BUREAU OF RECLAMATION

Executive Summary

San Diego Basin Study

U.S. Department of the Interior

City of San Diego
Public Utilities Department

December 2021

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The mission of the City of San Diego Public Utilities Department is to provide reliable water utility services that protect the health of our communities and the environment.

Cover Image: Lake Murray Reservoir, operated by the City of San Diego since 1950, was analyzed in the Basin Study as a site for a potential stormwater capture project. (courtesy City of San Diego)

San Diego Basin Study

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prepared by

Bureau of Reclamation
Lower Colorado Region
Engineering Services Office
Allison Odell, PE, Civil Engineer

City of San Diego
Public Utilities Department
Sarah Brower, Ph.D., Senior Water Resources Specialist
Andrew Funk, Natural Resources Planner

Bureau of Reclamation
Lower Colorado Region
Southern California Area Office
Leslie Cleveland, Water Resources Manager

Residents convert turf to water efficient landscapes as part of the City of San Diego's Water Conservation Program.
Courtesy City of San Diego

Contents

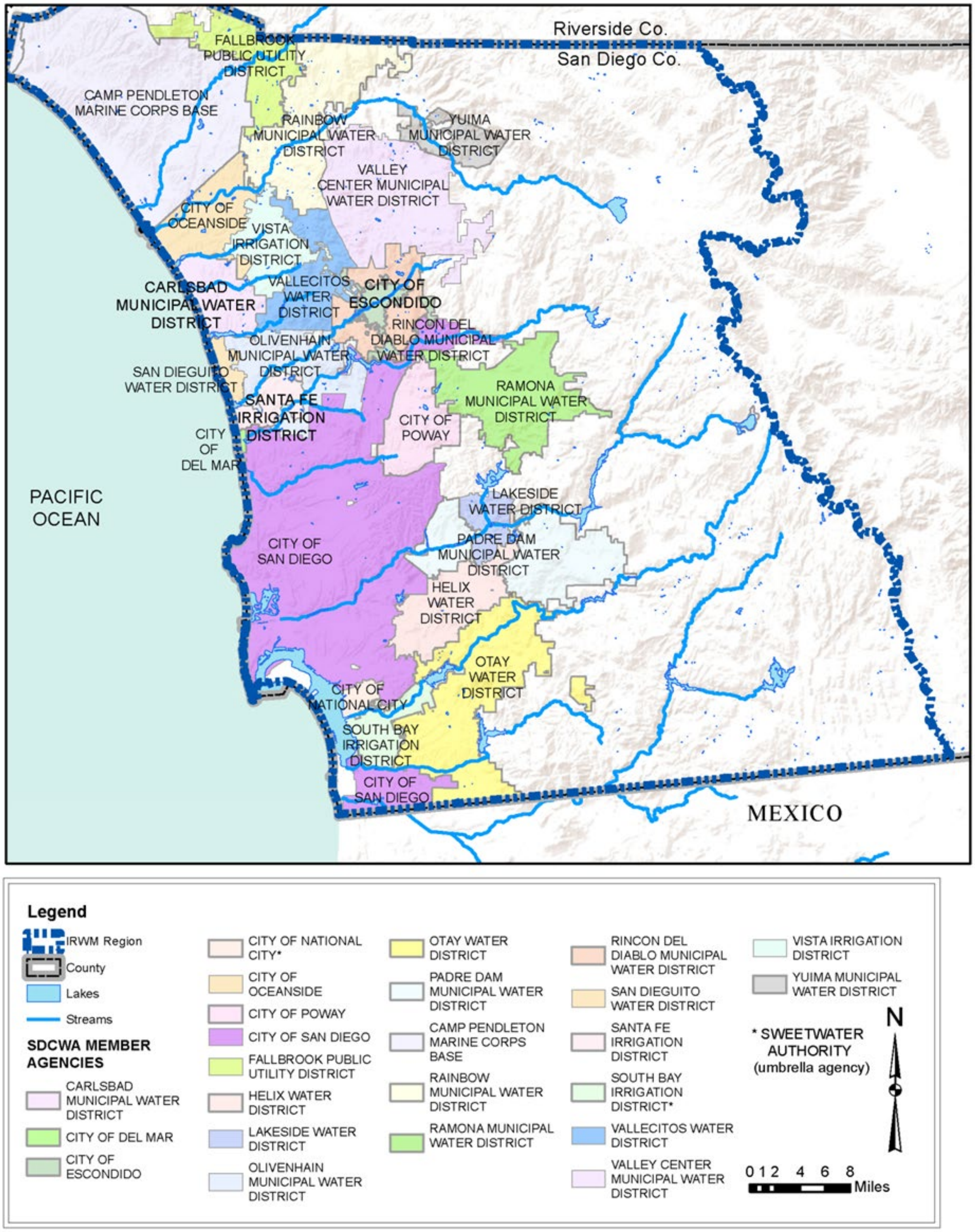


Figure 1. San Diego Basin Study Area. The Study Area delineates the area for which water supplies and demands were examined in the Basin Study. It is equivalent to the planning regions of the San Diego Integrated Regional Water Management Program and the San Diego County Water Authority 2015 Urban Water Management Plan. The Study Area is bounded on the north, west, and south by the San Diego County boundary and on the east by the boundaries of 11 regional watersheds.

1. Introduction

1.1. Purpose

The Bureau of Reclamation and the City of San Diego Public Utilities Department initiated the San Diego Basin Study (Basin Study) in April 2015 to determine potential climate change impacts on water supplies and demands within the San Diego region (Figure 1), and to analyze structural and non-structural concepts that can assist the region in adapting to the uncertainties associated with climate change. The Basin Study investigated:

- Changes to existing operating policies for regional water supply facilities
- Modifications to existing facilities and development of new facilities
- New water supply options

1.2. Study Approach

Climate change impacts and adaptations were investigated through an impacts assessment, trade-off analysis, and economic assessment. First, San Diego regional water supply system operations were modeled for six Portfolios of Concepts that represented various approaches to meeting water demands. The simulation results were analyzed using a set of impacts assessment metrics focusing on water delivery, energy, recreation, and flood control. The Concepts were then compared in a trade-off analysis that considered 13 evaluation objectives and an economic analysis for three categories of benefits.

The Basin Study was divided into two interrelated tasks. Task 1 comprised the project management aspects, while Task 2 addressed the scientific, engineering, and economic analyses that were completed to meet the study objectives. Task 2 was further divided into sub-Tasks 2.1 through 2.5, plus sub-Task 2.6 to prepare the Final Report.

Info Box 1. Definitions

Project: Actual or theoretical proposed modifications to existing facilities, construction of new facilities, modifications to system operations or policy, or other proposed activities.

Note: Most Basin Study projects are based on actual proposed projects listed in various regional planning documents. Other projects represent a theoretical project idea or type of project, but are not tied to a specific proposed implementation.

Concept: A group of similar projects that could be used to meet regional water demands.

Portfolio: A group of Concepts used for simulating and analyzing water system operations. Each portfolio contains a subset of Concepts.

1.3. Study Products

Products resulting from the Basin Study include the following:

- **Interim Reports** (Table 1) for each task of the Basin Study (Tasks 2.1 through 2.5) – Reports published during the study that describe each task in detail. These documents can be used to understand how the study methods and approach evolved over the course of the project.
- **Customized Trade-Off Analysis Tool** – A spreadsheet for performing trade-off analyses customized to meet the preferences and interests of individual organizations.
- **Final Report** – A comprehensive summary report of all Basin Study tasks, including details of methods and the resulting findings.
- **Executive Summary** (this document) – A brief report focusing on key findings of the Basin Study that is intended for use by leadership and decision-makers.

Table 1. San Diego Basin Study Tasks

Task	Description	Completion Date
2.1 – Water Supply and Water Demand Projections, Completed[1]	Characterized existing and projected future water supply and demand within the Study Area through review of existing literature and analysis of projected water supply and demand.	March 2016
2.2 – Downscaled Climate Change and Hydrologic Modeling[1]	Evaluated future local and imported water supplies through use of climate projections and hydrologic model simulations.	May 2016
2.3 – Existing Structural Response and Operations Guidelines Analysis[1]	Simulated baseline water system infrastructure and operations for a range of demand and climate scenarios and analyzed the impacts to water deliveries, energy, recreation, and flood control.	August 2017
2.4 – Structural and Operations Concepts	Simulated and compared baseline and potential future water supply system infrastructure and operations for a range of demand and climate scenarios and analyzed impacts to water deliveries, energy, recreation, and flood control.	December 2018
2.5 – Trade-Off Analysis and Opportunities	Compared potential future water supply system infrastructure and operations concepts using trade-off analysis and economic assessment.	June 2019

[1] Content in Interim Reports for Tasks 2.1, 2.2, and 2.3 was superseded by the information in the Task 2.4 and 2.5 Interim Reports and the Final Summary Report.

Info Box 2. Key Findings

The San Diego Basin Study resulted in these key findings:

- Continuing the region's active investments (as simulated in the Baseline Plus Portfolio) will have a number of benefits:
  - Improvements in water supply reliability, as indicated by a decreased occurrence of shortages (although shortages may not be completely eliminated)
  - Less dependence on imported water

- Promising options for future investments to further secure reliable water supplies can support other water management aspects such as flood control, recreation, and energy.

- Conservation and Water Use Efficiency (analyzed in the Enhanced Conservation and Urban and Agricultural Water Use Efficiency Concepts) would have a number of positive benefits for the region:
  - Reduced energy consumption
  - Fewer pipeline capacity issues
  - Increased reservoir storage, providing a direct benefit to recreation
  - Less dependence on imported water
  - Cost effective and scalable
  - Potentially large energy cost reduction

- Increasing supply volumes through Potable Reuse would have potential benefits:
  - Reduced shortage volumes
  - Lower dependence on imported water
  - Lower energy consumption

- Concepts such as Stormwater Capture, Watershed and Ecosystem Management, and Stormwater BMPs may have significant benefits and would be worth considering for implementation as part of the overall water system in the San Diego region.
  - Enhanced quality of life/recreation
  - Reduced vulnerability to climate change
  - Support environmental justice
  - Support healthy watersheds and improved water quality

- Many Concepts and projects are complementary and could be implemented as part of a suite of strategies to benefit the region in many ways. (For example, Water Use Efficiency [lower energy costs] combined with Potable Reuse [higher energy costs] can result in Improved Supply Reliability, and Minimized Energy Cost Impacts.)

2. Water Supply and Demand

The San Diego County Water Authority (SDCWA) and its member agencies are the primary suppliers of water within the Study Area (Figure 1). The SDCWA service area encompasses most of the western portion of San Diego County. It is divided into 24 member agency service areas, the largest of which is the City of San Diego.

2.1. Water Supply

The Basin Study examined local water supplies produced within the Study Area by SDCWA and its member agencies, as well as imported supplies from other regions (e.g., Colorado River Basin and the State Water Project).

Current and potential future water supplies, which generally correspond to the Concepts in Table 2, included local surface water, groundwater, recycled water, potable reuse, seawater desalination, firm water supply agreements (e.g., the Quantification Settlement Agreement), imported water purchases, gray water use, stormwater Best Management Practices (BMPs), and stormwater capture. Conservation was examined as a strategy to reduce demand, thereby reducing the supply volume needed to meet the region's demands.

2.2. Water Demand

The Basin Study examined water demands in the SDCWA service area. Together, SDCWA member agencies make up approximately 95% of the demands for San Diego County. Demands for unincorporated areas of the County that are not served by SDCWA but which are within the Study Area were not included because they are met by individual wells or small water systems.

Demand for water in the SDCWA service area falls into two classes of service: municipal and industrial (M&I), and agricultural. In fiscal year 2015, total demand was 539,361 acre-feet of which 92% was for M&I uses and 8% was for agricultural uses (San Diego County Water Authority, 2016). Agricultural demands have decreased significantly since 2007, when The Metropolitan Water District of Southern California (MWD) implemented mandatory restrictions on water it sold under agricultural rates. In the future, M&I demands are expected to grow while agricultural demands are expected to continue to decrease, leading to an even greater dominance of M&I demands in the region.

2.3. Climate Change Effects

Based on Coupled Model Intercomparison Project Phase 5 (CMIP 5) projections, climate change is projected to increase median annual precipitation across the San Diego region by 0% to 12% and increase median annual temperature by 1.5 to 4.5 degrees Fahrenheit, depending on the climate model selected. Climate change is anticipated to directly affect some supplies (e.g., local surface water and imported water) but may have minimal effects on others (e.g., desalination and recycled water). Climate change is also anticipated to affect water demands through effects on projected changes in precipitation and potential evapotranspiration.

3. Methodology

To determine potential effects of climate change on San Diego region water supplies and demands, an impacts assessment, trade-off analysis and economic assessment were performed using results from a water system simulation model and a stakeholder engagement process. The model simulated Portfolios (Table 3) of Concepts (Table 2), representing groups of similar strategies for meeting regional water demands. Concepts consisted of one or more specific projects representing actual proposed projects or theoretical project ideas. The impacts assessment compared impacts between Portfolios in the areas of water delivery, energy, recreation, and flood control. The trade-off analysis and economic assessment analyzed the effects of Concepts on a variety of benefit categories.

