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Energy Research and Development Division

FINAL PROJECT REPORT

Water-Energy Bank

Shifting California State Water Project Pumping Using Aquifer Storage

Gavin Newsom, Governor
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The authors especially acknowledge the contributions of one of the key team members, John Koreny, who unfortunately passed away a few months before the project's close. John was an experienced hydrogeologist and his expertise was paramount to the analysis of groundwater banking opportunities in Southern California that present load shift potential. Additionally, John's project management skills were critical in ensuring efficient and streamlined coordination, documentation, reporting, and quality assurance functions throughout the duration of the project.

PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs that spur innovation in energy efficiency, renewable energy, and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The California Energy Commission (Energy Commission) and the State's three largest investor-owned utilities – Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company – were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for California's electric consumers. Its benefits include:

- Providing societal benefits, including reducing dependence on fossil fuels.
- Reducing greenhouse gas emissions in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

This is the final report for the Water-Energy Bank Proof-of-Concept project (Contract Number EPC-16-029) conducted by Antelope Valley Water Storage, LLC, HDR Engineering, Inc., Energy+Environmental Economics, Inc., GEI Consultants, Inc., and Water and Energy Consulting, Inc.). The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

The growth of renewable energy generation, as a result of California energy and environmental policies, has caused a surplus of power during the spring months when there is ample solar and wind generation but relatively low electricity demand, resulting in relatively low energy costs. This imbalance between springtime renewable power supply and demand is projected to increase as more renewable energy is brought on-line. In contrast, during the summer months, there is insufficient renewable energy supply to meet all demands; this requires bringing temporary power on-line to meet demand, which then results in relatively high energy costs.

One of the largest uses of electricity in California (up to 3 to 4 percent of the total) is the California State Water Project, which pumps water over the Tejon Pass from Northern to Southern California. This report includes an analysis that determines the benefits of shifting water pumping from high to low energy demand periods by using aquifer storage at the Willow Springs Water Bank. This analysis indicates that shifting California State Water Project pumping can reduce both energy-related operating costs and greenhouse gas emissions, help California integrate renewable energy sources, and operate the power grid at a lower cost. The Willow Springs Water Bank aquifer storage facility can be used as a "water-energy bank" to create a seasonal shift in California State Water Project pumping while entirely preserving all aspects of the project's water supply deliveries, reliability, and timing to Southern California. This study characterizes both the potential amount of seasonal water shift and the potential cost and savings benefits of a water-energy bank under an avoided cost analysis and total resources cost savings framework.

Keywords: groundwater bank, energy storage, demand response, renewable energy, load shifting, avoided cost framework

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Introduction

Energy and environmental policy changes and market forces are driving changes in California's electric power supply-and-demand markets. Key policies established in California Senate Bill 350 and Senate Bill 100 establish a path to 100 percent carbon-free power sources for retail electricity by 2045, and greenhouse gas emission reduction to 80 percent below 1990 levels by 2050. The growth in renewable energy supply, the product of California's progressive energy and environmental policies, has caused a seasonal surplus of electricity. During the spring, there is ample solar and wind generation but relatively low electric demand, in turn resulting in relatively low energy costs. In contrast, electricity demand in the summer months exceeds the supply of renewable generation, particularly in the late afternoons and early evenings when air-conditioning pushes up consumer electric demand, during times of peak energy price. As more renewable energy supplies are brought on-line, the excess generation in the spring and fall will create challenges in balancing supply and demand.

The California State Water Project is a large water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants that serves 27 million people and irrigates about 750,000 acres of irrigated farmland statewide. Currently, a large amount of electricity is required to convey water from Northern to Southern California through the California Aqueduct. The five pumping plants south of the San Luis Reservoir (Dos Amigos, Buena Vista, Teerink, Chrisman and Edmonston) use up to 1,480 megawatts of electricity to convey water up and over the Tehachapi Mountains at Tejon Pass to Southern California, about 3 percent to 4 percent of typical statewide summer electricity demand.

The California Department of Water Resources has historically operated the State Water Project to deliver water while minimizing energy costs and complying with regulatory and contractual requirements. The physical limits and operational availability of facilities, however, as well as energy market conditions, constrain State Water Project operations. By operating both seasonally and hourly, California Department of Water Resources is still able to take advantage of available water supplies and reduce energy use during peak-demand hours.

Water storage reservoirs adjacent to the State Water Project could provide opportunities for the California Department of Water Resources to shift operations seasonally and hourly. Groundwater storage is a significantly lower-cost alternative than conventional above-ground reservoirs, which are costly to build and operate.

Project Purpose

The goal of this study is to determine cost savings from shifting the State Water Project pumping load from summer's high energy-demand periods to lower energy-demand periods without changing the timing, quantity, or reliability of Sacramento Delta water deliveries to Southern California. Electricity demand is relatively low during the daytime in spring and fall when solar generation is high, causing excess energy supply during these periods. As a result, water pumped and delivered by the State Water Project in spring costs less than in summer's high-demand, high-cost period. This situation creates a market incentive to seasonally shift State Water Project pumping from summer to spring. This study aims to determine additional cost savings and peak-energy use reductions, measured in megawatt-hours, by shifting State Water Project pumping to lower-demand times, measured in megawatts, hourly and seasonally.

Project Process

A preliminary evaluation of historical operations at Edmonston Pumping Plant was conducted to identify the potential benefits of shifting State Water Project pumping out of peak demand in the summer months. Ten years (2008 through 2017) of that historical operating data, provided by the California Department of Water Resources, was evaluated to determine the total amount of water pumped and energy used during summer months and daily peak demand periods. Historical pumping patterns and practices for ramping pumping up and down identified and established optimal pumping pattern scenarios that minimize pumping during daily peak demand hours without changing the total daily volume of water pumped. This approach was expanded further to consider integration of supplemental storage at Willow Springs Water Bank to enable seasonal load shifting, in the State Water Project pumping operations, away from peak hours. This concept forms the basis of the Water Energy Bank Study.

Willow Springs Water Bank is an aquifer water storage project located in Southern California's Antelope Valley, near the East Branch of the California Aqueduct. It has a storage capacity of 1 million acre-feet.

Under water-energy bank operations, State Water Project water is pre-delivered from San Luis Reservoir in the spring and stored in Willow Springs Water Bank until it is needed during the summer to offset reductions in State Water Project pumping.

An economic evaluation estimated the cost savings benefits of the water-energy bank from the perspective of wholesale market participants, electric utilities, and the broader State as a whole. Wholesale energy-price forecasts (measured in dollars per megawatt-hour) were developed for a range of projected renewable generation curtailment scenarios. The mid-curtailment scenario is roughly analogous to the application of California Senate Bill 100. Wholesale energy-price forecasts, along with output from the baseline and water-energy bank scenarios, were used to evaluate the cost-savings benefits of the water-energy bank.

Project Results

The historical Edmonston pumping analysis confirmed that the California Department of Water Resources operates the State Water Project to reduce energy use during peak energy consumption hours.

Supplemental storage at Willow Springs Water Bank can increase the potential for shifting peak electrical demand in the summer months. Results of the study, including aquifer water storage, showed the greatest potential to shift State Water Project pumping in normal water years, followed by wet years and dry years. In dry years, State Water Project operators already have the flexibility to reduce pumping during peak energy demand periods because less water is delivered relative to wet and normal years.

The project results in a net annual increase in total energy use because water must now be pumped from the Willow Springs Water Bank by extraction wells in addition to regular State Water Project pumping. However, by shifting pumping to lower-demand and lower-cost periods when renewable energy is more widely available, total energy costs and greenhouse gas emissions are lower since renewables then make up a larger percentage of the State's energy mix. On average, avoided-energy costs decreased for all year types and all curtailment scenarios except for wet water years in the low-curtailment scenario. The water-energy bank would likely not operate during wet years rather than incur increased cost.

For each economic analysis framework included in this study (Avoided Cost and Renewable Energy Solutions [RESOLVE]), average total avoided cost values were evaluated over the 82-year period of record for low-curtailment, mid-curtailment, and high-curtailment scenarios (Table ES-1). The higher value found in the avoided-cost framework is largely driven by significant generation capacity value. In all cases, the water-energy bank provides new operational flexibility to the State Water Project, which reduces operating costs and decreases greenhouse gas emissions.

Table ES-1: Average Total Avoided Cost Values ($ million/year)

Analysis Framework	Low-Curtailment	Mid-Curtailment	High-Curtailment
Avoided Cost Analysis Framework	$12.6	$23.1	$38.0
RESOLVE Framework	$4.6	$7.4	$20.9

Source: HDR, E3

Willow Springs Water Bank proposes to construct 40 megawatts of on-site solar and a 5-megawatt hydroelectric turbine to generate power during groundwater recharge. Onsite renewables will generate enough electricity to make the entire operation energy-negative.

There are a variety of factors that limit shifting State Water Project pumping into low-demand periods. Physical constraints include water availability, canal capacity, storage availability in the Willow Springs Water Bank and the San Luis Reservoir, pump on-and-off rates, and groundwater extraction capacity. A variety of contractual, physical, and operational factors, together with other potentially conflicting policies, could limit flexibility for reoperation of State Water Project facilities. These include State Water Project water-supply contract terms, deliveries of water, carryover storage requirements, and unknown future changes in operation and storage policies. All these limiting factors apply when examining the project's potential benefits.

Technology/Knowledge Transfer

Implementing the water-energy bank concept will require participation of multiple local and state entities including investor-owned utilities and the California Independent System Operator as well as various water resource management agencies and contractors. The primary benefits of the water-energy bank are better usage of renewable generation and reduced greenhouse gas emissions. The project will also require developing appropriate incentives to encourage stakeholder participation and for deployment of this concept. The team reached out to inform involved stakeholders from the water and energy sectors about the potential of the project and garner the institutional interest and support necessary to put the water-energy bank concept into operation.

Results of the project were shared with a diverse audience through various information-sharing avenues including conferences, presentations, and symposiums. These included the Association of California Water Agencies 2018 Fall Conference & Exhibition, the Smart Grid Observer Demand Response & Distributed Energy Resources World Forum 2018, the 2018 Electric Program Investment Charge Symposium, the 2019 VerdeXchange Conference and the American Water Works Association California-Nevada Spring Conference 2019. The water-energy bank concept was also featured in Water Energy Innovations' recently completed study, *Water Sector Over-Generation Mitigation and Flexible Demand Response.*

Two advisory committees provided another forum for obtaining feedback from key parties and technical experts on various aspects of the project. This continuous engagement with the two committees also resulted in additional speaking and presentation opportunities. The input of the committees' members has been incorporated into this report and has helped to better position the concept for the next phase, which will address implementation issues.

Because of institutional barriers, the target market for the water-energy bank concept is naturally long-term. Along with Willow Springs Water Bank, other groundwater banking operations in Southern California can be used to enhance State Water Project load shift potential. The size of this State Water Project peak load shift market is an estimated 208 megawatts (based on the historical analysis of Valley String's pumping plants). Another long-term target market consists of other aqueduct systems around the State that can similarly reduce their respective peak loads using strategically located water storage and replicating the concepts explored in this study. These other aqueducts represent 223 megawatts of advanced demand response potential. The study also looked at the potential of Central Valley agricultural operations for demand response where the estimated size of this target market is 1,113 megawatts. The beachhead market for agricultural demand response consists of large farming operations where advanced demand response can be tested. Once the cost advantage of pumping only during off-peak periods is demonstrated, the technology can be adopted by more farmers and spread rapidly. The long-term target market is California's agricultural sector, as well as in other western states that can replicate the concept and shave off their peak loads. After the project, the recipient plans to continue engaging the key parties through various avenues so that research findings can be effectively used to establish incentives and institutional bridges for eventual implementation.

Benefits to California

Water-supply and water-management benefits identified in this report include:

- Using additional storage in the Southern part of the State Water Project, like Willow Springs Water Bank, creates opportunities and added flexibility for the California Department of Water Resources to reduce energy-related operating costs while maintaining water deliveries.
- Additional water storage in Southern California benefits overall water supply reliability for State Water Project contractors. Full build-out of Willow Springs Water Bank will create opportunities to provide inexpensive storage for Southern California's water customers.
- Savings associated with these benefits highlighted in Table ES-1 .

The project's energy and economic conclusions included:

- If standard operating procedures could accommodate steeper pump ramping rates, the State Water Project could further reduce its energy use during peak demand hours.
- The Water-Energy Bank Project will help California integrate renewable energy into its energy mix and operate the power grid at lower cost.
- The Water-Energy Bank Project is in alignment with state policy (California Senate Bill 100 [De Leon, Chapter 312, Statutes of 2018]) for renewable resources and greenhouse gas emission reduction targets.
- The Water-Energy Bank Project helps address the imbalance in California's seasonal daily electricity supply and demand by reducing peak evening load in the high-demand summer and increasing load during solar over-generation hours in the spring; this reduces the need for conventional flexible generation on the power grid.
- Capacity to generate electricity, deferred need for new transmission lines, and ability of users to reduce electricity demand in response to signals are the most significant potential benefits from the Water-Energy Bank Project. Driven by the high cost of capacity in California's power grid, the water-energy bank shifts load from capacity-constrained peak summer hours to less-constrained spring hours.

- The Water-Energy Bank Project changes State Water Project operations to more fully utilize excess renewable generation and avoid greenhouse gas emissions from inefficient natural-gas-fired peaker plants. This both reduces emissions and allows California to reach California Senate Bill 100's environmental targets at lower cost to the state.
- This increased supply of renewable energy mandated by California Senate Bill 100 will likely increase the frequency of lower-cost periods in the spring. This increases the value that the Water-Energy Bank Project provides to the California Department of Water Resources; water users also benefit from lower energy costs to move and supply water.
- Greater societal benefits of this project include: stabilizing wholesale power prices, reducing greenhouse gas emissions and solar energy curtailments, and reducing the need for new infrastructure to meet the State's statutory energy goals.

While this report presents opportunities for the State Water Project to reduce electricity use during peak consumption hours, this is not a feasibility report. Rather, it characterizes the potential economic benefits in terms of the avoided cost of purchasing wholesale electricity to move State Water Project water, and in terms of reducing the need for the additional generation and transmission that support peak summertime electric loads. This report does not include operations and maintenance or other incidental costs associated with the Water-Energy Bank Project, nor does it include the issue of the water lost from the groundwater bank. Both of these must be addressed before identifying the potential long-term viability of the water-energy bank and would require analysis beyond the scope of this report.

Senate Bill 100 implementation will require renewed cooperation and the breakdown of institutional boundaries to succeed. Using existing infrastructure is fast and inexpensive. Substantial modifications to water infrastructure, however, have not traditionally been considered to be integral to meeting the electricity needs via the power grid. Since the State Water Project uses a relatively large percentage of California's peak-load electricity, novel approaches like the water-energy bank should be seriously considered to shift State Water Project pumping load to low-demand periods.

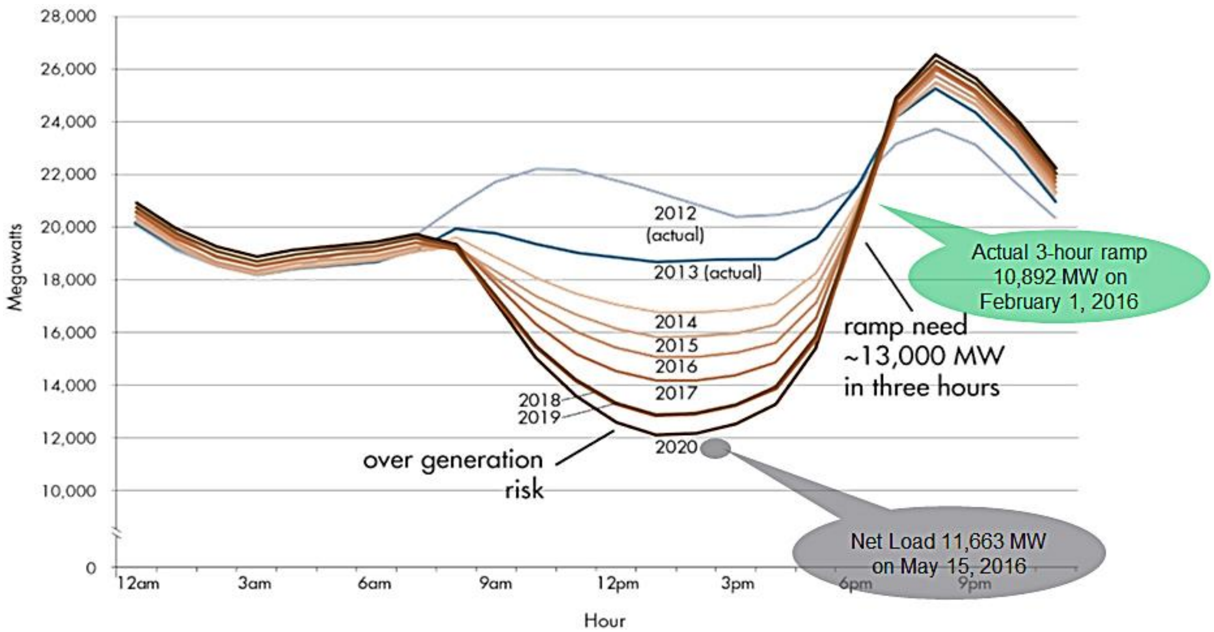
CHAPTER 1: Introduction

The California State Water Project (SWP) is a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants extending from Northern California to Southern California. The California State Water Project is operated by the California Department of Water Resources (DWR) and contractually supplies water to 29 water agencies throughout the State. These agencies together serve approximately 27 million people and roughly 750,000 acres of irrigated farmland. As the water moves in and out of reservoirs and through the California Aqueduct, a series of pumps operate in sync to convey water from the Sacramento and San Joaquin rivers (Delta) to both the San Joaquin Valley and Southern California. The electricity required to operate these pumps makes the SWP one of the largest energy users in the State.

Energy and environmental policy changes and market forces in California are driving development in wholesale electricity markets. Key policies aim to increase renewable energy generation and decrease greenhouse gas (GHG) emissions over the next 5 to 15 years and beyond. Additionally, the declining cost of solar electric generation is creating ongoing growth in the solar energy market sector. While increases in solar energy generation are a critical step in the evolution of California’s electric generation mix, it creates a unique challenge for the utility operators who must balance electricity supply and demand. One way to conceptualize this supply/demand imbalance is to analyze how net load is anticipated to change as more solar and wind generation comes on-line. “Net load” is electricity demand not met by renewable sources like wind and solar. The net load projected for each year through 2020 is shown in a graph described in the industry as the “duck curve,” named for its resemblance to a duck (Figure 1).

The curve on Figure 1 is a snapshot of the net load imbalance of solar energy in California for a 24-hour period on a typical spring day: May 16, 2016. Sunshine and cooler temperatures mean higher solar energy output and lower energy demand as electric customers use less electricity for air conditioning and heating. Over-generation is when the physical constraints of power plants cause the electricity produced to exceed the market’s ability to absorb additional generation. This scenario requires system operators to take otherwise-operating power plants—typically solar—off-line. The belly of the duck curve is formed in the middle of the day as the net load approaches potential over-generation and the need to curtail solar in order to align supply with demand. During the evening, as the sun sets and solar energy is no longer available as residential customers return home and increase their electricity use, the demand exceeds supply. The situation is similar in the summer when there is insufficient renewable generation in the evening to match the demand from residential and commercial use. During the spring and summer, therefore, other sources of generation must be brought on-line quickly in the evening to meet demand and compensate for the loss of solar.

Figure 1: Net Load "Duck Curve" for a Typical Spring Day



Net Load (difference between forecasted load and anticipated production) "Duck Curve" on May 16, 2016 (represents a typical spring day).

Source: California ISO, 2016

The wholesale energy market sets prices for electricity based on both hourly and seasonal supply and demand. During peak summer hours, high demand requires that more expensive power plants come on-line to meet those higher loads. As the sun sets in the summer evenings, solar energy generation decreases while high temperatures still drive high demand. This creates a high net load, leaving only inefficient natural gas-fired power plants to meet new load, driving wholesale energy prices even higher. Conversely, in the spring midday, excess solar creates an excess in supply that is not met by demand on the power grid, creating a low net load, and causing wholesale energy prices to fall. The difference between spring and summer wholesale energy prices creates a market incentive to seasonally shift power use from summer to spring and fall.

Willow Springs Water Bank (WSWB) is a groundwater banking facility located in Southern California's Antelope Valley. Two nearby regional aqueducts supply surface water for recharge. WSWB's Water-Energy Bank Project evaluates the opportunity to reduce the net load imbalance shown in the duck curve by using groundwater storage at WSWB to shift SWP pumping operations out of high-energy-demand periods to lower-energy demand, high-solar-generation periods while maintaining SWP water deliveries to its contractors. This study was a collaborative effort by WSWB; HDR, Inc. (HDR); Energy+Environmental Economics, Inc. (E3); GEI Consultants, Inc. (GEI); and

Water and Energy Consulting, Inc. (WEC) to develop tools, strategies, and analytical methods to evaluate the benefits of modifying SWP pumping operations to reduce electricity use during high-demand, high-cost periods and shift those operations to lower-demand, lower-cost periods. Figure 2 shows two of the SWP pumping plants evaluated.

Figure 2: Chrisman Pumping Plant (Left) and Edmonston Pumping Plant (Right)

Five of the SWP pumping plants (Dos Amigos, Buena Vista, Teerink, Chrisman and Edmonston) use up to 1,480 megawatts (MW) of power. This is up to 3 to 4 percent of the total typical summer California power use (35,000 to 40,000 MW). This project evaluates whether it is possible to change the timing of power use to lower-cost periods utilizing aquifer storage.

