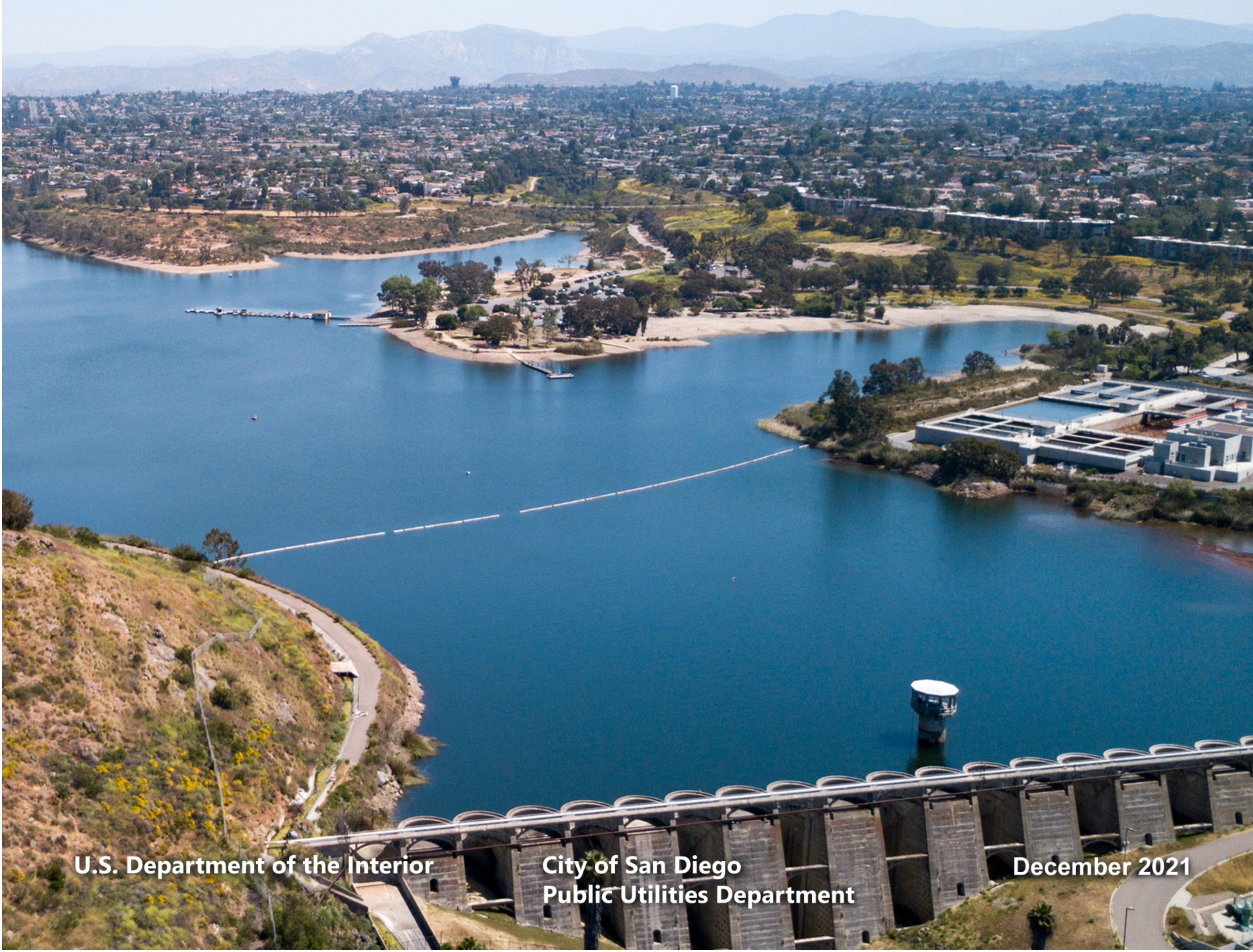
BUREAU OF RECLAMATION

Final Report

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: 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

Final Report

December 2021

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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 U.S. 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 local, State, or Federal funds.

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Acronyms and Abbreviations

AF	Acre-feet (1 AF = 43,560 cubic feet = 325,851 gallons)
AF/y	acre-feet per year
ANOVA	Analysis of Variance
Basin Study	San Diego Basin Study
BMP	Best Management Practice
City	City of San Diego
CMIP Phases 3 & 5	Coupled Model Intercomparison Project climate projections
CNDDB	California Natural Diversity Database
County	County of San Diego
CRA	Colorado River Aqueduct
CRBS	Colorado River Basin Study
DAC	Disadvantaged Community
DWR	California Department of Water Resources
EO	Evaluation Objectives
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
GPCD	Gallons Per Capita Per Day
IID	Imperial Irrigation District
IRWM	Integrated Regional Water Management
LMP	Locational Marginal Price
MCDA	Multi-criteria Decision Analysis
M&I	Municipal and Industrial

MAF	Million acre-feet
mgd	Million gallons per day
MSCP	San Diego County Multiple Species Conservation Program
MWD	The Metropolitan Water District of Southern California
MWh	Megawatt-hour(s)
NA	Not Applicable
NGO	Non-Governmental Organization
PET	Potential Evapotranspiration
QSA	Colorado River Quantification Settlement Agreement
RAC	Regional Advisory Committee
RCP	Representative Concentration Pathways
Reclamation	United States Department of the Interior, Bureau of Reclamation
RWMG	San Diego Regional Water Management Group
TOV	Twin Oaks Valley
SANDAG	San Diego Association of Governments
SDCWA	San Diego County Water Authority
SDPUD	City of San Diego Public Utilities Department
SSJBS	Sacramento-San Joaquin Basins Study
STAC	Study Advisory Committee
SWP	State Water Project
UWMP	Urban Water Management Plan
VIC	Variable Infiltration Capacity model
WRF	Water Reclamation Facility
WTP	Water Treatment Plant

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:

(1) For climate change scenarios, 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.

(2) For statistical analysis, the central tendency is a central or typical value for a probability distribution. The most common measures of central tendency are the arithmetic mean, median, and mode.

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.

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

GoldSim: A simulation software program for dynamically modeling complex systems in business, engineering, and science. GoldSim supports decision and risk analysis by simulating future performance while quantitatively representing the uncertainty and risks inherent in all complex systems.

IRWM Program: A California DWR program for supporting water resources planning under the Regional Water Management Planning Act (SB 1672). Integrated Regional Water Management (IRWM) is a collaborative effort to manage all aspects of water resources in a region. The fundamental principle of IRWM is that regional water managers, who are organized into regional water management groups, are best suited and best positioned to manage water resources to meet regional needs.

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

Portfolios: 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 projects listed as verifiable, additional planned, and conceptual in the 2015 San Diego County Water Authority (SDCWA) Urban Water Management Plan (UWMP), 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.

San Diego Basin Study Area: The area bounded on the north, west, and south by the San Diego County boundary and on the east by the boundaries of 11 Study Watersheds. The Study Area is the same as the San Diego IRWM Planning Region.

Study Watersheds: The entirety of the San Luis Rey, Carlsbad, San Dieguito, Peñasquitos, San Diego River, Pueblo, Sweetwater, and Otay watersheds and the portions of the San Juan, Santa Margarita, and Tijuana watersheds within San Diego County.

Urban Water Management Plans: Plans prepared and submitted to DWR by California's urban water suppliers every five years to meet the requirements identified in the California Water Code, Sections 10608 - 10656. Every urban water supplier that either provides over 3,000 acre-feet of water annually or serves more than 3,000 urban connections is required to assess the reliability of its water sources over a 20-year planning horizon and report its progress on 20% reduction in per-capita urban water consumption by the year 2020, as required in the Water Conservation Act of 2009.

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

Watershed: Surface drainage area upstream of a specified point on a watercourse. A geographical portion of the Earth's surface from which water drains or runs off to a single point.

Water Year: The 12-month period from October 1, for any given year, through September 30 of the following year. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 1999 is called the "1999" water year.

CWASim Model Terminology

Carryover: Carryover storage describes the minimum volume of water in a reservoir that should be carried over from year to year. The carryover pool or zone for a reservoir is designated by the reservoir's rule curve. In the CWASim model, water stored in the carryover pool is available to meet demands under certain conditions.

Demand Node: Single or multiple containers within the CWASim model that represent project demands for the SDCWA member agencies. Agencies with multiple supply types are represented by a demand node with multiple containers that each represent a supply type within that agency's portfolio.

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.

Realizations: Daily water system simulations that 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 of the realizations was the same for all runs, allowing direct comparison between scenarios and realizations.

Rule Curve: Reservoirs in CWASim are controlled by rule curves. The rule curves divide the reservoir storage into nine reservoir zones or "pools". The zones range from the *Dead Pool Zone* corresponding to the lowest possible water storage in the reservoir, to *Zone 1* corresponding to the reservoir flood zone.

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

1. Introduction

1.1 Authority

In 2009, recognizing that climate change poses a significant challenge to the sustainability of adequate and safe supplies of water, Congress passed the SECURE Water Act. The Act authorizes the Bureau of Reclamation, in conjunction with stakeholders, to evaluate and report on the risks and impacts on water supplies from a changing climate, and to identify appropriate adaptation and mitigation strategies using the best available science. As part of this effort, the Secretary of the Interior established the WaterSMART program in 2010, which authorizes the Department's bureaus to collaboratively work with State, tribal, and local governments, and non-governmental organizations to pursue reliable water supplies. Basin Studies, one of the tools of this program, define options for meeting future water demands within river basins of the western United States where imbalances in water supply and demand exist or are projected.

1.2 Purpose and Objectives

The purpose of the San Diego Basin Study (Basin Study) was to determine potential climate change impacts on water supplies and demands within the San Diego region, and to develop structural and non-structural concepts that can assist the region in ensuring reliable water supplies. The Basin Study investigated potential changes to existing operating policies for regional water supply facilities (i.e., dams, reservoirs, conveyance facilities, and water treatment and water recycling plants), modifications to existing facilities, and development of new facilities that could optimize reservoir systems, and additional new water supply options including desalination and indirect potable reuse.

1.3 Study Background

For more than 70 years, the San Diego area has relied on imported water as the primary source of supply for the region. With a strong military presence before, during, and immediately after World War II, San Diego's growing population was in desperate need of water supply solutions. In response, the Department of the Navy and the Bureau of Reclamation (Reclamation) constructed the San Diego Project, two large-diameter pipelines that connect the area to The Metropolitan Water District of Southern California's (MWD) infrastructure system, to bring in supplemental supplies from the Colorado River. The first pipeline was completed in 1947 and the second in 1954 (together known as the 'First Aqueduct'), which the San Diego County Water Authority (SDCWA) now owns and operates along with three additional large-diameter pipelines (collectively, the 'Second

Aqueduct') that deliver imported supplies into the region. Imported water from the Colorado River Basin and State Water Project (SWP) remains the region's predominant source of supply, comprising approximately 70% to 90% of the supplies utilized within the region. These imported supplies consist of water purchased from MWD and other imported supplies resulting from agreements that provide access to senior water rights on the Colorado River via long-term transfers. Imported water purchases are dependent on availability of water from MWD, while the long-term transfer agreements guarantee up to 200,000 AF/y by 2021 of conserved water from the Imperial Irrigation District (IID) and an additional 80,200 AF/y of water conserved through canal lining projects. The imported water purchases, the IID transfer water, and the canal lining water are wheeled through MWD's conveyance facilities to SDCWA aqueducts.

Prior to the introduction of imported water supplies, surface water reservoirs served as the primary source of water supply for the region. Local surface water supplies remain an integral part of the region's supply portfolio. As of 2015, local surface water (estimated to provide approximately 51,680 AF/y of supply, although it can vary substantially from year to year due to fluctuating hydrologic cycles) and seawater desalination (Carlsbad Desalination Plant, with a production capacity of 56,000 AF/y) provided the majority of local supplies (San Diego County Water Authority, 2016).

Two additional local supplies include recycled water and groundwater. Although groundwater provides some water supply to the San Diego region, unlike other large metropolitan areas within southern California, the region does not have large productive groundwater basins within its borders. This is due to a number of factors including limited productive sand and gravel (alluvial) aquifers, the relatively shallow nature of most existing alluvial aquifers, lack of rainfall and groundwater recharge, and degraded water quality resulting from human activities (San Diego County Water Authority, 2015).

While SDCWA and its member agencies have taken steps to diversify the region's supply portfolio through the development of local supplies, through the formation of agreements to access senior water rights on the Colorado River, and through conservation and water use efficiency improvements, the region remains highly reliant on imported water sources. The reliability of imported water deliveries in the San Diego region is uncertain due to recurring droughts in northern California and the Colorado River Basin, regulatory restrictions related to endangered species in the Bay-Delta that limit SWP deliveries, the potential for catastrophic events such as earthquakes, and climate change. Over the last 25 years, multi-year supply cutbacks have been experienced on three separate occasions (San Diego County Water Authority, 2017).

Future changes are anticipated to affect both water supply and demand in the San Diego region. As the San Diego region continues to grow in population, water demands are anticipated to increase (San Diego County Water Authority, 2016; San Diego County Water Authority, 2018a). Climate change is anticipated to increase median annual precipitation by 0% to 12% and increase median annual temperature by 1.5 to 4.5 degrees Fahrenheit, depending on the climate model selected (see Section 2.3) which will directly affect local surface water supply and regional water demand. Climate change is also anticipated to affect imported water supplies as a result of climate change impacts on the Sacramento-San Joaquin Basin (Bureau of Reclamation, 2016b) and Colorado River Basin (Bureau of Reclamation, 2012).

To meet current and future water supply reliability goals, it is essential that the region evaluate its existing system, identify ways to improve the ability to store imported and local water supplies when available, and develop new water supplies, making the region more resilient to drought, climate change, and water delivery service interruptions.

1.4 Study Approach

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

Table 1. San Diego Basin Study Analytical 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] Interim Reports for Tasks 2.1, 2.2, and 2.3 have been superseded by the Task 2.4 and 2.5 Interim Reports and this Final Report

A technical team was assembled to perform Tasks 2.1 through 2.5 and complete the Final Report and Executive Summary Report for Task 2.6. The team was comprised of staff from Reclamation's Lower Colorado Region Engineering Services Office, Reclamation's Denver Technical Service Center, Reclamation's Mid-Pacific Regional Office, the City of San Diego, and technical consultants.

Each sub-Task was documented in an Interim Report, and the final methodology, results, and conclusions are described in this Final Report. It is important to note that much of the information in the Task 2.1, 2.2, and 2.3 Interim Reports differs from the information documented in the Final Report. Inputs and tools evolved over the multi-year span of the Study as input data was refined and updated and available modeling tools advanced. For example, Tasks 2.1 and 2.2 used supply and demand projections based on the 2010 SDCWA Urban Water Management Plan (UWMP) while Tasks 2.3, 2.4, and 2.5 used projections based on the 2015 SDCWA UWMP. Task 2.3 also used an earlier version of the water system model than the version used for Tasks 2.4 and 2.5. Each Task built upon previous Tasks, and for each Interim Report, the methodology and analysis developed in previous Tasks was updated to use the best available information for the Study. Due to these evolutionary changes throughout the Study, Tasks 2.1 through 2.3 are superseded by Tasks 2.4 and

2.5, and this Final Report summarizes the methodology, results, and conclusions that are documented in detail in the Tasks 2.4 and 2.5 Interim Reports.

1.5 Stakeholder Engagement

Stakeholder engagement was a key part of this Basin Study and included both engagement with the Stakeholder Technical Advisory Committee and outreach to public stakeholders.

1.5.1 Stakeholder Technical Committee

A Stakeholder Technical Committee (STAC), comprised of technical-level individuals from Reclamation and the City of San Diego Public Utilities Department (SDPUD), as well as other water agencies, nongovernmental organizations (NGOs), and State and local government, provided technical support throughout all phases of the Study (Table 2). STAC meetings provided opportunities for the technical team to share information and consult with the STAC. At least one STAC meeting occurred for each Task, and the STAC was invited to review each Interim Report.

Table 2. San Diego Basin Study Stakeholder Technical Advisory Committee

Representation	Agency
Water Agencies	San Diego County Water Authority San Diego Public Utilities Department Helix Water District City of Poway Olivenhain Municipal Water District Santa Fe Irrigation District Otay Water District County of San Diego
Non-Governmental Organizations	San Diego Audubon Society Friends of Famosa Slough Surfrider Foundation San Diego Foundation
Regulatory/Environmental/ Research/Community Organizations	Scripps Institute of Oceanography U.S. Geological Survey San Diego Regional Water Board
Technical Consultants	Jacobs (formerly CH2M)

1.5.2 Public Stakeholders

Public stakeholders included individuals participating in the San Diego Integrated Regional Water Management Program (IRWM), which was made up of participants from water agencies, regulatory groups, environmental NGOs, academia, and community organizations. Known as the Regional Advisory Committee (RAC), this committee includes 28 voting members and 6 non-voting members (Reclamation is a non-voting member). These public stakeholders were given the opportunity to review portions of the Interim Reports at key points in the study process, and several public meetings to present the results and conclusions of each Task were held in San Diego (Table 3).

Table 3. Summary of San Diego Basin Study Stakeholder Outreach Meetings

Date	Type	Number of attendees (not including technical team)	Topics Discussed
November 2014		33	Discussed background on the WaterSmart Program, Basin Study purpose, objectives and tentative schedule. Provided overview of Task 2.2 climate modeling for the study.
February 2016	STAC	18	Provided an overview of Tasks 2.1 and 2.2. Released draft Interim Reports for Tasks 2.1 and 2.2 for public comment.
February 2017	STAC	11	Presented and discussed Task 2.3 results. Requested review of Task 2.3 results.
March 2017	Public	24	Presented results of Task 2.3 (baseline impacts on water supply and demand, delivery, recreation, hydropower, and flood control). Requested feedback on the Concepts to include and evaluate in Task 2.4. Developed proposed list of portfolios to model in Task 2.4.
April 2017	STAC	12	Gathered STAC input on portfolios that were proposed at the March Public Stakeholder meeting.
April 2017	IRWM RAC	45	Presented a status update on the San Diego Basin Study and the Task 2.3 Interim Report. Requested written comments from Public Stakeholders on the Task 2.3 Interim Report.
May 2017	STAC	20	Provided summary of the April STAC meeting discussion of Study portfolios. Discussed modifications made to the portfolios since April STAC meeting, and specific projects included within portfolio Concepts.
August 2017	Public (Held in conjunction with IRWM RAC Meeting)	50	Conducted a Public Workshop with RAC Meeting participants. Presented background information about the Study and its purpose, and a summary of the Task 2.3 and Task 2.4 Interim Reports.

Date	Type	Number of attendees (not including technical team)	Topics Discussed
			Presented a summary of future work included under Task 2.5 Interim Report Trade-off Analysis, providing an overview of the tradeoff analysis approach and purpose. The workshop focused on refining the draft list of Evaluation Objectives to include in the tradeoff analysis to evaluate Concepts. Following the presentation, the RAC broke out into discussion groups based on RAC caucuses. During the session, RAC members, joined by members of the public, discussed and provided feedback on the draft list of evaluation objectives. The groups were asked to consider the comprehensiveness of the list and to recommend any other objectives and performance measures for inclusion.
October 2017	IRWM RAC	57	Presented an update on the status of the San Diego Basin Study.
December 2017	IRWM RAC	41	Presented an update on the status of the Study. The City discussed the survey that was shared with stakeholders to help finalize the ranking process of Evaluation Objectives (EOs) and to provide relevant sources for their EO rankings. Thanked the RAC members who participated in the survey and shared information on the survey participation.
January 2018	STAC	19	Provided an update on the status of the Basin Study, as well as provided an overview and requested feedback on the Study's Task 2.5 Trade-off Analysis. Specifically requested feedback from the STAC relating to the scoring approach of each Performance Measure, which will be used to evaluate Adaptation Concepts.
			SDPUD convened a group of experts at a Regional Economic Impact Workshop. The goal of the workshop was to develop scores for the

Date	Type	Number of attendees (not including technical team)	Topics Discussed
March 2018	Regional Expert Economic Workshop	8	Evaluation Objective, *Regional Economic Impact*, for each Adaptation Concept included in Task 2.5 tradeoff analysis. There were five external workshop participants with expertise in economics, California and San Diego water issues and policy, and/or knowledge of the San Diego business community and industrial sector. At the workshop, participants were presented with scoring criteria and information about projects included in each concept. Each participant then provided a *Regional Economic Impact* score, ranging from 1 to 5, for each Adaptation Concept. Participants were not required to reach consensus as a group, though the group deliberated and discussed preliminary scores before finalizing their individual scores. Individual scores were averaged together to produce a final *Regional Economic Impact* score for each Adaptation Concept.
April 2018	IRWM RAC	38	Provided an update on Task 2.4 Interim Report preliminary results and the Task 2.5 Interim Report approach and Evaluation Objective scoring methodology.
April 2018	STAC	14	Presented the Task 2.4 preliminary results and Task 2.5 methodology (decision trees and scoring rubrics). Requested feedback on the preliminary results and methods of Task 2.4.
May 2018	STAC (via webinar)	19	Presented the preliminary results for Task 2.4 and the methodology for the Task 2.5 analysis. Requested and received feedback from the STAC on the preliminary Task 2.5 methodology before the June public meeting.
June 2018	Public	22	Presented preliminary results for Task 2.4 and Task 2.5. Requested stakeholder input on the draft Task 2.4 and Task 2.5 Interim Reports.
October 2018	Public	11	Presented results and conclusions of Task 2.4 of the Basin Study. Stakeholders then had the

Date	Type	Number of attendees (not including technical team)	Topics Discussed
			opportunity to discuss and ask questions about the findings.
December 2018	IRWM RAC	50	Provided an overview of the key findings from the Task 2.4 report, the purpose and methodology for Task 2.5, as well the initial results from the Task 2.5 Interim Report. Invited the RAC to attend the December SDBS Public meeting.
December 2018	Public	15	Presented the results and conclusions of Task 2.5 of the Basin Study. Stakeholders were given an opportunity to discuss and ask questions about the findings.

2. Study Area

2.1 Study Area Overview

The Study Area (Figure 1) 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 (IRWM) Plan and the SDCWA 2015 Urban Water Management Plan (UWMP). 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. Eight watersheds are completely within the Study Area (San Luis Rey, Carlsbad, San Dieguito, Los Peñasquitos, San Diego, Pueblo, Sweetwater, and Otay). Two northern watersheds (San Juan and Santa Margarita) and one southern watershed (Tijuana) are partially within the Study Area.

SDCWA and its member agencies (Table 4) are the primary suppliers of water within the Study Area. The SDCWA service area is entirely within the Study Area and 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, which makes up approximately one-third of the SDCWA service area (Figure 2). The Study Area overlapped numerous other municipal and water agency boundaries. Many other ongoing planning efforts examine portions of the Study Area, such as the UWMP produced by the City of San Diego (City of San Diego, 2015) and Urban Water Management Plans produced by other individual SDCWA member agencies.

Table 4. SDCWA Member Agencies

SDCWA Member Agencies	
Camp Pendleton Marine Corps Base	Padre Dam Municipal Water District
Carlsbad Municipal Water District	Rainbow Municipal Water District
City of Del Mar	Ramona Municipal Water District
City of Escondido	Rincon del Diablo Municipal Water District
City of Oceanside	San Dieguito Water District
City of Poway	Santa Fe Irrigation District
City of San Diego	Sweetwater Authority (City of National City and South Bay Irrigation District)
Fallbrook Public Utility District	Vallecitos Water District
Helix Water District	Valley Center Municipal Water District
Lakeside Water District	Vista Irrigation District
Olivenhain Municipal Water District	Yuima Municipal Water District
Otay Water District	

Figure 1. Overview of the San Diego Basin Study Area.

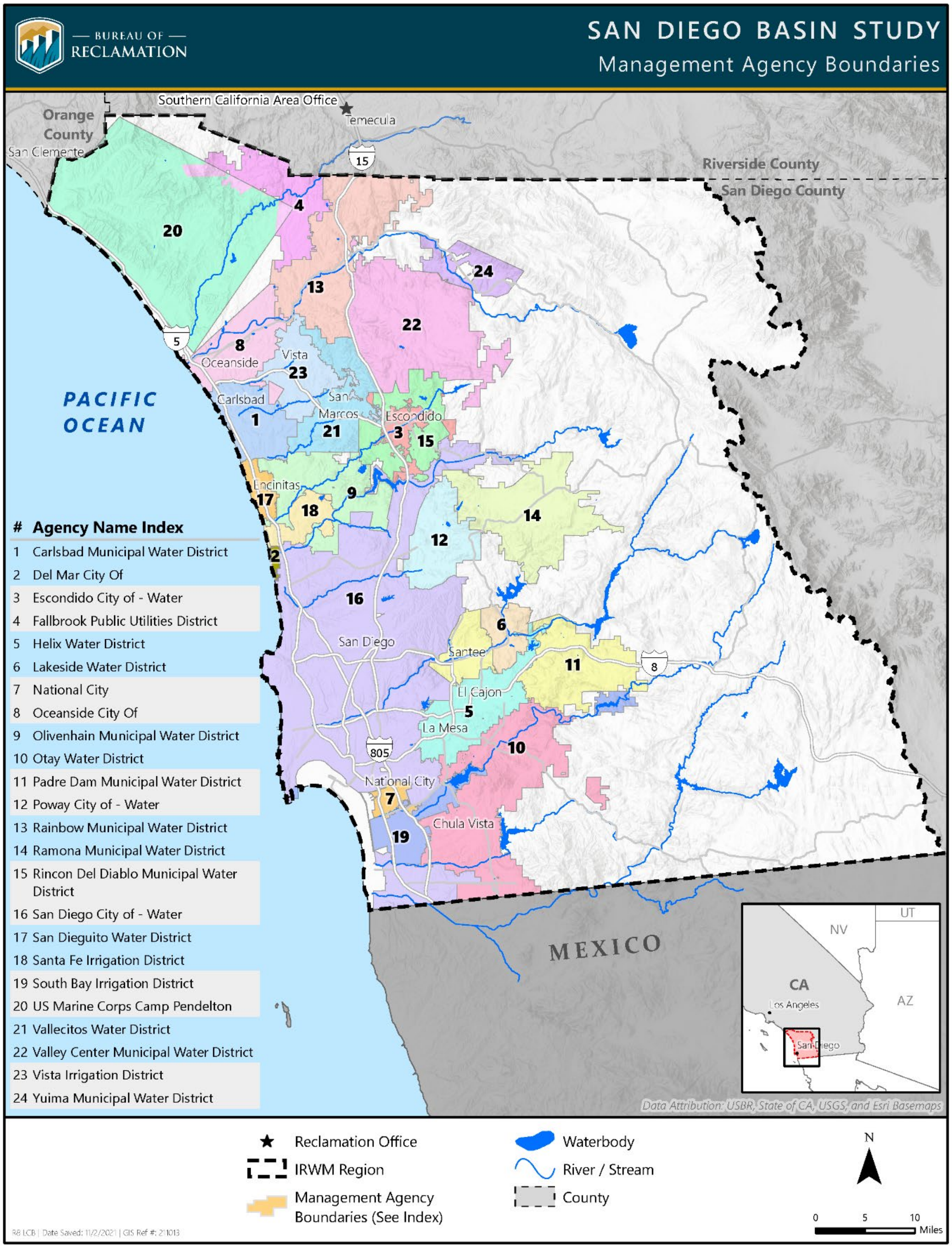

Figure 2. SDCWA member agency boundaries. SDCWA services the areas for each member agency depicted.

2.2 Management Structure and Coordination

This Basin Study joined diverse stakeholders in a collaborative approach to support future integrated water management activities in the San Diego area. The Study was cooperatively managed to facilitate communication among participating agencies and the public to provide efficient decision-making and document reviews.

The local partner for the Study, SDPUD, provides water, wastewater and recycled water services for residents of the city and surrounding communities. For more than 100 years, SDPUD has supplied water to the city through a combination of imported water, captured rainfall runoff from local reservoirs, recycled water for non-potable reuse, and conservation efforts. SDPUD oversees a municipal water system that includes more than 3,300 miles of distribution pipeline, nine reservoirs with a total capacity of 415,000 acre-feet (AF), and three water treatment plants, and delivers an average of 200 million gallons of water daily to 1.3 million customers in the cities of San Diego, Del Mar, Coronado, and Imperial Beach.

2.2.1 Water User Communities

In the San Diego area, several entities are responsible for distinct areas of water management. The region includes 21 stormwater management entities, flood control agencies, governmental agencies and NGOs that develop local watershed management plans to help conserve and protect watershed resources and habitats while ensuring protection of sensitive natural resources.

The San Diego Regional Water Management Group (RWMG) was formed in 2005 to manage development and implementation of an Integrated Regional Water Management Plan for the region. The RWMG consists of the:

- San Diego County Water Authority (SDCWA)
- City of San Diego (City)
- County of San Diego (County)

The combined jurisdiction of the three agencies encompasses the entire Region, with the water supply service areas of SDCWA and the City covering all urbanized portions of the Region. Collectively, the three RWMG agencies have key roles in water supply, wastewater treatment, watershed management, land use, and recreational aspects of water management within the Region.

2.2.1.1 San Diego County Water Authority

Covers 24 retail member agencies including:

- 6 cities
- 5 water districts
- 3 irrigation districts
- 8 municipal water districts
- 1 public utility district
- 1 military base

These agencies serve a combined population of 3.1 million (97% of the County's population) and support an annual regional economy of over $188 billion (San Diego Regional Water Management Group, 2013).

2.2.1.2 City of San Diego

The City Public Utilities Department (SDPUD) manages:

- 9 storage reservoirs
- 3 water treatment facilities
- 31 treated water storage facilities
- 3,213 miles of pipelines
- 2,900 miles of sewer line

SDPUD provides drinking water to 1.3 million customers (approximately half the population of San Diego County), operates two water recycling facilities with a combined treatment capacity of 45 million gallons per day, and maintains storm drain structures, pipelines and channels within the City.

2.2.1.3 San Diego County

The County Department of Public Works provides:

- limited wastewater and drinking water services to unincorporated communities
- stormwater conveyance service and maintenance
- erosion control and flood management services
- stormwater and watershed planning and protection programs and services

The County also manages several Multi-Species Conservation Program plans and the County's Agricultural Conservation Easement Program, maintains the groundwater and landscape ordinances, and manages environmental mitigation banks.

2.3 Study Area Climate

San Diego's climate is relatively mild year-round and large precipitation events are rare due to the semiarid nature of the region. Annual rainfall varies between an average of 10 inches near the coast to 40 inches near the inland mountains. Over 80 percent of the average annual rainfall occurs between December and March.

Climate change is anticipated to affect temperature and precipitation, which will impact local water supplies and demands in the Study Area and imported water supplies from regions outside the Study Area. To assess climate change impacts on supplies and demands for the Basin Study, two approaches were used: one approach for local surface water supplies and regional demands, and another approach for imported water supplies.

2.3.1 Local Climate Change Impacts

For local surface water supply impacts and demand impacts within the San Diego region, projections of temperature, precipitation, and hydrological parameters were obtained from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive (Bureau of Reclamation, 2013) which contains downscaled climate information (temperature and precipitation) and corresponding hydrology projections (e.g., surface runoff, baseflow, and evapotranspiration) for the contiguous United States. The archive provides access to climate and hydrologic projections at spatial and temporal scales relevant to water and natural resource managers and planners dealing with climate change. The archive includes both Coupled Model Intercomparison Project (CMIP) Phase 3 (CMIP3) climate projections of temperature and precipitation and CMIP Phase 5 (CMIP5) climate projections (Taylor et al., 2012; World Climate Research Programme, 2007; World Climate Research Programme, 2013), and corresponding hydrological simulations produced using the Variable Infiltration Capacity model (VIC) (Liang, X., E.F. Wood, and D.P. Lettenmaier, 1996; Liang, X., D. P. Lettenmaier, E.F. Wood, and S.J. Burges, 1994; Nijssen, B., D.P. Lettenmaier, X. Liang, S.W. Wetzel, and E. F. Wood, 1997). VIC is a large-scale, semi-distributed hydrologic model that calculates surface runoff and baseflow estimates for each grid cell and routes the flow to stream channels.

The CMIP5 projections were used for the Basin Study because they were the most recent projections. The CMIP5 archive includes 97 climate projections representing 31 Global Climate Models (GCMs) and four scenarios of greenhouse gas concentrations, known as Representative Concentration Pathways (RCPs). For the historical period, GCM models were constrained by observations of atmospheric conditions. Several alternative future atmospheric conditions are reflected in the RCPs. Two RCPs were examined for the San Diego region: RCP4.5, which reflects a low-growth or strong emissions controls scenario, and RCP8.5, which reflects a high-growth and limited emissions control scenario. In addition, many GCM modeling groups provided projections from the same model initialized from multiple climate states in order represent uncertainties stemming from natural low frequency climate variability (Bureau of Reclamation, 2013). Two future periods, the 2020s future time period (2020-2029) and the 2050s future time period (2050-2059), were selected to evaluate climate change impacts relative to a reference historical period (1990-1999) representing current climate.

Based on the CMIP5 projections, climate change was 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. For precipitation, annual precipitation was projected to increase by a range of 2% to 8% under RCP4.5 and by 1% to 3% under RCP8.5 in the 2020s time period. There was a broader range of projected precipitation change in the 2050s time period, ranging from no change to a 10% increase under RCP4.5 and ranging from no change to a 12% increase under RCP8.5. For temperature, annual temperature was projected to increase by a range of 1.5 to 1.8 degrees Fahrenheit under RCP4.5 and a range of 1.8 to 1.9 degrees Fahrenheit under RCP8.5 in the 2020s future period. In the 2050s future period even greater increases in temperature were projected, with a range of 3 to 3.4 degrees Fahrenheit under RCP4.5 and increases of 4.2 to 4.5 degrees under RCP8.5. Corresponding changes in local surface water supplies are discussed in Section 4.4.6.1 and corresponding changes in water demands are discussed in Section 4.3.

2.3.2 Climate Change Impacts on Imported Water

Results from the Sacramento-San Joaquin Basins Study (Bureau of Reclamation, 2016b) and Colorado River Basin Study (Bureau of Reclamation, 2012) were used to assess climate change impacts on imported water supplies, as discussed in Section 4.4.3.

2.4 Study Area Water Supplies

The Basin Study examined local supplies utilized within the Study Area by SDCWA and its member agencies, as well as imported supplies from other regions. Water supplies in the region were first characterized as part of Tasks 2.1 and 2.2, and subsequently updated as part of Tasks 2.3 and 2.4. Water supplies generally correspond to the Concepts discussed in Section 3.1 and were implemented in the CWASim model as described in Section 4.4. Climate change is anticipated to directly affect some supplies but have minimal effects on others, as discussed below. Modeling of climate change effects on supplies is discussed in the subsections of Section 4.4 that correspond to the affected supplies.

2.4.1 Local Surface Water

Water supply from surface water runoff in the Study Area represents a significant local water source in the SDCWA service area; however, surface water runoff only averaged 7% of the region's total annual water supply during the 2005-2015 years (San Diego County Water Authority, 2018). Rainfall contributes runoff to the major streams in the region, including the Otay River, San Diego River, San Dieguito River, San Mateo Creek, San Luis Rey River, Santa Margarita River, Santa Maria Creek, Sweetwater River, and Tijuana River. Many streams in the region are regulated by storage reservoirs whose primary purpose is to capture runoff as supply. Flood control is not a designated operating objective for these reservoirs, although operations for water supply can sometimes provide a secondary flood reduction benefit. For unregulated streams, more than 75% of the annual runoff volume generally occurs between December and April, and flows can drop to zero during the dry summer months. Modeling of surface water supplies is discussed in Section 4.4.6. Climate change is anticipated to affect surface water runoff, but the magnitude and direction of change is uncertain, as discussed in Section 4.4.6.1.

2.4.2 Groundwater

There are 24 groundwater basins underlying the Study Watersheds. All municipal groundwater supplies for the region are operated by SDCWA member agencies rather than SDCWA itself. SDCWA member agencies have produced an annual average of 18,944 AF/y of water supply from groundwater (San Diego County Water Authority, 2016). Groundwater is produced from either brackish groundwater desalination or municipal wells. In addition to municipal supplies, privately owned groundwater wells may be used by individual irrigators or households, but those users are outside the scope of the Basin Study.

The potential for production of groundwater in the Study Area is limited. The most productive types of aquifers are alluvial deposits that formed in narrow river valleys, but the extent of these sand and gravel aquifers is small and most are at shallow depths. Groundwater may also be produced from fractured bedrock and sedimentary deposits, but yields are small. Further, the limited rainfall in the region results in low groundwater recharge. There are also water quality concerns with available groundwater resources, such as contamination from septic tanks. High quality aquifers that produce water requiring minimal treatment have already been developed; therefore, future groundwater development in the region is focused on brackish groundwater (San Diego County Water Authority, 2015). Modeling of groundwater supplies is discussed in Section 4.4.2. Groundwater may be affected by climate change, as described in the Task 2.2 Interim Report, but groundwater supply volumes used in the Impacts Assessment modeling were assumed to be unaffected by climate change because they represented production volumes for specific facilities rather than overall potential groundwater supplies.

2.4.3 Potable Reuse

Potable reuse is the use of advanced treated wastewater for potable consumption. This supply is distinguished from recycled water by the level of treatment the water undergoes. Several San Diego region water agencies are currently planning for and/or developing indirect potable reuse projects, in which advanced treated wastewater will be introduced into an environmental buffer such as a surface water reservoir or groundwater basin, then extracted and treated at a surface water treatment plant for distribution through the potable distribution system. The three projects at the most advanced stage of planning are the City of San Diego's Pure Water, Padre Dam's East County Advanced Water Purification Program, and the City of Oceanside's Aquifer Augmentation project (San Luis Rey Water Reclamation Facility [WRF] - Short/Long-Term Expansion). In October 2017, the California Governor signed Assembly Bill 574 directing the State Water Resources Control Board (State Water Board) to create future regulations that allow direct potable reuse by December 31, 2023. Although groundwater recharge projects using recycled water have been in place since 1962, comprehensive groundwater recharge regulations were not adopted until 2014, as was required by California's Water Code section 13562 (California State Water Resources Control Board, 2018a) (California Legislative Information, 2011). Surface Water Augmentation Regulations (SBDDW-16-02) have been adopted by the State Water Board and are effective as of October 1, 2018 (California State Water Resources Control Board, 2018b). Modeling of potable reuse is discussed in Section 4.4.7. Climate change effects on potable reuse were not examined as part of the Basin Study, as climate change was assumed to have no direct effect on these supplies.

2.4.4 Recycled Water

Recycled water is water which, as a result of wastewater treatment, is suitable for a planned direct beneficial use that would not otherwise occur. Under current permitting regulations, recycled water may be used for non-potable uses such as irrigation of parks and golf courses, dust control, cooling, and toilet flushing. Approximately 30,000 AF of recycled water is reused annually by SDCWA member agencies and is distributed throughout the county through the "purple pipe" non-potable water system (San Diego County Water Authority, 2016). Modeling of recycled water is discussed in Section 4.4.8. Climate change effects on recycled water were not examined as part of the Basin Study, as climate change was assumed to have no direct effect on these supplies.

2.4.5 Seawater Desalination

In 2015, SDCWA added desalinated seawater to the water supply portfolio of the San Diego region. The Claude 'Bud' Lewis Carlsbad Desalination Plant (Carlsbad Desalination Plant), located adjacent to the Encina Power Station in Carlsbad, California, was constructed and is operated through a public-private partnership between SDCWA and Poseidon Resources. Poseidon Resources financed the construction of the Plant and entered into a 30-year water purchase agreement with SDCWA. The Carlsbad Desalination Plant was designed to produce 56,000 AF/y (50 million gallons per day [mgd]) of desalinated drinking water.

Two other seawater desalination projects in the San Diego area were under consideration in 2015 – Camp Pendleton and Rosarito Beach. These projects are not certain to proceed but are included in the Basin Study as conceptual projects. The proposed Camp Pendleton Desalination Plant project involves the development of an initial 50 mgd (56,000 AF/y) seawater desalination plant, with subsequent expansions at 50 mgd increments up to a maximum capacity of 150 mgd (168,000 AF/y), as modeled in the 2050 scenario. The proposed Rosarito Desalination Plant includes the production of about 56,000 AF/y (50 mgd), expandable to 112,000 AF/y (100 mgd), in Mexico, with excess water produced made available to Otay Water District (Otay Water District, 2017). Climate change effects on seawater desalination were not examined as part of the Basin Study, as climate change was assumed to have no direct effect on this supply.

2.4.6 Firm Water Supply Agreements

In 2003, the Colorado River Quantification Settlement Agreement (QSA) settled longstanding disputes among IID, MWD, and Coachella Valley Water District related to priority, use, and transfer of Colorado River water. The agreement established terms for distribution of Colorado River water among the parties for up to 75 years and facilitated actions to enhance the reliability of Colorado River water supplies. Two actions identified in the QSA were the transfer of water made available by lining the All-American and Coachella canals, and the transfer of water conserved by IID initially through land fallowing and then transitioning entirely to Imperial Valley system and on-farm conservation methods. These conservation efforts resulted in allocations of specific, firm annual volumes of water available to SDCWA. Modeling of QSA water supplies is discussed in Section 4.4.4. Because the QSA supply volumes are assumed to be firm annual delivery volumes, climate change effects on QSA water were not examined in the Basin Study.

2.4.7 Imported Water Purchases

Imported water purchased from MWD has been a primary source of supply for the San Diego region. MWD is a regional water wholesaler that supplies water to 26 member agencies, including SDCWA. MWD obtains its water from the SWP and the Colorado River Aqueduct (CRA) and stores it in in-region surface water storage (Diamond Valley, Matthews, and Skinner reservoirs) and other local reservoirs, in-region groundwater storage, Colorado River storage (Lake Mead Intentionally Created Surplus), and Central Valley and State Water Project storage (SWP carryover, flexible storage programs at terminal reservoirs of the SWP, and Central Valley groundwater banks). MWD uses the stored water to meet the demands of its member agencies. During wet and normal years, MWD available supplies generally exceed demands, allowing MWD storage to increase. During dry years, supplies are often insufficient to meet demands and water is extracted from MWD storage to meet member agency demands. When MWD storage reaches low levels, the MWD Board of Directors may implement water allocations to member agencies at less than full deliveries to protect against future dry years.

In addition to imported water purchased from MWD, purchases of water from other sources outside the San Diego region have been proposed. Modeling of imported water purchases is discussed in Section 4.4.3. Climate change effects on availability of imported supplies from MWD were based on the results of the Sacramento-San Joaquin Basins (Bureau of Reclamation, 2016b) and the Colorado River Basin (Bureau of Reclamation, 2012) studies. Effects of climate change on other imported water supplies was not examined in the Basin Study.