Table 2. San Diego Basin Study Concepts

Concept	Concept Description
Conveyance Improvement	Improve local / regional conveyance systems to increase supply reliability and operational flexibility, and reduce greenhouse gas (GHG) emissions by utilizing existing conveyance facilities and natural water courses, and modifying existing pump stations, pipelines, interties and bypasses.
Drought Restriction/ Allocation*	Implement temporary restrictions in water use to decrease demand or shift to other supply sources during periods of drought. Restrictions or allocations may be imposed at the local, regional, or State levels, and may include restrictions or allocations by water purveyors such as MWD.
Enhanced Conservation	Implement long-term or permanent restrictions in water use to decrease demand. Restrictions or allocations may be imposed at the local, regional, or State levels, and may include restrictions or allocations by water purveyors such as MWD.
Firm Water Supply Agreements*	Provide water supply by forming agreements for firm water supply volumes to be provided from external sources, such as the Quantification Settlement Agreement.
Gray Water Use	Offset potable water usage by encouraging, supporting and/or providing incentives for gray water system installation by residential customers.
Groundwater	Provide water supply by extracting and treating and/or desalinating groundwater from local freshwater and brackish aquifers and maintain sustainable groundwater supplies through implementation of projects to recharge groundwater basins with injected or infiltrated rainfall, recycled water, imported water, or a combination thereof.

Concept	Concept Description
Imported Water Purchases	Provide water supply by purchasing treated or untreated water from a water wholesaler outside the region, such as MWD.
Local Surface Water Reservoirs*	Provide water supply by capturing, storing, and treating surface water runoff in lakes or reservoirs.
Potable Reuse	Provide water supply by producing advanced treated water from wastewater for direct or indirect (e.g., reservoir or groundwater augmentation) potable use.
Recycled Water	Offset potable water use by providing non-potable recycled water use for landscape irrigation, industrial purposes or groundwater recharge.
Seawater Desalination	Provide water supply by utilizing or expanding existing facilities or constructing new facilities to remove salts from seawater.
Stormwater BMPs	Reduce adverse water quality impacts of stormwater through implementation of stormwater Best Management Practices (BMPs). BMPs are structural, vegetative, or management practices used to treat, prevent, or reduce stormwater runoff and pollution.
Stormwater Capture	Provide water supply by capturing stormwater through both centralized projects and regional decentralized efforts and treating it for both potable and non-potable uses.
Urban and Agricultural Water Use Efficiency	Increase water use efficiency by encouraging long-term behavioral change and implementing water use efficiency programs (e.g., rain barrel rebates, turf replacement credits, rebates for more efficient irrigation or plumbing fixtures, gray water system rebates).
Watershed and Ecosystem Management	Promote sustainable, high quality local water supplies through practices that support healthy ecosystems and improve or restore the condition of landscapes and biological communities. Such practices may include invasive species removal, restoration of native ecosystems, land acquisition for protection or enhancement, brush/forest management for wildfire risk reduction, remediation of aquifer and reservoir water quality through engineered or biological controls, management of non-point and point source pollution, and low impact development.

* These Concepts were included in the Baseline Portfolio and were not modified in any other Portfolios.

Table 3. Impacts Assessment Portfolios

Portfolio	Description	Concepts
Baseline	Projects designated as verifiable in SDCWA's 2015 Urban Water Management Plan (UWMP)	• Conveyance Improvements • Drought Restriction/Allocation • Firm Water Supply Agreements (e.g., Colorado River Quantification Settlement Agreement [QSA]) • Groundwater • Imported Water Purchases (e.g., MWD) • Local Surface Water Reservoirs • Potable Reuse • Recycled Water • Seawater Desalination (e.g., Carlsbad) • Urban and Agricultural Water Use Efficiency
Baseline Plus	Baseline projects and projects that are actively being pursued or have received funding between 2015 and 2017	• All Baseline Concepts • New or Modified Concepts ○ Conveyance Improvements ○ Gray Water Use ○ Groundwater ○ Potable Reuse (e.g., Pure Water San Diego Phase 1) ○ Recycled Water ○ Stormwater Capture ○ Urban and Agricultural Water Use Efficiency ○ Watershed and Ecosystem Management (e.g., Hodges Water Quality Improvement Program)
Enhanced Conservation	All Baseline Plus projects as well as a drastic reduction in demand through maximum conservation practices	• All Baseline Plus Concepts • New or Modified Concepts ○ Enhanced Conservation
Increase Supplies	All Baseline Plus projects, and planned and conceptual projects that focus on increasing regional water supplies	• All Baseline Plus Concepts • New or Modified Concepts ○ Gray Water Use ○ Groundwater ○ Imported Water Purchases (e.g., Cadiz Additional Supplies) ○ Potable Reuse (e.g., Pure Water San Diego Phase 2) ○ Recycled Water ○ Seawater Desalination (e.g., Rosarito and Camp Pendleton)

Portfolio	Description	Concepts
Optimize Existing Facilities	All Baseline Plus projects, and planned and conceptual projects that seek to enhance the efficacy of existing facilities	• All Baseline Plus Concepts • New or Modified Concepts ○ Conveyance Improvements
Watershed Health and Ecosystem Restoration	All Baseline Plus projects, and planned and conceptual projects that seek to minimize environmental impacts	• All Baseline Plus Concepts • New or Modified Concepts ○ Stormwater BMPs ○ Stormwater Capture ○ Watershed and Ecosystem Management (e.g., Sycamore Creek Restoration)

Info Box 3. Single Concept Portfolios

Single Concept Portfolios were used to provide input data at the Concept level for the Trade-off Analysis and Economic Assessment. The Portfolios included all non-Baseline projects corresponding to these 12 Concepts:

- Conveyance Improvement
- Enhanced Conservation
- Gray Water Use
- Groundwater
- Imported Water Purchases
- Potable Reuse
- Recycled Water
- Seawater Desalination
- Stormwater BMPs
- Stormwater Capture
- Urban and Agricultural Water Use Efficiency
- Watershed and Ecosystem Management

3.1. Modeling of Water System Operations

The Basin Study used the CWASim model to simulate operations of the water system in the Study Area. Model results were analyzed in the impacts assessment and used as inputs to the trade-off analysis and economic assessment. CWASim is a GoldSim model originally developed for SDCWA by Jacobs Engineering Group (formerly CH2M) in support of the 2013 Regional Facilities Optimization and Master Plan Update (San Diego County Water Authority, 2013; CH2M, 2015). GoldSim is a general purpose simulation software for dynamically modeling complex systems in business, engineering, and science. The original version of CWASim and a companion short-term operations model were extensively reviewed by SDCWA and were validated by comparison to historical measured monthly and annual flows at major delivery points and selected internal system flows.

CWASim simulates operations of the San Diego supply system by modeling water supplies, demands, and deliveries through a representation of the water supply infrastructure in the region. It runs on a daily timestep and represents the system with elements and connectors for reservoirs, water treatment plants, pipelines, delivery points, and other water supply infrastructure components. It includes representation of local and imported supply sources, member agency demands, SDCWA facilities, and member agency facilities that are connected to the SDCWA system. It does not include representation of member agency facilities that are not connected to the SDCWA system.

Operational logic describes how water is distributed throughout the system at each simulation timestep. It is a daily demand-driven mass-balance model, meaning that at any time step, the model aggregates and tries to meet demands from SDCWA member agencies under constraints of water supply availability, conveyance capacities, and operational rules. Although CWASim is not a hydraulic model, it does have hydraulic properties built into the logic. Input data provides the water supply and demand volumes that drive the operations of the system.

The Basin Study used a period-in-time approach in which simulations were performed for specific time periods (2015, 2025, and 2050) and climate and socioeconomic factors were held constant throughout the individual model runs.

CWASim model runs were performed for each of the six Impacts Assessment Portfolios and 12 Single Concept Portfolios for a range of demand and climate conditions. Observed 2015 demands, SDCWA UWMP 2025 demand projections, and UWMP demand projections extended to 2050 make up the three demand scenarios (2015, 2025, and 2050) that were used in the analysis (Figure 2). Although SDCWA updated its demand forecast in 2018, the modeling for the Basin Study was started before the update and is therefore based on the demand projections in the 2015 UWMP, which are higher than the SDCWA 2018 demand forecast. A current climate scenario and five climate change scenarios (central tendency, warm-wet, warm-dry, hot-wet, and hot-dry) make up the climate scenarios.

Water supply and conservation volumes were simulated based on a combination of inflow projections, facility production capacities, and conservation volumes. Supplies were modeled as either dynamic supplies, which could change on a daily basis depending on demand and system constraints, or as annual demand reductions. Imported supply availability was based on results from the Sacramento-San Joaquin Basin Study and the Colorado River Basin Study.

Each run represented a specific demand and climate condition and was made up of 85 realizations of daily water system simulations. The 85 realizations were run consecutively through the model, and the order of the realizations was the same for all runs, allowing direct comparison between scenarios and realizations. A single realization is one year in the 85-year-long time series of surface water inflows.

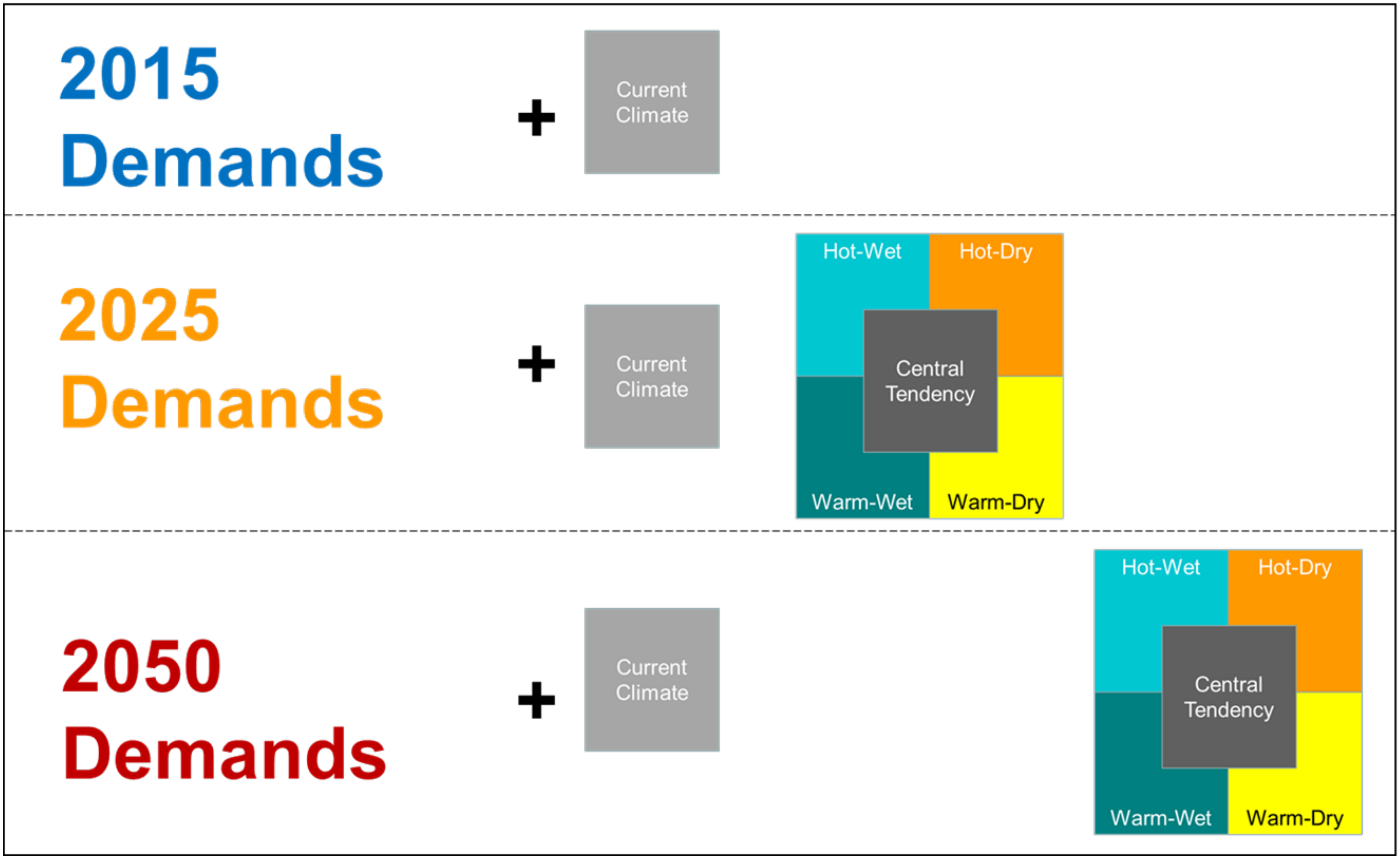


Figure 2. Demand and Climate scenarios used in the San Diego Basin Study

3.2. Impacts Assessment Methodology

To quantify impacts to water delivery, hydroelectric power, recreation, and flood control, a set of metrics summarized the CWASim model results for each climate and demand scenario and portfolio.

