's request, annual regional water data was allocated to a monthly profile. The methodology for determining the annual load curves is presented in Appendix D. The availability of the regional water balances for water years 1998-2005 was a major factor in the Study Team's recommendation to focus on these particular eight years for detailed study.

Below is a description of the primary types of water use and water resources that are documented in the regional water balances.

Water Use. The water balances report urban, agricultural, and environmental use by region and by water year.

- ***Urban Water Use.*** DWR regional planning areas get as much as possible of their data from local water agencies. The requirement to file Urban Water Management Plans (UWMP)[35] with DWR is improving the availability of data. When data are not available from local water agencies, DWR planning regions develop their own estimates.

  Urban end uses (Residential, Commercial, Industrial, and others) are also estimated by DWR planning areas. For example, Outdoor Water Use (Residential Exterior, Large Landscape) is purely an estimate as limited data are available to separate indoor from outdoor metered water uses. Some planning areas use the difference in volume of water treated and volume of wastewater treated as an indicator of the amount of exterior water use.

- ***Agricultural Water Use.*** Agricultural water use is obtained by a bottom-up estimate made by experts at DWR based on crop acreage, soil type, and other variables. The water use met by rainfall is subtracted from this estimate. The balance of water use is that which appears in the regional water balances and must be met by some form of supply. An estimate is needed because water used for agricultural purposes is not always metered (for example, on-farm ground water pumping).

  The methods of estimating agricultural water use and quality of data for estimates are relatively consistent across all planning areas and regions as the information is well documented and put through the same agricultural model. This is in contrast to urban

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[35] In 1983, the California Legislature enacted the Urban Water Management Planning (UWMP) Act (Division 6 Part 2.6 of the Water Code §§10610 - 10656) that requires every urban water supplier that provides water to 3,000 or more customers, or that provides over 3,000 acre-feet of water annually, to develop a UWMP to ensure the appropriate level of reliability in its water service sufficient to meet the needs of its various categories of customers during normal, dry, and multiple dry years. http://www.water.ca.gov/urbanwatermanagement/

water use which varies in estimation methods and data quality across different planning areas.

- ***Environmental Water Use.*** Environmental water use includes water required for managed wetlands, instream minimum flows, and required Delta outflow. Additionally, environmental water use accounts for uncontrolled flows in wild and scenic rivers.
    - *Managed wetlands* water use is estimated similar to agricultural water use. Information from each managed wetland is collected on the total acreage and type. Total use is calculated, and the use met by rainfall is subtracted. The balance of use is that which appears in the regional water balances and must be met by some form of supply.
    - *Instream flows* are those required to keep streams and downstream bodies of water at minimum levels. This amount of water cannot be used by others and must be allowed to continue flowing down the stream. Since no others can use it, instream flows are treated as a form of water use. Instream flows are managed by releases or diversions of water.
    - *Required Delta Outflow* is water required, under State Water Resources Control Board decisions, to be discharged through the Sacramento-San Joaquin Delta to San Francisco Bay in order to protect the water quality and thus, the beneficial uses within the Delta. These flows protect the Delta from the incursion of saline water from the Bay. This water is not used by exporters and is treated similar to instream flows for our modeling purposes.
    - *Wild and Scenic* flows are those in uncontrolled rivers and streams that are dedicated as “Wild” or “Scenic.” No water may be removed from these streams, thus they are treated as a water use. However, these rivers may feed controlled reservoirs further downriver and may eventually turn into supply (e.g., Upper Feather River). These waterways are uncontrolled; the amount of water that flows through them is attributable to natural runoff. Data collection is a simple stream flow measurement that is recorded by DWR. DWR recommended removing Wild and Scenic flows from Study 1 water use data since there are minimal controls on these flows and because they generally have no energy associated with them.

Water Supply. Surface water supplies include wholesale water and local deliveries. Wholesale water data are obtained from the regional water balances for the two largest wholesalers (SWP and CVP) as well as total diversions from the Colorado River (CR). Most of the deliveries by all other Study 1 wholesale agencies cannot be directly tracked to the regional balances because their numbers are consolidated with other water sources by type. For the remaining wholesale agencies, water data were developed from data provided to the Study Team by the wholesalers.

The Study Team compared the quantity of water presented in the regional water balances with the quantity reported in Bulletin 132. There was variance between the two sources in most years, as shown in Table 4-2.

Table 4-2. State Water Project Variance

	SWP Reported Deliveries (MAF)		
Water Year (Type)	**Regional Water Balance**	**Bulletin 132**	**Difference**
1998 (W)	2.14	1.73	19.1%
1999 (W)	2.71	2.53	6.7%
2000 (AN)	3.63	3.55	2.1%
2001 (D*)	2.10	1.99	5.4%
2002 (D)	2.90	2.55	12.2%
2003 (AN)	3.19	2.97	7.0%
2004 (BN)	3.20	3.20	-0.1%
2005 (BN)	3.41	3.24	4.9%

*As previously noted, 2001 is treated as a Critical year, for purposes of this study

To determine the source of these variances, the Study Team interviewed DWR planning staff who advised that the SWP figures in the water balances are compiled by the planning regions that make adjustments at the regional level. The reasons for these adjustments were not documented, and further investigation by the Study Team into these variances did not reveal a clear pattern. The Study Team chose to rely on the data presented in the water balances because they are vetted by DWR staff and are a more complete source of water data.

Other water supplies in the model are local surface water, groundwater, recycled water, and desalination.

- Historic recycled and desalinated water by region documented in the water balances are provided in the model as default values. Users can override these default values.
- Groundwater and local surface water are used as balancing supplies in the model, computed as a function of use in a particular region by water year type. Specifically, after all of the use in the region is met by available wholesale surface water, recycled water and desalinated water, available groundwater and local surface water supplies are called upon to meet the balance of in-region water use.

The amount of in-region water supplies that can be drawn upon to meet increased water demand is capped to represent an upper limit of supply available from local surface reservoirs and streams. These upper limits were obtained by examining historic data in each hydrologic region: details are available in Appendix H.

4.6 Inputs

To run the model, users must supply a few inputs.

1. First, a demand scenario is required. Users can choose between a low demand or a high demand scenario based on estimates by DWR for statewide water supply planning purposes. The demand assumptions are described in Appendix F.

2. Additionally, users can input a low, high or average case for water transfers via CRA to MWD. MWD can purchase surplus water from other Colorado River water recipients and transport it via the CRA to its service area. For more description on CRA transfers, see Appendix C – CRA section.

3. Delta flow restrictions can also be specified by the user. Users can input a specific percentage to restrict Delta flows. Alternatively, by applying a negative percent change, this input can be used to increase the amount of Delta flow to approximate conditions such as the construction of additional storage upstream of the Delta or an isolated facility (Peripheral Canal). These options are further detailed in Appendix D.

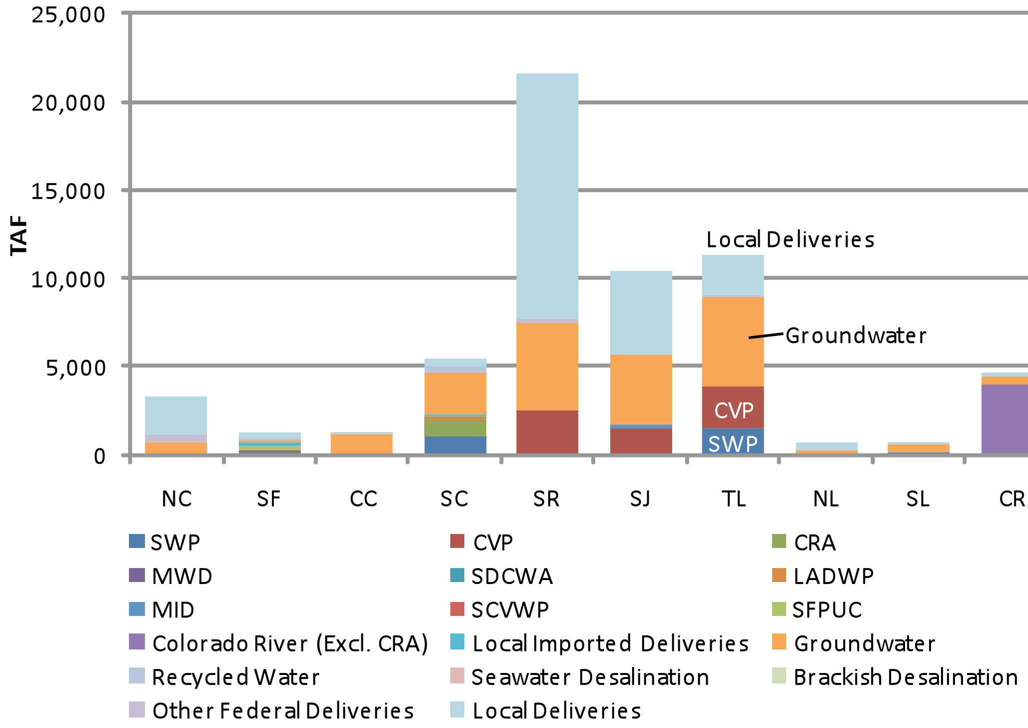
4. Finally, users can change demand and local supply parameters. For demand, users can adjust the percent change for several demand variables by region, including urban landscaping, urban interior and agricultural irrigation. These changes can represent conservation measures imposed by the state, or other changes described in Chapter 5. For supply, users can increase the amount of available surface storage, recycled water, and desalination by region.

4.7 Outputs

The primary outputs of the model are water deliveries and energy use by hydrologic region. These are produced for each water year for baseline (2010) conditions, and for future years 2020 and 2030.

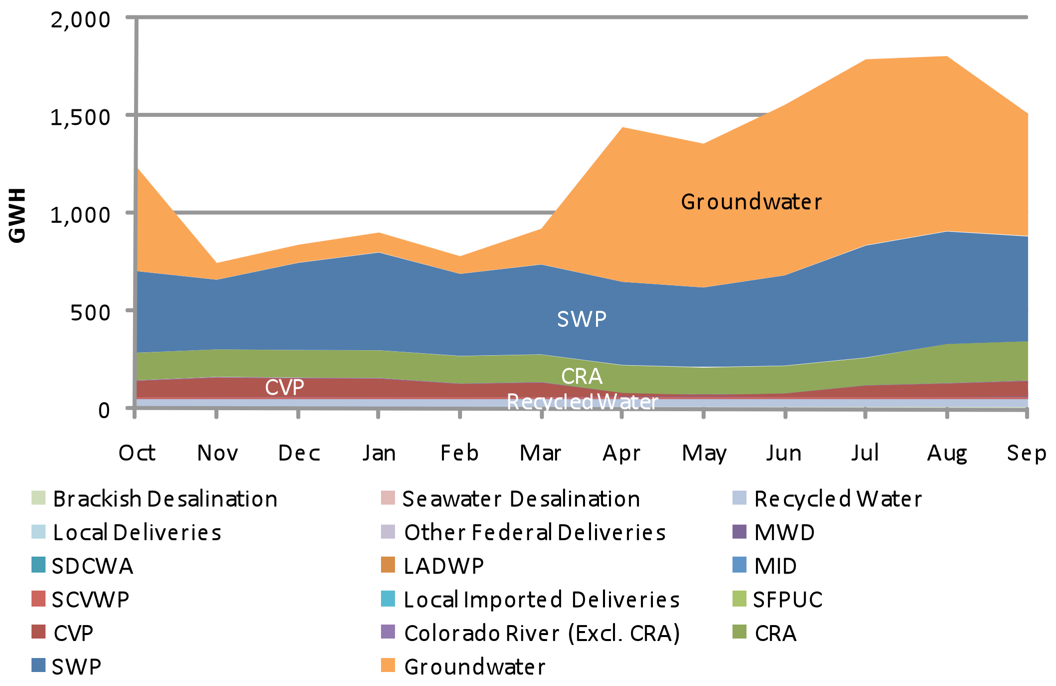
The model outputs water deliveries by supply type by hydrologic region, as illustrated in Figure 4-4.

Figure 4-4. Water Deliveries by Region



The model also outputs energy used to deliver water by source in each water year. A monthly energy profile is then produced, showing how each source of water uses energy at different times of the year. This is illustrated in Figure 4-5.

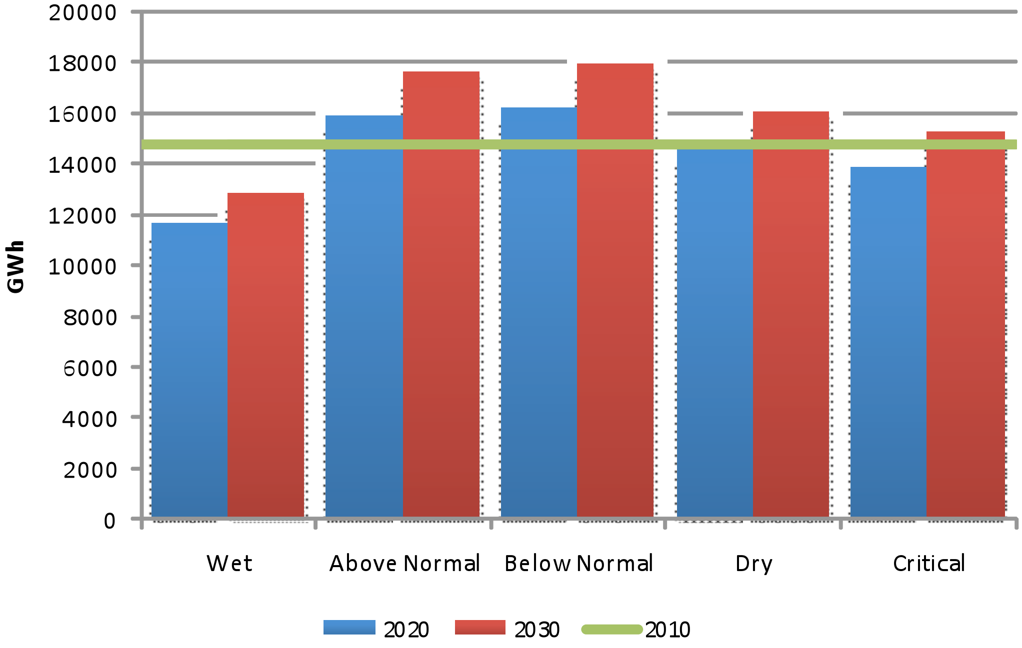
Figure 4-5. Monthly Energy Profile by Water Type



Note: All listed suppliers' energy use are included on the graph; however many are too small in magnitude to be able to discern. Major energy users are labeled for clarity.

The model then rolls up regional water and energy data to compute statewide energy use by water year type. Figure 4-6 illustrates how statewide energy use in future years compare to baseline 2010 conditions.

Figure 4-6 Statewide Energy Consumption



The model is structured to facilitate evaluation of changes in water and energy under changed conditions. Scenario analyses are described in the next chapter.

4.8 Model Limitations

While the next chapter will explain the types of scenarios that the model can be used to test, there are a few scenarios that this model was not intended to perform. The model also does not include economic parameters, which are important in water allocation decisions

1. First, the model was not meant to model the effects of climate change. DWR and other key stakeholders advised that effects of climate change are unlikely to be seen in the 2020 and 2030 time frame, so including this functionality does not offer any additional insights.