2.4.8 Other Water Supplies and Conservation

Other water supplies such as gray water or stormwater capture are currently unused in the San Diego region, or their use is minimal and has negligible effect on the overall regional water supply. However, in the future, these supplies could be developed or utilized to a greater extent. The potential for development and/or expansion of water supplies including gray water use (Section 4.4.5) stormwater BMPs (Section 4.4.10), and stormwater capture (Section 4.4.11) was evaluated in the Basin Study. Climate change is not anticipated to directly affect these types of supplies and was not evaluated in the Basin Study.

There is also potential for system infrastructure improvements or watershed management changes to increase availability of water supplies. Watershed and ecosystem management (Section 4.4.13) and conveyance improvements (Section 4.5.2) were also examined in the Basin Study. Climate change impacts were not evaluated for these approaches, except indirect effects due to climate change impacts on surface water supplies and imported water supplies.

Conservation is currently extensively used in the San Diego region to reduce demands on water supplies. Expansion of water conservation was examined in the Basin Study as described in Sections 4.4.1 (Enhanced Conservation) and 4.4.12 (Urban and Agricultural Water Use Efficiency). Climate change was assumed to have no direct effect on water conservation and was therefore not evaluated.

2.5 Study Area Water Demands

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. Unincorporated areas of the County that are not served by SDCWA but are within the Study Watersheds were included in the Study Area for purposes of accounting for local water supplies, but their water demands 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 AF 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 MWD implemented mandatory restrictions on water it sold under agricultural rates. Agricultural products produced in the San Diego region include avocados, citrus, cut flowers, and nursery products, along with crops and livestock for local markets. In fiscal year 2005, agricultural demands made up 13% of water use, while in 2015, only 8% of the total water demand was for agricultural use (San Diego County Water Authority, 2015). 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. Climate change is anticipated to affect water demands, as discussed in Section 4.3.

2.6 Study Area Water Resources Infrastructure and Operations

The Basin Study examined water resources infrastructure and facilities operations within the Study Area that contribute to the storage, treatment, and distribution of local and imported water supplies (Figure 3 and Figure 4). The infrastructure components are described briefly in this section. Further discussion of infrastructure, including modifications to facilities and operations and construction of new facilities is included in Chapter 4.

The San Diego region has 21 major reservoirs as shown in Figure 3. Of the 21 reservoirs, the 18 reservoirs that are connected to the SDCWA system were simulated in the water system modeling. The remaining seven reservoirs were excluded from CWASim because of their small volume or because they are not connected to the SDCWA system and only serve local demands.

Conveyance facilities (pipelines and pump stations) in the San Diego region transport water from imported water delivery points and water treatment plants to delivery points in the region. Water purchased from MWD or transferred via the QSA is imported into the San Diego region through MWD facilities. SDCWA takes delivery of treated and untreated imported water from MWD six miles south of the Riverside-San Diego County line at a point known as the "MWD Delivery Point." Water then flows southward to the SDCWA service area through five large diameter pipelines owned and operated by SDCWA that make up the First and Second Aqueducts.

The First Aqueduct alignment includes Pipelines 1 and 2 and extends from the MWD Delivery Point to San Vicente Reservoir. The two pipelines are operated as a single unit. North of the Crossover Pipeline, Pipelines 1 and 2 deliver treated water from MWD. South of the Crossover Pipeline, Pipelines 1 and 2 deliver untreated water.

Pipelines 3, 4, and 5 make up the Second Aqueduct alignment. The pipelines are divided into several reaches. Depending on the pipeline and reach, these pipelines convey treated or untreated water and are operated independently or as a unit. Pipeline 3 conveys treated or untreated water between the MWD Delivery Point and Lower Otay Reservoir. Pipeline 4 conveys treated or untreated water from the MWD Delivery Point to the southern portion of San Diego County. Pipeline 5 conveys untreated water from the MWD Delivery Point to water treatment plants in the southern portion of San Diego County.

Lateral pipelines that run generally eastward or westward convey water throughout the San Diego region to treatment plants, reservoirs, or delivery points for member agencies. There are also a variety of smaller conveyance facilities in the water distribution system used for retail purposes which transport water to its point of use. For example, the City of San Diego oversees approximately 3,300 miles of distribution pipeline delivering water to approximately 276,000 service connections (City of San Diego, 2015).

Most of the treated and untreated water in San Diego County relies on gravity to flow through the conveyance system. The SDCWA and the City of San Diego also operate pump stations to move water uphill when necessary, and aid in meeting daily, seasonal, and emergency needs.

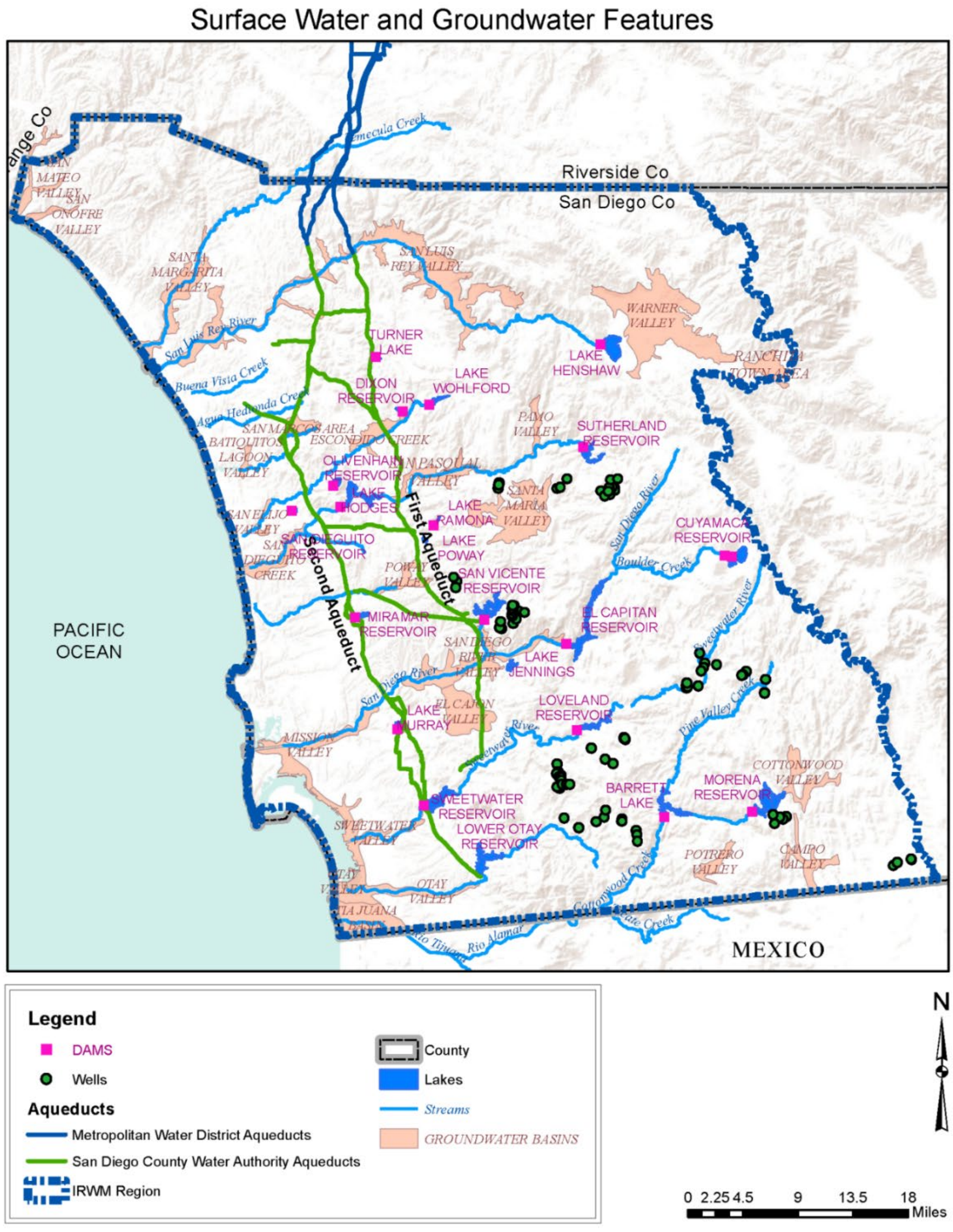

Figure 3. Surface and groundwater features in the San Diego Basin Study Area.

As of 2015, the San Diego region had one operational desalination plant (Carlsbad) and two others were being considered. See Section 2.4.5 for more information about desalination facilities. Twelve water treatment plants were available to remove contaminants from raw water and treat the water to levels pure enough for human consumption. The San Diego regional water system also had 19 water reclamation facilities, which are used to treat water for non-potable uses. Water treatment plants and desalination facilities within the Study Area are shown in Figure 4.

Water and Wastewater Treatment and Desalination Facilities

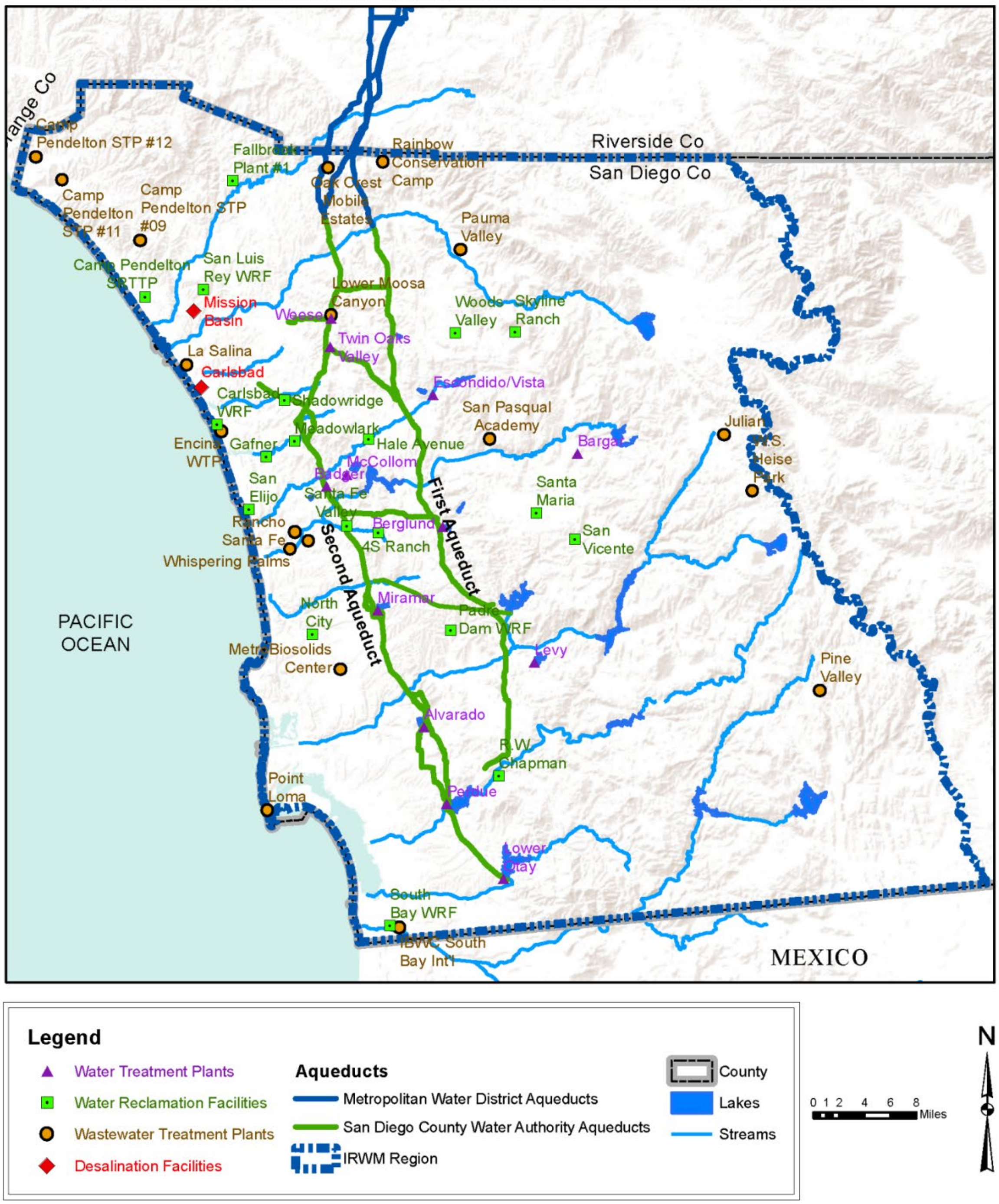

Figure 4. Water and wastewater treatment and desalination features in the San Diego Basin Study Area.

3. Current and Future Water Management Strategies

The purpose of the San Diego Basin Study was to determine potential changes in water supplies and demands, and analyze structural and non-structural concepts within the San Diego Basin that can assist the region in adapting to future uncertainties. These strategies were identified through a stakeholder engagement process and organized into Concepts for the purposes of analysis.

3.1 Concepts

San Diego Basin Study Concepts (Table 5) represented groups of similar strategies that are currently used or could be used to meet the water demands of the region. Used as the basis for analysis in the Basin Study, these Concepts were developed through review of existing studies and projects, as well as consultation with stakeholders at IRWM Regional Advisory Committee (RAC) meetings and Stakeholder Technical Committee (STAC) meetings in the fall of 2017.

Table 5. San Diego Basin Study Concepts

Concept	Narrative 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.

Concept	Narrative Concept Description
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.
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

Concept	Narrative Concept Description
	through engineered or biological controls, management of non-point and point source pollution, and low impact development.

* These Concepts are included in the Baseline Portfolio and are not modified in any other portfolios.

3.2 Projects

Concepts were defined by one or more "projects," which represent actual, potential, or theoretical proposed modifications to existing facilities, construction of new facilities, modifications to system operations, modifications to policy, or other proposed activities. Most projects in the Basin Study were based on actual proposed projects, including projects listed as verifiable, additional planned, and conceptual in the 2015 SDCWA UWMP (San Diego County Water Authority, 2016), the 2013 SDCWA Master Plan (San Diego County Water Authority, 2013), the 2013 IRWM Plan (San Diego Regional Water Management Group, 2013), or other similar planning documents and lists. Other projects represent a theoretical project idea or type of project but were not tied to a specific proposed implementation.

3.3 Portfolios

Portfolios were developed for the purpose of simulating and analyzing groups of related projects. Two sets of portfolios were developed for the Basin Study: Impacts Assessment Portfolios used in the Impacts Assessment conducted in Task 2.4, and Single Concept Portfolios used in the Task 2.5 Trade-Off Analysis.

3.3.1 Impacts Assessment Portfolios

Each Impacts Assessment Portfolio contained projects from one or more Concepts. These portfolios were modeled and analyzed to determine the resulting impacts to water deliveries, flood control, energy, and recreation. One Impacts Assessment Portfolio represented Baseline conditions, while five additional portfolios consisted of projects that are planned or conceptual. Impacts Assessment Portfolios were developed by consulting with public stakeholders and STAC members about potential groupings of projects that would be of interest. The Impacts Assessment Portfolios and corresponding Concepts are listed in Table 6.

Table 6. Task 2.4 Impacts Assessment Portfolios

Portfolio	Description	Concepts
Baseline	Projects designated as verifiable in SDCWA's 2015 UWMP	• Conveyance Improvements • Drought Restriction/Allocation • Firm Water Supply Agreements (e.g., 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 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)

Portfolio	Description	Concepts
		○ Potable Reuse (e.g., Pure Water San Diego Phase 2) ○ Recycled Water ○ Seawater Desalination (e.g., Rosarito and Camp Pendleton)
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)

* A Concept may be included in more than one portfolio, but the projects associated with that Concept differ for each portfolio (e.g., projects are only associated with a single portfolio, with the exception of Baseline projects).

3.3.1.1 Baseline Portfolio

The Baseline Portfolio represented the system as it existed in 2015, with some minor modifications to include projects that were implemented during 2015 (e.g., Carlsbad Desalination Plant) or for which there was very high confidence that they will be implemented (e.g., the full QSA annual transfer volume). Water supplies included in the Baseline Portfolio are those from projects that were designated as verifiable in SDCWA's 2015 UWMP. Infrastructure simulated in the CWASim model for the Baseline Portfolio included 18 reservoirs connected to the regional system, the Carlsbad Desalination Plant, and pipelines, pump stations, and water treatment plants at 2015 facility capacities. Concepts included in this Portfolio were Firm Water Supply Agreements, Groundwater, Imported Water Purchases, Local Surface Water Reservoirs, Recycled Water, Seawater Desalination, and Urban and Agricultural Water Use Efficiency.

3.3.1.2 Baseline Plus Portfolio

The Baseline Plus Portfolio represented the near-term future supply sources, infrastructure, and operations of the San Diego region water system. It contained projects from the Baseline Portfolio, as well as projects that were actively being pursued as of fall 2017 and/or received funding between 2015 and 2017. Although these projects were not designated as verifiable in the SDCWA 2015 UWMP, it was believed that they were close enough to verifiable status to be included in this

Portfolio. Projects that were in advanced planning or design stages, but were not yet operational, such as Phase 1 of the Pure Water San Diego program, were included. Since these projects have a high certainty of implementation, this Portfolio allowed for a direct comparison of conceptual strategies to the adaptation strategies that are already being pursued in the region. In addition to Concepts from the Baseline Portfolio, new or modified Concepts included in the Baseline Plus Portfolio were Conveyance Improvements, Gray Water Use, Groundwater, Potable Reuse, Recycled Water, Stormwater Capture, Urban and Agricultural Water Use Efficiency, and Watershed and Ecosystem Management.

3.3.1.3 Enhanced Conservation Portfolio

The Enhanced Conservation Portfolio examined water conservation beyond currently planned levels. The purpose of this Portfolio was to explore the potential for demand reductions to improve delivery reliability under future climate and demand uncertainty. This Portfolio represented 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. The demand reduction defined by this Portfolio represents additional conservation, beyond what is required by Senate Bill 7 of the Seventh Extraordinary Session of 2009, which aims for a 20 percent statewide reduction in urban per capita water use by 2020 (referred to as the '20x20 guidelines' outlined in SBX7-7). The Portfolio did not specify or assume any particular projects or strategies to reduce demand, nor did it specify reductions in the per capita water use specific to individual member agencies. Instead, the Portfolio was a high-level analysis of simulated demand reduction at the regional scale, which may be achieved by a broad range of demand reduction strategies or projects implemented by either the public or private sectors. This Portfolio represented and included a single additional project and Concept beyond the Baseline Plus Portfolio – Enhanced Conservation.

In May 2018 the California Governor signed into law SB 606 and AB 1668 which set new long-term water efficiency goals through a mandated 55 gallons per capita per day (GPCD) requirement for indoor usage and more efficient standards based on a percentage of evapotranspiration for outdoor use. It was not known what the effect of the new legislation would be on assumptions contained in SDCWA's 2015 UWMP that were used in this Basin Study, but the additional conservation assumed in this Portfolio was consistent with the potential for more restrictive requirements of the new 2018 water use efficiency legislation. However, the analysis of conservation in the Basin Study was not restricted to either indoor or outdoor use and did not reflect the demand reduction expected by these bills. While the results of the Enhanced Conservation Portfolio provided valuable information on the impact of conservation in various impact areas, it is important to note that the Study results should not be interpreted as representations of the conservation expected to be achieved by these bills.

New infrastructure beyond what was presented in the Baseline Plus Portfolio was not introduced in this Portfolio. In addition to Concepts from the Baseline Plus Portfolio, the only new or modified Concept was Enhanced Conservation.

3.3.1.4 Increase Supplies Portfolio

The Increase Supplies Portfolio consisted of conceptual projects that were focused on increasing regional water supplies, as well as projects that were included in the Baseline Plus Portfolio. These projects are typically in the pre-planning or pre-feasibility analysis phase. In addition to Concepts from the Baseline Plus Portfolio, new or modified Concepts included Gray Water Use, Groundwater, Imported Water Purchases, Potable Reuse, Recycled Water, and Seawater Desalination. The Increase Supplies Portfolio was the only portfolio beyond the Baseline Plus Portfolio to incorporate Potable Reuse projects.

3.3.1.5 Optimize Existing Facilities Portfolio

The Optimize Existing Facilities Portfolio was focused on enhancing the efficiency of existing facilities by replacing, repairing, or maintaining existing infrastructure to maximize its operation. It consisted of conceptual projects that are typically in the pre-planning and pre-feasibility analysis phase, as well as projects that were included in the Baseline Plus Portfolio. This Portfolio did not introduce new infrastructure to the system, and solely focused on optimizing the infrastructure already in place. The only new/modified Concept associated with this Portfolio was the Conveyance Improvements Concept.

3.3.1.6 Watershed Health and Ecosystem Restoration Portfolio

The Watershed Health and Ecosystem Restoration Portfolio was focused on efforts intended to restore or create natural habitats and minimize environmental impacts. It contained conceptual projects that are typically in the pre-planning or pre-feasibility analysis phase, as well as projects that were included in the Baseline Plus Portfolio. In addition to Concepts from the Baseline Plus Portfolio, new or modified Concepts included Stormwater BMPs, Stormwater Capture, and Watershed and Ecosystem Management. Although many of the Stormwater BMPs, Stormwater Capture, and Watershed and Ecosystem Management projects associated with this Portfolio may provide demonstrable benefits, they were unable to be modeled as they do not have a specific water supply volume or operational impact on the San Diego system that can be described with model inputs or logic. The Trade-off Analysis presents a more complete assessment of the effects of the Concepts included in this Portfolio.

3.3.2 Single Concept Portfolios

Single Concept Portfolios were used to provide input data at the Concept level for the Trade-off Analysis and Economic Assessment described in Task 2.5.

The portfolios included all non-Baseline projects corresponding to the 12 Concepts listed below:

- 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

4. 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 in Task 2.4 and used as inputs to the Trade-off Analysis and Economic Assessment in Task 2.5.

4.1 Model Overview

CWASim is a GoldSim model originally developed for SDCWA by Jacobs (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.

4.2 Modeled Scenarios

CWASim model runs were performed for each of the six Impacts Assessment Portfolios and 12 Single Concept Portfolios described in Chapter 3 with the demand and climate scenarios described below. For the Impacts Assessment Portfolios, there were three demand scenarios (2015 demands, 2025 demands, and 2050 demands) and six climate scenarios (current climate, central tendency climate, hot-dry climate, warm-dry climate, hot-wet climate, and warm-wet climate), combining for a total of 13 scenarios per portfolio (only current climate was simulated for the 2015 demand scenarios) and 78 total model runs. For the Single Concept Portfolios, a single model run for 2050 demands and central tendency climate was done for each portfolio, resulting in a total of 12 model runs. Table 7 and Table 8 list the modeled scenarios.

Each run 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, described in Section 4.4.6.1.3.

Table 7. Summary of Impacts Assessment Portfolio Scenarios

Scenario Name	Supply Projections	Demand Projections
Portfolio[1]_2015_cc	current climate	2015 demands, current climate
Portfolio[1]_2025_cc	current climate	2025 demands, current climate
Portfolio[1]_2050_cc	current climate	2050 demands, current climate
Portfolio[1]_2025_ct_2020s	2020s central tendency climate	2025 demands, 2020s central tendency climate
Portfolio[1]_2025_ww_2020s	2020s warm-wet climate	2025 demands, 2020s warm-wet climate
Portfolio[1]_2025_wd_2020s	2020s warm-dry climate	2025 demands, 2020s warm-dry climate
Portfolio[1]_2025_hw_2020s	2020s hot-wet climate	2025 demands, 2020s hot-wet climate
Portfolio[1]_2025_hd_2020s	2020s hot-dry climate	2025 demands, 2020s hot-dry climate

Scenario Name	Supply Projections	Demand Projections
Portfolio[1]_2050_ct_2050s	2050s central tendency climate	2050 demands, 2050s central tendency climate
Portfolio[1]_2050_ww_2050s	2050s warm-wet climate	2050 demands, 2050s warm-wet climate
Portfolio[1]_2050_wd_2050s	2050s warm-dry climate	2050 demands, 2050s warm-dry climate
Portfolio[1]_2050_hw_2050s	2050s hot-wet climate	2050 demands, 2050s hot-wet climate
Portfolio[1]_2050_hd_2050s	2050s hot-dry climate	2050s hot-dry climate

[1] Abbreviations were used in the scenario names, replacing the term 'Portfolio': Baseline (B), Baseline Plus (B+), Enhanced Conservation (EC), Increase Supplies (IS), Optimize Existing Facilities (OEF), and Watershed Health and Ecosystem Restoration (WE).

Table 8. Summary of Single Concept Portfolio Scenarios

Concept	Scenario Name	Supply Projections	Demand Projections
Stormwater BMPs	BMP_TA_2050_ct	2050s central tendency climate	2050 demands, central tendency climate
Conveyance Improvement	CI_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Desalination	DE_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Enhanced Conservation	EC_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Gray Water Use	GRU_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Groundwater	GW_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Imported Water Purchases	IWP_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Potable Reuse	PR_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Recycled Water	RW_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Stormwater Capture	SW_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Urban and Agricultural Water Use	UW_TA_2050_ct	2050s central tendency climate	2050s central tendency climate
Watershed and Ecosystem Management	WE_TA_2050_ct	2050s central tendency climate	2050s central tendency climate

4.3 Water Demand Modeling

Water demand projections for the Basin Study consisted of annual projections of agricultural and M&I demands for five hydrologic year types for each of the 13 time period and climate change projection group combinations. The projections were developed to quantify how demands in the Study Area may be expected to change between 2015 and 2050. From year to year, demands may increase or decrease based on annual weather conditions (e.g., dry or wet years). Over longer time periods such as the planning horizon of the Basin Study, demands may increase or decrease based on trends in factors such as population, demographics, and economic climate, changes in laws and regulations, shifts in demand type (e.g., shifts from agricultural demands to M&I demands), and changes in climate (e.g., long-term shifts in temperature or precipitation). The Basin Study demand projections accounted for these factors by using annual gross demand projections from the SDCWA 2015 UWMP, extending them to 2050, and adjusting them for projected climate change impacts.

4.3.1 Gross Demands

Gross demands are the total water demands for each member agency. Demands were calculated outside the model and provided as a model input. 2015 gross demands were equivalent to actual demands in 2015 as documented in the SDCWA 2015 Annual Report (San Diego County Water Authority, 2015). Although SDCWA updated its demand forecast in 2018 to reflect changes in demand trends since the publication of the 2015 UWMP, the update occurred too late in the Basin Study process to be incorporated into the Study. Therefore, the Basin Study used demand projections from the 2015 UWMP, which are higher than the SDCWA 2018 demand forecast (San Diego County Water Authority, 2018a). Gross demand projections for 2025 and 2050 were based on the demand projections in the 2015 SDCWA UWMP. Because the projections only extended to 2040, regression equations were developed for each member agency and hydrologic year type to extend the demand projections to 2050. The 2020-2040 long range demand projections for each hydrologic year type were linearly regressed against population projections for 2020 to 2040 from the SANDAG Series 13 dataset (SANDAG, 2013). The regression coefficients were then used to project demands for 2045 and 2050. Current climate gross demands are shown in Figure 5.

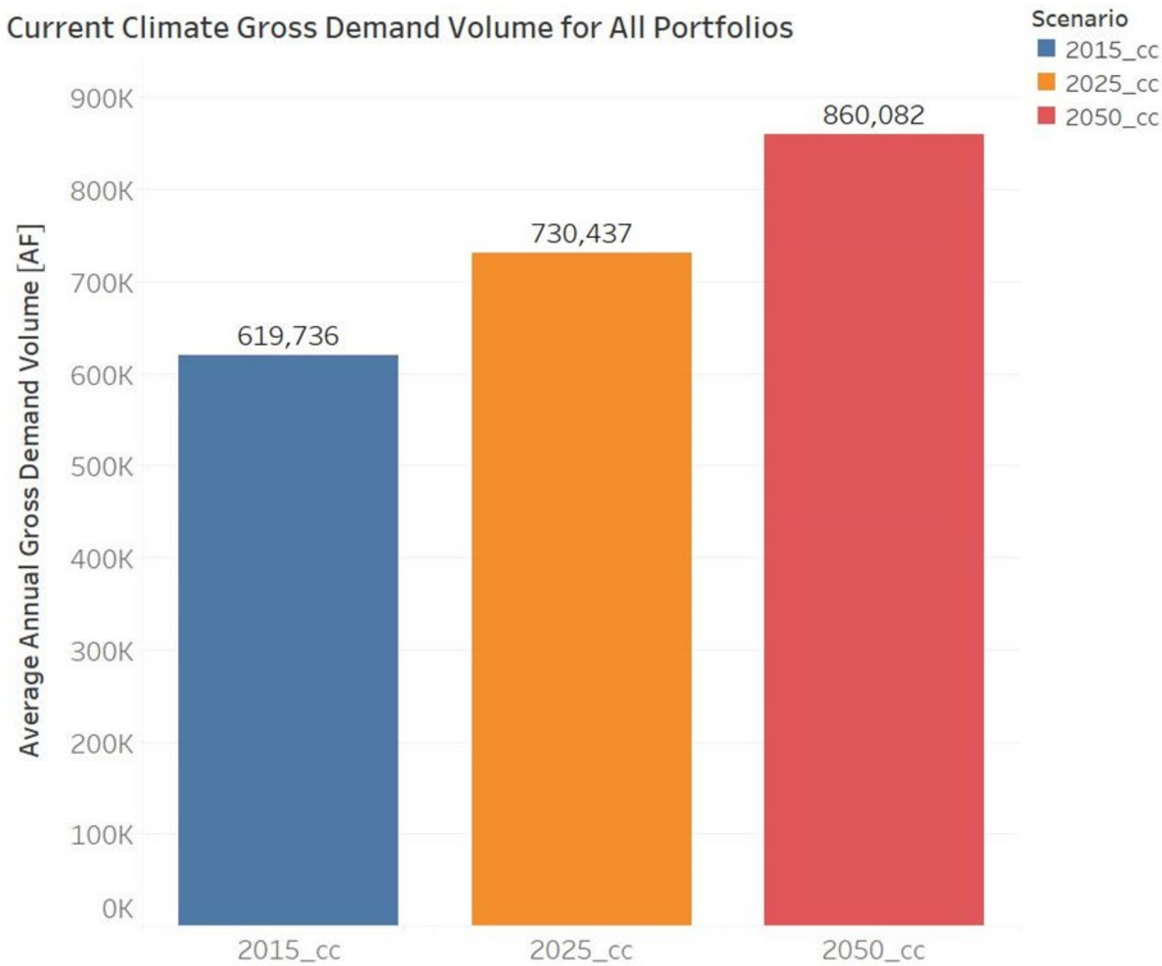

Figure 5. Current climate gross demand values averaged over all realizations. Gross demand projections remain the same for all portfolios.

Climate change adjusted demands (Figure 6) were calculated by applying a set of climate change adjustment factors for each time period and climate change projection group to the unadjusted projections. The adjustment was done individually for each member agency demand node using the same adjustment factor for all hydrologic year types. Demand adjustment factors were calculated with a spreadsheet model that relates projected changes in precipitation and potential evapotranspiration (PET) to changes in demand. The model was developed and calibrated as part of the analysis for the 2013 SDCWA Master Plan (San Diego County Water Authority, 2013) and applied to the San Diego Basin Study. The spreadsheet model requires input values of modeled historical and future precipitation and PET for grid cell locations representing each SDCWA member agency for each climate change scenario. For the San Diego Basin Study, the input precipitation and PET data was obtained from the same set of hydrology projections as the surface water supply projections (see Section 4.4.6.1.3).

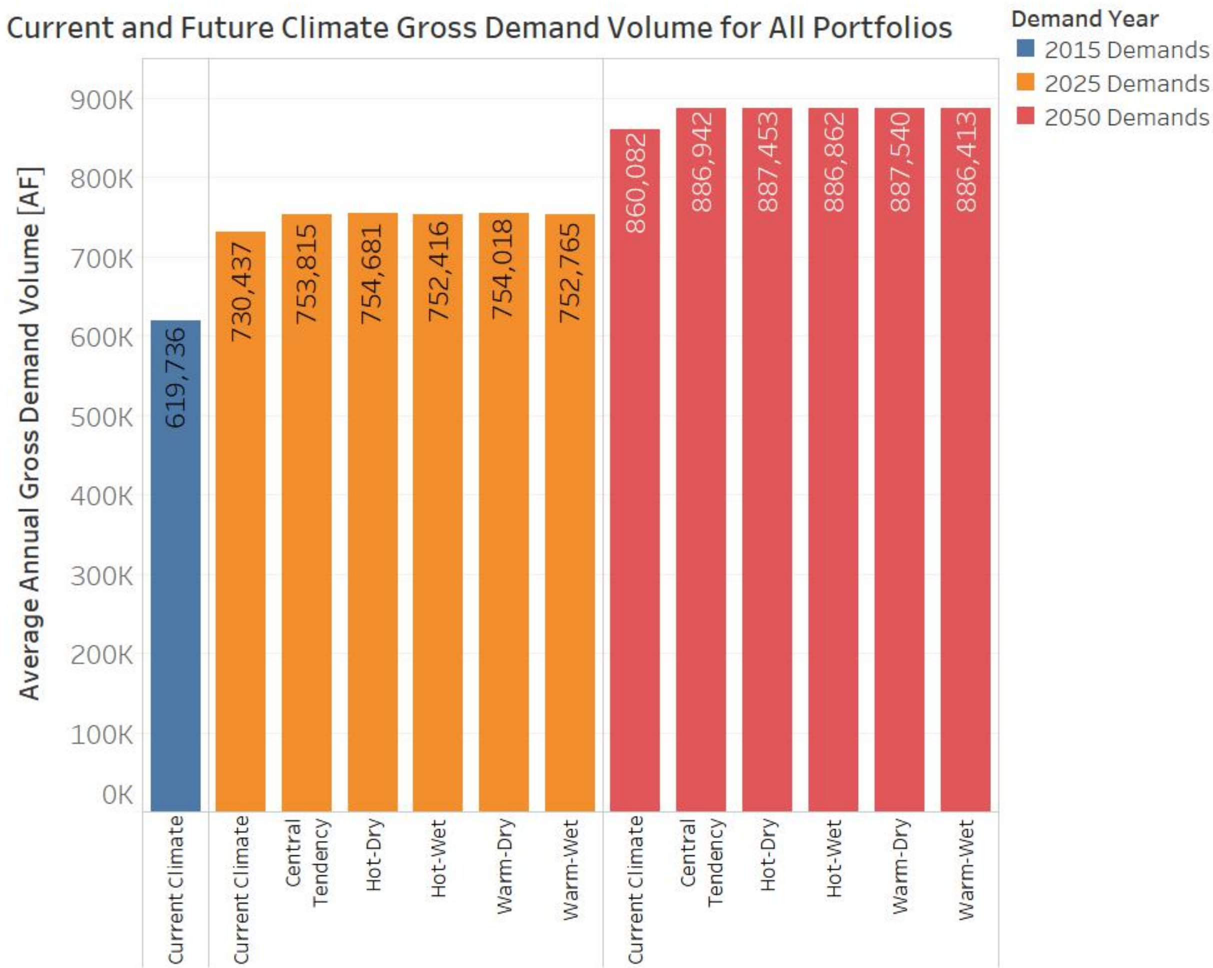

Figure 6. Current and future climate gross demands averaged across all realizations in each scenario. Gross demand projections remain the same for all portfolios.

4.3.2 Net Demands

Net demands calculated within the model are the remaining demands after modeled demand reductions are subtracted from the gross demands. Demand reductions are supplies or conservation volumes that are modeled as directly reducing demands. Gray Water, Groundwater, some Imported Water Purchases, some Potable Reuse, Stormwater BMPs, Stormwater Capture, and Urban and Agricultural Water Use Efficiency are all treated as demand reductions.

These existing supplies and conservation volumes are assumed to be used to meet demands prior to use of any other supply options and therefore they reduce demands on all other sources. They are assumed to be constant annual values that are subtracted from the gross demand volume inputs.

4.4 Water Supply and Conservation Modeling

Water supply and conservation volumes were simulated in the CWASim model based on a combination of inflow projections, facility production capacities, and conservation project volumes. All Concepts except Conveyance Improvement and Drought Restriction/Allocation included at least one project that provides water supply or conservation. The CWASim model had the ability to explicitly model supplies from Local Surface Water Reservoirs, Groundwater, Recycled Water, Seawater Desalination, Potable Reuse, Firm Water Supply Agreements (QSA), Imported Water Purchases, and conservation (Enhanced Conservation and Urban and Agricultural Water Use Efficiency). Some of these water supplies (Local Surface Water Reservoirs, Seawater Desalination, some Potable Reuse, Firm Water Supply Agreements, and Imported Water Purchases from MWD) were dynamically simulated in the model on a daily basis. Water supplies from Concepts listed below were represented as annual demand reductions in the CWASim model, as described in Section 4.3.2 (Net Demands). The supply volumes were defined by the projects associated with the Concepts. The supply volume from a project may vary between demand scenarios (2015, 2025, or 2050) but does not change between climate scenarios.

- Gray Water Use (included as Conservation volume)
- Groundwater (included as Groundwater volume)
- Imported Water Purchases (only the Cadiz Additional Imported Supplies project, included as Conservation volume)
- Recycled Water (included as Recycled Water volume)
- Potable Reuse (included as Recycled Water volume, with the exception of Pure Water San Diego which was implemented via model logic due to operational complexity)
- Stormwater BMPs (included as Conservation volume)
- Stormwater Capture (included as Conservation volume)
- Urban and Agricultural Water Use Efficiency (included as Conservation volume)

4.4.1 Enhanced Conservation

Enhanced Conservation was included in the Enhanced Conservation Impacts Assessment Portfolio and the Enhanced Conservation Single Concept Portfolio. Enhanced Conservation was modeled as a demand reduction, with the demand reduction volume calculated as described below.

4.4.1.1 Calculation of Enhanced Conservation Volume

Enhanced Conservation was defined as a 1% reduction in water demand (GPCD per year), starting in 2020 when it is assumed that the 20x20 targets outlined in SBX7-7 are reached. The additional conservation required to achieve Enhanced Conservation was calculated in a three-step process:

1) Calculate regional target demands for 2025 and 2050 assuming a 1% reduction in GPCD. To accomplish this, the 20x20 target (584,949 AF/y) was converted to GPCD and a 1% reduction in GPCD per year for future demand scenarios was calculated for 2025 and 2050.

GPCD values for 2025 and 2050 were calculated using population projections provided by the 2015 UWMP and the SDCWA staff. Calculate total conservation volume required to achieve Enhanced Conservation regional target demands values.

2) Calculate Enhanced Conservation volume required in addition to Baseline and Baseline Plus conservation volumes to achieve total regional conservation volume for the Enhanced Conservation Portfolio (Table 9).

Table 9. Conservation Volumes for Baseline, Baseline Plus, and Enhanced Conservation Portfolios

Projected Demand Reduction			
Portfolio	2015 (AF/y)	2025 (AF/y)	2050 (AF/y)
Baseline Portfolio conservation volume	50,000	89,110	155,468
Baseline Plus Portfolio conservation volume (in addition to Baseline)	0	781	2,874
Enhanced Conservation Portfolio conservation volume (in addition to Baseline and Baseline Plus)	0	52,265	179,582
Total Enhanced Conservation Portfolio conservation volume	50,000	142,156	337,924

Note: This table only lists demand reduction volumes for the Enhanced Conservation and Urban and Agricultural Water Use Efficiency Concepts. Other Concepts modeled as demand reductions in CWASim are not included in this table.

The total regional Enhanced Conservation amount was then divided among member agency demand nodes for use in the CWASim model. The Enhanced Conservation Portfolio projected conservation volumes were incorporated in the model as demand reductions (see Section 4.4) for each time period of the model analysis: 2015, 2025, and 2050. The Gross Demand values, total Enhanced Conservation Portfolio conservation volumes, and the difference between Gross Demand and Conservation are shown in Table 10.

Table 10. Gross Demands Minus Enhanced Conservation Portfolio Volume

Projected Conservation Volumes			
	2015 (AF/y)	2025 (AF/y)	2050 (AF/y)
Gross Demand (Normal Years, no climate change)	619,739	722,507	845,488

Projected Conservation Volumes			
	2015 (AF/y)	2025 (AF/y)	2050 (AF/y)
Total Enhanced Conservation Portfolio conservation volume (includes conservation from the Baseline and Baseline Plus Portfolios)	50,000	142,156	337,924
Gross Demand minus Total Enhanced Conservation Portfolio conservation volume	569,739	580,351	507,564

4.4.2 Groundwater

Nine Groundwater projects were included in the Baseline Portfolio. Two additional Groundwater projects were included in the Baseline Plus Portfolio. Nine additional Groundwater projects were included in the Increase Supplies Portfolio. All Groundwater projects were included in the Groundwater Single Concept Portfolio.

Groundwater projects were implemented in the CWASim model as demand reductions.

4.4.3 Imported Water Purchases

Imported Water Purchases from MWD were included in the Baseline Portfolio. The Increase Supplies Portfolio included additional imported supplies from Cadiz, California, to the Otay Water District. Both of these Imported Water Purchases projects were included in the Imported Water Purchases Single Concept Portfolio.

MWD Imported Water Purchases were modeled dynamically in CWASim as described below. The Cadiz Additional Imported Supply project was modeled as a demand reduction.

4.4.3.1 MWD Purchases Modeling

MWD purchase deliveries were determined based on supply priorities and requests for treated and untreated water. The volume of imported water available for purchase from MWD was determined in the CWASim model by the logic for MWD supply allocation, which used projections of deliveries to MWD from the State Water Project and Colorado River Basin to model available MWD supplies.

Deliveries to MWD from the State Water Project were derived from the modeling performed for the Sacramento-San Joaquin Basins Study (SSJBS) which extends from January 2015 through September 2099 (Bureau of Reclamation, 2016b). Deliveries to MWD from the Colorado River were derived from the modeling performed for the Colorado River Basin Study (CRBS) which extends from January 2012 through December 2060 (Bureau of Reclamation, 2012). The Colorado River deliveries were extended to cover the entire 85-year CWASim simulation period (85 realizations) by taking the average of deliveries from 2048 through 2060 and extending that figure through September 2099. This 13-year period was chosen to maintain consistency in the reduced deliveries expected to begin in 2048.

Because the SSJBS and CRBS used different scenarios than those implemented in the San Diego Basin Study, the SSJBS and CRBS results were mapped to the scenarios for the San Diego Basin Study. Two areas were considered in the scenario mapping: temperature and precipitation conditions, and time period. Table 11 shows the San Diego Basin Study scenarios and the associated SSJBS and CRBS scenarios.