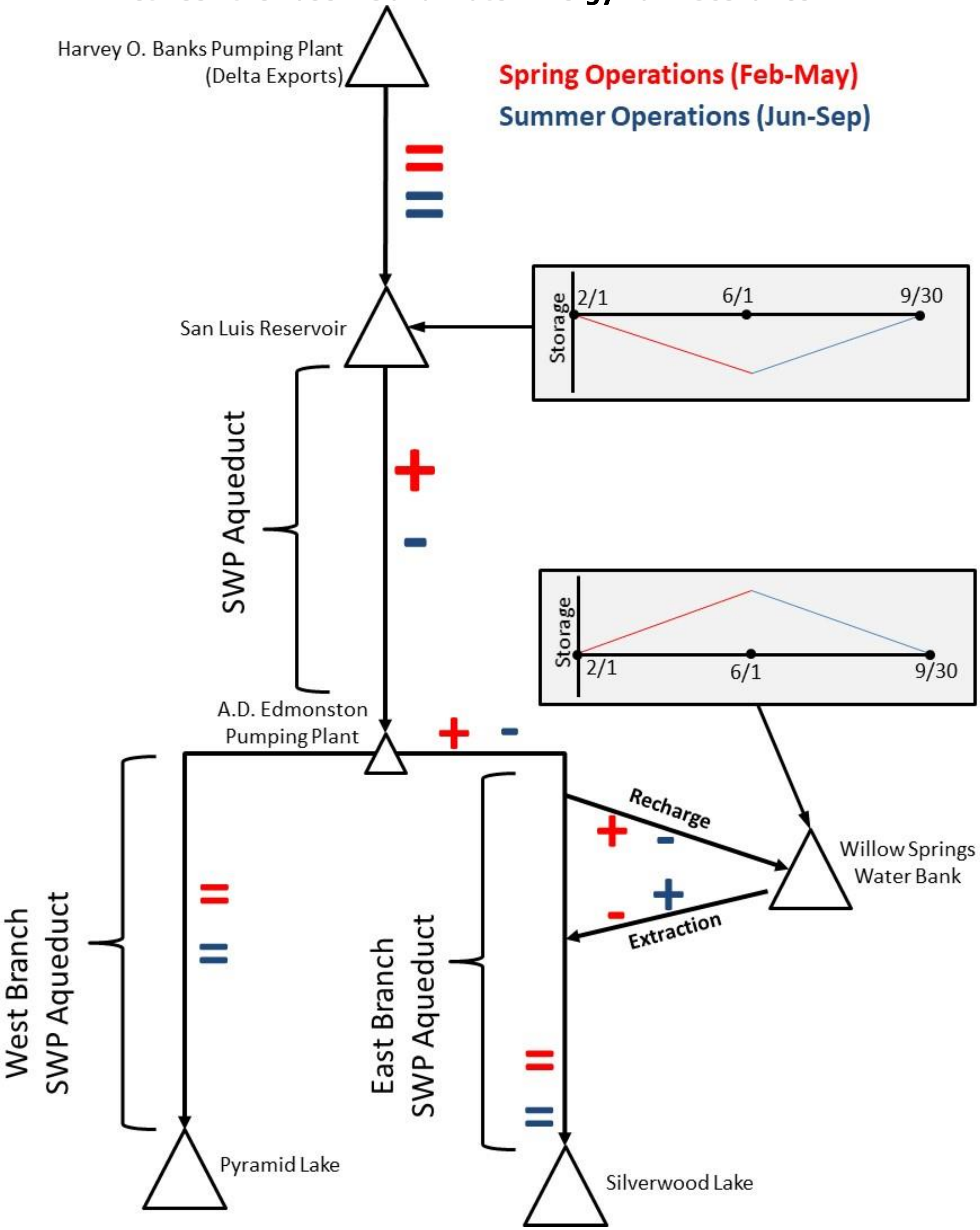
Source: DWR

1.1 Project Purpose and Goal

The Willow Springs Water Bank received a grant under the California Energy Commission's EPIC Grant No. 16-029 to evaluate the potential energy and cost benefits of shifting the timing of SWP's pumping operations. The project began with an evaluation of historical Edmonston pumping operations to show how daily operations might have been rescheduled if the only operational goal was to minimize pumping during peak energy consumption hours without other limiting factors. The project was then expanded to include an examination of the potential to shift SWP pumping at the Dos Amigos, Buena Vista, Teerink, Chrisman, and Edmonston pumping plants from summer high-energy-demand periods to spring's lower-energy-demand periods, using supplemental water storage south of the Edmonston Pumping Plant.

Operations of the project are illustrated in Figure 3.

Figure 3: Schematic Showing Simulated Seasonal Changes in SWP Operations Between the Baseline and Water-Energy Bank Scenarios



Source: HDR

In Figure 3, operational changes in the spring (between February and May) are shown in red; operational changes in the summer (between June and September) are shown in blue. In spring, water is moved from San Luis Reservoir through SWP aqueducts and five pumping plants and delivered to the WSWB and stored in aquifers. This water is then extracted from the WSWB aquifer using a well and pipeline system during the summer and delivered from WSWB back to the aqueduct where it then flows to Southern California users. This summer pumping is accomplished using the lower-cost daytime or early-morning electricity available from renewable generation from the transmission grid and from WSWB's on-site renewable resource generation project. Southern California's SWP water deliveries downstream from WSWB would be unchanged (timing, reliability, quantity) in all cases, in both spring and summer. The San Luis Reservoir and WSWB's water storage would be returned to the unshifted end-of-September volume. Other SWP operations, including Delta exports and West Branch SWP Aqueduct flows would remain unchanged. Willow Springs Water Bank is able to provide aquifer storage to enable a shift in SWP pumping from summer to spring while maintaining SWP deliveries to water users.

This study evaluates the technical feasibility and projected benefits of shifting SWP pumping to lower-cost periods as a way to meet California's statutory requirements for reliable energy resources, renewable energy integration, and greenhouse gas (GHG) emission reductions.

1.2 Project Overview

A preliminary evaluation for the project examined historical operations at Edmonston Pumping Plant to identify any remaining potential for shifting SWP pumping out of peak electric demand hours during the summer months. Based on that Edmonston Pumping Plant operating data, provided by DWR, a 10-year period from 2008 to 2017 was evaluated to determine total amounts of water pumped and energy used throughout the summer months. Historical pumping patterns and practices for ramping pumping capacity up and down were identified to establish optimal pumping pattern scenarios that would minimize pumping during the daily peak energy consumption hours without varying the total daily volume of water pumped. This approach was expanded further to consider the integration of supplemental storage at Willow Springs Water Bank to seasonally shift SWP pumping operations to reduce pumping during those high-load peak hours. This concept is the foundation of the Water-Energy Bank Study.

The baseline for the analysis integrating aquifer water storage is an existing CalSim II model scenario, developed by WSWB for its Water Storage Investment Program (WSIP) grant application to store surplus SWP water as groundwater during wet periods and allowing its subsequent use during dry periods. Model output is representative of a 2030 level of development and climate change conditions. The baseline scenario was post-processed for this analysis to shift SWP pumping out of summer months and into spring months to take advantage of electricity price market incentives. The period of record analyzed is water years 1922 through 2003 (a water year starts October 1 and ends on September 30).

The approach for analyzing the integrated water and energy bank (Water-Energy Bank Scenario) follows:

1) Using the baseline scenario as a starting point, identify opportunities to modify SWP pumping plant operations in spring months to pre-deliver water to WSWB during low-demand, low-cost energy periods.
2) Using the same methods to identify opportunities to modify SWP pumping plant operations in summer months to reduce power use and cost during high-demand, high-cost periods, targeting six hours of pump-free time per day.
3) Identify whether spring or summer limits the shift of water within each year to determine the possible annual net shift. Re-operate SWP and WSWB operations (flow and storage) to determine the net annual shift by pre-delivering water in spring and curtailing water deliveries in summer.
4) Develop monthly wholesale energy-price forecasts ($/megawatt-hour [MWh]) from the Renewable Energy Solutions (RESOLVE) model for a range of projected renewable generation curtailment scenarios.
5) Calculate monthly net energy use and the cost to convey water through the SWP and to extract groundwater from WSWB during spring and summer months under the Water-Energy Bank Scenario and a baseline scenario using forecasted wholesale energy prices.
6) Compute the difference in electricity cost from shifting the valley-string pumping plant pumping from high-demand summer to low-demand spring periods. Evaluate results over the long-term period of record and by hydrologic water-year type.
7) Determine lifetime economic value to the power grid from avoided costs and other California Public Utilities Commission (CPUC) avoided-cost benefits such as generation capacity and transmission and distribution deferrals.
8) Use operating characteristics and technical constraints determined from the avoided costs analysis to model the water-energy bank as a flexible load resource in the RESOLVE framework. This analysis determines the benefit of the water-energy bank from a resource procurement framework.

CHAPTER 2: Background Information

This chapter provides background information on current California renewable energy policy, California's State Water Project (SWP) and the Willow Springs Water Bank (WSWB).

2.1 California Renewable Energy Policy Drivers

The growth of renewable energy is driving notable change in the California electric power supply system. The change is a result of environmental and energy policy initiatives as well as market forces. Key environmental and energy policy initiatives include:

- Fifty percent of retail electricity from renewable power (mainly solar and wind) by 2026, 60 percent by 2030 and 100 percent from carbon-free power by 2045 (California Senate bills (SB) 350 and 100)
- Greenhouse gas (GHG) emissions reduction goals to 80 percent less than 1990 levels by 2050 (California Air Resources Board, 2017)
- Regulations in the next four to nine years requiring power plants using coastal water for cooling to either repower, retrofit or retire (State Water Resources Control Board, 2015)
- Increased use of distributed generation technologies that generate and distribute electricity at or near where it will be used
- An executive order for five million zero-emission vehicles by 2030 (Executive Order (EO) B-48-18)
- Decreasing construction costs of solar power generation facilities (Figure 4)

Figure 4: Solar Star Facility in the Antelope Valley, California.

California energy policy is driving the increase of renewable greenhouse gas-free solar energy projects.

Source: SunPower

Renewable electricity generation from wind and solar is different from conventional generation, as it can generate electricity only when wind and solar resources are available. The output of wind and solar farms is subject to both variability and uncertainty, meaning that the output fluctuates over short time periods in a manner that is unpredictable. This creates challenges for electric-system operators. Electricity systems with a lot of variable generation, such as solar or wind power, require either greater operational flexibility or operating reserves to respond to changes in demand and fluctuations in the amount of wind and solar resources on various timescales. Electricity delivery systems must have some degree of flexibility to serve changing demands. However, as more variable generation is added to a system, this flexibility may become exhausted, creating challenges for system operators when maintaining system reliability.

The California Public Utilities Commission is responsible for ensuring the State's ability to provide reliable energy supply. To meet this objective, the CPUC conducted a planning proceeding[1] to consider policies and programs related to long-term and integrated resource planning. The California Public Utilities Commission's Integrated Resource Planning (IRP) proceeding involved a decision to adopt a planning process designed to ensure that the electric sector is on track to help the State achieve its 2030 GHG emissions reduction targets. The Integrated Resource Planning Proceeding evaluated need with a 10-year forecast of overall electric system demands, local

1 CPUC proceedings are a formal judicial process used to evaluate a variety of requests related to industries that the CPUC regulates. A proceeding can be a request, complaint, or application by a person, group, or company, or it can be a CPUC initiated investigation or rulemaking, etc. The purpose of the proceedings is to establish an evidentiary record on which CPUC decisions will be based (California Public Utilities Commission, 2016).

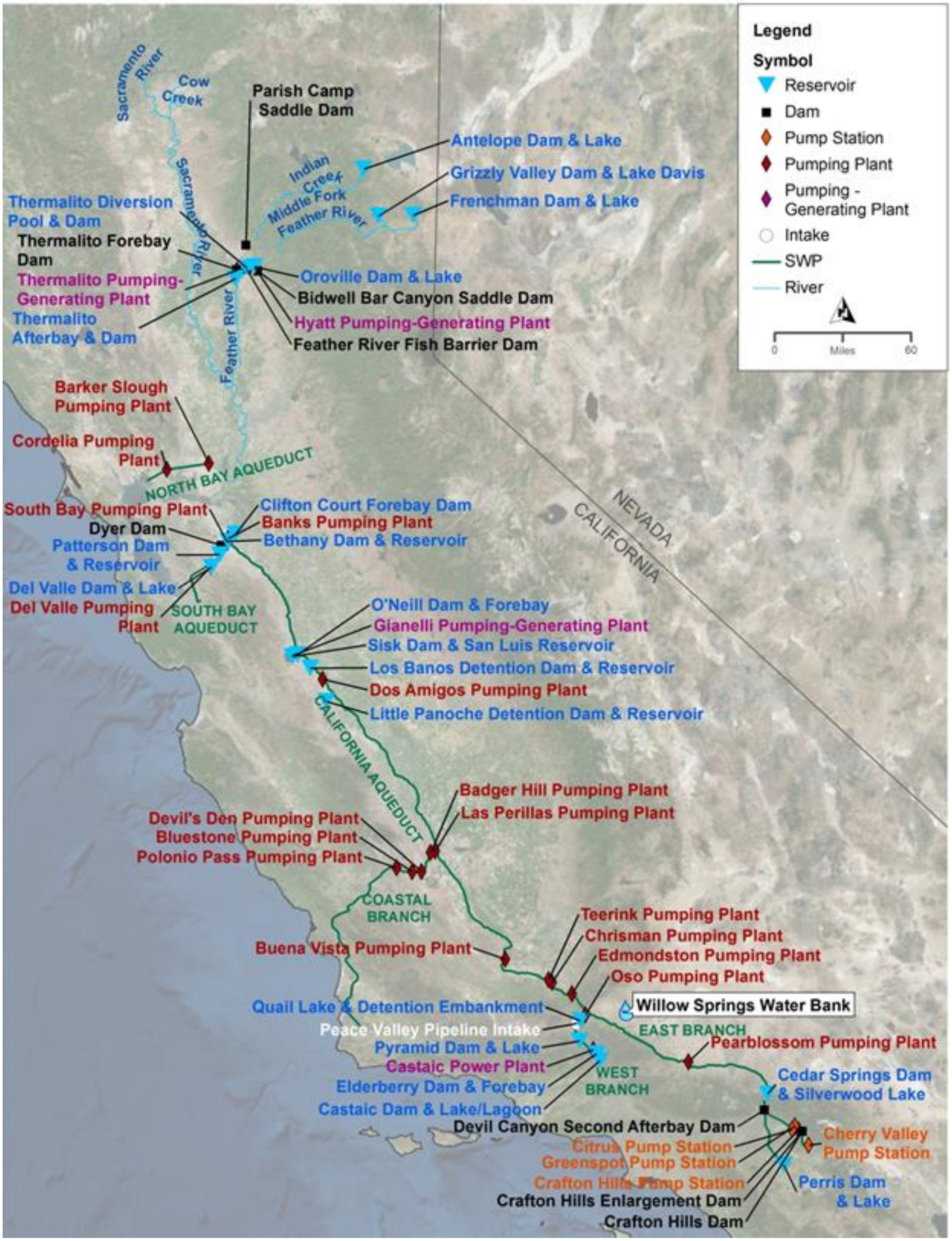
requirements specific to areas with transmission limitations, and flexibility needs to integrate additional renewable resources. The Integrated Resource Planning proceeding considered scenarios with different combinations of available energy resources, including renewables (e.g., wind, solar, geothermal), conventional resources (natural gas), and renewable integration methods such as flexible loads or energy storage; these combinations of available resources are referred to as resource portfolios. The Integrated Resource Planning proceeding included analysis of several unique resource portfolio scenarios.

2.2 State Water Project

The Department of Water Resources operates the California SWP. The State Water Project is a water delivery system that includes reservoirs, aqueducts, canals, pipelines, power plants, and pumping stations between the Feather River watershed, including Oroville Reservoir, located in Northern California, and the SWP's terminal reservoirs in Southern California (Figure 5 and Figure 6). The system is designed, constructed and operated to convey water from sources in the north through the California Aqueduct to areas within the West and East branches of the aqueduct in the south. The State Water Project provides water supply to 29 water agencies that distribute water to farms, homes, and industry, serving approximately 27 million people. The project also provides flood control, power generation, and recreational benefits while operating to protect fish and wildlife.

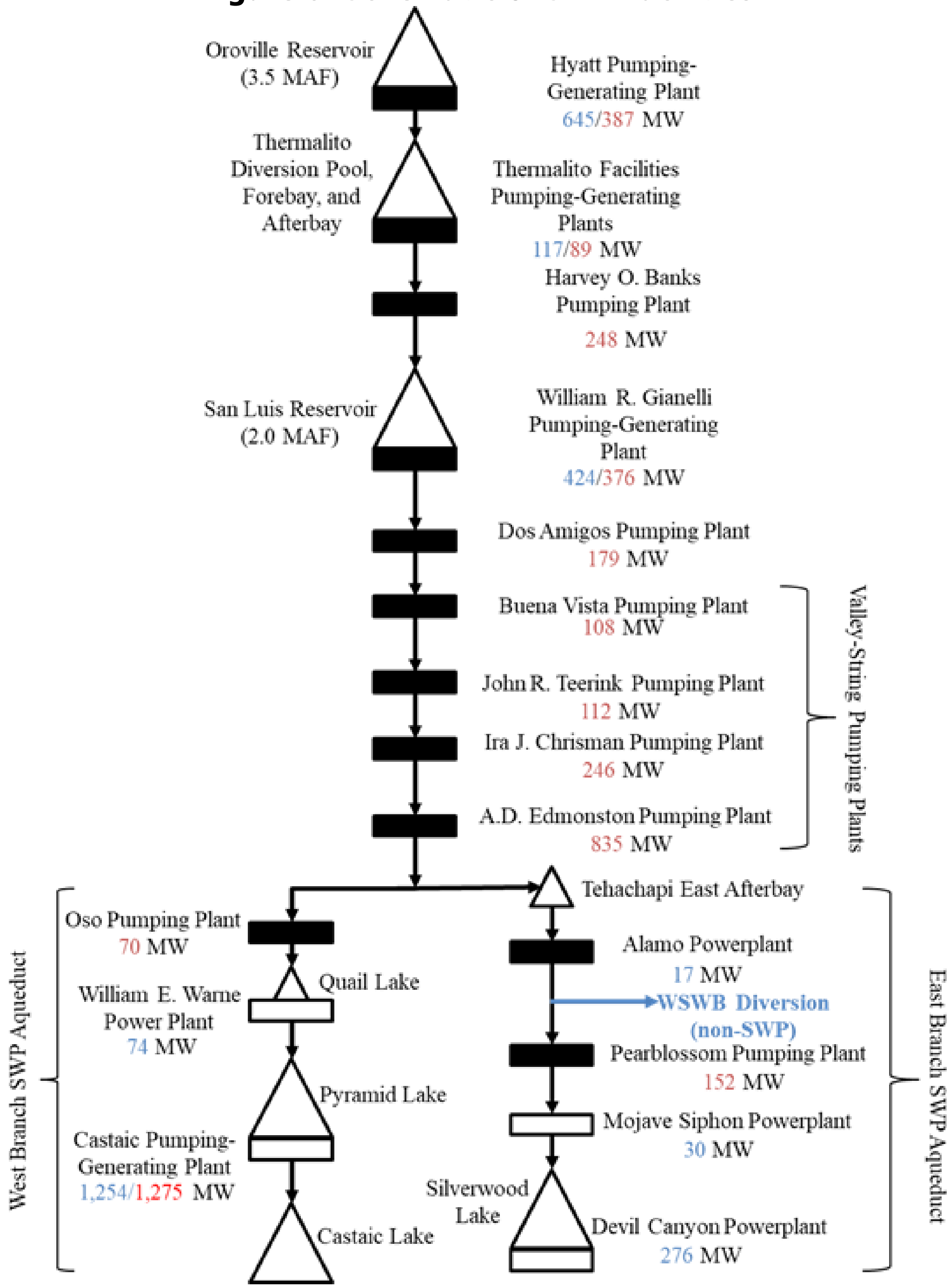
Oroville Reservoir, located in Northern California, has a storage capacity of 3.5 million acre-feet (MAF), providing water to the SWP, flood control for the Feather and Sacramento rivers, and environmental water supplies along the Feather River, Sacramento River, and Delta. Water stored in Oroville Reservoir is distributed south through the Delta at the Harvey O. Banks (Banks) Pumping Plant. Water pumped through Banks Pumping Plant in the fall, winter, and spring is stored in San Luis Reservoir, a facility jointly owned by DWR and the United States Bureau of Reclamation (USBR). San Luis Reservoir is located in Central California and has a storage capacity of 2 MAF, shown in Figure 7. San Luis Reservoir releases are made to the SWP and the Central Valley Project (CVP) for deliveries to the San Francisco Bay Area, the Central Coast, the San Joaquin Valley, and Southern California according to contracts and water supply demands. Approximately half of San Luis Reservoir capacity is available for the SWP to store water and the remaining capacity is used by the CVP or is inactive storage.

Figure 5: SWP Facilities Map



Source: HDR

Figure 6: Schematic of SWP Facilities



Schematic of SWP Facilities with maximum pumping[2] and generating capacities.[3]

Source: HDR

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2 Department of Water Resources, Bulletin 132-2016, Table 1-3, Page 8.

3 Department of Water Resources, Bulletin 132-2016, Table 1-4, Page 9.

Figure 7: Aerial View of San Luis Reservoir

Source: DWR, 1999

State Water Project water releases from San Luis Reservoir are conveyed through the California Aqueduct, shown in Figure 8, by a series of five pumping plants.

Figure 8: Aerial View of the East Branch of the California Aqueduct

Source: DWR

These five plants, Dos Amigos, Buena Vista, Teerink, Chrisman and Edmonston pumping plants use up to 1,480 megawatts (MW) of power to convey water up and over the Tehachapi Mountains to the West and East Branches of the aqueduct in Southern California. The power to operate the pumps is three to four percent of the total typical summer California power demand (35,000 to 40,000 MW). Buena Vista, Teerink, Chrisman, and Edmonston pumping plants are also known as the "Valley String" pumping plants.

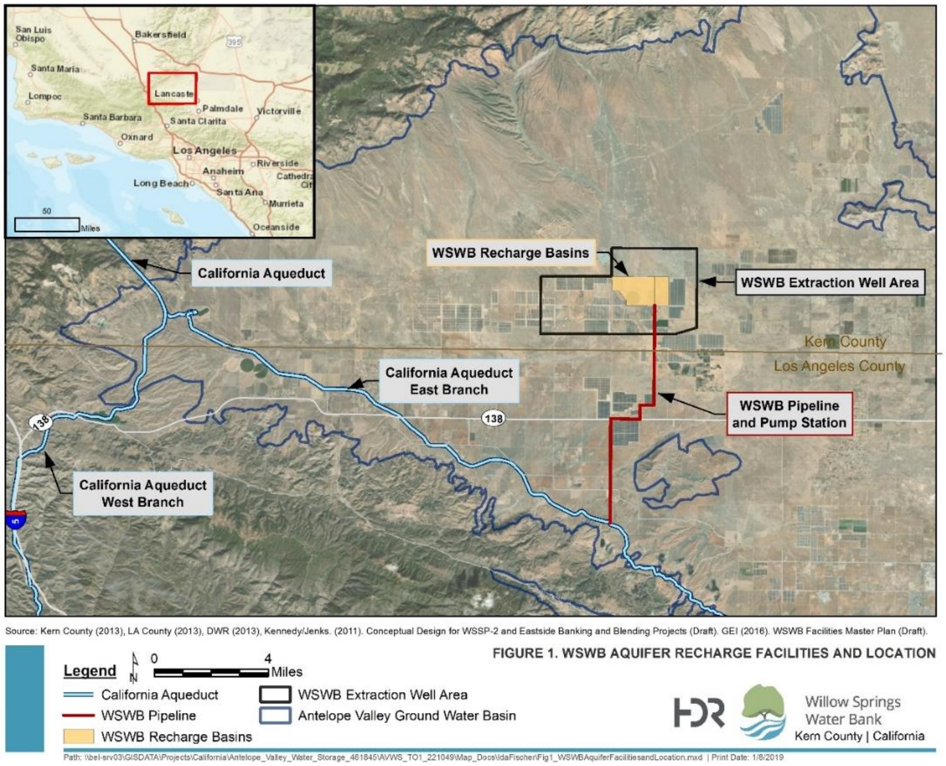
Department of Water Resources operates the SWP with the goal of delivering water as available and in accordance with SWP water supply contracts. Water availability is based on hydrologic conditions and storage operations within the SWP. Department of Water Resources makes water-movement-timing decisions throughout the SWP seasonally and hourly to take advantage of favorable hydrological conditions and to minimize energy-related costs to meet multiple operational needs and conditions. While the main goal is to deliver water, conservation and scheduling of electricity play large roles in managing the project. Water availability, water demand, available storage, facility constraints, and energy pricing influence overall SWP operations and daily pumping plant patterns.