2. Secondly, the model estimates the energy impacts of single years. It is not structured to evaluate multi-year sequences of hydrology, such as three dry years in a row, or a dry year preceded by two wet years. The model shows results for a single water year type, independent of prior years. Users could modify inputs to reflect, for example, a year that was preceded by a multi-year drought by decreasing local surface water availability and decreasing delta flows for the year modeled.

3. Finally, the model does not project changes to environmental flows (instream and managed wetlands). Environmental flows are specified by regulation. DWR uses a fairly

constant number for environmental flows throughout its 30 years water supply planning horizon. Consequently, this assumption is held static in this model.

Appendix M, Model User's Manual, includes instructions for running the model and specific information on model inputs and results. The model will be available online from the CPUC.

5 Scenario Development

5.1 Purpose and Overview

The Study Team developed two scenarios to illustrate the impact of future conditions on water deliveries and energy consumption associated with those water deliveries in the state. Scenario analysis describes a process of hypothesizing about potential future conditions and then projecting the impacts of those potential future conditions. In the context of Study 1, scenarios were developed to represent the range of potential water deliveries and their associated energy requirements given a wide variety of changes in variables, including but not limited to:

- ***Changes in California's Water Supply Portfolio***; e.g., changes in hydrology; changes to the quantity and location of surface and groundwater supplies; and changes in the mix of water resources in regional and statewide water supply portfolios.

- ***Changes in the Quantity, Timing and Location of Water Consumption***; e.g., due to changes in population; changes in agricultural vs. urban water demand; changes in policies; and changes in water end-use technologies.

- ***Changes in Water Delivery Operations***; e.g., due to changes in policies, regulations, water delivery commitments and/or infrastructure (e.g., more or less conveyance or storage capacity at key points in the wholesale water system).

The Study Team met with stakeholders to discuss the types of factors that they believed would be most significant in terms of energy impacts. Stakeholders advised that many variables affect both the amount and timing of wholesale water deliveries throughout California. Stakeholders stated that since (1) there are so many policy options, and (2) it is impossible to say which are most "likely" to be in effect by 2020 or 2030, the best approach was to develop a set of assumptions that establish a range of potential outcomes via a high case and a low case, and compare the case results. By selecting a high and low case, these scenarios would model most possible outcomes of various policies that may be implemented in the future. The Study Team followed this advice of the stakeholders and developed two bounding scenarios. For additional information about the types of policies that were discussed with stakeholders, see Appendix K.

Draft future scenarios were presented to key stakeholders to solicit feedback. The scenarios presented in this report incorporate the input of these stakeholders who include: California Department of Water Resources (DWR), California Energy Commission (CEC), State Water Resources Control Board (SWRCB), Natural Resources Defense Council (NRDC), and Pacific Institute. In addition, a Director of the Water Replenishment District of Southern California was interviewed.

Each bounding scenario assumed different levels of infrastructure changes that could occur. Each scenario's assumptions associated with these infrastructure changes are described in the Delta Flow Restrictions Assumptions Section.

The Study Team developed two future scenarios to run using the predictive model; these are both then compared against a base case. The Base Case and future scenarios are described below and discussed in detail in this section.

Table 5-1. Scenarios Evaluated Through Study 1

Scenario	Time Period	Assumptions
Base Case	**"Today" = 2010**	• Current year hydrology (used "Above Normal") • Current year water demand • Current year water supply portfolio • Current water policies
Low Energy Scenario	**2020 & 2030**	For each of 5 types of hydrology years: • Low water demand projections • Portfolio of future water policies that are expected to reduce the energy intensity of the Supply & Conveyance segment of the water use cycle (e.g., aggressive urban water conservation, increased use of recycled water, and new surface water storage)
High Energy Scenario	**2020 & 2030**	For each of 5 types of hydrology years: • High water demand projections • Portfolio of future water policies that are expected to increase the energy intensity of the Supply & Conveyance segment of the water use cycle (e.g., minimal urban water conservation, aggressive growth in seawater and brackish water desalination, minimal construction of new recycled water supply, new surface water storage, and infrastructure changes allowing increased Delta withdrawals)

5.2 Scenario Assumptions and Inputs

The policies and projections that drive the inputs to the two scenarios and Base Case condition are summarized in Table 5-1. Each input and the assumptions behind them are described in greater detail in the rest of this chapter.

Table 5-2. Scenario Drivers

Driver	Base Case	Low Energy Scenario	High Energy Scenario
Demand	Current Trends	Low	High
Policies Affecting Demand	None	Conservation policy to further reduce urban demand 20% in 2020 and 25% in 2030	Conservation policy to further reduce urban demand 20% in 2020 and 20% in 2030
Bay Delta Operations and Flow Restrictions	Current operations	Added storage upstream of the delta	Added storage upstream of the delta and completion of "isolated facility"
Colorado River Aqueduct Imports	900 TAF/year	1,200 TAF/year	800 TAF/year
Brackish Water and Seawater Desalination Capacity	Current infrastructure	Current infrastructure	Construction of all new planned capacity
Recycled Water Capacity	Current infrastructure	Meet SWRCB goals of 2,000 TAF in 2030	Meet SWRCB mandate of 300 TAF in 2030
Local Surface Storage Capacity	Current infrastructure	Increase capacity by 2% in each region	Current infrastructure

5.3 Demand Assumptions

The demand projections used for Scenarios 1 and 2 are the "Low Demand" and "High Demand," respectively. The data used for these inputs in both 2020 and 2030 are detailed in Appendix F. Demand input was developed based on DWR future projections. As the agency responsible for statewide water planning, the Study Team views DWR's demand assumptions as authoritative.

The Base Case applies DWR's "Current Trends" projection. The current trends projection calibrates to historic demand in 2000 and projects demand in 2010 assuming existing water usage trends from 2000-2005 would continue until 2010.

The Low Energy Scenario assumes low demand in 2020 and 2030. In the agricultural sector demand follows DWR's "Low Water Demand" projection, statewide demand decreases from the 2010 base case by 4 percent in 2020 and 8 percent in 2030. The urban demand departs from DWR's "Low Water Demand" projection. The Study Team assumed urban demand will remain at 2010 levels in both 2020 and 2030. In comparison, DWR projects statewide urban demand to increase 2 percent by 2020 and 4 percent by 2030.

The High Energy Scenario assumes high demand in the future in 2020 and 2030, following DWR's "High Resource Intensity" projection. Demand in the agricultural sector still decreases in this projection (a 1.5 percent decrease in 2020 and a 4.4 percent decrease in 2030); however, not as much as in the low demand scenario. Demand in the agricultural sector still decreases in this projection; however, its change is not as dramatic: a 1.5 percent reduction in 2020 and a 4.4 percent reduction in 2030. Urban demand increases significantly: this scenario assumes statewide urban demand increases 18 percent by 2020 and 40 percent by 2030.

5.4 Policies Affecting Demand

Policies in both the low and high energy scenarios promote incremental demand reductions on top of the demand projections selected for each scenario. Incremental demand reductions affect the urban sector alone, agricultural demand is not reduced.

The Base Case scenario assumes no incremental demand reduction beyond the Baseline Demand. The Low Energy Scenario assumes a 20 percent incremental demand reduction in all urban uses in 2020 and a 25 percent reduction in 2030. The High Energy Scenario assumes a 20 percent reduction in all urban uses in both 2020 and 2030.

These assumptions originate from the Governor's goal of reducing urban water demand by 20 percent in 2020. This goal was codified into law by Senate Bill No. 7 (SB 7) in November 2009. SB 7 sets a standard of achieving a 20 percent per capita decrease in urban water use; however, multiple possible baselines were established and alternative methods of establishing a baseline and accounting for reductions can be developed by DWR before December 2010. Because of the uncertainty in exact baseline and implementation of this policy, the Study Team chose to model a 20 percent reduction in all urban uses in each scenario regardless of the levels of demand or ultimate per capita water use in each scenario. The assumption of 25 percent conservation in 2030 was made to represent further conservation in the 10 years following 2020.

5.5 Delta Flow Restrictions Assumptions

Many parties are discussing potential water related infrastructure projects. However, it is still uncertain which particular infrastructure projects will eventually be constructed. Thus, each bounding scenario assumed different levels of infrastructure changes. The major infrastructure projects being discussed pertain to additional storage upstream from the Delta and the construction of an "isolated facility"[36] to bypass the Delta.

The combination of additional storage for the SWP and the CVP upstream of the Delta, the construction of an "isolated facility," and the Wanger Decision all have the effect of altering flow restrictions in the Delta; this is how the Study Team models these changes.

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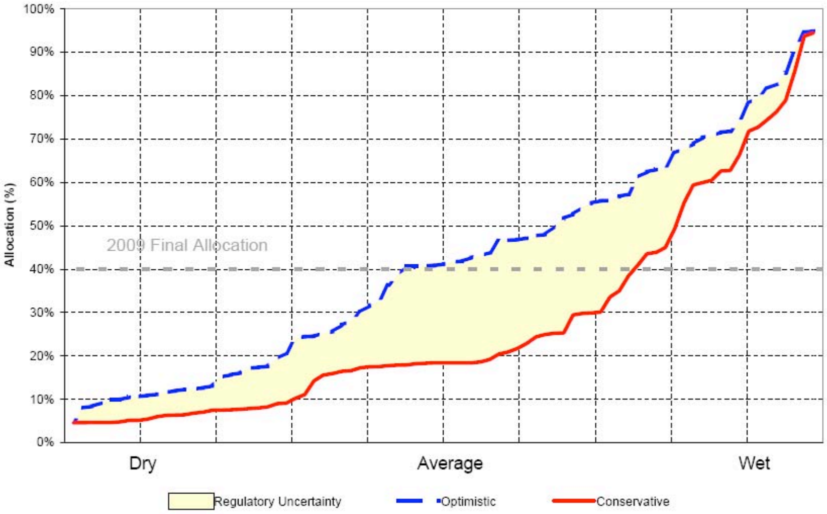
[36] Also referred to as "Delta Conveyance" or "Peripheral Canal".

Increasing Delta exports increases deliveries and energy consumption and generation by the SWP and the CVP. The High Energy Scenario assumes infrastructure changes that allow further increases in Delta withdrawals than those changes in the Low Energy Scenario.

The Base Case assumes current infrastructure and operations will remain in place in 2010. The effects of the Wanger Decision on annual Delta exports to the water projects are modeled to reduce deliveries via the Delta 20 percent below historic levels. This is based on information obtained from DWR's 2010 Forecasted Supply Allocation made in 2009, as illustrated in Figure 5-1. The forecast estimates regulatory uncertainty to have a maximum effect of approximately 20 percent. Thus, the Study Team chose 20 percent for its baseline Delta pumping reduction.

Figure 5-1. Forecasted 2010 SWP Supply Allocation



Source: DWR, 2010

The Low Energy Scenario assumes that currently proposed storage facilities upstream of the Delta will be constructed in the future. These facilities include Sites (perhaps 1.8 MAF) and Temperance Flat (perhaps 1.2 MAF) Reservoirs proposed to be built to enhance water supply. These proposed sites could become partially active by 2020, possibly allowing increased flows through and withdrawals from the Delta. This scenario assumes the partial operation of these facilities in 2020 and full operation in 2030 would have the effect of increasing Delta withdrawals. To model this scenario, a 15 percent reduction in Delta withdrawals is assumed in 2020 while a 0 percent reduction (no reduction below contracted amounts) is assumed in 2030.

The High Energy Scenario assumes currently proposed storage facilities upstream of the Delta are constructed in conjunction with an isolated facility to bypass the Delta. In addition to the storage assumption in the Low Energy Scenario, the High Energy Scenario assumes the construction of an isolated facility allows more water to be conveyed through the Delta than was possible under previous physical capacities and regulatory restrictions. The Study Team assumes the partial operation of these facilities in 2020 and full operation in 2030 would have the effect of increasing Delta withdrawals. To model this circumstance, a 0 percent reduction in Delta withdrawals is assumed in 2020 (no reduction below contracted amounts) while Delta withdrawals in 2030 increase 20 percent above currently contracted amounts (modeled by setting a “-20 percent reduction” for 2030). An input value of -20 percent assumed Delta withdrawals by the SWP and CVP can increase 20 percent above historic levels in 2030 with the completion of these facilities.

5.6 Colorado River Aqueduct Transfer Assumptions

MWD imports water via the Colorado River Aqueduct (CRA). In addition to its allocated share of the Colorado River, the MWD seeks additional supplies that can be brought through CRA. MWD negotiates with other recipients of Colorado River water for access to their unutilized allocations, though the amount available varies year to year. Increased imports lead to increased energy consumption by CRA facilities; each scenario contains varying assumptions regarding the amount of imports. For more information on CRA imports see Appendix C – CRA Section.

Each scenario, including the baseline, assumes a different amount of transfers are available to the MWD via CRA. In the Base Case, the MWD’s imports via CRA are assumed to be “Average”, 900 TAF; in the Low Energy Scenario, imports are assumed to be “High”, 1.2 MAF; and in the High Energy Scenario, imports are assumed to be “Low”, 800 TAF. These levels were indicated by interviews with MWD staff; more information can be found in Appendix C – CRA Section.

5.7 Local Supply Parameter Assumptions

Additional supplies from recycled water, brackish water desalination, and seawater desalination become available in varying levels in each scenario. Recycled water has a low energy intensity compared to brackish water and seawater desalination. The use of recycled water is strongly promoted in the Low Energy Scenario while desalination technologies are strongly promoted in the High Energy Scenario. Assumptions on current existing capacity were obtained from state surveys and databases, while future capacities were obtained from state mandates and goals and sites that have been currently proposed but not yet built. Details on data sources and methods used by the Study Team can be seen in Appendix I.

The Base Case assumes all currently installed capacity for recycled water, brackish water desalination, and seawater desalination remains in operation in 2010. These assumptions are embedded in the model and are not editable by users. The baseline assumptions for capacity in each region are summarized in Table 5-3.

Table 5-3. Baseline Capacity for Brackish Desalination, Seawater Desalination, and Recycled Water

Region	Brackish Desalination	Seawater Desalination	Recycled Water
NC	0	0	17,346
SF	3,900	0	40,370
CC	0	2,504	25,295
SC	86,187	148	275,494
SR	0	0	10,139
SJ	0	0	33,547
TL	0	0	108,532
NL	0	0	5,758
SL	0	0	18,753
CR	0	0	9,747
Total	**90,087**	**2,652**	**544,981**

The Low Energy Scenario assumes aggressive growth in recycled water production statewide. This assumption is based on implementation of State Water Resources Control Board's (SWRCB) goals of 1 MAF of new capacity built by 2020 and 2 MAF in 2030. This new capacity is incremental to existing capacity and is proportioned to each region in California based on current urban water demand (see Appendix I for details). The Low Energy Scenario assumes no new brackish water or seawater desalination facilities as these supplies typically lead to high energy use.

The High Energy Scenario assumes aggressive growth in seawater desalination and brackish water desalination in the state. Growth in recycled water is also present, but less aggressive than in the Low Energy Scenario. The High Energy Scenario assumes all currently planned brackish water and seawater desalination facilities become fully operational by 2030; of these, 50 percent will become operational in 2020. Information on the location of each proposed facility was mapped to the corresponding region. New recycled water supplies assume the implementation of the SWRCB's mandates of 200 TAF of new capacity built by 2020 and 300 TAF in 2030. Similar to the Low Energy Scenario, capacity is proportioned to each region in California based on current urban water demand. See Appendix I for details on all calculations and sources.