Table 11. Mapping of Climate Scenarios Across San Diego, Sacramento-San Joaquin, and Colorado River Basin Studies

San Diego Basin Study Scenarios	Associated Sacramento-San Joaquin Basins Study Scenarios	Associated Colorado River Basin Study Scenarios
Current Climate	Reference No Climate Change (RF)	Historical Climate
Central Tendency	Central Tendency (CEN)	Median estimate from 112 traces
Hot-Wet	Hot-Wet (HW)	Mean of traces with annual temperature and precipitation change greater than median (32 traces)
Hot-Dry	Hot-Dry (HD)	Mean of traces with annual temperature change greater than median and precipitation change less than median (24 traces)
Warm-Wet	Warm-Wet (WW)	Mean of traces with annual temperature change less than median and precipitation change greater than median (22 traces)
Warm-Dry	Warm-Dry (WD)	Mean of traces with annual temperature and precipitation change less than median (34 traces)

Temperature and precipitation scenario mapping was done using separate methods for the SSJBS and the CRBS. In the SSJBS, five ensemble-based climate scenarios were used representing warm-dry (WD), warm-wet (WW), hot-dry (HD), hot-wet (HW), and central tendency (CEN) change conditions. These scenario definitions are largely consistent with the definitions used in the San Diego Basin Study, so the SSJBS modeling results for the State Water Project deliveries to MWD were directly incorporated into the Basin Study for their respective climate scenarios. The CRBS utilized 112 individual climate projections, and did not have an ensemble-based set of results that could be directly mapped to the San Diego Basin Study scenarios. In this case, changes in annual temperature and annual precipitation were computed for all climate projections (period of 2036-2065 compared to 1971-2000), and each projection was assigned to one of four categories representing warm-dry, warm-wet, hot-dry, and hot-wet, based on the computed change in annual temperature and precipitation in comparison to the median change. Once the projections were assigned to the four categories, the MWD delivery results were averaged from the projections in each category. Finally, a fifth category was created from the median of all projections.

Through these steps, an adjusted set of MWD deliveries (Table 12) was developed that reflects the changes anticipated for the specific climate scenarios and timeframes that were consistent with the San Diego Basin Study period-in-time approach.

Table 12. MWD Imported Water Supply Projections

Demand Scenario	Climate Scenario	SWP Projections (AF/y)	CRA Projections (AF/y)
2015, 2025, and 2050	current climate	1,411,197	712,030
2025	central tendency	1,387,251	727,978
2025	warm-wet	1,538,716	797,890
2025	warm-dry	1,161,431	735,452
2025	hot-wet	1,526,116	752,215
2025	hot-dry	1,158,547	722,165
2050	central tendency	1,403,956	727,978
2050	warm-wet	1,608,063	797,890
2050	warm-dry	1,230,763	735,452

Demand Scenario	Climate Scenario	SWP Projections (AF/y)	CRA Projections (AF/y)
2050	hot-wet	1,541,808	752,215
2050	hot-dry	1,085,458	722,165

4.4.4 Firm Water Supply Agreements

In the Baseline Portfolio (and in all other portfolios), the Firm Water Supply Agreement Concept included a single project that represents imported supplies from the QSA. This project was implemented in the CWASim model by model logic, but it was assumed that the supply is constant for all scenarios at the full agreement value of 280,200 AF/y. Although it is possible that water supply agreements such as the QSA could change (i.e., changes in water supply availability could affect the supply volume) or be renegotiated in the future, the model runs assumed that the QSA would remain in place as described.

4.4.5 Gray Water Use

One Gray Water Use project, Conservation Home Makeover in the Chollas Creek Watershed, was included in the Baseline Plus Portfolio. In the Increase Supplies Portfolio, the Gray Water Pilot Project was also included. Both projects were included in the Gray Water Use Single Concept Portfolio. Both Gray Water Use projects were implemented as demand reductions.

4.4.6 Local Surface Water Reservoirs

Local Surface Water Reservoirs were included in the Baseline Portfolio (and in all other portfolios). No additional reservoirs were added by projects in other portfolios, but reservoir storage and/or release capacities were modified in some portfolios by projects in other Concepts as shown in Table 13.

Of the 21 reservoirs in the San Diego region, CWASim modeled the 18 reservoirs that are connected to the SDCWA system. The remaining three reservoirs shown in Table 13 were excluded from CWASim because of their small volume or because they are not connected to the SDCWA system and only serve local demands. Of the 18 modeled reservoirs, only 10 receive surface water inflows, as described below. Supplies from the Local Surface Water Reservoirs are dependent on inflow projections, described below in Section 4.4.6.1.

Reservoirs may store local surface water, imported MWD water, water transferred from another reservoir, potable reuse water stored in a reservoir, or a combination of water from multiple sources. For the purposes of water delivery reporting in the model results, Local Surface Water deliveries were separated from deliveries of Imported Water, Potable Reuse water, and transfers between reservoirs.

Table 13. San Diego Region Reservoirs

Reservoir	Owner	Water Source(s)	In CWASim Model?	Natural inflows received in CWASim?[1]	Modeled Capacity (Total) AF[2, 3]
Lake Wohlford	City of Escondido	surface water transfers local runoff	Yes	Yes	6,940
El Capitan Reservoir	City of San Diego	local runoff	Yes[4,5]	Yes	50,733[6]
Hodges Reservoir	City of San Diego	imported untreated water local runoff	Yes[4,5]	Yes	33,600
Lower Otay Reservoir	City of San Diego	imported water surface water transfers local runoff	Yes[4,5]	Yes	49,849
Morena Reservoir	City of San Diego	local runoff	Yes	Yes	50,200
Sutherland Reservoir	City of San Diego	local runoff	Yes[7]	Yes	31,960
San Vicente Reservoir	City of San Diego	imported untreated water local runoff	Yes[4,5]	Yes	272,528
Olivenhain Reservoir	SDCWA	local runoff imported water	Yes[5]	No	25,382
San Dieguito Reservoir	San Dieguito Water District/ Santa Fe Irrigation District	imported water surface water transfers local runoff	Yes	No	883

Reservoir	Owner	Water Source(s)	In CWASim Model?	Natural inflows received in CWASim?[1]	Modeled Capacity (Total) AF[2, 3]
Loveland Reservoir	Sweetwater Authority	local runoff	Yes	Yes	25,400
Sweetwater Reservoir	Sweetwater Authority	local runoff imported untreated water	Yes	Yes	20,207[9]
Dixon Reservoir	City of Escondido	imported untreated water local runoff	Yes[7]	No	2,610
Lake Jennings	Helix Water District	imported untreated water	Yes[7]	No	9,790
Lake Poway	City of Poway	imported untreated water	Yes[7]	No	3,320
Lake Ramona	Ramona Municipal Water District	imported untreated water	No[8]	No	NA
Barrett Reservoir	City of San Diego	surface water transfers local runoff	Yes	Yes	37,900
Miramar Reservoir	City of San Diego	imported untreated water	Yes	No	6,050
Murray Reservoir	City of San Diego	imported water local runoff	Yes[7]	No	5,200
Lake Henshaw	Vista Irrigation District	local runoff groundwater	Yes	No	53,400

Reservoir	Owner	Water Source(s)	In CWASim Model?	Natural inflows received in CWASim?[1]	Modeled Capacity (Total) AF[2, 3]
Lake Cuyamaca	Helix Water District	local runoff	No[8]	NA	NA
Lake Turner	Valley Center Municipal Water District	imported water	No[8]	NA	NA

1 See Section 4.4.6.1 for additional details on natural reservoir inflows.

2 Modeled reservoir capacities are different from 2015 SDCWA UWMP reservoir capacities in that the CWASim model simulated a flood surcharge pool for each reservoir. SDCWA UWMP capacities only account for usable storage, freeboard, and the dead pool zone, and do not account for a flood surcharge pool.

3 Unless otherwise noted, capacities remained the same for the remaining portfolio model runs.

4 Analyzed for recreation impacts (See Section 6.3).

5 Analyzed for flood control impacts (See Section 6.4).

6 Capacity increased to 112,807 AF in the Optimize Existing Facilities Portfolio 2050 scenarios due to implementation of the San Diego Reservoir Intertie, which removes a restriction on El Capitan (storage level at El Capitan Dam was restricted to 700 foot elevation by the DWR Division of Safety of Dams, which translates to a reservoir capacity of 50,733 AF).

7 Included in CWASim model, but not included in Reservoir Operations metrics (See Section 6.1.5).

8 Not included in CWASim due to small volume and/or lack of connection to regional water system.

9 Capacity increased to 28,079 AF in the Baseline Plus Portfolio 2025 and 2050 scenarios due to implementation of the Sweetwater Reservoir Wetlands Habitat Recovery Project.

4.4.6.1 Local Surface Water Reservoir Inflow Projections

Surface water supplies from precipitation runoff and stream baseflow were modeled as historical monthly reservoir inflows to the 10 reservoirs in the San Diego region that receive the majority of surface water flow. The projections were developed by multiplying historical reservoir inflows by change factors, representing percentage changes in reservoir inflows for future climate scenarios.

4.4.6.1.1. Historical Reservoir Inflows

The historical reservoir inflow dataset (Figure 7) came from a reconstructed dataset of reservoir inflows developed for a previous basin simulation model called Confluence (San Diego County Water Authority, 2013).

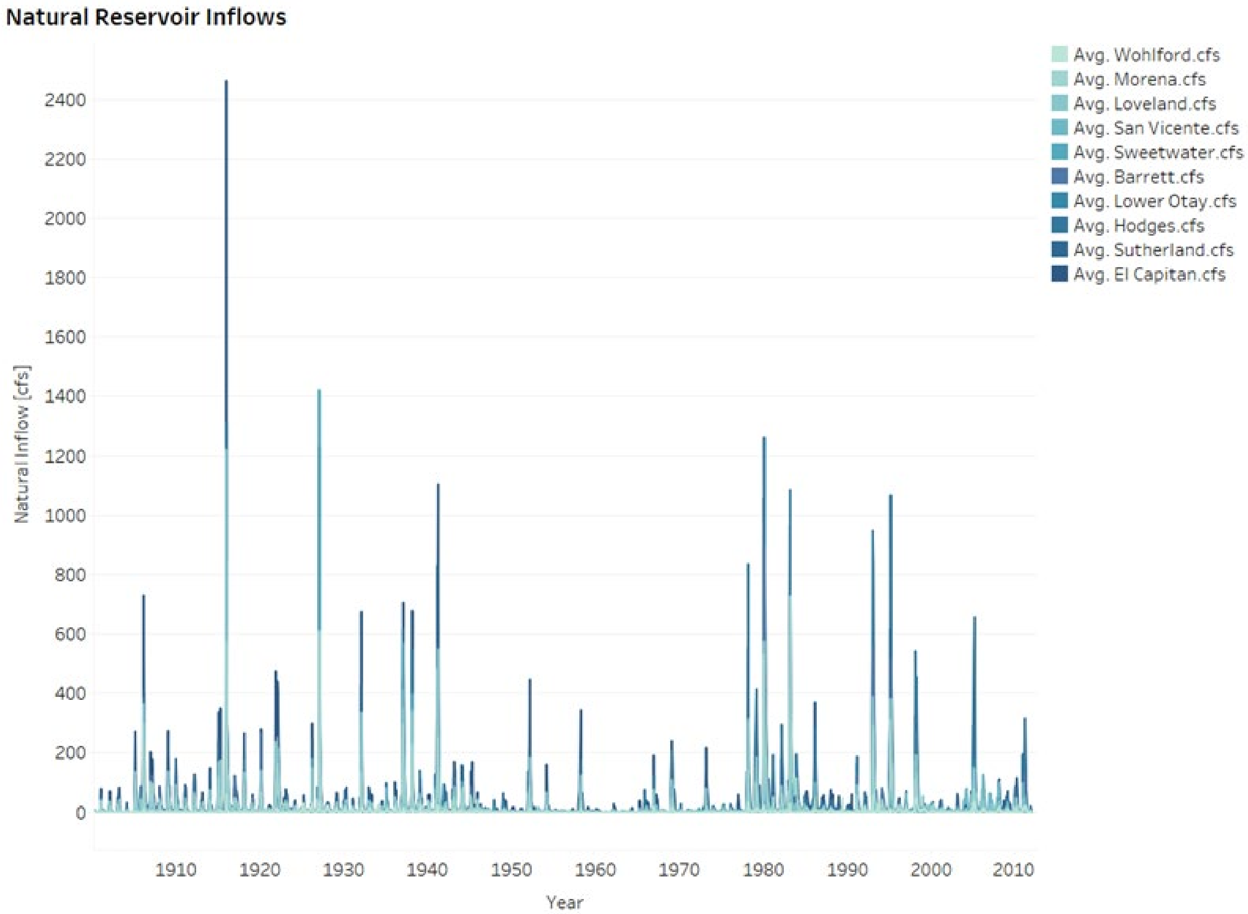

Figure 7. Natural reservoir inflow dataset, 1900-2011.

4.4.6.1.2. Calculation of Change Factors

The change factors were developed by comparing modeled historical reservoir inflows to modeled future reservoir inflows from archived simulations of streamflow under climate change scenarios. A multiplicative factor value of 1 indicated no change from historical, while a value between 0 and 1 indicated a decrease in future inflow, and a value greater than one indicated an increase in future inflow compared to historical.

First, climate change scenarios were identified from the temperature and precipitation projections in the downscaled CMIP5 Climate and Hydrology Projections archive (see Section 2.3.1) by grouping projections according to percentiles. Mean annual changes in precipitation (in percent) and temperature (in degrees Fahrenheit), between the 1990-1999 current climate period, the 2020s future time period (2020-2029), and the 2050s future time period (2050-2059) were calculated for all GCMs and RCPs in the CMIP5 archive. Then the 10th, 50th, and 90th percentile values were calculated for both temperature change and precipitation change and used to group the CMIP5 projections into five climate change scenarios for each time period: hot-wet, hot-dry, central tendency, warm-wet, and warm-dry. The 10 CMIP5 projections closest to the percentile intersections were used to inform each climate change scenario for each time period (Figure 8).

Second, for each scenario, the VIC hydrological projections from the downscaled CMIP5 Climate and Hydrology Projections CMIP5 archive were used to calculate modeled historical and future natural streamflow values for reservoir inflow locations at each of the 10 reservoirs that receive surface water inflows in the CWASim model. For each inflow location, the upstream grid cells reflecting the watershed of that point were identified using a digital elevation model. Summing the streamflow values for each grid cell within the watershed gave an estimate of the naturalized streamflow at that location. This 'natural' streamflow does not reflect any management or operation within the watershed.

Finally, monthly change factors were calculated by comparing modeled historical reservoir inflows to modeled future reservoir inflows. For each of the future time periods (2020s and 2050s), the mean change in streamflow across the 10 projections in each scenario was computed, resulting in one change factor per month (e.g., January), per scenario (e.g., hot-dry), and per time period (e.g., 2020s).

4.4.6.1.3. Local Surface Water Reservoir Inflow Projections for CWASim

To obtain surface water projections for use in the CWASim model, the change factors were applied to the 85-year-long (1900-1984) set of historical reconstructed reservoir inflows to calculate future reservoir inflows for the 2020s and 2050s. Calculated average annual natural reservoir inflows are shown in Table 14. A comparison of natural reservoir inflows to modeled reservoir capacity is shown in Table 15.

4.4.7 Potable Reuse

One Potable Reuse project was included in the Baseline Portfolio, the San Luis Rey WRF – Short/Long Term Expansion Project. The East County Advanced Water Purification Program (both Phase 1 and Phase 2) and Pure Water San Diego Phase 1 were added in the Baseline Plus Portfolio. Phase 3 of the East County Advanced Water Purification Program, Phase 2 of the Pure Water San Diego Program, and five other potable reuse projects were added in the Increase Supplies Portfolio. The Potable Reuse Single Concept Portfolio included all Potable Reuse projects.

Two potable reuse projects, Pure Water Phase 1 and Pure Water Phase 2, were dynamically modeled in the CWASim model. The remaining potable reuse supplies were modeled as demand reductions.

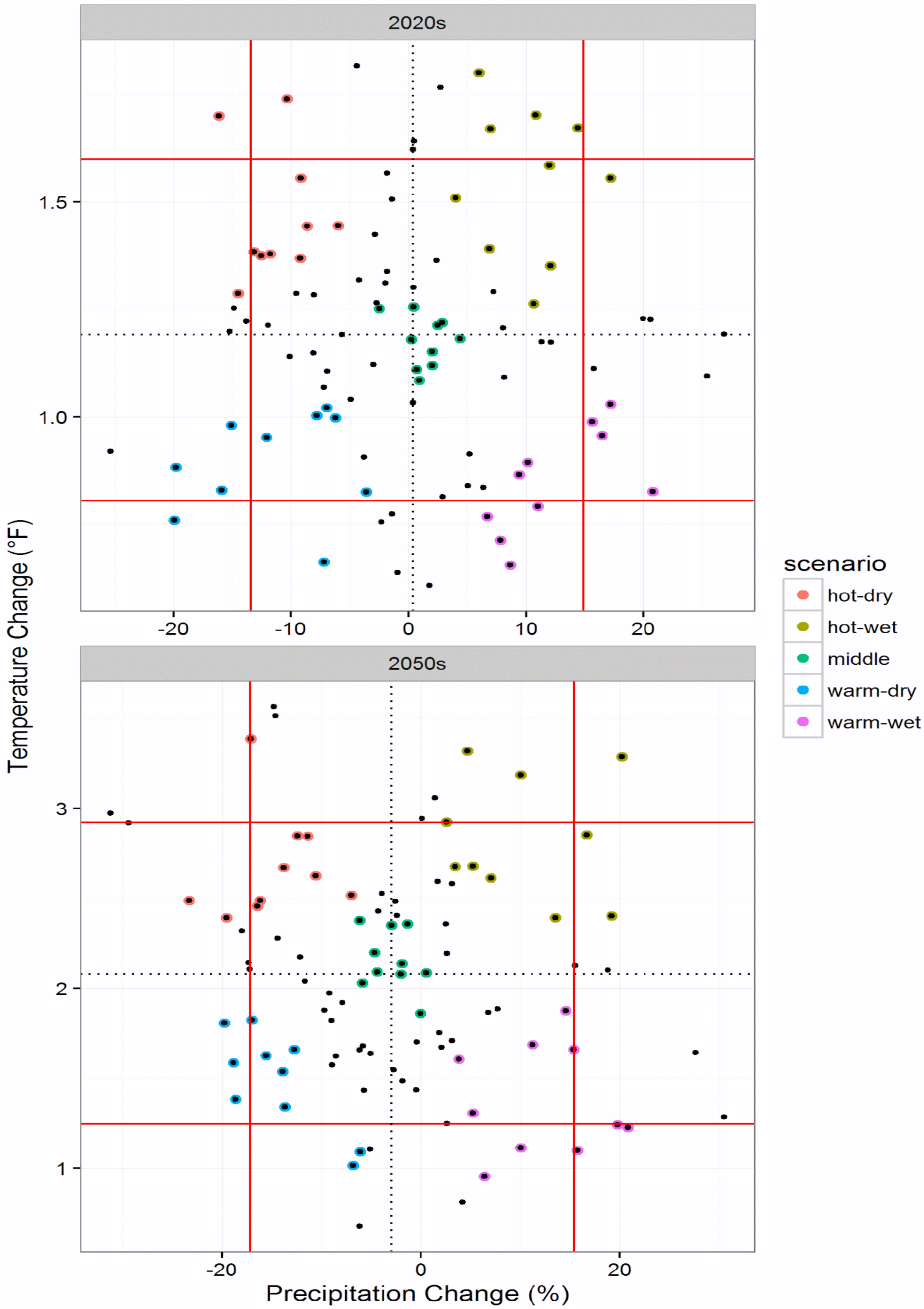

Figure 8. Projection groupings for developing climate change scenarios. Solid red lines represent 10th and 90th percentiles, while dashed gray lines represent 50th percentiles.

Table 14. Climate-Adjusted Natural Inflows

Reservoir	Historical Natural Inflow (AF) (Current Climate)	Climate-Adjusted Natural Inflow (AF)									
		2020s Climate					2050s Climate				
		ct	ww	wd	hw	hd	ct	ww	wd	hw	hd
Barrett	12,500	12,600	14,400	10,800	13,600	10,700	11,400	14,600	10,400	13,000	10,100
El Capitan	27,700	27,200	26,600	27,400	28,000	26,900	26,900	27,700	26,000	28,000	26,100
Hodges	19,000	19,600	22,600	16,800	21,400	16,900	18,100	23,000	16,100	20,800	15,900
Loveland	13,000	13,100	15,300	11,100	14,300	11,100	12,100	15,400	10,700	13,800	10,500
Lower Otay	6,700	6,700	7,800	6,000	7,100	6,000	6,200	7,600	5,900	7,000	5,700
Morena	10,200	10,500	11,900	8,800	11,300	8,700	9,500	12,200	8,400	10,900	8,100
San Vicente	8,400	8,600	10,100	7,400	9,200	7,400	7,900	9,900	7,200	9,100	6,900
Sutherland	11,600	11,800	13,600	10,000	12,800	10,100	10,800	13,800	9,600	12,300	9,500
Sweetwater	7,400	7,500	8,700	6,500	8,100	6,500	6,900	8,700	6,200	7,800	6,000
Wohlford	1,400	1,500	1,800	1,200	1,600	1,200	1,300	1,800	1,100	1,600	1,100

Table 15. Comparison of Natural Inflow to Modeled Reservoir Capacity

Reservoir	Historical Natural Inflow (AF) Current Climate	Modeled Reservoir Capacity (AF)	Natural Inflow / Reservoir Capacity
Barrett	12,500	37,900	33%
El Capitan	27,700	50,733	55%
Hodges	19,000	33,600	57%
Loveland	13,000	25,400	51%
Lower Otay	6,700	49,849	13%
Morena	10,200	50,200	20%
San Vicente	8,400	272,528	3%
Sutherland	11,600	31,960	36%
Sweetwater	7,400	20,207	37%
Wohlford	1,400	6,940	20%

4.4.8 Recycled Water

Thirty-one Recycled Water projects were included in the Baseline Portfolio. Three additional projects were included in the Baseline Plus Portfolio, and 27 additional projects were included in the Increase Supplies Portfolio. All Recycled Water Projects were included in the Recycled Water Single Concept Portfolio.

Recycled water supplies were implemented in the CWASim model as demand reductions.

4.4.9 Seawater Desalination

The Basin Study included four Seawater Desalination projects. Only the Carlsbad Desalination Plant project was included in the Baseline Portfolio. The Increase Supplies Portfolio included three Seawater Desalination projects in addition to the Baseline Portfolio project: re-rating of the Carlsbad Desalination Facility for higher flow, the Camp Pendleton Desalination Facility, and the Rosarito Beach Desalination Facility. The Seawater Desalination Single Concept Portfolio included all four projects categorized by the Seawater Desalination Concept.

Seawater Desalination was modeled dynamically in CWASim. The capacity of each desalination plant determined the maximum amount of water that can be supplied from the plant and requests from demand nodes in the CWASim model determined the simulated daily deliveries.

4.4.10 Stormwater BMPs

Twenty-nine Stormwater BMP projects were included in the Watershed Health and Ecosystem Restoration Portfolio. These same projects were also included in the Stormwater BMPs Single

Concept Portfolio. Of these projects, eight could be simulated in the CWASim model. These were implemented as demand reductions.

4.4.11 Stormwater Capture

One Stormwater Capture project was included in the Watershed Health and Ecosystem Restoration Portfolio. This same project was also included in the Stormwater Capture Single Concept Portfolio. It was modeled as a demand reduction.

4.4.12 Urban and Agricultural Water Use Efficiency

The Baseline Portfolio included one Urban and Agricultural Water Use Efficiency project which captured observed and projected conservation volumes as of the 2015 SDCWA UWMP. The Baseline Plus Portfolio included additional projected conservation from projects such as the Regional Drought Resilience Program and San Diego Water Use Reduction Program. All Urban and Agricultural Water Use Efficiency projects were implemented in the model as demand reductions.

For the Baseline Portfolio, the 2015 volume was calculated as the difference between observed 2015 Gross and Adjusted Demands as reported in the SDCWA 2015 Annual Report. Projected future conservation savings for 2025 were taken from the SDCWA 2015 UWMP, which used the Alliance for Water Efficiency Water Conservation Tracking Tool to develop conservation projections. Conservation was assumed to increase for 2045 and 2050 at the same rate of increase from 2035 to 2040 reported by the 2015 UWMP. The conservation values were proportioned out to each member agency based on the amounts of conservation in the year 2020 as reported in the 2015 UWMP.

4.4.13 Watershed and Ecosystem Management

No Watershed and Ecosystem Management projects were included in the Baseline Portfolio. The Baseline Plus Portfolio incorporated four projects associated with the Watershed and Ecosystem Management Concept. Two of these projects were unable to be accounted for in the CWASim model. The other two projects associated with this Concept that were able to be modeled were Hodges Water Quality Improvement Program and Sweetwater Reservoir Wetlands Habitat Recovery. Both projects were implemented through model logic.

Fourteen additional Watershed and Ecosystem Management projects were included in the Watershed Health and Ecosystem Restoration Portfolio, but none of those projects were able to be modeled.

The Watershed and Ecosystem Management Single Concept Portfolio included all Watershed and Ecosystem Management projects (although only two could be modeled).

4.5 Water Conveyance Modeling

4.5.1 Conveyance Facilities

4.5.1.1 Pipelines and Pump Stations

Pipelines (Table 16) were represented in CWASim by both elements and links connecting elements. Elements described pipeline characteristics and operational logic, and links allowed water to be transferred between elements by the model logic. Multiple elements and links may represent different reaches of the same pipeline. Detailed hydraulic characteristics such as friction coefficients were not included in the CWASim model.

The First Aqueduct alignment includes Pipelines 1 and 2 and extends from the MWD Delivery Point to San Vicente Reservoir. The two pipelines are operated as a single unit. North of the Crossover Pipeline, Pipelines 1 and 2 deliver treated water from MWD. South of the Crossover Pipeline, Pipelines 1 and 2 convey untreated water.

Pipelines 3, 4, and 5 make up the Second Aqueduct alignment. The pipelines are divided into several reaches. Depending on the pipeline and reach, these pipelines convey treated or untreated water and are operated independently or as a unit. Pipeline 3 conveys treated or untreated water between the MWD Delivery Point and Lower Otay Reservoir. Pipeline 4 conveys treated or untreated water from the MWD Delivery Point to the southern portion of San Diego County. Pipeline 5 conveys untreated water from the MWD Delivery Point to water treatment plants in the southern portion of San Diego County stopping at Miramar.

Table 16. San Diego Region Pipelines

Pipeline Name	Owner	Water Type	Conveys water from	Conveys water to	In CWASim Model?	Modeled Capacity (cfs)
Pipeline 1 and 2 (First Aqueduct)	SDCWA	Treated (North of Crossover Pipeline) and Untreated (South of Crossover Pipeline)	MWD Delivery Point	San Vicente Reservoir	Yes	190 at MWD Delivery Point
Pipeline 3 (Second Aqueduct)	SDCWA	Treated or Untreated	MWD Delivery Point	Lower Otay Reservoir	Yes	P3 + P5 capacity is 720[3] for except for OEF Portfolio 2050s scenarios P3 + P5 capacity is 895 in OEF Portfolio 2050s scenarios
Pipeline 4 (Second Aqueduct)	SDCWA	Treated or Untreated	MWD Delivery Point	Southern San Diego County	Yes	395 except for OEF Portfolio 2050s scenarios 135 in OEF Portfolio 2050s scenarios

Pipeline Name	Owner	Water Type	Conveys water from	Conveys water to	In CWASim Model?	Modeled Capacity (cfs)
Pipeline 5 (Second Aqueduct)	SDCWA	Untreated	MWD Delivery Point	Southern San Diego County stopping at Miramar	Yes	P3 + P5 capacity is 720[3] for except for OEF Portfolio 2050s scenarios P3 + P5 capacity is 895 in OEF Portfolio 2050s scenarios
Crossover Pipeline	SDCWA	Untreated	Second Aqueduct near Twin Oaks Valley Water Treatment Plant	First Aqueduct near Escondido-Vista Pipeline Pump Station	Yes	200
North County Distribution Pipeline	SDCWA	Treated	Second Aqueduct (Pipeline 4) near the Weese Filtration Plant	Oceanside, Vista Vallecitos, and Rainbow member agencies	Yes, in aggregate fashion by delivery of water from Second Aqueduct	Modeled in aggregate fashion by delivery of water from Second Aqueduct
Tri-Agency Pipeline	SDCWA	Treated	Second Aqueduct	Vista, Carlsbad, and Oceanside member agencies	Yes, in aggregate fashion by delivery of water from Second Aqueduct	Modeled in aggregate fashion by delivery of water from Second Aqueduct

Pipeline Name	Owner	Water Type	Conveys water from	Conveys water to	In CWASim Model?	Modeled Capacity (cfs)
Ramona Pipeline	SDCWA	Treated	Second Aqueduct	Ramona, Olivenhain, and the City of San Diego member agencies	Yes	104
San Vicente Pipeline/ Tunnel[1,2]	SDCWA	Untreated	Second Aqueduct (Pipeline 5)	San Vicente, El Capitan, and Jennings Reservoirs and the Levy Water Treatment Plant (WTP)	Yes	444 West to East
			San Vicente Reservoir	Second Aqueduct (Pipeline 5)	Yes	444 East to West[6]
Valley Center Pipeline	SDCWA	Treated	Second Aqueduct (Pipeline 4)	First Aqueduct (Pipelines 1 & 2)	No[7]	NA[7]
Olivenhain-Hodges Pipeline[1]	SDCWA	Untreated	Lake Hodges	Olivenhain Reservoir	Yes	760
			Olivenhain Reservoir	Lake Hodges	Yes	760
El Monte Pipeline	City of San Diego	Untreated	San Vicente and El Capitan Reservoirs	Murray Reservoir or Alvarado WTP	Yes	150[5]
	SDCWA	Untreated	First Aqueduct	Sweetwater Reservoir	No	NA

Pipeline Name	Owner	Water Type	Conveys water from	Conveys water to	In CWASim Model?	Modeled Capacity (cfs)
La Mesa-Sweetwater Extension		Treated	Levy WTP	Otay Water District and Sweetwater Authority Member Agencies	Yes, through ECRTWIP[2]	Modeled through ECRTWIP
Moreno-Lakeside Pipeline	SDCWA	Untreated	San Vicente Pipeline/ Tunnel	Levy WTP	Yes	93 West to East from San Vicente Pipeline[1] 124 East to West from San Vicente Pipeline[1]
Sutherland-San Vicente Conduit	SDCWA	Untreated	Sutherland Reservoir	San Vicente Reservoir	Yes	50
Pomerado Pipeline	SDCWA	Untreated	Second Aqueduct (Pipeline 5)	Second Aqueduct (Pipelines 3 & 4)	Yes	220
Rancho Pipeline	SDCWA	Untreated	Untreated conveyance downstream of Rancho Peñasquitos	Second Aqueduct (Pipeline 5)	Yes	600
SD12 Pipeline (section of Pipeline 4)	SDCWA	Untreated	30-inch interconnect	Alvarado WTP	Yes	150

Pipeline Name	Owner	Water Type	Conveys water from	Conveys water to	In CWASim Model?	Modeled Capacity (cfs)
			connecting Pipelines 3 & 4			
Second Crossover Pipeline	SDCWA	Untreated	Second Aqueduct near Twin Oaks Valley Water Treatment Plant	First Aqueduct near Escondido-Vista Pipeline Pump Station	Yes, but only implemented in the Optimize Existing Facilities Portfolio	130
The 30 Inch Pipeline[4]	SDCWA	Untreated	SD12	Pipeline 3	Yes	70

[1] Capable of bi-directional flow

[2] East County Regional Treated Water Improvement Program

[3] Actual capacity was 780 cfs in 2015, but capacity was modeled as 720 cfs for 2015 and 2025 scenarios because capacity is expected to decrease to 720 cfs by 2025.

[4] Theoretical maximum capacity was 90 cfs in 2015, but modeled as 70 cfs to reflect normal operating conditions.

[5] Theoretical maximum capacity was 175 cfs and actual maximum was 124 cfs in 2015. Modeled as 150 cfs as an average operational maximum.

[6] Actual capacity is 441 cfs.

[7] Actual capacity is 140 cfs. CWASim models the Valley Center Pipeline indirectly through the allocation logic.

CWASim includes six elements representing pump stations. Five elements were operational as of 2015, and one additional pump station (North County Pump Station 2) had not yet been constructed (Table 17). The model's pump station elements include maximum flow capacities that are set by the user and distribute flows among the member agencies.

Table 17. Major Pump Stations in the San Diego Region

Pump Station	Owner	Water Type	Use	In CWASim Model?	Baseline Modeled Capacity (cfs)[1]
Escondido	SDCWA	Untreated	MWD untreated water enters the station from the Crossover Pipeline and P12_10 and is pumped to Dixon Reservoir.	Yes	20
Miramar	SDCWA	Treated	MWD treated water enters the station from the Miramar WTP and is pumped to San Diego 11.	Yes	60
Valley Center (P2A)	SDCWA	Treated	Used to deliver Twin Oaks Valley WTP treated water to north county agencies.	Yes	41
North County Pump Station 2	NA	Treated	Did not exist as of 2015.	Yes, but only used in the New North Pipe Operation, which is not included in model runs.	NA
San Vicente	SDCWA	Untreated	MWD untreated water is pumped from San Vicente Reservoir through a surge tank toward Junction 770.	Yes	300[2]

Pump Station	Owner	Water Type	Use	In CWASim Model?	Baseline Modeled Capacity (cfs)[1]
Olivenhain	SDCWA	Untreated	Can receive and/or deliver MWD untreated water between Olivenhain Reservoir and Pipe 5. When water is transferred from Olivenhain Reservoir into Hodges Reservoir, the process generates up to 40 megawatts of hydroelectricity, helping offset some of the project operating costs.	Yes	314
Lake Hodges Pump Station	SDCWA	Untreated	Pumps MWD untreated water between Lake Hodges Reservoir and Olivenhain Reservoir.	No	NA
Twin Oaks Valley	SDCWA	Untreated	Used only as part of the Emergency Storage Project	No	NA

[1] Unless otherwise noted, capacities remain the same for the remaining portfolio model runs.

[2] Capacity increased to 444 cfs in the Baseline Plus 2050 scenario due to implementation of San Vicente 3rd Pump Drive and Power project. This capacity is used for 2050 scenarios in all portfolios except Baseline.

4.5.2 Conveyance Improvement

The Conveyance Improvements Concept in the Baseline Portfolio represented water treatment plants, pump stations, and pipelines as they existed in the Study Area in 2015. Two projects in the Baseline Plus Portfolio were associated with Conveyance Improvement: Mission Trails Projects Alternative 1, which will increase untreated water conveyance capacity south of the Miramar WTP and allow for increased imported water storage at Lower Otay, and San Vicente 3rd Pump Drive and Power, which will increase pumping capacity at the San Vicente Pump Station. Four additional Conveyance Improvement projects were included in the Optimize Existing Facilities Portfolio. They included Pipeline 3/Pipeline 4 Conversion, which involves converting an existing portion of Pipeline 4 from treated to untreated water service and converting a similar portion of Pipeline 3 from untreated to treated water service to alleviate untreated water delivery constraints; San Diego County Reservoir Intertie, which would improve water storage operations through interconnections between various water storage reservoirs; Second Crossover Pipeline, which would increase untreated water conveyance between the Second and First Aqueduct; and Dulzura Conduit Replacement, which would replace and renovate most of an 11-mile-long open channel concrete conduit that is over 100 years old and deteriorating. These projects were implemented in the model runs via model logic. All Conveyance Improvement projects were included in the Conveyance Improvement Single Concept Portfolio.

5. Impacts Assessment Methodology

Basin Studies are required to consider eight impact areas: Water Delivery, Hydroelectric Power, Recreation, Flood Control, Habitats, Endangered/Threatened Species, Water Quality, and Ecological Resiliency (Bureau of Reclamation, 2016a). The Impacts Assessment completed in Task 2.4 of the San Diego Basin Study assessed Water Delivery, Hydroelectric Power (as energy generation and consumption), Recreation, and Flood Control. It should be noted that Habitats, Endangered/Threatened Species, Water Quality, and Ecological Resilience were not analyzed in Task 2.4, since the CWASim model does not have a method for quantifying environmental impacts. These impacts were instead assessed in the Trade-off Analysis in Task 2.5 of the Basin Study.

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. 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.

Impact metrics (Table 18) quantified the CWASim model simulation results for each impact area (Water Delivery, Recreation, Energy, and Flood Control), and were divided into a Metric Category, Metric Subcategory, and Metric Group. The four impact areas each served as a Metric Category, which were further divided into Metric Subcategories. For example, the Metric Category Water Delivery is subdivided into the Metric Subcategories of Demands, Deliveries, Shortage, Conveyance, and Reservoir Operations. The Metric Category Energy is subdivided into the Metric Subcategories of Generation and Consumption. Metric Subcategories can be further defined by Metric Groups (i.e., Pipeline Flow is within the Metric Subcategory of Conveyance, which is within the Metric Category of Water Delivery). Each impact metric group contains one or more metrics pertaining to a particular location, facility, water supply type, water demand type, or other specific feature (e.g., the metric group Treatment Plant Utilization contains separate metrics for Alvarado WTP, Miramar WTP, and the other treatment plants).

Table 18. Impact Assessment Metrics

Metric Category	Metric Sub-category	Metric Group	Timestep	Description
Water Delivery	Demands	Gross Demand Volume	Annual Monthly	Gross demands of SDCWA member agencies
Water Delivery	Deliveries	Delivery and Conservation	Annual Monthly	Total conservation volume and total water deliveries to SDCWA member agencies: • Enhanced Conservation • Groundwater • Imported Water Purchases • Firm Water Supply Agreements • Gray Water Use • Local Surface Water • Potable Reuse • Recycled Water • Seawater Desalination • Stormwater BMPs • Stormwater Capture • Urban and Agricultural Water Use Efficiency • Watershed and Ecosystem Management
Water Delivery	Shortage	Shortage Volume	Annual	Magnitude of demand SDCWA-wide that is unable to be met by the available supplies and/or limited by conveyance system capacity. The Shortage Volume can be compared to the 20,000 AF shortage threshold, which represents the shortage volume that could be mitigated within the San Diego system through short-term drought restrictions or operational changes.

Metric Category	Metric Sub-category	Metric Group	Timestep	Description
Water Delivery	Conveyance	Pipeline Flow Volume	Monthly	Average pipeline flow volumes during the month for five pipeline locations: • Pipeline 4 just south of Twin Oaks Valley WTP, which serves treated water to Carlsbad, Vista, and Vallecitos member agencies • Pipeline 3 30-inch interconnect, which conveys untreated water near Murray Reservoir • Crossover Pipeline, which conveys untreated water • MWD Delivery Point treated water conveyed through Pipelines 1, 2, and 4 • Untreated
Water Delivery	Conveyance	High Pipeline Utilization Summer Count	Annual	Number of days that pipeline flow exceeds 95% of capacity during the summer for five pipeline locations: • Pipeline 4 just south of Twin Oaks Valley WTP, which serves treated water to Carlsbad, Vista, and Vallecitos member agencies • Pipeline 3 30-inch interconnect, which conveys untreated water near Murray Reservoir • Crossover Pipeline, which conveys untreated water • MWD Delivery Point treated water conveyed through Pipelines 1, 2, and 4 • Untreated
Water Delivery	Conveyance	High Pump Station Utilization	Annual	Number of times per year that pump station exceeds 95% of capacity for 70% of pumping days for the following pump station locations: • San Vicente; 70% of pumping days = 107 days • P2A; 70% of pumping days = 171 days

Metric Category	Metric Sub-category	Metric Group	Timestep	Description
Water Delivery	Conveyance	Treatment Plant Utilization	Annual	Average annual treatment plant flow at the following plants divided by annual treatment plant capacity, expressed as a percentage: • Alvarado • Badger • Escondido • Levy • Miramar • Olivenhain • Otay • Poway • Perdue • Twin Oaks Valley • Weese
Water Delivery	Reservoir Operations	Reservoir Storage	Monthly	End of month reservoir storage volume for the following reservoirs: • Barrett • El Capitan • Hodges • Loveland • Lower Otay • Miramar • Morena • Olivenhain • San Vicente • Sweetwater • Wohlford

Metric Category	Metric Sub-category	Metric Group	Timestep	Description
Water Delivery	Reservoir Operations	Reservoir Releases	Monthly	Total reservoir release volume used to meet demands during the month: • Barrett • El Capitan • Hodges • Loveland • Lower Otay • Miramar • Morena • Olivenhain • San Vicente • Sweetwater • Wohlford
Water Delivery	Reservoir Operations	End of September Reservoir Storage	Annual	Volume remaining in the reservoir at the end of September, including storage in all modeled reservoir pools, for the following reservoirs: • Hodges • El Capitan • San Vicente • Lower Otay • Olivenhain
Energy	Generation	Energy Generation	Annual Monthly	Total energy generated at Miramar, Alvarado, and Twin Oaks Valley Water Treatment Plants, the Rancho Peñasquitos Hydroelectric Facility, Hodges Pump Storage Hydroelectric Facility, and the SDCWA offices in San Diego and Escondido

Metric Category	Metric Sub-category	Metric Group	Timestep	Description
Energy	Consumption	Energy Consumption	Annual Monthly	Total energy consumed to treat and deliver water, including consumption by supply sources, conveyance, treatment, pumped storage, and offices
Recreation	Recreation	End of September Reservoir Elevation	Annual	Reservoir elevation on September 30th of each simulation year for the following reservoirs: • El Capitan • Hodges • Lower Otay • San Vicente
Flood Control	Flood Outflow	Flood Outflow Volume	Annual Monthly	Total outflow volume from the following reservoirs on days when the reservoir is operating in the flood pool: • El Capitan • Hodges • Lower Otay • San Vicente • Olivenhain
Flood Control	Flood Outflow	Number of Days with Flood Outflows	Annual	Number of days with flood outflows from the following reservoirs: • El Capitan • Hodges • Lower Otay • San Vicente • Olivenhain

The metric results were visualized using charts and graphs to aid in comparison among demand and climate scenarios and comparison among portfolios. Inspection of the plots yielded numerous observations regarding differences in impacts between scenarios and portfolios. For some of the annual metrics, the observations of differences were then verified using statistical analysis. This was performed for Surface Water Deliveries, Desalination Deliveries, Shortage Volume, High Pipeline Utilization for the untreated location, Treatment Plant Utilization for all 11 locations, End of September Storage for five locations, Energy Generation and Energy Consumption, End of September Reservoir Elevation for four locations, and Flood Outflow Volume and Number of Days with Flood Outflows for four locations. Statistical analysis was not performed for Demands because it was a model input. Statistical Analysis was not performed for Delivery metrics for Enhanced Conservation, Urban and Agricultural Water Use Efficiency, Firm Water Supply Agreements, Groundwater, Imported Water Purchases, Recycled Water, Potable Reuse, Stormwater BMPs, Gray Water Use, or Stormwater Capture because they were modeled as demand reductions. Statistical analysis was not done for High Pipeline Utilization, except for the Untreated Pipeline, or High Pump Station Utilization because the results of those metrics were zero or nearly zero for all portfolios and scenarios. Statistical analysis was not performed for the monthly metrics.