Daily SWP pumping plant patterns are constrained by the maximum number of pumps that can be turned on or off in an hour, also known as the maximum ramping rate. The maximum ramping rate is influenced by equipment and personnel limitations, power grid conditions, hydraulic limitations of the aqueduct conveyance facilities, or other factors. Department of Water Resources coordinates pumping of the five pumping plants as part of typical SWP operations, making adjustments as appropriate to minimize energy use during peak energy consumption hours. An analysis of historical DWR pumping data (2008 through 2017) for Edmonston Pumping Plant shows that ramping of pumps on or off is typically one-to-three pumps per hour, with a maximum of five pumps per hour. Higher pump ramping rates in response to energy demand (pumps off during the high demand periods) would enable further decreases in energy use during peak-energy-consumption hours.

2.3 Willow Springs Water Bank

Willow Springs Water Bank is a groundwater banking project located in Antelope Valley near Rosamond, California (Figure 9). Willow Springs Water Bank is also near two regional aqueducts that supply surface water for recharge, including the California Aqueduct East Branch (delivering SWP water to Southern California) and the Los Angeles Aqueduct No. 2 (conveying water from Owens Valley to Los Angeles). Willow Springs Water Bank is located on approximately 1,838 acres of agricultural land and is designed to infiltrate surface water through rapid infiltration basins. The project is partially built with expansion facilities proposed to be constructed in the near future, increasing the current storage capacity from 500,000 acre-feet (AF) to 1,000,000 AF (Buehler et al., 2017).

Figure 9: WSWB Aquifer Recharge Facilities and Location

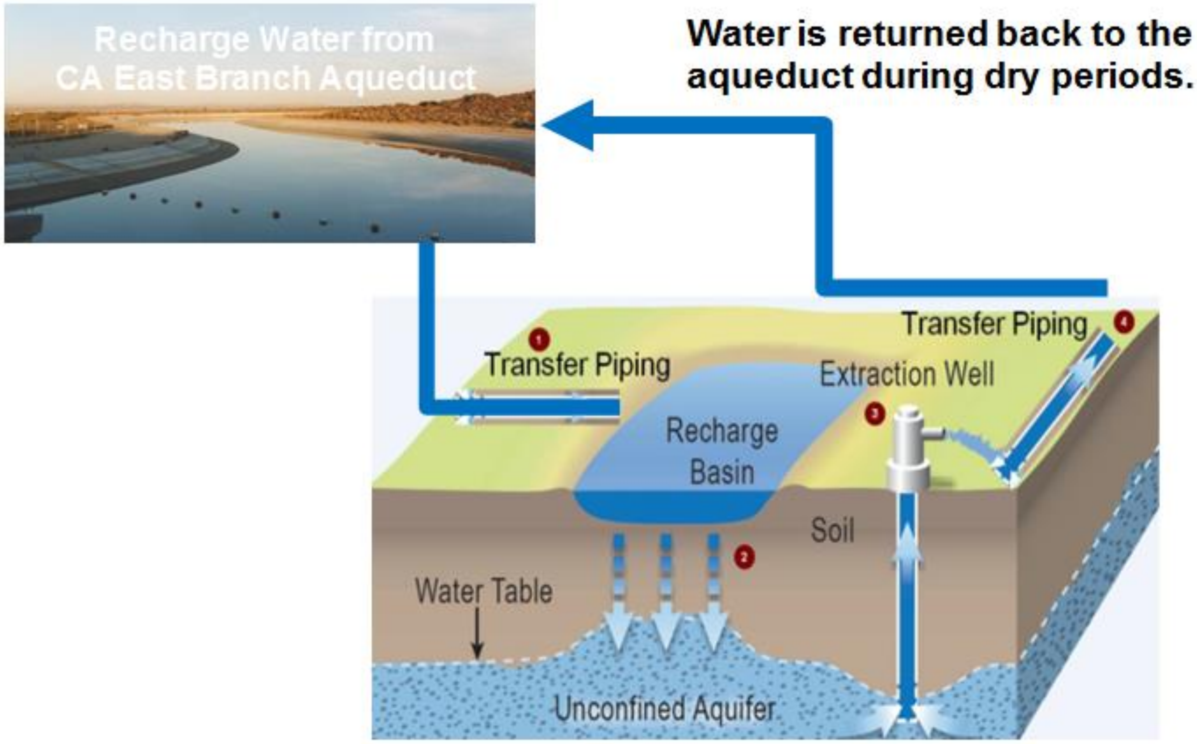


Source: HDR

With the one million AF approved storage capacity, WSWB will have a recharge capacity of 280 TAF per year (387 cubic feet per second [cfs] on a continuous basis) using approximately 1,000 acres of recharge basins. Approximately 60 to 90 extraction wells will allow extractions of up to 225 TAF per year (311 cfs on a continuous basis). Extracted water will be conveyed for deliveries using 250 cfs of pump back capacity to pump water to the California Aqueduct East Branch and 60 cfs to Antelope Valley-East Kern Water Agency's (AVEK) West Feeder Canal (GEI Consultants, Inc., 2016).

An 84-inch bi-direction pipeline will convey flow between the East Branch California Aqueduct and WSWB (Figure 10). During extraction operations, a pump station, located near the base of the pipeline will pump extracted water from the lower elevation water bank facilities to the higher elevation California Aqueduct. The energy required to extract and deliver water to the aqueduct is 1,100 MWh/TAF. During recharge operations, water from the East Branch California Aqueduct will generate up to 5.2 MW through a turbine rated for 250 cfs. Flow greater than 250 cfs will bypass the turbine.

Figure 10: Schematic of WSWB Aquifer Recharge, Storage and Recovery Operations



Source: WSWB

The location and size of WSWB provides an opportunity to capture flows during wet years, enhance the efficiency and flexibility of SWP operations, improve water supply reliability, contribute towards the recovery of the Delta, minimize evaporative losses, and maintain the preservation of agricultural land use. Willow Springs Water Bank aquifer storage could also be used to supplement emergency water supply currently provided by surface water reservoirs.

CHAPTER 3: Water and Power Operations Analysis

This chapter summarizes the water and power operations analysis methods and results. More complete information on methods and a more-detailed summary of results are presented in the Project Technical Report (WSWB, 2018).

An analysis of historical Edmonston pumping operations confirms that the California Department of Water Resources (DWR) manages State Water Project operations to reduce energy use during peak energy consumption hours. Over a 10-year period (2008 through 2017), the average power requirement to convey water through the Valley String pumping plants in summer was 596 (MW), out of a total capacity of 1,301 MW. During peak energy consumption hours, this value was reduced to 321 MW. If a ramping rate of four pump units per hour was implemented consistently, the average power requirement during peak energy consumption hours could have been further reduced by approximately 208 MW to 113 MW. Supplemental storage south of Edmonston Pumping Plant can further increase potential for shifting peak electrical load in summer months.

In spring, energy demand is relatively low and solar and wind generation is high, resulting in excess energy supply. As a result, wholesale energy prices are less costly in spring than in high-demand, high-cost summer months. A water/power operations analysis was performed for this study to assess the capacity to shift SWP water deliveries from high energy-demand months to lower energy-demand spring months to take advantage of low-cost wholesale energy prices. Seasonal shifts in SWP pumping and the associated decreased energy costs were evaluated without changing the amount or timing, quantity or reliability of Sacramento Delta water and the water delivered to Southern California water users (DWR, 2018).

Seasonal shifts in SWP pumping were accommodated by utilizing the WSWB to maintain the timing and quantities of water deliveries to SWP contractors in Southern California downstream of WSWB. The operations analysis evaluated the need, capacity, and limitations to shift SWP pumping out of summer months to achieve 6-hours of pump free time per day. The summer shifting period analyzed was June through September. Spring pre-delivery months were February through May.

3.1 SWP-WSWB Water-Energy Bank Evaluation Methods

For this study, the baseline analysis is an existing CalSim II model scenario that WSWB developed for the Water Storage Investment Program grant application to store surplus SWP water as groundwater during wet periods, allowing subsequent use during dry periods. The baseline scenario is representative of projected SWP and CVP operations in year 2030. The baseline scenario was post-processed and analyzed to determine the amount of SWP pumping that could be shifted from the high-demand summer months to the low-demand spring months for the Water-Energy Bank evaluation. The two scenarios used to estimate the amount of SWP pumping that could be shifted were as follows:

- Baseline Scenario – Representative of projected 2030 SWP and CVP operations and based on the CalSim II model output generated by WSWB in support of the Water Storage Investment Program grant application process. The baseline scenario serves as a comparison for the Water-Energy Bank Scenario.
- Water-Energy Bank Scenario – Representative of projected 2030 SWP and CVP operations, and pumping plant load shifting operations from summer into spring.

Water movement operations under the Water-Energy Bank Scenario were based on output generated by a spreadsheet tool that post-processed the baseline scenario output. The goal of Water-Energy Bank operations is to reduce SWP pumping during the six peak energy-use evening hours in summer months when renewable energy is unavailable and power cost is high, while maintaining a consistent water supply to SWP contractors and without modification to Sacramento-San Joaquin River Delta exports. The spreadsheet tool accomplishes this by pre-delivering water from San Luis Reservoir to WSWB in the spring for storage in the groundwater bank. In subsequent summer months, the water is extracted from groundwater storage (using wells) at WSWB and delivered back to the aqueduct during the summer daytime or early-morning period when there is relatively low-cost renewable energy available. The tool maintains mass balance between spring and summer months within each year, while considering physical limitations of the SWP and WSWB. Examples of physical limitations include SWP pump ramping rates (the rate at which pumps can be turned on or off), canal capacities, storage capacities, and aquifer recharge rates. For the analysis, reoperation of SWP facilities was limited to the project area from San Luis Reservoir to WSWB, as illustrated in Figure 3.

Willow Springs Water Bank can operate under three different operating modes:

- Recharge – surface water is placed into groundwater storage through rapid infiltration basins.
- Extraction – groundwater is pumped from below ground into surface reservoirs and then pumped into the East Branch SWP Aqueduct.
- Neutral – water is neither recharged to nor extracted from the groundwater aquifer.

Guidelines for WSWB operations for the Water-Energy Bank are as follows:

- In spring months when WSWB is in neutral or recharge mode, water is delivered into WSWB from San Luis Reservoir within the limits of the recharge capacity of WSWB.

- Willow Springs Water Bank cannot operate in extraction and recharge mode simultaneously. Therefore, in spring months when WSWB is operating in extraction mode in the baseline scenario water cannot be pre-delivered from San Luis Reservoir into WSWB.
- In summer months when WSWB is in neutral mode in the baseline scenario, the ability to offset SWP pumping is limited by the extraction well pumping and pipeline capacity of WSWB.
- In summer months when WSWB is operating in extraction mode in the baseline scenario, the ability to pump additional extraction water for the Water-Energy Bank Project to offset SWP pumping is limited by the remaining extraction capacity of WSWB.

In summer months when WSWB extraction capacity is the limiting factor, the SWP pumping plants upstream of WSWB can only eliminate pumping by an amount equal to the volume extracted from WSWB. The spreadsheet tool simulated a targeted elimination of SWP pumping for six evening hours when power cost is high, or an elimination of SWP pumping up to 25 percent of capacity (6 hours out of 24 hours in a day) in summer months. It is a target because a 25 percent pump-free time is not always possible due to physical constraints within the water conveyance network (available storage capacity in San Luis Reservoir or WSWB, and pumping capacity at pumping plants or WSWB).

The groundwater extraction capacity from WSWB in summer months from pumping over 19 summer hours to avoid peak power cost hours at maximum extraction capacity (311 cfs) is approximately 488 AF per day. The groundwater recharge capacity to WSWB in spring months over 24 hours at maximum recharge capacity (387 cfs) is approximately 768 AF per day. WSWB extraction volumes in summer months often limit the amount of shift possible over a year, balancing spring flow increases and summer flow decreases.

The period of record for the Water-Energy Bank and baseline scenarios is water years 1922 through 2003 (82 years), which is the period of record built into CalSim II; a water year is defined as a 12-month period from October 1 through September 30 of the following year. Baseline scenario model output, along with the physical WSWB limitations just described, were used as the input data to the spreadsheet tool. Spring and summer shifts were applied to Baseline Scenario pumping plant volumes for each year in the period of record.

3.1.1 Single Year Example of Proposed Pumping Shift

An example year, 1940, is used to help explain how SWP pumping is shifted from high-energy-demand periods using WSWB aquifer storage to facilitate the shift. The example illustrates the difference between the baseline and Water-Energy Bank scenarios. State Water Project operations north of San Luis Reservoir and south of WSWB are identical between the two scenarios, as illustrated in Figure 3. Year 1940 is classified as an above normal hydrologic year in the CalSim II model which means that the year is representative of somewhat wetter than average conditions.

Table 1 summarizes monthly water and power operations for the baseline and Water-Energy Bank scenarios. Under the baseline scenario, WSWB is recharged in July and August. For the remaining months, WSWB is idle (neutral) and is neither recharging nor extracting. Under the Water-Energy Bank scenario operations, water is pre-delivered from San Luis Reservoir storage to WSWB in four spring months from February through May, including pre-delivery of July and August SWP spill capture recharge water simulated by the baseline scenario. A total of 87.5 TAF of water pumping corresponding to an energy requirement of 253.4 gigawatt-hours (GWh) was shifted out of summer and into spring months.

Table 1: Summary of Baseline and Water-Energy Bank Operations for 1940

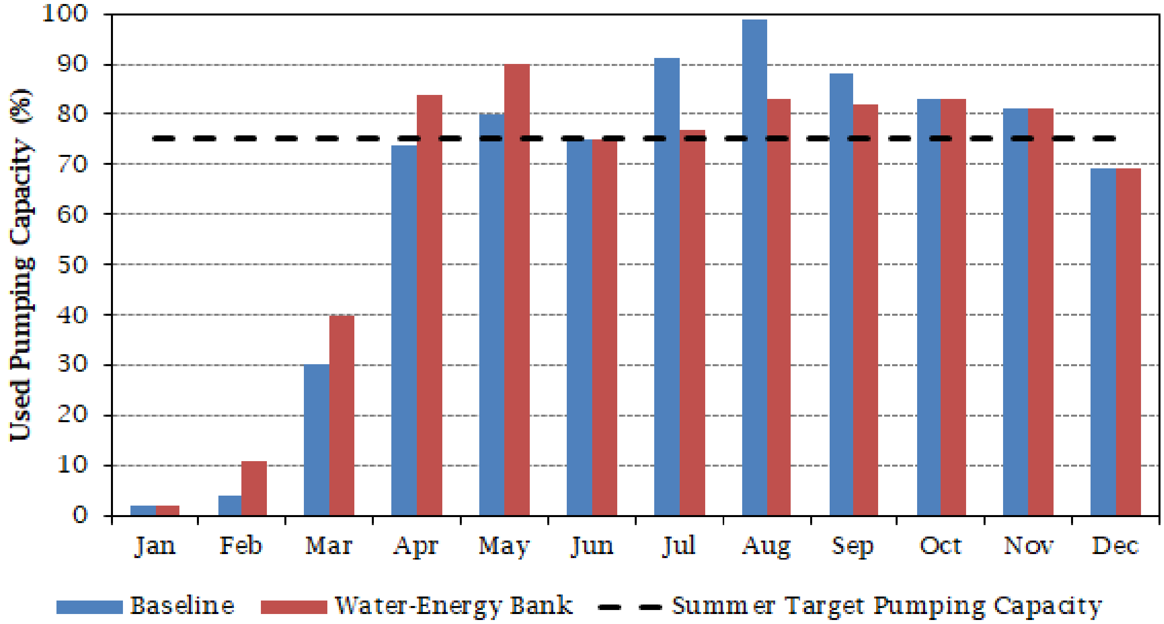
Month	WSWB Monthly Operations Baseline	WSWB Monthly Operations Water-Energy Bank	SWP Pumping Volume Shift (TAF)	WSWB and SWP Net Energy Shift (GWh)
January	NEUTRAL	NEUTRAL	0.0	0.0
February	NEUTRAL	RECHARGE	16.9	56.3
March	NEUTRAL	RECHARGE	23.8	77.9
April	NEUTRAL	RECHARGE	23.0	81.7
May	NEUTRAL	RECHARGE	23.8	84.5
June	NEUTRAL	EXTRACTION	-0.5	-1.3
July	RECHARGE	EXTRACTION	-33.4	-101.8
August	RECHARGE	EXTRACTION	-38.9	-116.8
September	NEUTRAL	EXTRACTION	-14.7	-33.5
October	NEUTRAL	NEUTRAL	0.0	0.0
November	NEUTRAL	NEUTRAL	0.0	0.0
December	NEUTRAL	NEUTRAL	0.0	0.0

Extraction: WSWB is extracting water out of storage. Recharge: WSWB is recharging water into storage. Neutral: WSWB is idle and is not recharging or extracting water. Spring pre-delivery months are green shading; summer shift months are blue.

Source: HDR

Figure 11 presents the monthly SWP pumping capacity for example year 1940, used for both scenarios. The targeted pumping capacity of the SWP pumping plants during summer months is 75 percent of the total pumping capacity (six hours of pump free time during high-energy demand evening periods, on average). June was the only summer month when the 6-hour average pump free target (75 percent of pumping plants maximum pumping capacity) was fully achieved. In July through September, SWP pumping was reduced, but the 75 percent target was not met because the capability to shift SWP pumping was limited by the capacity of WSWB to extract groundwater to maintain deliveries to Southern California. With extraction capacity as the limiting factor, the use of multiple groundwater banks or addition of extraction wells could help meet the targeted pumping capacity. Additional groundwater extraction capacity of 388 cfs would be required to meet the targeted summer SWP pumping capacity in all summer months of this example year.

Figure 11: Monthly Used Pumping Capacity at SWP Pumping Plants for the Baseline and Water-Energy Bank Scenarios for Example Year 1940

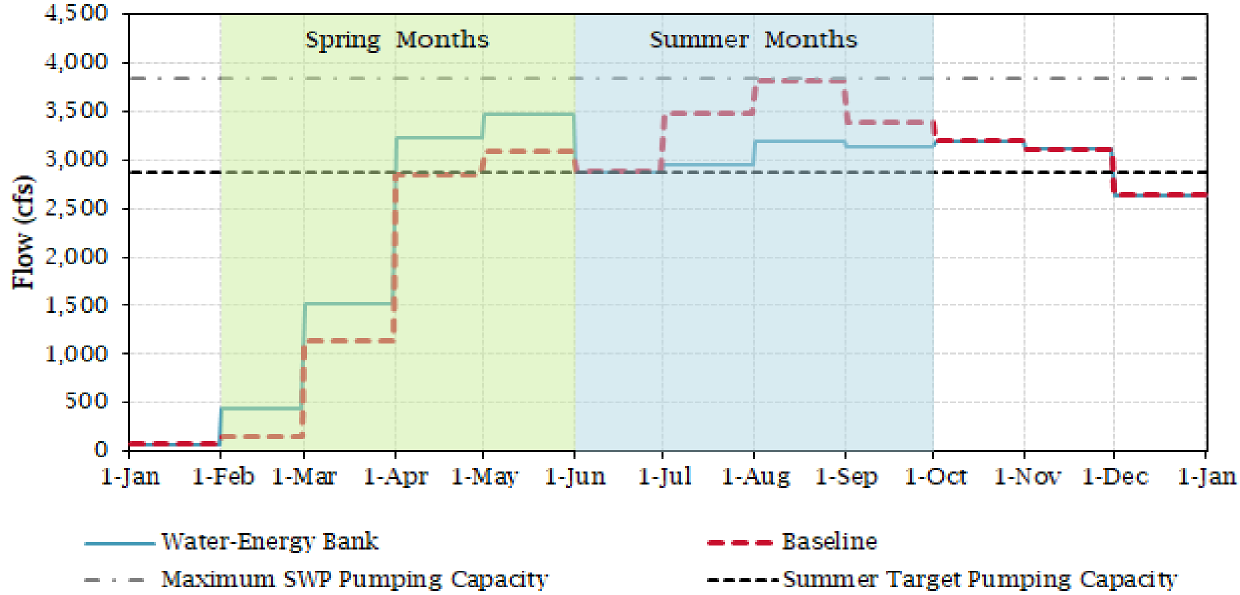


Source: HDR

Figure 12 shows SWP pumping for the baseline and Water-Energy Bank scenarios for example year 1940. (Six hours of pump free time, on average, results in a summer target pumping capacity of 2,880 cfs.) In spring months, there is an increase in pumping under the Water-Energy Bank scenario compared to the baseline scenario. There also is an equivalent decrease in pumping in summer months.

Figure 13 shows the net energy used to convey water between San Luis Reservoir and WSWB for the baseline and Water-Energy Bank scenarios for the example year 1940. Net energy includes power requirements of the SWP to convey water plus the power requirement of WSWB to extract groundwater.

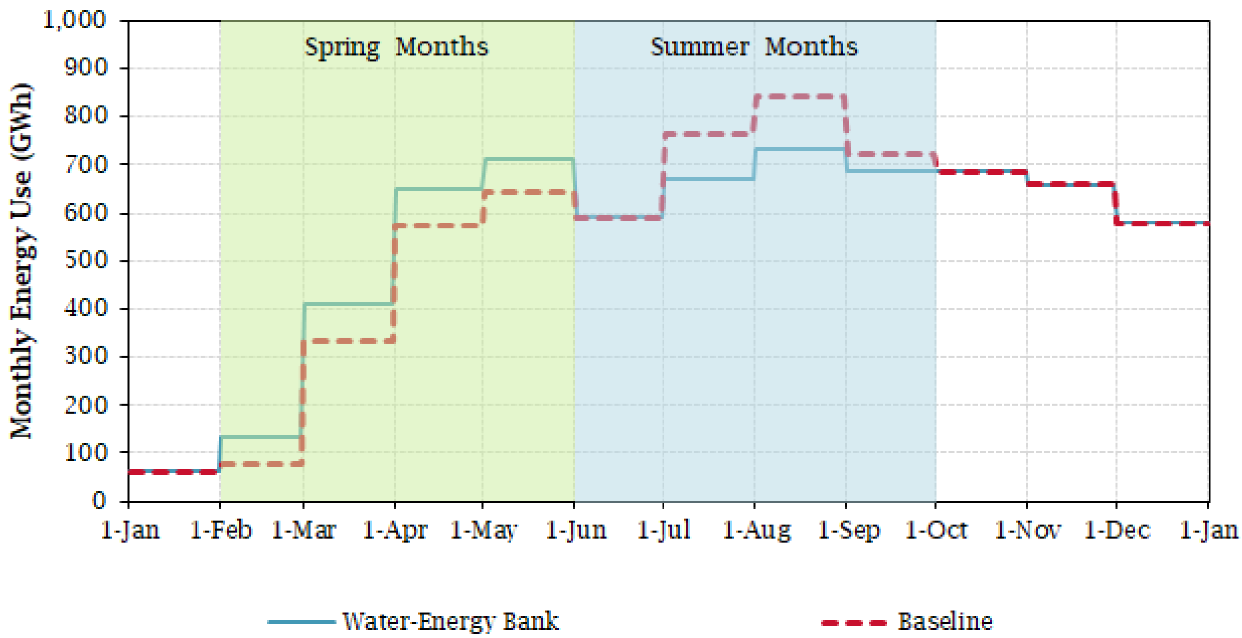
Figure 12: Example Year 1940 SWP Pumping for the Baseline and Water-Energy Bank Scenarios



Spring pre-delivery is shaded in green and summer shift is shaded in blue.

Source: HDR

Figure 13: Example Year 1940 Net Energy Use to Convey Water Between San Luis Reservoir and WSWB for the Baseline and Water-Energy Bank Scenarios



Spring pre-delivery is shaded in green and summer shift is shaded in blue.