Metric outputs from the CWASim model evaluated the performance of the San Diego regional water system in four impact categories:

1) Water Delivery
2) Energy
3) Recreation
4) Flood Control

The metrics were analyzed and compared across the modeled climate and demand scenarios and portfolios to identify how climate, demand, and water resources infrastructure may affect the impact areas. Climate scenarios consisted of current climate, central tendency climate, hot-dry climate, warm-dry climate, hot-wet climate, and warm-wet climate. The three demand scenarios consisted of 2015 demands, 2025 demands, and 2050 demands (Figure 2).

Current climate 2015 demands were 619,736 acre-feet (AF). Demands were higher for the 2025 demand scenario (increase of 110,000 AF) than for the 2015 demand scenario, and higher for the 2050 demand scenario (increase of 130,000 AF) than for the 2025 demand scenario, due to increases in population and other socioeconomic factors. Central tendency demands were higher than current climate (increase of 23,000 AF for 2025 and increase of 27,000 AF for 2050) due to changes in temperature and precipitation. Although demand values differed between central tendency climate and other future climate scenarios (hot-dry, hot-wet, warm-dry, or warm-wet), the differences were small. The increases in population from 2015 to 2025 and 2050 had a larger effect on overall demand than climate change.

3.3. Trade-Off Analysis Methodology

The trade-off analysis compared the ability of Concepts to achieve Evaluation Objectives identified by regional stakeholders. It resulted in a relative ranking of Concepts that represents a screening of promising Concepts rather than a prioritized list of recommended approaches.

Info Box 4. Evaluation Objectives

- Address Climate Change Through Greenhouse Gas Reduction
- Climate Resilience
- Cost Effectiveness
- Environmental Justice
- Optimize Local Supplies/Independence
- Project Complexity
- Protect Habitats, Wildlife, and Ecosystems
- Provide for Scalability of Implementation
- Reliability and Robustness
- Quality of Life/Recreation
- Regional Economic Impact
- Regional Integration and Coordination
- Water Quality and Watersheds

There were four basic steps involved in the trade-off analysis:

1. Identify Evaluation Objectives to quantify benefits and challenges of Concepts
2. Determine the Relative Importance of Evaluation Objectives
3. Place Values on Evaluation Objectives using Performance Measures
4. Evaluate and Combine Evaluation Objective Scores for Each Concept

Each Evaluation Objective was quantified on a 1 to 5 scale so that different Evaluation Objectives could be added, averaged, or otherwise compared.

A total of 26 Performance Measures (Table 4) was developed to quantify the 13 Evaluation Objectives. Performance Measures were quantified using model metrics, Geographic Information Systems (GIS) analyses, surveys of identified experts and stakeholders, or combinations of the three sources.

The relative importance of each Evaluation Objective was based on the results of an online survey implemented by the City of San Diego. The survey consisted of 13 questions that allowed stakeholders to rate the Evaluation Objectives on a scale of least important to most important. The survey, which was sent to the Study Technical Advisory Committee (STAC) and the Integrated Regional Water Management (IRWM) stakeholder list, resulted in 71 responses.

Table 4. Performance Measures associated with Evaluation Objectives

Performance Measure	Performance Measure Description	Type of Input Data
Address Climate Change through Greenhouse Gas (GHG) Reduction		
GHG Mitigation	Mitigate GHG emissions through carbon storage and sequestration (e.g., habitat conservation and/or restoration)	Survey Responses
Climate Resilience[1,2]		
Sea Level Rise Vulnerability	Vulnerability to sea level rise: Project/Concept is located in an area with low risk to structural damage from sea level rise	GIS
Flood Risk Management	Effect on the likelihood and/or the impact of floods due to precipitation through prevention (e.g., avoiding infrastructure development in flood prone areas), protection (e.g., constructing flood control and protection facilities), preparedness (e.g., informing and educating citizens of flood risks, developing emergency response plans), and management (e.g., reservoir operation modifications to store water during floods, smooth out peak hydrographs, and transfer water to other locations)	GIS
Warming and Fire Vulnerability	Vulnerability to extreme weather (e.g., heat waves), and wildfire (e.g., portfolio reduces vulnerability of the region to extreme heat and/or fire)	GIS

Performance Measure	Performance Measure Description	Type of Input Data
Cost Effectiveness		
Capital Costs	Total present value capital costs to the region and customers/developers, over planning period	Survey Responses
O&M Costs	Total present value O&M costs to the region and customers/developers	Survey Responses
Potential for External Funding	Potential for external funding	Survey Responses
Environmental Justice		
Environmental Justice	Effect on fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (considering interests of stakeholders both inside and outside of the Basin)	GIS & Survey Responses
Disadvantaged Communities (DACs)	Effect on DACs (areas throughout California which most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, health conditions like asthma and heart disease, as well as air and water pollution, and hazardous wastes). *Note: California Department of Water Resources defines a DAC as a community that has a median household income of less than 80% of the State's median household income ($51,026 in 2015). A severely disadvantaged community is defined as having a median household income less than 60% of the State's median household income ($38,270 in 2015) (California Department of Water Resources, 2016).*	GIS
Optimize Local Supplies/Independence		
Local Supply	Level of local supply	Survey Responses
Project Complexity		
Project Complexity and Feasibility	Complexity and feasibility related to regulatory compliance, number of agencies/approvers, property ownership, public opinion/acceptance/practicality of implementation	Survey Responses
Protect Habitats, Wildlife, and Ecosystems		
Impacts to Ecosystems	Impact on ecosystems and ecosystem services	Survey Responses & GIS
Impacts to Native Species	Impact on native species	Survey Responses & GIS

Performance Measure	Performance Measure Description	Type of Input Data
Impacts to Threatened/Endangered Species	Impact on endangered/threatened species	Survey Responses & GIS
Provide for Scalability of Implementation		
Project Phasing	Flexibility for project phasing and expansions	Survey Responses
Quality of Life/Recreation		
Green Space/Open Space	Potential for green space/open space benefits and other improvements to quality of life	Survey Responses
Recreation Opportunities	Impact on recreation opportunities such as swimming, boating, and fishing as an incidental benefit to water supply storage and conveyance	Literature Review, Survey Responses, & Model Metrics
Regional Economic Impact		
Regional Economic Impact	Potential for local job creation and regional economic impact (e.g., to tourism and other industries)	Survey Responses and Expert Panel
Regional Integration and Coordination		
Coordination	Level of integration and/or coordination with other projects/entities, leveraging existing assets or bolstering existing projects	Survey Responses
Education and Outreach	Level of community involvement/engagement, education and outreach to encourage water use efficiency, conservation, and water quality protection through special events, print and online educational materials, demonstration projects, and other outreach activities	Survey Responses
Reliability and Robustness [2]		
Water Shortage Volume	Water shortage volume	Model Metrics
Vulnerability of Water Supply Facilities and Infrastructure	Vulnerability of water supply facilities and infrastructure (e.g., diversity of supplies, resilience of conveyance system, age of infrastructure, ability to meet growth demands, etc.)	Survey Responses
Carryover Storage & Reservoir Augmentation	Effect on the ability to use the storage capacity of surface storage reservoirs for carryover storage, emergency storage, surface water capture, potable reuse, and optimizing supplies in drought situations	Survey Responses
Water Quality and Watersheds		
Stormwater and Wastewater Discharges	Effect on volume of stormwater and wastewater discharge to rivers and ocean	Survey Responses

Performance Measure	Performance Measure Description	Type of Input Data
Groundwater Quality	Potential water quality impacts to local groundwater basins.	Survey Responses, GIS
Surface Water Quality	Effect on surface water bodies listed on the EPA's 303(d) list.	Survey Responses, GIS

[1] Data for directly evaluating resilience was not readily available or known for the majority of projects and, thus, an analysis of a project's ability to increase climate resilience was outside the scope of the study. Therefore, the Performance Measures for the Climate Resilience Evaluation Objective were focused on evaluating the vulnerability of individual projects to the impacts of climate change (e.g., warming and fire, sea level rise, and flooding).
[2] Regional resilience to drought was included in the Evaluation Objective Reliability and Robustness.

After identifying the Evaluation Objectives, determining their relative importance, and placing values on the Concepts for each using the Performance Measures, Evaluation Objective values associated with each Concept were combined with the relative importance of the Evaluation Objectives to estimate a total trade-off analysis score that accounted for all effects. Additional statistical analysis evaluated the potential for bias in the trade-off analysis scores that were obtained by using mean survey results to calculate Performance Measure values. The trade-off analysis scores were re-calculated using median survey results as a sensitivity analysis. In addition, two trade-off analyses using example subsets of Evaluation Objectives were completed to demonstrate how stakeholders may apply the trade-off analysis process and data to meet their specific needs.

3.4. Supplemental Economic Assessment Methodology

An economic assessment provided supplemental information to the trade-off analysis. It examined the effects of Concepts for three categories of benefits that could be quantified in monetary terms: water supply reliability, recreation, and energy usage. This assessment was based on model results combined with values from the literature. Model results for shortages relative to the Baseline were combined with the economic value of shortages from the literature. Monthly reservoir elevations were input into a recreation visitation model developed based on values from the literature and then the results were combined with the value of recreation from the literature. Model results for net energy were combined with the avoided cost of energy generation from the literature. The values for each effect were computed relative to the Baseline model results and summed to calculate a net economic benefit.

4. Results

4.1. Impacts Assessment Results

Info Box 5. Key Findings of the Impacts Assessment

- All Portfolios beyond Baseline showed a shift in water deliveries away from imported water to meet increasing demands.
- Water delivery shortages were largest in the Baseline and lowest in Enhanced Conservation.
- There was an increase in energy consumption in all Portfolios except Enhanced Conservation. The increase was smallest in Increase Supplies.
- Recreation and Flood Control impacts varied by reservoir and Portfolio.
    - Boat ramps were frequently inaccessible at El Capitan, except in Optimize Existing Facilities.
    - Boat ramp accessibility improved at Lower Otay in all Portfolios beyond Baseline.
    - Days with flood outflows decreased at Hodges Reservoir in Portfolios beyond Baseline.

4.1.1. Water Delivery

Over the range of modeled scenarios, total water deliveries increased between 2015, 2025, and 2050 to meet increasing demands, but the mix of supplies used to meet the increasing demands depended on the Portfolio (Figure 3). Between the Baseline Portfolio and other Portfolios, there was a shift in water deliveries away from imported water purchases. In the Enhanced Conservation Portfolio, the shift was due to reduced overall water demands, which allowed more of the demand to be met by local sources. Increases in local supply sources, such as in the Baseline Plus, Increase Supplies, and Watershed Health and Ecosystem Restoration Portfolios, and improvements in system operations such as in the Optimize Existing Facilities Portfolio, enabled more demand to be met with local supplies instead of purchased water imports. The effect was particularly strong for the Increase Supplies and Enhanced Conservation Portfolios, indicating that both demand-side approaches (i.e., conservation) and supply-side approaches (i.e., new water supply sources) can be effective at reducing dependence on imported water. In addition to the reliability benefits of reducing dependence on imported water to meet water demands, the Basin Study found evidence that decreasing imported water use may also provide benefits to regional energy consumption.

Water supply shortages occurred in all Portfolios (largest shortages in Baseline and smallest in Enhanced Conservation) but represented only up to 2% of the total annual demand on average. These shortages were worst under Baseline conditions, future demand scenarios, and hot-dry and warm-dry climate scenarios (Figure 4).

A shortage threshold of 20,000 AF was used in the Basin Study to represent the shortage volume that could be mitigated within the San

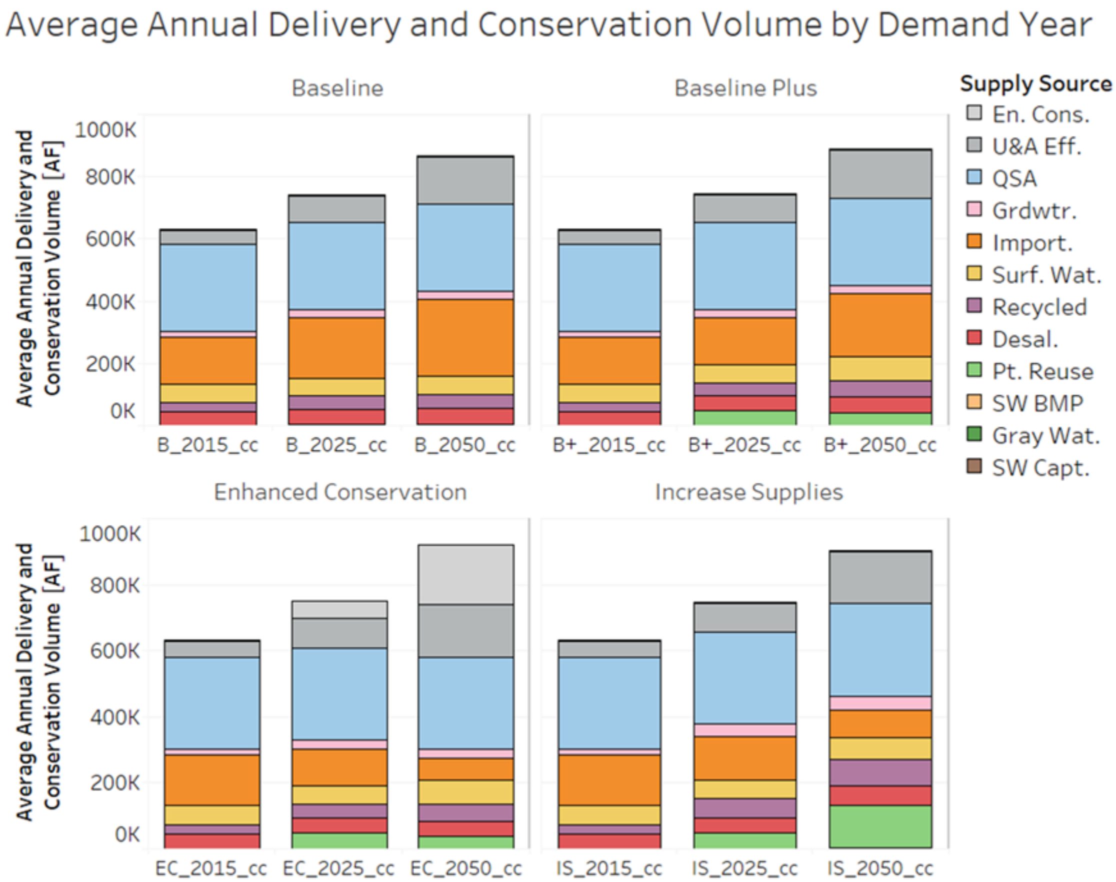


Figure 3. Average Annual Delivery and Conservation Volume by Demand Year for Baseline, Baseline Plus, Enhanced Conservation, and Increase Supplies. Watershed Health and Ecosystem Restoration and Optimize Existing Facilities deliveries are similar to Baseline Plus. Potable Reuse is included in the Baseline Portfolio for 2025 and 2050 demands, and Gray Water and Stormwater Capture Concepts are included in Portfolios beyond Baseline, but delivery volumes are small and are not visible in the figures.