6. Impacts Assessment Results

The sections in this Chapter describe the Impacts Assessment results for each of the four impact metric categories described in Section 5. Section 6.1 discusses Water Delivery, Section 6.2 discusses Energy, Section 6.3 discusses Recreation, and Section 6.4 discusses Flood Control. Impact metrics are further divided into subcategories and groups as shown in Table 18. For each metric group, the text describes key similarities and differences within and across portfolios and climate (current, central tendency, hot-dry, warm-dry, hot-wet, and warm-wet) and demand (2015 demands, 2025 demands, and 2050 demands) scenarios. Where possible, differences between portfolios and demand scenarios are attributed to Concepts (and specific projects in some cases) that can be identified as drivers. The differences between climate scenarios are attributed to differences in the supply and demand inputs associated with the scenarios. Key model results are discussed and supported with figures.

6.1 Water Delivery

The primary purpose of the San Diego regional water system is to deliver water supplies to meet the demands of member agencies. Therefore, water delivery impacts are related to the amount of water delivered to meet demands and the quantity of unmet demand. Conveyance system and reservoir operations support water delivery; thus, quantification of impacts to those infrastructure components also provides greater understanding of impacts to water delivery. Water delivery impacts were measured by demands, water delivery volumes, shortage volume and frequency, conveyance system operations (pipeline flows and treatment plant utilization), and reservoir storage and releases.

Overall, as demands increased due to increasing population, water deliveries also proportionally increased to meet the demands. 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.

Shortages occurred in some portfolios but represented only up to 2% of the total annual demand on average. Shortages were worst under Baseline conditions, future demand scenarios, and in hot-dry and warm-dry climate scenarios. In the Baseline Portfolio, shortages above the 20,000 AF shortage threshold occurred in 6% of the realizations in the hot-dry climate scenario for 2025 demands, and 28% of the realizations in the hot-dry climate scenario for 2050 demands, due in part to an increase in demands but largely due to a drier climate. These results indicate that climate change is likely to result in increased shortages if no changes are implemented beyond the Baseline. As discussed in Section 4.2, the realizations represent an 85-year-long time series of hydrologic data, so these results indicate a 28% chance of shortage in a given year for the Baseline Portfolio under hot-dry climate in the 2050 demand scenario. 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 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, 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 lower in the Enhanced Conservation, Increase Supplies, and Optimize Existing Facilities Portfolios for 2050 demands. Reservoirs operated within the ranges specified by the 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, which may be attributed to the primary inflow source (i.e., local runoff versus imported water). For reservoirs that showed impacts from climate change, wet scenarios generally had higher reservoir storage than dry scenarios.

6.1.1 Demands

Demands indicate the water supply needed for municipal, industrial, and agricultural uses. The demands metric measured the gross annual demands of SDCWA member agencies as input into the model. Larger values indicated higher demand projections for SDCWA member agencies. Gross demands are a model input calculated as described in Section 4.3. Demand projections were modeled for various climate scenarios: current climate, hot-dry climate, warm-dry climate, hot-wet climate, warm-wet climate, and central tendency climate. Current climate 2015 demands were actual demands from 2015, the current climate 2025 demand projections were taken from the SDCWA 2015 UWMP, and the current climate 2050 demand projections were extended from the projections in the SDCWA 2015 UWMP. Although there is inherent uncertainty in future demands resulting from uncertainties in projections of future population and socio-economic factors, analysis of this type of uncertainty was outside the scope of the Basin Study. SDCWA updated its demand forecast in 2018 to account for changes in socioeconomic trends, but the update was developed too late to be incorporated in the Basin Study process. Uncertainty in demands due to uncertainty in future climate was captured in the Basin Study through adjustment of the demand projections for climate change scenarios. 2025 and 2050 demand projections for the climate change scenarios were calculated by adjusting the current climate demands based on factors related to projected changes in precipitation and potential evapotranspiration (PET). Demand inputs were the same for all portfolios but varied with demand scenario and climate scenario.

Demands were projected to increase by approximately 15% from 2015 to 2025 and 18% from 2025 to 2050 for all climate scenarios. As shown in Figure 9, current climate 2015 demands were 619,736 AF, and 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 180,000 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 differ between central tendency climate and other future climate scenarios (hot-dry, hot-wet, warm-dry, or warm-wet), the differences are small. These results indicate that the increase in population from 2015 to 2025 and 2050 has a greater effect on overall demand than climate change. Climate change does have an effect on demand, but the effect is only apparent when comparing current climate and future climate scenarios within a demand scenario (e.g., comparing 2025 current climate to 2025 central tendency or 2025 hot-dry).

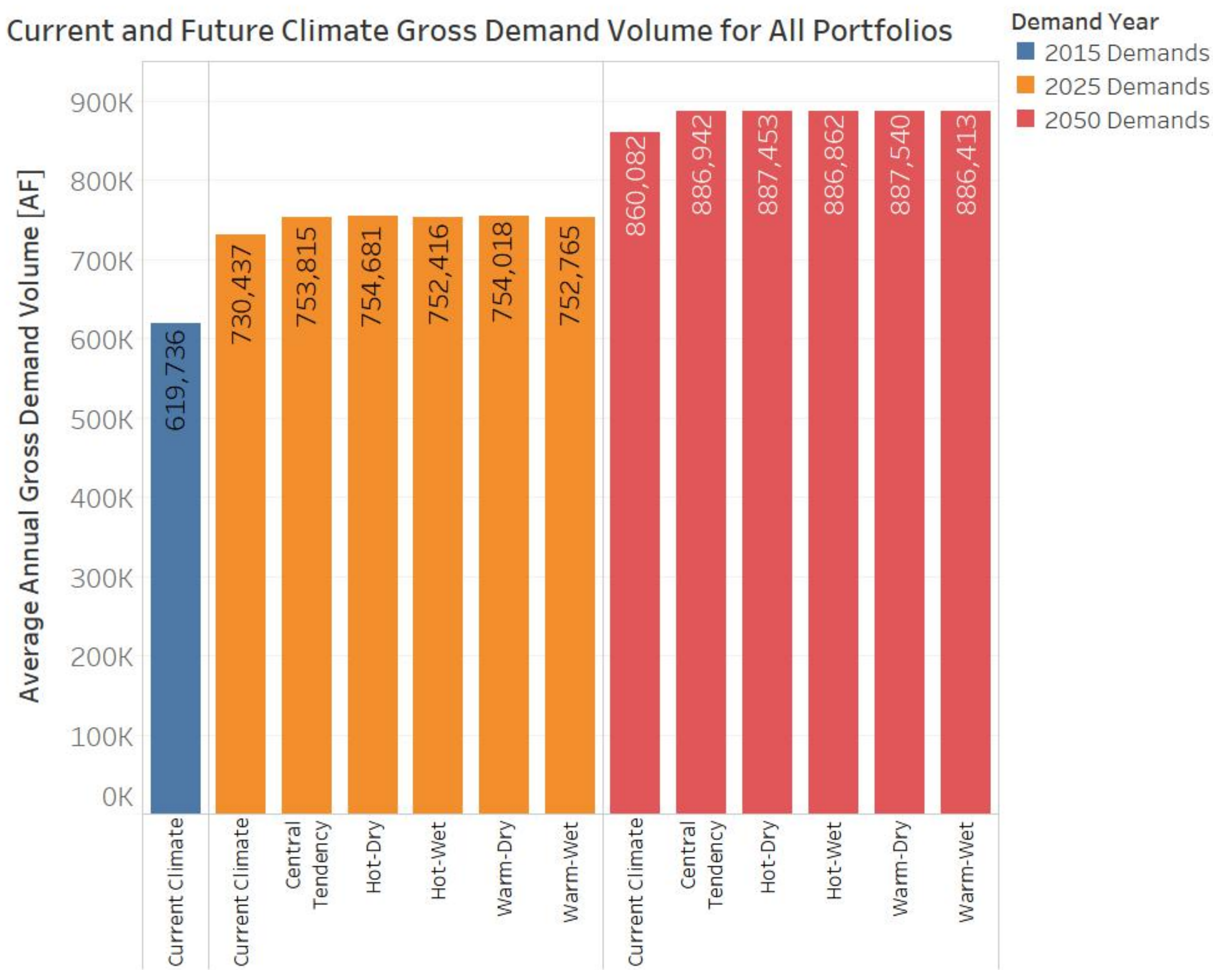

Figure 9. Gross Demands for 2015, 2025, and 2050 demands compared across climate scenarios for all portfolios.

6.1.2 Deliveries and Conservation

Delivery metrics described water volumes that are delivered to meet SDCWA member agency demands. The metrics measured the total water deliveries to SDCWA member agencies from surface water reservoirs, groundwater, recycled water, potable reuse, gray water use, stormwater capture, stormwater BMPs, desalination, firm water supply agreements, and imported water purchases. As described in Section 4.4, some supply sources were modeled dynamically through model logic (firm water supply agreements, some imported water purchases, surface water, some desalination, and some potable reuse) and others were modeled as demand reductions (recycled water, groundwater, some imported water purchases, some desalination, some potable reuse, stormwater BMPs, gray water use, and stormwater capture). In addition, conservation (described by projects in the Enhanced Conservation, and Urban and Agricultural Water Use Efficiency Concepts) was included with delivery metrics because it represented a demand reduction that affects the water volume that must be delivered to meet demands. Larger values of delivery metrics indicated that more water volume is being delivered to SDCWA member agencies or conserved by member agencies.

Deliveries and conservation volumes varied depending on climate and demand scenario, and portfolio. Figure 10 shows the average annual delivery and conservation volumes associated with each portfolio for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

Overall, total deliveries increased as demands increased[1], but the types of water delivered varied depending on portfolio and demand scenario, and climate change scenarios may increase or decrease delivery amounts relative to current climate. Firm Water Supply Agreements (QSA) deliveries were assumed to be the same across all portfolios, demand scenarios, and climate scenarios. Conservation (Urban and Agricultural Water Use Efficiency and Enhanced Conservation) was unaffected by climate but varied between portfolios. Delivery types modeled as demand reductions (such as recycled water and groundwater [see Section 4.4]) were not affected by climate change scenarios, but did change based on portfolio (projects may be included or not included in a particular portfolio) and demand scenario (projects may not be implemented in all demand scenarios, or the supply amount may vary between demand scenarios as projects are assumed to expand). Supply types modeled dynamically differed between portfolios (depending on whether that project was included or not), between demand scenarios (higher demands due to population increases require larger deliveries), and climate scenarios (increased demands due to temperature and precipitation changes require increased deliveries). Supply types modeled as demand reductions (see Section 4.4) differed between portfolios (depending on whether that project is included or not) and demand scenarios (depending on projected supply volume from the project for a given demand scenario), but did not differ between climate scenarios.

Overall, 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

[1] Average Total Annual Delivery Volume did not equal the Average Annual Demand Volume due to supply shortages that occur in some years of the model simulations and due to complexities in water delivery accounting. Delivery metrics for individual supply types summed to a larger volume than the total demand minus shortage, resulting in an apparent oversupply of between 1% and 7%. The apparent oversupply was the result of inconsistencies in water accounting assumptions that assign deliveries to supply sources. For example, imported water deliveries from QSA and MWD purchases are measured as total volume imported to the San Diego County water system, but other deliveries are counted after release from reservoirs. MWD untreated water imported to reservoirs is subject to evaporation, but this evaporation is not accounted for in the delivery amount, resulting in an apparent oversupply. In addition, imported water mixes with local supplies such as surface water and potable reuse water in reservoirs, resulting in double-counting in certain situations and at certain reservoirs, resulting in an apparent oversupply. However, the impacts of this discrepancy were negligible in the overall conclusions of the San Diego Basin Study. While some specific reported delivery values (primarily imported water and surface water) were slightly increased, the trends and changes observed in the delivery results were accurate. Because this issue only impacted water delivery accounting, no other metrics were impacted.

reduced overall water demands, which allowed more of the demand to be met by local sources. Increases in local supply sources such as potable reuse, desalination, and gray water 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. These results showed that both demand-side and supply-side options were effective in reducing reliance on imported water.

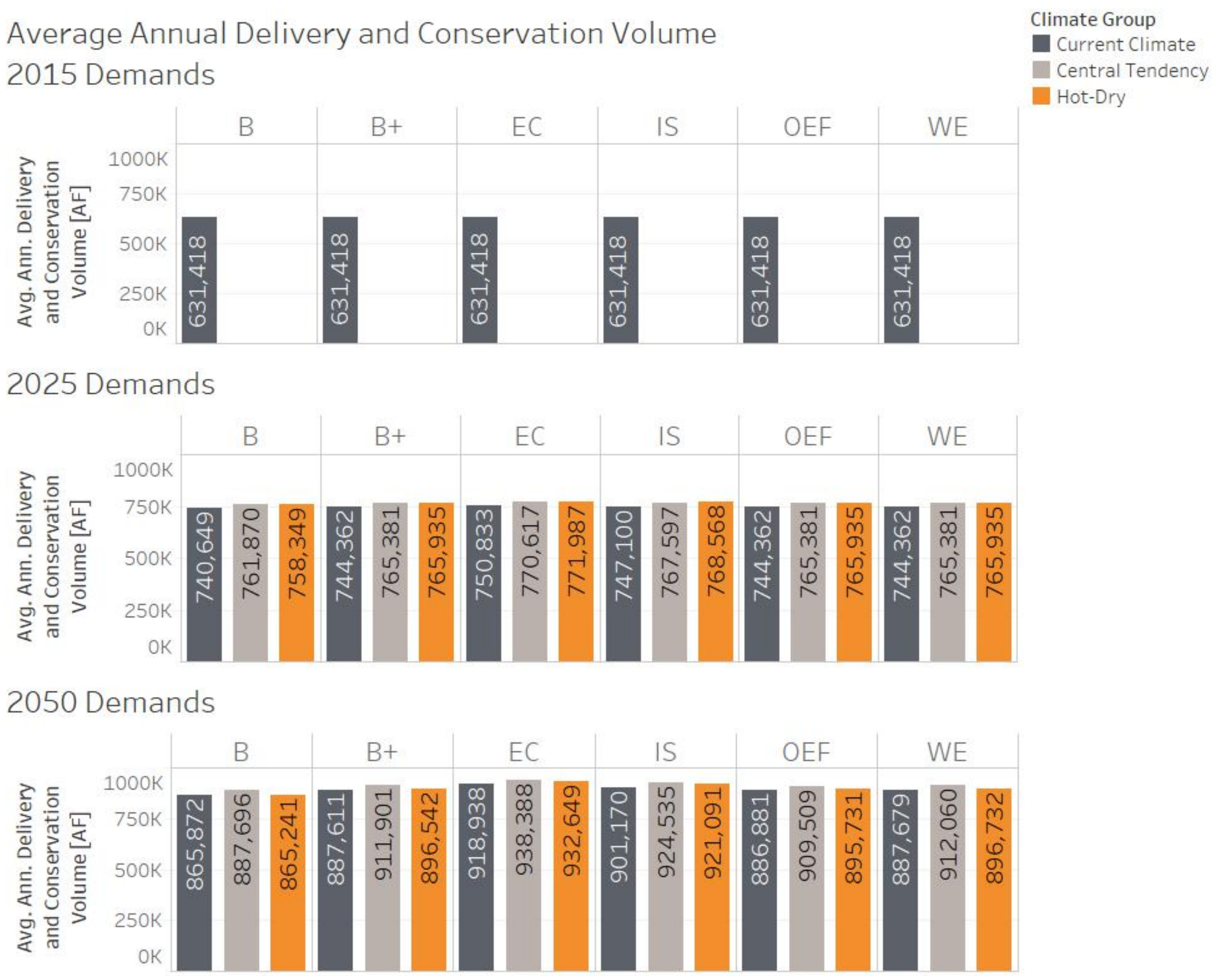

Figure 10. Average Annual Delivery Volume for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

6.1.3 Shortage Volume

The Shortage Volume metric measured the magnitude of regional demand that was unable to be met by the available supplies and/or limited by conveyance system capacity. Non-zero shortage volumes indicated that supplies were insufficient to meet demands or that conveyance system capacity limits deliveries. Larger values indicated larger supply-demand imbalances or capacity limitations.

Average Annual Shortage Volumes for each portfolio compared across all demand scenarios and selected climate scenarios are shown in Figure 11. There were no shortages for any portfolios for 2015 demand scenarios. For 2025 and 2050 demand scenarios, all portfolios had shortages in at least one climate scenario, with hot-dry climate scenarios having the most shortages. The highest annual average shortage volume was 22,000 AF (about 2% of annual demand) for the Baseline Portfolio 2050 demands and hot-dry climate scenario, indicating that climate change and changes in demand may have a significant effect on water reliability in the region. Conversely, large shortages were avoided in the Increase Supplies and Enhanced Conservation Portfolios, indicating that there are options available to prevent shortages, even in a hot-dry climate. The Shortage Volume was zero for all portfolios for 2015 demands under current climate. On a monthly scale, shortage volumes were smallest from December through May. The largest shortage volumes typically occurred during the months of June through November, with peak shortages in August and September.

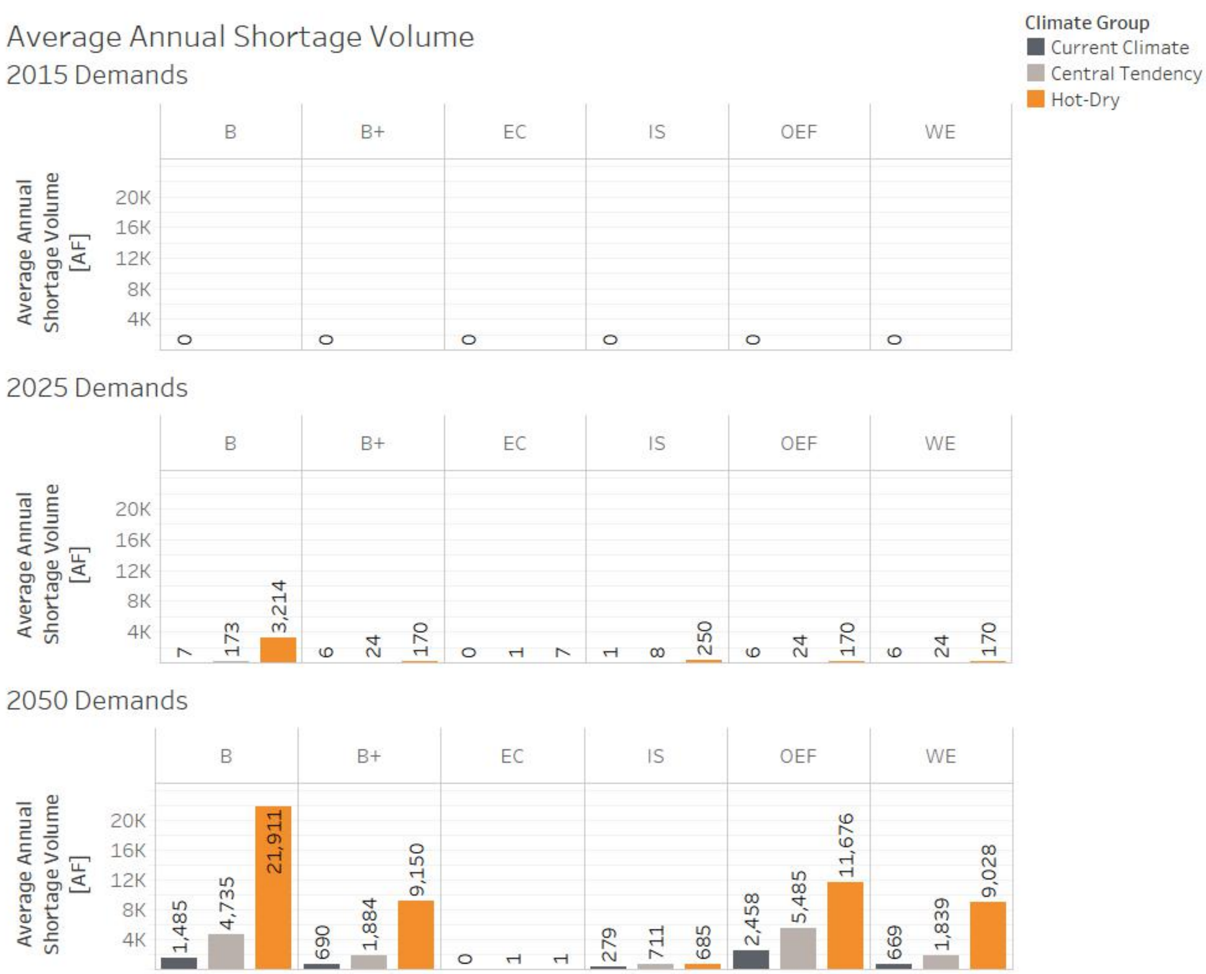

Figure 11. Shortage Volume for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

Comparing demand scenarios, Shortage Volume was higher for 2025 demands than for 2015 demands. It was also higher for 2050 demands than for 2025 demands in all portfolios for current climate, central tendency climate, and hot-dry climate, except for the Enhanced Conservation Portfolio. In the Enhanced Conservation Portfolio, Shortage Volume was lower for 2050 demands than for 2025 demands with hot-dry climate. However, the magnitude of the Shortage Volume was small in the Enhanced Conservation Portfolio (less than 10 AF/y), so the difference is likely inconsequential.

Comparing portfolios, shortage volumes were smallest in the Enhanced Conservation Portfolio, with shortages averaging less than 10 AF/y for both 2025 and 2050 demands for current, central tendency, and hot-dry climate. Shortage volumes were larger in the Baseline Portfolio than in other portfolios for both 2025 and 2050 demands, except for the Optimize Existing Facilities Portfolio for 2050 demands. Average shortage volumes appeared to differ between Baseline Plus and Optimize Existing Facilities, but the ANOVA statistical results were inconclusive, likely because the metric results did not meet the normality and equal variance assumptions required for the statistical analysis. For 2050 demands under current climate, the Shortage Volume was higher in the Optimize Existing Facilities Portfolio than the Baseline and Baseline Plus Portfolios. The same was true under central tendency climate, but only for the Baseline Plus Portfolio. For hot-dry climate, Optimize Existing Facilities had lower shortages than Baseline, but there was no statistical evidence of a difference between Optimize Existing Facilities and Baseline Plus.

A number of factors influenced shortage volumes between scenarios and portfolios, as well as differences between realizations within the same model run. Comparing scenarios and portfolios, the shortage volumes observed in the Basin Study results are dependent on the available water supply in each modeled scenario and portfolio. For example, all portfolios assumed a consistent availability of imported water from the QSA and imported purchases while each portfolio differed in the volumes of other supply types. Both within a given model run and between model runs, larger shortage volumes (such as those observed in the Baseline Portfolio) were typically associated with water supply shortages, while smaller shortage volumes (such as those observed in the Increase Supplies Portfolio) appeared to be caused by conveyance system limitations. Comparing realizations within a given model run, another factor that may be a driver of shortage volume is the relative dryness or wetness of a year compared to normal. Generally, drier year types, as characterized by reservoir inflows, corresponded with larger shortage volumes. However, the dryness of preceding years also appeared to influence shortage volume in some cases. Examining the Baseline Portfolio, the realization with the largest shortage volume was preceded by six dry years. Other realizations did not follow this pattern, however, indicating that while dryness of a particular year and the dryness of preceding years generally corresponds to larger shortage volumes, other factors such as conveyance capacity and supply availability also influence shortage volume.

6.1.3.1 Shortage Threshold Analysis

A shortage threshold of 20,000 AF represents the shortage volume that could be mitigated within the San Diego system through short-term drought restrictions or operational changes. To better understand the frequency of shortage above the shortage threshold, the total number of realizations (years) within each model run with shortages above the threshold was calculated and plotted as a percentage of the 85 realizations in each model run.

Average Annual Shortage Volumes for the Baseline Portfolio compared across all demand scenarios and all climate scenarios are shown in Figure 12. The Baseline Portfolio yielded no realizations above the shortage threshold of 20,000 AF for current climate 2015 and 2025 demands but showed two realizations above the shortage threshold for 2025 demands under warm-dry climate and multiple realizations above the shortage threshold for 2025 demands under hot-dry climate. For 2050 demands there was one realization above the shortage threshold for the current climate, two realizations above the shortage threshold for central tendency climate, and multiple realizations above the shortage threshold for hot-dry and warm-dry climates.

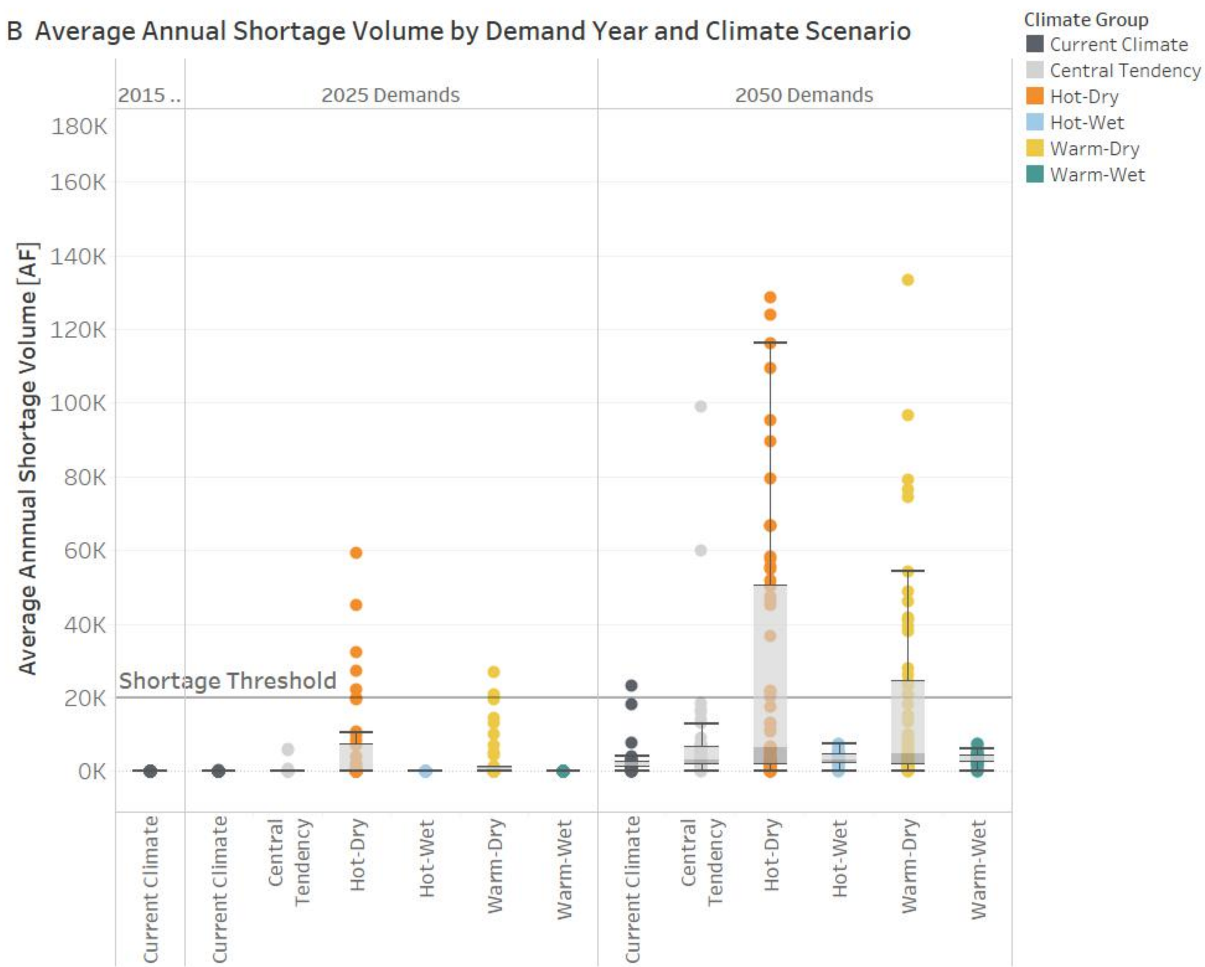

Figure 12. Shortage Volume compared to the 20,000 AF shortage threshold for the Baseline Portfolio.

Average Annual Shortage Volumes for the Baseline Plus Portfolio compared across all demand scenarios and all climate scenarios are shown in Figure 13. In the Baseline Plus Portfolio there were no realizations above the shortage threshold for current climate in 2015, 2025, or 2050 demands;

however, there was one realization above the shortage threshold for central tendency climate in 2050 demands, and multiple realizations above the shortage threshold for hot-dry climate and warm-dry climates in 2050 demands. The Watershed Health and Ecosystem Restoration Portfolio (Figure 14) was similar to the Baseline Plus Portfolio.

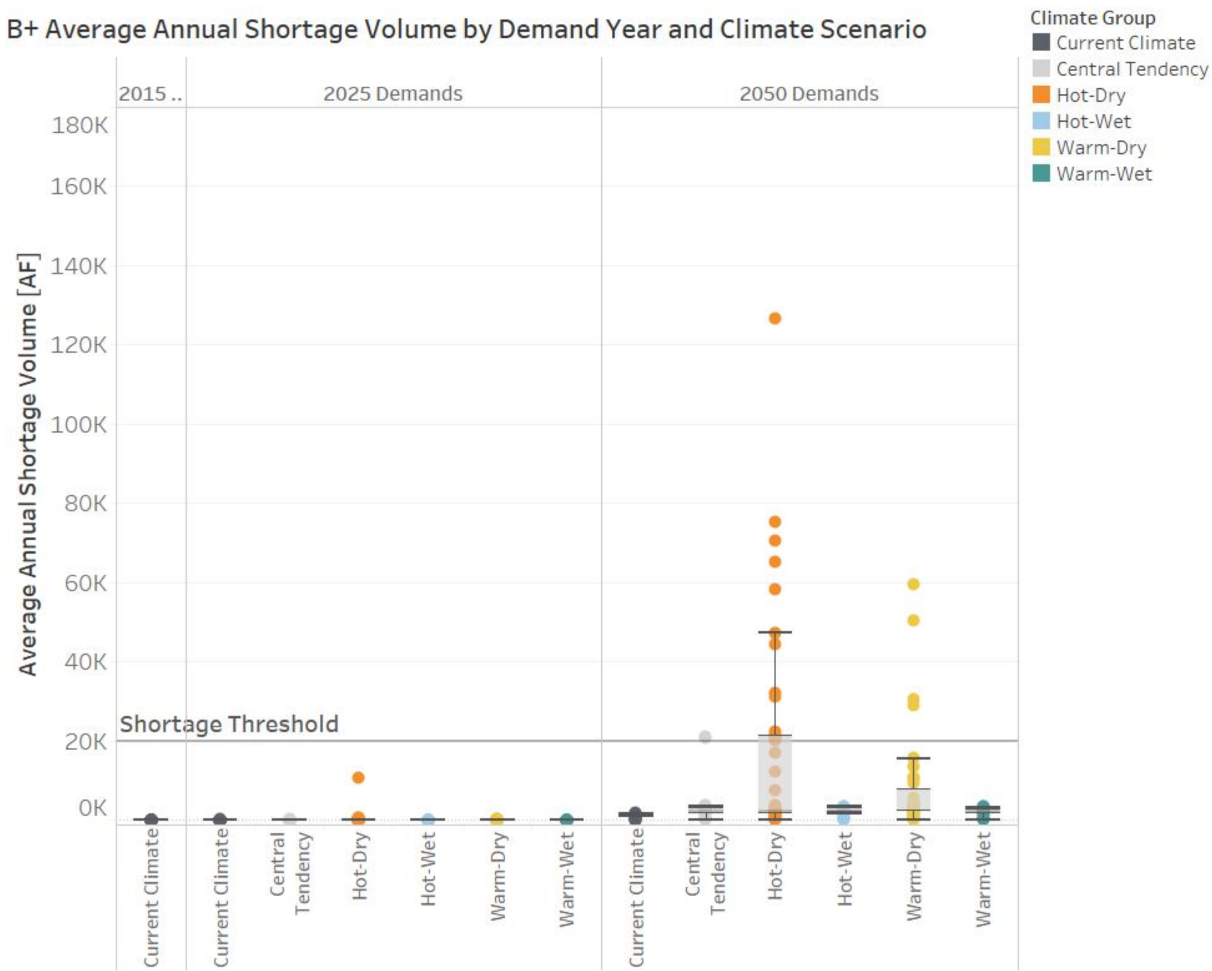

Figure 13. Shortage Volume compared to the 20,000 AF shortage threshold for the Baseline Plus Portfolio.

Average Annual Shortage Volumes for the Watershed Health and Ecosystem Restoration Portfolio compared across all demand scenarios and all climate scenarios are shown in Figure 14. Like the Baseline Plus Portfolio (Figure 13), there were no realizations above the shortage threshold for current climate in 2015, 2025, or 2050 demands in the Watershed Health and Ecosystem Restoration Portfolio; however, there was one realization above the shortage threshold for central tendency climate in 2050 demands, and multiple realizations above the shortage threshold for hot-dry climate and warm-dry climates in 2050 demands.

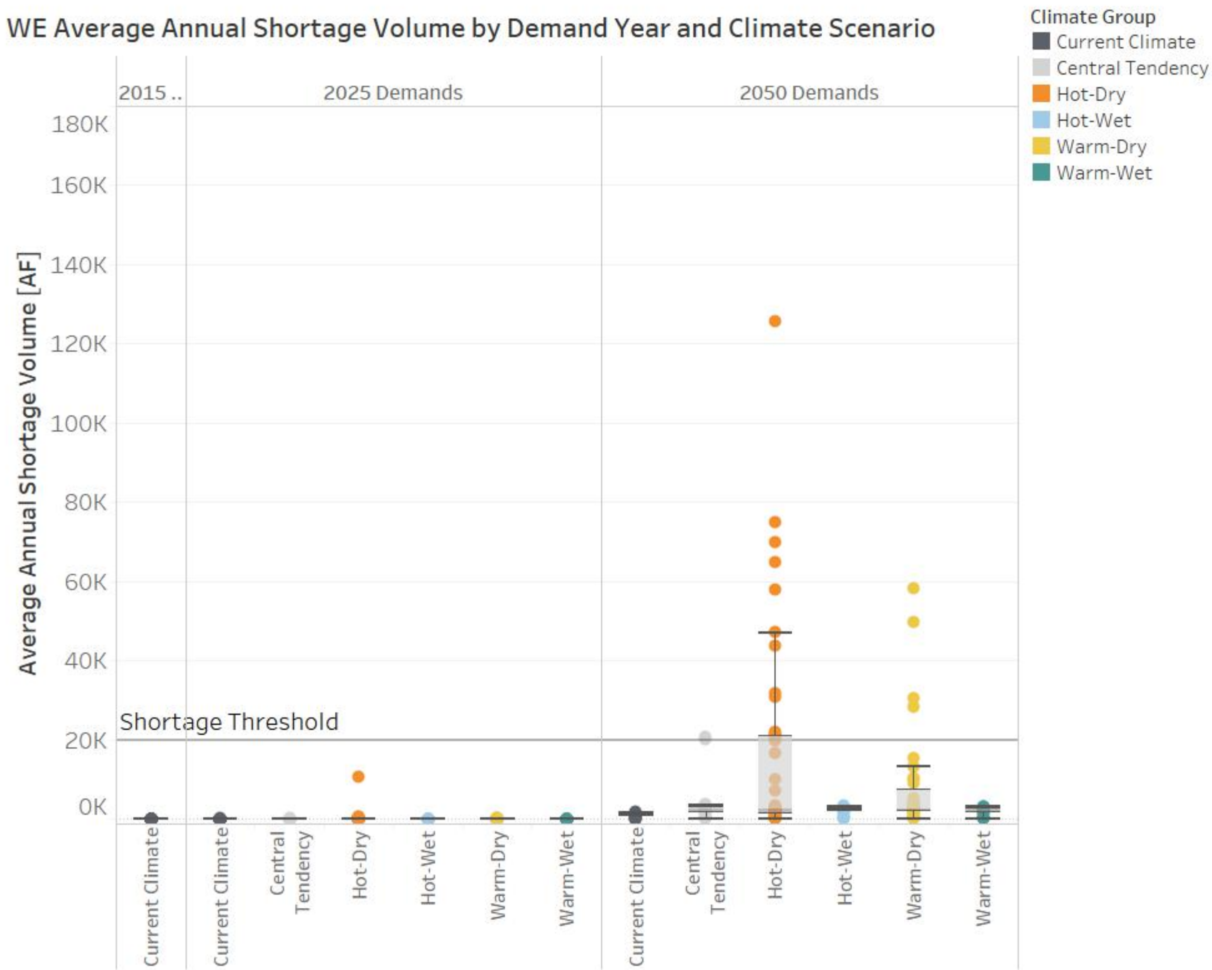

Figure 14. Shortage Volume compared to the 20,000 AF shortage threshold for the Watershed Health and Ecosystem Restoration Portfolio.

No realizations were close to or above the shortage threshold for the Enhanced Conservation Portfolio (Figure 15).

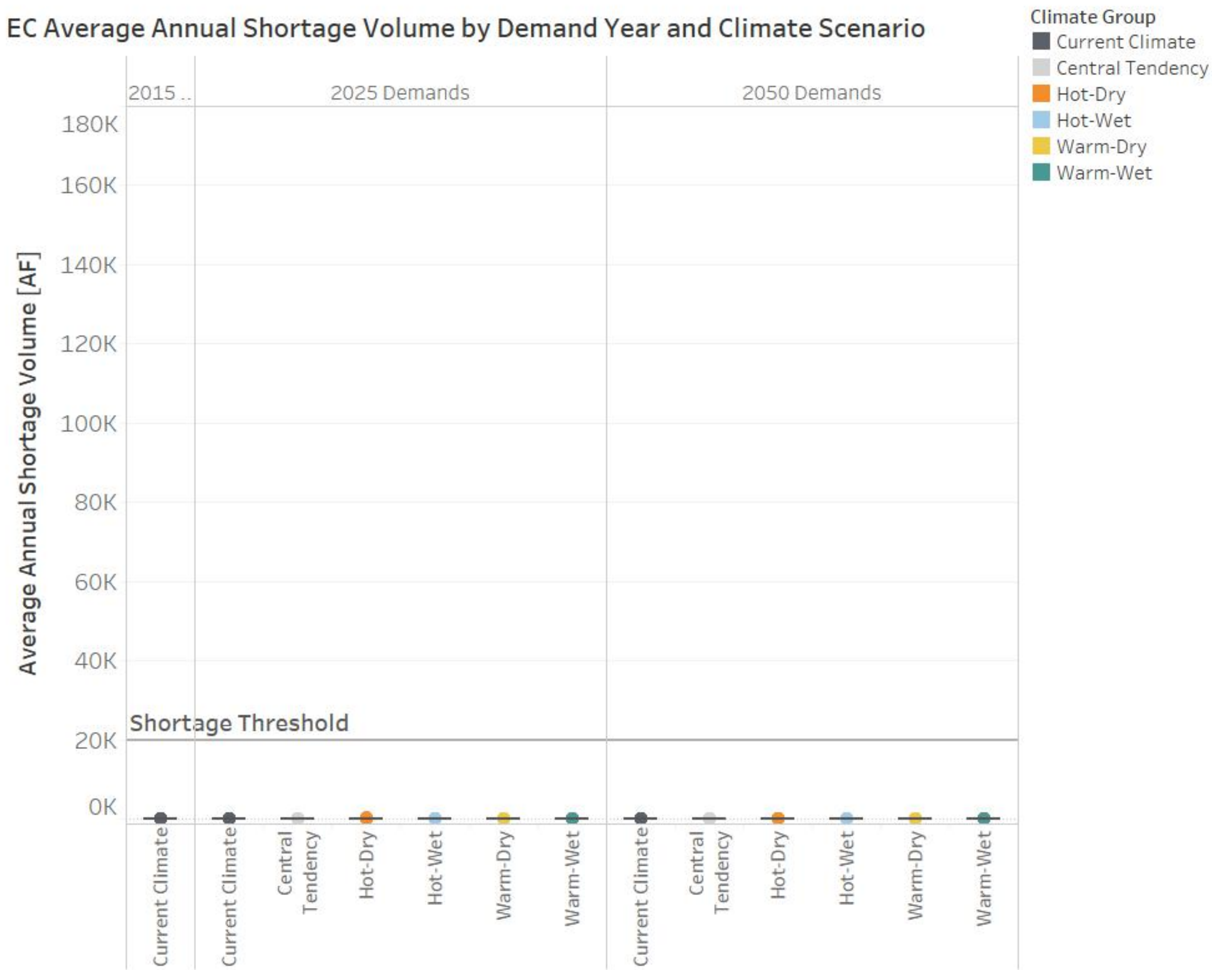

Figure 15. Shortage Volume compared to the 20,000 AF shortage threshold for the Enhanced Conservation Portfolio.

Although there was one realization close to the shortage threshold in 2025 demands under hot-dry climate for the Increase Supplies Portfolio, no realizations were above the shortage threshold for this Portfolio (Figure 16).

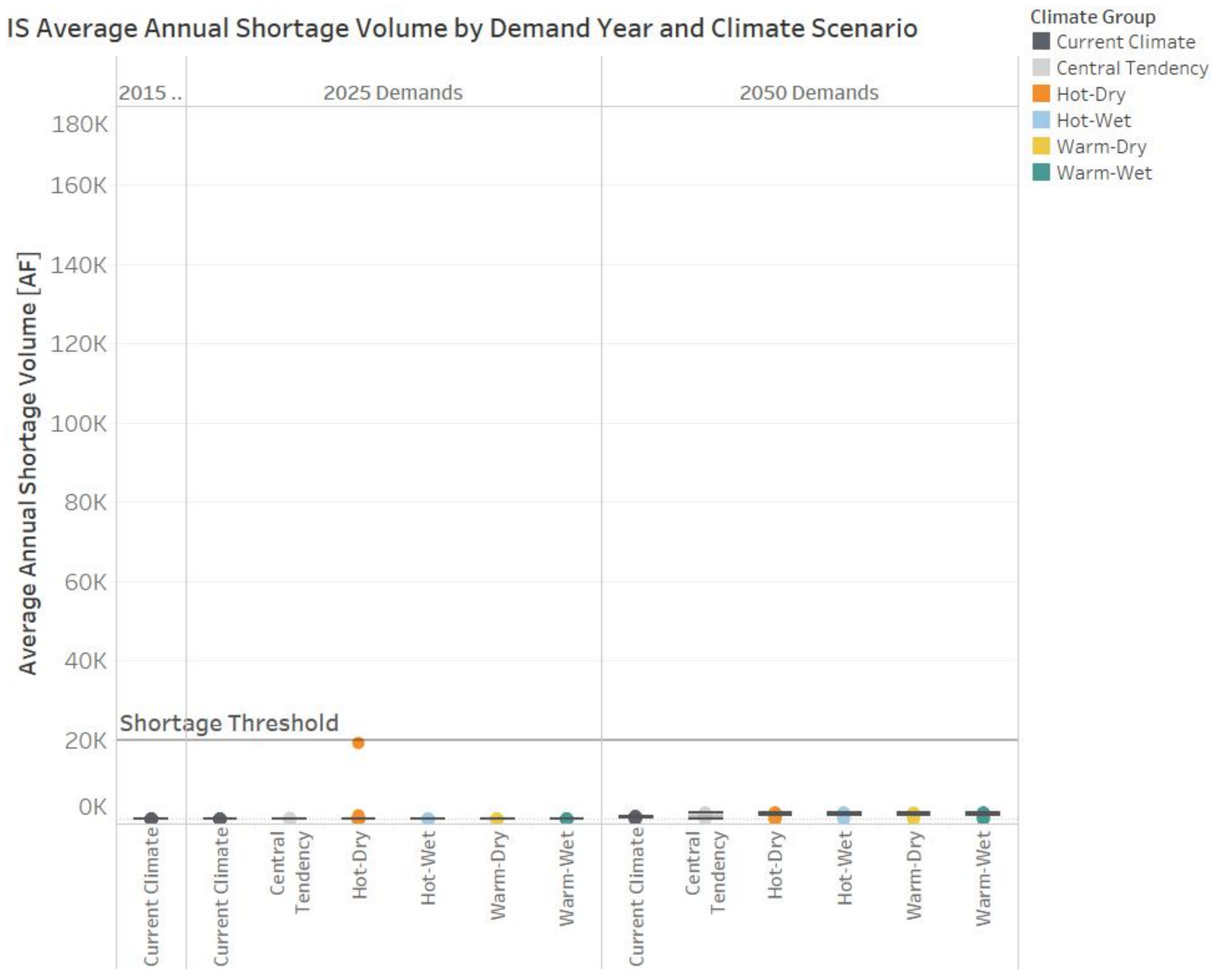

Figure 16. Shortage Volume compared to the 20,000 AF shortage threshold for the Increase Supplies Portfolio.