5.8 Local Surface Storage Assumptions

Local surface storage provides additional local supply that has low energy intensity; these supplies can be used in lieu of high energy intensity supplies such as groundwater or imported water. The Low Energy Scenario features increased local supply while the High Energy Scenario does not. The Base Case scenario assumes all current local storage facilities remain in operation during 2010.

The Low Energy Scenario assumes local storage capacity increases a total of 2 percent above current capacity in each region by 2030; half of this new capacity (a 1 percent increase) is available in 2020. The High Energy Scenario assumes no new capacity becomes available in either 2020 or 2030. This increase in storage is translated to a volume increase using data obtained from DWR on the total current surface water storage capacity in each region; this calculation can be found in Appendix H.

The Study Team reviewed the *Safe, Clean, and Reliable Drinking Water Supply Act of 2010,* an $11.14 billion general obligation bond, of which $455 million are dedicated to local drought relief projects. Drawing from the drought relief fund, local agencies can construct additional surface storage supplies to increase supply reliability. This amount of funding will only allow for a modest increase in local surface water storage. Thus, the Study Team estimated a statewide increase in water storage capacity of 2 percent over the forecast period (i.e., 2030).

5.9 Quantified Inputs for Scenarios

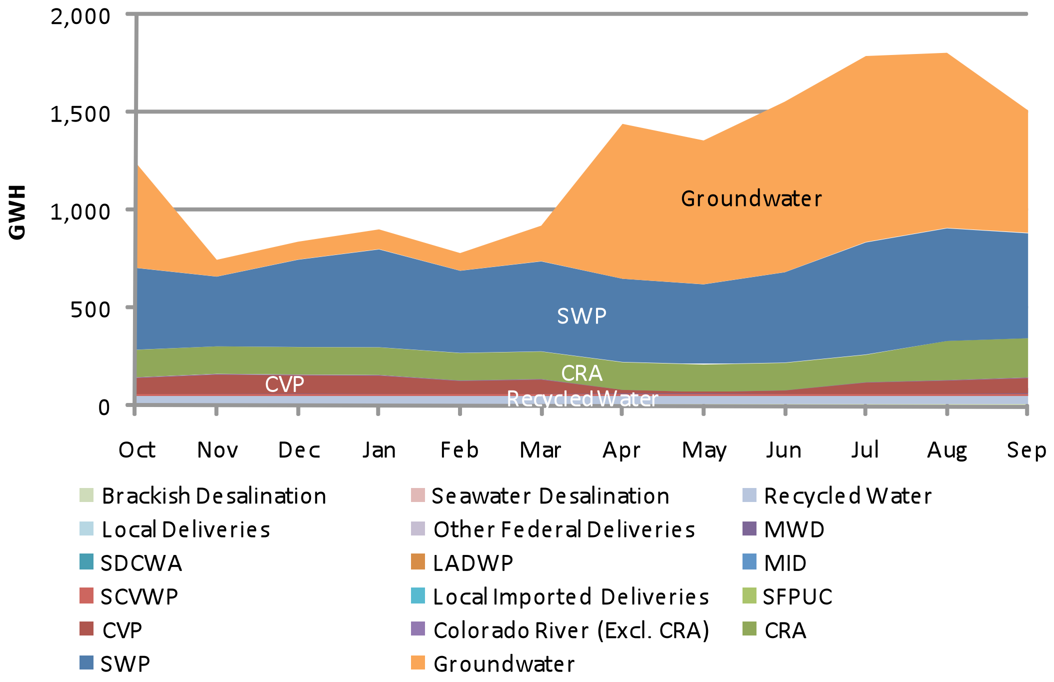
The quantified values for each input to each scenario are summarized in Appendix J. Inputs for both low and high energy scenarios were input to the model. Inputs for the Base Case are embedded in the model and not alterable by users. This enables estimating the potential future energy impacts under the low and high energy scenarios by comparing the projected results to "today."

5.10 Scenario Outputs

The Study Team completed its scenario analysis by running the two scenarios described in Chapter 5 through the model. This section discusses the results of the scenario analysis.

Results show the majority of energy consumption in the state under current conditions is attributed to groundwater pumping (see Figure 5-2). Under most future scenarios, groundwater pumping and the SWP are the two largest energy consumers. The larger energy consumer (groundwater vs. SWP) varies by scenario and type of hydrology year. Other major energy consumers under current conditions include CRA and CVP. In future scenarios, the increased use of recycled water and desalination technologies cause those supplies to emerge as major energy users as well.

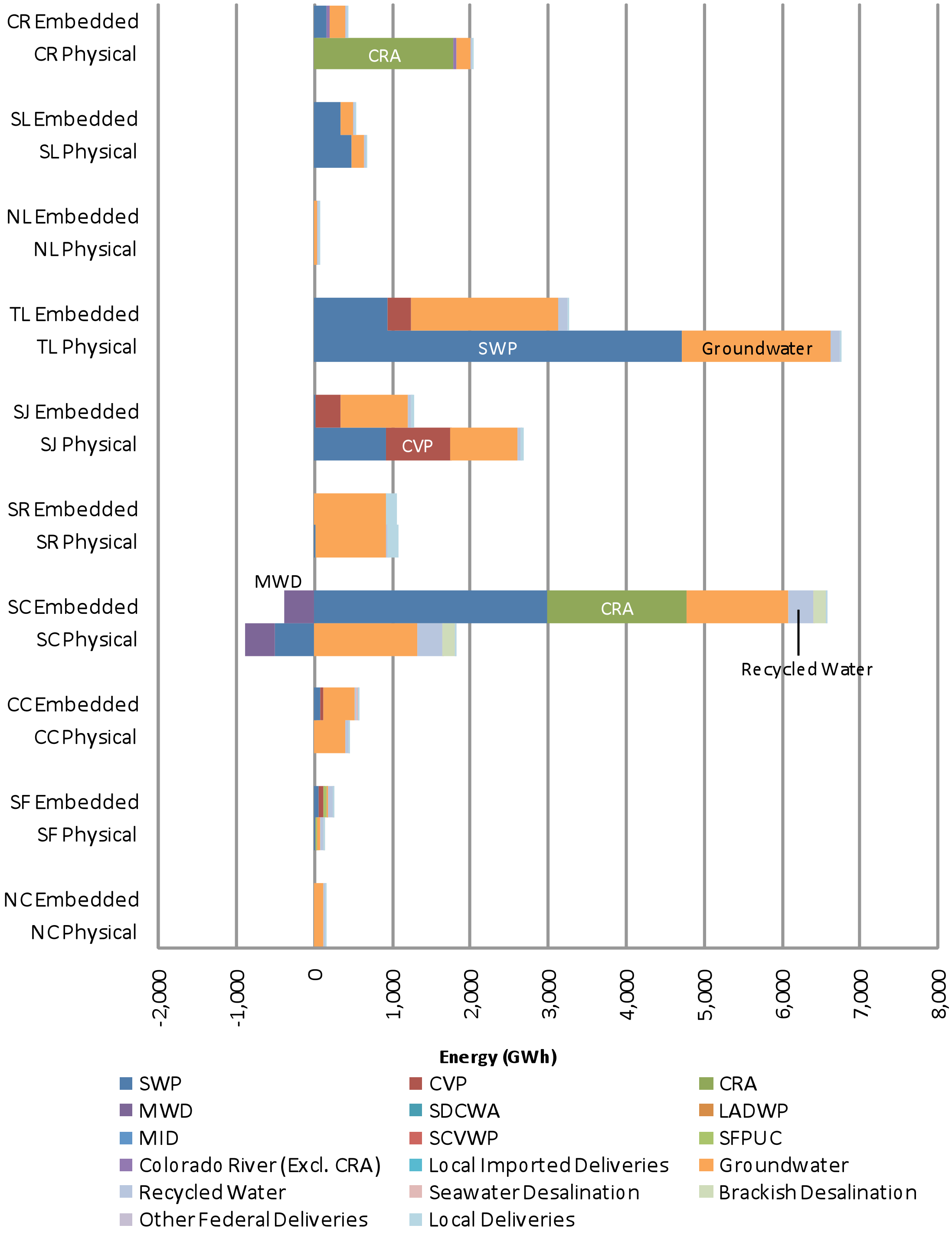
Figure 5-2. 2010 Baseline Monthly Energy Profiles of Statewide Water Delivery Operations



Additional analysis shows the majority of energy consumption by California water systems occurs in the Tulare Lake Region (Figure 5-3). Much of this energy is attributed to the SWP as several large pump stations are physically located in the region to pump water over the Tehachapi Mountains to southern California. While a relatively small amount of energy is used in this region, the South Coast has the largest embedded energy associated with water deliveries to the region. Water transported to the South Coast via the SWP and the CRA require significant amounts of pumping.

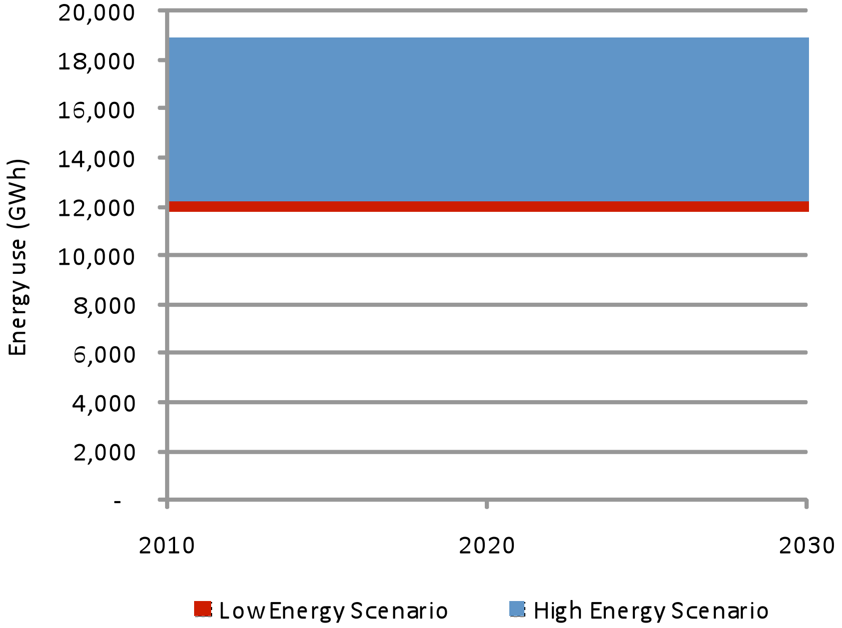
Note that the amounts shown in Figure 5-3 for embedded energy only include energy embedded in the Supply and Conveyance segment of the water use cycle. These numbers would need to be adjusted to include water treatment and distribution, and wastewater treatment, in order to represent the full value of energy embedded in a unit of water.

Figure 5-3. 2010 Physical and Embedded Energy by Supply and Region



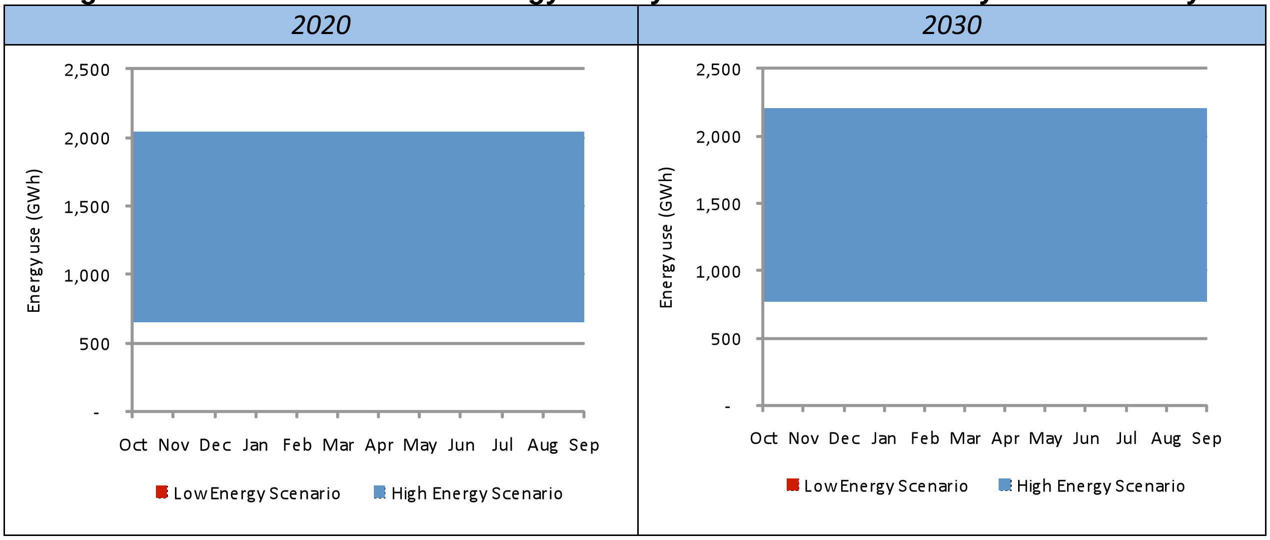
Analysis revealed the possible range of future energy consumption by the two scenarios, as illustrated in Figure 5-4. The range created within each scenario is due to the effect that hydrology has on available supplies and energy use.

Figure 5-4. Future Statewide Energy Use by the California Water System



Annual energy use is disaggregated into monthly energy use statewide. These monthly energy ranges for both Scenarios in 2020 and 2030 can be seen in Figure 5-5.

Figure 5-5. Future Statewide Energy Use by the California Water System - Monthly



The full scenario analysis results (Figures 5-6 through 5-19) include information on: statewide energy consumption for each water year type, monthly energy consumption by water supply, water deliveries to each region by supply, and physical energy consumption and embedded energy associated with each supply in each region. Detailed results are highlighted for three water year type: Wet, Below Normal, and Critical. These three year types represent the extremes of water supply available and energy use by the water system. Detailed results for Above Normal and Dry water year types can be obtained from the model.