Source: HDR

In spring, San Luis Reservoir storage is lowered relative to the baseline, as water is pre-delivered into storage at WSWB. San Luis Reservoir storage recovers, relative to the baseline, throughout the summer as otherwise-delivered water is allowed to accumulate. Conversely, WSWB aquifer storage increases in the spring relative to the baseline, and then recovers in summer. In this example year, neither WSWB maximum storage nor San Luis Reservoir minimum storage is limiting the amount of possible shift.

3.1.2 Aquifer Leave Behind

Not all aquifer recharge water is able to be extracted, resulting in a 10 percent leave behind (10 percent of the water is lost to the aquifer). The spreadsheet tool is not able to make up the resulting aquifer leave behind from Water-Energy Bank scenario operations. The spreadsheet tool tracks the additional volume that would be necessary to offset Water-Energy Bank operations but does not include this volume in the annual water balance between spring and summer pumping plant volume shifting. It is assumed that additional leave behind would come from other local water sources, based on lowest cost.

3.2 Water Operations Analysis Results

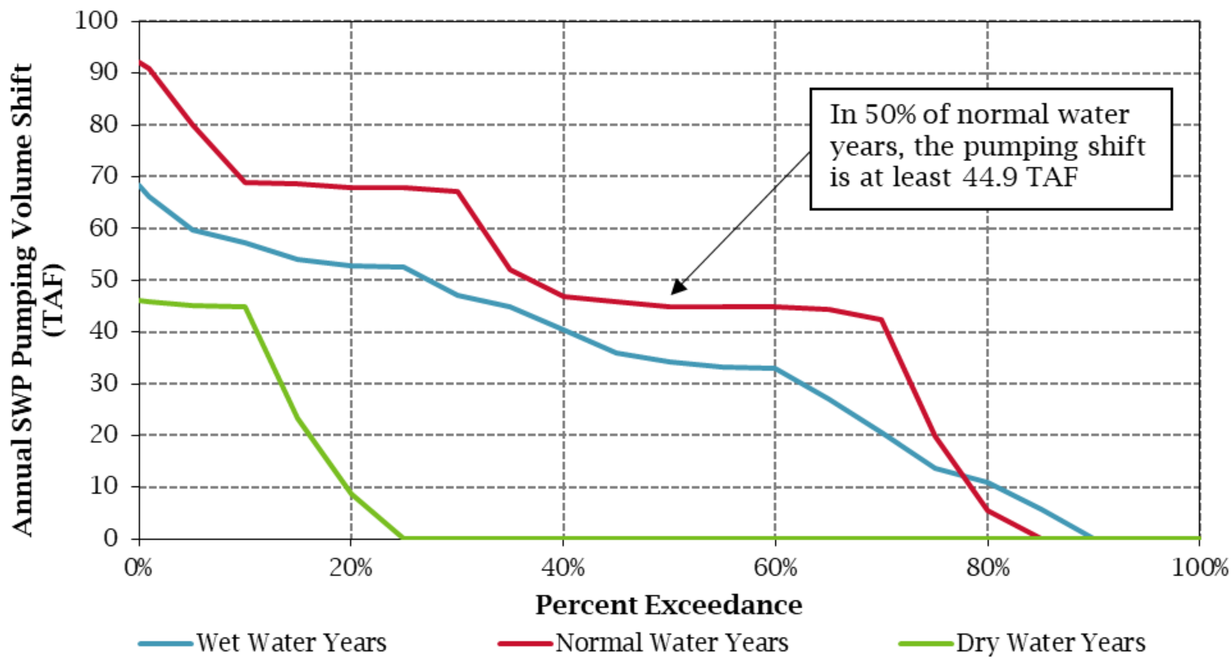
The water operations analysis determines the amount of SWP pumping that can potentially be shifted from summer months to spring months using WSWB aquifer storage to maintain deliveries to Southern California. Results of the Water-Energy Bank scenario were compared to the baseline scenario to determine the timing and quantity of annual pumping volume that could be seasonally shifted from the summer months to spring months. Results were evaluated based on the 82-year period of record and by hydrologic water-year type. Water operations analysis results were categorized into three hydrologic water-year types, including wet, normal, and dry, based on the Climate Changed Sacramento Valley Index, calculated in CalSim II. This index, originally specified in the 1995 State Water Resources Control Board (SWRCB) Water Quality Control Plan, is used to determine the Sacramento Valley water-year type as implemented in SWRCB D-1641. Wet includes only wet water years, normal includes above normal and below normal water years, and dry includes dry and critical water years.

The analysis indicates that the greatest potential to shift SWP pumping occurs in normal water years (43.1 TAF), followed by wet years (32.9 TAF) and dry years (7.8 TAF). Potential shifting of water in dry years is less than other hydrologic year types because less water is delivered to Southern California in dry and critical year types due to supply limitations. Also, SWP operators have capacity to reduce pumping during peak-hour periods. Therefore, during a dry year, DWR is already shifting pumping from the high energy-demand (and high cost) 6-hour (evening) summer periods. The analysis shows that in most wet and normal years some shift of pumping volume out of summer months is feasible.

There is also more potential to shift pumping in normal and wet water years due to summer SWP spill capture recharge operations in the baseline scenario. In summer months with spill capture recharge, SWP pumping reductions can be a combination of spill capture recharge plus groundwater extraction from WSWB, allowing for additional shift potential.

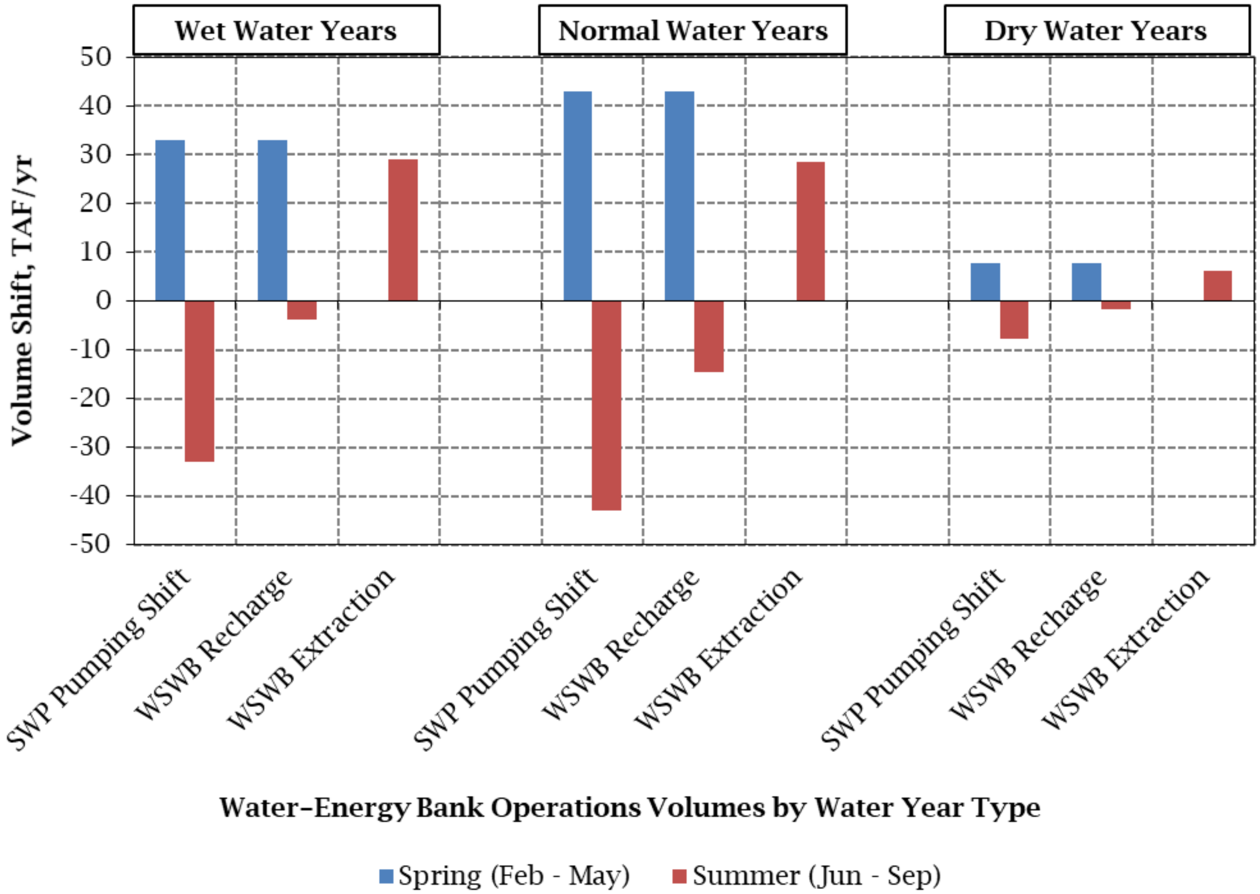
Figure 14 shows the total pumping volume shift per year by percent exceedance and water-year type. For example, in 50 percent of normal water years, the pumping volume shift is at least 44.9 TAF. Figure 15 shows the average seasonal volume shift of pumping, WSWB recharge and WSWB extraction.

Figure 14: Annual SWP Pumping Volume Shift out of Summer Months, by Percent Exceedance and Water-Year Type



Source: HDR

Figure 15: Water-Energy Bank Scenario Seasonal Average Volume Shifts by Water-Year Type



Relative to the baseline scenario.

Source: HDR

Pre-delivering SWP spill capture recharge in spring months is advantageous in maximizing the annual pumping volume shift. For example, the annual volume shift in the 1 percent exceedance year, the largest shift in the period of record, is 92 TAF. Of that volume, 62 TAF is pre-delivered spill-capture water that is independent of deliveries to SWP contractors, so no equivalent water-bank extraction is required. The other 30 TAF is pre-delivered water that must be extracted in summer months to maintain deliveries to SWP contractors downstream of WSWB. In the analysis, the summer volume shift prioritizes recharge water first and water that must be re-extracted from WSWB second.

3.3 Power Operations Analysis Results

The amount of energy required for the simulated flow volumes at pumping and generating plants was estimated using water flow-to-energy conversion factors. The energy required to pump water out of WSWB was determined based on an estimated depth to groundwater during pumping (350 feet) and the elevation head required to pump water back up the aqueduct (400 feet). State Water Project pumping plant energy factors, previously determined by DWR, range from 159 to 272 MWh/TAF, and generating plant energy factors range from 0 to 206 MWh/TAF. The energy required to extract (pump and deliver) water from WSWB to the East Branch California Aqueduct is 1,100 MWh/TAF. The energy required to move water from San Luis Reservoir to WSWB is approximately 3,400 MWh/TAF.

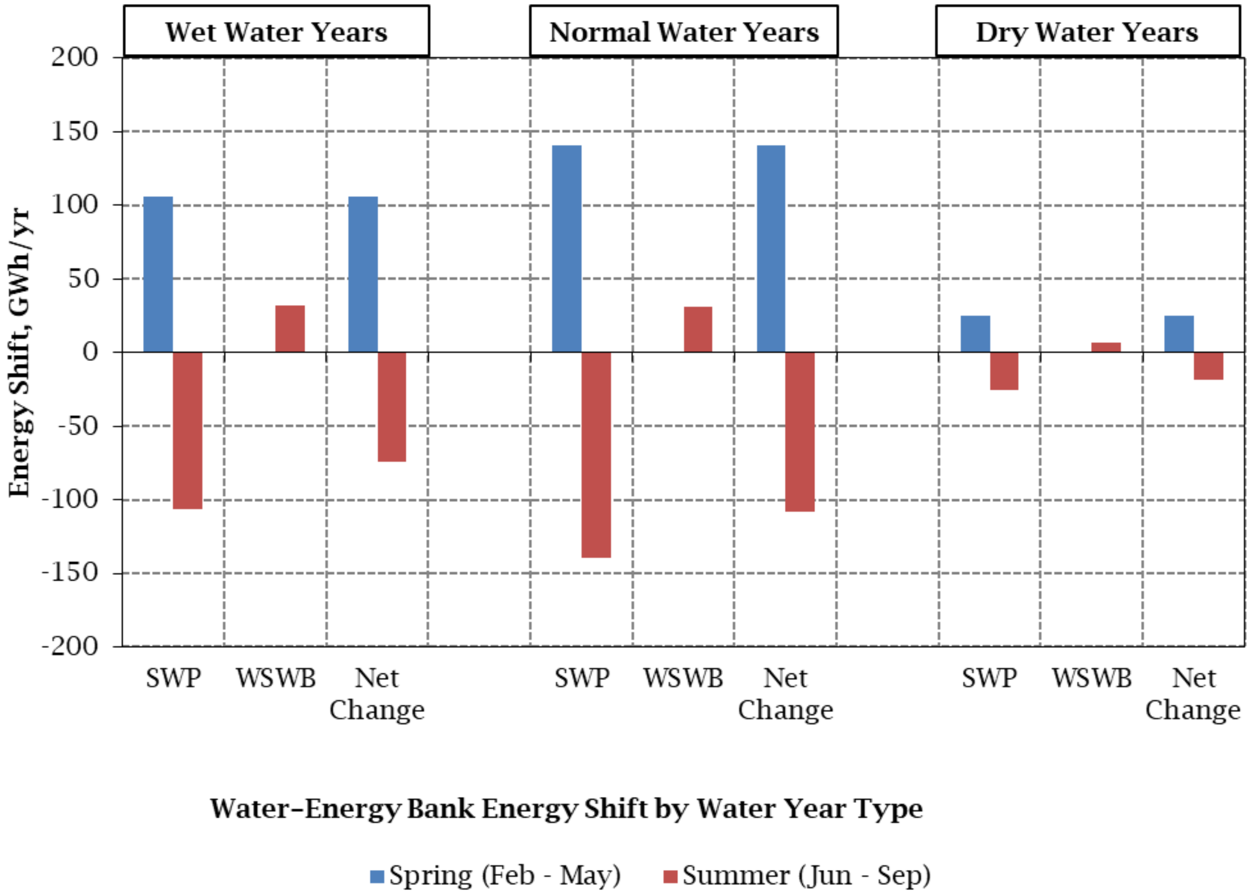
The energy needed to operate the SWP and WSWB, in addition to the energy generated by the SWP, were calculated for the baseline and the Water-Energy Bank scenarios. The difference in energy use was calculated for the Water-Energy Bank relative to the baseline. The average annual increase in net energy used to shift water deliveries between summer and spring months is 31.5 GWh in wet years, 32.8 GWh in normal years, and 6.7 GWh in dry years. However, even though overall energy use increases as a result of the Water-Energy Bank Project, the timing of the water use is shifted from higher-energy-demand periods to lower-energy-demand periods; therefore the total energy costs are reduced significantly. Figure 16 shows the average seasonal energy shift for pumping, WSWB recharge, and WSWB extraction.

The net energy required in the Water-Energy Bank Scenario to maintain water supply deliveries to Southern California was greater than in the baseline scenario in all years when seasonal shifts occurred. Pre-delivered water to WSWB was extracted as needed to provide a continuous, uninterrupted water supply downstream of WSWB.

Figure 17 shows spring energy use for the baseline and Water-Energy Bank scenarios, and the net difference, by percent exceedance. Figure 18 shows summer energy use for the baseline and Water-Energy Bank scenarios, and the net difference, by percent exceedance. Figure 19 shows the annual difference in energy use between the water-energy bank and baseline scenarios, by percent exceedance and by water-year type. The annual difference in energy used is a combination of the increase in pumping energy, and changes to annual generation at the powerhouses, which can either increase or decrease. In some years, increases in generation offset increases in pumping.

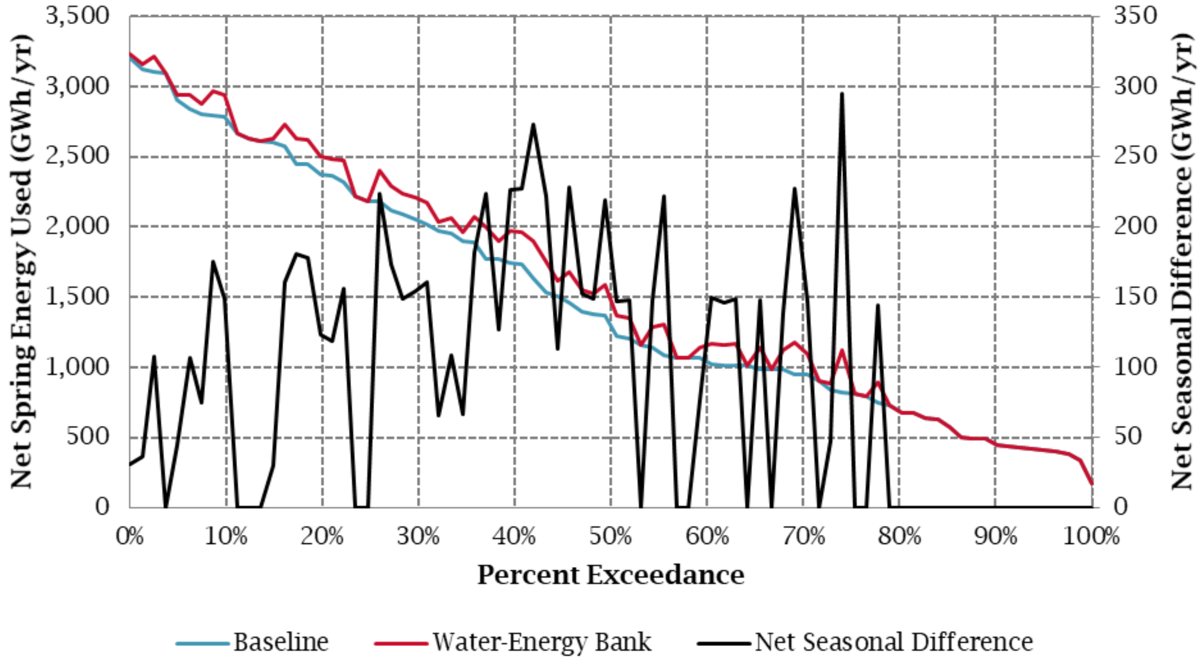
In 39 percent of years of the 82-year period of record, there was no increase in energy used because no seasonal shift was necessary or possible.

Figure 16: Water-Energy Bank Scenario Annual Average Seasonal Energy Shift from the Baseline to Water-Energy Bank Scenario



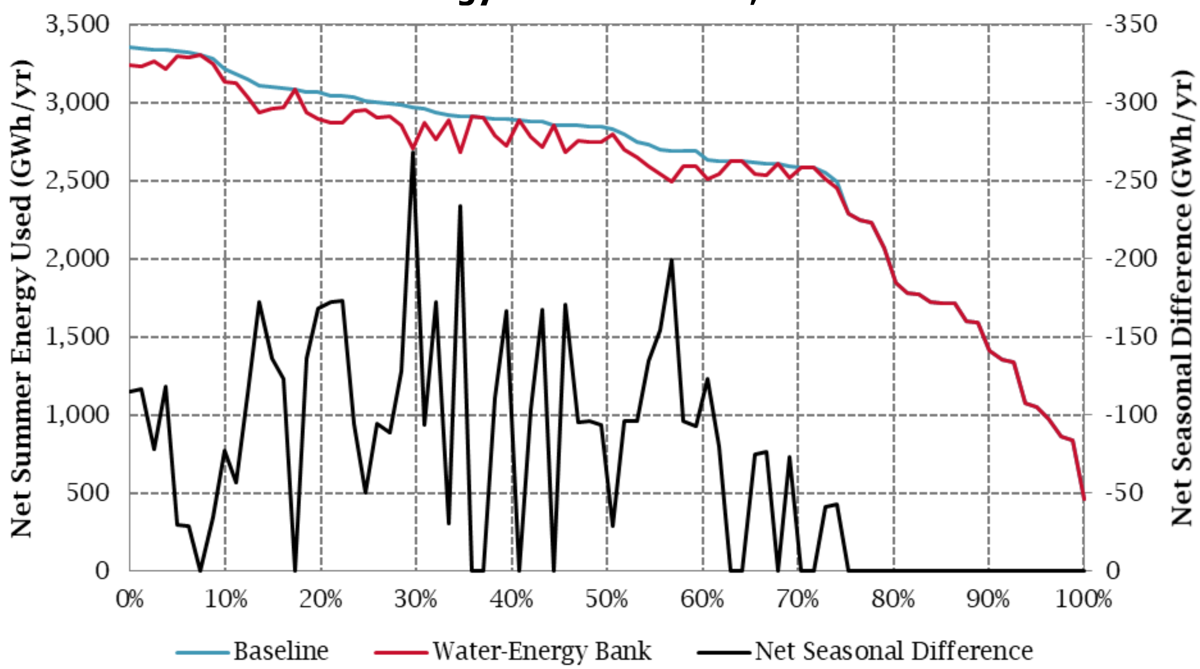
Source: HDR

Figure 17: Net Energy Used in Spring, by Percent Exceedance, for the Baseline and Water-Energy Bank Scenarios, and the Net Difference



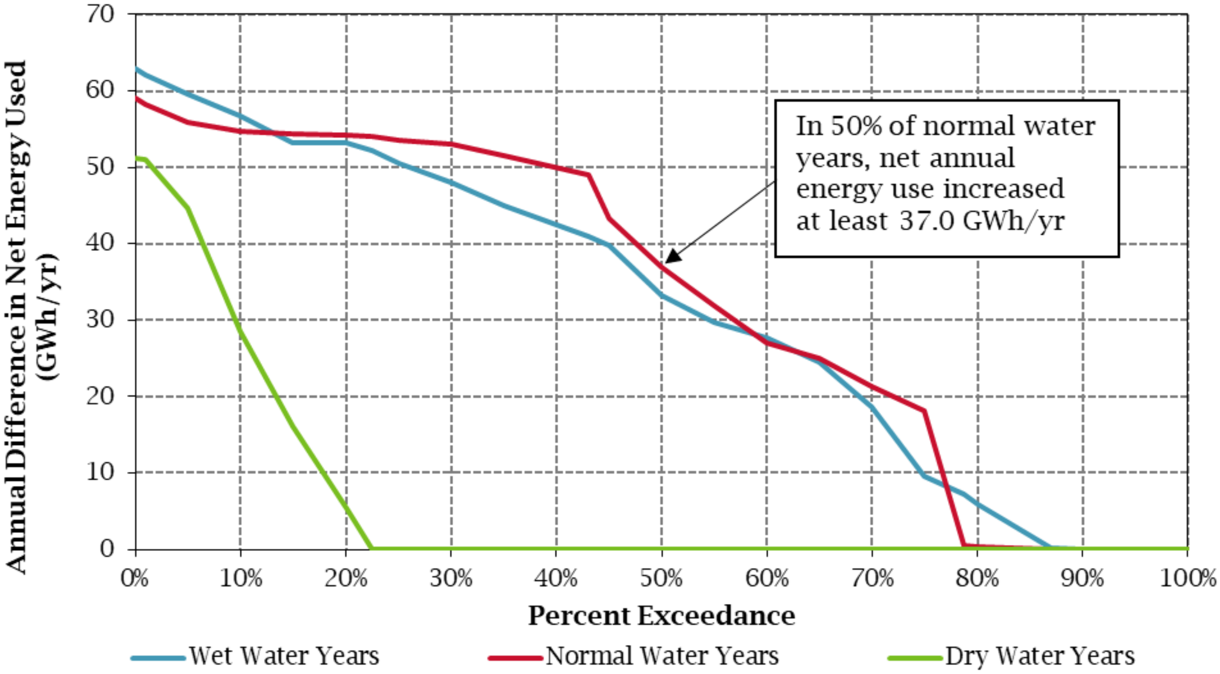
Source: HDR

Figure 18: Net Energy Used in Summer, by Percent Exceedance, for the Baseline and Water-Energy Bank Scenarios, and the Net Difference



Source: HDR

Figure 19: Difference in Annual Net Energy Used to Deliver SWP Water between the Water-Energy Bank and Baseline Scenarios, by Percent Exceedance and Water-year Type



Source: HDR

CHAPTER 4: Economic and Emissions Reduction Benefit Evaluation

This section provides a summary of the economic and emissions reduction benefit methods and results. More complete information on methods and a more-detailed summary of results are presented in the Project Technical Report (WSWB 2018).