Average Annual Shortage Volumes for the Optimize Existing Facilities Portfolio compared across all demand scenarios and all climate scenarios are shown in Figure 17. In the Optimize Existing Facilities Portfolio, there was one realization above the shortage threshold for central tendency climate and many realizations above the shortage threshold in the hot-dry climate and warm-dry climate in 2050 demands. The percentage of realizations above the Shortage Threshold was slightly lower in this Portfolio compared to the Baseline Portfolio (Figure 12), but there were no significant differences in realizations above the Shortage Threshold between this Portfolio and the Baseline Plus Portfolio (Figure 13) for current climate, central tendency climate, and hot-dry climate (although the average Shortage Volume was higher in the Optimize Existing Facilities Portfolio, it did not have more realizations above the 20,000 AF shortage threshold).

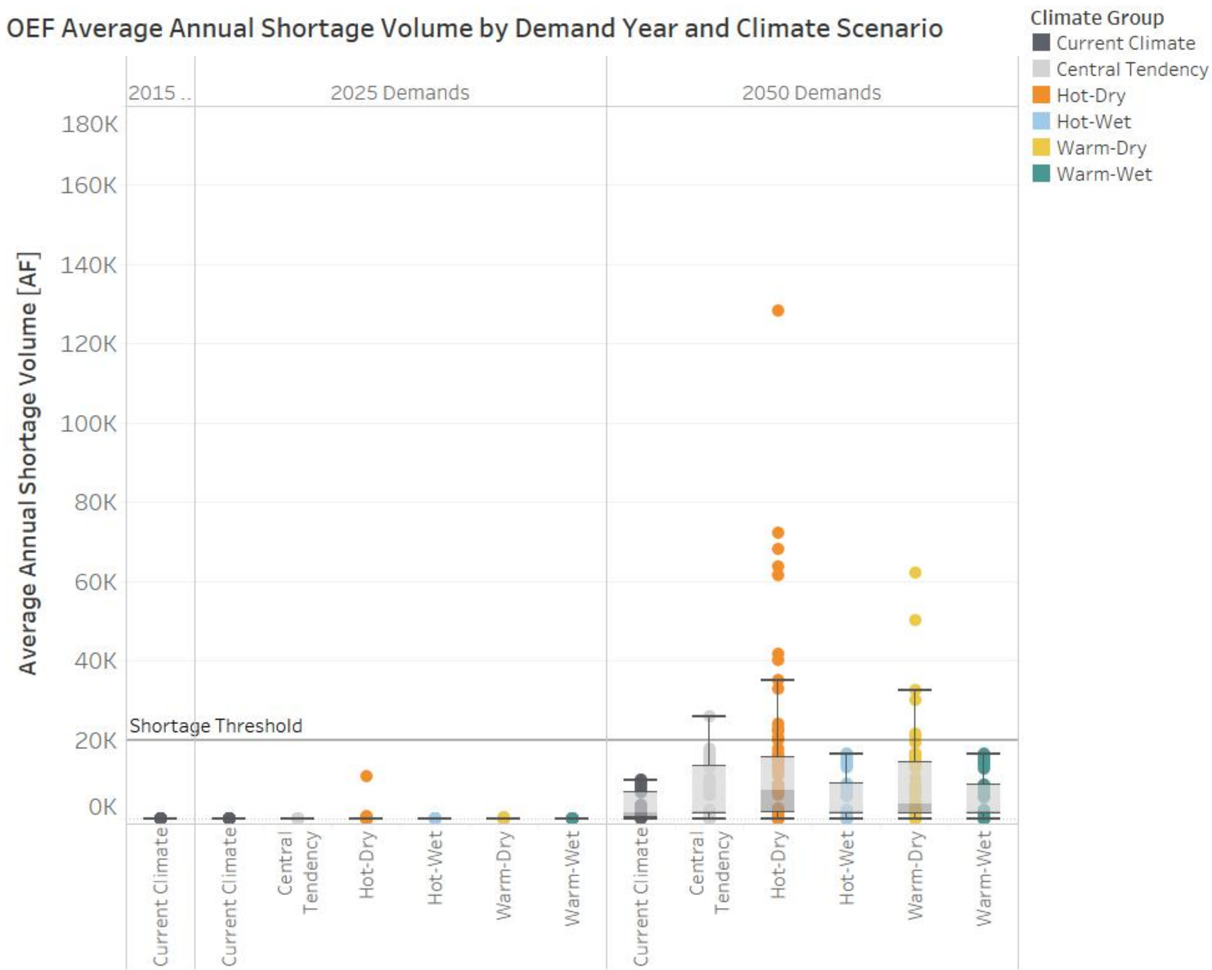

Figure 17. Shortage Volume compared to the 20,000 AF shortage threshold for the Optimize Existing Facilities Portfolio.

6.1.4 Conveyance System Operations

The conveyance system includes pipelines, pump stations, and water treatment plants that move water throughout the San Diego region and treat raw water for use to meet demands. Without adequate conveyance capacity, the system may not be able to move water supplies from their sources to storage, treatment plants, or water users. Even in cases where water supply is not limiting, conveyance capacity may be a constraint on the system and could result in shortage. Larger shortage volumes are typically associated with water supply shortages, while smaller shortage volumes appear to be caused by conveyance system limitations, as is the case for the low shortage volume observed with the Increase Supplies Portfolio for 2050 demands under hot-dry climate. Conveyance-based shortages occur when pipelines, pump stations, or water treatment plants are operating at or near full capacity, causing a bottleneck in the supply system. For the system to work effectively, it is important to have some excess capacity in the conveyance system. If there is insufficient capacity, conveyance issues could be exacerbated in the case of unexpected pipeline or pump station failures or during maintenance outages.

Overall, pipeline flow was a possible constraint on the system and potentially contributed to shortages, 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, 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 lower in the Enhanced Conservation, Increase Supplies, and Optimize Existing Facilities Portfolios for 2050 demands.

6.1.4.1 Pipeline Flow Volume

The Pipeline Flow Volume metric described the average monthly pipeline total flow volume for five pipeline locations: Pipeline 4 just south of Twin Oaks Valley (TOV) WTP, which conveys treated water for Carlsbad, Vista, and Vallecitos member agencies; the 30-Inch, an interconnect which conveys untreated water near Murray Reservoir; the Crossover Pipeline, which conveys untreated water between the Second and First Aqueducts; the MWD Treated Pipeline, which conveys water from the MWD Delivery Point through Pipelines 1, 2, and 4; and the Untreated Pipeline that conveys water purchased from MWD that requires further treatment at San Diego-area Water Treatment Plants before it can be delivered to customers. The Pipeline Flow Volume metric indicated where pipeline flow volumes are higher on average. Higher pipeline flow volumes may lead to pipeline capacity constraints. Larger volumes indicate pipeline deliveries at a location are typically higher.

Current climate Monthly Average Pipeline Flow Volumes for the Baseline Portfolio for all pipelines compared across all demand scenarios are shown in Figure 18. The relative magnitude of water volume conveyed by each of the five pipelines was consistent across portfolios, with flows in the Untreated Pipeline (just south of the MWD delivery point) consistently the largest, followed by MWD Treated, Pipeline 4 just south of TOV WTP, Crossover, and the 30-Inch. Flows in the Untreated Pipeline were almost equal to the other four pipeline flows combined, with an average monthly flow of about 31,000 AF (approximately 72% of the pipeline capacity) for Baseline. MWD Treated and Pipeline 4 just south of TOV deliver nearly equal amounts of water, with an approximate monthly average of 9,000 AF (26% of capacity) and 10,000 AF (37% of capacity), respectively for Baseline. The Crossover Pipeline conveys a lesser monthly average of approximately 5,000 AF (42% of capacity) for Baseline, and the 30-Inch Pipeline conveys even less with a monthly average of approximately 1,000 AF (24% of capacity) for Baseline. Averaging across all months, the volume conveyed by each pipeline was similar across climate scenarios for four of the five pipelines. For the 30-Inch Pipeline, there was generally more conveyance in the hot-dry and warm-dry scenarios than the hot-wet and warm-wet scenarios. The Baseline Portfolio had the largest flow volumes for the pipelines, followed closely by the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios, which had similar flow volumes. The flow volumes for the Increase Supplies Portfolio were slightly less than for Baseline Plus. Enhanced Conservation had the lowest flow volumes for all evaluated pipelines.

Most of the pipeline locations analyzed in the Basin Study deliver the largest flow volumes in the summer months, with a peak in flow occurring between June and September. This is true for MWD Treated, Pipeline 4 just south of TOV, and Untreated, which are the three pipelines with the highest flow volume. Although the Crossover Pipeline does not have a significant peak like the other pipelines, Pipeline Flow Volume is higher in June and September than in December and March. For the 30-Inch Pipeline, flow peaks twice: once in May and again in September. Figure 18 shows the Monthly Average Pipeline Flow Volume for the Baseline Portfolio.

Although there were some differences in Pipeline Flow Volume between portfolios for 2025 and 2050 demands, the monthly trend was similar for all portfolios. Pipeline Utilization is analyzed for summer months based on this trend (higher flow volume in summer months).

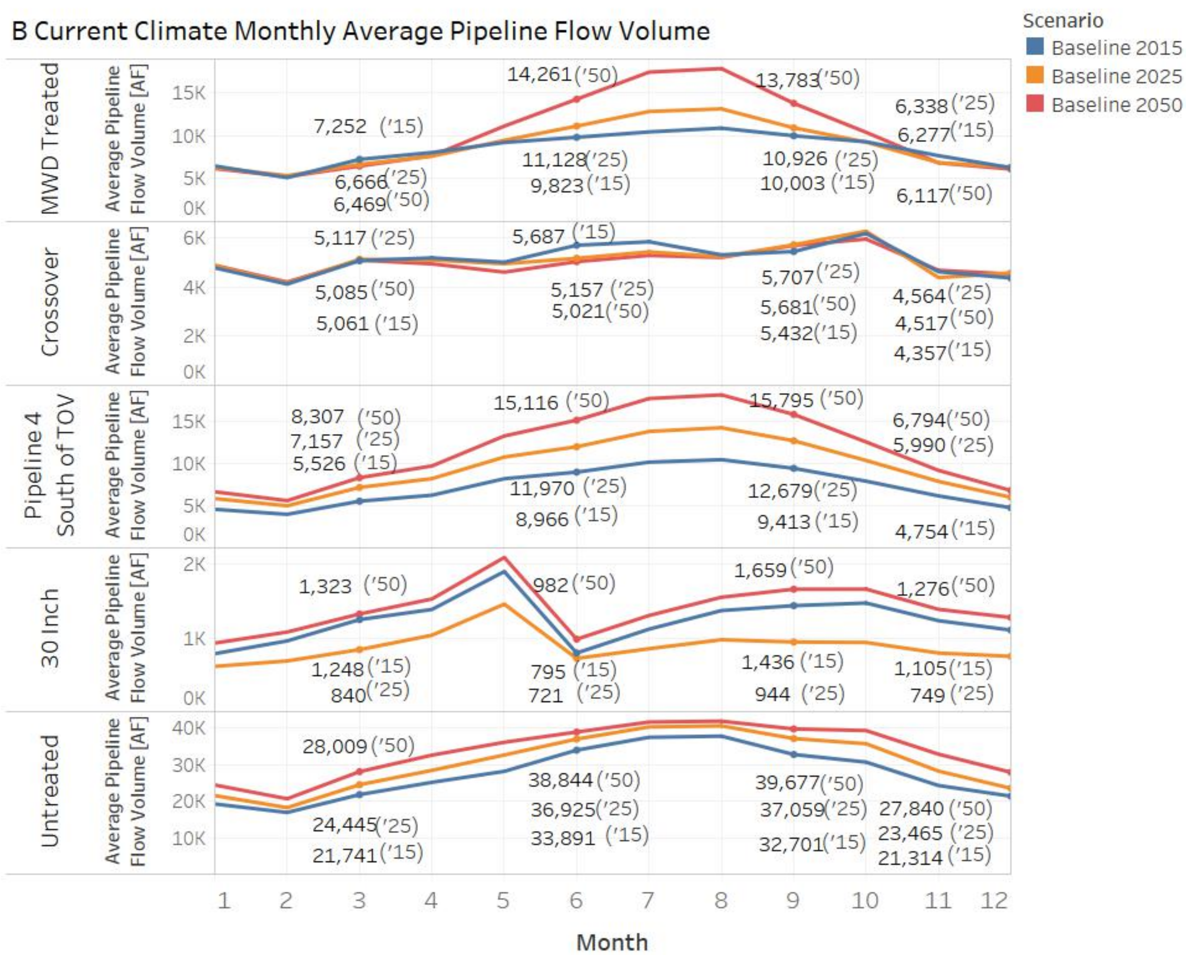

Figure 18. Monthly Average Pipeline Flow Volume in the Baseline Portfolio under current climate.

6.1.4.2 High Pipeline Utilization Summer Count

The High Pipeline Utilization Summer Count metric described the number of days that pipeline flow exceeds 95% of capacity during the summer months (June through September) for five pipeline locations: Pipeline 4 just south of Twin Oaks Valley WTP, which serves treated water to Carlsbad, Vista, and Vallecitos member agencies; the 30-Inch, an interconnect which conveys untreated water near Murray Reservoir; the Crossover Pipeline, which conveys untreated water between the Second and First Aqueducts; the MWD Treated Pipeline, which conveys water from the MWD Delivery Point through Pipelines 1, 2, and 4; and the MWD Untreated Pipeline that conveys water purchased from MWD which requires further treatment at San Diego-area water treatment plants before it can be delivered to customers. It was important to quantify high pipeline utilization because it may indicate that pipeline capacity is limiting water deliveries, which could lead to shortages in the region. Water usage is typically highest in the summer, which means that pipeline capacity is most likely to be a limiting factor in water deliveries during the summer. Larger numbers of days indicate that high summer pipeline utilization is more frequent. The Untreated Pipeline is the only pipeline with an operationally significant number of days when pipeline utilization exceeds 95%. The other four pipelines average less than two days of exceedance for all portfolios and climate scenarios, with many portfolios and scenarios having zero days of exceedance.

Average High Pipeline Utilization Summer Count for the Untreated Pipeline compared across all demand scenarios and selected climate scenarios is shown in Figure 19. For the Baseline Portfolio, under current climate, the number of days with flow greater than 95% of capacity was higher for 2025 demands (average of 71 days) than for 2015 demands (average of 40 days) for the Baseline Portfolio. There was also a difference in number of days of exceedance between 2025 demands (average of 71 days) and 2050 demands (average of 86 days) for the Baseline Portfolio, although this result was not supported by the ANOVA statistical analysis.

Similarly, for Baseline Plus, the High Pipeline Utilization Summer Count metric appeared to be higher for 2025 demands than for 2015 demands, but ANOVA statistical evidence of a difference was limited. However, there was statistical evidence that the number of days of exceedance is higher for 2050 demands than for 2025 demands. For the Enhanced Conservation, Increase Supplies, and Optimize Existing Facilities Portfolios, there was no statistical evidence of a difference in Pipeline Utilization between 2015 and 2025 demands, but the number of days of exceedance was lower for 2050 demands than for 2025 demands. The Watershed Health and Ecosystem Restoration Portfolio was very similar to Baseline Plus when comparing number of pipeline capacity exceedances across demand scenarios for current climate scenarios.

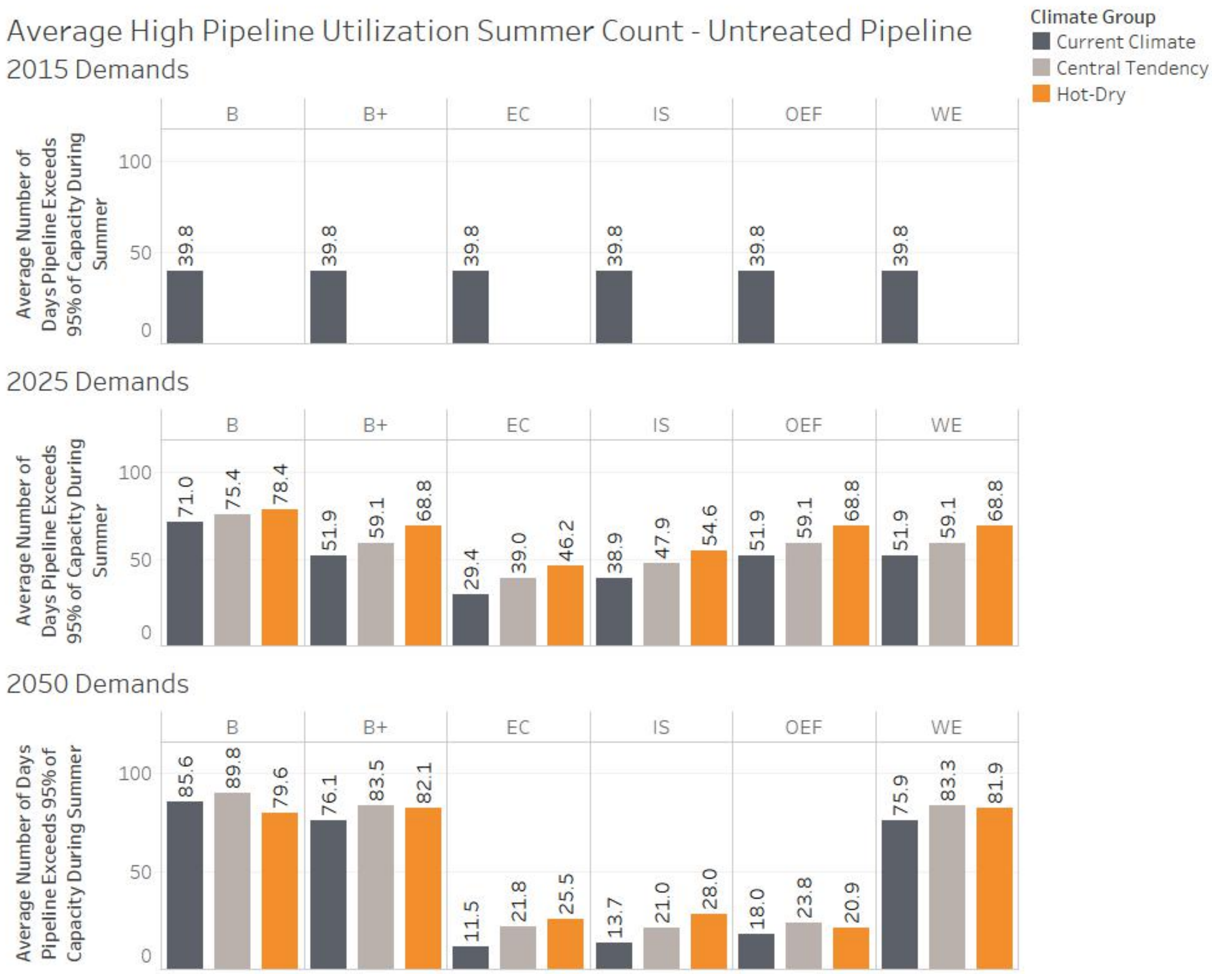

Figure 19. High Pipeline Utilization Summer Count at the Untreated Pipeline location for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

Comparing Untreated Pipeline utilization between the Baseline and Baseline Plus Portfolios under current climate, there was no statistical evidence based on the ANOVA analysis of a difference for 2015 or 2050 demands, but Baseline showed a higher number of days of exceedance for 2025 demands. Comparing Baseline Plus to the other portfolios, for 2025, Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration were very similar, while Enhanced Conservation and Increase Supplies had fewer days of capacity exceedance than Baseline Plus. For 2050, Watershed Health and Ecosystem Restoration was again similar to Baseline Plus, but Optimize Existing Facilities had a lower number of exceedances, as did Enhanced Conservation and Increase Supplies. The difference between the Baseline Plus and Enhanced Conservation Portfolio can be attributed to the Enhanced Conservation Concept, which increased the conservation volume and consequently decreased the volume of water that must be delivered through pipelines. The difference between the Baseline Plus Portfolio and the Increase Supplies Portfolio may be attributable to the Increase Supplies Portfolio's wider range of water supply sources, which may reduce the system's dependence on MWD untreated water supplies. The difference in Untreated Pipeline utilization between the Baseline Plus and Optimize Existing Facilities Portfolios can be attributed to the Pipeline 3/Pipeline 4 Conversion project, which increases the capacity of the system to deliver MWD Untreated supplies while reducing the capacity for MWD Treated supplies (this does not appear to cause an increase in the number of days with exceedances for the MWD Treated pipeline).

Comparing climate scenarios (Figure 19), there was statistical evidence based on the ANOVA analysis of differences in Pipeline Utilization at the Untreated location only in the Enhanced Conservation Portfolio for 2050 demands. In the Enhanced Conservation Portfolio for 2050 demands, utilization was lower for the current climate than for central tendency climate. Climate scenarios did not appear to have a significant impact for all other demands and portfolios.

These results indicated that the possibility of shortages caused by pipeline capacity limitations occurs during summer months, and that the impact of increased demand from 2015 to 2025 to 2050 has a larger impact on pipeline utilization than the impact of climate scenarios. The number of days where MWD Untreated pipeline utilization exceeded 95% capacity was lower in the Enhanced Conservation, Increase Supplies, and Optimize Existing Facilities Portfolios than in the Baseline, Baseline Plus, and Watershed Health and Ecosystem Restoration Portfolios. This indicates that water shortages caused by conveyance limitations are less likely to occur in the Enhanced Conservation, Increase Supplies, and Optimize Existing Facilities Portfolios, based on results for the MWD Untreated pipeline.

6.1.4.3 High Pump Station Utilization

The High Pump Station Utilization metric measured the number of times per year that pump station flow exceeds 95% of capacity for 70% of pumping days for two pump station locations: San Vicente and Valley Center (P2A). High pump station utilization indicated that pump stations are frequently operated near their pumping capacity which could lead to difficulty moving water through the regional system. Larger numbers of days indicated that pump station maximum utilization is more frequent. Under current climate, there were no occurrences of greater than 95% usage for either of the two pump stations analyzed for 2015, 2025, or 2050 demands. This was expected, since the San Vicente Pump Station is sized for high emergency service volumes, and the P2A pump station primarily serves agricultural demands that have been declining. Climate scenarios did not have a significant impact on pump station utilization as there were no occurrences of greater than 95% pump station usage in any climate scenario.

6.1.4.4 Treatment Plant Utilization

Raw water supplies such as surface water and untreated imported water must be treated before use. The Treatment Plant Utilization metric described the percentage of treatment plant capacity that is used on an annual basis. This was a measure of whether the treatment plant capacity is large enough to support the demand for water supplies that require treatment or can be used to identify treatment facilities that may be underutilized. Both high and low utilization can be problematic, as high utilization could indicate insufficient treatment capacity and low utilization could indicate stranded capacity. Significant expansion of treatment plant capacity in the region occurred in the early to mid-2000s, prior to system-wide decreases in demand from conservation legislation and changes in consumer water use and landscaping. Additional local treated supplies, such as desalination and recycled water supplies that offset treated water use, also contribute to excess capacity at treatment plants, even during peak season. Shifts from imported to local untreated supplies may change utilization at individual plants, but would not be expected to affect overall treatment plant utilization.

Utilization was calculated individually for 11 treatment plants in the San Diego system: Alvarado, Badger, Escondido, Levy, Miramar, Olivenhain, Otay, Poway, Perdue, Twin Oaks Valley, and Weese. The system-wide average treatment plant utilization was the average of the individual treatment plant utilization metrics for the 11 treatment plants. Since treatment plant utilization was calculated in the model, it only accounted for treating raw water from supplies implemented as model logic. This included supplies such as Pure Water San Diego Phase 1, which is discharged to Miramar Reservoir, then treated at the Miramar WTP. This did not include supplies modeled as demand reductions, such as potable reuse projects other than Pure Water, recycled water, groundwater, and others as described in Section 4.4. These supplies would require treatment and should be considered when interpreting results. Treatment plant utilization metrics were not analyzed for the Carlsbad, Camp Pendleton, or Rosarito desalination plants which supply treated water to meet member agency demands.

Comparing demand scenarios, the largest increase in the system wide average treatment plant utilization between 2015, 2025, and 2050 occurred in the Baseline Portfolio (54% average utilization in 2015 demands, 55% in 2025 demands, and 58% in 2050 demands), while the largest decrease occurred in the Enhanced Conservation Portfolio (54% average utilization in 2015 demands, 49% in 2025 demands, and 37% in 2050 demands), followed by the Increase Supplies Portfolio (54% average utilization in 2015 demands, 52% in 2025 demands, and 50% in 2050 demands). The system-wide average for treatment plant utilization was similar between 2015, 2025, and 2050 demand scenarios for the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios (54% in 2015 demands, 54% in 2025 demands, and 56% in 2050 demands). The increase in utilization in the Baseline Portfolio can be attributed to the increase in water demand, which is primarily met by increases in imported raw water. The decrease in utilization in the Enhanced Conservation Portfolio can be attributed to the decrease in water demand resulting from the Portfolio's large conservation volume. The decrease in utilization in the Increase Supplies Portfolio can be attributed to the additional recycled water and groundwater projects implemented in that Portfolio, which are modeled as demand reductions and not included in treatment plant utilization values, along with the addition of Camp Pendleton and Rosarito Desalination Plants, which are also not included in treatment plant utilization values. The lack of trend across demand scenarios in the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios can be attributed to the addition of a number of projects in Baseline Plus that were modeled as demand reductions, thereby reducing demand on water supplies that are included in the modeled treatment plant utilization.

6.1.5 Reservoir Operations

San Diego region reservoirs store local surface water and/or imported water for use in meeting water demands. Reservoirs are generally operated to store inflows for water supply and may therefore store peak flows during flood situations. In doing so, they may prevent flooding of downstream communities, but they are not operated specifically for flood control. Reservoir Operations metrics included monthly Reservoir Storage, monthly Reservoir Releases, and End of September Storage. Storage and Release metrics were available for 11 of the 18 reservoirs in CWASim, and End of September Storage was analyzed for 5 of the 18 reservoirs. Although CWASim simulated all 18 reservoirs, the model was not configured to output metric values for all reservoirs. The other reservoirs that were not described by metric outputs are some of the smaller reservoirs. These metrics were used to understand impacts to water delivery, such as the amount of stored water available to meet demands and the amount of water actually released to meet demands.

Reservoirs in CWASim were controlled by rule curves which divided reservoir storage into different reservoir zones or "pools", such as the flood zone, seasonal pool, carryover storage, emergency pool, and dead pool. The seasonal pool was available for normal use in meeting water demands, while the carryover pool described the minimum volume of water that should be carried over from year to year and is only used as a "last resort" for meeting demands. The emergency pool was not utilized in the Basin Study model runs, and the dead pool represented storage that cannot be accessed for water supply. These reservoir pools were developed based on actual reservoir operations and may vary throughout the year to account for seasonal differences in operating policies. Reservoir releases are typically only made to meet demands. Releases made in addition to those used to meet demands occur when the reservoir is operating in its flood pool.

Overall, reservoirs operated within the ranges specified by the 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.

6.1.5.1 Reservoir Storage

The Reservoir Storage metric described the volume of water stored in the reservoir. Reservoir storage can provide information about normal water supply storage, emergency storage, and/or flood storage, depending on the value of storage relative to the reservoir's rule curve. The monthly Reservoir Storage metric reported the average end of month storage value from the daily model simulation. Values should be compared to rule curves and reservoir releases to interpret the potential impact of higher or lower storage. In accordance with the rule curves, for most reservoirs, reservoir storage peaks in March or April and declines through December, with exceptions at

Hodges and Loveland. Storage at Hodges peaks in June, while storage at Loveland is at its peak from April to December, then declines to its lowest storage level in January.

6.1.5.2 Reservoir Releases
The Reservoir Releases metric quantified the volume released from reservoirs each month for water supply. This did not include flood outflows above the water supply volume, which occur when the reservoir is in the flood pool. Further analysis of flood outflows can be found in Section 6.4. Values should be compared to rule curves and reservoir storage to interpret the potential impact of larger or smaller releases. Larger releases generally mean more water is being used for water supply. Smaller releases may mean that there is a lack of water stored in the reservoir that can be released, that operational rules such as the rule curve or release restrictions prevent higher releases of stored water, or that the demand for water does not require higher releases, either because the demand is small or because it is being met by other sources of water.

6.1.5.3 End of September Storage
The End of September Storage metric was a measure of reservoir carryover storage that can be used for supply in the next year. End of September Storage was used because September is at the end of summer, which is the season with the highest water demands. End of September Storage was calculated for five reservoirs: El Capitan, Hodges, Lower Otay, Olivenhain, and San Vicente. For reservoirs with a designated carryover (Hodges, Olivenhain, and San Vicente), the carryover pool is the minimum volume of water that should be carried over from year to year. For reservoirs with no designated carryover pool (El Capitan and Lower Otay), water may be carried over in the seasonal pool. Seasonal pool storage can also supplement carryover storage in reservoirs with a designated carryover pool. For some reservoirs, a portion of the volume in the carryover pool is made up of emergency storage that is only available in drought situations and/or dead pool volume that cannot be accessed for normal water supply.

Overall, End of September Storage was above the carryover pool (if it exists) or above the emergency storage and within the seasonal pool (if there is no designated carryover pool) for all reservoirs, except for San Vicente which was above the emergency storage pool but below the carryover pool. Climate scenarios had no or limited impacts on End of September Storage. Although it might be expected that there would be more visible effects of climate change (e.g., End of September Storage would be lower for hot-dry and warm-dry climates and higher for warm-wet and hot-wet climate than central tendency climate), this was not necessarily the case. The lack of climate change impact was likely due to the availability of diverse supply sources that enable reservoir operations to follow the rule curves while the overall system meets demands. Some scenarios may have somewhat higher or lower storage due to increases or decreases in precipitation, but all reservoirs meet the operational targets of the rule curves in all scenarios, indicating that reservoir operations are generally resilient to the changes in reservoir inflows expected with climate change.

6.2 Energy

Energy is used for pumping water supplies through pipelines, for treating raw water for potable use, for treating wastewater for non-potable or potable reuse, and for desalinating seawater. The Energy Generation metric measured energy generated at seven facilities associated with the water system: Miramar, Alvarado, and Twin Oaks Valley Water Treatment Plants; the Rancho Peñasquitos and Hodges Pump Storage Hydroelectric Facilities; and the SDCWA offices in San Diego and Escondido. The Energy Consumption metric measured the energy consumed to treat and deliver water, including consumption by supply sources, conveyance, treatment, pumped storage, and offices. Energy generation at water system facilities can offset some of the consumption by facilities in the water system.

Average Annual Energy Consumption for all portfolios compared across all demand scenarios for selected climate scenarios is shown in Figure 20. 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 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 (2,115,645 MWh average annual consumption for 2050 demands and current climate) and the lowest occurred in the Enhanced Conservation Portfolio (1,549,046 MWh average annual consumption for 2050 demands and current climate), followed by the Increase Supplies Portfolio (1,859,337 MWh average annual consumption for 2050 demands and current climate). Average annual consumption for the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios (approximately 2,025,000 MWh for current climate) was lower than consumption in the Baseline for current climate and central tendency climate, but similar to the Baseline with hot-dry climate for 2050 demands. These results indicate that these portfolios may reduce energy consumption, though this impact is dependent on climate and not realized under hot-dry climate conditions for 2050.

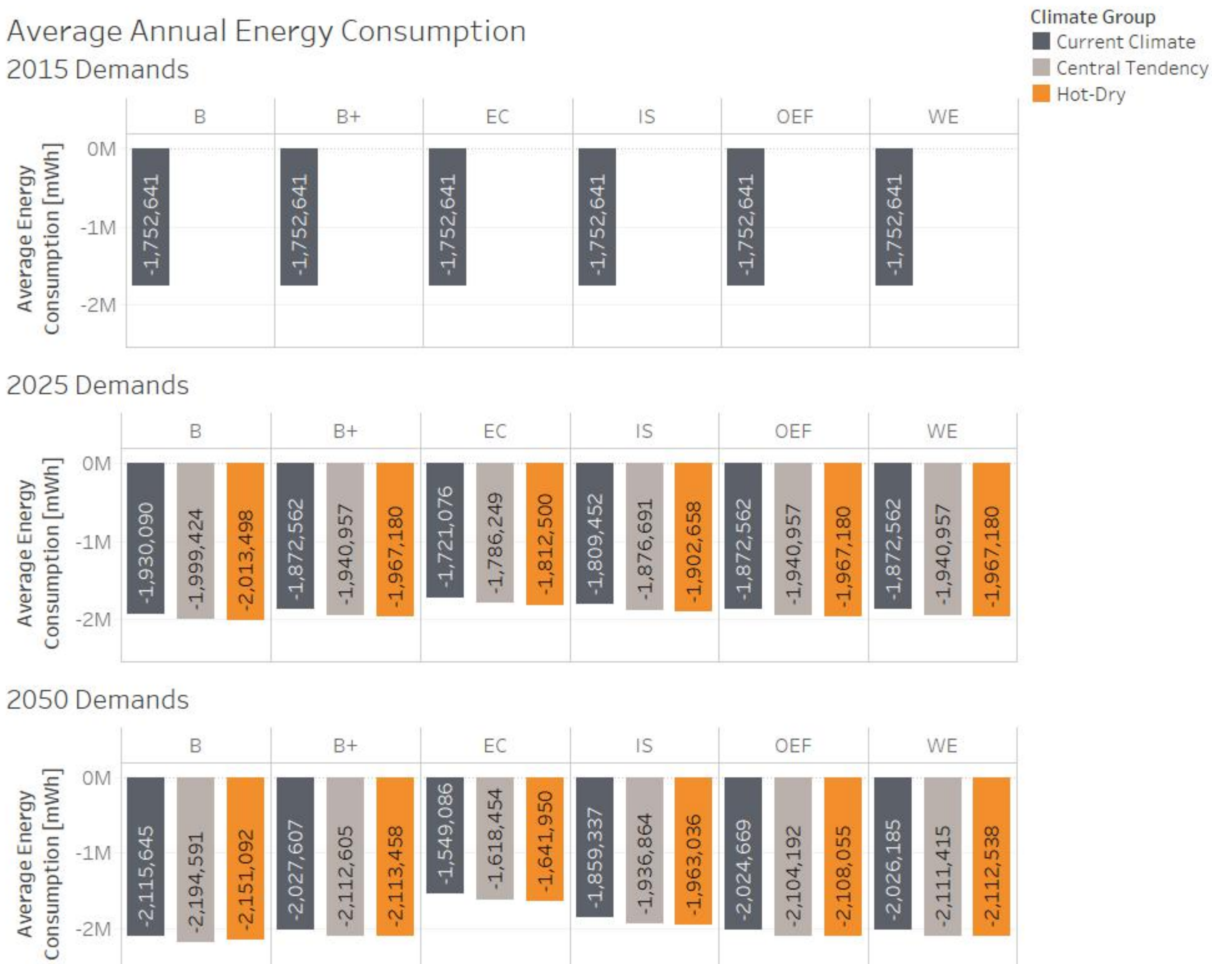

Figure 20. Annual Energy Consumption for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

A comparison of Average Annual Generation and Consumption for the Baseline, Enhanced Conservation, and Increase Supplies Portfolios compared across all demand scenarios for current climate is shown in Figure 21. Under current climate, statistical evidence based on the ANOVA analysis showed that Energy Generation is higher in the Baseline Portfolio than all other portfolios for both 2025 and 2050 demands; however, these differences were minimal compared to the order of magnitude of the Energy Generation. In the Baseline Portfolio, Energy Consumption was 10% larger for 2025 demands (1,930,090 MWh average annual consumption) than for 2015 demands (1,752,641 MWh average annual consumption) and 10% larger for 2050 demands (2,115,645 MWh average annual consumption) than for 2025 demands, which may be attributed to increased demand and energy needed to treat and convey water to a growing population. Consumption was also 7% to 9% larger for 2025 and 2050 demands than for 2015 demands in the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios. However, there was no difference in consumption between 2015 and 2025 demands in the Enhanced Conservation

Portfolio, and 2050 demands were 9% to 10% lower than 2025 demands, depending on the climate scenario. In the Increase Supplies Portfolio, Energy Consumption was 3% higher for 2025 demands than for 2015 demands, yet there was no statistical difference between 2025 and 2050 demands.

The lower energy consumption in the Enhanced Conservation Portfolio indicated that demand is a major driver of energy consumption; when demands on the system are smaller due to the Enhanced Conservation project, energy consumption decreases. Reduced water demand in the Enhanced Conservation Portfolio translated into reduced need for imported water and lower utilization of water conveyance facilities and treatment plants, and thus, reduced energy consumption. The lower energy consumption in the Increase Supplies Portfolio indicated that the additional supply projects implemented in that Portfolio, such as Pure Water Phase 2 and additional Recycled Water and Groundwater Projects, do not necessarily increase energy consumption, and in fact may be able to provide water using equal or less energy than supply sources such as imported water in the Baseline Portfolio. Offsetting some supply volume with a lower energy intensive supply option reduces the energy required to meet the demand. Also, shifting the water supply mix to locally controlled supplies enables the energy supply mix of projects and the potential to incorporate energy generation into projects to be considered as part of regional project planning and design, rather than dependent on external decision-makers.

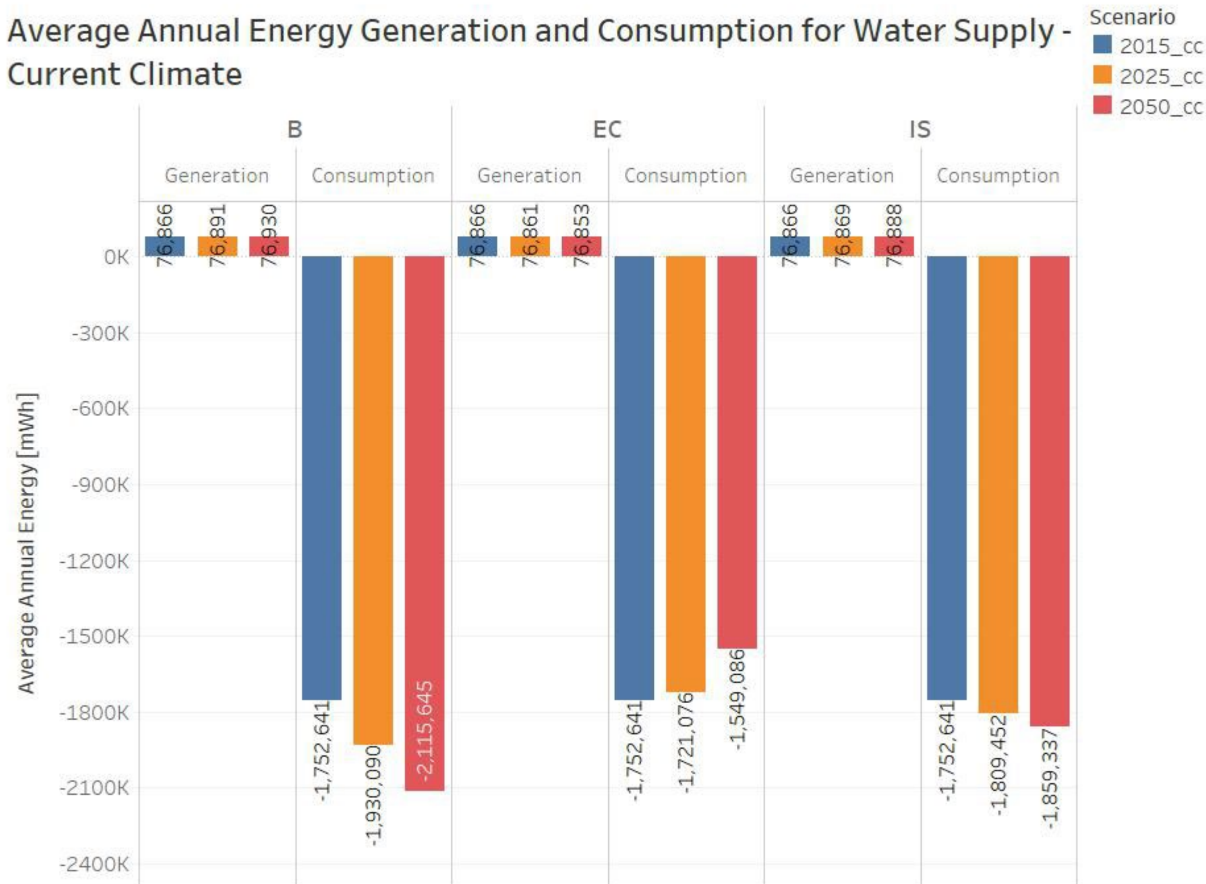

Figure 21. Energy Generation and Energy Consumption for the Baseline, Enhanced Conservation, and Increase Supplies Portfolios compared across 2015, 2025, and 2050 demand scenarios for current climate.

A comparison of Average Annual Generation and Consumption for the Baseline Portfolio compared across all demand scenarios and all climate scenarios is shown in Figure 22. Climate scenarios appeared to have a slight impact on energy consumption, with consumption increasing between current climate and all future climate scenarios based on the ANOVA analysis. In all portfolios energy consumption was lower with current climate than with central tendency climate, but there was no statistical evidence of differences between central tendency and hot-wet, hot-dry, warm-wet, or warm-dry climates for either 2020s climate or 2050s climate.