Figure 5-6. Statewide Energy Consumption Scenario 1

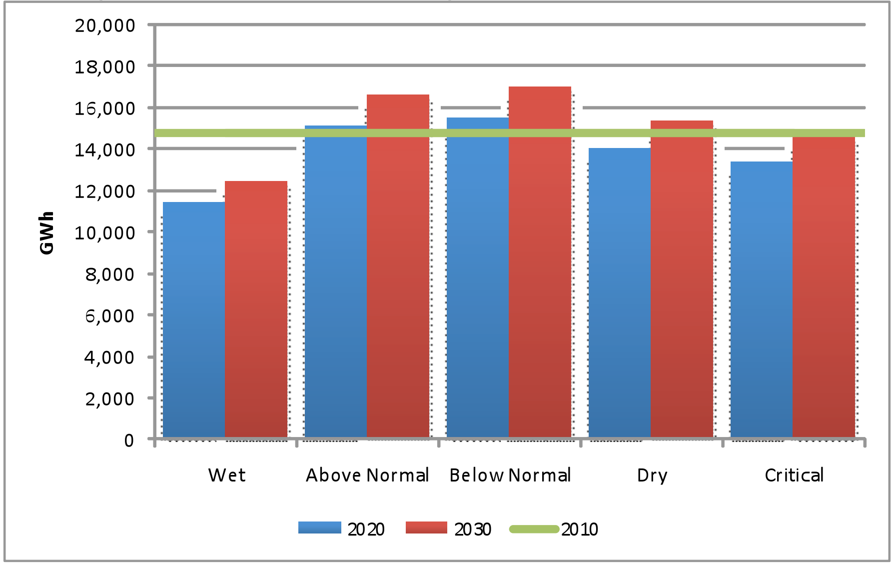


Figure 5-7. Statewide Energy Consumption Scenario 2

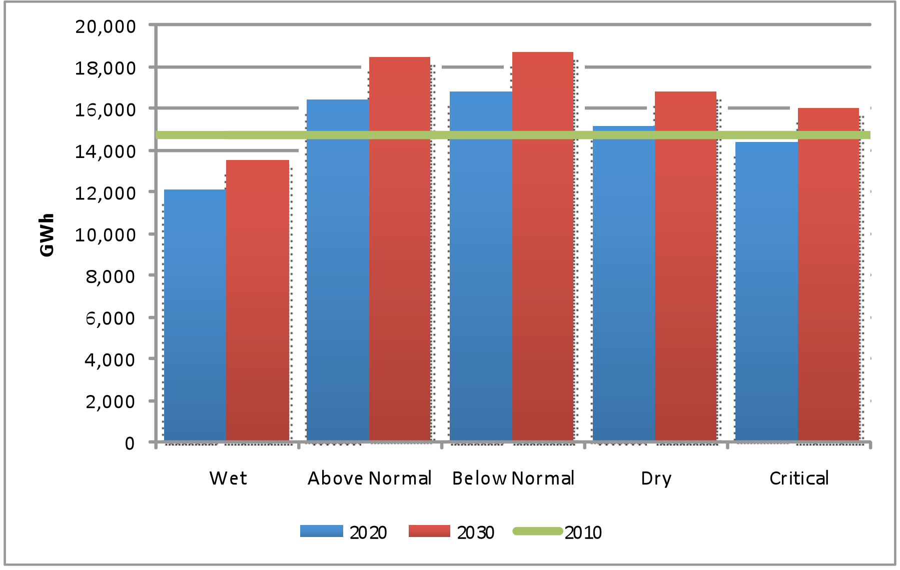


Figure 5-8. Monthly Energy Profiles - Wet Year Type

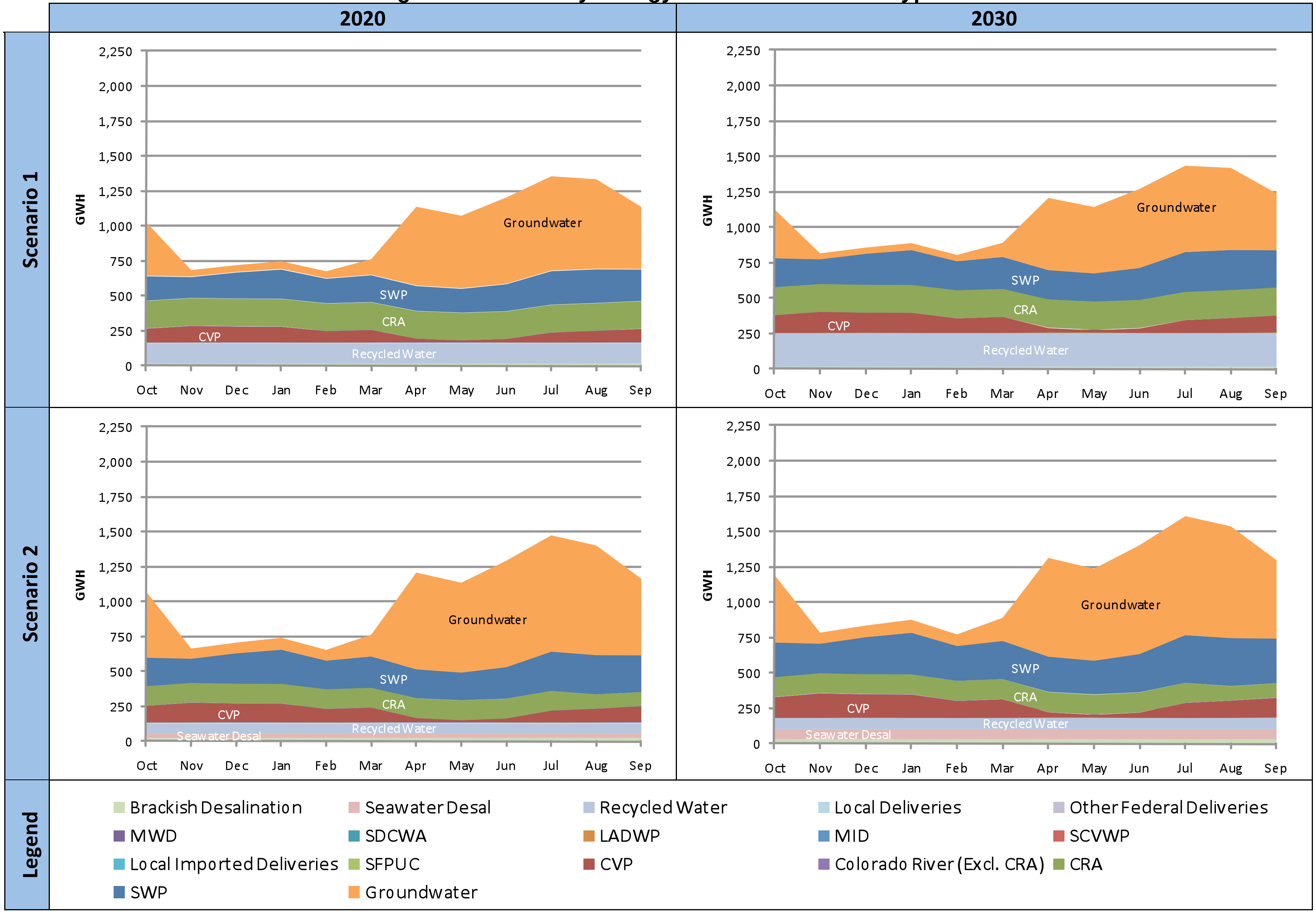


Figure 5-9. Water Deliveries by Supply - Wet Year Type

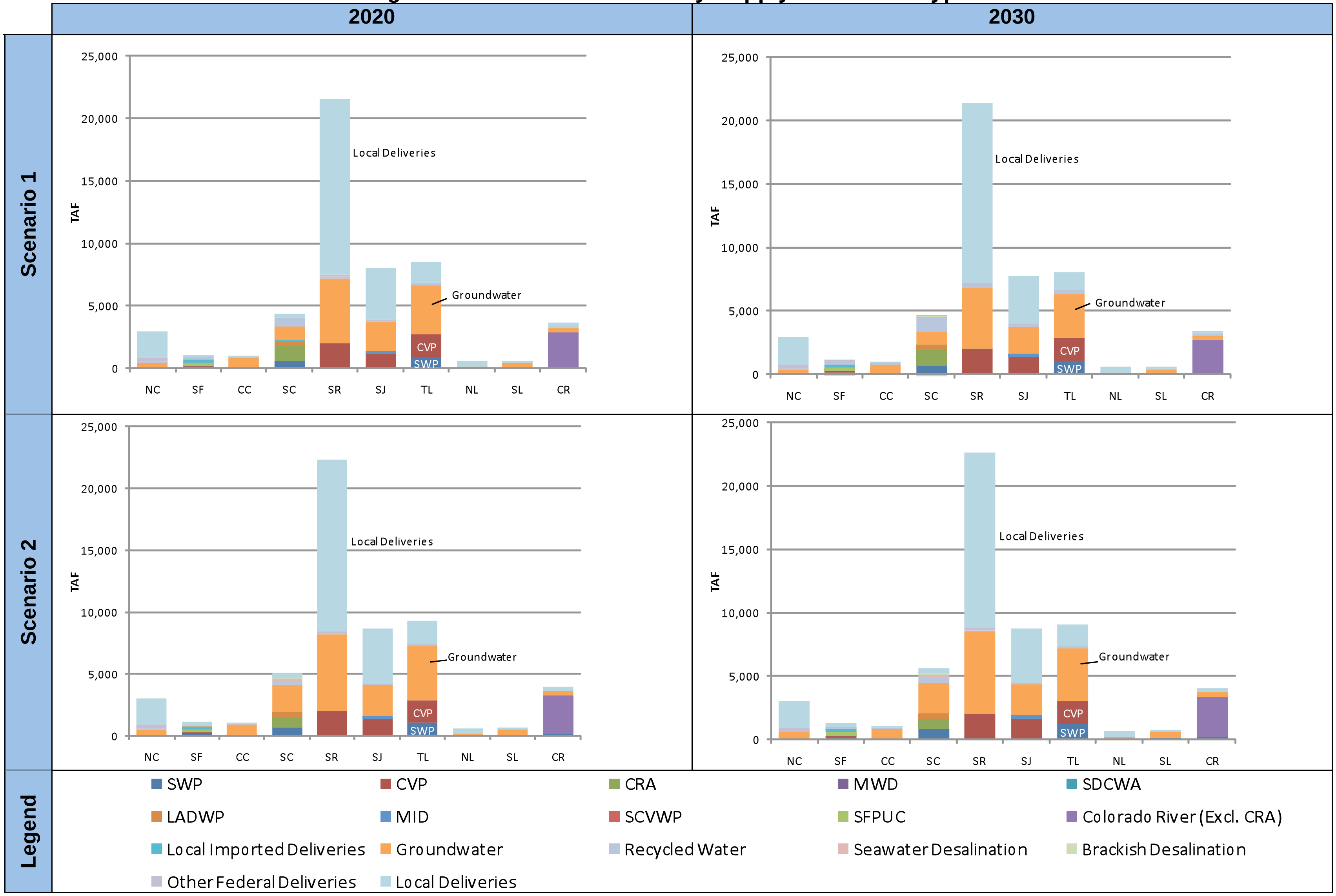


Figure 5-10. Embedded and Physical Energy Use - Wet Year Type, 2020

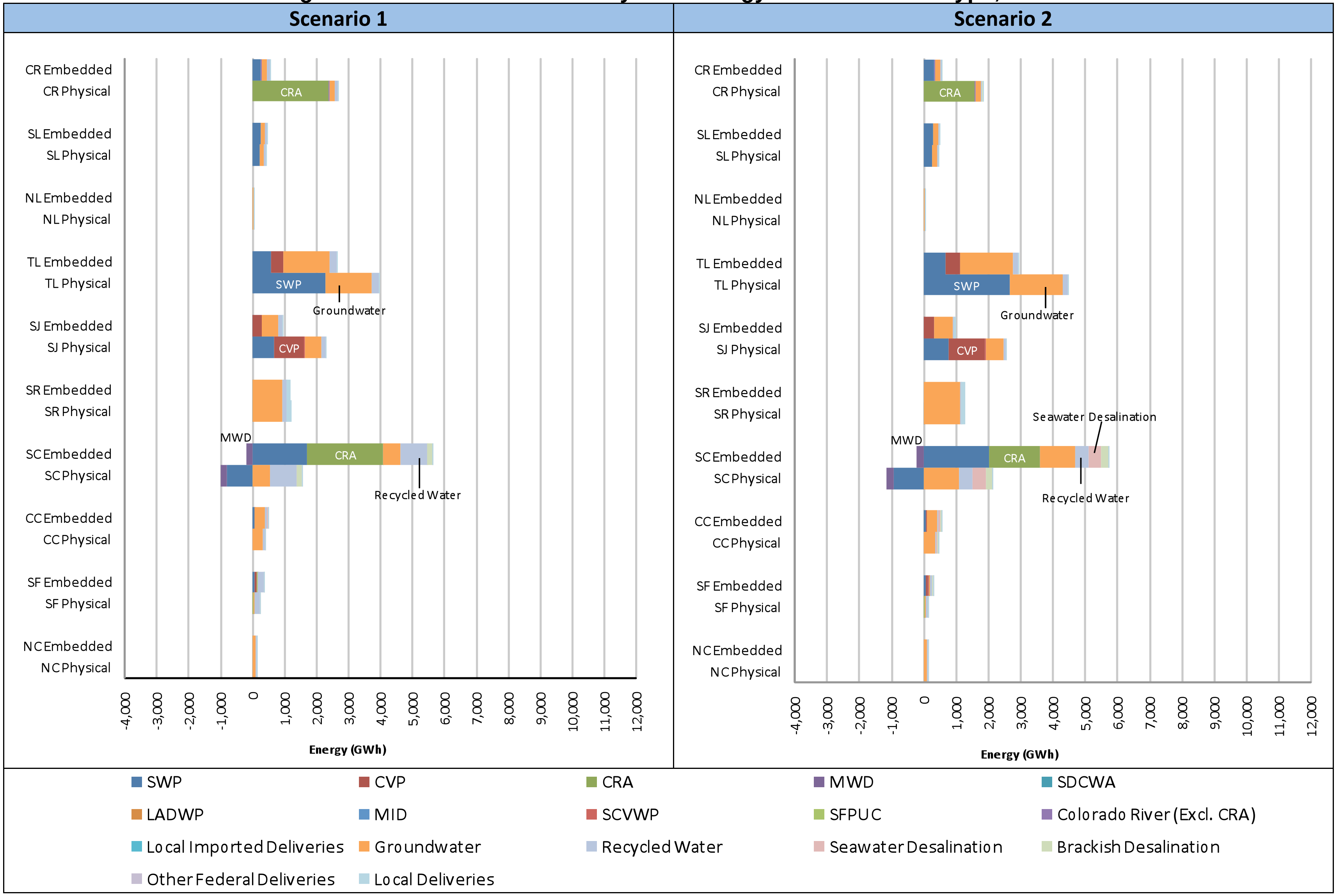