Diego system through short-term drought restrictions or operational changes. In the Baseline Portfolio, shortages above this shortage threshold occurred 6% of the time in the hot-dry climate scenario for 2025 demands, and 28% of the time in the hot-dry climate scenario for 2050 demands. The Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios all reduced the occurrence and magnitude of shortage, and the Enhanced Conservation and Increase Supplies Portfolios eliminated shortages above the shortage threshold for all climate and demand scenarios.

Conveyance system limitations may contribute to shortages if pipeline capacity is not great enough to convey the water needed to meet demands. In the simulated system operations, pipeline flow appeared to be a possible constraint, but pump station utilization and treatment plant utilization did not appear to constrain operations of the system. The Untreated Pipeline, which conveys water from the MWD delivery point to connections with other facilities, conveyed the most flow and was the most highly used, with summer utilization frequently over 95% of capacity in all Portfolios. Utilization of the Untreated Pipeline was highest in the Baseline Portfolio and lowest in the Enhanced Conservation (due to decreased demands), Increase Supplies (due to decreased demands on imported water compared to Baseline Plus), and Optimize Existing Facilities (most likely due to Pipeline 3/Pipeline 4 conversion) Portfolios for 2050 demands.

In addition to delivery volumes and shortages, the water delivery impacts analysis also examined reservoir storage and releases. Reservoirs operated within the ranges specified by their rule curves in all scenarios and Portfolios, indicating that operations are generally flexible enough to accommodate changes in demand and climate, as well as changes in operations of other components of the water system.

Climate change affected reservoir storage at some reservoirs but did not appear to have an effect at others. For reservoirs that showed impacts from climate change, wet scenarios generally had higher reservoir storage than dry scenarios.

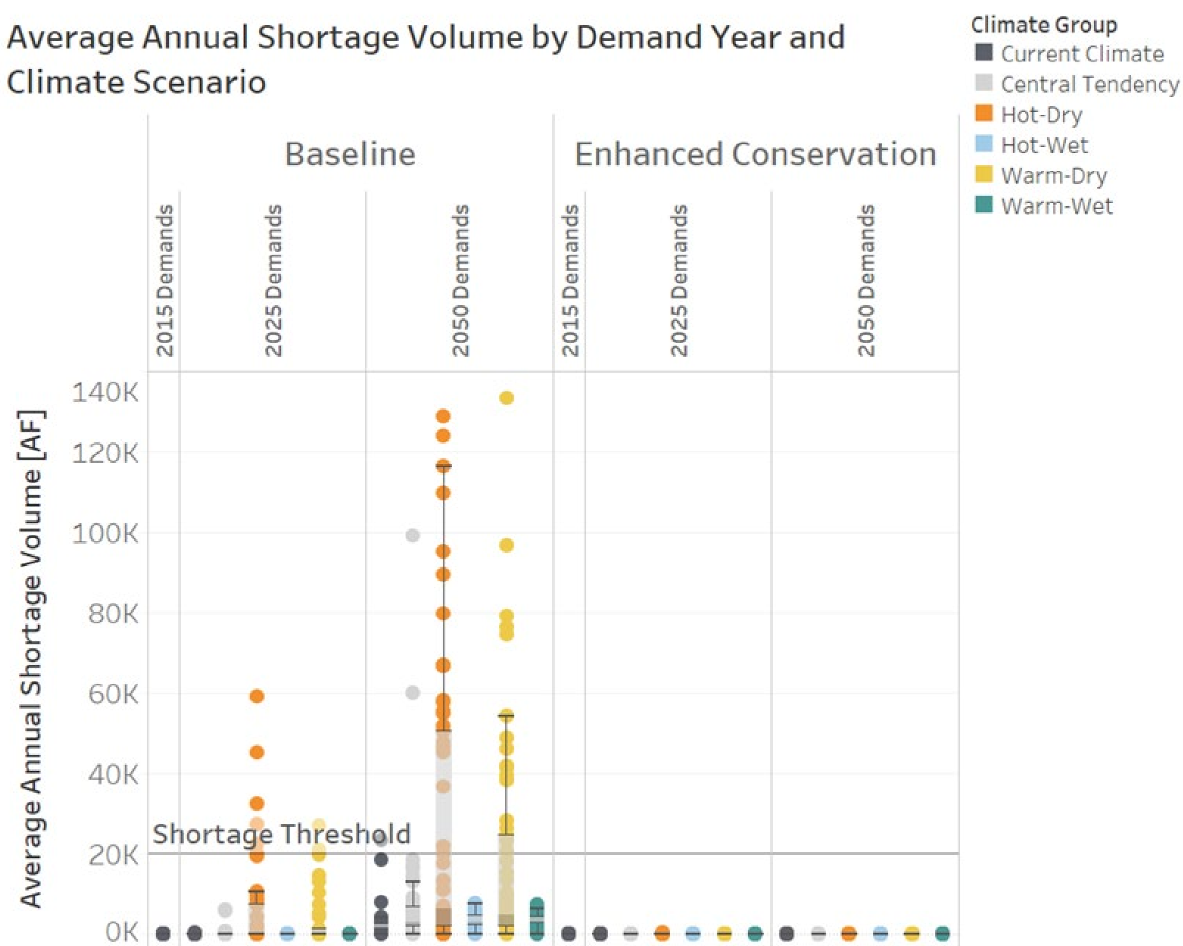


Figure 4. Average Annual Shortage Volume by demand year and climate scenario for Baseline Portfolio (largest shortages) and Enhanced Conservation Portfolio (smallest shortages).

4.1.2. Energy

Energy impacts were quantified by energy consumption to treat and deliver water, including supply sources, conveyance, treatment, pumped storage, offices, and by energy generation at water system facilities (Figure 5). In all Portfolios for 2015 demands and current climate, modeled energy generation offset about 4% of the modeled consumption for the San Diego region, with average annual generation of approximately 76,000 megawatt-hours (MWh) and average annual consumption of approximately 1,732,000 MWh. For both 2025 demands and 2050 demands across all climate scenarios, the highest energy consumption occurred in the Baseline Portfolio and the lowest occurred in the Enhanced Conservation Portfolio. Compared to the Baseline Portfolio for 2050 demands and current climate, there was a 4% reduction in energy consumption with the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios, a 27% reduction with the Enhanced Conservation Portfolio, and a 12% reduction with the Increase Supplies Portfolio. Lower usage of imported water contributed to the lower energy consumption in the Increase Supplies Portfolio, which consumed less energy than the Baseline, and Baseline Plus Portfolios even though it included projects that are typically considered energy-intensive such as Seawater Desalination.

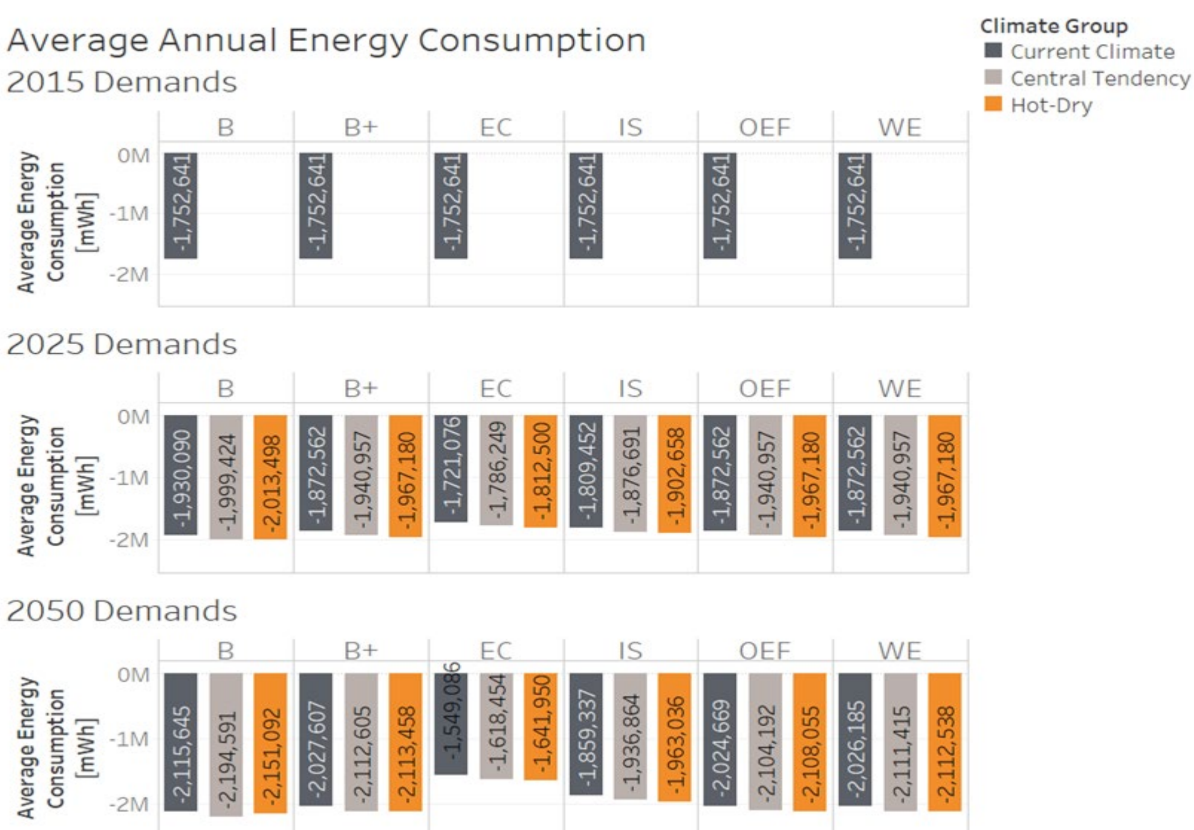


Figure 5. Average Annual Energy Consumption for each Portfolio with current climate, central tendency climate, and hot-dry climate for the 2015, 2025, and 2050 demand scenarios.

4.1.3. Recreation

Impacts to Recreation were quantified using boat ramp accessibility at the end of September by comparing the boat ramp elevation to the End of September Elevation for El Capitan, Hodges, Lower Otay, and San Vicente Reservoirs. End of September Elevation varied between Portfolios for all reservoirs, but significant recreation impacts as measured by boat ramp inaccessibility only occurred for El Capitan Reservoir and Lower Otay Reservoirs, and recreation was impacted to a very limited extent for Hodges and San Vicente Reservoirs.

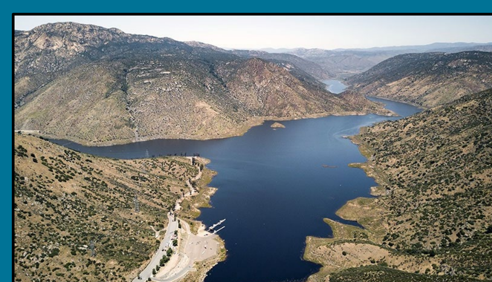
There were no model realizations below the boat ramp elevation in any of the Portfolios for San Vicente, and the reservoir elevation was significantly increased in 2050 in the Increase Supplies Portfolio due to Pure Water San Diego Phase 2.