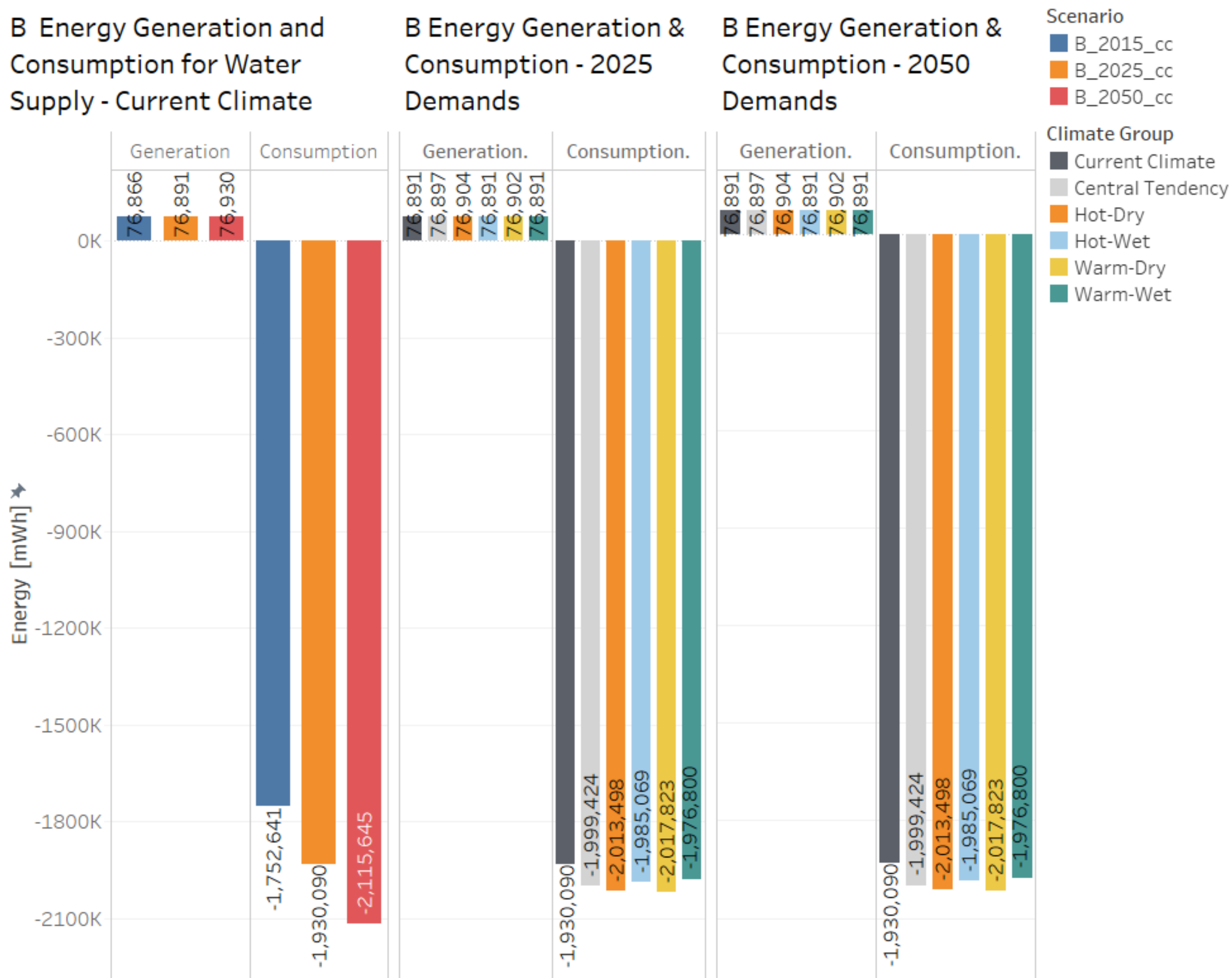

Figure 22. Average Annual Energy Generation and Consumption for the Baseline Portfolio for all demand and climate scenarios.

6.3 Recreation

Impacts to Recreation were measured by boat ramp accessibility at the end of September for four reservoirs popular with recreational users. When the End of September Elevation metric was greater than the boat ramp elevation, the boat ramp was considered accessible. Water demands are highest during the summer months, so End of September Elevation was a measure of reservoir elevation when there is typically less storage. Recreation impacts were evaluated at El Capitan, Hodges, Lower Otay, and San Vicente. Both individual realizations and the average for all realizations were evaluated.

Overall, 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 and Lower Otay Reservoirs, and recreation was impacted to a very limited extent for Hodges Reservoir. At El Capitan, as many as 88% of realizations had End of September Elevation below the boat ramp in the Baseline Portfolio (Figure 23). The impacts were improved somewhat in the Baseline Plus, and Watershed Health and Ecosystem Restoration Portfolios, improved somewhat more by the Enhanced Conservation and Increase Supplies Portfolio, and eliminated in the Optimize Existing Facilities Portfolio (Figure 23). For Lower Otay, 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, indicating that all the portfolios have benefits to recreation at Lower Otay. At Hodges there were no realizations below the boat ramp elevation in the Baseline Portfolio; however, up to 1.2% of realizations were below the boat ramp elevation in 2050 for the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios. Reservoir elevation never dropped below the boat ramp for San Vicente.

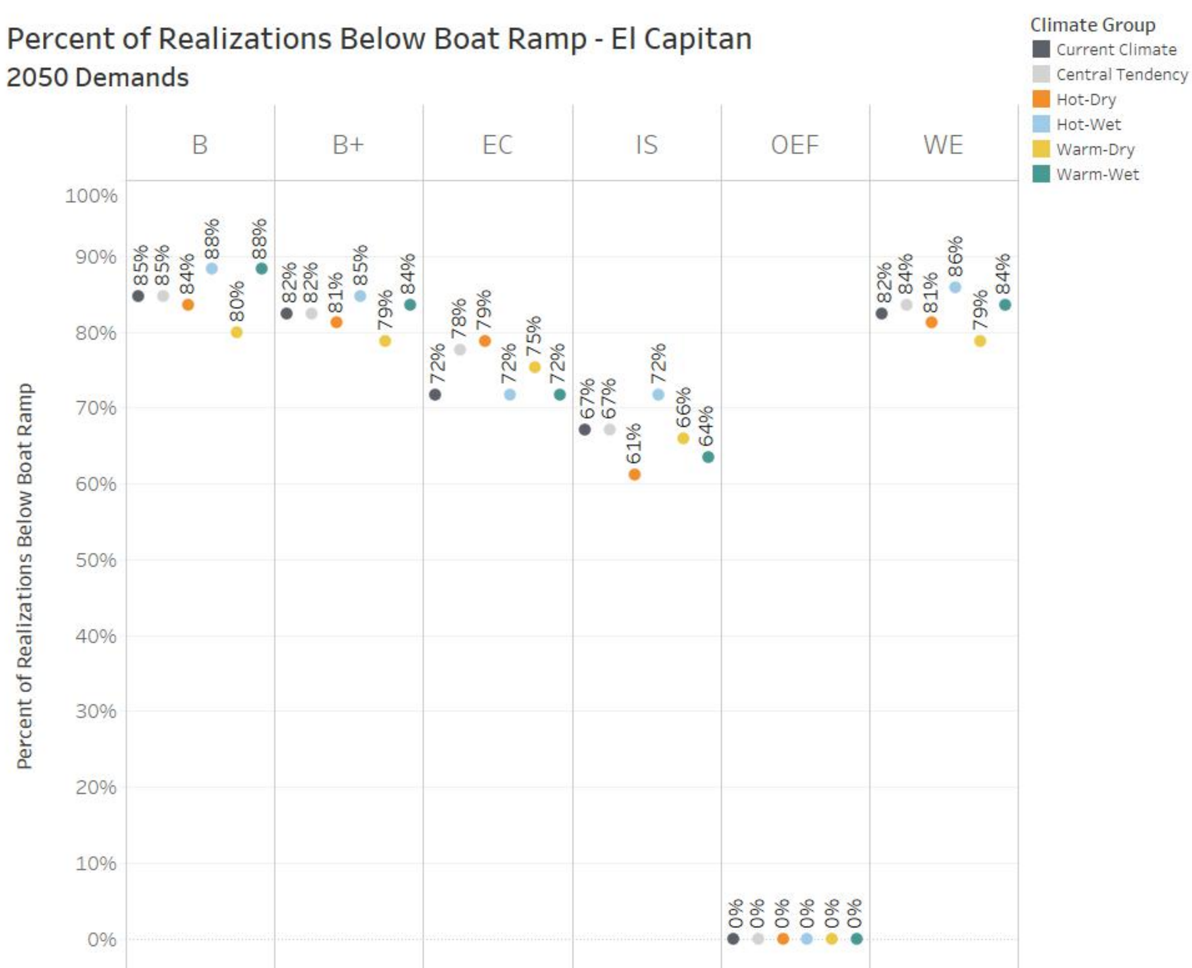

Figure 23. Percent of realizations with El Capitan Reservoir Elevation below the boat ramp elevation for 2050 demands across all climate scenarios and portfolios.

6.4 Flood Control

In the San Diego region, reservoir releases are primarily made in response to water delivery requests, and there are no required minimum outflows from reservoirs. Although reservoirs are primarily operated for water supply, during situations of high inflows or high reservoir storage resulting from storms, water may be released or spilled as flood outflows from the reservoir. In the CWASim model, flood outflows occurred when a reservoir's storage was within the flood pool. Flood control impacts were measured by the Number of Days with Flood Outflows and by the Flood Outflow Volume metric, which included the volume released to meet demands and the additional flood outflow volume. Flood outflows may indicate constraints in the conveyance system to move water for optimal storage, as well as a lack of demand during high inflow periods. Larger flood outflow volumes indicated larger volumes of water that could not be stored in the reservoir. Larger numbers of days with flood outflows indicated higher frequency of insufficient storage volume. Flood outflows could represent an opportunity to capture additional local water supply. A high flood outflow volume may indicate high water loss. Reservoirs evaluated for flood control impacts were El Capitan, Hodges, Lower Otay, San Vicente, and Olivenhain.

The overall impacts on flood control varied by reservoir due to the effects of specific projects or Concepts on those reservoirs. Flood impacts were only observed for El Capitan, Hodges, and Lower Otay Reservoirs. No flood outflows occurred in any portfolios at San Vicente or Olivenhain Reservoirs. At El Capitan, there were no differences between portfolios or scenarios for 2025 demands, but for 2050 demands there were more flood outflows in the Increase Supplies Portfolio most likely due to increased water supplies requiring storage, and there were fewer flood outflows in the Optimize Existing Facilities Portfolio most likely due to the San Diego Reservoir Intertie. For Hodges Reservoir, flood impacts were the same for all portfolios for the 2015 and 2025 demand scenarios but differed in the 2050 demand scenarios due to the implementation of the Hodges Water Quality Improvement Program which allows more water to be released from Hodges on a given day to meet demands, resulting in a corresponding decrease in reservoir storage. Decreased reservoir storage, as well as the increased release capacity from the project, have flood control benefits, since the reservoir can store more flood water and release more of it as controlled releases for water supply rather than as part of flood outflows. In flood situations, the increased releases for water supply also reduces the total number of days required to evacuate the excess storage resulting in a lower number of days with flood outflows. At Lower Otay, flood outflows were increased in the Enhanced Conservation Portfolio most likely due to lower demand for water stored in the reservoir.

Climate change did not have a strong effect on flood control impacts, although inspections of the plots indicate some differences. For San Vicente and Olivenhain there were no flood outflows in any scenarios, so the impacts could not be assessed. For El Capitan, Hodges, and Lower Otay, number of flood outflows and flood outflow volumes appeared to vary between climate scenarios (Figure 24), with lower flood outflow volumes for hot-dry and warm-dry climates and higher flood outflow volumes in warm-wet and hot-wet climates, and central tendency being somewhat similar to current climate. The observed differences at these reservoirs were not supported by the ANOVA analysis, which indicated no statistical evidence of a difference between current climate and central tendency climate or between central tendency climate and any other climate change scenarios. Variability and skew in the number of flood outflows and flood outflow volume were the likely cause of the lack of statistical significance based on ANOVA.

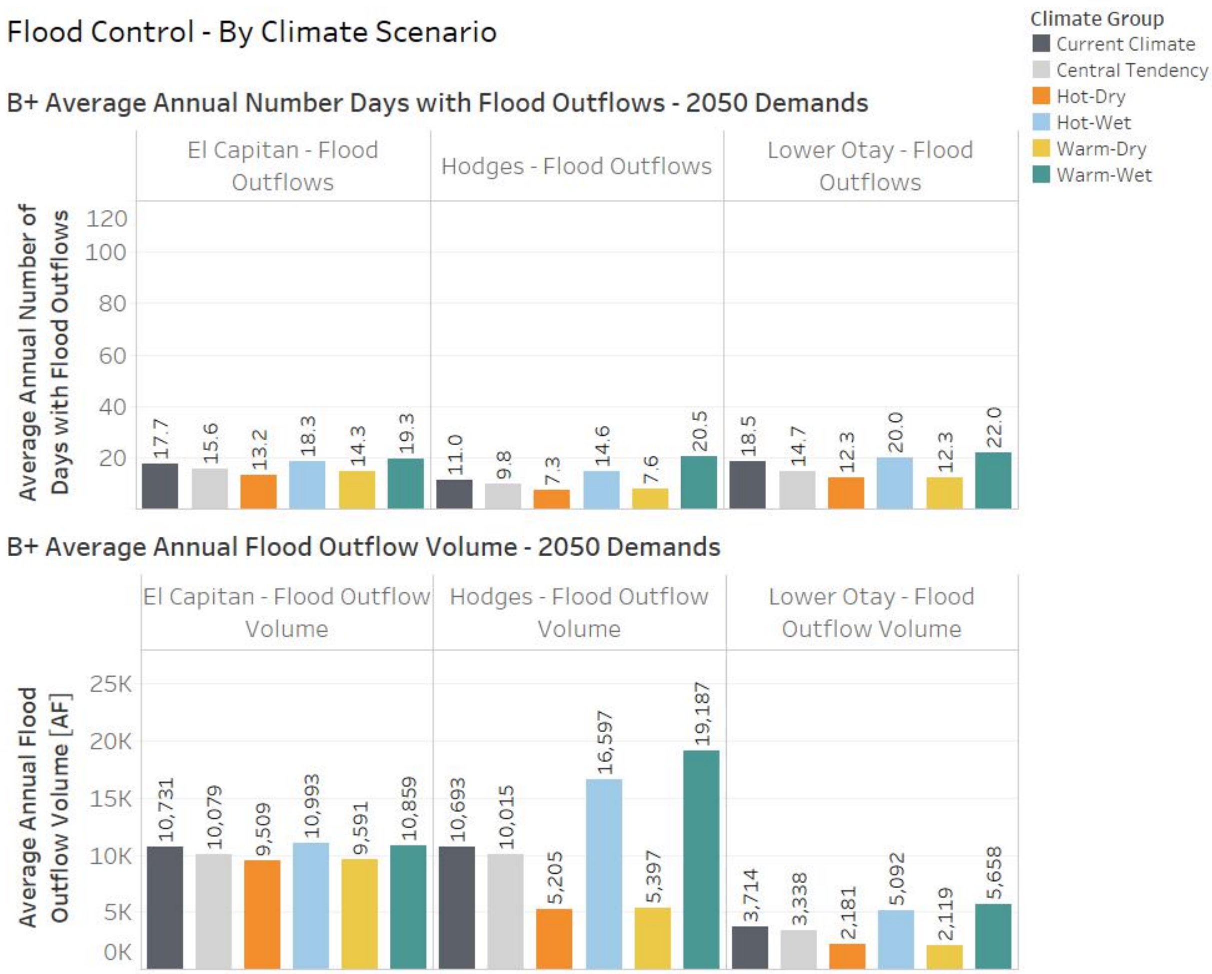

Figure 24. Flood control results for 2050 demands and all climate scenarios in the Baseline Plus Portfolio.

7. Trade-Off Analysis Methodology

A trade-off analysis is an application of Multi-Criteria Decision Analysis (MCDA), which is a general framework for evaluating complex decision-making situations with multiple and often conflicting objectives. MCDA can address the inevitable trade-offs that occur when a decision leads to a desirable change in one or more objectives while simultaneously resulting in an undesirable change in another objective. Most multi-criteria problems have conflicting criteria and as a result there is no unique solution that can optimize all the criteria simultaneously. MCDA, such as a trade-off analysis, incorporates several decision-making steps including development of evaluation criteria, weighting of criteria, criteria scoring for concepts or alternatives, and comparing concepts or alternatives based on the criteria weights and scores.

The San Diego Basin Study Trade-off Analysis compared the Concepts described in Section 3.1 based on a set of 13 Evaluation Objectives, which were weighted and then scored using one or more Performance Measures. These Concepts represent a set of planned or conceptual projects that are being considered in the region. The intent of the Trade-off Analysis is to provide information that can help make decisions about future investments. Therefore, the Trade-off Analysis does not evaluate existing assets or projects (e.g., projects within the Baseline Portfolio, as defined in the Task 2.4 Interim Report). The information gathered to score the Concepts was rooted in model results and project-specific data, supplemented by information gathered about each Concept as a whole. An overview of the steps used to complete the San Diego Basin Study Trade-off Analysis is included below and sections detailing each of the steps follow.

Step 1: Identify Evaluation Objectives

First, a set of 13 Evaluation Objectives was identified to allow comparison between Concepts. Evaluation Objectives represent the range of criteria that stakeholders and decision-makers may want to consider when comparing Concepts. Each Evaluation Objective was quantified on a 1 to 5 scale so that different Evaluation Objectives could be added, averaged, or otherwise compared.

Step 2: Determine the Relative Importance of Evaluation Objectives

Second, the relative importance of the Evaluation Objectives was determined using a survey. To make objective choices between the Concepts, which have varying effects as measured by the Evaluation Objectives, information was needed to evaluate the relative importance of the 13 Evaluation Objectives. In a trade-off analysis, the relative importance of different effects is typically accomplished by either asking a representative sample of the affected population for comparisons of value for different objectives/effects, reviewing completed studies that have estimated values for different objectives/effects, or by reviewing laws and regulations that apply to different objectives/effects. A survey was implemented as part of the Basin Study to gather opinions and values of the population affected by water management in the San Diego region to determine the relative importance of the different Evaluation Objectives. The weighting of the Evaluation Objectives reflects the preferences of affected groups, agencies, and decision-makers within the Study Area. The weighted sum of the Evaluation Objectives scores leads to an aggregate function that can be used to compare Concepts.

Step 3: Place Values on Evaluation Objectives using Performance Measures

Third, one or more Performance Measures for quantifying the value of the Evaluation Objectives for each Concept was identified for each Evaluation Objective. Performance Measures were calculated using data from model run output metrics, literature review, geospatial analysis, quantitative or qualitative estimates of value from surveys of identified experts and stakeholders, or a combination of data sources.

Step 4: Evaluate and Combine Evaluation Objective Scores for Each Concept

The final step of the trade-off analysis was to aggregate the individual Performance Measures scores associated with each Concept for the Evaluation Objectives and combine the scores with the relative importance of the Evaluation Objectives to estimate a total score for the Concept across all Evaluation Objectives. The results provide a baseline evaluation of the Concepts and provide information that is directly relevant to water managers in the region who are making decisions about potential future investments. The number of Evaluation Objectives included in the trade-off analysis can be changed to evaluate the sensitivity of alternative preferences to the types of objectives that are considered important by decision-makers and the public. A decision-making tool was developed as an affiliate product of this report, which is a Microsoft Excel spreadsheet entitled "Customized Tradeoff Analysis Tool" published as part of the Task 2.5 Interim Report. This tool enables users to customize the trade-off analysis to reflect their preferences. Options for customization include selecting a subset of Evaluation Objectives to include in the trade-off analysis and adjusting Evaluation Objective weights or scores. This decision-making support tool also enables the trade-off analysis to be updated as new information and science becomes available or as priorities in the region change.

7.1 Identification of Evaluation Objectives

The first step in the Basin Study Trade-off Analysis was to identify the Evaluation Objectives that were used for comparison of Concepts. Evaluation Objectives represent the range of criteria that stakeholders and decision-makers may want to consider when comparing Concepts. They were developed in the summer of 2017 through consultation with the STAC and public stakeholders, including discussion at two IRWM RAC meetings in October and December 2017. These Evaluation Objectives were used as the basis for comparison of Concepts in the Task 2.5 Trade-off Analysis.

The 13 Evaluation Objectives considered in this analysis (Table 19) are an inclusive, but not exhaustive, list of the effects associated with the Concepts evaluated in the Trade-off Analysis. For example, other potential effects such as changes in flood damages and greenhouse gas emissions were not included due to limitations in data and understanding of connections between Concepts and effects on resources and activities. There are likely to be other examples of potential effects that were not included in the analysis in addition to the two mentioned above, but discussions among the Bureau of Reclamation, the City of San Diego, IRWM stakeholders, and the STAC identified the 13 primary Evaluation Objectives included in this analysis.

Table 19. Evaluation Objective Definitions

Evaluation Objective	Narrative Objective Description
Address Climate Change Through Greenhouse Gas Reduction	Concepts that reduce greenhouse gas emissions through energy efficiency improvements, industrial process modifications, transitions from fossil fuel to renewable energy sources, or by increasing carbon sequestration through habitat protection, restoration, or other activities that store carbon.
Climate Resilience	Concepts that directly or indirectly improve the regional resilience to the impacts of climate change: sea level rise, flooding, wildfire, and extreme heat. Note that 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 in the Climate Resilience Evaluation Objective are focused on evaluating the vulnerability of individual projects to the impacts of climate change (e.g., warming and fire, sea level rise, and flooding). Also note that regional resilience to drought is included in the Reliability and Robustness Evaluation Objective.
Cost Effectiveness	Concepts that reduce capital and operation and maintenance costs to the region and/or have a strong potential for external funding.
Environmental Justice	Concepts that consider environmental justice issues, provide access to reliable/cost effective drinking water, distribute project benefits equitably throughout the basin, and/or directly benefit Disadvantaged Communities (as defined by the Department of Water Resources).
Optimize Local Supplies	Concepts that increase local water supplies and/or reduce the reliance on imported water.
Project Complexity	Concepts that reduce inherent challenges associated with project complexity or feasibility (e.g., regulatory compliance, number of agencies/approvers, property ownership, public opinion/acceptance/practicality of implementation).
Protect Habitats, Wildlife, and Ecosystems	Concepts that reduce impacts to ecosystems and threatened or endangered species.

Evaluation Objective	Narrative Objective Description
Provide for Scalability of Implementation	Concepts that provide flexibility in project phasing and expansion.
Quality of Life/Recreation	Concepts that increase green/open space benefits and other improvements to quality of life, including providing recreational opportunities such as swimming, boating, and fishing.
Regional Economic Impact	Concepts that increase the potential for local job creation and regional economic activity (e.g., tourism and other industries).
Regional Integration and Coordination	Concepts that support community engagement, education, and coordination with regional partners to leverage existing assets and projects, reduce project barriers, and/or build community support and knowledge of water issues.
Reliability and Robustness	Concepts that provide a reliable supply of drinking water, capable of meeting regional demand under normal, drought, and emergency conditions. This Objective includes management strategies to optimize infrastructure for the purposes of providing a robust and reliable water supply.
Water Quality and Watersheds	Concepts that reduce stormwater and wastewater discharges to rivers and the ocean, and reduce water quality impacts to water resources, including groundwater basins, surface waters, and 303(d) listed water bodies.

7.2 Determination of the Relative Importance of Evaluation Objectives

The second step in the San Diego Basin Study Trade-off Analysis was to gather opinions and values of the population affected by water management in the San Diego region to determine the relative importance of the different Evaluation Objectives. In order to solicit the input of stakeholders on the relative importance of Evaluation Objectives, an online survey was distributed by the City of San Diego to the region's stakeholders. The survey consisted of 13 questions that allowed stakeholders to rate the Evaluation Objectives on a scale of least important to most important. Results of this survey were used to develop weights that reflect the importance of each Evaluation Objective to the San Diego Basin Study Area, which were then used to calculate weighted scores for each Concept.

The survey was developed, distributed, and compiled by the City of San Diego. It was distributed via email in November 2017 to 546 people, including the IRWM stakeholder list and 59 tribal contacts, and was open for responses until early February 2018. As part of the survey, respondents were asked to provide their affiliation and area of expertise. In total, the survey received 71 responses from 13 different areas of expertise. This equates to a 13% response rate, though it should be noted that some emails were undeliverable and, therefore, the response rate may be underestimated. The sum of respondents for all areas of expertise illustrated in Table 20 is greater than the total number of survey responses because several respondents indicated multiple areas of expertise.

Table 20. Areas of Expertise Represented

Area of Expertise	Number of Respondents
Ecology/Biology	15
Watershed Science/Limnology	20
Conservation, Restoration, Mitigation	22
Oceanography/Marine Science	6
Engineering – Design	16
Engineering – Construction	12
Climate Change	18
Community Outreach and Education	19
Environmental Policy/Planning/Analysis	28
Disadvantaged Communities	9
Finance	8
Water Utility – Operations	21
Other[1]	18

[1] Other areas of expertise included Water Use Efficiency and Demand Mitigation, Real Estate, Solid Waste/Recycling, Environmental Program Management, Leak Detection, and Conservation Non-Profit.

7.2.1 Calculation of Evaluation Objective Weights

Next, the Evaluation Objective weights were calculated by estimating the average importance rating for each Evaluation Objective for all respondents. The average importance rating was estimated for each Objective and then normalized by the score for the highest rated Evaluation Objective. For example, if the highest average importance rating is a 9 out of 10, then all average ratings are divided by 9 and the result multiplied by 10 to obtain the normalized rating. These results are presented in Table 21.

Table 21. Evaluation Objective Importance Weights and Rankings based on the Average of All Responses

Evaluation Objective	Importance Weight	Rank
Water Quality and Watersheds	10.0	1
Reliability and Robustness	10.0	1
Climate Resilience	9.6	3
Optimize Local Supplies	9.4	4
Protect Habitats, Wildlife, and Ecosystems	9.2	5
Environmental Justice	8.7	6
Regional Integration and Coordination	8.5	7
Cost Effectiveness	8.5	7
Address Climate Change Through Greenhouse Gas Reduction	8.2	9
Regional Economic Impact	7.8	10
Provide for Scalability of Implementation	7.7	11
Quality of Life/Recreation	7.4	12
Project Complexity	7.3	13

7.3 Placement of Values on Evaluation Objectives Using Performance Measures

Each Evaluation Objective was measured by one or more Performance Measures. Performance Measures were scored through use of model metrics, surveys of identified experts and stakeholders, and/or geospatial analysis using GIS software. Performance Measures are listed and described in Table 22 and the types of input data are described in detail below.

Table 22. Performance Measures associated with Evaluation Objectives

Performance Measure	Performance Measure Description	Type of Input Data
Address Climate Change through GHG Reduction		
GHG Mitigation	Mitigate greenhouse gas 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
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

Performance Measure	Performance Measure Description	Type of Input Data
Disadvantaged Communities (DACs)	Effect on Disadvantaged Communities (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.)	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
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 expansion	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

Performance Measure	Performance Measure Description	Type of Input Data
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, 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
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

7.3.1 Types of Performance Measure Inputs

Performance Measures were scored through use of model metrics, surveys of identified experts and stakeholders, and geospatial analysis using GIS software. Economic analysis would typically only include purely quantitative measures. However, a majority of the Evaluation Objectives could not be quantified solely by Performance Measures calculated from GIS and/or model metrics. Therefore, quantitative data (model metrics and GIS analysis) was combined with qualitative data obtained through surveys to place values on the Performance Measures. The combination of quantitative and qualitative data is made possible through the trade-off analysis process.

7.3.1.1 Model Metrics

As described in Section 3.3.2, Single Concept portfolios corresponding to the following 12 Concepts were used to provide input data for the Trade-off Analysis and Economic Assessment:

- 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

7.3.1.2 Surveys of Identified Experts and Stakeholders

Information from surveys of identified experts and stakeholders and a workshop of regional economic experts helped quantify the effects of each Concept on the Evaluation Objectives on a Likert scale (rating scale). Information obtained from individuals with knowledge and expertise of projects and areas potentially affected by projects is a commonly used source for evaluating impacts when empirical data on project performance are lacking. The knowledge of individuals with relevant expertise is very useful when it is not possible to gather relevant empirical data needed to measure the impacts of different projects. In many cases, individual experts or stakeholders may be the only source of information available to evaluate site-specific impacts associated with projects or Concepts. However, the use of data based on information from experts or stakeholders creates unique challenges for project evaluation. The information provided can vary greatly based on differences in experience, area of expertise, and other factors. General consensus can be used to deal with this variation when there is a sufficient number of responses to achieve consensus.

Information from identified experts and stakeholders was gathered through questionnaires that were developed and distributed by the City of San Diego. The respondents included individuals with knowledge of specific projects and those with broad knowledge of the general Concepts. Two surveys were conducted using two different questionnaires: a general Concept-level questionnaire and a project-specific questionnaire, which enabled a broad range of identified experts and stakeholders to be included. Surveys of five attendees at a Regional Economic Impact Workshop were also used to develop scores for the Regional Economic Impact Evaluation Objective.

The Concept-level questionnaires were developed to gather information needed to complete scoring. The Concept-level questionnaire was sent by the City of San Diego to the STAC (26 individuals) and the IRWM RAC members (28 individuals) in March 2018 (some individuals serve on both the STAC and RAC). There were 16 Concept-level survey responses, representing 16 agencies or organizations (six non-governmental organizations, nine government agencies, and one academic institution), for all Concepts except Enhanced Conservation. There were no responses for the Enhanced Conservation Concept because this Concept was originally included in the Urban and Agricultural Water Use Efficiency Concept, but was split out as a separate Concept after the survey questionnaires were distributed. Therefore, Enhanced Conservation was given a value of NA for all Concept-level questionnaire calculations.

In March 2018, project-level questionnaires were sent to designated project managers or subject matter experts for all but two of the 120 projects included in the Trade-off Analysis[2]. For this project-level survey, each recipient was provided with a questionnaire specific to their organization's projects. Therefore, each project could only receive one response. Of the 37 project-level survey questionnaires that were distributed (representing 118 projects), 21 responses were received representing 87 projects, or about 73% of the total projects. The respondents consisted of 20 government agencies and one academic institution. Although a response was received for the Enhanced Conservation project, this response was not used in the analysis because the Enhanced Conservation Concept was not included in the Concept-level survey. Therefore, Enhanced Conservation was given a value of NA for all project-level questionnaire calculations.

The number of project-level survey responses for each Concept is shown in Table 23. Since only one project-level questionnaire was distributed for each project, the maximum number of responses was equal to the number of projects in the Concept. Four Concepts had responses rates of 100% (Conveyance Improvement, Enhanced Conservation, Imported Water, and Stormwater Capture). All other Concepts had response rates above 50%. Although response rates were relatively high, some respondents did not provide responses for all survey questions. Therefore, some projects had

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[2] Two projects were excluded from the survey due to errors in survey distribution. Both projects were in the Stormwater BMPs Concept, which contains 29 projects. Responses were received for 20 of the 29 Stormwater BMPs projects. Therefore, although two projects were not included in the survey, the other survey responses provided sufficient data to characterize the effects of Stormwater BMPs projects in the Trade-off Analysis.

fewer responses on those questions than on the survey as a whole. In cases where there were more than three project-level survey responses, scores were based on the average of the mean project-level score and the mean Concept-level score. In cases where there were three or fewer project-level survey responses, the Concept-level survey results were combined with the project-level responses and then averaged to calculate a score. In cases where there were no project-level survey results (project-level result of NA), the mean of the Concept-level survey results was used as the basis for the score. In cases where there were no Concept-level survey results (Concept-level result of NA), the Concept received a score of NA regardless of whether there were project-level survey results.

Table 23. Project-level Survey Responses for Each Concept

Concept	Number of Projects	Number of Project-Level Survey Responses	Percent of Projects with Responses
Recycled Water	28	18	64
Stormwater BMPs	29	20	69
Watershed and Ecosystem Management	18	14	78
Groundwater	11	9	82
Potable Reuse	12	8	67
Urban and Agricultural Water Use Efficiency	7	5	71
Conveyance Improvement	6	6	100
Seawater Desalination	3	2	67
Gray Water Use	2	1	50
Stormwater Capture	2	2	100
Imported Water	1	1	100
Enhanced Conservation[1]	1	1	100
Total	120[2]	87	73

[1] A project-level survey was received for Enhanced Conservation, but this Concept was not included in the Concept-level survey, so it was given a score of NA for all Performance Measures using survey responses.
[2] Two projects in the Stormwater BMPs Concept were excluded from the survey due to errors in survey distribution, so only 118 projects were included in the survey.

7.3.1.3 Geospatial Analysis

Geospatial analysis of individual projects was used to quantify values of Performance Measures and/or components of Performance Measures in relation to key factors of interest, such as proximity of projects to areas inhabited by endangered/threatened species, and to fire hazard safety zones, ecologically important habitats, disadvantaged communities, and impaired surface and groundwater water bodies. The project-level results were then aggregated to the Concept-level as described for each Performance Measure. This analysis enabled a quantitative approach to developing scores for Performance Measures for which geospatial data was available and relevant to the performance measure. For example, geospatial data on fire hazard severity was used to score the Warming and Fire Vulnerability Performance Measure by determining a project's proximity to moderate, high, and very high fire hazard severity zones (as defined by California Department of Forestry and Fire Protection [CAL FIRE]). Each project was mapped using GIS software based on its proposed location in the region, as identified in local and regional planning documents. Then the project locations were analyzed in conjunction with other geospatial data, such as flood hazard zones or disadvantaged communities, to calculate the Performance Measure values.

One limitation of the geospatial analysis was its dependence on a single specific project location within the Study Area. Seven projects (Enhanced Conservation, Graywater Pilot Project, Pipeline 3/4 Conversion, Rainwater Harvesting, San Diego Water Conservation Program, San Diego Water Use Reduction Program, and Second Crossover Pipeline) could not be mapped because of their distributed nature. Although these projects could potentially have location-specific impacts, it was not possible to assign a single value to their impacts. Therefore, they were assigned scores of NA for all geospatial analysis calculations. Three projects (Rosarito Desalination Plant, Rincon Customer-Driven Demand Management Program, and Cadiz Additional Imported Supplies) could not be mapped due to their locations outside the Study Area. Analysis of effects outside the Study Area was beyond the scope of the Basin Study. Therefore, these projects were also assigned scores of NA in all geospatial analysis calculations.

Another limitation of the geospatial analysis was that it only analyzed the specific project location and did not account for facilities or areas that the project is dependent on or areas or facilities that are dependent on the project location. Although a project may have shown no impact on a Performance Measure since it is located outside a vulnerable area, the geospatial analysis did not capture the location of facilities that the project is dependent on. For example, if a pump station located in a vulnerable area was damaged in a storm, then a water treatment plant that used that pump station may become inoperative, even though it was not directly exposed to that vulnerability. This type of analysis, however, was outside the scope of this Study and would require additional research.

7.4 Evaluation Objective Scoring Methodology

Each Evaluation Objective was measured by one or more Performance Measures, which were scored using one or more types of input data. Performance Measure scores were then averaged to obtain an Evaluation Objective Unweighted Score. The Unweighted Score was then weighted as described in Section 7.5. A generic example of the scoring process based on the use of specific data sources, performance measures, and methods of combining performance measures is illustrated in Figure 25. Decision trees for each Evaluation Objective, which provide a visual representation of the scoring methods, are provided below and the full set of decision trees for all Evaluation Objectives and Performance Measures is available in the Task 2.5 Interim Report.

The Evaluation Objective Unweighted Scores were calculated at the Concept-level. As mentioned above, many sources of information were used to score each Concept, some of which were collected at the project-level. For example, surveys of interested parties were completed at the Concept-level and for specific projects within a Concept. For most Concepts, the mean of the Concept-level survey responses and the mean of the project-level were averaged to derive the final scores. However, due to the small number of projects in some Concepts and/or the response rate to the project-level surveys, some Concepts had very small number of project-level survey responses (Table 23). For Concepts that had three or fewer survey responses (either due to the low number of projects and/or the low response rate), the Performance Measure score was based on the average of all survey responses at the project-level and Concept-level combined. This essentially treated the project-level survey responses as additional Concept-level responses to prevent undue influence of individual survey responses on the final Performance Measure score.

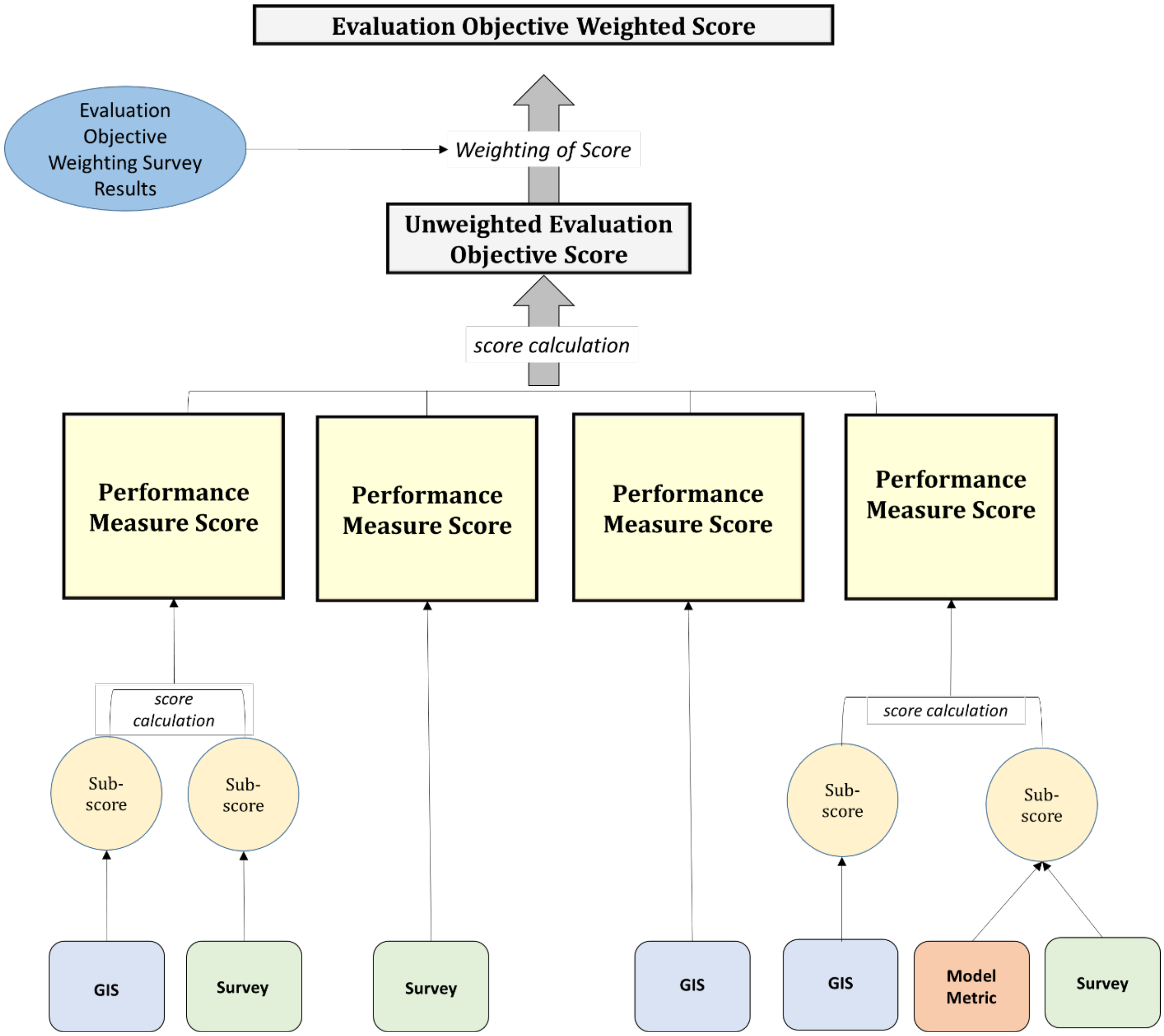


Figure 25. Evaluation Objective scoring.

The Performance Measure scores ranged from 1 to 5. The score structure was designed to reflect negative, neutral and positive characteristics of projects and Concepts. A score of 4 or 5 indicated that the project or Concept had a moderate or strong positive effect, respectively, on the Performance Measure. A score of 3 indicated that that project or Concept had a neutral or unknown effect on the Performance Measure. A score of 1 or 2 indicated that the project or Concept had a strong or moderate negative effect, respectively, on the Performance Measure. The Enhanced Conservation Concept was given a score of NA for all survey questions because it was developed after the surveys were distributed. This Concept was originally included in the Urban and Agricultural Water Use Efficiency Concept, but was split out as a separate Concept after the survey was distributed.

7.4.1 Address Climate Change Through Greenhouse Gas Reduction Evaluation Objective

The Address Climate Change Through Greenhouse Gas Reduction Evaluation Objective contained a single Performance Measure: GHG Mitigation (Figure 26). The GHG Mitigation Performance Measure was evaluated based on survey responses at both the Concept- and project-level. Both the Concept-level and project-level surveys included a general question about the extent to which projects included in a Concept would mitigate greenhouse gas emissions through carbon storage and sequestration. Scores were on a scale of 1 to 5.

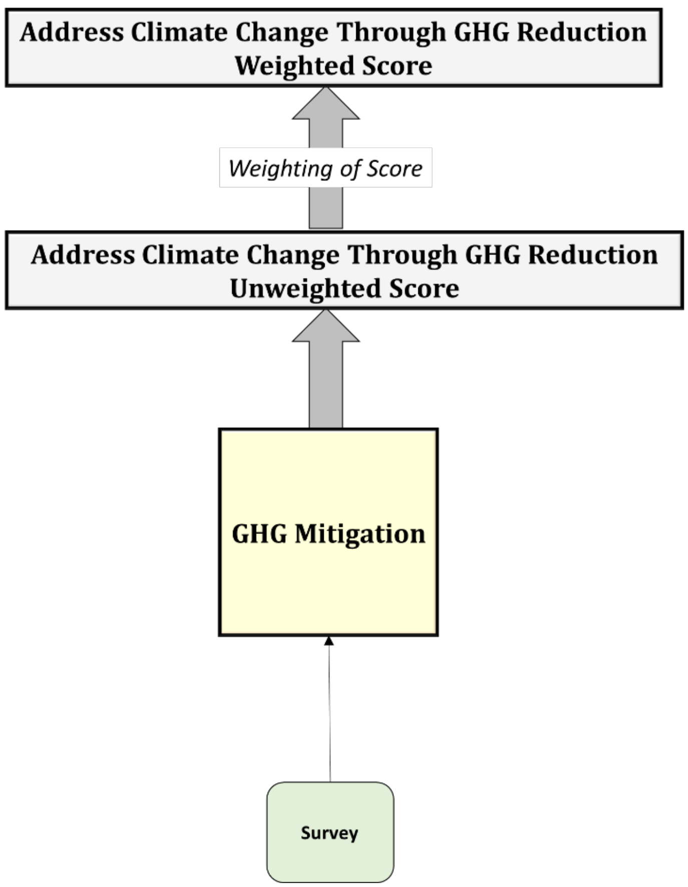


Figure 26. Decision tree for the Address Climate Change Through GHG Reduction Evaluation Objective.