Figure 5-11. Embedded and Physical Energy Use - Wet Year Type, 2030

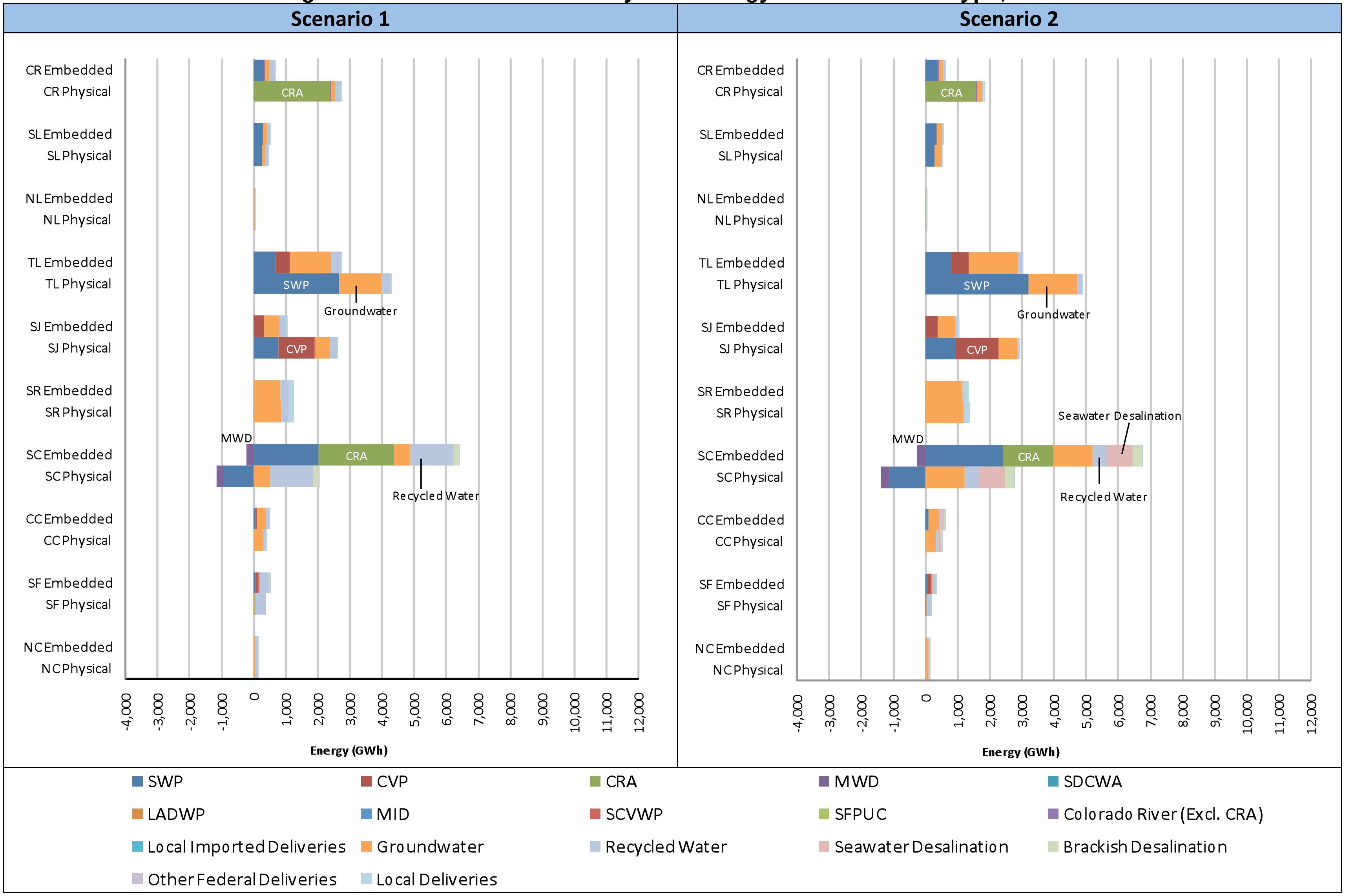


Figure 5-12. Monthly Energy Profiles - Below Normal Year Type

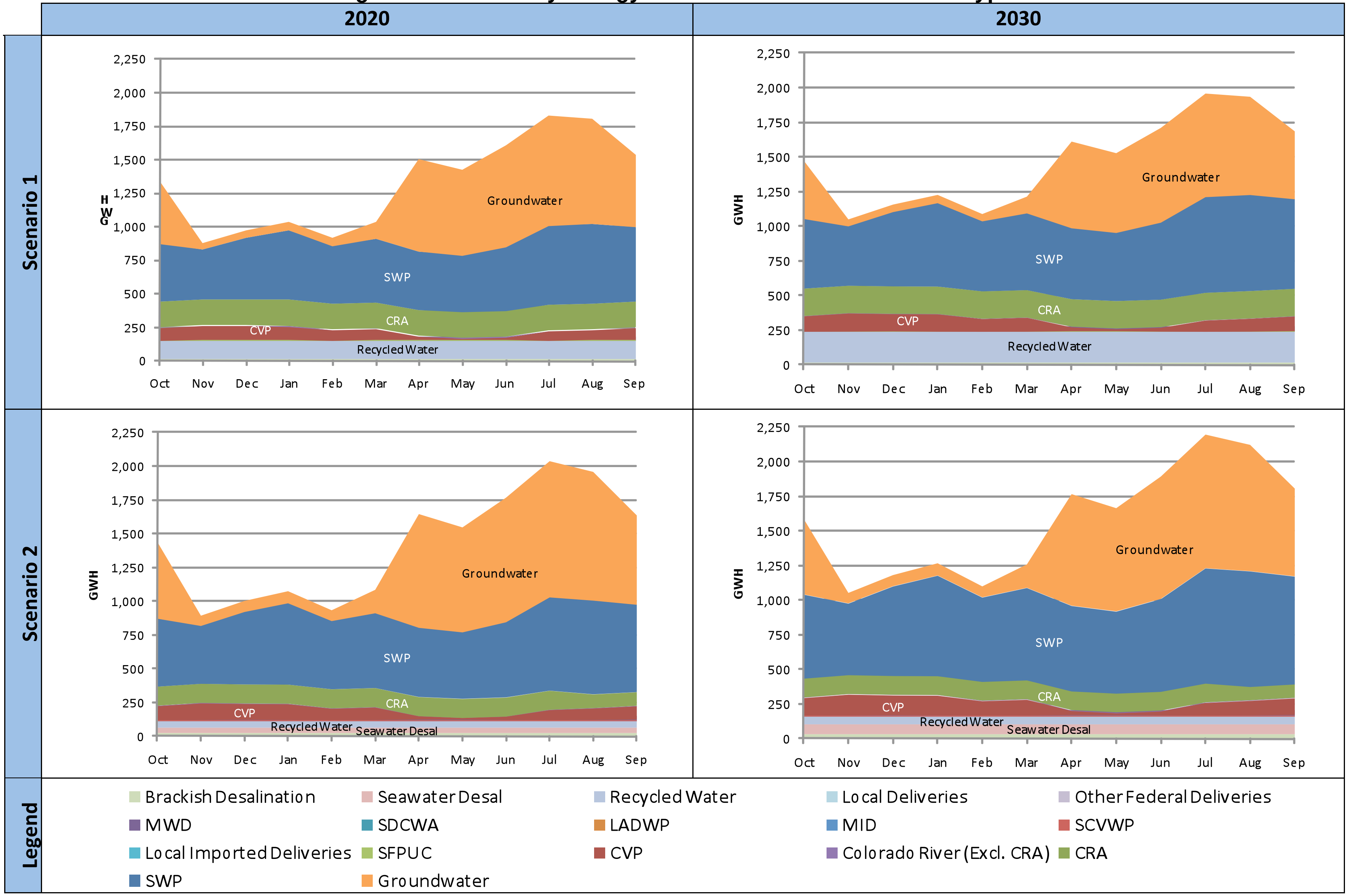


Figure 5-13. Water Deliveries by Supply - Below Normal Year Type

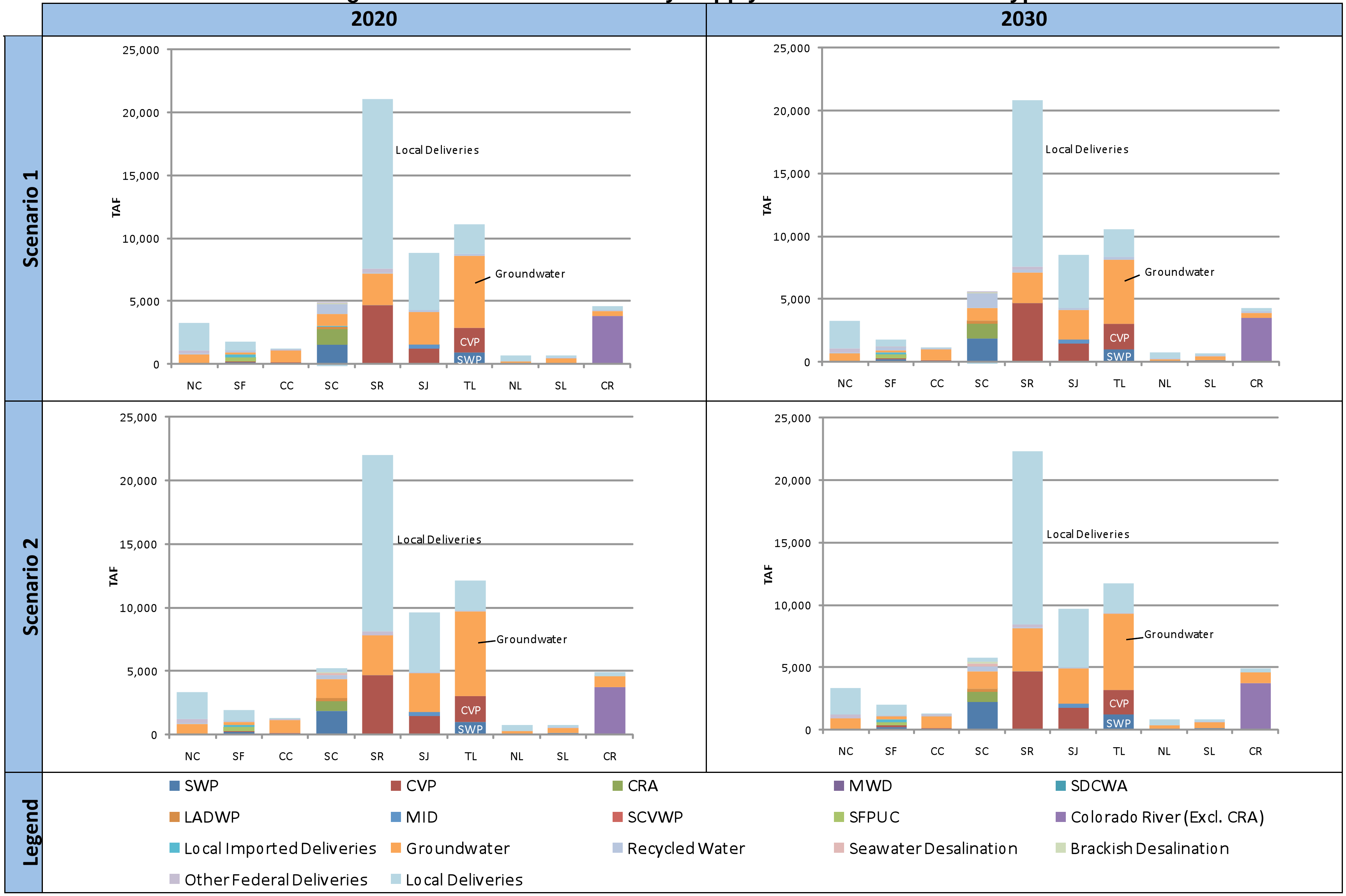


Figure 5-14. Embedded and Physical Energy Use - Below Normal Year Type, 2020

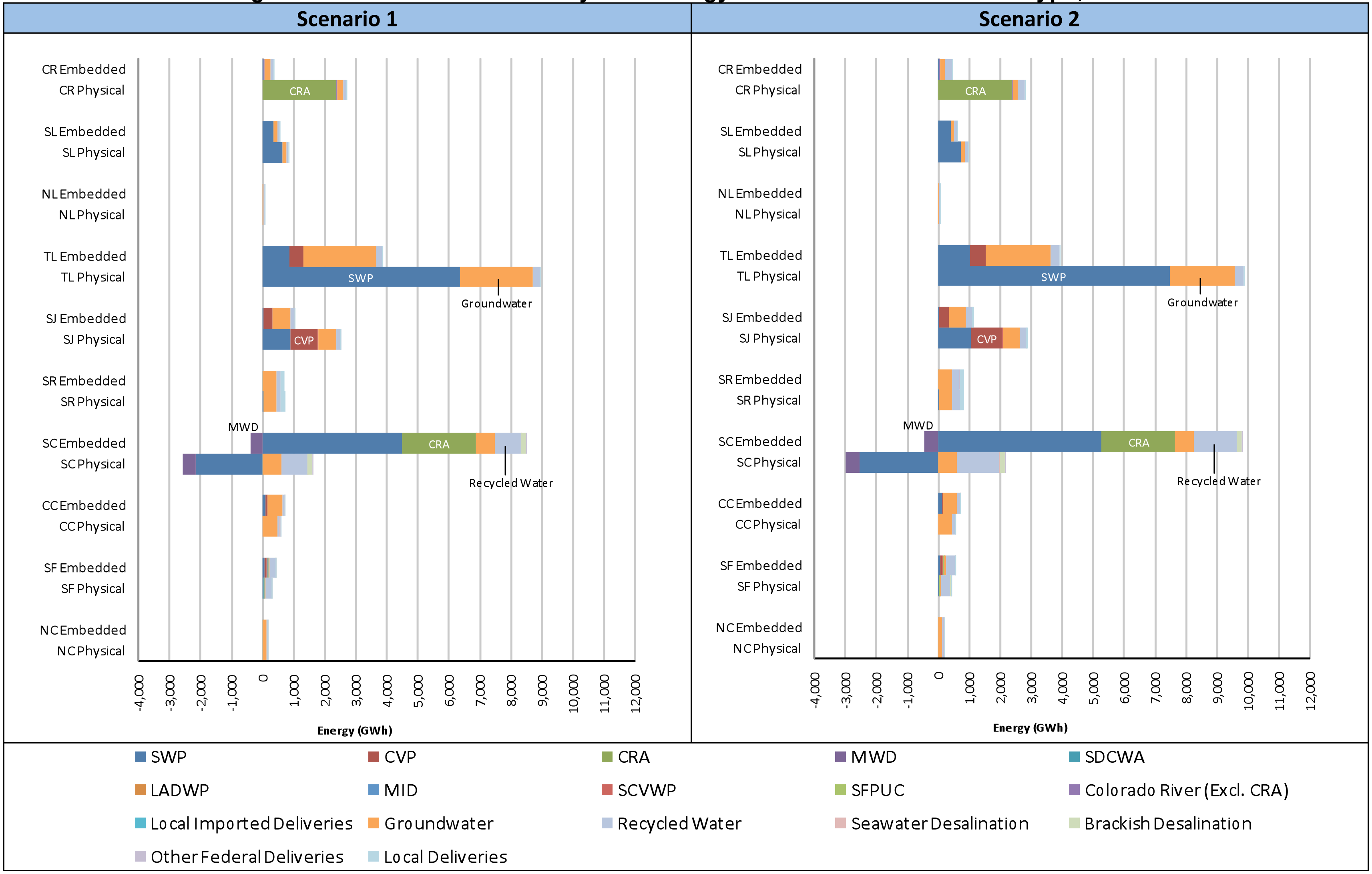