As part of this study, the value of shifting SWP pumping using WSWB as a water-energy bank was evaluated. The economic analysis involved two separate approaches to evaluate wholesale energy price forecasts:

- Avoided Cost Framework – The first approach follows the avoided cost framework adopted by the CPUC for evaluating distributed energy resources (DER). The avoided cost framework has been developed over the last 20 years and is the standard approach employed by both the CPUC and the California Energy Commission (CEC) to evaluate DER, including demand response (DR). The avoided cost approach evaluates benefits based on costs that a load-serving entity, such as an investor-owned utility, avoids by minimizing wholesale energy purchases during peak capacity hours. This approach is currently used by the CPUC to evaluate all distributed energy resources, including energy efficiency, rooftop solar, energy storage, and demand response.
- Renewable Energy Solutions (RESOLVE) Framework – The second approach uses the RESOLVE Model from the CPUC's Integrated Resources Plan to quantify the potential value of the water-energy bank in providing capital investment and operational cost savings over the 2018 to 2030 timeframe, as the penetration or renewable generation increases. Given a portfolio of potential energy resources, the RESOLVE Model develops least-cost electricity sector supply plans to meet California's ambitious GHG emission reductions and renewable energy goals. Generally, new flexible resources generate value by allowing the State to build less new renewable energy generation and fewer renewable integration solutions, while still meeting statewide policy goals.

Three curtailment scenarios were modeled under each framework (Table 2). Renewables curtailment, in the context of this study, refers to instances when utilities must turn off renewable generation during periods of oversupply on the power grid. Because supply and demand on the power grid must always remain balanced, if energy supply exceeds consumer demand, utilities must reduce, or curtail, their energy generation to match demand. In a future with a large renewables portfolio, some degree of curtailment will be necessary during periods when renewables generation exceeds the capacity of the power grid. Projections of low, mid, and high-curtailment scenarios were modeled to assess how the market may react in a future of high-renewable generation:

- Low Curtailment – This scenario assumes that there will be relatively fewer periods when renewable energy generation will need to be curtailed to balance supply and demand. It assumes the State will only meet minimum policy targets for renewables and energy storage, as set by SB350.
- Mid Curtailment – This scenario assumes that there will be some periods when renewable energy generation will need to be curtailed to balance supply and demand. As the "most-likely" case, this scenario assumes that the State will exceed existing policy goals and procure grid resources in line with the State's emission goals. This scenario also assumes some degree of overachievement on statewide renewables targets. To integrate the additional renewables to some extent, this scenario assumes additional regional integration, allowing for more imports and exports. SB100 Note: The mid-curtailment scenario is generally consistent with the trajectory of renewables procurement laid out in the recently enacted California legislation SB100, which mandates the increase of renewable energy generation and the reduction of greenhouse gas emissions through 2030. Due to the timing of this analysis in this project, which mostly preceded the release of SB100, there are some discrepancies between this scenario and SB100. Notably, the scenario in this report does not assume additional renewable energy build-out beyond 2030.[4]
- High Curtailment – This scenario assumes that there will be more frequent periods when renewable energy generation will need to be curtailed to balance out supply and demand. The high-curtailment scenario is based on an aggressive GHG mitigation policy. Despite assumptions of a similar level of regional integration as the low-curtailment scenario, increased renewable generation in the high-curtailment scenario results in a higher amount of curtailment hours.

Table 2: Curtailment Scenario Assumptions

Curtailment Scenario	Assumed Renewables Portfolio Standard by 2030	Assumed Statewide Energy Storage in Gigawatts (GW)
Low Curtailment	50%	1.3 GW
Mid Curtailment	60%	2.5 GW
High Curtailment	80%	4 GW

Source: E3

4 On September 10, 2018, Governor Jerry Brown signed into law Senate Bill 100 (SB100), California Renewables Portfolio Standard Program: Emissions of Greenhouse Gases which sets a target of 100 percent carbon-free electricity in California by 2045. SB100 also amends the State's existing renewable portfolio standard (RPS), setting new RPS targets of 50 percent renewables by 2026 and 60 percent renewables by 2030.

4.1 Economic and Emissions Reduction Benefits Under the Avoided Cost Framework

The Avoided Cost Framework is the standard approach of the CPUC and the CEC for evaluating distributed energy resources, and represents the marginal costs of operating the power grid as it exists today. Distributed energy resources are small, local generation facilities connected to the power grid's distribution system. Based on existing markets, the CPUC evaluates the State's distributed energy resources using an "Avoided Cost Calculator" tool to calculate the hourly cost of delivered electricity that is 'avoided' by distributed energy resources (CPUC, 2018). This approach assumes that distributed energy resources reduce system costs on the margin while the resource portfolio and underlying power grid operations remain unchanged.

In the Avoided Cost Framework, the water-energy bank provides benefit to the power grid as a flexible load that can shift energy consumption into lower energy demand, lower cost hours based on price signals. From an energy perspective, this means shifting consumption into hours with lower wholesale energy costs. Similarly, from an emissions perspective, this means shifting load into hours with lower emissions. From a power/peak capacity perspective, this means shifting consumption out of hours that are setting the peak capacity requirements of the power grid. Reduced peak capacity eases strain on the electric system and defers upgrades to the transmission and distribution system which delivers electricity to consumers.

Individual sub-sections are provided for each of the categories evaluated, including:

- Avoided Energy Costs (Wholesale Energy Benefits). These are the cost savings from purchasing wholesale electricity during time periods with lower prices.
- Avoided Loss Costs: These are the benefits from decreasing energy use from the avoided energy loss due to the inefficiencies in the transmission and distribution systems.
- Avoided Generation Capacity Costs: This is the benefit from reductions in power that the California Independent System Operator (California ISO) must procure to meet peak energy demands in the open market.
- Avoided Transmission and Distribution. This is the benefit from reducing the need for new infrastructure and equipment for transmission and distribution capacity expansion.
- Avoided Emissions. This is the value of short-run marginal emissions reductions which are the emissions associated with increasing or decreasing load for the power grid's marginal generator (the plant that responds to marginal load changes).

The methods for each of these categories are presented in Sections 4.1.1 to 4.1.5 and detailed results are provided for avoided energy costs and the avoided emissions categories in Sections 4.1.1 and 4.1.5. Summary results are provided for all categories in Section 4.1.6.

4.1.1 Avoided Energy Costs (Wholesale Energy Benefit)

Avoided energy costs (also referred to as wholesale energy benefits) are the cost savings from purchasing wholesale electricity during time periods with lower prices. The economic analysis of the Water-Energy Bank involved calculating avoided wholesale energy costs for each year of the water/power operations analysis (presented in Section 3), using forecasted energy prices (for years 2020, 2025, 2030, 2035, and 2040), and by curtailment scenario (low-curtailment, mid-curtailment, and high-curtailment) are summarized in Tables 3 through 6, Tables 7 through 10, and Tables 11 through 14, respectively:

- Low-Curtailment: The wholesale energy benefit of the Water-Energy Bank is a net reduction of cost during dry and normal years, ranging from $0.114-0.145 million per year. (Wet years are shown as an increase in cost; however, the water bank would likely just shut down during wet years under this scenario rather than incur an increase in cost.)
- Mid-Curtailment: The wholesale energy benefit of the Water-Energy Bank is a net reduction of cost for dry, wet and normal years, ranging from $0.505-2.544 million per year.
- High-Curtailment: The wholesale energy benefit of the Water-Energy Bank is a net reduction of cost for dry, normal and wet years, ranging from $1.615-4.728 million per year.

There is limited value in the avoided energy cost benefits in wet and dry years because of limited operational flexibility in these years. In wet years, there is an excess of water for the SWP to move and little opportunity to shift load into lower-priced hours. In dry years, there is less water for the SWP to deliver, and the SWP and Water-Energy Bank are already pumping in the lower-cost periods. However, in normal water years, there is additional operational flexibility that allows project operators to shift more energy from high-priced hours to low- or negatively-priced hours.

Table 3: Low-Curtailment Cost Projection, 1922 to 2003
SWP Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$5,273,312	($6,024,225)	$0	($750,914)
Normal Years	$6,387,537	($7,978,896)	$0	($1,591,359)
Dry Years	$931,979	($1,386,984)	$0	($455,005)

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).
[1] Water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 4: Low-Curtailment Cost Projection, 1922 to 2003
SWP Generation Revenue

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$309,912	($336,811)	$0	($26,898)
Normal Years	$369,417	($426,995)	$0	($57,578)
Dry Years	$25,979	($84,686)	$0	($58,707)

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 5: Low-Curtailment Cost Projection, 1922 to 2003
WSWB Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$0	$1,417,883	$0	$1,417,883
Normal Years	$0	$1,419,330	$0	$1,419,330
Dry Years	$0	$309,639	$0	$309,639

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 6: Low-Curtailment Cost Projection, 1922 to 2003
Combined SWP & WSWB Net Operating Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$4,963,399	**($4,269,532)**	$0	$693,868
Normal Years	$6,018,120	**($6,132,572)**	$0	**($114,452)**
Dry Years	$931,979	**($1,077,345)**	$0	**($145,366)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 7: Mid-Curtailment Cost Projection, 1922 to 2003
SWP Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$5,117,914	**($6,567,833)**	$0	**($1,449,919)**
Normal Years	$5,317,485	**($8,895,171)**	$0	**($3,577,686)**
Dry Years	$183,280	**($1,666,087)**	$0	**($1,482,807)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 8: Mid-Curtailment Cost Projection, 1922 to 2003
SWP Generation Revenue

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$271,930	**($300,524)**	$0	**($28,594)**
Normal Years	$293,435	**($381,962)**	$0	**($88,528)**
Dry Years	**($2,252)**	**($75,377)**	$0	**($77,629)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 9: Mid-Curtailment Cost Projection, 1922 to 2003
WSWB Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$0	$916,428	$0	$916,428
Normal Years	$0	$944,767	$0	$944,767
Dry Years	$0	$208,402	$0	$208,402

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 10: Incremental Benefit/Cost for the Water-Energy Bank Scenario for the Mid-Curtailment Cost Projection, 1922 to 2003
Combined SWP & WSWB Net Operating Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$4,845,985	**($5,350,880)**	$0	**($504,896)**
Normal Years	$5,024,050	**($7,568,442)**	$0	**($2,544,391)**
Dry Years	$185,532	**($1,382,307)**	$0	**($1,196,776)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] water-year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 11: High-Curtailment Cost Projection, 1922 to 2003
SWP Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$3,828,509	**($6,937,808)**	$0	**($3,109,298)**
Normal Years	$3,535,347	**($9,492,878)**	$0	**($5,957,531)**
Dry Years	**($139,152)**	**($1,785,136)**	$0	**($1,924,288)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 12: High-Curtailment Cost Projection, 1922 to 2003
SWP Generation Revenue

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$183,888	**($304,097)**	$0	**($120,208)**
Normal Years	$182,984	**($385,619)**	$0	**($202,636)**
Dry Years	**($8,801)**	**($76,703)**	$0	**($85,504)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 13: High-Curtailment Cost Projection, 1922 to 2003
WSWB Pumping Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$0	$978,684	$0	$978,684
Normal Years	$0	$1,026,518	$0	$1,026,518
Dry Years	$0	$224,137	$0	$224,137

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

Table 14: High-Curtailment Cost Projection, 1922 to 2003
Combined SWP & WSWB Net Operating Costs

Water Year Type[1]	Spring (Feb-May)	Summer (Jun-Sep)	Fall/Winter (Oct-Jan)	Annual
Wet Years	$3,644,621	**($5,655,027)**	$0	**($2,010,406)**
Normal Years	$3,352,363	**($8,080,740)**	$0	**($4,728,377)**
Dry Years	**($130,351)**	**($1,484,297)**	$0	**($1,614,648)**

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the Spill Capture Scenario. Black values are positive (costs), red values are negative (savings).

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.1.

Source: HDR

4.1.2 Avoided Loss Costs

Avoided loss costs (also referred to as system loss benefits) are defined in this analysis as the avoided costs for energy loss due to the inefficiencies in the transmission and distribution systems. During peak hours, when the system is more constrained, losses are typically higher as a result of higher levels of electricity flowing through the transmission and delivery systems. Higher losses require more electricity generation to serve the same amount of load on the power grid. As a result, the costs to serve load to consumers increase.

The system loss benefit stream considers the change in energy consumption with and without the Water-Energy Bank and multiplies it by the system losses cost stream. The system losses cost stream is the product of hourly wholesale energy prices and the loss factor from the respective Time of Use (TOU) period. Loss factors represent the ratio between average load loss and peak load loss over a period of time from inefficiencies in the transmission and distribution systems. Loss factors are defined by the Avoided Cost Calculator for each investor-owned utility, in each TOU period (CPUC, 2018).

4.1.3 Generation Capacity

Generation capacity benefits derive value from the Water-Energy Bank's ability to reduce power use from the grid in peak hours. This reduction in power use decreases the power that California ISO must procure to meet peak energy demands. The economic value of this benefit is the cost of contracting this power in the open market, in $/kW-yr.

The reduction in peak load represents the average reduction in SWP pumping load during peak hours for a given scenario, price forecast year, water year, and month. Peak load reductions are based on energy needs to pump water (in MWh/TAF) at the five SWP pumping plants included in the analysis. Peak hours include the six peak evening hours (typically 4 p.m. to 10 p.m.). July, August, and September are typically the peak load months.

The analysis of the Water-Energy Bank uses two potential generation capacity values, based on data from the 2018 update of the CPUC Avoided Cost Calculator.[5] The low generation capacity value assumes a scenario in which the State has too many capacity resources. This drives the generation capacity value below what is effectively the cost of constructing a new combustion turbine power plant (often referred to as Cost of New Entry). The high generation capacity value assumes a scenario in which there will be a more immediate need for new capacity resources on the power grid; because of this, the near-term generation capacity value is closer to the Cost of New Entry. In relation to the analyzed curtailment scenarios, the low- and mid-curtailment scenarios assume the low generation capacity value, while the high-curtailment scenario assumes the high generation capacity value.

5 Low Generation Capacity Value is based on a Resource Balance Year of 2049, with an initial generation capacity cost of $36/kW-yr. High Generation Capacity Value is based on a Resource Balance Year of 2018. Both values are taken from the Avoided Cost Calculator as the Capacity Value Adjusted for Losses.

4.1.4 Transmission & Distribution Deferral

Transmission and distribution deferral (or transmission deferral) benefits include the value of reducing the need for new infrastructure and equipment for transmission and distribution capacity expansion. Utilities often install upgrades in large increments; reducing peak capacity lessens the strain on the electric system and allows utilities to defer transmission and distribution upgrades for multiple years or avoid the upgrades altogether. Deferring an upgrade for multiple years generates value, based on the time-value of money, while indefinite upgrade deferrals generate value at the total cost of the avoided upgrade. While other avoided cost benefit streams broadly apply to a large region, both the value and hourly allocation of transmission and distribution deferral are location-specific. Transmission and distribution costs are specific to a utility; this analysis uses costs for Southern California Edison (SCE) from the CPUC Avoided Costs Calculator.

Due to data constraints, the analysis assumes that the transmission marginal cost applies directly to this case. Grid operators or transmission asset owners would need to confirm location-specific values. Neither Edmonston Pumping Plant nor WSWB connect to local power distribution grids, so this report does not factor in potential distribution value.

The Water-Energy Bank analysis assumes no transmission deferral value for the low-curtailment scenario, while the mid- and high-curtailment scenarios include transmission deferral values.

4.1.5 Avoided Emissions

This section describes evaluation of GHG emission reductions from the water-energy project and from construction of a 40-MW solar generation project and a 5.2-MW hydroelectric generation project at WSWB as part of the project (details of on-site WSWB renewables projects are discussed in the next chapter). Renewable generation would power the WSWB pumps that deliver groundwater from the aquifer back up to the California Aqueduct.

4.1.5.1 Avoided Emissions Analysis Method

Avoided emissions value is the value of short-run marginal emissions reductions. Short-run marginal emissions are the emissions associated with increasing or decreasing load for the power grid’s marginal generators (plants that responds to changes in load) or from constructing renewable energy at the WSWB. At any given point in time, if load increases, a marginal generator will come on-line or increase its output; if load decreases, the marginal generator will turn down its output. Short-run marginal emissions assume that the installed generation resource mix on the grid will not change with changes to the load.

Each power plant has an associated heat rate (plant efficiency) depending on physical characteristics and where it is operating relative to its load curve (Figure 20). The avoided emissions analysis calculates marginal change in emissions (reported in tCO_2-e/MWh, or tons of carbon dioxide-equivalent per megawatt-hour) from the heat rate and carbon intensity of the power plant's fuel. Since California has no coal plants, the analysis assumes natural gas power plants are the only marginal generator types that have direct carbon emissions. The hourly marginal heat rate is based on hourly electricity prices and forecasted natural gas prices. Higher electricity prices in any given hour correspond to a higher assumed marginal heat rate, while lower prices correspond to a lower assumed marginal heat rate. The analysis assumes that the marginal heat rate cannot exceed 11,000 British thermal units (BTU) per kilowatt-hour (kWh) (Btu/kWh), as there are few natural gas generators that are less efficient than that. Conversely, the analysis assumed that 5,500 Btu/kWh is the minimum possible heat rate for a conventional generator.

Figure 20: Heat Map of the Assumed Marginal Emissions Rate (tCO_2-e/MWh), Averaged by Month and Hour for the Mid-Curtailment Scenario in 2030

Hour of Day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0.33	0.31	0.32	0.31	0.32	0.34	0.38	0.39	0.22	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.33	0.36	0.37	0.38	0.37	0.36	0.34
Feb	0.34	0.33	0.31	0.31	0.33	0.35	0.37	0.30	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.31	0.34	0.37	0.36	0.36	0.35	0.34
Mar	0.25	0.23	0.23	0.28	0.28	0.25	0.15	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.25	0.30	0.29	0.35	0.33	0.31	0.28
Apr	0.21	0.16	0.14	0.14	0.22	0.25	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.27	0.40	0.35	0.38	0.37	0.37	0.35
May	0.25	0.12	0.09	0.06	0.12	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.38	0.42	0.41	0.40	0.41	0.41	0.37
Jun	0.29	0.31	0.30	0.30	0.30	0.23	0.11	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.06	0.13	0.13	0.28	0.37	0.35	0.33	0.36	0.35	0.32
Jul	0.36	0.36	0.35	0.34	0.34	0.34	0.20	0.04	0.04	0.06	0.06	0.02	0.00	0.03	0.05	0.10	0.31	0.48	0.50	0.47	0.40	0.39	0.39	0.38
Aug	0.36	0.37	0.37	0.37	0.37	0.38	0.35	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.36	0.48	0.51	0.47	0.44	0.44	0.42	0.38
Sep	0.40	0.39	0.37	0.36	0.38	0.39	0.35	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.42	0.50	0.52	0.49	0.46	0.43	0.42	0.42
Oct	0.35	0.35	0.35	0.35	0.35	0.35	0.37	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.21	0.35	0.38	0.38	0.39	0.39	0.38	0.37	0.36
Nov	0.36	0.35	0.34	0.34	0.34	0.36	0.38	0.32	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.33	0.36	0.36	0.36	0.36	0.35	0.36	0.36
Dec	0.35	0.34	0.34	0.33	0.34	0.35	0.38	0.39	0.16	0.05	0.00	0.00	0.00	0.00	0.01	0.14	0.32	0.33	0.36	0.36	0.36	0.36	0.35	0.35

Source: E3

Avoided emissions are equal to the marginal emissions rate multiplied by the change in electricity consumption as a result of the Water-Energy Bank. The value of the avoided emissions is the product of the calculated avoided emissions and the value of emissions reductions. In 2018, following the IRP Proceedings, the CPUC published a value of GHG emissions to evaluate distributed energy resources.[6] This value, referred to as the CPUC GHG Adder, assigns value to emissions reductions from distributed energy resources based on the estimated price of incremental emissions reductions from supply resources (e.g., solar + storage). Statewide energy procurement targets (driven by GHG emissions targets) and reduced emissions from a given distributed energy resource will, in turn, reduce the amount of renewable energy that investor-owned utilities and other load-serving entities must procure. In effect, avoided emissions represent the benefit of additional renewable energy integration within the avoided cost framework.

6 CPUC 2018, Page 106: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M209/K771/209771632.PDF

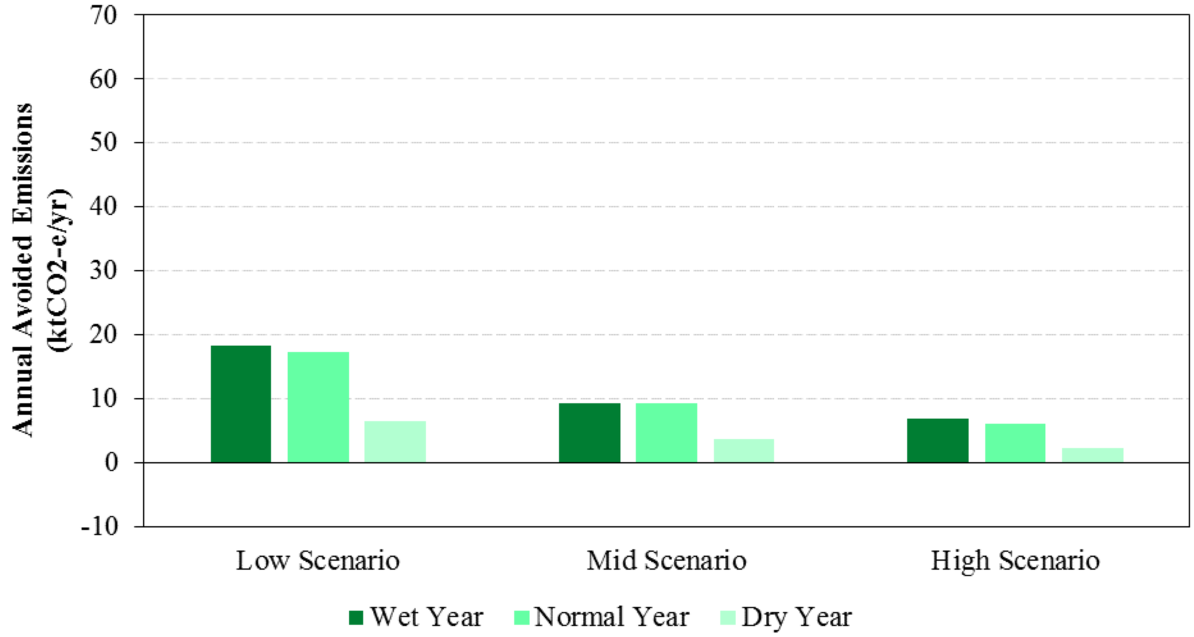
During midday hours when solar is the marginal generator, emissions rates are typically zero. Emissions rates are highest in the summer evening peak period. Since load from the SWP pumping plants shifts into lower emissions hours, there is a reduction in annual emissions. This effect is balanced out to some extent by an increase in emissions from the new load of the Water-Energy Bank. In total, even with the increased load, there is a net decrease in emissions.