7.4.2 Climate Resilience Evaluation Objective

The Climate Resilience Evaluation Objective included three Performance Measures: Sea Level Rise Vulnerability, Flood Risk Management, and Warming and Fire Vulnerability (Figure 27). The Climate Resilience Unweighted Score was equal to the average of Sea Level Rise Vulnerability and Flood Risk Management Scores multiplied by the Warming and Fire Vulnerability Score. This score was then converted to a 1 to 5 scale for comparison with the other Evaluation Objectives. Stakeholders identified climate resilience as an important objective to consider when evaluating projects. However, during development of the Performance Measures associated with climate resilience, it was recognized that 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 within 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), and did not directly evaluate the ability of a project to increase regional resilience to climate change (e.g., by actively reducing the San Diego region's exposure or sensitivity to a particular climate impact). For example, a project may increase regional resilience to fire if it removes invasive species that are known to increase fire risk. This Evaluation Objective did not include an analysis of drought resilience, as this factor was evaluated in the Evaluation Objective Reliability and Robustness.

To evaluate vulnerability, this Evaluation Objective relied on geospatial data to evaluate projects in relation to these climate risk factors. The Sea Level Rise Performance Measure was evaluated using geospatial data from the U.S. Geological Survey Coastal Storm Modeling System (CoSMoS) accessed through the Point Blue Our Coast, Our Future website (U.S. Geological Survey, 2018). The Flood Risk Management Performance Measure was evaluated using geospatial data from the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer Web Map Service (U.S. Department of Homeland Security, Federal Emergency Management Agency, 2018). The Warming and Fire Vulnerability Performance Measure was evaluated using geospatial data from CAL FIRE Fire Hazard Severity Zone Maps (San Diego Association of Governments, 2018) combined with project-level survey responses. Scores were determined based on the proximity of each project in a Concept to areas of potential inundation due to sea level rise, potential flood inundation zones, and fire hazard severity zones.

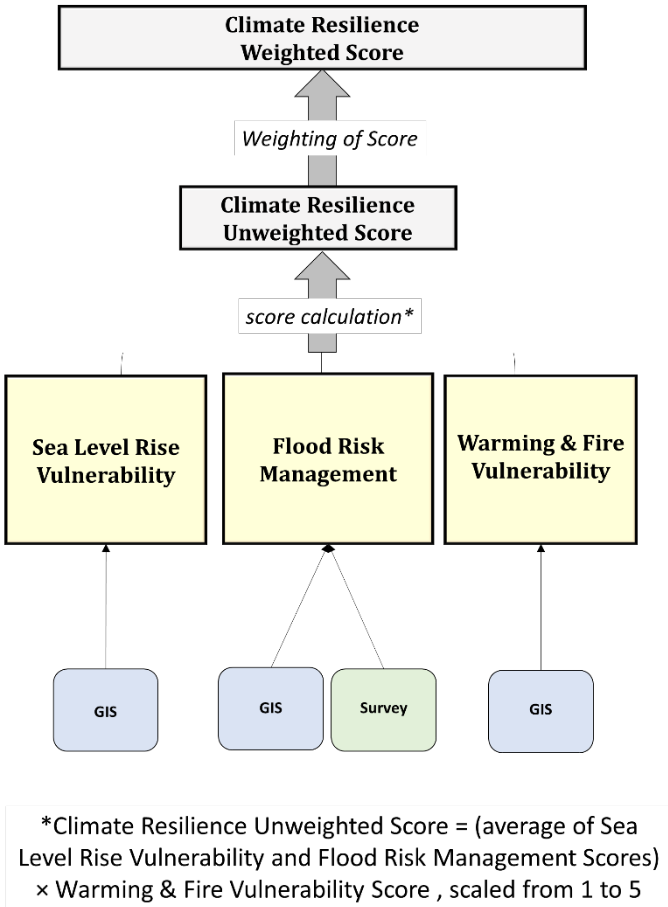


Figure 27. Decision tree for the Climate Resilience Evaluation Objective.

7.4.3 Cost Effectiveness Evaluation Objective

The Cost Effectiveness Evaluation Objective included three Performance Measures: Capital Costs, O&M Costs, and Potential for External Funding, that were averaged together to calculate the Evaluation Objective Unweighted Score (Figure 28). Capital costs are the total present value of capital costs to a region and customers/developers over the planning period and may include up-front construction/modification costs, planning costs, engineering costs, environmental compliance costs, or other costs required for project completion. The Capital Cost Performance Measure score in this analysis was evaluated through a survey question asking about the capital costs associated with the implementation of projects within a Concept. O&M costs are the total present value of operation, maintenance, and periodic replacement costs to customers/developers required for continued service of a project. These costs may include materials, labor, energy, and any other recurring costs necessary to support continued project service. The O&M Costs Performance Measure was scored in the same way as the Capital Costs Performance Measure, with a survey question asking about the O&M costs associated with the implementation of projects in within a Concept. The Potential for External Funding Performance Measure was evaluated by a project-level survey regarding the potential for external funding. The potential for external funding has an impact on the portion of project costs that must be paid by customers/developers within the local region, reducing the financial cost of the project to the region, but it does not have an impact on the actual cost of the project and instead only redistributes project costs. The survey question asked to what extent a project was expected to be funded by external sources.

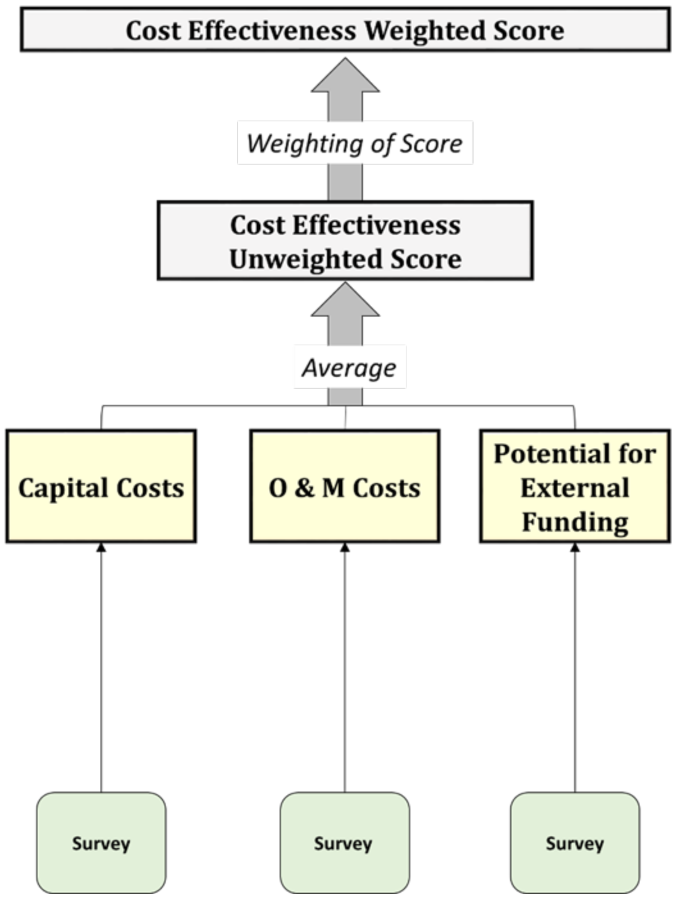


Figure 28. Decision tree for Cost Effectiveness Evaluation Objective.

7.4.4 Environmental Justice Evaluation Objective

The Environmental Justice Evaluation Objective included two Performance Measures: Environmental Justice and Disadvantaged Communities (DACs) (Figure 29).

The Environmental Justice Performance Measure addressed the fair treatment of people of all social and economic backgrounds with respect to actions that have potential environmental effects. Fair treatment implies that no group of people should bear a disproportionate share of negative effects of an action. The negative effects of an action can be considered disproportionately distributed if the percentage of negative to total effects imposed on a specific group is greater than the percentage of the total population represented by that group. A group can be defined by race, ethnicity, income, community, or some other grouping. An evaluation of potential environmental justice concerns requires an understanding of where project influences are likely to occur and where potentially affected groups are located.

A separate but closely related Concept is Disadvantaged Communities. This Performance Measure was included in addition to the Environmental Justice Performance Measure because the Integrated Regional Water Management Program has specific funding allocations and program goals for DACs, as defined by the California Department of Water Resources (DWR). DWR 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). Both Performance Measures were based on a combination of project-level survey data and GIS data.

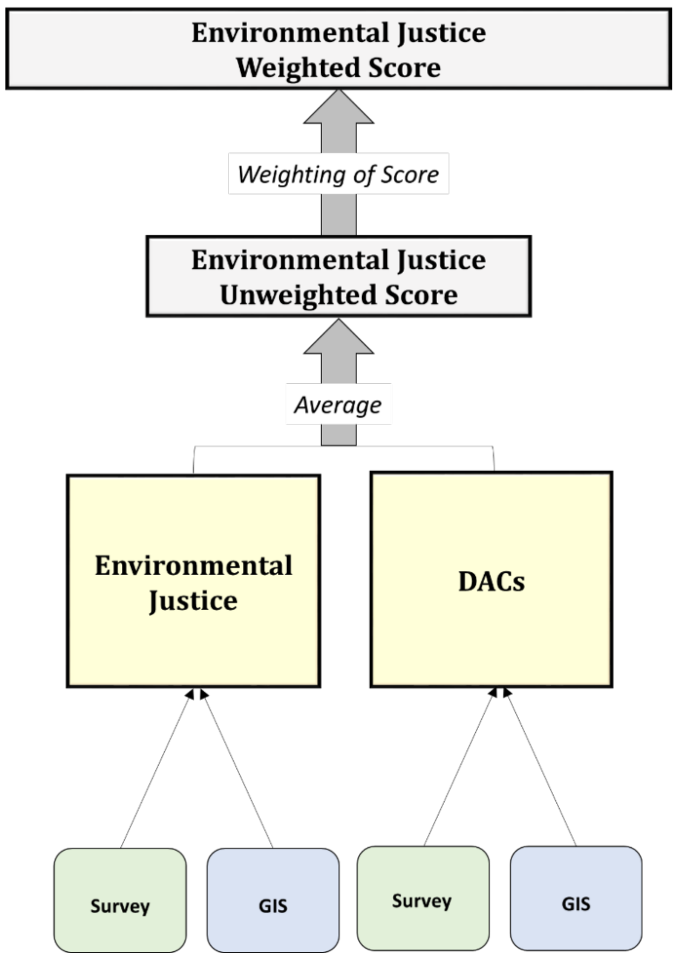


Figure 29. Decision tree for the Environmental Justice Evaluation Objective.

7.4.5 Optimize Local Supplies Evaluation Objective

The Optimize Local Supplies Evaluation Objective included one Performance Measure, Local Supply (Figure 30). The Local Supply Performance Measure score was derived from a single survey question, which asked whether the project increases local water supply. The intent of this question was to evaluate a Concept or project's ability to provide locally-sourced water supply.

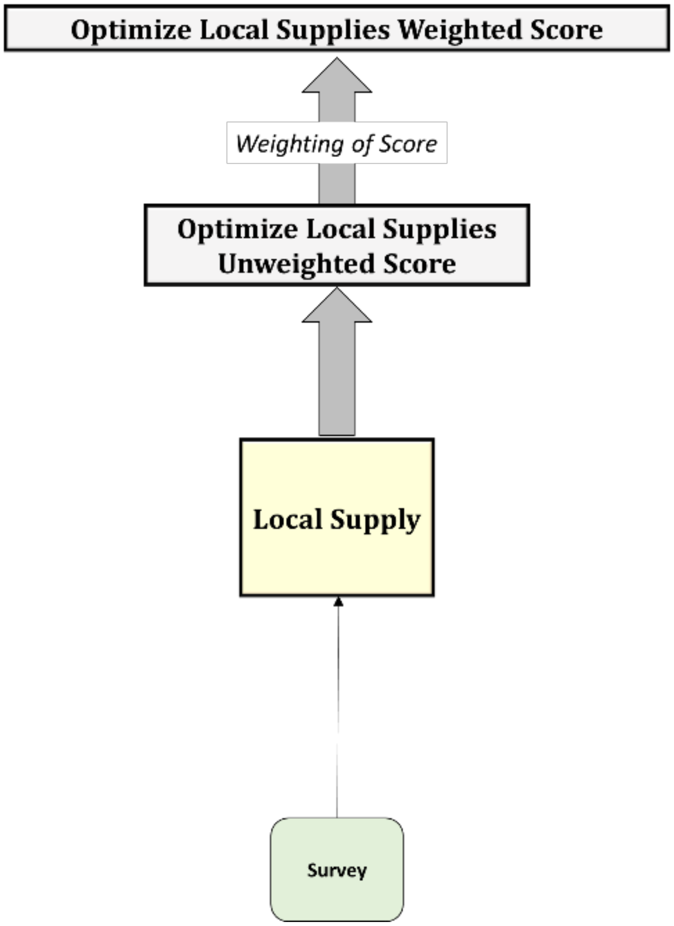


Figure 30. Decision tree for the Optimize Local Supplies Evaluation Objective.

7.4.6 Project Complexity Evaluation Objective

The Project Complexity Evaluation Objective was based on one Performance Measure: Project Complexity and Feasibility (Figure 31). This Performance Measure was evaluated by a survey question related to project implementation within a Concept. Considerations included regulatory compliance, number of agencies or approvers involved, property ownership, public opinion, acceptance, and practicality of implementation.

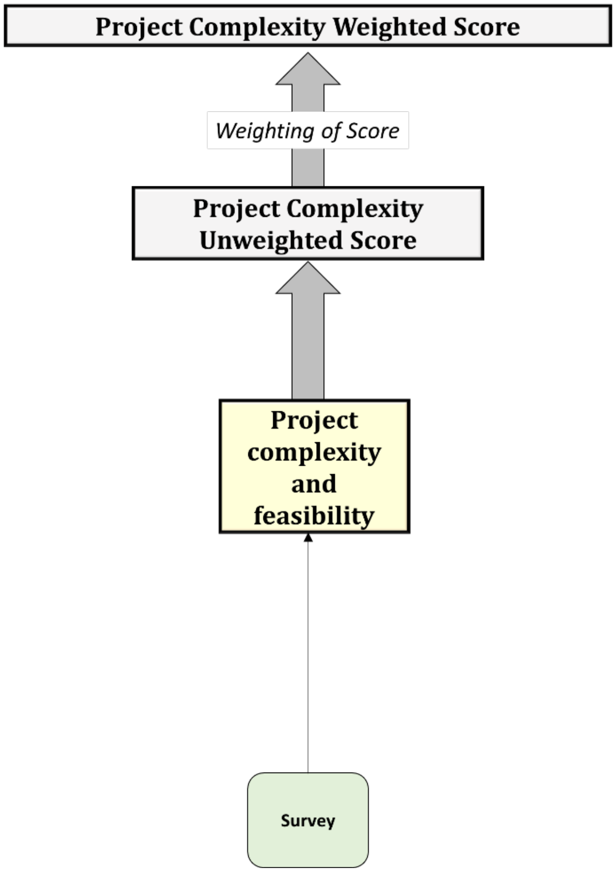


Figure 31. Decision tree for the Project Complexity Evaluation Objective.

7.4.7 Protect Habitats, Wildlife, and Ecosystems Evaluation Objective

The Evaluation Objective Protect Habitats, Wildlife, and Ecosystems included three Performance Measures: Impacts to Ecosystems, Impacts to Threatened and Endangered Species, and Impacts to Native Species (Figure 32). For each Performance Measure, first a project-level survey question was asked about the likely impact to ecosystems, with possible responses of negative, neutral or positive. Then a GIS analysis was performed using project locations and relevant geospatial data.

The Impacts to Ecosystems Performance Measure used geospatial data available from the San Diego Association of Governments (SANDAG) Regional GIS Data that characterizes ecologically important habitats including those that represent managed habitats, sensitive habitats, mitigation areas, sensitive water bodies, preserved lands, and habitats that support rare, threatened, and endangered species. The data layers used to collectively represent "ecologically important habitats" included habitats defined within the Multiple Species Conservation Program (MSCP) and the Multi-Habitat Planning Area, the proposed MSCP North and East County Plan Areas, Environmentally Sensitive Areas, and the 100-Year Floodway.

The Impacts to Threatened and Endangered Species and Impacts to Native Species Performance Measures used geospatial data from the California Natural Diversity Database (CNDDB) and SANBIOS. The CNDDB, a product of the California Department of Fish and Wildlife's

Biogeographic Data Branch (www.wildlife.ca.gov/Data/CNDDB), is a database of the status and locations of California's rare species and natural community types. The CNDDB includes all federally and state listed plants and animals, all species that are candidates for listing, all species of special concern, and those species that are considered "sensitive" by government agencies and the conservation community. This data features species observed from 1875 to 2017 within 10 miles of San Diego County. SANBIOS, a product of the County of San Diego, is part of the State of California's Biological Information and Observation System (BIOS) database (bios.dfg.ca.gov/). It is a catalog of species observations recorded by professional biologists from the County of San Diego and various other agencies and firms. The species are classified as sensitive, invasive, or neither and the date of species observations ranges from 1856 to 2016. These data serve as a baseline catalog of species records in the MSCP preserve systems in the incorporated areas of San Diego County. It is important to note these observations are an indication of confirmed species presence at the time of the survey, but offer no indication of species absence.

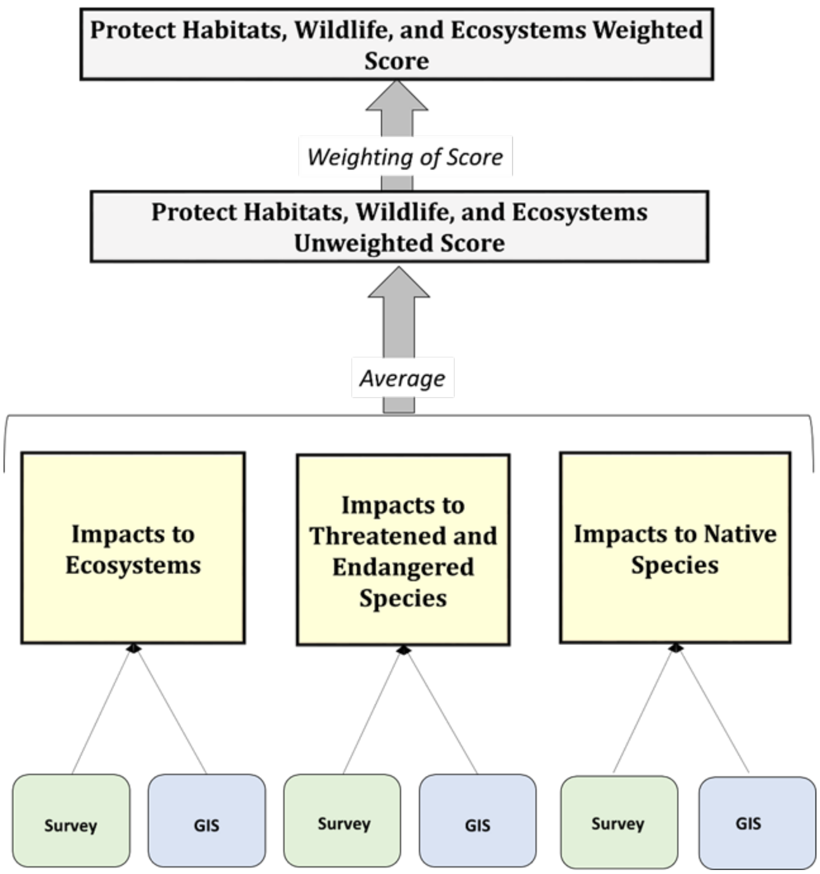


Figure 32. Decision tree for the Protect Habitats, Wildlife, and Ecosystems Evaluation Objective.

7.4.8 Provide for Scalability of Implementation Evaluation Objective

The Provide for Scalability of Implementation Evaluation Objective included one Performance Measure: Project Phasing (Figure 33). This Evaluation Objective considered the possibility for project phasing and expansion. Difficulty in scaling back, phasing, or expansion creates a barrier to accommodating changes in regional needs and planning. Provide for Scalability of Implementation

Performance Measure scores were based on a single survey question regarding the ability for project phasing and expansion.

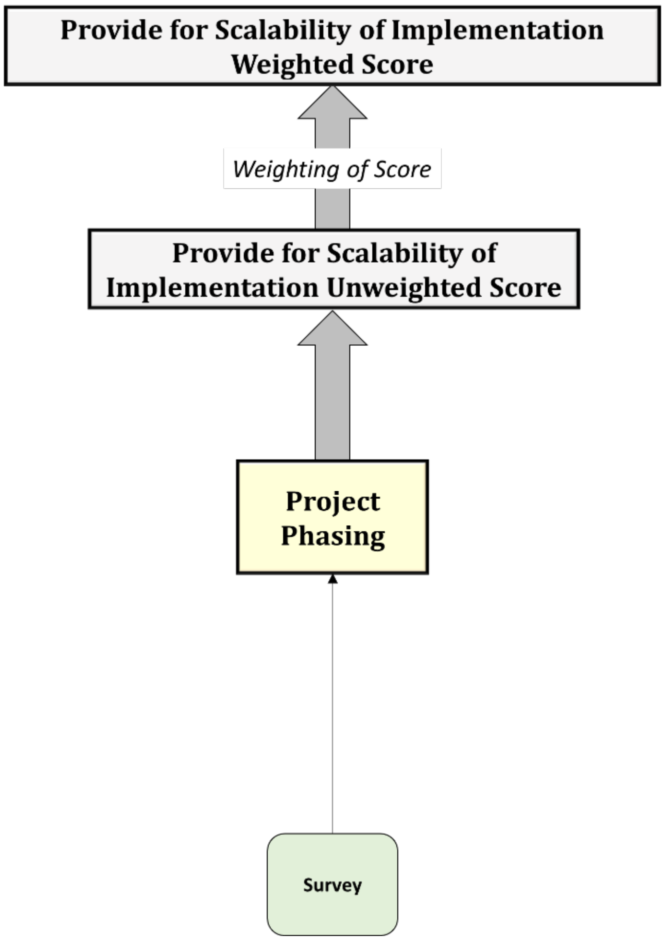


Figure 33. Decision tree for the Provide for Scalability of Implementation Evaluation Objective.

7.4.9 Quality of Life/Recreation Evaluation Objective

The Quality of Life/Recreation Evaluation Objective was calculated using two Performance Measures: Green Space/Open Space and Recreation Opportunities (Figure 34). The Green Space/Open Space Performance Measure was calculated from two sub-scores: Green Space/Open Space, which addressed the extent to which a Concept increases green space or open space or increases the quality of existing green space or open space, and Quality of Life, which addressed the extent to which the Concept increases quality of life considering impacts such as air pollution, noise/nuisance impacts, increased urbanization, view obstruction or enhancement, and cultural enrichment. Both sub-scores were based on the results of surveys of identified experts and stakeholders. The Recreation Opportunities Performance Measure was based on two sub-scores: Recreation Opportunities, which was based on the results of surveys of identified experts and stakeholders that asked about the extent to which the Concept would impact recreation opportunities such as trails/hiking, community gathering space, wildlife watching, swimming, boating, and fishing as incidental benefits to water supply storage and conveyance, and Visitation

Impact from Changes in Reservoir Elevation, based on recreation visitation modeling at three reservoirs. The two Quality of Life Performance Measures were averaged to derive the Quality of Life/Recreation Evaluation Objective unweighted score.

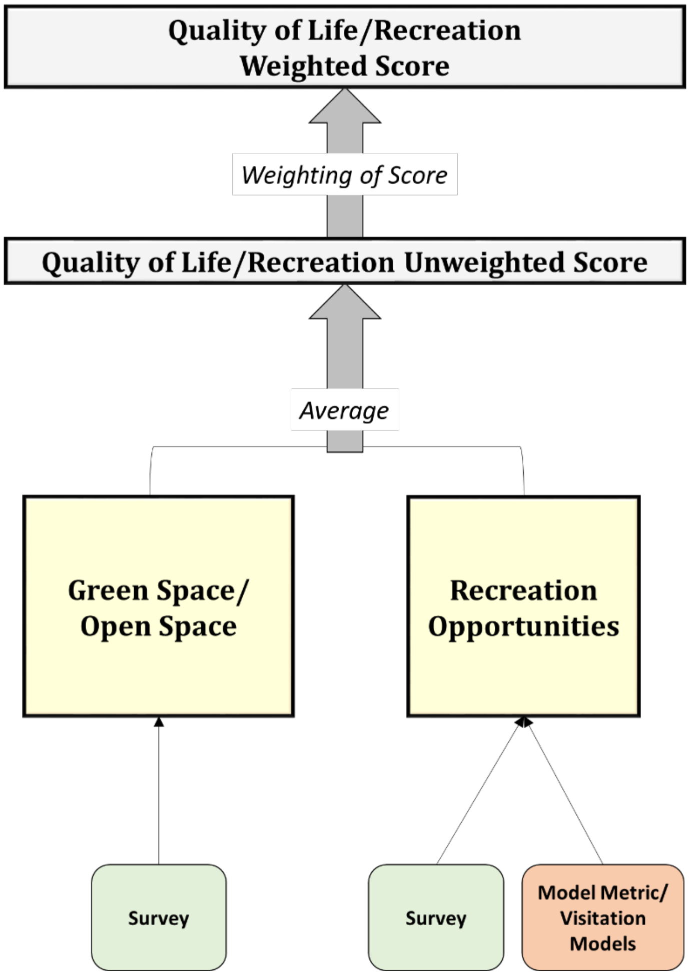


Figure 34. Decision tree for the Quality of Life/Recreation Evaluation Objective.

7.4.10 Regional Economic Impact Evaluation Objective

The Regional Economic Impact Evaluation Objective included one Performance Measure: Regional Economic Impact (Figure 35). This Evaluation Objective quantified the effect of a project or group of projects on income, employment, and the value of output produced in the region where a project is located as well as the potential impact of the project(s) on water rates. Regional impacts could potentially include short-term impacts from construction expenditures, long-term impacts from operation, maintenance, and replacement expenditures, and long-term impacts from changes in population and businesses supported by a project or Concept. The total regional impacts associated with the location of an industry in a region are the sum of direct, indirect, and induced effects. Direct effects represent impacts on the industry that is immediately affected. Indirect effects account for inter-industry transactions. Induced effects measure the effects of the changes in household income on demand for goods and services such as housing, restaurants, and retail sales. The regional impacts associated with changes in water rates are the result of changes in income or revenues of water users. The Regional Economic Impact Performance Measure was calculated based on two sub-scores: the Project-level Regional Economic Impacts Sub-score, based on project-level survey response, and the Expert Panel Regional Economic Impact Sub-score, based on responses from a panel of regional economic experts. The project-level surveys included four questions related to regional economic impacts: (1) whether the project would generate general regional economic impacts (affect employment, income, or regional production); (2) the potential of a project to generate regional economic impacts beyond capital and operation and maintenance expenditures; (3) the extent of impacts if they occur; and (4) the extent to which the project has the potential to increase or decrease water rates. The original intent was to use all four project-level questions to score the Concepts, but Questions 2, 3, and 4 had large numbers of missing responses and there was no corresponding Concept-level question to provide additional data, so these questions could not be included in the analysis. Therefore, the Regional Economic Impact Evaluation Objective was based only on Question 1 from the project-level survey along with supplemental data from an expert panel.

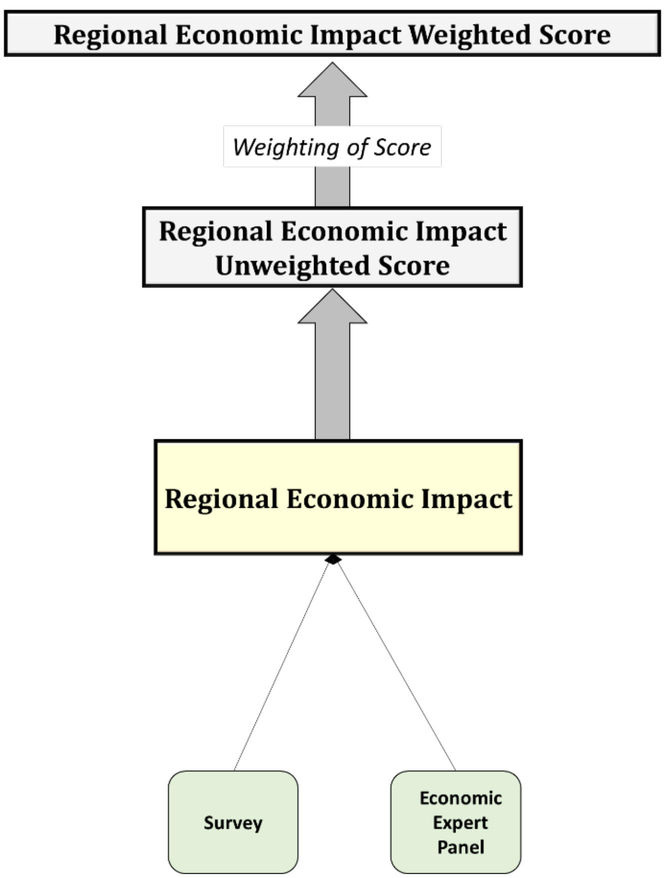


Figure 35. Decision tree for the Regional Economic Impact Evaluation Objective.

7.4.11 Regional Integration and Coordination Evaluation Objective

The Regional Integration and Coordination score was based on two Performance Measures: Coordination, and Education and Outreach (Figure 36). Both Performance Measures were scored based on data from surveys of identified experts and stakeholders. The Coordination Performance Measure was based on two sub-scores, Integration and Leveraging. The Integration sub-score related to the level of integration or coordination that is required for projects/entities to implement a project within a Concept. The Leveraging question asked if leveraging existing assets or bolstering existing projects was required to implement a project within a Concept. The Education & Outreach Performance Measure was determined from a survey question that asked what level of education and outreach would be achieved by projects within a Concept. Opportunities or plans for outreach events, educational or promotional materials, K-12 education, workshops and trainings, and creating space for community gatherings were considered.

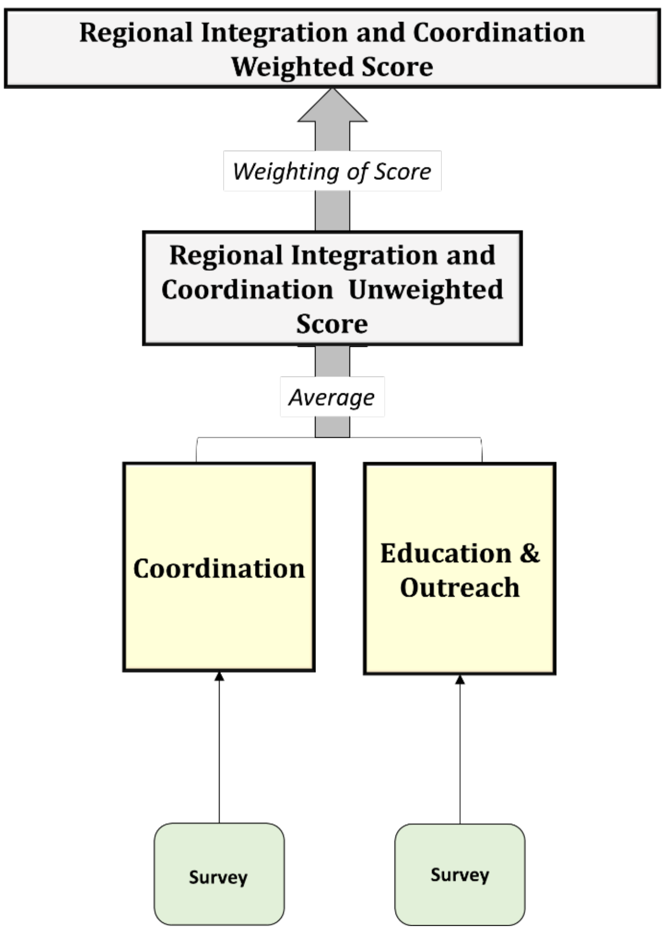


Figure 36. Decision tree for the Regional Integration and Coordination Evaluation Objective.

7.4.12 Reliability and Robustness Evaluation Objective

The Reliability and Robustness Evaluation Objective included three Performance Measures: Water Shortage Volume, Vulnerability of Water Supply Facilities and Infrastructure, and Carryover Storage & Reservoir Augmentation (Figure 37).

Water Shortage Volume was based on the results of the Single Concept model runs. The Shortage Volume metric measured the magnitude of regional demand that was unable to be met by the available supplies and/or limited by conveyance system capacity. Non-zero shortage volume indicated that supplies were insufficient to meet demands or that conveyance system capacity limited deliveries. Larger values indicated larger supply-demand imbalances or capacity limitations. To use the model output for comparison of Concepts, the reduced shortage volume relative to the Baseline was calculated by subtracting the Baseline average annual shortage volume from the average annual shortage volume for each Concept-specific model run. Negative values indicated that shortages were larger for a given Concept than in the Baseline run. Positive values indicated that shortages were smaller for a given Concept than in the Baseline run.

The Vulnerability of Water Supply Facilities and Infrastructure Performance Measure was based on four sub-scores that were based on the results of surveys of identified experts and stakeholders. The first sub-score related to the ability of a Concept to increase the diversity of water supply. The second sub-score evaluated the extent to which the Concept increases the resilience of the conveyance system such as an ability to withstand or recover from impacts such as pipeline failures. The third sub-score evaluated the impact of the Concept on aging infrastructure. The fourth sub-score used to evaluate Concepts for Vulnerability of Water Supply Facilities and Infrastructure addressed the effect of a Concept on problems associated with insufficient wastewater flows to move solid waste.

Carryover Storage and Reservoir Augmentation was scored based on responses to a survey question regarding the impact of a project or Concept on the ability to use the storage capacity of reservoirs.

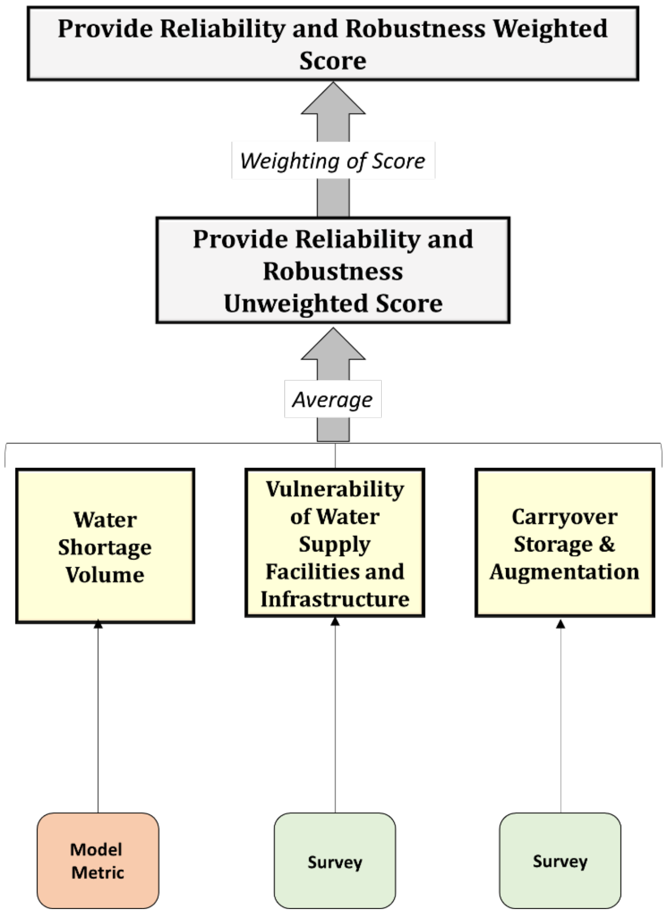


Figure 37. Decision tree for the Reliability and Robustness Evaluation Objective.

7.4.13 Water Quality and Watersheds Evaluation Objective

The Water Quality and Watersheds Evaluation Objective was based on three Performance Measures: Stormwater and Wastewater Discharges, Surface Water Quality, and Groundwater Quality (Figure 38). The Stormwater and Wastewater Discharges Performance Measure was calculated based on two sub-scores: discharges to freshwater or estuarine bodies and discharges to marine water bodies. Impacts to freshwater and estuarine water bodies were distinguished from marine water bodies, given the distinct nature of projects that impact the volume or quality of wastewater discharged via ocean outfalls versus projects discharging to non-marine water bodies. The sub-scores were based on a direct or long-term increase or decrease in the volume of or resilience to stormwater or wastewater discharged to receiving waters, a limited or temporary change in discharge, or no or an unknown effect that results in a neutral effect.

A combination of survey results and the CalEnviroScreen Tool was used to develop scores for the Surface Water Quality and Groundwater Quality Performance Measures. The survey of identified experts and stakeholders included questions to determine the likely impact of a project on surface water quality and groundwater quality (negative impact, no/unknown impact, positive impact). Once the likely impact was determined, projects were evaluated using geospatial data from the CalEnviroScreen Tool. For Groundwater Quality, the analysis used the Groundwater Threats indicator, which was scored based on each Census Tract's proximity to groundwater contamination sites. The Surface Water Quality Performance Measure Score was calculated using the "Impaired Water Bodies" CalEnviroScreen indicator, which represents the number of pollutants listed in waterbodies and the proximity of those waterbodies to each Census Tract.

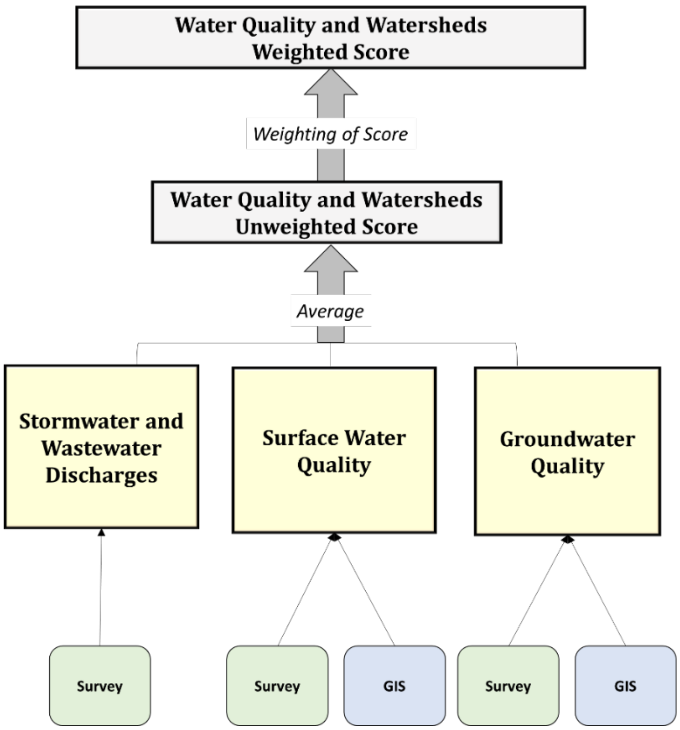


Figure 38. Decision tree for the Water Quality and Watersheds Evaluation Objective.

7.5 Evaluate and Combine Evaluation Objective Scores for each Concept

The final step of the Trade-off Analysis was to aggregate the individual Performance Measures scores associated with each Concept for the Evaluation Objectives and combine the scores with the relative importance weights of the Evaluation Objectives to estimate a total score for the Concept across all Evaluation Objectives.

First, the Performance Measures Scores were calculated for each Concept using the scoring methodology described in Section 7.4. Then the scores for all Performance Measures associated with an Evaluation Objective were aggregated for each Concept as described in Section 7.4. Next the Evaluation Objective weights described in Section 7.2.1 were multiplied by the individual Evaluation Objective scores and divided by 10 (the highest possible importance weight) to derive the weighted score that accounts for the importance of each Evaluation Objective.

The number of Evaluation Objectives included in the Trade-off Analysis can be changed to evaluate the sensitivity of alternative preferences to the types of objectives that are considered important by decision-makers and the public. The Customized Trade-Off Analysis Tool published as part of the Task 2.5 Interim Report can aid in evaluating variations in combinations of Evaluation Objectives and weights of importance.

8. Trade-Off Analysis Results

The scoring results by Evaluation Objective for each Concept are summarized below. The last section combines the individual Evaluation Objective results with the weights of importance for each Evaluation Objective to estimate weighted total performance measures for each Concept. These results can then be used to provide relevant information to water managers in the region who are making decisions about potential future investments.

8.1 Trade-Off Analysis Results by Evaluation Objective

The following sections provide Concept-level Trade-off Analysis results for each Evaluation Objective. The results can be used to compare the performance of individual Concepts for a specific Evaluation Objective. The results show a wide variation in the effectiveness of different Concepts in addressing specific Evaluation Objectives. For example, Seawater Desalination ranks very high in terms of achieving Climate Resilience and Optimizing Local Supplies objectives, but ranks low in terms of Project Complexity and Cost Effectiveness. On the other hand, the Urban and Agricultural Water Use Efficiency Concept ranks high in terms of Optimizing Local Supplies, Project Complexity, Cost Effectiveness, and Address Climate Change Through Greenhouse Gas Reduction as well as Environmental Justice/Disadvantaged Communities, and Scalability. However, the Urban and Agricultural Water Use Efficiency Concept ranks low for Reliability and Robustness.

8.1.1 Address Climate Change Through Greenhouse Gas Reduction

The Address Climate Change Through Greenhouse Gas Reduction Evaluation Objective included a single Performance Measure: GHG Mitigation. The GHG Mitigation Performance Measure was derived from survey responses at both the project-level and Concept-level. Scores were on a scale of 1 to 5, with a score above 3 indicating that a Concept or project achieves GHG mitigation and a score below 3 indicating that a Concept or project reduces or eliminates mitigation that was in place. Out of 87 total project-level responses, there were six missing responses for the GHG mitigation question. Enhanced Conservation was given a score of NA because it was not included in the surveys. The Address Climate Change through Greenhouse Gas Reduction Evaluation Objective scoring results are shown in Table 24 and Figure 39.

The highest scoring Concepts were Urban and Agricultural Water Use Efficiency, with a score of 3.75, and Watershed and Ecosystem Management, with a score of 3.63. The lowest scoring Concepts were Seawater Desalination, with a score of 2.35 and Imported Water Purchases, with a score of 2.38. No Concept scored above 4.0 or below 2.0. The low scores for Imported Water Purchases and Seawater Desalination were due to very low Concept-level survey scores (2.33 for Imported Water and 2.20 for Seawater Desalination). The high Urban and Agricultural Water Use Efficiency score is due to a high project-level survey score (4.50).