Figure 5-15. Embedded and Physical Energy Use - Below Normal Year Type, 2030

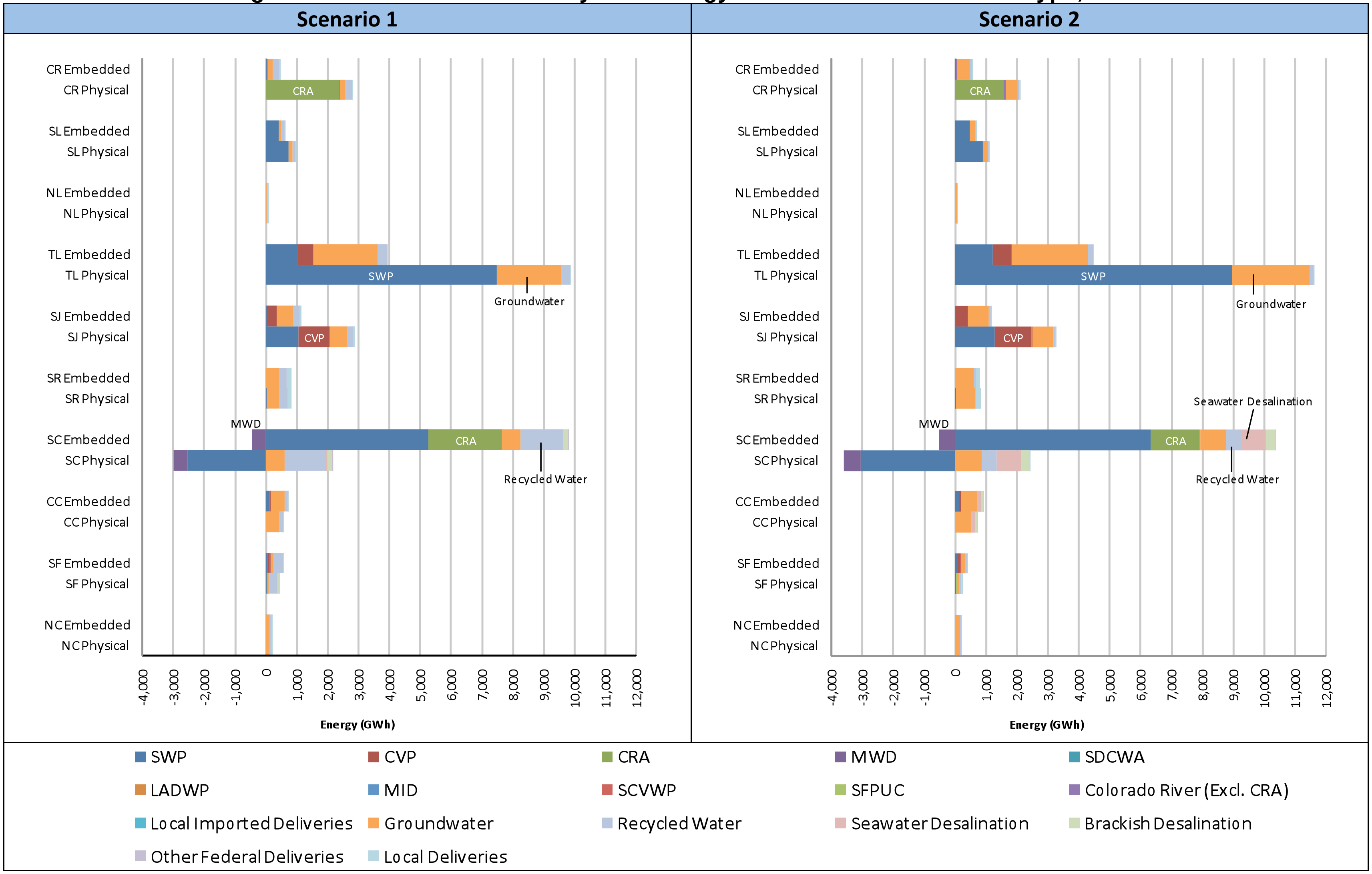


Figure 5-16. Monthly Energy Profiles - Critical Year Type

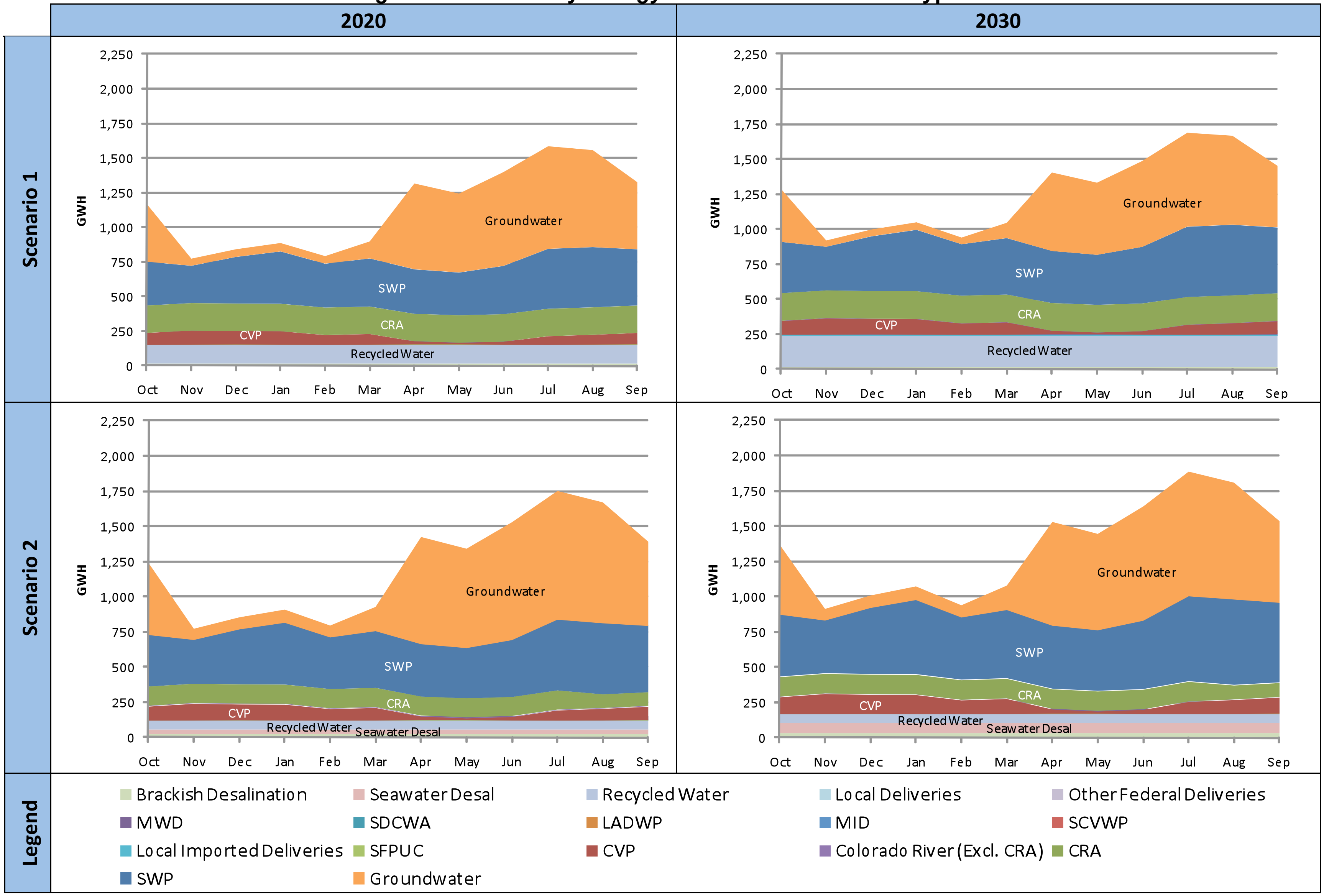


Figure 5-17. Water Deliveries by Supply - Critical Year Type

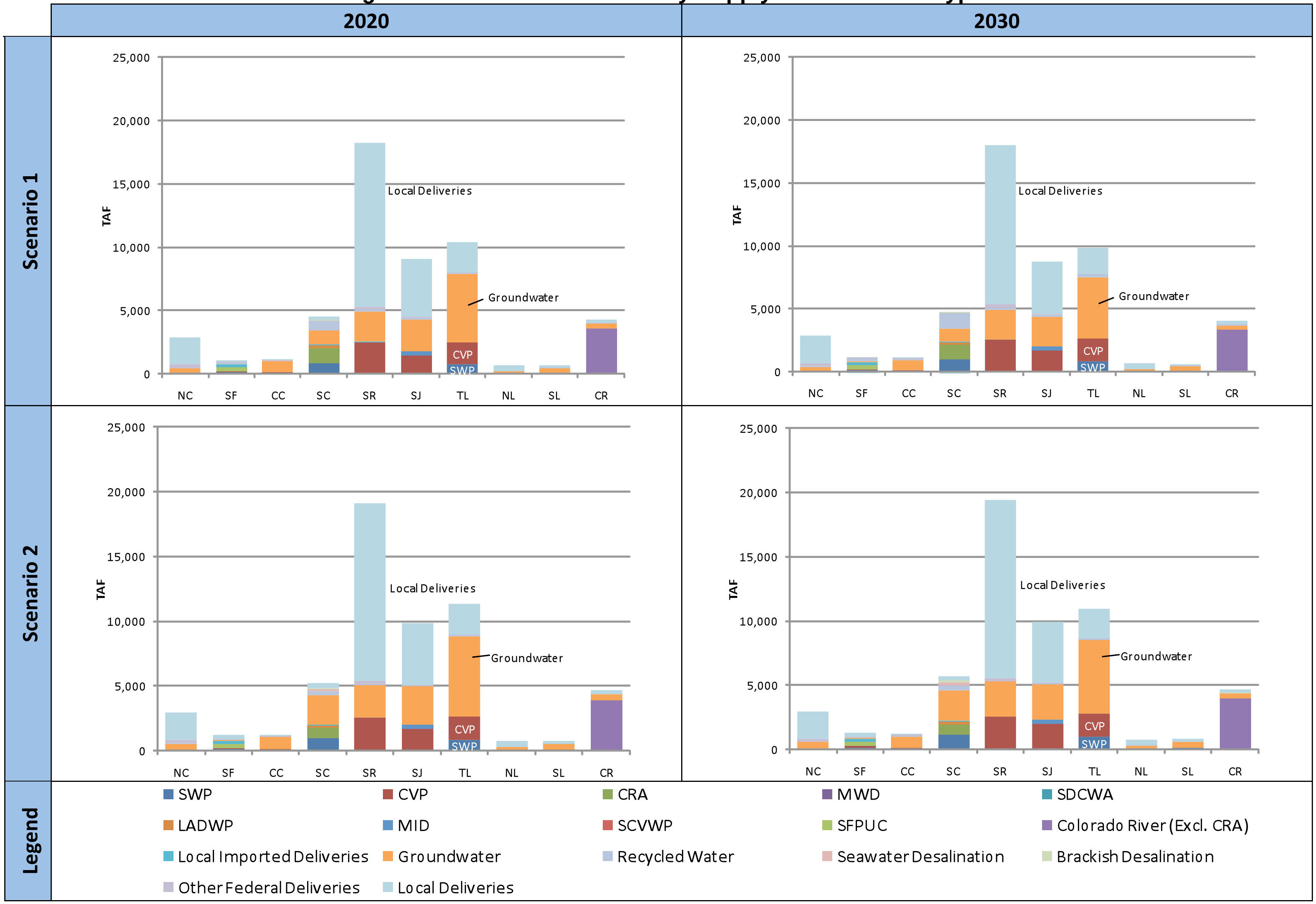


Figure 5-18. Embedded and Physical Energy Use - Critical Year Type, 2020

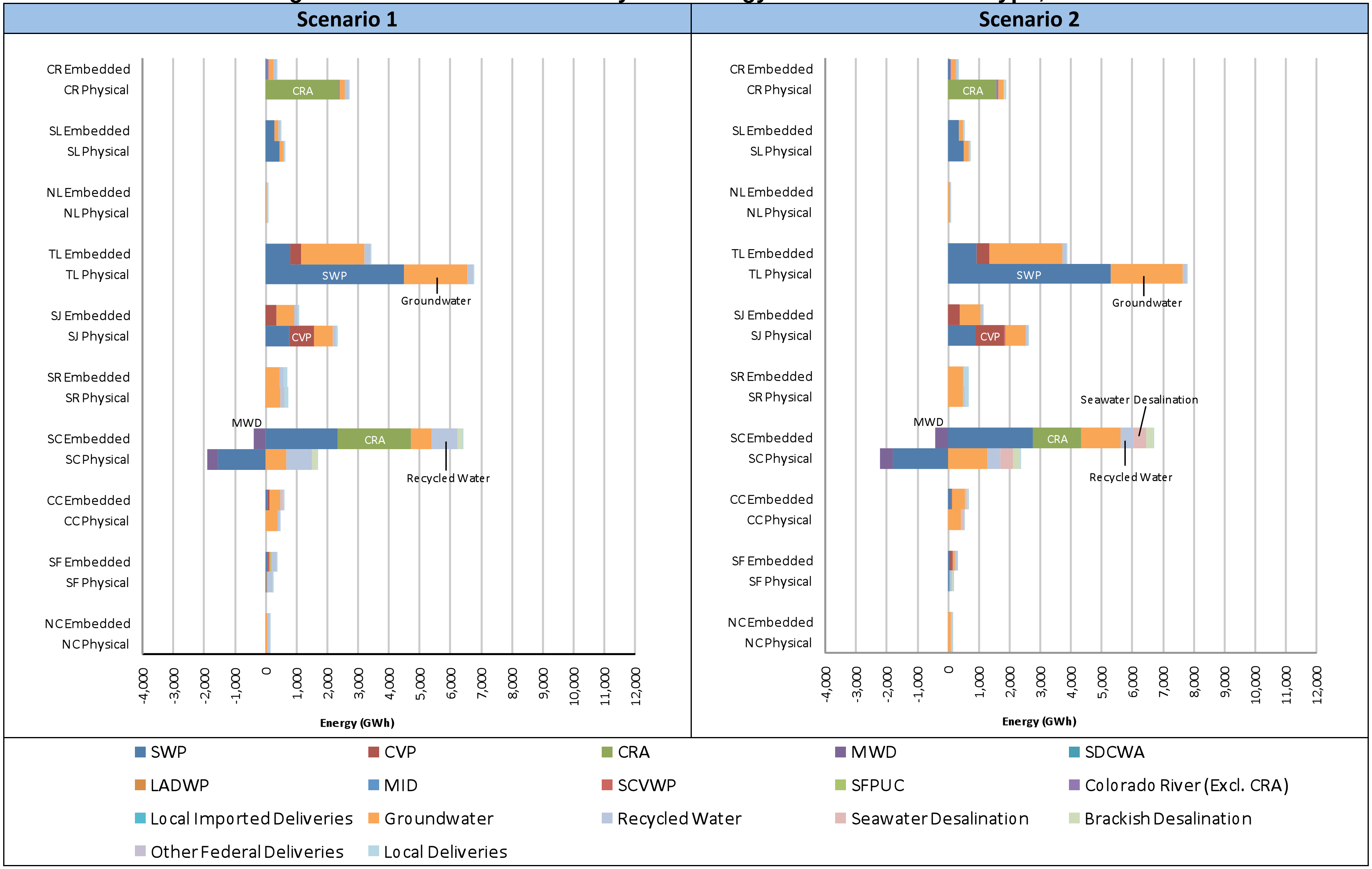
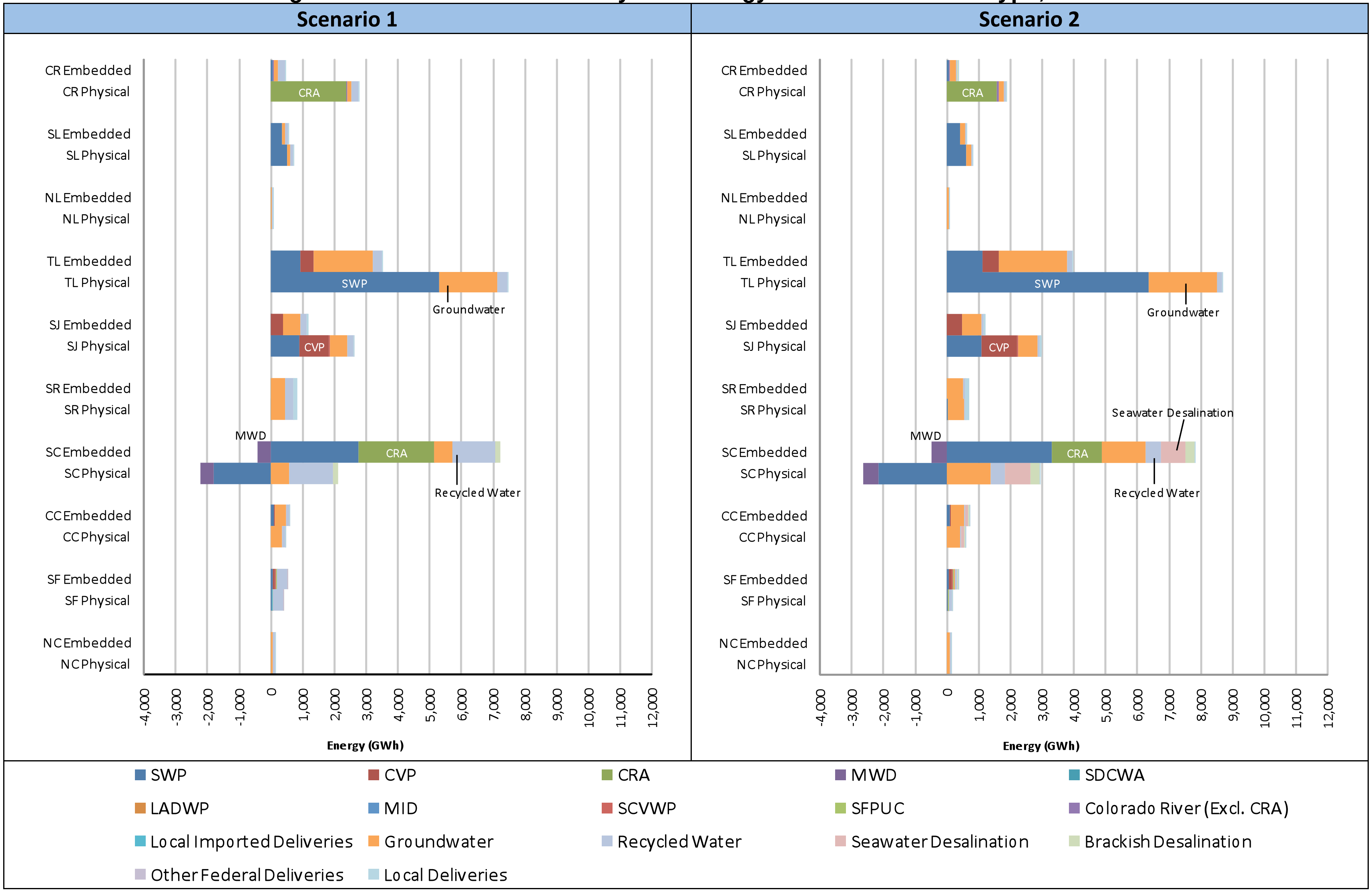