Emissions value is not additive to the Cap-and-Trade market value, as wholesale energy market prices already factor in the Cap-and-Trade market value. The value for avoided emissions in this report, therefore, is the difference between the CPUC's reported value and the Cap-and-Trade market price assumed in the energy price forecasts. It should be noted that in California's current regulatory landscape this value of emissions is a societal value and not readily monetized like other avoided costs revenue streams.

4.1.5.2 Avoided Emission Results

Avoided emissions from WSWB's on-site renewable generation are calculated for each Water-Energy Bank curtailment scenario. Figure 21 shows that on-site renewable generation has a bigger impact in the low-curtailment scenario than it does in the high-curtailment scenario. Avoided emissions in the high-curtailment scenario are lower because the power grid is cleaner in the high-curtailment scenario, and there are less grid emissions to avoid. For example, in the high-curtailment scenario, during high-solar production hours, the marginal generator on the grid is often solar energy; any additional generation from on-site renewables in those hours will only offset solar energy, which has no emissions.

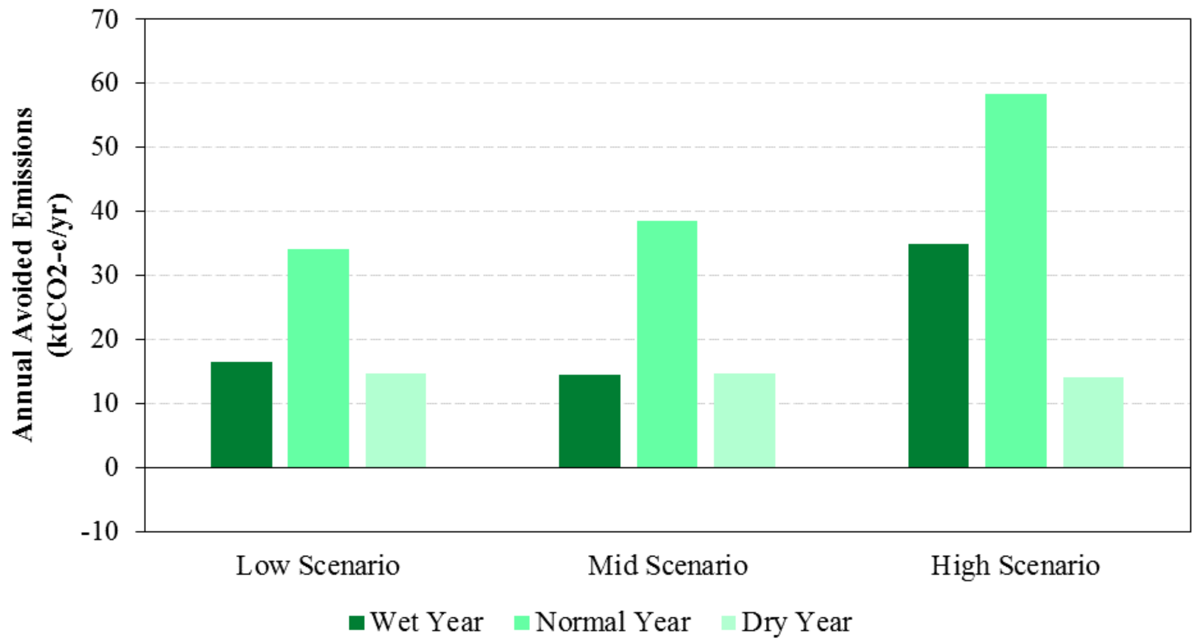
Figure 21: Average Annual Water-Energy Bank Avoided Emissions from WSWB On-site Renewable Generation



Source: HDR

The total avoided emissions for WSWB's on-site hydropower and solar generation projects and the Water-Energy Bank are shown in Figure 22.

Figure 22: Combined Average Annual Avoided Emissions from the Water-Energy Bank and WSWB On-site Renewable Generation



Source: HDR

The Water-Energy Bank and the associated on-site renewable energy have total emissions reductions of 15 to 60 ktCO_2-e/yr. This is the equivalent of removing 3,000 to 12,500 passenger vehicles off the road or providing electricity for 1,600 to 6,500 homes.[7] The addition of on-site generation provides enough additional emissions offsets for the total project to, on average, have emissions reductions in each water-year type, and in each scenario.

4.1.6 Avoided Cost Economic and GHG Emissions Benefits: Annualized Lifetime Results

Avoided costs are calculated annually for each water-year type, and for each curtailment scenario, and are summarized in Figure 23, annualized during 2020–2040.[8] This view shows the potential bounds of value, depending on the distribution of water-year types in the future.

Generation capacity and transmission deferral are the most significant potential benefit streams. As there is little difference in calculated peak load reduction between the low, mid, and high scenarios, the difference in value of generation capacity and transmission deferral value between scenarios is highly dependent on the assumed value of these fields, in $/kW-yr. The analysis shows that the greatest value from shifting SWP pumping occurred in normal water years ($26.8 to 72.2 million per year), with lesser benefits during the wet years ($11.5 to 38.9 million per year) and dry years ($8.0 to 18.3 million per year). The potential to shift water deliveries in dry years is less than other hydrologic year types because less water is delivered to Southern California. In dry years, SWP operators already have the flexibility to reduce pumping during peak energy demand periods.

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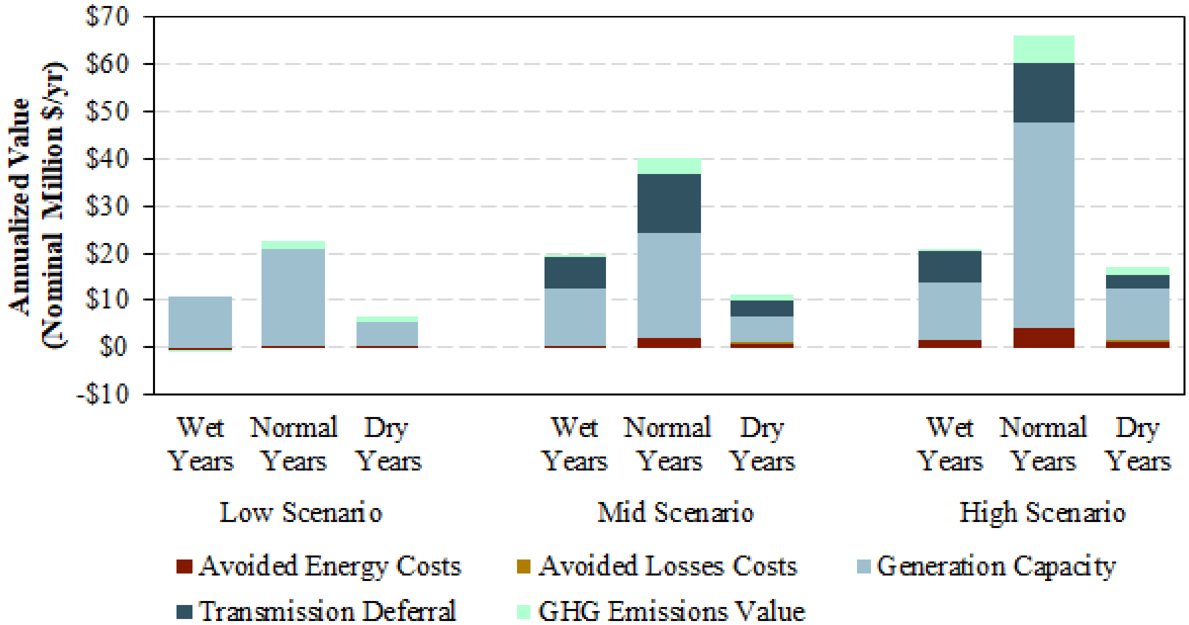
7 EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

8 Assuming a 5 percent Real Discount Rate and a 2.3 percent Inflation Rate. These assumptions are consistent with the 2018 update of the CPUC Avoided Cost Calculator

Figure 23: Total Avoided Cost Value for Each Water Year Type in Each Curtailment Scenario, Annualized During 2020-2040



Source: HDR

Further driving this value of the water-energy bank is the assumption that the distribution of water years in the future will be similar to the historical distribution of water-year types. In these scenarios, dry years, normal years, and wet years, are expected to occur with relatively similar frequency to one another. If future weather years are more concentrated in dry years and wet years, with less normal water years, the total potential value of the water-energy bank will diminish. A sense of the upper and lower bounds for this can be inferred from Figure 23.

4.2 Economic Benefits under the RESOLVE Framework

The RESOLVE Framework values the water-energy bank from a resource procurement perspective. While the Avoided Costs Framework evaluates costs based on how the power grid is operated today, the RESOLVE framework evaluates costs based on how the grid will change in the future. This perspective represents the avoided costs associated with building new renewable energy generation and integration solutions and new power generation/transmission facilities to meet statewide energy targets. By factoring in changes in fixed and operating costs for the power grid, the RESOLVE Framework reflects the value of the water-energy bank as a resource in the CPUC IRP Proceedings (E3, 2017).

Compared to the Avoided Cost Framework, the RESOLVE Framework better captures the renewable integration benefits of distributed energy resources, which are critical to meeting the State's GHG emissions reductions and Renewable Portfolio Standard (RPS) targets. Distributed energy resources provide value by reducing capital investment and operating costs in the electric system. The Avoided Cost Framework only partially captures the benefits of renewables integration. Although the RESOLVE Framework more accurately represents the benefits of flexible loads for renewables integration, it underrepresents the location-specific benefits.

4.2.1 Valuing the Water-Energy Bank Flexible Load Benefits Using RESOLVE

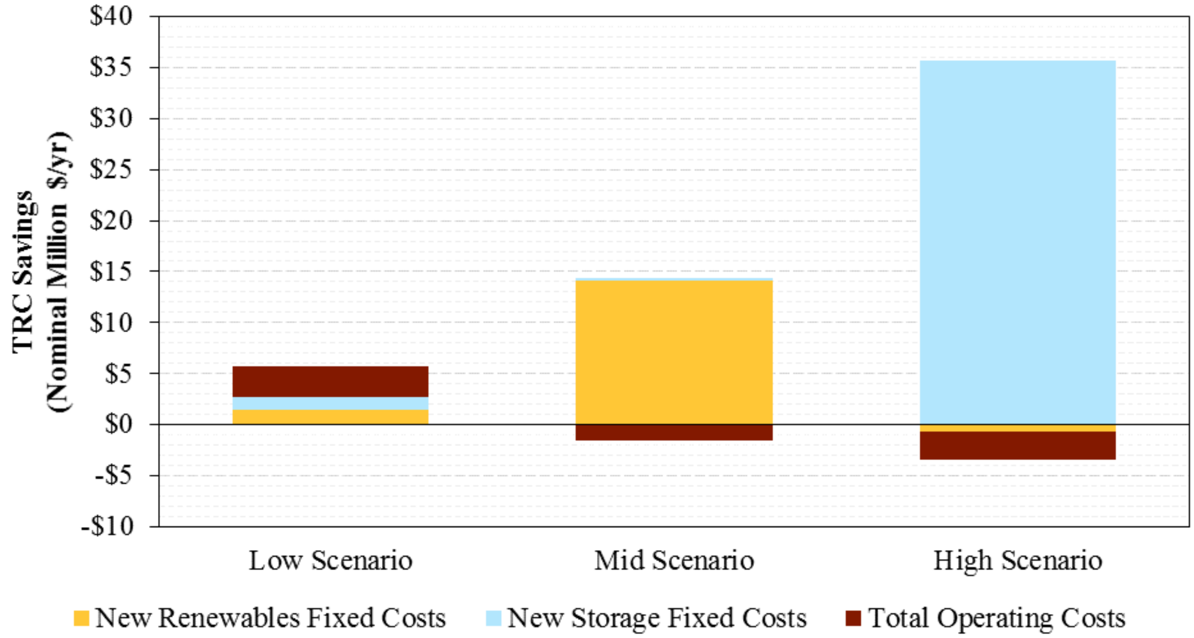
Renewable Energy Solutions (RESOLVE) represents value through total resource cost. The total resource cost is the present value of all fixed costs (capital, financing, and fixed operations and maintenance (O&M) associated with new infrastructure), and all operating costs (fuel costs, start costs, carbon costs, variable O&M, etc.) for each year from 2018 through 2030 and beyond. Renewable Energy Solutions (RESOLVE) calculates the total resource cost of operating the power grid by selecting an optimal, least cost resource portfolio that meets State targets with existing and new resources. The optimized resource portfolios typically consist of candidate renewable electricity resources—new wind and solar plants, for example—and corresponding integration solutions—energy storage, new transmission infrastructure, or flexible loads—to meet California's RPS goals or GHG emissions targets.

In RESOLVE, to increase the level of renewable energy on the grid, each incremental unit of renewable energy comes from the least expensive resource and is balanced to whatever extent necessary by the next least expensive integration solution. As the level of renewables on the grid increases, integrating those renewables, or curtailing otherwise useful energy becomes more expensive. Adding in a flexible load resource, such as the water-energy bank, reduces the costs for the State to meet statewide targets by either reducing the amount of renewable energy resources or integration solutions procured. Due to the current regulatory structure of California's electricity sector, the full extent of these calculated benefits is not readily monetized for a project developer or an investor-owned utility. However, ratepayers would benefit from these cost savings through cheaper retail electricity rates.

4.2.2 Results of RESOLVE Analysis

Figure 24 shows the various cost savings and cost increases as a result of having the water-energy bank on the system under the RESOLVE Framework.

Figure 24: RESOLVE Total Resource Cost Savings for the Water-Energy Bank Project (2030), by Curtailment Scenario



Source: E3

In the low-curtailment scenario, there are modest savings in each category—new renewables' fixed costs, new storage fixed costs, and total operating costs. In the mid-curtailment scenario, the presence of the water-energy bank drives down fixed costs of new solar generation, which likely leads to a reduction in curtailment hours. A slight increase in operating costs counters these savings in the mid-curtailment scenario. In the high-curtailment scenario, a reduction in fixed storage costs represents the majority of savings as the water-energy bank is likely able to provide the same services. The potential benefit is substantially greater in the high-curtailment scenario because of the larger concentration of renewable energy on the power grid, relative to the low and mid-curtailment scenarios. Flexible loads such as the water-energy bank become more beneficial as it becomes more difficult to integrate the next incremental amount of renewable generation.

While RESOLVE's linear optimization model finds a slightly different optimal resource portfolio for each curtailment scenario, the general trend shows that the water-energy bank effectively serves as a lower cost option to new solar generation and storage, allowing the State to achieve its energy targets at a lower total resource cost.

4.3 Summary of Economic and Emission Reduction Benefits Results

Table 15 summarizes projected results for the year 2030, by water-year type (wet, normal, and dry) for hydrologic, energy, and economic benefits. The analysis shows that the greatest potential to shift SWP pumping occurred in normal water years (43.1

TAF/yr.), followed by wet years (32.9 TAF/yr.), and dry years (7.8 TAF/yr.). Potential to shift water deliveries in dry years is less than other hydrologic year types because less water is delivered to Southern California. In dry years, SWP operators already have the flexibility to reduce pumping during peak energy demand periods.

The average annual net increase in energy used to shift water deliveries between summer and spring months was 31.5 GWh in wet years, 32.8 GWh in normal years, and 6.7 GWh in dry years. However, the timing of the energy use is shifted from higher-energy-demand periods to lower-energy-demand periods, thereby reducing overall costs. Average net operating cost, or avoided energy costs, decreased for all year types and all curtailment scenarios except for wet water years in the low-curtailment scenario. The water bank would likely shut down during wet years under this scenario rather than incur a cost increase.

Under the Avoided Cost Framework, the average total avoided cost value over the 82-year period of record for the low, mid, and high-curtailment scenarios were $12.6, $23.1, and $38.0 million per year, respectively. (Table 15 provides a breakdown of these results by water-year type). Under the RESOLVE framework, the average total avoided cost value for the low, mid, and high-curtailment scenarios were $4.6, $7.4, and $20.9 million per year, respectively. The higher value found in the Avoided Cost Framework is largely driven by significant generation capacity value. In all cases, the water-energy bank presents new operational flexibility to the SWP, which reduces operating costs and decreases greenhouse gas emissions. The total avoided emissions from both the WSWB on-site hydropower and solar generation projects and the Water-Energy Bank Project are 15 to 60 ktCO_2-e/yr. This is the equivalent of removing 3,000 to 12,500 passenger vehicles off the road or serving the energy for 1,600 to 6,500 homes.[9]

9 EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 15: Water-Energy Bank Analysis Results Summary for 2030 Scenario

	Wet Water Year	Normal Water Year	Dry Water Year
Average Seasonal Volume Shift (TAF)	32.9	43.1	7.8
Average Net Difference in Spring Energy Used (GWh/yr.)	106.2	141.0	25.3
Average Net Difference in Summer Energy Used (GWh/yr.)	**(74.7)**	**(108.2)**	**(18.6)**
Average Net Difference in Annual Energy Used (GWh/yr.)	31.5	32.8	6.7
Low-Curtailment Economic Analysis			
Avoided Energy Costs (Million $/yr.)	**($0.69)**	$0.11	$0.15
Avoided Losses Costs (Million $/yr.)	**($0.07)**	$0.03	$0.02
Generation Capacity (Million $/yr.)	$13.14	$25.06	$6.59
Transmission Deferral (Million $/yr.)	$0.00	$0.00	$0.00
Avoided Emissions Value (Million $/yr.)	**($0.87)**	$1.61	$1.24
Total Avoided Costs (Million $/yr.)	$11.51	$26.82	$8.00
RESOLVE Total Resource Cost Savings (Million $/yr.)			$4.6
Mid-Curtailment Economic Analysis			
Avoided Energy Costs (Million $/yr.)	$0.50	$2.54	$1.20
Avoided Losses Costs (Million $/yr.)	$0.06	$0.26	$0.12
Generation Capacity (Million $/yr.)	$15.03	$27.45	$6.97
Transmission Deferral (Million $/yr.)	$4.33	$7.91	$2.01
Avoided Emissions Value (Million $/yr.)	$0.94	$4.97	$1.82
Total Avoided Costs (Million $/yr.)	$23.93	$48.76	$13.54
RESOLVE Total Resource Cost Savings (Million $/yr.)			$7.4
High-Curtailment Economic Analysis			
Avoided Energy Costs (Million $/yr.)	$2.01	$4.73	$1.61
Avoided Losses Costs (Million $/yr.)	$0.19	$0.45	$0.15
Generation Capacity (Million $/yr.)	$23.73	$44.25	$11.24
Transmission Deferral (Million $/yr.)	$4.25	$7.92	$2.01
Avoided Emissions Value (Million $/yr.)	$5.76	$9.27	$1.87
Total Avoided Costs (Million $/yr.)	$38.94	$72.24	$18.31
RESOLVE Total Resource Cost Savings (Million $/yr.)			$20.9

Note: All values shown are the difference in results from Water-Energy Bank Scenario and the baseline Scenario. Black values are positive, red values in parentheses are negative.

Source: E3

Not included in the economic analysis is the use of on-site renewables to offset additional costs incurred from additional groundwater extraction pumping from WSWB. Willow Springs Water Bank proposes to construct 40 MW of on-site solar and a 5-MW hydroelectric turbine to generate electricity during groundwater recharge. On-site renewables will generate approximately 97.8 GWh/yr., which is greater than the 53.4-GWh average annual energy need to operate the water-energy bank. For this analysis, energy used to extract groundwater from WSWB came from the grid at wholesale power prices.

The combined benefit streams in the Avoided Cost Framework show a large discrepancy in value between water years; the different curtailment scenarios exaggerate this discrepancy even further (Figure 23). Normal water years are potentially the most beneficial, when surplus operational flexibility is the greatest, while dry years exhibit the least potential benefit. The benefit streams based on peak load reduction, generation capacity, and transmission deferral contribute the most to the overall potential value of the water-energy bank. Generation capacity and transmission deferral benefit streams are significantly greater than avoided energy costs, meaning the water-energy bank will need to provide verifiable peak load reductions to the system to realize its full benefit.

The RESOLVE Framework exhibits lesser total resource cost savings (and therefore lesser calculated benefit of the water-energy bank) than the Avoided Cost Framework because RESOLVE represents fewer capacity-based values. The transmission and deferral value in the Avoided Cost Framework is location-specific. However, the RESOLVE Framework does not represent this same value because the model does not evaluate transmission costs within load-balancing regions (geographic regions that balance energy supply and demand). Furthermore, with new energy storage, solar and other renewable generation, RESOLVE forecasts a surplus of generation capacity resources on the system. The excess of generation capacity resources drives down the value of generation capacity in the RESOLVE Framework and exhibits a lesser overall value compared to the Avoided Cost Framework.

The economic analysis aimed to monetize water-energy bank benefits from the perspective of wholesale market participants, utilities, and the State of California. The Avoided Cost Framework breaks down the value of the water-energy bank into several benefit streams based on existing markets, while the RESOLVE Framework offers an interesting glimpse into the potential added value of integrating renewable energy generation within developing markets. Key stakeholders can then use this economic analysis to determine the economic value proposition of the water-energy bank and whether the project is economically viable.

CHAPTER 5: WSWB On-Site Renewables Evaluation

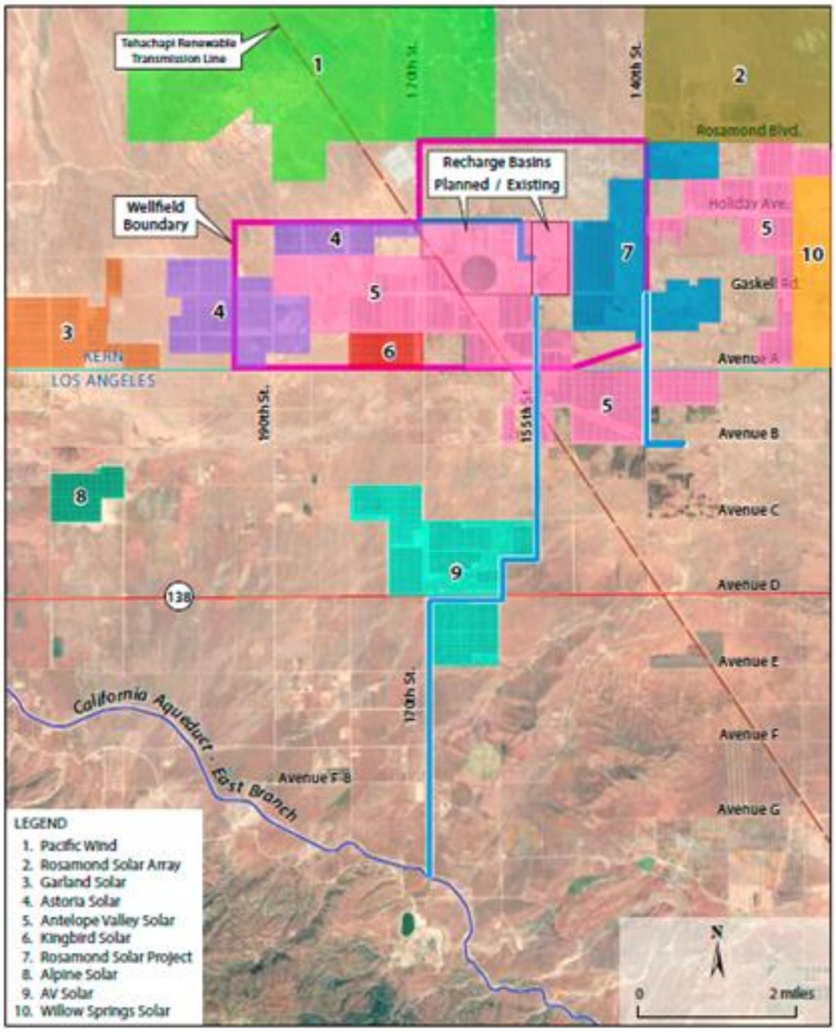
Access to wholesale energy prices is important to the success of the water-energy bank. Without access to wholesale energy prices, WSWB would need to purchase retail power at substantially higher cost for its wells and pumping plant. The water-energy bank could access wholesale power pricing (1) through DWR, which has access to wholesale energy prices, and (2) by installing on-site renewable energy. Institutionally, it may be challenging for WSWB to obtain wholesale power as Southern California Edison may object that the water-energy bank is reducing its potential retail sales. On-site renewable energy may be a more practical option.