At El Capitan (Figure 6), as many as 88% of realizations had End of September Elevations below the boat ramp in the Baseline Portfolio. The impacts were improved somewhat in the Baseline Plus and Watershed Health and Ecosystem Restoration Portfolios, improved somewhat more in the Enhanced Conservation and Increase Supplies Portfolios, and eliminated in the Optimize Existing Facilities Portfolio. For 2050 demands, the Optimize Existing Facilities Portfolio was the only Portfolio to have no realizations below the boat ramp elevation at El Capitan, which can be attributed to the San Diego Reservoir Intertie project that allows for greater flexibility in reservoir management and removes restrictions on the operable pool.

At Hodges Reservoir, there were no realizations below the boat ramp elevation in the Baseline Portfolio; however, 1.2% of realizations were below the boat ramp elevation in 2050 for three Portfolios: the Baseline Plus (central tendency, hot-dry, and warm-dry climate scenarios), Optimize Existing Facilities (hot-dry and warm-dry climate scenarios), and Watershed Health and Ecosystem Restoration (central tendency, hot-dry, and warm-dry climate scenarios) Portfolios.

Info Box 6. Project Highlight: San Diego Reservoir Intertie

The San Diego Reservoir Intertie would allow storage operations in San Vicente and El Capitan Reservoirs, and the Santee-El Monte Groundwater Basin to be optimized as a "reservoir system" for the benefit of water supply reliability. Local supply and imported supply could be stored and moved between any of these storage facilities to reduce spills and maximize imported water storage opportunities. Water from all three storage facilities could also be released through existing pipelines to Lake Murray and the Alvarado Water Treatment Plant for distribution into the existing treated water system.



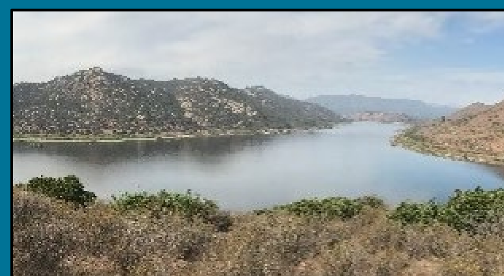
El Capitan Reservoir
Courtesy City of San Diego

This can be attributed to the Hodges Water Quality Improvement Program, which improves water quality at Hodges, allowing for greater usage of water from this reservoir.

For Lower Otay (Figure 7), up to 45% of realizations had End of September Reservoir Elevations below the boat ramp in the Baseline Portfolio. This was improved in all Portfolios and completely eliminated in the Enhanced Conservation Portfolio. The Baseline Portfolio was the only Portfolio with realizations below the boat ramp elevation at Lower Otay for 2025 demands.

Info Box 7. Project Highlight: Hodges Water Quality Improvement Program

Hodges Water Quality Improvement Program projects being implemented by the City of San Diego Public Utilities Department will improve water quality within Hodges Reservoir, allowing more water to be released to supplement the region's supplies.



Hodges Reservoir
Courtesy City of San Diego

Info Box 8. Project Highlight: Pure Water San Diego

Pure Water San Diego is the City of San Diego Public Utilities Department's proposed program to provide an additional safe, secure, and sustainable local drinking water supply for San Diego. The program plans to use advanced water purification technology to supply the City's North City, Central Area and the South Bay regions with potable recycled water. The program is expected to add a cumulative total (Phase 1 and Phase 2) of 93,000 AF per year (83 million gallons per day) of potable recycled water to the City's supply portfolio by completion in 2035.

North City Water Reclamation Plant
Courtesy City of San Diego

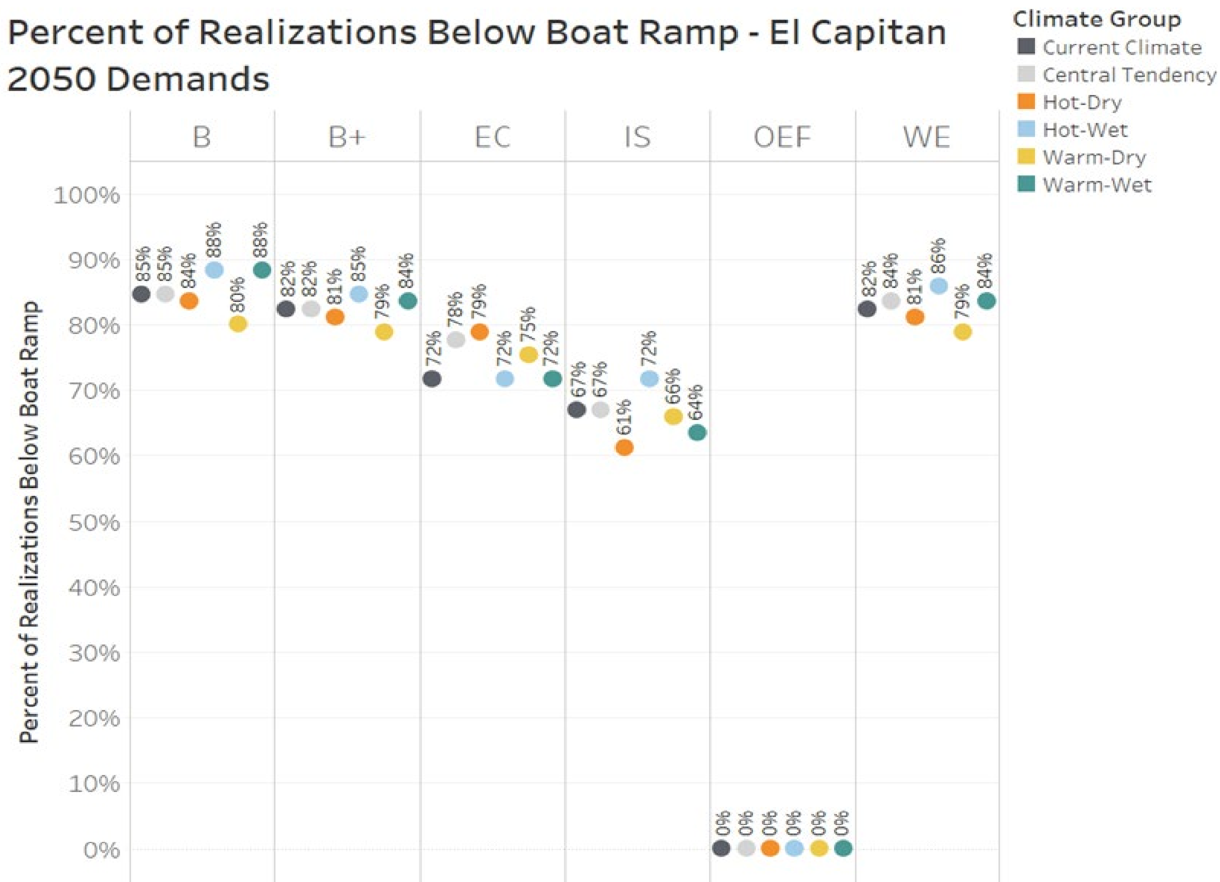


Figure 6. Percent of realizations below the El Capitan Reservoir boat ramp elevation for 2050 demands across all climate scenarios and Portfolios.

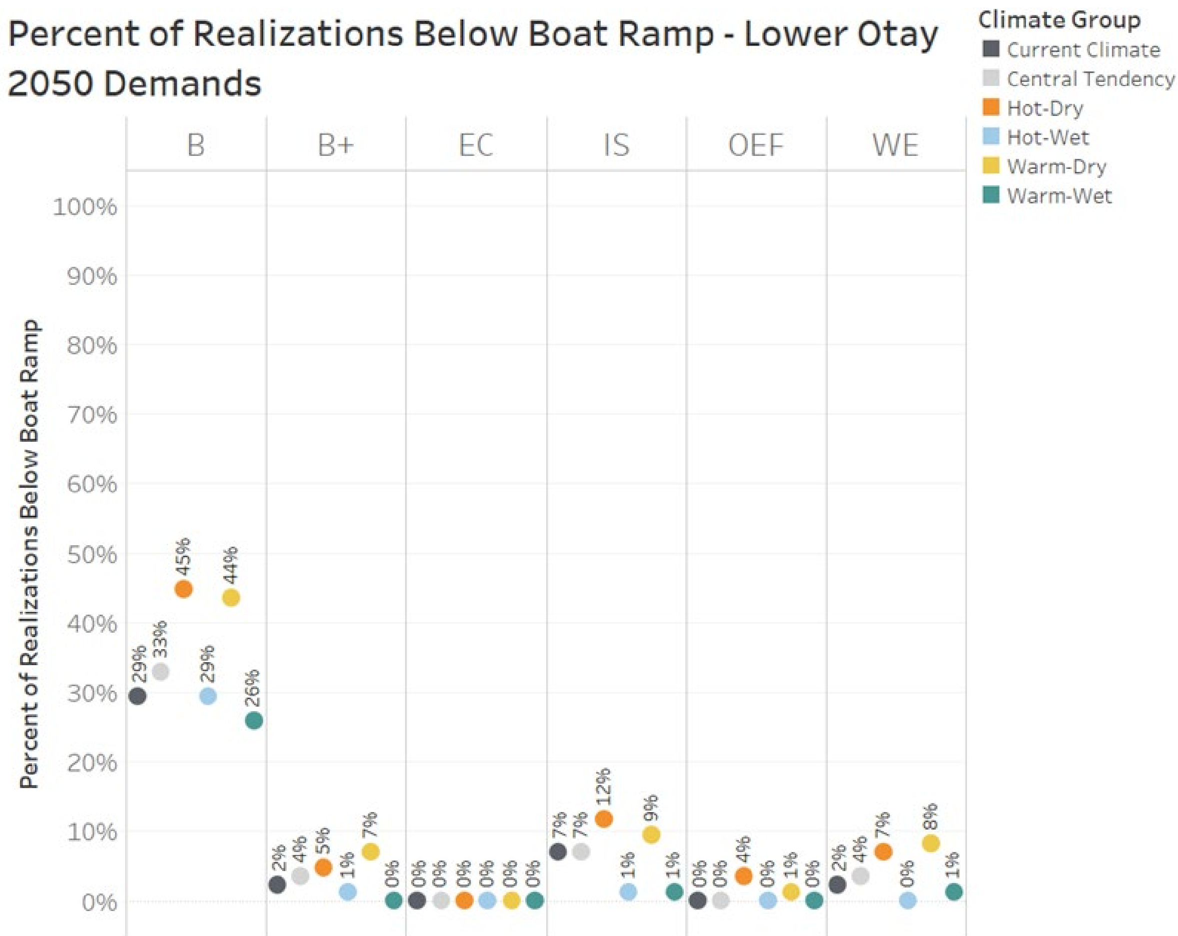


Figure 7. Percent of realizations below the Lower Otay Reservoir boat ramp elevation for 2050 demands across all climate scenarios and Portfolios.

4.1.4. Flood Control

Flood control impacts, as measured by number of days with flood outflows and annual flood outflow volume, were evaluated at five of the region's reservoirs: El Capitan, Hodges, Lower Otay, San Vicente, and Olivenhain. Of these five reservoirs, flood impacts were only observed for El Capitan, Hodges, and Lower Otay Reservoirs. No flood outflows occurred at San Vicente or Olivenhain Reservoirs.

At El Capitan (Figure 8), there were no differences between Portfolios or scenarios for 2025 demands. In 2050 the Increase Supplies Portfolio had the most flood outflows (141% more than Baseline and 109% more than Baseline Plus under current climate), most likely due to increased water supplies requiring storage. There were also fewer flood outflows in the Optimize Existing Facilities Portfolio (about 60 to 70% less than Baseline and Baseline Plus), most likely due to the San Diego Reservoir Intertie, which allows for greater operational flexibility at El Capitan.