Figure 5-19. Embedded and Physical Energy Use - Critical Year Type, 2030



5.10.1 Sources

DWR. *Forecasted 2010 SWP Supply Allocation*. http://www.water.ca.gov/news/newsreleases/2009/12012009allocationgraph.pdf. Accessed January 2010.

DWR. *2009 Comprehensive Water Package*. November 2009

6 Summary of Findings

The primary purpose of Study 1 is to increase understanding of the relationship of energy and water Supply & Conveyance systems in the State of California. The desired outcome of this study is a predictive model that estimates the potential range of statewide energy impacts under a variety of future scenarios.

Water system operations are the primary determinant of energy use by the state's Supply & Conveyance systems. Hydrology is useful in understanding the seasonal impacts of water supplies and demand in California. However, many other non-hydrology factors such as storage, water rights, contractual obligations, and policies have a much more significant impact on water operations decisions.

The Study Team's approach was to first conduct a detailed analysis of energy use by nine large wholesale water systems that collectively comprise 70 percent of all wholesale surface water conveyance in California. Energy drivers, design and operating characteristics, contractual commitments, and other key factors were studied and documented in detail for the period 1998-2005. This period was selected because it more fairly represents the resources and infrastructure conditions water operators are dealing with today. In addition, DWR has prepared detailed statewide and regional water balances for that period that help to estimate the impact of wholesale water deliveries as well as other sources of water such as groundwater and local water surface supplies. Further, the state's future water resource portfolio is expected to include significant quantities of recycled and desalinated water. The expected change in water resources will likely have a significant impact on the quantity and timing of water-related energy use.

During the process of collecting, analyzing and compiling water-energy data, the Study Team encountered significant data challenges that needed to be addressed with the participating water agencies and other key stakeholders to adjust and resolve. The Study Team met extensively with DWR staff and managers about the operations of the SWP, how water operations are being modified to account for Judge Wanger's decision on withdrawals from the Delta, and the process for compiling the regional water balances and the types of estimates and adjustments that are made by DWR to balance supply and demand by hydrologic region. MWD provided insights as to its water supply challenges and how that affects the operation of the CRA. Each agency that provided data reviewed and approved its profile in Appendix C.

As the Study Team grappled with these data issues, choices were made in the model design to ensure that the best possible data sources were used wherever possible. Energy intensities were developed at the facility level wherever possible and, where not possible, at key points of wholesale water deliveries. Significant variations in energy intensity were flagged for discussion and resolution with the subject agencies. As the most reliable source of information about how various types of water resources are applied to meet water demand, DWR's regional water balances were used as the overarching framework for the model. This allows users to change assumptions of both demand and supplies by hydrologic region.

One of the primary data gaps encountered was the lack of information about the amount of energy used to pump groundwater. Since groundwater supplies about 30 percent of all water used in California, this was a significant gap that could not be overlooked. Since many groundwater wells are privately owned and the owners are not required to record and report water pumping and associated energy consumption, the Study Team needed to estimate the amount of energy used for groundwater by applying average pump efficiency factors to data about the depth-to-groundwater by groundwater basin. These data were then mapped to hydrologic regions and energy service providers for use in the model.

These efforts resulted in an interesting picture that has never before been discernible: that is, during the summer months in which statewide energy use is highest (June, July, and August), groundwater pumping requires more energy than the SWP, the CVP, and the CRA combined. See Figures 6-1 and 6-2 for details.

Figure 6-1. Monthly Energy Consumption in 2010 by California Water Supplies

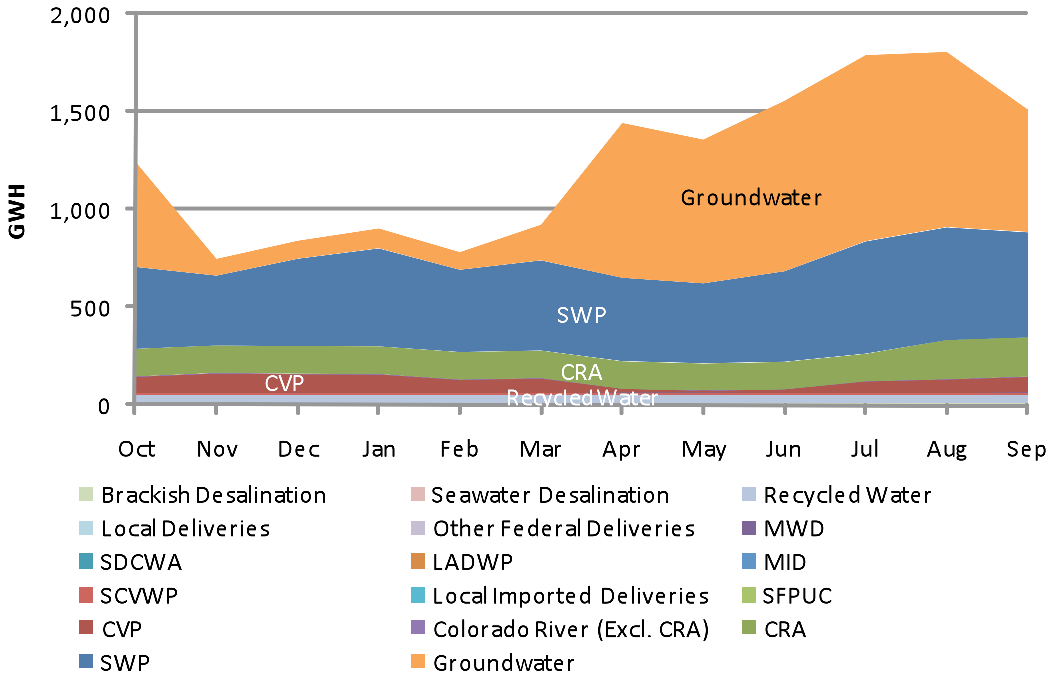
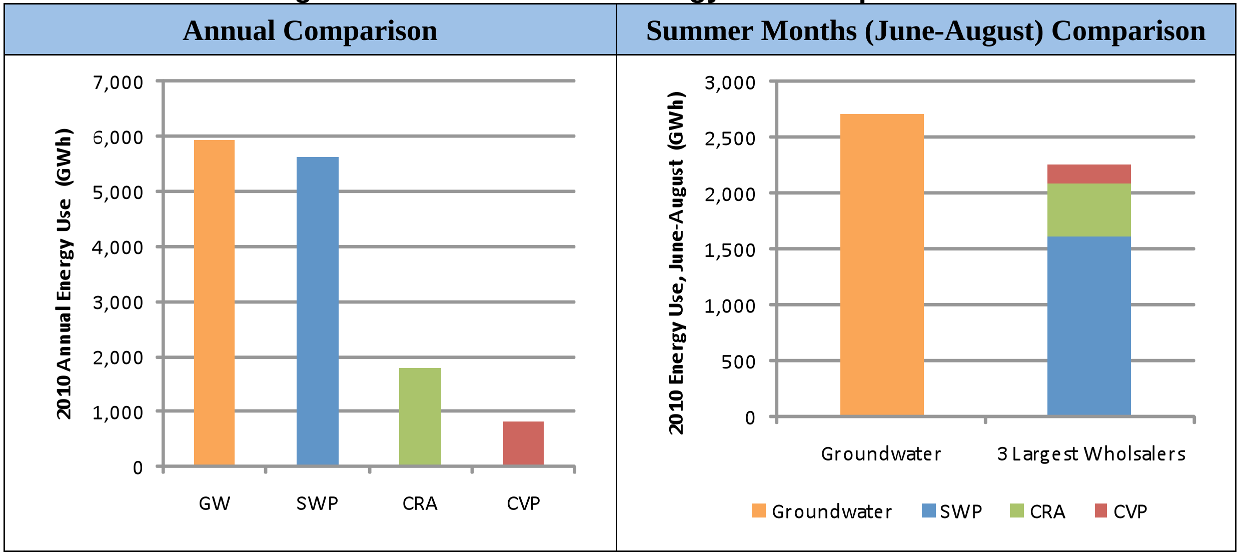


Figure 6-2. Groundwater Energy Use Comparison



Annual Comparison

Summer Months (June-August) Comparison

The ultimate deliverable for this study is a predictive model that can be used to facilitate policy deliberations about the state's water-energy relationship. The Study Team decided to develop the model in an Excel workbook to increase transparency and understanding of the relationships of the nine water agencies and other water resources to the regional water balances. In addition, using the Excel spreadsheet as a platform enabled creating user input screens at the level of each hydrologic region which substantially increases both the user friendliness and the usefulness of the model to a wide range of potential users.

Because there are many proposed water policies with no clear winner, knowledgeable stakeholders were consulted to help develop scenarios for evaluation through the model. These stakeholders included water managers, policymakers and external third parties (such as The Pacific Institute and the Natural Resources Defense Council) that are actively studying water-energy issues on their own. All of these stakeholders advised that there was no single set of future policies that they deemed "most likely." Consequently, they recommended that the Study Team construct two scenarios: a high energy case and a low energy case, to establish likely upper and lower energy bounds that can represent the range of potential impacts of future events that cannot be accurately predicted. The Study Team incorporated that advice into its model design and scenario analyses, relying upon industry experts to help develop the supply and demand assumptions that were used to represent those cases in each hydrologic region. The model design allows users to change key assumptions that may have significant variability in the future, such as the estimated impact of Judge Wanger's decision on SWP operations which no one, including DWR, can yet predict.

The result of this collaboration with water agencies and other key stakeholders resulted in the following findings:

- Significant amounts of the energy used by the participating nine large water agencies is self produced and supplemented by purchases from the wholesale power market. Only small quantities of energy are provided by the state's investor-owned utilities (IOUs). The only wholesaler identified in this study that purchases retail energy from an IOU was the SCVWD who purchases approximately 15 percent of the energy use for one of its smaller pumping plants from PG&E.

- Groundwater pumping accounts for more of the energy used than deliveries of surface water. As noted earlier, groundwater pumping accounts for more energy use than the surface water pumping of the state's 3 largest water agencies combined during the summer months. Unfortunately, there is no reliable data source to help identify how much of the energy used to pump groundwater is supplied by the IOUs. The Study Team believes that a proxy of 50 percent is conservative and reasonable. This finding is particularly notable since prior water-energy studies have focused primarily on the impacts of the SWP which does not use IOU energy for its water pumping. Through this study, it appears that the greatest opportunity to reduce water-related energy consumption of IOU energy may be by reducing groundwater usage.

- Presently, recycled water and desalinated water account for less than 1 percent of the state's water resources. These water resources will play a much larger role in the state's future water supply portfolio. The energy impact of this shift in water resources is not easily determinable because there is huge variability in water agencies' energy experience to-date. However, given the definition of the recycled water energy – that it should be computed as the amount of incremental energy used to increase the quality of wastewater effluent to at least tertiary standards – recycled water is expected to remain a relatively low energy intensity source of water supplies. Desalted water, however, requires significant quantities of energy to remove the salts and other minerals from brackish or seawater, with desalted seawater rivaling the energy intensity of the SWP. From the perspective of IOU energy, the shift towards increased quantities of desalted water in the state's water supply portfolio is significant because desalination plants are expected to site their facilities within IOU service areas and may become IOU customers.

7 Recommendations

7.1 Summary

Prior studies relied primarily on the CEC’s 2005 and 2006 studies. Studies 1 and 2 are the most extensive data collection and analysis effort conducted thus far about energy use by California’s water sector.

- Study 1 focused on estimating the amount of energy consumed by the Supply and Conveyance segments of the water use cycle. Through that study, detailed water-energy data were collected that also enable estimating the energy intensity of primary wholesale water supplies throughout California.

- Study 2 focused on collecting and compiling detailed water-energy data at the retail water and wastewater agency functional level.

Both studies observed wide variability in the energy intensities of water transportation (conveyance) and delivery (distribution) systems. The amount of energy needed to serve water to any particular customer depends on the distance and elevation over which that water must be transported.

However, Study 2 also observed wide variability among functional components in retail water and wastewater systems. It would be difficult from these data to select a single value as indicative of the “typical” energy intensity of water and wastewater treatment. This may be in part due to the fact that the contribution of key energy drivers to the energy intensity of any particular functional component could not be readily determined from the data that were available. It may also be because each treatment plant is configured uniquely, and there are distinct differences in the key energy drivers in each.

In Chapter 3, Energy Use by California’s Wholesale Water Systems, the Study Team documented the range of variance found in the energy intensities observed in the functional components of the participating water and wastewater agencies. There was no clear pattern that could point to a single value to be used as a proxy for any segment of the water use cycle or its sub-segments, nor was there sufficient basis to select proxies by geographic or hydrological region. In fact, while Studies 1 and 2 addressed the questions raised in the respective scopes of work, both pointed to a need for additional data, methods and tools. The types of data, methods, and tools identified through these studies are described generally below, along with an illustration of how the data from the two studies can be integrated to compute embedded energy in water.

7.2 Recommendations

Based on the data collected through Studies 1 and 2, the Study Team believes that the amount of electricity used by the water sector is higher than the CEC's conservative estimates in 2005.