5.1 Energy Neutrality

Willow Springs Water Bank will use on-site renewables to power its wells and pumping plant. The goal is to make the water-energy bank "energy neutral" and avoid additional GHG creation. In other words, enough on-site renewable energy will be generated to at least equal the energy requirement of the wells and pumping plant.

Willow Springs Water Bank is in an area with access to large amounts of open land. It is also a prime solar and wind resource area. Willow Springs Water Bank is located near other very large solar and wind facilities (Figure 25), which shows that WSWB is in the center of 10 large solar and wind projects. The large gray circle in the pink area of Figure 25 is roughly the center of WSWB.

Figure 25: Existing Solar and Wind Projects near WSWB



Source: Kern County, Google Earth, 2018

Access to wholesale power prices makes groundwater storage equivalent to drawing down a surface reservoir. It can be accomplished by getting power from an entity that has access to wholesale power prices such as DWR. It can also be accomplished by installing renewable energy on-site, which is institutionally more practical.

On-site generation is necessary to provide the equivalent of wholesale power market pricing. This is to match the wholesale price of power available to the five pumping plants downstream from San Luis Reservoir. Without this access, WSWB wells and pumping plant would have to pay SCE retail prices for electricity. Retail prices are roughly double wholesale prices.

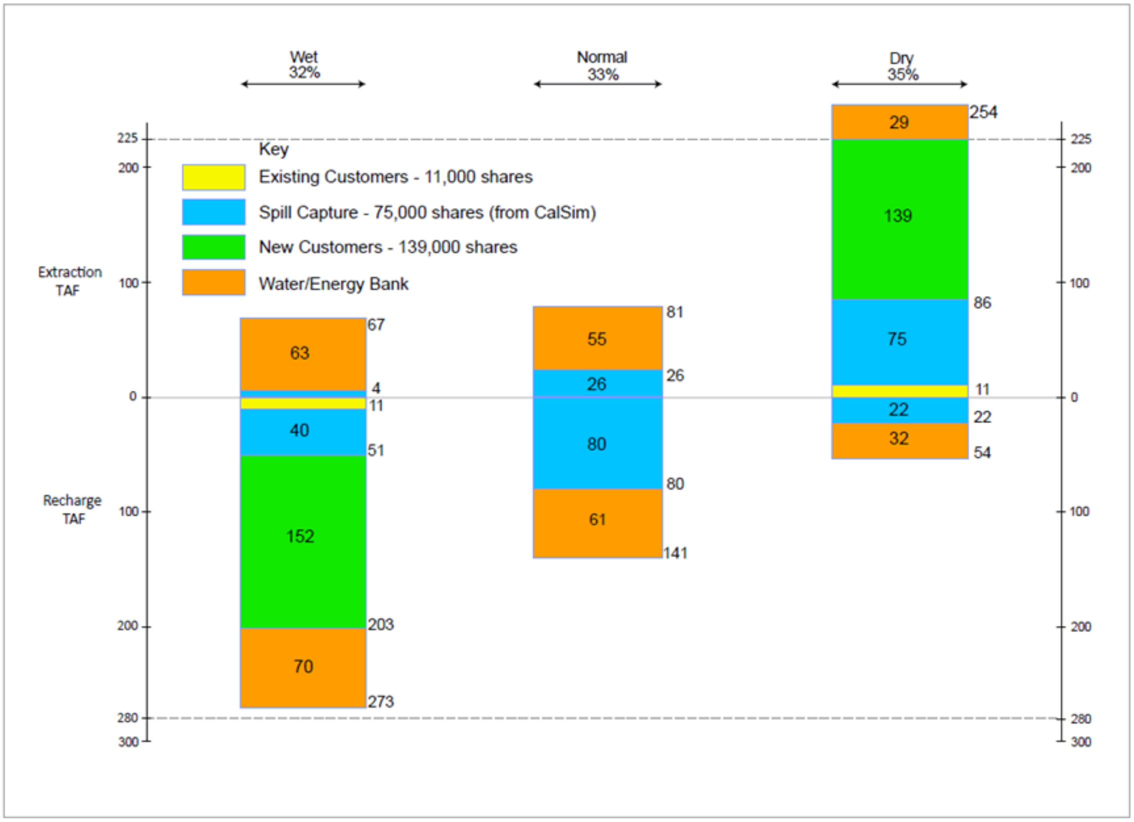
5.2 Multi-Purpose Operations

Willow Springs Water Bank is planning to provide multiple functions from the same water banking facility. This enables traditional water banking for water supply customers, the water-energy bank to shift electric load, and SWP spill capture through conjunctive use (Figure 26).

- Water Bank (Supply) – Water bank operations as a traditional groundwater bank require recharge in a wet year and extraction in a dry year. Willow Springs Water Bank is often idle in an average or normal year when neither recharge nor extraction occurs; typical of most groundwater banks. Willow Springs Water Bank was originally developed using this business model. During most months, WSWB's facilities would be idle.
- Water-Energy Bank – The water-energy bank shifts when imported water is delivered to Southern California. It enables a 4-month seasonal shift. Water is recharged to the water bank in the spring and extracted in the summer.
- SWP Spill Capture – Willow Springs Water Bank can be used to capture spill water that otherwise would flow to the ocean and be lost. This spill capture is used for fish protection, backstopping, water supply, and water basin leave behind. As climate change becomes more pronounced, annual spill capture may increase. Willow Springs Water Bank captures more of these spills as floods intensify in frequency and duration.

Overlapping recharge and extraction operations may help reduce energy needs because in some months, recharge will cancel extractions. For example, recharge in the summer for spill capture will cancel the need for extractions in the summer for the water-energy bank; imported water can simply flow through to Southern California rather than being banked. This saves energy for extraction pumping and money that can be used toward purchasing water from other local sources to account for the 10 percent aquifer leave behind.

Figure 26: Multipurpose WSWB Operations



Source: WSWB

5.3 Multi-Use Analysis

Table 16 through Table 18 show the combined operations of a traditional water bank, SWP spill capture, and the water-energy bank for various hydrologic years. The table provides monthly values in TAF for storing (recharging) water in the groundwater bank and water being extracted from the groundwater bank (negative numbers) by hydrologic year and program.

Table 16: Monthly Operation of Water Supply, Water-Energy Bank, and SWP Spill Capture – Wet Water Years (TAF)

Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Supply	0	12	12	13	13	9	8	8	8	0	0	0
Water-Energy Bank	0	10	10	10	10	-15	-16	-16	-16	10	10	10
SWP Spill Capture	0	0	0	0	0	0	6	7	7	7	7	6

Note: Positive numbers are recharge, negative numbers are extraction. Maximum monthly recharge is 23 TAF. Maximum monthly extraction is 19 TAF. Recharge is 10 percent greater than extraction due to basin leave behind. Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.2.

Source: WSWB, WEC

Table 17: Monthly Operation of Water Supply, Water-Energy Bank, and SWP Spill Capture – Normal Water Years (TAF)

Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Supply	0	0	0	0	0	0	0	0	0	0	0	0
Water-Energy Bank	0	15	15	15	16	-13	-14	-14	-14	0	0	0
SWP Spill Capture	0	0	0	0	0	0	13	13	14	14	13	13

Note: Positive numbers are recharge, negative numbers are extraction. Maximum monthly recharge is 23 TAF. Maximum monthly extraction is 19 TAF. Recharge is 10 percent greater than extraction due to basin leave behind. Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.2.

Source: WSWB, WEC

Table 18: Monthly Operation of Water Supply, Water-Energy Bank, and SWP Spill Capture – Dry Water Years (TAF)

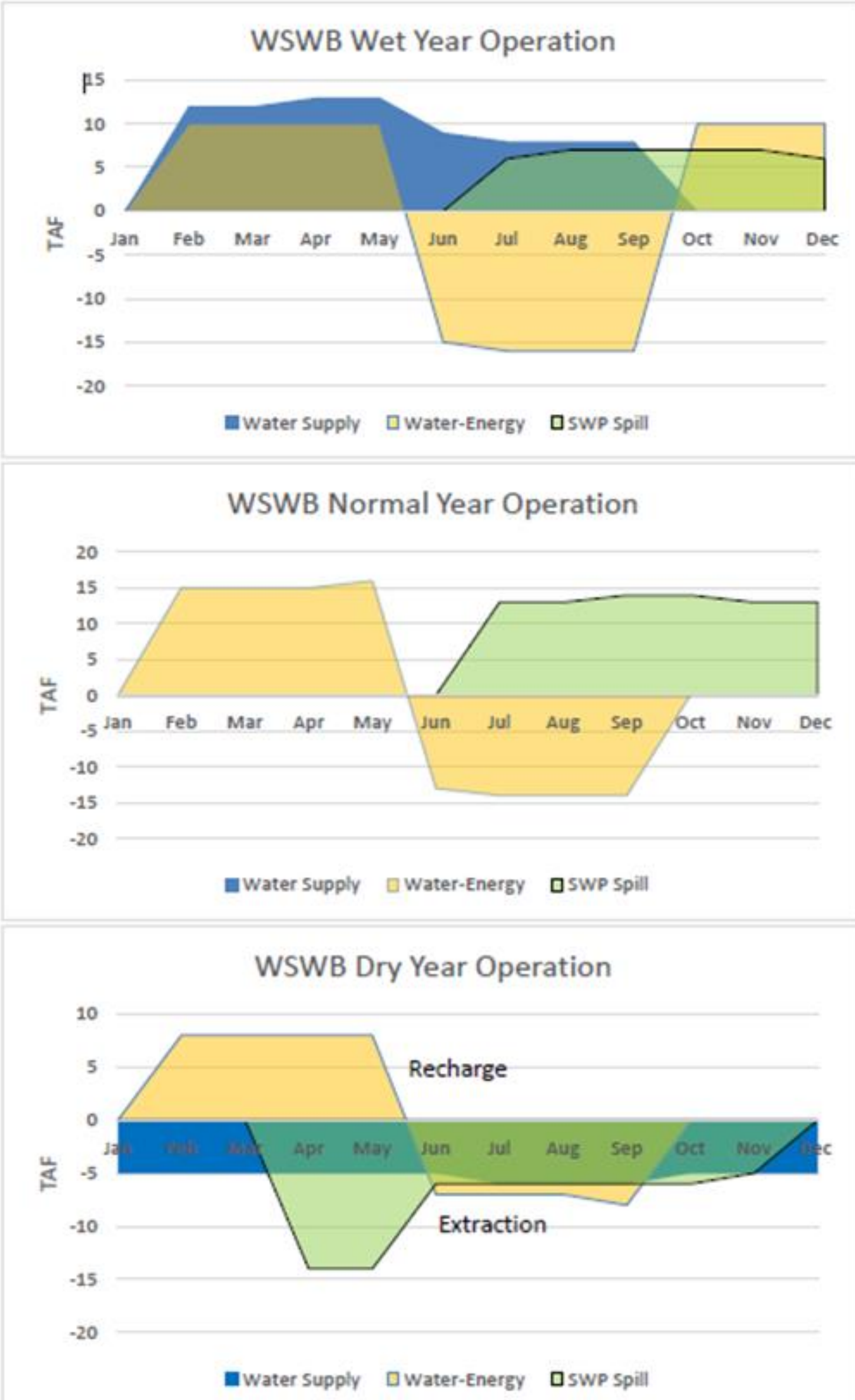
Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Supply	-5	-5	-5	-5	-5	-5	-6	-6	-6	-5	-5	-5
Water-Energy Bank	0	8	8	8	8	-7	-7	-7	-8	0	0	0
SWP Spill Capture	0	0	0	-14	-14	-6	-6	-6	-6	-6	-5	0

Note: Positive numbers are recharge, negative numbers are extraction. Maximum monthly recharge is 23 TAF. Maximum monthly extraction is 19 TAF. Recharge is 10 percent greater than extraction due to basin leave behind. Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.2.

Source: WSWB, WEC

Figure 27 graphically depicts monthly operations of WSWB during the various water-year types, showing recharge (positive values) and extractions (negative values). During wet years all three programs are recharging water at WSWB, and only the water-energy bank seasonal shift operation is doing any extraction. During normal years water-energy bank and SWP spill capture are recharging water, and only the water-energy bank is extracting. During dry years all programs are extracting water from WSWB, and the water-energy bank is continuing to operate as a seasonal shift, withdrawing water during the spring months.

Figure 27: Monthly Operations of WSWB by Hydrologic Year



Source: WEC

Water supply, water-energy bank, and SWP spill capture functions can be accommodated with the same WSWB facilities. Table 19 shows the frequencies of extractions and recharge, by year-type, for the period evaluated for all 3 programs (water supply, water-energy bank, and SWP spill capture).

Table 19: Combined WSWB Operations by Hydrologic Year Type

Water Year Type[1]	Extractions (TAF)	Recharge (TAF)
Wet	67	193
Normal	81	141
Dry	167	54

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.2.

Source: WEC

Energy neutrality depends on the volume of water needed for recharge and extraction at WSWB. Figure 26 shows the projected water bank operations. It shows wet, normal, and dry year annual operations for existing customers, spill capture, new customers, and the water-energy bank. More water is extracted in a dry year. More water is recharged in a wet year. In a normal year, WSWB is less active.

The average energy use in all three water-year types is shown in Table 20. Annual water volumes for the water-energy bank are averaged. The average extractions from WSWB are 48.5 TAF/yr. Extraction energy needs are 1.1 GWh/TAF for well and pump station needs. The average annual need for water-energy bank operations is 53.4 GWh/yr.

Table 20: Energy Needs of WSWB Wells and Pumping Plant by Water-Year Type

Water Year Type[1]	Extraction Flow, All Purposes (TAF[2])	Extraction Flow, Water-Energy Bank (TAF[2])	Energy Need, All Purposes (GWh[3])	Energy Need, Water-Energy Bank (GWh[3])	On-site Energy Generation (GWh)	Net Energy (GWh)	Comments
Wet	67	63	73.7	69.3	**(97.8)**	**(24.1)**	Sell surplus energy to grid
Normal	81	55	89.1	60.5	**(97.8)**	**(8.7)**	Sell surplus energy to grid
Dry	254	29	279.4	31.9	**(97.8)**	181.6	Buy SCE energy

Note: Black values are positive, red values in parentheses are negative.

[1] Water year types are based on Climate Changed Sacramento Valley Index based year types, as described in Section 3.2.

[2] From Figure 26.

[3] Energy needs based on 1.10 GWh/TAF for well and pump station lifts

Source: WEC, E3

Average energy produced from the 40 MW of solar and 5.2 MW of hydro is 97.8 GWh. This is based on 40 MW of solar arrays producing 10 MW of net power (25 percent of the nameplate capacity) and the hydro producing 1.16 MW per the *Multiple Usage Analysis* working paper (Water and Energy Consulting, 2018).

The overall energy produced on-site of 97.8 GWh/yr. is greater than the 53.4 GWh/yr. needed to operate the water-energy bank. On-site generation is also greater than the average energy requirement for the water-energy bank in all three water-year types. This meets the requirement for energy neutrality. Total on-site energy is greater than average annual needs because pumps cannot be shut off when the sun goes down. On-site reservoirs enable water supply during the non-solar hours, but some pumping is still needed.

5.4 Initial Screening

The process used to evaluate on-site renewables is shown in Figure 27 and Figure 28. An initial screening was performed, followed by field studies. The initial screening was used to rule out impractical options. The field studies were needed to determine if the details of on-site renewables could actually be installed and operated.

The water-energy bank builds on prior energy studies. Those include EPC-15-049, *Groundwater Bank Energy Storage Systems*. That study established the optimal size of an on-site hydroelectric turbine at 5.2 MW. It also developed locations for two on-site reservoirs needed for pumped storage: a lower reservoir at WSWB and an upper reservoir near the California Aqueduct. Both reservoirs could hold 103 AF in size.

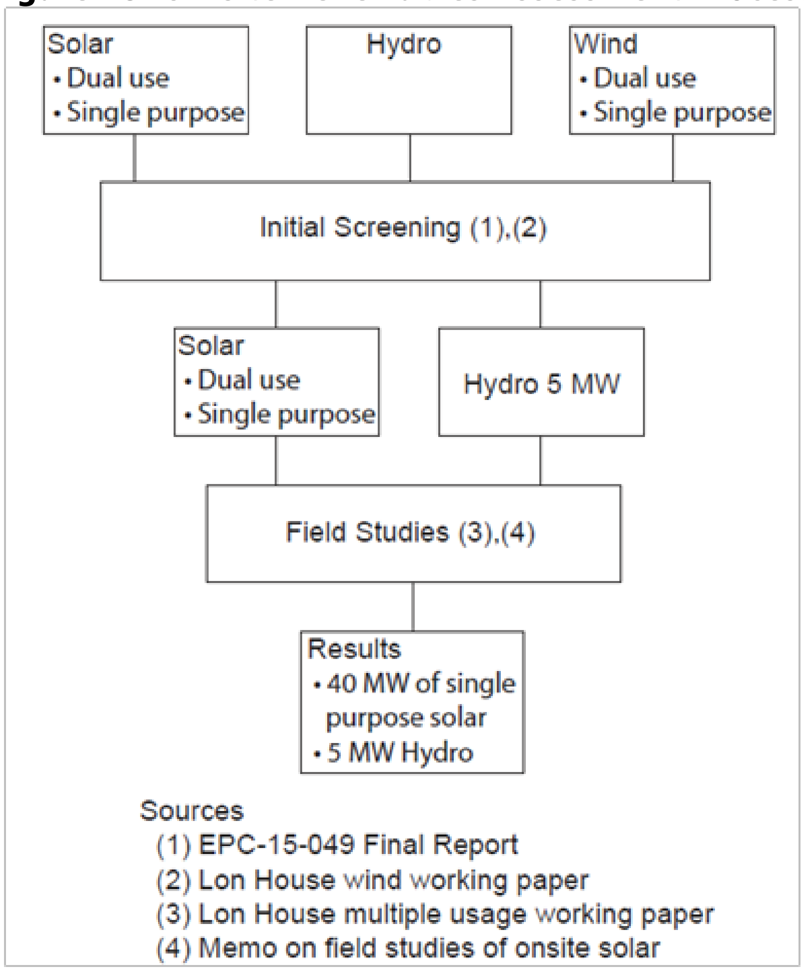
Additional studies by Water and Energy Consulting established that 40 MW of solar and 5.2 MW of hydro would make the water-energy bank energy neutral (Water and Energy Consulting, 2018). They also include an evaluation of on-site wind potential (Water and Energy Consulting, 2017). On-site renewables could be built on land dedicated to that single-purpose or on land used for percolation ponds.

An analysis was performed to determine the best way to install renewable generation on site. Solar, hydro, and wind were evaluated. Both single-purpose and dual-purpose wind and solar facilities were evaluated. Single-purpose renewables would be built on dedicated land. Dual purpose solar and wind would be built on top of percolation ponds. On-site hydro was assessed as part of a prior Energy Commission EPC-15-049 project (California Energy Commission, 2017).

An initial screening of the on-site options eliminated nonviable options. On-site solar and hydro were determined to be viable. This is partly based on the large number of nearby solar facilities. The area is well suited for solar power. The EPC-15-049 study established the viability of on-site hydro.

On-site wind was found to be nonviable (Water and Energy Consulting, 2017). This is due to local opposition to utility scale wind turbines in the area. Local opposition groups are well organized and have made it clear that they do not want any more wind turbines built in their community due to their aesthetic impact. Additionally, wind power is not as economical as on-site solar.

Figure 28: On-site Renewables Assessment Process



Source: WSWB

5.5 Field Evaluation

Hydropower turbines are a well-established technology. No field studies were necessary. They can be incorporated into the planned pump station design.

On-site solar was assessed for single-purpose and dual-use solar arrays. Single-purpose solar is well established so no further field studies are needed. Dual-use solar is novel. It involves the construction of a solar array on top of existing percolation ponds. Most of the uncertainty involves operational issues: is the operation of percolation ponds compatible with the operation of a solar array with single axis trackers?

Preliminary design drawings and plan views for 160-acre and 320-acre dual-use solar arrays were developed. This was done in conjunction with SunPower Corporation, a major provider of solar equipment. A non-disclosure agreement was signed with SunPower to protect its intellectual property of being able to operate a solar array above standing water in the ponds. Consequently, no details are included in this memo other than that the panels would be 9 feet off the ground. Vehicles to maintain the solar array would have to pass underneath the trackers and on top of the percolation pond area.

Operators of WSWB and other water banks were consulted regarding pond maintenance under solar panels. These operators included staff from Rosamond Community Services District, Kern Water Bank, and the Water Replenishment District of Southern California. Two problems were discovered. The first is that a backhoe needed for routine maintenance and pipe repairs is 11 feet high. It could not be operated under solar panels that are 9 feet off the ground.

Additionally, it was determined that vehicles with rubber tires should not be used on percolation ponds. They compact the soil. This necessitates more frequent ripping or scrapping. Only tracked vehicles should be used on percolation ponds. Contact with the percolation soils should be avoided if possible. Because vehicles with tires are required to maintain solar panels, the dual-use solar option was determined to be nonviable.

Willow Springs Water Bank plans to operate in most water-year types (Figure 27). This means it will not have long periods when it is idle. Most water banks, however, percolate in wet years, extract in dry years, and may be idle in normal years. Because WSWB will operate more frequently than that, it is important to be conservative in operational assumptions. Drying cycles will be incorporated into operations and land acquisition for recharge basins. It is assumed that percolation ponds will need to be in a drying cycle about 1/3 of the time. This necessitates requiring about 50 percent more land so that 1/3 of the basins can be out of service for drying.

No additional field work was performed on site because both the recommended on-site hydropower turbine and single-purpose solar arrays are well-developed technologies.

5.6 WSWB On-Site Renewables Conclusions

Based on a multiple usage analysis, 40 MW of on-site solar and a 5.2-MW hydroelectric turbine are needed to make WSWB energy neutral. These will be installed on site or on nearby lands, and will generate approximately 97.8 GWh/yr., which is greater than the 53.4 GWh/yr. needed to operate the water-energy bank.

Installation of on-site renewables must be coordinated with the build-out of WSWB. Willow Springs Water Bank must be built out first because the wells cannot extract water until water is in WSWB. On-site renewables should be built after the recharge facilities are operational.

CHAPTER 6: Benefits and Limitations of Study

This study evaluated the potential to shift SWP water deliveries from high energy-demand periods to low energy-demand periods using WSWB aquifer storage facilities as a water-energy bank. This chapter summarizes the benefits and limitations of the water-energy bank.