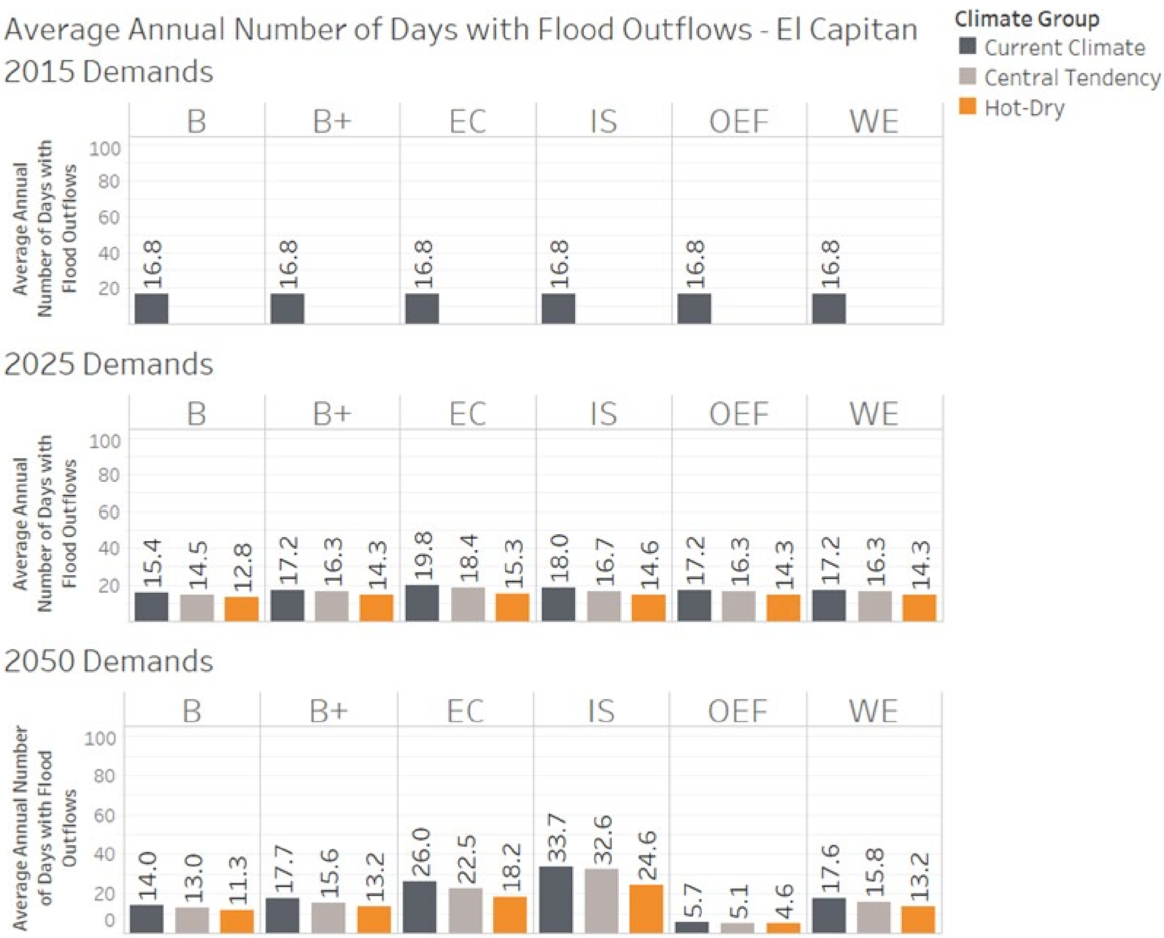


Figure 8. Average number of days with flood outflows at El Capitan Reservoir for each Portfolio with current climate, central tendency climate, and hot-dry climate for the 2015, 2025, and 2050 demand scenarios.

For Hodges Reservoir (Figure 9), flood impacts were the same for all Portfolios for the 2015 and 2025 demand scenarios but significantly reduced in the 2050 demand scenarios for Portfolios beyond Baseline due to implementation of the Hodges Water Quality Improvement Program, which allows higher releases of water from Hodges Reservoir to the regional water system, resulting in decreased potential for flood outflows.

At Lower Otay, flood outflows were highest in the Enhanced Conservation Portfolio for 2050. They were increased between 57 and 101% from the Baseline Portfolio, dependent on climate scenario, most likely due to lower demand for water stored in the reservoir. For El Capitan, Hodges, and Lower Otay, flood impacts appeared to vary between climate scenarios, with lower flood outflow volumes for hot-dry and warm-dry climates, higher flood outflow volumes in warm-wet and hot-wet climates, and central tendency being somewhat similar to current climate.

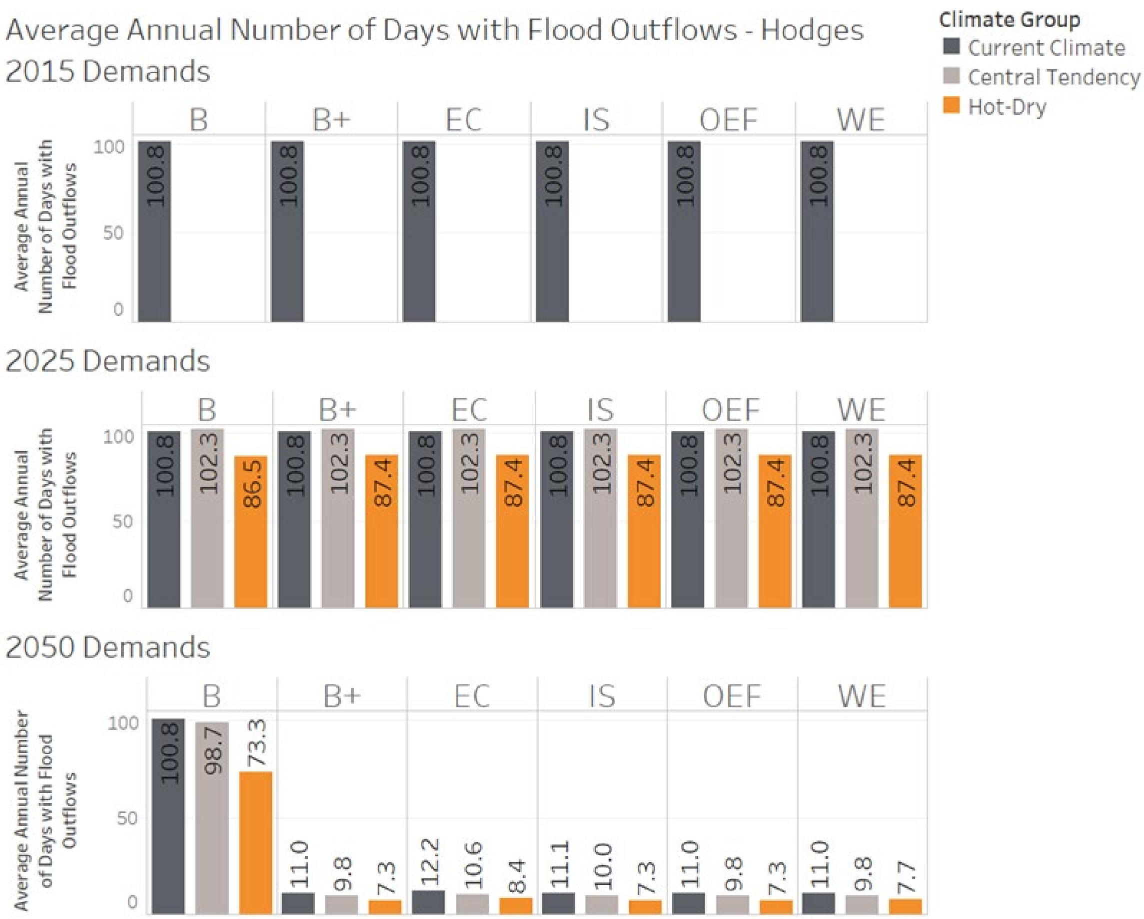


Figure 9. Average number of days with flood outflows at Hodges Reservoir for each Portfolio with current climate, central tendency climate, and hot-dry climate for the 2015, 2025, and 2050 demand scenarios.

4.2. Trade-off Analysis Results

The trade-off analysis (Figure 10) indicated that the Urban and Agricultural Water Use Efficiency Concept generated the greatest overall positive effects as defined by the Evaluation Objectives. Five additional Concepts scored within 10% of the highest-scoring Concepts: Watershed and Ecosystem Management, Stormwater Capture, Recycled Water, Potable Reuse, and Stormwater BMPs. Groundwater and Conveyance Improvement were within 15% of the highest-scoring Concept. Scores for all the Evaluation Objectives were not available for Enhanced Conservation, Gray Water Use, Imported Water Purchases, and Seawater Desalination, so they could not be directly compared. However, even with one missing Evaluation Objective, Gray Water Use had a point total above Conveyance Improvement, indicating that if it had been scored on all Evaluation Objectives, it may have performed relatively well.

Given the level of analysis, this result does not represent a prioritized list of Concepts recommended for implementation. Instead, it can be used to identify promising Concepts for further analysis and consideration.

The average importance ratings for the Evaluation Objectives (Table 5) indicate the relative importance of the Evaluation Objectives. The results are normalized on a 1 to 10 scale, with 10 most important and 1 least important. The Evaluation Objective weights developed from the survey responses indicated that Reliability and Robustness, Water Quality and Watersheds, Climate Resilience, Optimize Local Supplies, and Protect Habitats, Wildlife, and Ecosystems had the highest level of importance, with average importance weights that were 9.2 or higher on a 10-point scale. Concepts targeting and generating positive effects for these five Evaluation Objectives will tend to provide the greatest level of overall benefit to the region. However, other impact categories are still important and should not be ignored.

The next tier of importance included Environmental Justice, Cost Effectiveness, Regional Integration and Coordination, and Address Climate Change Through Greenhouse Gas Reduction, with importance weights ranging from 8.7 to 8.2 on a 10-point scale.

The third tier of importance included Regional Economic Impact, Scalability of Implementation, Quality of Life/Recreation, and Project Complexity with importance weights ranging from 7.8 to 7.3.

Trade-off analyses can also be completed to evaluate specific subsets of Evaluation Objectives that are of interest to decision-makers. As part of this Study, two additional trade-off analyses were completed using two subsets of Evaluation Objectives: one that represented cost and feasibility aspects and another that represented environmentally-related factors.

Info Box 9. Key Trade-off Analysis Findings

- The top scoring concept was Urban and Agricultural Water Use Efficiency.
- Potable Reuse was the highest-scoring Concept for both Reliability and Robustness and Water Quality and Watersheds, the Evaluation Objectives weighted with the highest importance by stakeholders.
- Analysis of significant differences between Concepts using mean survey results indicated low potential for bias.

Including only a sub-set of Evaluation Objectives clearly changed the order of the Concepts in the trade-off analysis results from the order using all Evaluation Objectives. This demonstrated the potentially large influence that different perspectives of regional objectives, as reflected through the use of different subsets of Evaluation Objectives, can have on the trade-off analysis results. This also showed the value of the Customized Trade-Off Analysis Tool developed as part of this Study, as it enables individual entities to evaluate Concepts based upon personal preference and customized Evaluation Objective weights as well as particular Evaluation Objectives included in their assessments.

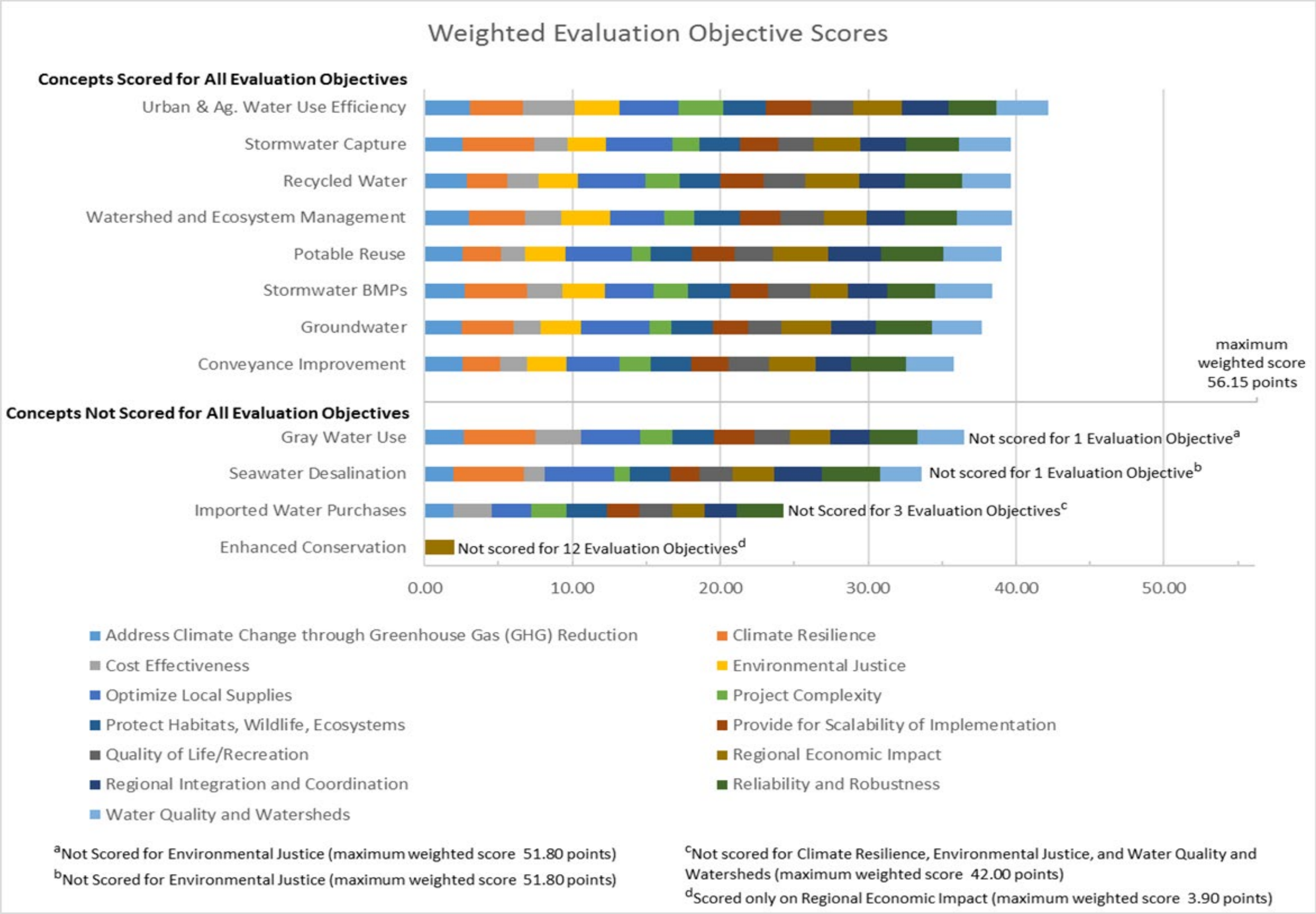


Figure 10. Trade-off analysis results for each Concept by Evaluation Objective, using mean survey scores for calculation of Performance Measures.