In Appendix N, Comparison of Study 1 and Study 2 Findings with Prior Studies, electricity use by the Supply and Conveyance segment alone was shown to exceed the amount of electricity use reported by the CEC for all water sector use (i.e., including water treatment and distribution, wastewater collection and treatment, and recycled water production and distribution). In the absence of better data, the Study Team recommends conservative adjustments which we believe understate the amount of energy embedded in the state's water. These conservative estimates increase water sector electricity use in 2001 from 4.9 percent to 7.7 percent. The Study Team does not, however, have a basis for increasing the CEC's estimate that 19.2 percent of all electricity used in California is in some way related to water, since the increase in water sector use may be a reallocation of electricity counted towards water end use.

The primary significance of these findings is that the value of energy embedded in water is higher than that initially estimated in the CEC's 2005 and 2006 studies. Notably, the estimates developed by the CEC were purposely conservative because the CEC did not want to overstate the potential water-energy relationship.[37] Since water sector energy use establishes the value of energy deemed "embedded" in a unit of water, the energy value of water efficiency measures increases as more electricity consumption is allocated to the water sector itself.

The key recommendations indicated by these studies entail improving the body of water-energy data, methods and tools to enable more accurate measurement of the state's water-energy relationships. In particular, the Study Team recommends the following actions:

- Collect more water-energy data, and with more granularity
- Develop and adopt a methodology for computing the energy embedded in a unit of water
- Quantify water losses throughout the water use cycle

These recommendations are discussed below.

Collect more water-energy data, and with more granularity. Better data is needed about electricity requirements for groundwater and for water and wastewater treatment.

1. Groundwater Energy. Study 1 indicates that groundwater energy is much larger than previously realized. During summer months, electricity used for groundwater exceeds

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[37] Interview with Lorraine White, Senior Energy Specialist and Advisor to Commissioner Anthony Eggert, California Energy Commission, May 19, 2010.

the amount of electricity used by the three largest wholesale water systems (SWP, CVP and CRA) combined. Data on the amount of energy used for groundwater pumping is very spotty. Very good data is available in adjudicated basins, very little data is available in other places, where groundwater pumping is not adjudicated. In addition to being a very significant component of embedded energy in water, groundwater energy is important because much of it is provided by the state's IOUs. Unfortunately, how much of it is provided by the IOUs is presently undeterminable from existing data.[38]

2. <u>Treatment Energy</u>. The amount of energy used to treat water and wastewater is typically computed at the plant level. Although engineering studies enable estimating the relative amount of energy needed for different types of treatment technologies, energy meters do not capture data at a level that would facilitate validating those engineering assumptions.

As noted earlier, given the tremendous variability in water conveyance and distribution systems, the energy intensity of water transport and delivery systems need to be computed separately for each water agency.

There are a number of near-term opportunities for significantly improving the state's knowledge about electricity use by the state's water sector:

- <u>Advanced Metering Infrastructure (AMI)</u>. The state's IOUs have commenced replacement of existing meters with advanced meters that have the ability to capture real-time energy consumption data. The AMI conversion is expected to be completed within about five years. This existing activity provides a near-term opportunity to significantly improve the state's understanding of its water-energy relationships for no incremental cost – the CPUC need only direct the IOUs to prioritize water sector electricity uses for near-term conversion to AMI.

- <u>The Water-Energy Load Profiling (WELP) Tool</u> developed through Study 2 can be used to develop detailed water-energy load profiles for all water and wastewater agencies in California. Water and wastewater agencies could be required to provide the data needed to develop these detailed water-energy load profiles as a condition for accessing IOU energy incentives. During the conduct of Studies 1 and 2, the Study Team found that water and wastewater agencies cited limited staff time as the greatest obstacle to participation. Water and wastewater agencies dealing with cutbacks in staffing had great difficulty providing the detailed water and energy data that was required by Study 2, in

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[38] During the course of this study, members of the Internal Working Group and Study Team contacted both water and energy utilities to identify more data about groundwater pumping. Both water and energy sector stakeholders stated that little information is presently available about the amount of energy used to pump groundwater.

particular. Since energy utilities have at least half of the data, a partnership seems logical.

In addition, all of the medium to large-size water and wastewater treatment facilities have SCADA systems that can be set up to monitor and report energy use by functional components, if desired. The state's IOUs could work with water and wastewater agencies to identify opportunities to increase monitoring and reporting of energy use by high priority segments and sub-segments of the water use cycle.

Develop and adopt a methodology for computing energy embedded in water. Study 2 required collection of the short- and long-run marginal water supplies for participating water agencies. The purpose of this task was to provide a basis for computing the value of energy embedded in water. Study 1 provided much of the data that would be needed to compute the energy embedded in the Supply and Conveyance segment of the water use cycle, while Study 2 focused on collecting data about energy used in water treatment and distribution, wastewater treatment, and incremental treatment (if any) needed to produce usable recycled water.

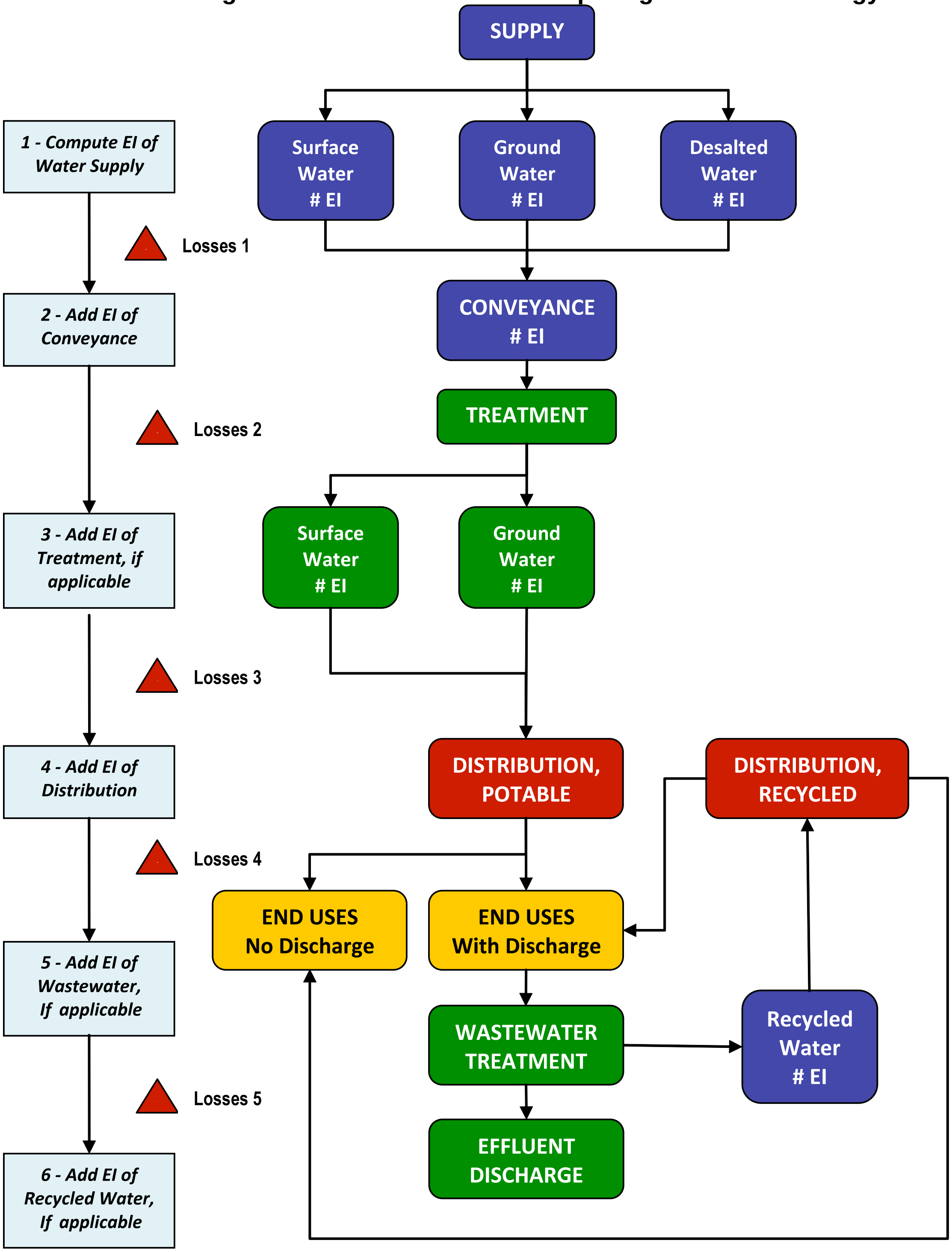
Quantify water losses throughout the water use cycle. Prior studies indicate that losses in the water system are substantial. There is significant variability, depending on the type of facility(s), the climate, and the condition of the system. Reservoirs and aqueducts are open to the atmosphere and thus experience high losses due to evaporation. Aqueducts also tend to have high rates of seepage. Pipelines have fewer losses due to evaporation but depending on the age, condition and type of materials used, can have significant losses due to leaks. Water system losses have been documented along all segments of the water use cycle. Even newly constructed distribution systems can experience losses of 5 percent, while mature systems in dense urban areas may experience losses as high as 10 to 15 percent or more. All of the energy used along all segments of the water use cycle need to be accounted for in computing embedded energy, including energy that may have been used to transport, treat or deliver water that is lost and not delivered to water end users.

7.3 A Framework for Computing Embedded Energy

Ultimately, the goal of Studies 1 and 2 was to enable selecting values to insert along the segments of the water use cycle to determine the amount of energy embedded in a unit of water. Whether that computation is made at the level of a single agency, a region, or statewide is a matter of policy.

The diagram below illustrates the way in which data from Studies 1 and 2 could be integrated in order to compute the amount of energy embedded in a unit of water.

Figure 7-1. Framework for Computing Embedded Energy



The key steps and associated issues that should be considered when computing energy embedded in water - whether at the individual agency level, regionally, or statewide - are described below. Losses should be included in the computations. For example, if a particular water supply source starts at 1,000 AF at the beginning of the water use cycle but, after losses, results in delivering 800 AF of water supply to end users, all of the energy used to produce and deliver that water along all segments of the water use cycle, including the missing 200 AF, should be counted. Whether or not this value needs to be separately computed depends on how the energy data are collected and computed at each segment.

1. ***Compute EI of Water Supply***. As discussed in both Studies 1 and 2, nearly 98 percent of the state's water use by the urban and agricultural sector is met by the two primary sources of water: surface water (67 percent) and groundwater (31 percent). The remainder is met by desalted and recycled water supplies. The energy intensity (EI) of each water resource depends on a number of factors, including the quality and location of the water supply.

   - *Surface water* tends to be a relatively low EI resource because it is ready to be applied to beneficial uses.

   - *Groundwater* tends to have a higher EI than surface water because energy is needed to pump water to the surface before it can be used.

   - *Desalted water* may either be pumped from aquifers or drawn from brackish surface water sources, such as the ocean. By definition, water resources are not deemed "water supply" until they are usable. Consequently, brackish water resources must be desalted before they can be considered "water supplies." Typically, the process of desalting water is higher on an average EI basis than groundwater pumping. The amount of energy needed for desalting depends on the quality of the water – the higher the salt content of the water, the more energy is needed to remove the salts. Consequently, seawater desalination is one of the highest EI water resources.

   - *Recycled water* is produced from wastewater effluent. The amount of energy needed to treat wastewater to a quality needed for safe discharge in accordance with public health regulations is accounted for as wastewater treatment energy. The EI of recycled water is thus the amount of incremental energy, if any, needed to treat the effluent to a higher quality as may be needed to serve the targeted beneficial uses.

   <u>Supply Losses (Losses 1)</u>: Although losses occur during the process of water production, those losses need not be separately accounted for in the embedded energy computation, since the EI of the water supply is typically already computed net of water supply production losses.

2. ***Add EI of Conveyance***. The EI of conveyance of wholesale water supplies depends on the distance and elevation that the water must traverse. The State Water Project (SWP) provides an excellent illustration of how conveyance EI varies at each delivery point along the system,[39] with the highest EI occurring at the points after which SWP water must be pushed a total of 2,000 feet over the Tehachapi Mountains.

   <u>Conveyance Losses (Losses 2)</u>. The state's water conveyance systems transport large volumes of water supply from one region to another. These systems tend to be large diameter pipelines or lined or unlined channels. Conveyance systems tend to have substantial losses through pipeline leaks, aqueduct or canal seepage, and evaporation. The largest systems that transfer water across the state traverse hundreds of miles. Most leaks in underground pipelines go undetected for many years; and even when they are known to leak, the cost of digging up and repairing the pipelines is a significant economic deterrent. The actual magnitude of losses in the state's wholesale water conveyance systems is unknown. More research is needed to quantify these losses.

3. ***Add EI of Water Treatment***. Not all water supplies need treatment. Depending on the quality of the source water supplies and the quality needs of their intended uses, no treatment may be required – for example, to apply some surface or groundwater supplies to agricultural irrigation, or even for potable uses.

   - In the past, high quality water resources may only have been treated with lime (e.g., to remove carbonates that make water "hard" and/or to adjust the pH to reduce corrosion) and then dosed with chlorine to kill bacteria and other micro-organisms. Now that it is known that that chlorine and other chemical disinfectants can cause carcinogenic by-products, other treatment methods are used. The particular treatment technologies and processes needed depend on the end use of the water. Drinking water has the highest requirements, and typically has the highest treatment EI.

   - Reverse osmosis (RO) is used to remove salts and minerals from brackish water. The water produced through RO is already of drinking water quality. The energy used to desalt water is accounted for in the Supply segment of the water use cycle. Consequently, no additional energy is likely needed for desalted water in the Treatment segment.

   <u>Treatment Losses (Losses 3)</u>. The volume of treated water produced is always less than the amount of influent. Typically, the EI would be measured as the average energy used to produce the total amount of water treated. More research is needed to quantify these losses.

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[39] See Chapter 3 in Study 1 for full results on all studied wholesale supplies.

4. ***Add EI of Distribution***. As for Conveyance EI, the primary drivers of Water Distribution EI are distance and elevation. This can vary significantly across agencies and even within an agency's service territory.

   Distribution Losses (Losses 4). Distribution system losses are highly variable. More research is needed to quantify these losses.

5. ***Add EI of Wastewater***. Not all water end uses are discharged to sewers. Only indoor end uses (and only a percentage of total indoor water use) should include a component for wastewater treatment. Some portion of outdoor water uses may end up in sewers.

   Wastewater Treatment Losses (5). Water is lost during the solids removal processes of wastewater treatment. This is an important factor to consider especially when the wastewater will then be treated further to produce recycled water. The volume of recycled water produced will be less than the treatment plant influent. More research is needed to quantify these losses.

6. ***Add EI of Recycled Water***. Incremental energy needed to increase the quality of wastewater effluent to standards needed for the intended water reuse is accounted for in the Recycled Water segment of the water use cycle.

Appendix A Glossary

Appendix B Hydrologic Region Profiles

Appendix C Wholesale Agency Profiles

Appendix D Model Documentation

Appendix E Water Balance Definitions

Appendix F Future Demand Projections

Appendix G Groundwater Energy Use

Appendix H Surface Storage and Groundwater Limits

Appendix I Desalination and Recycled Water Supply

Appendix J Scenario Inputs

Appendix K Scenarios Memo

Appendix L Literature Review

Appendix M Model User’s Manual

Appendix N Comparison of Study 1 and Study 2 Findings with Prior Studies