6.1 Study Benefits

The water-energy bank's role as a flexible load resource provides benefit to California by shifting load out of hours when energy costs are highest and demand is greatest, into hours with lower costs and lower demand. The water-energy bank can shift 18.6 GWh/yr. to 108.2 GWh/yr. of energy out of the peak summer months, depending on water-year type. This shift directly results in lower wholesale energy costs to deliver water to Southern California. Department of Water Resources and SWP contractors will see a reduction in average energy costs as a result of their participation in the Water-Energy Bank Project. The primary benefit of the water-energy bank, however, accrues to the grid. Reducing peak demand reduces the need to operate expensive peaker plants, while less strain on the electric grid defers upgrades to the transmission system, benefitting investor-owned utilities and California ISO. Under the avoided cost analysis framework, the average total avoided cost value for the low, mid, and high-curtailment scenarios were $12.6, $23.1, and $38.0 million per year, respectively. Under the RESOLVE framework, the average total avoided cost value for the low, mid, and high-curtailment scenarios were $4.6, $7.4, and $20.9 million per year, respectively. The higher value found in the Avoided Cost Framework is largely driven by significant generation capacity value. In all cases, the water-energy bank presents new operational flexibility to the SWP, which reduces operating costs.

The Water-Energy Bank Project will help California integrate renewable energy and operate the grid at lower cost. By pre-delivering SWP water in spring months, energy demand increases in periods at risk of generation curtailment. Generation curtailment is necessary when there is an oversupply of renewable energy generation. Utilizing excess power in spring months means more of California's energy demand can be met by available renewable resources. Operation of the water-energy bank reduces the need for peak power, reduces peak transmission capacity, and increases renewable generation.

6.1.1 Greenhouse Gas Emission Reduction Benefits

One benefit of the Water-Energy Bank Project is to help California cost-effectively achieve its mandated goal of 100 percent carbon-free electricity and associated GHG emission reductions by 2045. The water-energy bank, and its associated on-site renewable power electricity have total emissions reductions of 15 to 60 ktCO_2-e/yr. in the mid-curtailment scenario. This is the equivalent of removing 3,000 to 12,500 passenger vehicles off the road (Figure 29), or delivering that energy to 1,600 to 6,500 homes.[10] The addition of on-site generation provides enough additional emissions offsets for the total project to, on average, have emissions reductions in each water-year type, and in each scenario.

Figure 29: The Water-Energy Bank, and the Associated WSWB Reduce Emissions

Total GHG emissions reductions of 15 to 60 ktCO_2-e/yr. is the equivalent of removing 3,000 to 12,500 passenger vehicles off the road.

Source: Google

Figure 22 (Chapter 4) shows total emission reductions (in thousand tons of CO_2-equivalent per year (ktCO_2-e/yr.) in 2030 for each curtailment scenario. There are significant emission reductions in each scenario, with normal water years showing the greatest potential avoided emissions. The difference in emissions between scenarios depends on two primary factors – the extent of flexibility in the system and the number of hours with zero emissions generation on the margin to shift load. For example, in summer evening peak hours, if a hypothetical inefficient natural gas combustion turbine

10 EPA Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

is on the margin, a decrease in pumping load will correspond with a reduction of load. The combustion turbine will respond to the reduced load, decreasing emissions. Conversely, during spring peak-solar hours, if a hypothetical solar generation plant is being curtailed (the marginal resource), an increase in pumping load would force the solar generator on-line, resulting in no emissions increase.

By modifying SWP operations to utilize excess renewable generation, the water-energy bank avoids emissions from inefficient natural gas peaker plants. As a result, California is able to reach its SB100 targets at a lower cost to the State.

6.1.2 Water Supply Reliability Benefits

This study analyzed a potential scenario in which SWP water is released from San Luis Reservoir and stored in the WSWB aquifer water storage project in the spring to allow a reduction of SWP pumping in the summer. To replace the summer water not delivered through the SWP aqueduct, the pre-delivered water is extracted from WSWB and moved back into the aqueduct to maintain water supply deliveries.

Having additional water storage available in the Southern part of the SWP system provides an opportunity to shift SWP pumping into lower energy demand periods, while maintaining the quantity, reliability and timing of water deliveries to Southern California. Many agricultural, municipal and industrial operations in Southern California rely heavily on DWR to deliver their allocated SWP water reliably and on schedule. The water-energy bank's ability to maintain all aspects of water supply reliability, quantity, and timing of deliveries to Southern California while reducing costs and GHG emissions represents a significant potential benefit to DWR and the SWP water users and the State of California.

6.2 Study Limitations

There are a variety of factors that constrain or limit the evaluation of the effects from a shift in SWP pumping from high to low-energy demand periods. Physical constraints include water availability, canal capacity, WSWB and San Luis Reservoir available storage, pump ramping rates, and WSWB extraction capacity. Also, a variety of contractual, physical, and operational factors, together with other potentially conflicting policies, could limit flexibility for modifying operations within this subset of SWP facilities. These include SWP water supply contract terms, deliveries of water, carryover storage requirements, unknown future changes in operation, and storage policies. Results of this study have shown that there are financial incentives to shift SWP pumping into lower-energy-demand periods, but other factors must still be overcome to fully realize the project.

Diversions from the Delta are limited based on DWR's water rights, biological opinions, agreements, and other regulatory constraints. Water quality and fish-flow requirements in the fall, winter, and spring restrict Delta diversions, but there are fewer restrictions in the summer months during the periods of peak water supply demand. State Water

Project water deliveries have helped shape California's development for over half a century. During that time, many conditions that affect SWP operations have evolved. While California's population has grown dramatically, the experience of recent droughts has led to the enactment of new laws aimed at reducing water use. Meanwhile, market conditions and an increase in the value of water have driven a change in cropping patterns across California, leading to more permanent crops and a hardening of agricultural water demand. While these factors have generally increased the need for reliable delivery of SWP water supplies, many other emerging issues increasingly constrain SWP operations.

State and federal regulations restrict SWP exports from the Sacramento-San Joaquin Delta at certain times and under certain conditions. These regulations continue to evolve as a result of efforts by agencies including DWR, USBR, and the California State Water Resources Control Board. The net effect of the agencies' most recent efforts to monitor and control Delta water exports will likely include additional regulatory constraints on SWP operations.

Both the regulatory environment affecting the SWP and the physical environment continue to evolve. Climate change is affecting the amount of snowpack expected in the Sierra Mountains, placing more stress on water-storage operations. Warmer temperatures are generally increasing water use of native vegetation and landscaping across the State. Sea level rise threatens coastal communities and increases risk of levee failure in the Sacramento-San Joaquin Delta, which would affect SWP operations.

State Water Project water deliveries are also subject to the terms of long-term water-supply contracts. These terms include requirements for distributing annual water deliveries on a monthly basis for specific SWP contracting agencies. In addition to annual water deliveries, SWP water contracting agencies have contractual rights to delivery of intermittent water supplies, carryover supplies, and exchange and transfer water supplies. Scheduling these deliveries requires close coordination between DWR and the SWP contracting agencies. Changes to SWP operations (volume and timing of water deliveries) that include WSWB will need to account for water delivery scheduling consistent with the SWP long-term water-supply contracts. The quantity and timing of deliveries to water users were not changed relative to the baseline in the analysis.

Physical limitations of the Water-Energy Bank Project include WSWB extraction capacity and the capacity of SWP pumping plants and conveyance facilities. The water-energy bank analysis assumed pumping and power use at the five pumping plants in the analysis could shift from peak demand periods (when energy cost is high) to lower-demand periods when energy cost is lower. This assumption involved a maximum ramping rate of four pumps on or off per hour, based on historical pumping data. State Water Project pumping plants are also limited by both planned and unplanned equipment outages. For example, DWR is implementing a long-term program to replace the original pumps at Edmonston Pumping Plant with higher-efficiency units.

Because of WSWB extraction capacity limitations, more water can be delivered in spring months than in summer months. By limiting extraction well pumping during summer months to avoid pumping in more expensive peak demand hours, groundwater extraction constraints limit seasonal shifts in SWP deliveries by 20.4 TAF/yr., on average. Insufficient flow capacity in the California Aqueduct can also limit seasonal shifting. In wet years, deliveries to SWP contractors are less constrained and often utilize most, if not all of the capacity of the California Aqueduct south of San Luis Reservoir. As a result, there is limited available capacity to pre-deliver water in spring months.

In addition, rehabilitation of aging infrastructure places operational constraints on SWP facilities. For example, construction of new spillway facilities after the failure of the main spillway at Oroville Dam in 2017 placed constraints on storage levels in Lake Oroville. Additionally, subsidence from over-pumping groundwater aquifers in the San Joaquin Valley has reduced conveyance capacity in sections of the California Aqueduct. Ongoing subsidence is likely to further reduce conveyance capacity. These limitations affect the maximum amounts of water that the SWP can convey to Southern California under the most potentially constrained circumstances.

While acknowledging these limitations, it is the conclusion of the team that there are significant potential benefits to be realized from shifting SWP pumping into lower-demand and lower-cost periods, using aquifer storage to make that shift.

CHAPTER 7: Conclusions and Recommendations

7.1 Conclusions

The following summarizes the water-supply and water-management conclusions of this report:

- A significant limitation in minimizing pumping during peak energy consumption hours is the maximum ramping rates of SWP pumps.
- Using additional storage in the southern part of the SWP, like WSWB, creates opportunities for DWR to operate SWP pumping plants to reduce energy-related operating costs while maintaining SWP water deliveries.
- Additional water storage (WSWB) in Southern California benefits overall water supply reliability for SWP contractors. Full build-out of WSWB will create opportunities to sell aquifer storage to other water users including Antelope Valley-East Kern Water Agency, Metropolitan Water District of Southern California, and San Diego County Water Agency.
- Current DWR operations make use of available flexibility of the SWP, while focusing on water supply reliability and infrastructure management. There are opportunities to modify SWP operations to take advantage of daily energy price variability while maintaining water supply deliveries, using existing infrastructure.
- Operation of SWP pumping plants to take advantage of daily energy price variability will cause additional starts and stops of pumps, in turn causing additional wear and tear on pump infrastructure, possibly increasing the cost of routine operations and maintenance. This added cost was not included in the water-energy bank analysis.

The following summarizes energy and economic conclusions:

- Department of Water Resources has historically managed SWP operations to reduce energy use during peak energy consumption hours. From 2008 through 2017, average total summer power requirement for the Valley String pumping plants was 596 MW, which was reduced to 321 MW during peak energy consumption summer hours.
- If an Edmonston ramping rate of four pump units per hour was implemented consistently, the historic average power requirement during peak energy consumption hours could have been further reduced from 321 MW to 113 MW, a 208-megawatt reduction.
- The Water-Energy Bank Project is in alignment with State policy (SB100) regarding renewable resources targets and GHG emission reduction targets.

- The Water-Energy Bank Project will help California integrate renewable energy and operate the grid at lower cost. Under the avoided cost analysis framework, the average total avoided cost value for the low, mid, and high-curtailment scenarios were $12.6, $23.1, and $38.0 million per year, respectively. Under the RESOLVE framework, the average total avoided cost value for the low, mid, and high-curtailment scenarios were $4.6, $7.4, and $20.9 million per year, respectively. The higher value found in the avoided cost framework is largely driven by significant generation capacity value. In all cases, the water-energy bank presents new operational flexibility for the SWP, which reduces operating costs.
- The water-energy bank addresses the imbalance in seasonal energy supply and demand by shifting energy consumption out of summer months and into spring months when there is ample solar and wind generation but relatively low demand for power. The water-energy bank can reduce summer peak energy consumption by 18.6 GWh/yr. to 108.2 GWh/yr., depending on water-year type.
- On an average summer day, the water-energy bank can reduce instantaneous peak load by as much as 1,480 MW and an average of 296 MW (based on model output, an Edmonston pump ramping rate of 4 units per hour, and on the maximum power usage of the five pumping plants south of San Luis Reservoir).
- Generation capacity, transmission deferral and demand response benefits are the most significant potential benefits from the water-energy bank. This is driven by the high cost of capacity resources on the grid. The water-energy bank effectively shifts load from capacity-constrained peak summer hours to less-constrained spring hours.
- State Water Project operations can be modified to use excess renewable generation and avoid GHG emissions from less efficient natural gas peaker plants. The water-energy bank, and its associated on-site renewable power generation have total emissions reductions of 15 to 60 ktCO2-e/yr. This is the equivalent of removing 3,000 to 12,500 passenger vehicles and further advances California's efforts to reach its SB100 targets at lower cost to the State.
- Department of Water Resources and water users benefit by moving water in lower-cost periods, which reduces energy costs. Cost-saving benefits will depend on actual wholesale market prices. The increased supply of renewable energy envisioned by SB100 is likely to increase the frequency of lower-cost periods in the spring. This increases the value that the water-energy bank provides.
- Greater societal benefits of this project include helping to stabilize wholesale power prices, reducing GHG emissions, reducing solar curtailment, and reducing the need for new infrastructure to meet the State's energy goals.
- Planned on-site solar energy production will help offset the cost to extract water from WSWB in high-price summer months.

- The cost analysis did not include the cost to implement the water-energy bank, which is outside the scope of this study.

While this report provides an analysis of the potential opportunities associated with using the WSWB as a water-energy bank, it is not a feasibility report. Willow Springs Water Bank is first and foremost a water storage facility, with its greatest benefits derived from storing surface water and later extracting it, as described for the baseline scenario. This report identified the potential benefits to the SWP of using WSWB to facilitate shifting pumping load throughout the SWP aqueduct from summer months to spring months without compromising water supply reliability to SWP customers. This report has characterized the potential economic benefits, both in terms of the avoided costs associated with the energy costs to move SWP water, and in terms of reducing the need for additional generation and transmission assets to support the summertime load. The report does not, however, include any additional O&M costs associated with wear and tear from increased starts and stops of pumping units; nor does the report include the "leave-behind" water lost from the groundwater bank. Both of these elements would be required to identify the potential long-term viability of WSWB as a water-energy bank, and would require analysis outside of the scope of this report.

7.2 Implementation and Next Steps

Implementation of this project requires crossing institutional boundaries between many state and local entities. State officials have typically not considered substantial modifications to the water infrastructure to be an integral part of helping the grid meet energy needs. However, since the SWP uses a relatively large percentage of California's peak-load energy, it presents a unique opportunity to explore novel approaches to shift SWP pumping loads to low-demand periods.

California's environmental targets mandate, through SB100, that generation be 100 percent carbon free by 2045. This ambitious goal will require significantly more renewable energy and energy storage. Load shifting, a benefit of the water-energy bank, is a critical component in addressing the evening ramp-up created by more on-line renewables. The water-energy bank's ability to shift seasonal load is especially valuable to avoid curtailment of renewable generation.

The water-energy bank provides new demand-response capabilities, using existing infrastructure. Current water delivery practices can be modified to provide energy benefits. The use of primarily existing infrastructure makes implementation both fast and cost-effective. Other than the addition of on-site renewable energy facilities to power the groundwater extraction wells, the project does not require any new infrastructure.

The primary institutional barriers result from the diverse entities that must cooperate to achieve potential demand-response and load-shifting benefits. To implement the project, DWR must adjust its operations and SWP contractors must agree to a seasonal change in the source of their water. Similarly, as the beneficiaries, utilities must finance the necessary incentives to enable this demand response, and California ISO must coordinate the benefits.

Once state and local agencies overcome the institutional barriers and WSWB is built out, operation of the entire water-energy bank can begin. Willow Springs Water Bank's anticipated full build-out date is 2028. Prior to that time, the water-energy bank can partially operate.

A demonstration project, conducted with DWR and the Energy Commission, is recommended as a next-step follow-up to yield vetted performance data and devise practical strategies to overcome institutional barriers. To accomplish this, the Recipient will monitor and respond to the Energy Commission's technology demonstration and deployment program area funding opportunities that are aimed at peak load shaving. In the interim, the Recipient will continue the build-out of the WSWB as well as continue its outreach to relevant parties, including DWR, to get them on board for the demonstration.

7.2.1 Other Potential Opportunities to Provide Energy-Related Benefits to the State Water Project

Additional storage at strategic locations along the SWP may provide additional operational flexibility. There are areas near the SWP with suitable soil and aquifer characteristics both upstream of the Edmonston Pumping Plant in the San Joaquin Valley and downstream in the Southwest Mojave Desert.

Among the other technologies that could provide seasonal pump-load shifting opportunities are large Central Valley farming operations and other large aqueduct systems in California and groundwater banks. An investigation was conducted to evaluate the potential for load shifting from these three areas of opportunity.

Agricultural electricity use is derived heavily from groundwater pumping and water-year type. In dry years, growers increase pumping of their wells to offset decreased surface water supplies. This variability in agricultural electric load, based on water-year type, makes it difficult to anticipate demand on the grid. However, using largely existing infrastructure and configuring agricultural pumping operations to provide advanced demand response guarantees that the load will not occur during the peak. Agricultural advanced demand response can shift SWP water deliveries by using the aquifer as the lower reservoir and surface storage as the upstream reservoir to meet water demands when well pumps are off (instead of being used for peak hydroelectric generation, as in conventional pumped storage).

Similarly, aqueduct systems built to convey water around the State can be a new source of large-scale advanced demand response. Because water can easily store energy on a seasonal basis, aqueduct advanced demand response can shift water deliveries out of the summer and into the winter and spring months to address seasonal energy mismatches.

Daily advanced (bi-directional) demand response at Central Valley agricultural operations could ultimately shift 1,113 MW of California's agricultural electric load. Combined with up to 431 MW of the aqueduct pumping load, this totals 1,544 MW of advanced demand-response potential. Shifting water delivery to the curtailment season is equivalent to seasonal energy storage and provides unique capabilities to increase renewable generation use that cannot be duplicated by batteries. There would not be a change in the amount of water pumped or delivered, just a shift in the timing of its pumping.

The major impediments to advanced demand response of agricultural systems and aqueducts are market, institutional, and financial. Market barriers come from a lack of established ways to monetize this alternative to building new sources of energy storage. Institutional barriers exist because water infrastructure is owned and controlled by a wide range of growers and water agencies that must agree to cede partial control to others. Growers and aqueduct system operators must be confident that their water reliability will not be compromised, that daily and annual deliveries will remain the same, that electric rates will be stable and predictable, and that their costs will be reduced. Financial barriers exist because funding must be found to pay for the water storage facilities necessary to make this work.

Field testing and future research is needed to develop the technical, financial, and operational resources and tools needed to enable rapid commercialization of advanced demand response throughout the State and drive up the time-of-use participation rate to 95 percent. Future research should focus on developing the necessary mechanisms to change the status quo and shift the peak electrical load associated with aqueduct and groundwater pumping facilities. Implementation could be rapid as utilities implement the new rate structures that strongly reward off-peak pumping. Water storage is relatively inexpensive and well established, especially when built in rural areas. The mechanism to finance new water storage is one of the barriers that needs to be overcome with recommended demonstration projects. Once the cost advantages of pumping only during the off-peak period is demonstrated, the technology can spread rapidly.

Similar to agricultural and aqueduct systems in California, other groundwater banks that receive water from the SWP have the potential to help shift load out of peak periods by enhancing storage and increasing flexibility in SWP aqueduct operations. Groundwater banks, specifically those south of Edmonston Pumping Plant, can use the principles demonstrated by the WSWB study to pre-deliver SWP water during the spring, when energy prices are relatively low, allowing for a reduction in SWP pumping in the summer, when energy prices are relatively high.

Twelve existing aquifer recharge projects south of Edmonston Pumping Plant were identified as potential candidates to provide supplemental storage in the vicinity of the aqueduct. A variety of conditions were assessed for each of these aquifer recharge projects, including location, infrastructure, contracts, and operational flexibility.

Due to the unavailability of quantified information about the groundwater banks' recharge and extraction capacity and the amount of SWP water they receive, it is not presently possible to characterize the amount of seasonal SWP load shifting possible through a re-operation of other Southern California groundwater banks. However, sufficient information was gathered to identify potential candidates for further study, as well as eliminate several candidates from further study. Based on available information regarding their facilities and operations, the groundwater banks were categorized into three tiers: (1) Tier 1 candidates are optimal for participation in a water-energy banking program; (2) Tier 2 candidates demonstrate potential for participation in a water-energy banking program but pose some challenges; and (3) Tier 3 candidates are poor candidates for participation in a water-energy banking program and should be excluded from further analysis. Table 21 summarizes the aquifer recharge projects classified as Tier 1 and Tier 2 candidates.

Table 21: Tier 1 and Tier 2 Potential Candidates for a Water-Energy Bank Program

Water Bank Operating Agency	Primary Function	Access to SWP Water Supply
Tier 1 Candidate		
Antelope Valley-East Kern Water Bank	Water supply/Groundwater basin management	SWP Table A Contractor (144,844 AF/yr.)
Tier 2 Candidates		
Mojave Water Agency	Water supply/Groundwater basin management	SWP Table A Contractor (85,800 AF/yr.)
Orange County Water District	Water supply/Groundwater basin management	Subcontractor to MWD
San Bernardino Valley Municipal Water District	Water supply/Groundwater basin management	SWP Table A Contractor (102,600 AF/yr.)
Three Valleys Municipal Water District	Water supply/Groundwater basin management	Subcontractor to MWD

Source: HDR

The Tier 1 and Tier 2 candidates have the potential for participation but require further research to refine opportunities for participation in a water-energy banking program and quantify possible benefits of seasonal load shifting. Direct engagement with each of the groundwater recharge projects' operating agencies is likely necessary to collect information that was not available for this study, such as information about aqueduct and pipeline capacities, recharge capacity, extraction capacity, and the amount of SWP water recharged. With this information, a study similar to the one conducted for WSWB could be completed and the groundwater bank's potential for seasonal SWP load shifting realized.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AF	acre-feet
AVEK	Antelope Valley East-Kern Water Agency
BTU	British thermal unit
California ISO	California Independent System Operators
CalSim II	A water operations model developed to simulate the CVP and SWP.
cfs	cubic feet per second
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent; a common unit for quantifying greenhouse gas emissions as an amount of carbon dioxide which would have an equivalent global warming impact
CPUC	California Public Utilities Commission
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
Demand Response	Change—typically a decrease—in end use electricity consumption to balance supply and demand on the electric grid, often during peak hours
DER	Distributed energy resources
DWR	California Department of Water Resources
E3	Energy+Environmental Economics, Inc.
EO	Executive Order
EPIC (Electric Program Investment Charge)	The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
GEI	GEI Consultants, Inc.
Generation Capacity	Peak electricity output of all power plants connected to a given electric system, designed to meet or exceed the peak system demand

Term	Definition
GHG	greenhouse gas
GW	gigawatt
GWh	gigawatt-hours
HDR	HDR, Inc.
IRP	Integrated Resource Planning
$ktCO_2$-e/yr.	thousand tons carbon dioxide-equivalent per year
kWh	kilowatt-hours
MAF	million acre-feet
MW	megawatt
MWh	megawatt-hours
O&M	operations and maintenance
Project	Water-Energy Bank Project
RESOLVE	Renewable Energy Solutions; an economic model simulating the California power/energy systems and markets.
RPS	Renewable Portfolio Standard
SB	Senate Bill
SCE	Southern California Edison
SWP	California State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TOU	Time of Use
Transmission Capacity	Peak electricity throughput of a transmission system using existing transmission infrastructure
USBR	United States Bureau of Reclamation
WEC	Water and Energy Consultants, Inc.
WSWB	Willow Springs Water Bank
/yr.	per year

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