Table 5. Evaluation Objective importance weights based on an average of all responses

Evaluation Objective	Average of all responses
Reliability and Robustness	10.0
Water Quality and Watersheds	10.0
Climate Resilience	9.6
Optimize Local Supplies	9.4
Protect Habitats, Wildlife, and Ecosystems	9.2
Environmental Justice	8.7
Cost Effectiveness	8.5
Regional Integration and Coordination	8.5
Address Climate Change Through Greenhouse Gas Reduction	8.2
Regional Economic Impact	7.8
Scalability of Implementation	7.7
Quality of Life/Recreation	7.4
Project Complexity	7.3

4.2.1. Identification of Concept Strengths and Weaknesses

The unweighted scores that Concepts received on individual Evaluation Objectives in the context of their overall final weighted ranking can provide insight into the strengths and weaknesses of Concepts as well as how Concepts may complement each other. For example, Urban and Agricultural Water Use Efficiency was the highest overall scoring Concept. Its lowest single Evaluation Objective score was for Reliability and Robustness, with an unweighted score of 3.20. This is a relatively neutral score. Potable Reuse was the fifth highest Concept in overall combined scoring but scored highest for the Reliability and Robustness Evaluation Objective, with a score of 4.19, indicating that a strength of Potable Reuse projects is their reliability and robustness. Therefore, combining some Potable Reuse projects with projects in the Urban and Agricultural Water Use Efficiency Concept could bolster regional Reliability and Robustness.

Similarly, combining projects from the Watershed and Ecosystem Management Concept with projects from the Urban and Agricultural Water Use Efficiency Concept could improve regional protection of habitats, wildlife, and ecosystems. Urban and Agricultural Water Use Efficiency had a near-neutral score for the Protect Habitats, Wildlife, and Ecosystems Evaluation Objective (3.08) and it had its lowest unweighted Evaluation Objective score for this Evaluation Objective. The Watershed and Ecosystem Management Concept had the highest Protect Habitats, Wildlife, and Ecosystems score of all Concepts (3.35), so the combination of the two Concepts would have additional benefits to habitats, wildlife, and ecosystems.

Another example of potential complementary Concepts is Seawater Desalination and Urban and Agricultural Water Use Efficiency or Gray Water. The Seawater Desalination Concept had the lowest individual Evaluation

Objective score for Cost Effectiveness. Urban and Agricultural Water Use Efficiency and Gray Water Use both had the two highest scores for Cost Effectiveness. Therefore, it may be possible to compensate for the low-cost effectiveness score of Seawater Desalination by also implementing some Urban and Agricultural Water Use Efficiency or Gray Water projects to improve overall cost effectiveness of regional water supplies.

There are many possible combinations of projects within Concepts that could potentially improve overall performance that are too numerous to discuss here. But, the above examples demonstrate the process that could be used to identify these performance-improving combinations.

4.3. Supplemental Economic Assessment Results

The economic assessment examined effects of Concepts in three categories of benefits (municipal and industrial water supply reliability [reduced shortages], recreation [reservoir visitation], and energy usage) that could be quantified in monetary terms. Results are shown in Table 6 and Figure 11.

Enhanced Conservation provided the highest net value for the three benefit categories that were analyzed, primarily as a result of its high positive energy usage reduction values (less energy used compared to Baseline). The negative net benefits associated with the Seawater Desalination Concept were driven by the negative net energy usage reduction value (more energy used compared to Baseline). Water supply reliability had only a moderate impact on overall Concept ranking for the economic assessment, and recreation values played a comparatively small role in the economic assessment results.

Info Box 10. Key Economic Assessment Findings

- The net effects for the three categories of benefits analyzed are positive relative to the Baseline for all Concepts except Seawater Desalination.
- Enhanced Conservation generated the greatest overall positive benefit relative to the Baseline, primarily due to energy reduction.

The economic assessment indicated there are positive benefits due to reduced water supply shortages associated with all the Concepts relative to Baseline conditions. Enhanced Conservation generated the greatest benefits of reduced water shortage compared to the Baseline conditions, followed by Potable Reuse and Seawater Desalination.

Differences in the value of recreation activities relative to the Baseline were significantly smaller than differences in the value of water shortages and the change in the value of net power. Conveyance Improvement generated the greatest recreation benefit, followed by Potable Reuse and Enhanced Conservation. There were slightly positive or near zero benefits associated with the value of recreation activity for all the Concepts except Watershed and Ecosystem Management, which had negative recreation benefits due to the inclusion of the Hodges Water Quality Improvement Program as one of the two projects in this Concept that could be modeled. This project enables larger releases of stored water, resulting in lower reservoir elevations and corresponding reduced recreation visitation.

The reduction in net energy usage relative to the Baseline varied widely between Concepts. The reduction in net energy usage for Enhanced Conservation was more than three times larger than the next highest Concept. This large decrease in energy usage can be explained by the significantly lower water deliveries required with the implementation of Enhanced Conservation that reduce energy costs for imported water treatment and conveyance. This reduced energy usage resulted in an estimated monetary savings of $20,000,000 per year, which may be considered relative to the cost of managing declining flows in the wastewater system resulting from conservation. This exemplifies how information gathered from the economic assessment may help identify opportunities and monetary savings that could be used to re-invest in the water or wastewater system and address any related issues.

Potable Reuse, Recycled Water, and Groundwater also had net energy usage values that represented significant reductions compared to the Baseline. Net energy relative to Baseline was negative for Seawater Desalination and slightly negative for Conveyance Improvement, indicating an increase in energy usage would be required for those Concepts compared to Baseline.

The net annual values, including all three quantified and monetized effects for each Concept, are shown in Table 6.

The economic assessment supplemented the trade-off analysis by providing a sense of the differences in economic value associated with the Concepts. However, the economic values in this assessment only represented a small subset of the total effects included in the trade-off analysis. The activities and resources that cannot be monetized still have value, and therefore, this economic assessment should <u>not</u> be considered a complete economic analysis for use in a full benefit-cost type of analysis. However, the assessment does provide information that can be used to assess the economic effects of each Concept on water supply reliability, recreation, and energy use. The results of the economic assessment are presented in Figure 11.

Table 6. Estimated value of quantified and monetized effects relative to the Baseline

Concept	Annual Value of a Change in Water Shortages Relative to Baseline	Annual Change in the Value of Recreation Opportunities Relative to Baseline	Annual Value of a Change in Net Power Relative to Baseline	Net Annual Value of Quantified and Monetized Economic Effects Relative to Baseline
Conveyance Improvement	$167,800	$319,300	-$139,297	$347,803
Enhanced Conservation	$3,228,600	$69,549	$17,935,706	$21,233,855
Gray Water Use	$272,800	$1,123	$230,735	$504,658
Groundwater	$1,305,300	$3,083	$1,147,135	$2,455,518
Imported Water	$237,300	-$72	$520,798	$758,026
Potable Reuse	$2,185,100	$163,309	$4,948,425	$7,296,834
Recycled Water	$1,419,900	$2,032	$2,751,385	$4,173,317
Seawater Desalination	$1,883,700	$406	-$1,928,869	-$44,763
Stormwater BMPs	$8,200	$143	$8,031	$16,374
Stormwater Capture	$68,200	$311	$53,416	$121,927
Urban & Agricultural Water Use Efficiency	$230,500	$406	$268,484	$499,390
Watershed & Ecosystem Management	$195,700	-$82,790	$459,355	$572,265

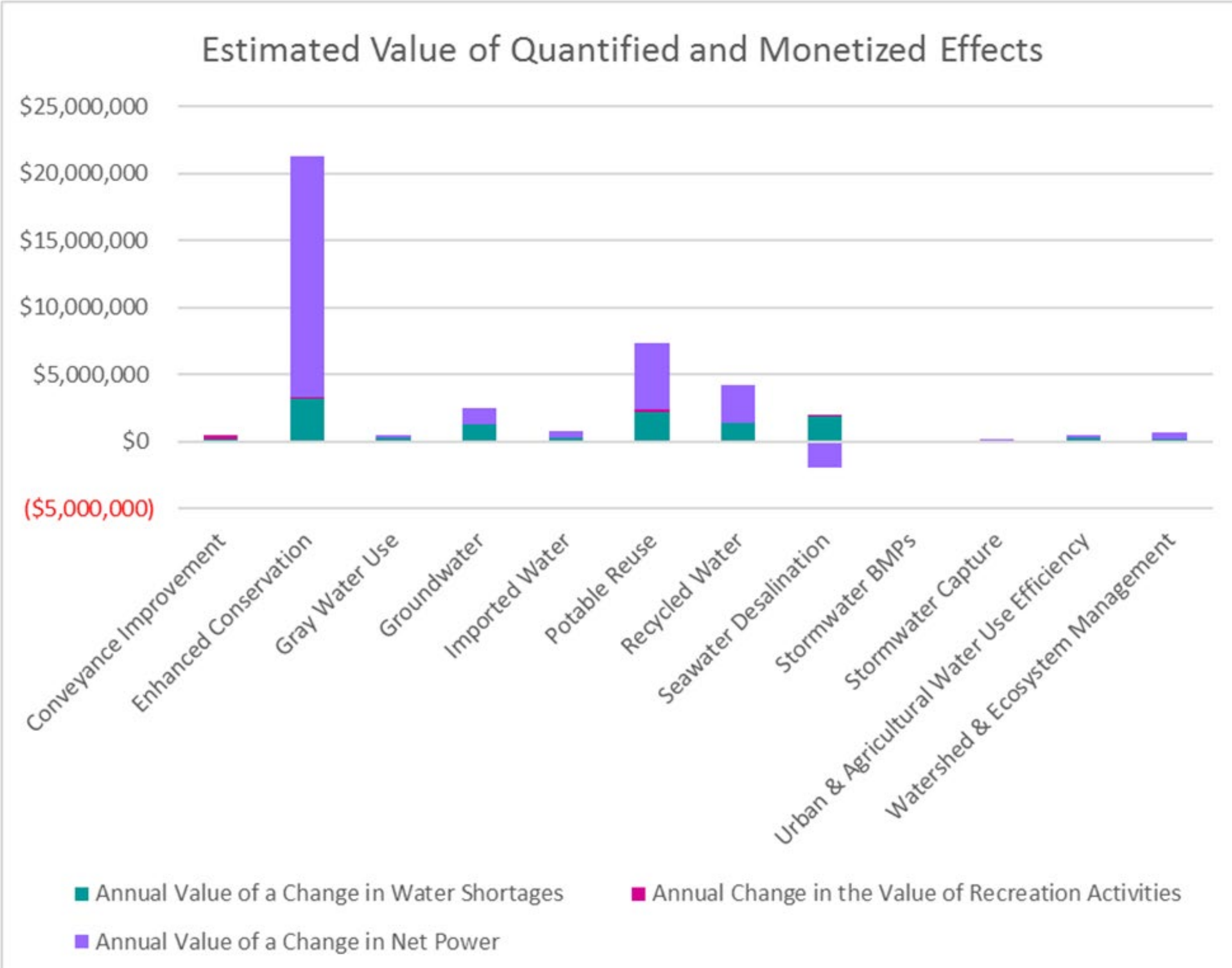


Figure 11. Net annual value of quantified and monetized effects for each Concept for the three categories of benefits analyzed in the economic assessment.

4.4. Comparison of Economic Assessment to Trade-Off Analysis Ranking

Although the economic assessment and trade-off analysis share some common measures, they represent very different perspectives. An economic assessment is based only on effects that can be quantified and monetized while a trade-off analysis can include a wider range of effects because monetization of effects, and in some cases, precise quantitative measures, are not necessary as part of a trade-off analysis.

There was some consistency in the Concept rankings for the trade-off analysis based on all the Evaluation Objectives and the economic assessment, but there were also several differences. The comparative rankings are shown in Table 7. Since the trade-off analysis for the Imported Water Purchases, Enhanced Conservation, Gray Water Use, and Seawater Desalination Concepts did not include all the Evaluation Objectives, the trade-off analysis and economic assessment results were not compared for these Concepts.

Table 7. Comparison of Concept rankings for the trade-off analysis and economic assessment

Concept	Trade-off analysis Ranking based on all Evaluation Objectives and Mean scores	Economic Assessment Ranking
Conveyance Improvement	8	9
Enhanced Conservation	NA	1
Gray Water Use	NA	7
Groundwater	7	4
Imported Water	NA	5
Potable Reuse	5	2
Recycled Water	4	3
Seawater Desalination	NA	12
Stormwater BMPs	6	11
Stormwater Capture	3	10
Urban & Agricultural Water Use Efficiency	1	8
Watershed & Ecosystem Management	2	6

Urban and Agricultural Water Use Efficiency was the top scoring Concept in the trade-off analysis but ranked 8th in the economic assessment, the largest difference in Concept ranking between the two analyses. The second largest difference for scored Concepts was Stormwater Capture (10th in the economic assessment, 3rd in the trade-off analysis). There was also a fairly large difference between the ranking of Stormwater BMPs (6th in the trade-off and 11th in the economic assessment). Conveyance Improvement and Recycled Water had very similar rankings for the trade-off analysis and the economic assessment.

An important consideration when comparing the economic assessment results with the trade-off analysis results is the exclusion of energy effects in the trade-off analysis. The value of changes in net energy usage is included in the economic assessment and is the major driving factor in the economic assessment results.

5. Limitations and Opportunities

The impacts assessment, trade-off analysis, and economic assessment can all be used to gain insight into future challenges and opportunities for the San Diego region. The Basin Study used the best available information to perform these analyses. However, data limitations, assumptions, and simplifications are present in the analysis and will have some effect on the results. Despite these limitations, the results are still valuable for assisting in decision-making regarding future investments in water supply management.

Info Box 11. Impacts Assessment Limitations

- Demands used in the Study were characterized by the 2015 SDCWA UWMP, which are higher than the updated 2018 demand forecast, and may differ from the full re-estimation for the 2020 UWMP.
- Imported Water Supplies were assumed to remain available for the duration of the Study.
- Effects on the conveyance system and reservoirs were not simulated for projects modeled as demand reductions (e.g., recycled water, groundwater, some potable reuse, etc.).
- Projects were modeled based on best available information about their capacities and water supply volumes at the time the model runs were performed.

Simulation modeling of future water system operations is a powerful tool for providing insights into potential impacts of factors such as climate change and increasing demand. However, it must also incorporate simplifications of system operations and assumptions about future conditions. These assumptions and simplifications are documented throughout the Task 2.4 Interim Report and Final Report. One assumption was that the QSA would remain constant through 2050 with a supply volume of 280,000 AF/y, however users of the Basin Study should consider potential for changes. Similarly, MWD supplies from State Water Project and Colorado River Basin were assumed to remain available. If availability of one or both these imported supplies was reduced, the region could experience greater shortages than those observed in the Basin Study results.

As many projects modeled in the Basin Study were at a very early stage of planning, there have been some changes in anticipated volumes/capacities. Users of the Basin Study should consider the projects to be examples of the types of projects that could be implemented and approximations of potential impacts.

The Portfolio approach simplified analysis and aided in understanding the causes of changes in metric values, but it does not reflect the actual future for water system development and adaptation. Instead, it is likely that San Diego's future water system will contain a mix of conceptual projects from some or all Portfolios. It may be beneficial to consider interaction of Concepts and Portfolios. For example, implementing projects from the Increase Supplies Portfolio may pair well with an intertie project from the Optimize Existing Facilities Portfolio to increase water supply reliability while at the same time allowing for better management of reservoir storage to decrease the number of flood outflows.

Info Box 12. Limitations of the Trade-off Analysis

- The following Concepts did not receive scores for all Evaluation Objectives due to limited data:
  - Imported Water Purchases
  - Enhanced Conservation
  - Seawater Desalination
  - Gray Water Use
- The economic assessment was limited in scope and does not represent a full range of costs and benefits.

Imported Water Purchases Concept was only scored for Evaluation Objectives that did not require GIS data because the single project in the Concept could not be mapped since it was located outside the Study Area. In addition, it was not scored for the Optimize Local Supplies Evaluation Objective because the survey respondent for the project-level survey data misinterpreted the question and the survey response could not be used.

Similar to Imported Water, the Enhanced Conservation Concept could not be mapped to a specific location, in this case because the Concept is conceptualized as being implemented throughout the entire region. Additionally, the Enhanced Conservation Concept was originally included in the Urban and Agricultural Water Use Efficiency Concept but was split out as a separate Concept after stakeholder feedback. This occurred after the performance measure scoring surveys were distributed; therefore, this Concept only had a score for the Regional Economic Impact Evaluation Objective.

Both Gray Water Use and Seawater Desalination had missing project-level survey data for the Environmental Justice Evaluation Objective.

It may be possible to gain insight into how the Enhanced Conservation Concept would score by its similarities to the Urban and Agricultural Water Use Efficiency Concept. Enhanced Conservation focuses on water restrictions imposed at the local, regional, or State level, while Urban and Agricultural Water Use Efficiency focuses on behavioral changes that encourage water efficiency. Despite their differences, the relative scores for some Evaluation Objectives may be quite similar due to similarities in the actual conservation practices implemented. With the similarities and differences between these two Concepts in mind, it may be possible to estimate the scores of Enhanced Conservation, and, if desired, an agency could use the Customized Trade-off Analysis Tool (published as part of the Task 2.5 Interim Report) to perform an analysis with the estimated scores.

Despite the limitations related to this effort, the trade-off analysis and economic assessment completed as part of the Basin Study can assist in decision-making as the San Diego region considers future investments in water supply management.

6. Conclusion

Based on the analyses completed in the San Diego Basin Study, there are a range of adaptation strategies that the region can employ to adapt to water supply and demand imbalances.

The impacts assessment analysis compared six Portfolios of Concepts in four areas: water delivery, energy, recreation, and flood control. It identified that, under the Baseline Portfolio, the region is vulnerable to the impacts of increasing demand and climate change.

In particular:

- shortages of up to 2% of the total annual demand on average are expected to occur and the region will continue to rely on imported water,
- there may be an increase in issues associated with high pipeline utilization for the untreated MWD pipeline, and
- there may be higher energy consumption.

The region's active investments and planned projects included in the Baseline Plus Portfolio may begin to address these vulnerabilities, particularly by diversifying the sources of water and reducing demands; however, shortages were not completely eliminated in the Baseline Plus Portfolio. Modeled implementation of the Increase Supplies and Enhanced Conservation Portfolios made notable reductions to shortages and improved some of the other key impacts of interest. These results suggest that continued investment in both supply enhancement and diversification, as well as demand reduction is needed to meet projected future demands and reduce vulnerability to the impacts of climate change. While the Optimize Existing Facilities Portfolio may not address challenges such as water reliability or reduced dependence on imported water (compared to Baseline Plus), it does maximize the region's existing infrastructure and allow for improved reservoir management that may provide flood control benefits. Although many environmental projects included in the Watershed Health and Ecosystem Restoration Portfolio were unable to be modeled, they would likely exhibit positive environmental impacts.

Simulations of all Portfolios beyond the Baseline resulted in shifts in water deliveries away from imported water and showed fewer realizations above the shortage threshold of 20,000 AF. This effect was particularly strong for the Increase Supplies and Enhanced Conservation Portfolios. A decrease in energy consumption was also observed in all Portfolios beyond the Baseline, which may be related to the decrease in imported water deliveries. The increased water availability and management flexibility associated with all Portfolios generally appeared to raise the End of September Elevation of all reservoirs and improve boat ramp accessibility, which reduces vulnerability to drought and maintains access to reservoirs for recreation. Flood control impacts varied between Portfolios and reservoirs. For example, there were increases in flood outflows for El Capitan in the Increase Supplies Portfolio but decreases in the Optimize Existing Facilities Portfolio. The Optimize Existing Facilities Portfolio reduced the amount of flood outflows at El Capitan, due to the San Diego Reservoir Intertie.

In the trade-off analysis, the top scoring Concept was Urban and Agricultural Water Use Efficiency. Five other Concepts scored within 10% of the top scoring Concept (Watershed and Ecosystem Management, Stormwater Capture, Recycled Water, Potable Reuse, Stormwater BMPs). Two additional Concepts scored within 15% of the top scoring Concept (Groundwater and Conveyance Improvement). Due to data limitations, not all Concepts could be scored on all Evaluation Objectives and therefore could not be directly compared to the others. Imported Water Purchases, Enhanced Conservation, Seawater Desalination, and Gray Water Use each lacked scores for one or more Concepts.

The supplemental economic assessment indicated there are positive benefits associated with all the Concepts relative to Baseline conditions, except for Seawater Desalination. The economic assessment included evaluation of the value of water supply reliability, recreation, and net energy usage. All values for water supply reliability were positive, and all but two Concepts had positive values for recreation and net energy. Enhanced Conservation provided the highest net value for the three benefit categories that were analyzed, primarily as a result of its high positive energy usage reduction values (less energy used compared to Baseline). The negative net benefits associated with the Seawater Desalination Concept were driven by the negative net energy usage reduction value (more energy used compared to Baseline). Water supply reliability had only a moderate impact on overall Concept ranking for the economic assessment and recreation values played a comparatively small role in the economic assessment results.

As a whole, the results and conclusions of the Basin Study can be used by stakeholders to identify promising Concepts that address the impacts of climate change and increasing demands on water supplies within the San Diego region. The impacts assessment results can be used to gain insight into potential impacts of implementing various Concepts. The trade-off and supplemental economic assessment results can provide supporting data for use in estimating the potential benefits of projects and Concepts as part of grant applications or when determining which projects merit more detailed examination.

Disclaimer

The Basin Study is a technical assessment and does not provide recommendations or represent a statement of policy or position of the Bureau of Reclamation, the Department of the Interior, or the City of San Diego. The Basin Study does not propose or address the feasibility of any specific project, program or plan. Nothing in the Study is intended, nor shall the Study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the Study represents a commitment for provision of Federal funds.

The Metropolitan Transit System Trolley highlights the "Waste No Water" Campaign, part of the City of San Diego's ongoing water use efficiency education programs .
Courtesy City of San Diego

Supporting Material

Acronyms and Abbreviations

AF	acre-feet (1 AF = 43,560 cubic feet = 325,851 gallons)
Basin Study	San Diego Basin Study
BMP	Best Management Practice
City	City of San Diego
CMIP5	Coupled Model Intercomparison Project
County	County of San Diego
DAC	Disadvantaged Community
GHG	Greenhouse Gases
GIS	Geographic Information System
IRWM	Integrated Regional Water Management
M&I	Municipal and Industrial
MWD	The Metropolitan Water District of Southern California
MWh	Megawatt-hour(s)
QSA	Colorado River Quantification Settlement Agreement
SDCWA	San Diego County Water Authority
STAC	Study Technical Advisory Committee
UWMP	Urban Water Management Plan

Modeled Portfolio and Climate Scenario Abbreviations

B	Baseline Portfolio
B+	Baseline Plus Portfolio
EC	Enhanced Conservation Portfolio
IS	Increase Supplies Portfolio
OEF	Optimize Existing Facilities Portfolio
WE	Watershed Health and Ecosystem Restoration Portfolio
cc	Current Climate
ct	Central Tendency Climate
hd	Hot-dry Climate
wd	Warm-dry Climate
hw	Hot-wet Climate
ww	Warm-wet Climate

Glossary

Central Tendency: For climate change scenarios in the Basin Study, the central tendency is the 50th percentile of temperature change and precipitation change from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) temperature and precipitation projections.

Concept: San Diego Basin Study Concepts represent groups of similar strategies or projects that could be used to meet the water demands of the region. These Concepts are used as the basis for analysis in the Study. Concepts were defined to characterize existing and potential future approaches. Concepts are defined by one or more Projects.

CWASim: A GoldSim model originally developed for SDCWA by CH2M in support of the 2013 Regional Facilities Optimization and Master Plan Update to simulate the regional water system. The model was adapted and updated for use in the San Diego Basin Study.

Demand Scenario: Specific time periods (2015, 2025, and 2050 for the Basin Study) in which demand projections were generated and simulated in the CWASim model.

Evaluation Objective: Criteria developed through stakeholder input to characterize desired outcomes.

Performance Measures: Metrics to calculate Evaluation Objective scores based upon a combination of survey responses, modeling results and/or GIS analyses.

Portfolios: Portfolios were developed for the purpose of simulating and analyzing groups of related Concepts. Each Portfolio contains a subset of Concepts.

Projects: Projects represent actual or theoretical proposed modifications to existing facilities, construction of new facilities, modifications to system operations or policy, or other proposed activities. Most SDBS Projects are based on actual proposed projects including those listed as verifiable, additional planned, and conceptual in the 2015 SDCWA Urban Water Management Plan, the 2013 SDCWA Master Plan, the 2013 IRWM Plan, the 2017 Stormwater Resources Plan, or other similar planning documents and lists. Other projects represent a theoretical project idea or type of project, but are not tied to a specific proposed implementation.

Realizations: Daily water system simulations were based on an 85-year-long time series of surface water inflows to reservoirs. Each model run was made up of 85 realizations, where each realization represents a set of historical hydrologic data (i.e., one year of the 85-year-long time series). The 85 realizations were run consecutively through the model, and the order was the same for all runs, allowing direct comparison between scenarios and realizations.

Timestep: The unit of time used for simulation modeling or analysis of results. The CWASim model uses a timestep of one day, meaning the model simulates operations on a daily basis. The results of the daily simulations are aggregated to monthly or annual timesteps for analysis.

Verifiable Projects: As defined in the SDCWA 2015 UWMP, projects with "substantial evidence and adequate documentation regarding implementation and supply utilization."

Figures and Tables

Figures

Tables

Info Boxes

References

California Department of Water Resources. (2016). *2016 Integrated Regional Water Management Grant Program Guidelines*. Retrieved from https://water.ca.gov/Work-With-Us/Grants-And-Loans/IRWM-Grant-Programs/Proposition-1

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