Table 24. Address Climate Change through GHG Reduction Evaluation Objective Unweighted Scores

Concept	Address Climate Change through GHG Reduction Evaluation Objective Unweighted Scores
Conveyance Improvement	3.19
Enhanced Conservation	NA
Gray Water Use	3.25
Groundwater	3.03
Imported Water Purchases	2.38
Potable Reuse	3.19
Recycled Water	3.52
Seawater Desalination	2.35
Stormwater BMPs	3.35
Stormwater Capture	3.18
Urban & Agricultural Water Use Efficiency	3.75
Watershed & Ecosystem Management	3.63

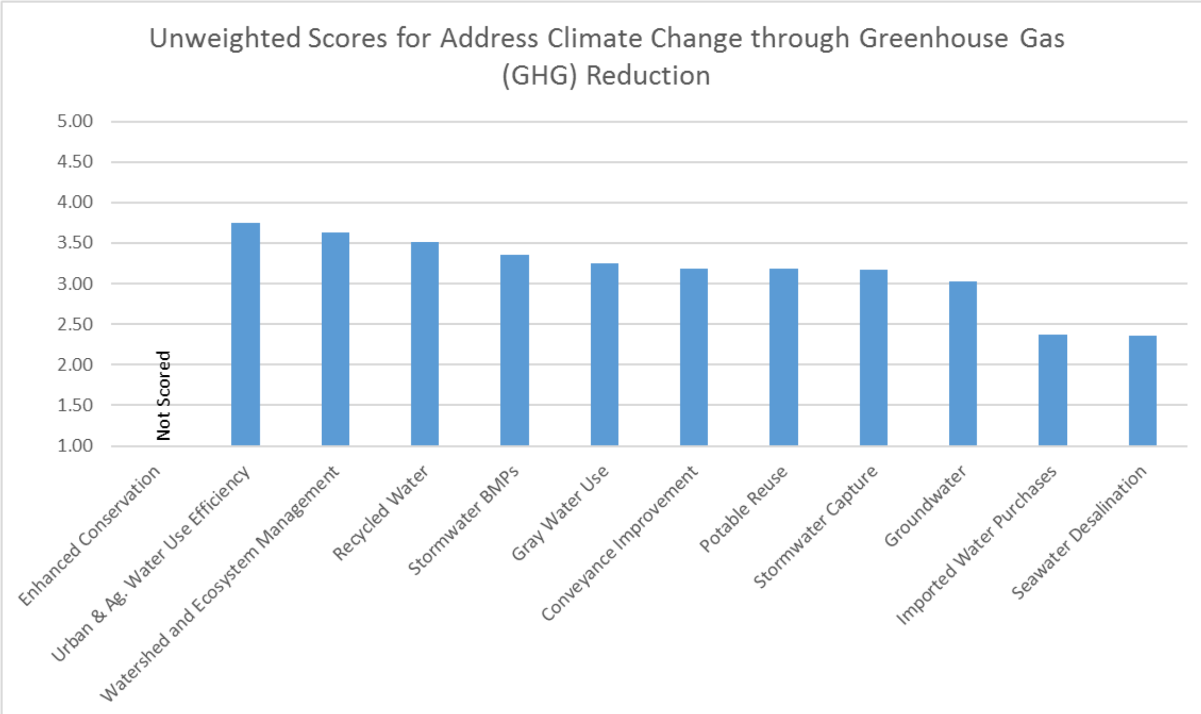


Figure 39. Address Climate Change through Greenhouse Gas Reduction Evaluation Objective unweighted scores.

8.1.2 Climate Resilience

The Climate Resilience Evaluation Objective included three Performance Measures: Sea Level Rise Vulnerability, Flood Risk Management, and Warming and Fire Vulnerability. GIS analysis of the location of projects in vulnerable areas was the sole basis for the project and Concept scores, except for Flood Risk Management which also included a survey response component. The Sea Level Rise Performance Measure score was evaluated on a scale of 1 to 3, with projects located within a zone of potential inundation receiving a score of 1 and projects located outside the zone of potential inundation receiving a score of 3. The Flood Risk Management Performance Measure was based on a 1 to 5 scale, with projects designed to have no direct impact on stormwater (i.e., no mitigation of flooding impacts, may be vulnerable to flooding) receiving scores of 1 to 3 depending on their location relative to flood hazard zones, and projects having a direct impact on stormwater (i.e., designed to reduce the volume of stormwater runoff or improve water quality) receiving scores of 3 to 5 depending on their location relative to flood hazard zones. The Warming and Fire Vulnerability Performance Measure scores were based on a scale of 1 to 3, with a project located within a very high fire hazard severity zone receiving a score of 1, a project located within a high fire hazard severity zone receiving a 1.5 score, a project located within a moderate fire hazard severity zone receiving a score of 2, and a project located outside any fire hazard severity zone receiving a 3.

The overall Climate Resilience scores are presented in Table 25 and Figure 40. The Climate Resilience scores ranged from a low of 2.57 for Conveyance Improvement to a high of 5.00 for Gray Water Use, Seawater Desalination, and Stormwater Capture. The average score across all

Concepts for which scores were calculated was 3.88. The Gray Water Use, Seawater Desalination, and Stormwater Capture Concepts all had the highest scores, which indicated that projects within these Concepts are located in areas that are resilient to the impacts of climate change. The Conveyance Improvement, Potable Reuse, and Recycled Water Concepts were the lowest scored Concepts, which indicated that projects within these Concepts are located in areas that are particularly vulnerable to the impacts of climate change.

Table 25. Climate Resilience Evaluation Objective and Associated Performance Measure Scores

Concept	Warming and Fire Vulnerability Performance Measure Score	Flood Risk Management Performance Measure Score	Sea Level Rise Vulnerability Performance Measure Score	Calculated Climate Resilience Evaluation Objective Score[1]	Climate Resilience Evaluation Objective Raw Score[2]
Conveyance Improvement	1.60	2.30	3.00	4.24	2.57
Enhanced Conservation	NA	NA	NA	NA	NA
Gray Water Use	3.00	2.50	3.00	8.25	5.00
Groundwater	2.45	2.18	2.82	6.14	3.72
Imported Water	NA	NA	NA	NA	NA
Potable Reuse	1.63	2.54	2.83	4.37	2.65
Recycled Water	1.80	2.29	2.86	4.64	2.81
Seawater Desalination	3.00	2.50	3.00	8.25	5.00
Stormwater BMPs	2.74	2.22	3.00	7.16	4.34
Stormwater Capture	3.00	2.50	3.00	8.25	5.00
Urban & Agricultural Water Use Efficiency	2.25	2.50	3.00	6.19	3.75
Watershed & Ecosystem Management	2.47	2.31	3.00	6.56	3.97

[1] Climate Resilience Calculated Score = (average of Sea Level Rise Vulnerability and Flood Risk Management Scores) × Warming and Fire Vulnerability Score

[2] Score scaled from 1 to 5

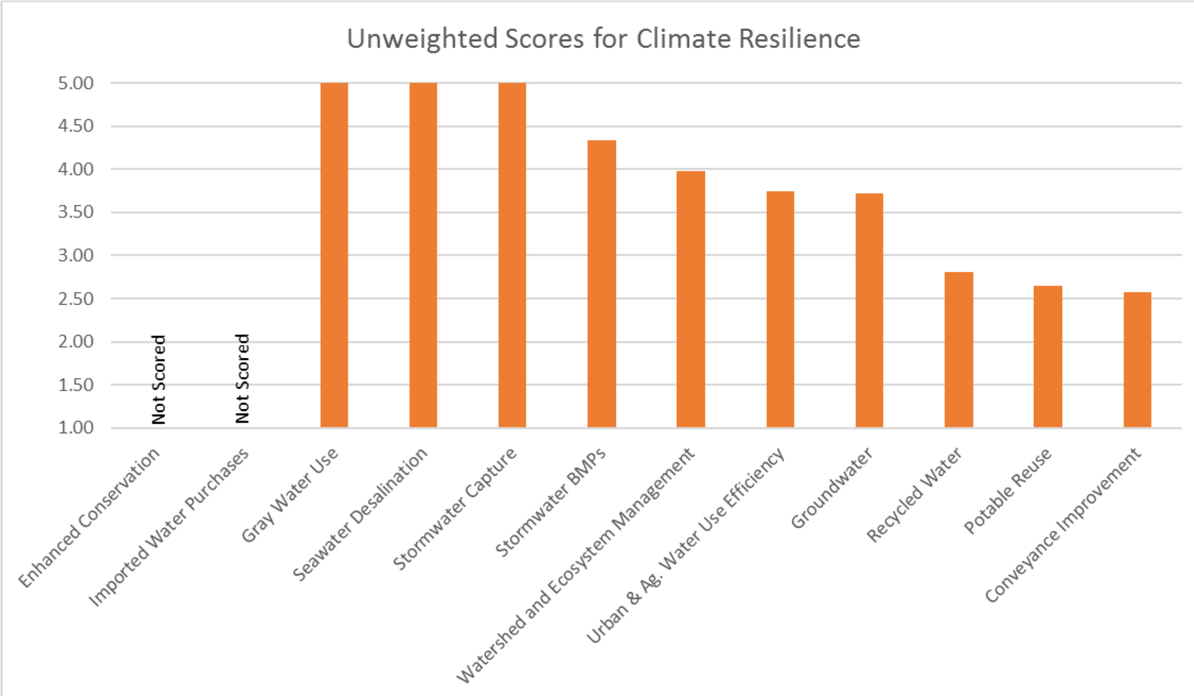


Figure 40. Climate Resilience Evaluation Objective unweighted scores.

8.1.3 Cost Effectiveness

Three Performance Measures were included in the Cost Effectiveness Evaluation Objective: Capital Costs, O&M Costs, and Potential for External Funding. Capital Costs and O&M Costs were scored on a scale of 1 to 5. A very costly/high cost project or Concept received a score of 1, a moderately costly or variable cost project or Concept received a score of 3, and an inexpensive/low cost project or Concept received a score of 5. Potential for External Funding was also scored on a scale of 1 to 5. If no external funding was/is expected, a score of 1 was assigned. If the project was/is expected to be partially funded by external sources, a score of 3 was assigned. If the project was/is expected to be fully funded by external sources, a score of 5 was assigned.

The Cost Effectiveness Evaluation Objective Performance Measure scores and Evaluation Objective scores by Concept are shown in Table 26 and Figure 41. It should be noted that higher scores represent lower (more desirable) costs. Urban and Agricultural Water Use Efficiency had the highest score, with a score of 4.10. Gray Water Use and Imported Water Purchases also scored relatively high, with scores of 3.67 and 3.08, respectively. For the Capital Costs and O&M Costs Performance Measures, a score of 3 indicated moderate or variable costs while a score of 1 indicated high costs and a score of 5 indicated low costs. Therefore, the final results indicated that Urban and Agricultural Water Use Efficiency was judged to have the lowest costs overall, followed by Gray Water Use and Imported Water Purchases. Each of the other Concepts had a score between 1.91 and 2.92, indicating that survey respondents judged them to have moderate or variable to high costs. Seawater Desalination and Potable Reuse were rated as least cost effective. The cost effectiveness scores were based entirely on project-level survey responses and were therefore based on limited data in some cases, as described in Section 7.4. Generally, the cost effectiveness scores were quite low, indicating that most of the Concepts were viewed as being expensive or that there is limited funding for them. This may be a relative comparison to past projects that tended to be lower cost and perhaps easier to implement.

Table 26. Cost Effectiveness Evaluation Objective and Associated Performance Measure Scores

Concept	Capital Costs Performance Measure Scores	O&M Costs Performance Measure Scores	External Funding Performance Measure Scores	Cost Effectiveness Evaluation Objective Unweighted Scores
Conveyance Improvement	1.98	3.33	1.33	2.22
Enhanced Conservation	NA	NA	NA	NA
Gray Water Use	3.82	4.18	3.00	3.67
Groundwater	1.75	1.93	2.75	2.14
Imported Water	3.00	3.24	3.00	3.08
Potable Reuse	1.19	2.14	2.40	1.91
Recycled Water	2.13	3.00	2.38	2.50
Seawater Desalination	1.33	1.56	2.00	1.63
Stormwater BMPs	2.79	3.14	2.68	2.87
Stormwater Capture	2.22	2.78	3.00	2.67
Urban & Agricultural Water Use Efficiency	4.16	4.35	3.80	4.10
Watershed & Ecosystem Management	2.83	2.79	3.14	2.92

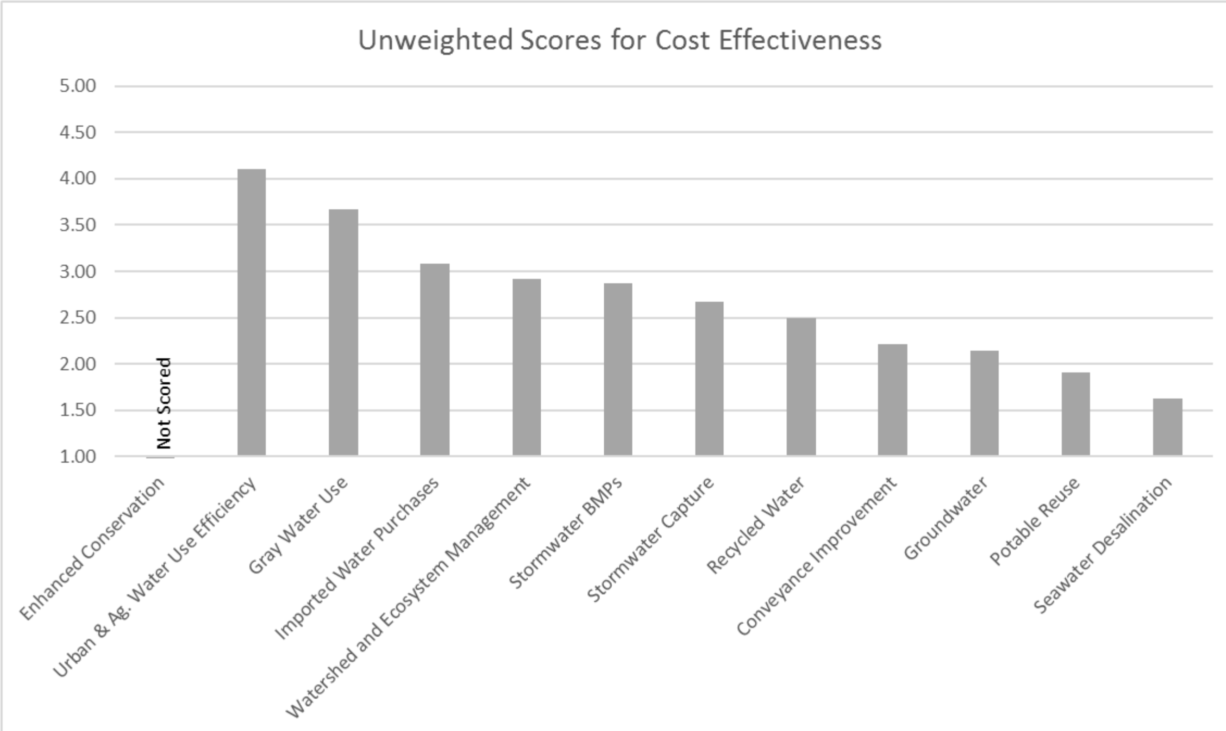


Figure 41. Cost Effectiveness Evaluation Objective unweighted scores.

8.1.4 Environmental Justice

The Environmental Justice Evaluation Objective included two Performance Measures: Environmental Justice and Disadvantaged Communities (DACs). The Environmental Justice Performance Measure score incorporated GIS analysis and survey questions. The Environmental Justice Performance Measure addressed the fair treatment of people of all social and economic backgrounds with respect to projects that have potential environmental effects. The Environmental Justice Performance Measure scores ranged from 1 to 5, where a score of 1 represented the greatest potential adverse Environmental Justice Performance Measure impact and a score of 5 represented the greatest potential beneficial impact. A score of 3 represented a neutral impact. The DAC Performance Measure evaluated the proximity of projects to DACs and whether projects had a positive, negative or neutral impact on the community. The DACs Performance Measure scores were based on a combination of project-level survey responses and GIS-based scores. Scores for the DACs Performance Measure ranged from 1 to 5, where a score of 1 or 2 indicated a negative impact on a DAC, a score of 3 indicated a neutral or unknown impact, and a score of 4 or 5 represented a positive impact on a DAC.

The Environmental Justice Evaluation Objective scores are presented in Table 27 and Figure 42. The highest scoring Concept was Watershed and Ecosystem Management, with a score of 3.79. The lowest scoring Concepts were Conveyance Improvement and Stormwater Capture, with scores of 3.0. Enhanced Conservation, Imported Water, Gray Water Use, and Seawater Desalination did not receive scores because they received scores of NA for one or both Performance Measures. All the Concepts that received Environmental Justice scores were expected to have a neutral or positive impact on Environmental Justice and Disadvantaged Communities (i.e., they scored 3.0 or above). This indicated the projects under consideration within the Concepts considered in this analysis may generally lead to improved conditions that support Environmental Justice and Disadvantaged Communities.

Table 27. Environmental Justice Evaluation Objective and Associated Performance Measure Scores

Concept	Environmental Justice Performance Measure Scores	DACs Performance Measure Scores	Environmental Justice Evaluation Objective Unweighted Scores
Conveyance Improvement	3.00	3.00	3.00
Enhanced Conservation	NA	NA	NA
Gray Water Use	NA	NA	NA
Groundwater	3.17	3.00	3.08
Imported Water	NA	NA	NA
Potable Reuse	3.25	3.00	3.13
Recycled Water	3.09	3.00	3.05
Seawater Desalination	NA	3.00	NA
Stormwater BMPs	3.41	3.14	3.28
Stormwater Capture	3.00	3.00	3.00
Urban & Agricultural Water Use Efficiency	3.00	4.00	3.50
Watershed & Ecosystem Management	3.58	4.00	3.79

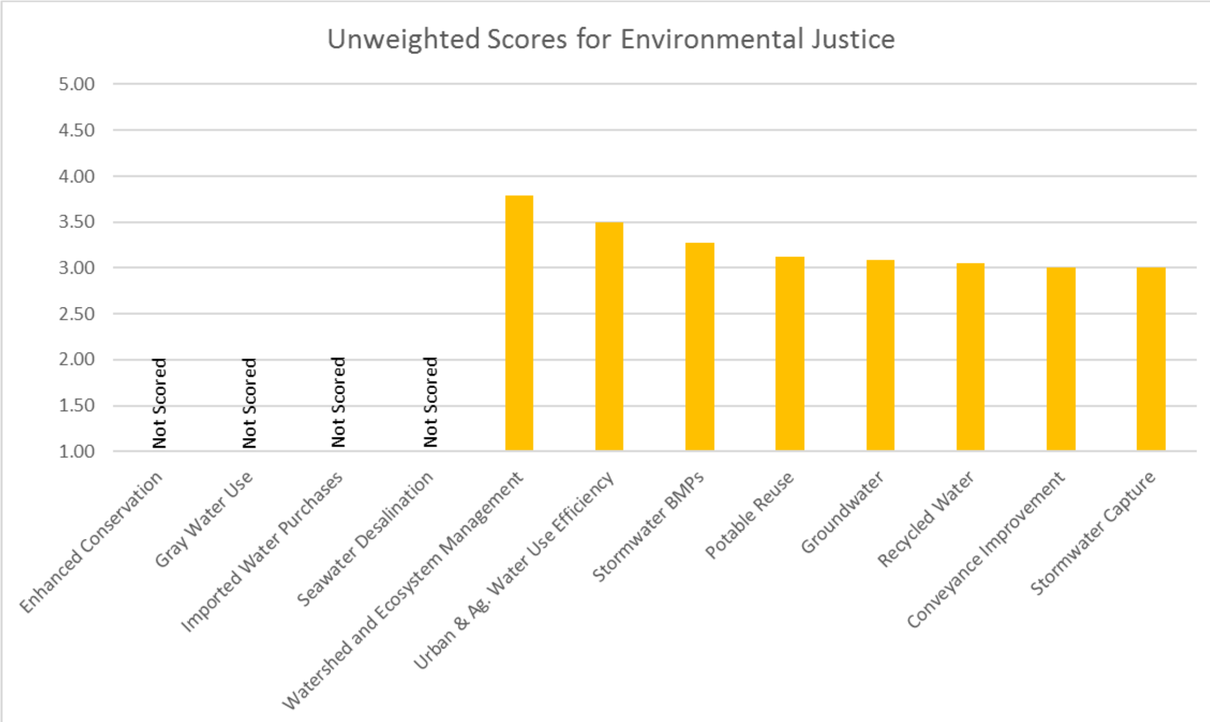


Figure 42. Environmental Justice Evaluation Objective unweighted scores.

8.1.5 Optimize Local Supplies

The Optimize Local Supplies Evaluation Objective included one Performance Measure, Local Supplies. The Local Supply Performance Measure score was derived from a single survey question, which asked whether the project or Concept increases or decreases local water supply. A direct or long-term decrease in local water supply resulted in a score of 1, an indirect or temporary decrease in local water supply was a 2, a neutral or unknown impact on local water supply was a 3, an indirect or temporary increase in local water supply was a 4, and a direct or long-term increase in local water supply resulted in a score of 5. This question was asked at both the project-level and Concept-level. The Local Supply Performance Measure scores were calculated as the averages of responses to both the project-level and Concept-level expert surveys to the local supply question. There was a total of 72 project-level survey responses for the local supply question out of 87 survey responses and 16 Concept-level survey responses. Enhanced Conservation was given a score of NA because it was not included in the surveys. Imported Water was initially given a score of 5, indicating a direct or long-term increase in local water supply, based on the project-level survey response for the single project (Cadiz Additional Imported Supplies) in that Concept. However, the score was changed to NA after review by the technical team. Imported Water Purchases did not represent a water supply that is sourced locally, and would therefore be expected to score low. The survey response may have been due to a misinterpretation of the question, or the respondent may have interpreted the response to mean that that importing water would make more supply available locally. Because of the possible misinterpretation of the question, the survey response was removed from the analysis and the project-level survey score for the Concept was given a score of NA. The Optimize Local Supplies results are presented in Table 28 and Figure 43 below.

The highest scoring Concept was Seawater Desalination with a score of 5.00, closely followed by Groundwater, Recycled Water, Potable Reuse, and Stormwater Capture. These five Concepts were all within 0.22 point of each other, ranging from 4.78 to 5.00 points. These Concepts would be expected to score high for this Evaluation Objective given that they are focused on local sources. The lowest score (2.81) was for Imported Water Purchases. The average score for Optimize Local Supplies was 4.27.

Similar to the Environmental Justice and DACs Evaluation Objective, all the Concepts, except for Imported Water Purchases, had a positive effect in terms of Optimizing Local Supplies. The highest scoring Concepts for Optimize Local Supplies were Seawater Desalination, Groundwater, Recycled Water, Potable Reuse, and Stormwater Capture.

Table 28. Optimize Local Supplies Evaluation Objective Scores

Concept	Optimize Local Supplies Evaluation Objective Unweighted Score
Conveyance Improvement	3.80
Enhanced Conservation	NA
Gray Water Use	4.24
Groundwater	4.97
Imported Water	2.81
Potable Reuse	4.84
Recycled Water	4.91
Seawater Desalination	5.00
Stormwater BMPs	3.53
Stormwater Capture	4.78
Urban & Agricultural Water Use Efficiency	4.26
Watershed & Ecosystem Management	3.85

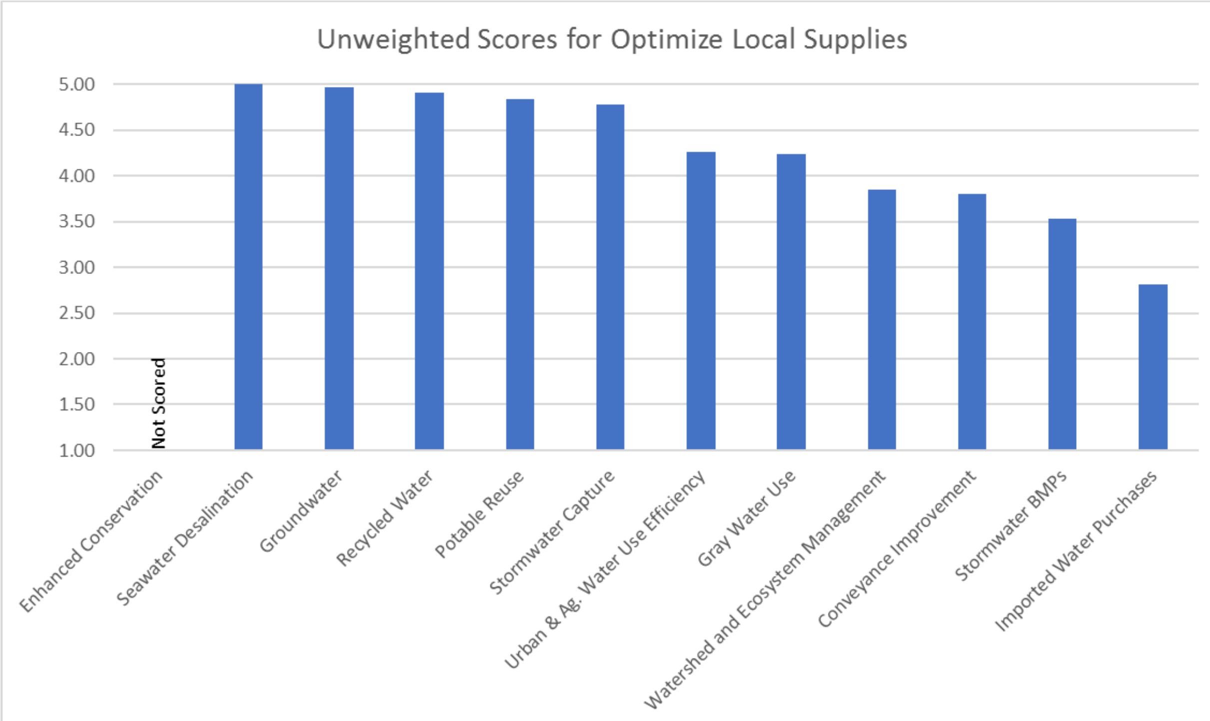


Figure 43. Optimize Local Supplies Evaluation Objective unweighted scores.

8.1.6 Project Complexity

The Project Complexity Evaluation Objective was based on one Performance Measure, Project Complexity and Feasibility. The Project Complexity and Feasibility Performance Measure was quantified using responses to a survey question about feasibility and complexity at both the project- and Concept-levels. It was scored on a scale of 1 to 5, with highly complex projects/Concepts receiving a score of 1, moderately complex projects/Concepts receiving a score of 2, unknown complexity or feasibility receiving a score of 3, moderately simple projects/Concepts receiving a score of 4, and simple projects/Concepts receiving a score of 5. Complete Project Complexity results are presented in Table 29 and Figure 44. Enhanced Conservation was given a score of NA because there were no Enhanced Conservation Concept projects included in the project-level survey and it was not included as a Concept in the Concept-level survey. The highest scoring Concepts for the Project Complexity and Feasibility Performance Measure were Urban and Agricultural Water Use Efficiency with a score of 4.13 and Imported Water Purchases with a 3.26. The lowest scoring Concepts were Seawater Desalination with a score of 1.47 and Potable Reuse with a score of 1.75. The average score for all Concepts was a score of 2.74.

Table 29. Project Complexity Evaluation Objective Scores

Concept	Project Complexity Performance Measure and Evaluation Objective Unweighted Scores
Conveyance Improvement	2.95
Enhanced Conservation	NA
Gray Water Use	3.06
Groundwater	2.01
Imported Water	3.26
Potable Reuse	1.75
Recycled Water	3.13
Seawater Desalination	1.47
Stormwater BMPs	3.11
Stormwater Capture	2.46
Urban & Agricultural Water Use Efficiency	4.13
Watershed & Ecosystem Management	2.83

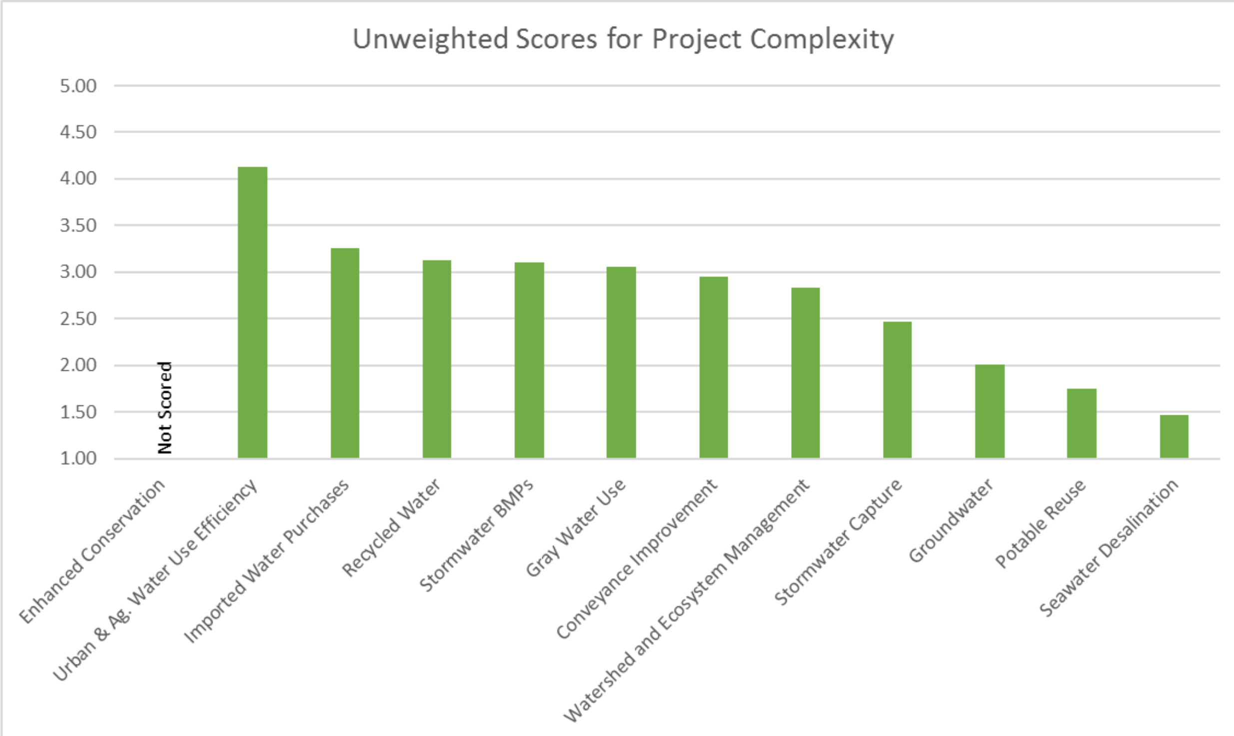


Figure 44. Project Complexity Evaluation Objective unweighted scores.

8.1.7 Protect Habitats, Wildlife, and Ecosystems

The Evaluation Objective Protect Habitats, Wildlife, and Ecosystems included consideration of three Performance Measures: Impacts to Ecosystems, Impacts to Native Species, and Impacts to Threatened and Endangered Species. The Impacts to Ecosystems, Impacts to Threatened and Endangered Species, and Impacts to Native Species Performance Measure scores were based on a combination of project-level survey data and GIS data. The survey asked whether projects might have a positive, neutral or negative impact on habitats, wildlife, and/or ecosystems, which was then related to the project location and proximity to sensitive species or habitats. Each Performance Measure was scored on a scale of 1 to 5, with negative impacts resulting in scores of 1 or 2, neutral or unknown impacts resulting in scores of 3, and positive impacts resulting in scores of 4 or 5.

The resulting Protect Habitats, Wildlife, and Ecosystems Performance Measure scores and overall Evaluation Objective scores are shown in Table 30 and Figure 45. Seven of the 12 Concepts had neutral 3.0 Evaluation Objective scores. One Concept, Enhanced Conservation, did not receive a score due to a lack of survey and GIS data. Four Concepts received scores greater than 3.0: Watershed and Ecosystem Management with a score of 3.35, Stormwater BMPs with a score of 3.19, Urban and Agricultural Water Use Efficiency with a score of 3.08, and Groundwater with a score of 3.06.

The scores of 3.0 for Conveyance Improvement, Gray Water Use, Imported Water Purchases, Recycled Water, Seawater Desalination, and Stormwater Capture were the direct result of the project-level survey responses indicating neutral or no impact for projects within that Concept. The score of 3.0 for Potable Reuse was due to all projects being located outside of managed habitats and in areas where there are no threatened, endangered, or native species as indicated by the GIS analysis. Four Concepts (Groundwater, Stormwater BMPs, Urban and Agricultural Water Use Efficiency, and Watershed and Ecosystem Management) had non-neutral Protect Habitats, Wildlife, and Ecosystems Evaluation Objective scores due to either non-neutral survey responses or locations that have impacts on managed habitats, threatened, endangered, or at-risk species, or native species.

Table 30. Protect Habitats, Wildlife, and Ecosystems Evaluation Objective Scores

Concept	Impacts to Ecosystems Performance Measure Scores	Impacts to Threatened and Endangered Species Performance Measure Scores	Impacts to Native Species Performance Measure Scores	Protect Habitats, Wildlife, and Ecosystems Performance Measure and Evaluation Objective Unweighted Scores
Conveyance Improvement	3.00	3.00	3.00	3.00
Enhanced Conservation	NA	NA	NA	NA
Gray Water Use	3.00	3.00	3.00	3.00
Groundwater	3.00	3.00	3.18	3.06
Imported Water	3.00	3.00	3.00	3.00
Potable Reuse	3.00	3.00	3.00	3.00
Recycled Water	3.00	3.00	3.00	3.00
Seawater Desalination	3.00	3.00	3.00	3.00
Stormwater BMPs	3.23	3.08	3.26	3.19
Stormwater Capture	3.00	3.00	3.00	3.00
Urban & Agricultural Water Use Efficiency	3.00	3.00	3.25	3.08
Watershed & Ecosystem Management	3.36	3.06	3.64	3.35

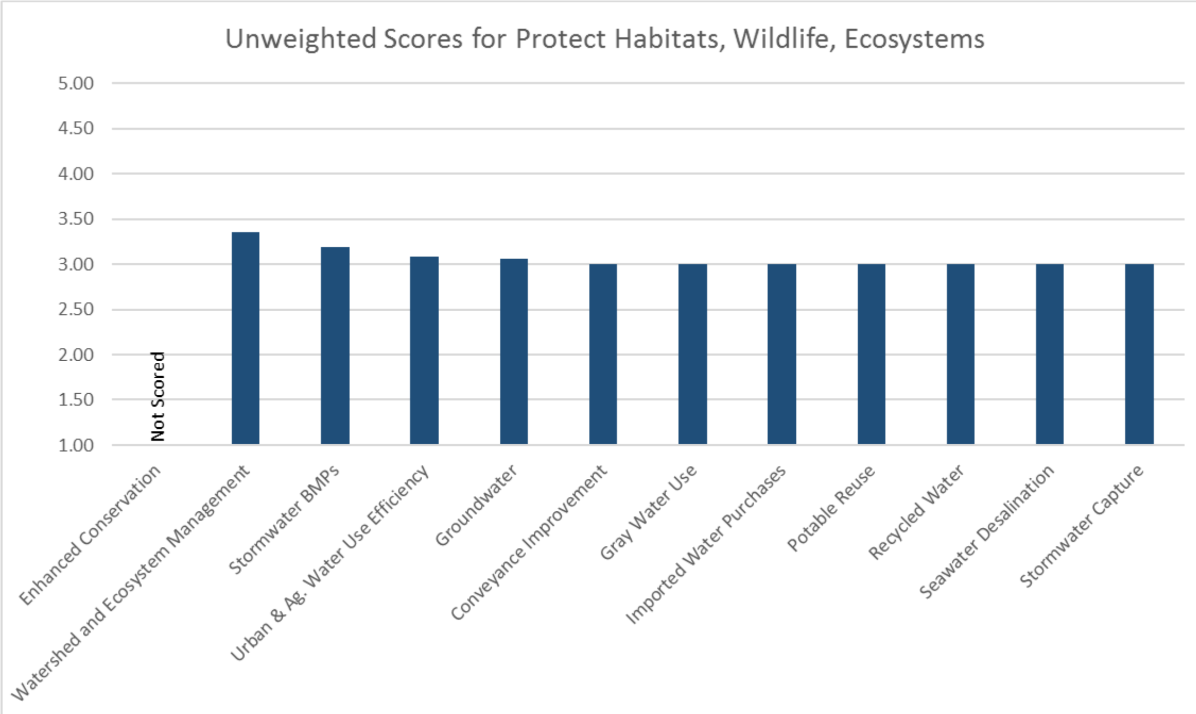


Figure 45. Protect Habitats, Wildlife, and Ecosystems Evaluation Objective unweighted scores.

8.1.8 Provide for Scalability of Implementation

The Scalability of Implementation Evaluation Objective scores were based on one Performance Measure, Project Phasing. The Project Phasing Performance Measure was based on survey responses at the project- and Concept-levels to a question about project potential for phasing and expansion. Extreme difficulty in scaling back, phasing, or expansion resulted in a score of 1. A score of 2 indicated moderate difficulty to expand or phase the project. A score of 3 indicated no or unknown difficulty to expand or phase the project. A 4 meant the project could be easily modified to accommodate a subsequent phase or expansion. Last, a score of 5 indicated that the project is planned and designed to accommodate a subsequent phase or expansion. The Provide for Scalability of Implementation Evaluation Objective scores are presented in Table 31 and Figure 46.

The average score was 3.37. The highest score was 4.07 for Urban and Agricultural Water Use Efficiency. Several projects within this Concept included water conservation rebate programs that are either designed to be phased or can be easily expanded. The lowest score was 2.53 for Seawater Desalination. Nine of the 11 scored Concepts had a score above a neutral 3.0 value. Enhanced Conservation was given a score of NA because it was not included in the surveys.

Table 31. Scalability of Implementation Evaluation Objective Scores

Concept	Scalability of Implementation Evaluation Objective Unweighted Scores
Conveyance Improvement	3.27
Enhanced Conservation	NA
Gray Water Use	3.60
Groundwater	3.07
Imported Water	2.80
Potable Reuse	3.78
Recycled Water	3.85
Seawater Desalination	2.53
Stormwater BMPs	3.22
Stormwater Capture	3.38
Urban & Agricultural Water Use Efficiency	4.07
Watershed & Ecosystem Management	3.50

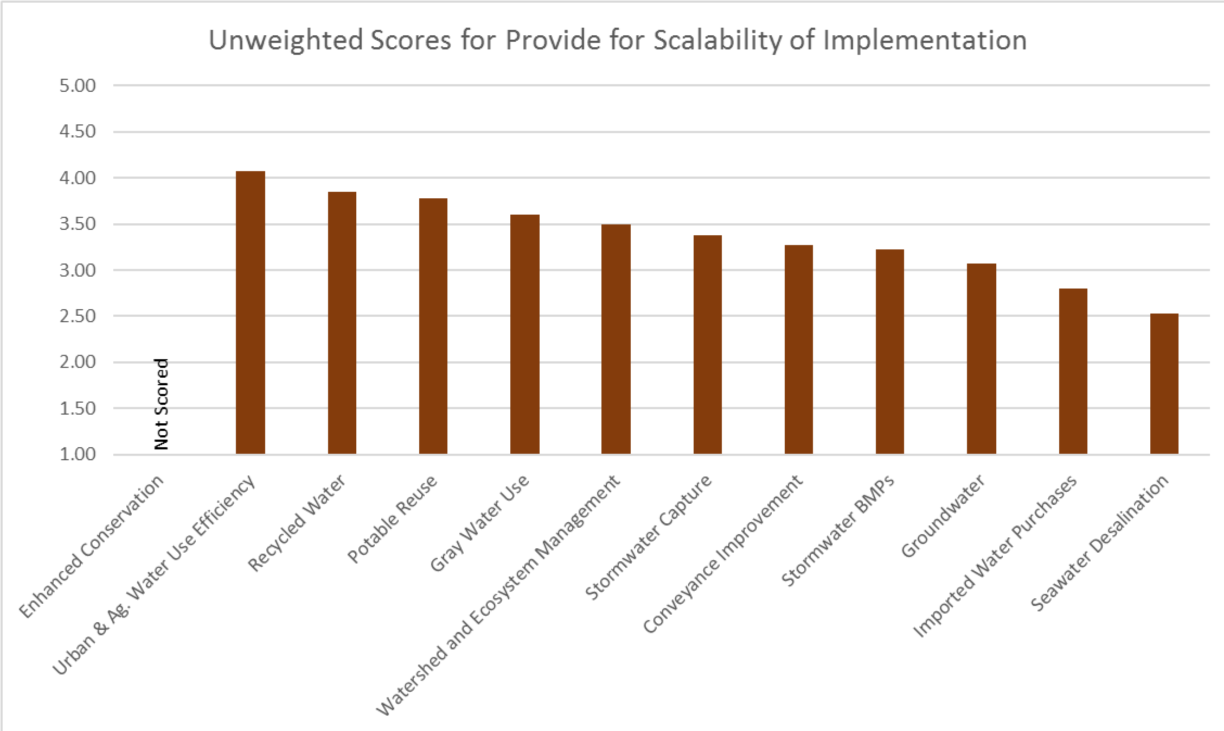


Figure 46. Scalability of Implementation Evaluation Objective unweighted scores.

8.1.9 Quality of Life/Recreation

The Quality of Life/Recreation Evaluation Objective included two Performance Measures, Green Space/Open Space and Recreation Opportunities. The Green Space/Open Space Performance Measure was the average of two sub-scores: Green Space/Open Space and Quality of Life. The Green Space/Open Space Performance Measure was scored on a scale of 1 to 5, with scores of 1 and 2 indicating negative impacts (e.g., reductions in green space quantity or quality, air pollution, noise/nuisance impacts, increased urbanization, view obstruction), scores of 3 indicating no impacts, and scores of 4 or 5 indicating positive impacts (e.g., creation of green space, cultural enrichment). The Recreation Opportunities Performance Measure is the average of two sub-scores: Recreation Opportunities and Visitation Impacts for Changes in Reservoir Elevation. The Recreation Opportunities Performance Measure was scored on a scale of 1 to 5, with scores of 1 or 2 indicating negative impacts (reduction in recreation opportunities or recreation site visitation), a score of 3 indicating no or unknown impacts, and scores of 4 or 5 indicating positive impacts (increase in recreational opportunities or recreation site visitation). All the sub-scores except Visitation Impacts for Changes in Reservoir Elevation were derived directly from the average of project- and Concept-level survey question responses which evaluated projects/concepts for their ability to provide green space/open space and improve quality of life. The Visitation Impacts for Changes in Reservoir Elevation sub-score was derived from recreation visitation modeling results based on modeled changes in reservoir elevation at four reservoirs.

Final Quality of Life/Recreation scores are presented in Table 32 and Figure 47. The Overall Quality of Life/Recreation scores ranged from 3.02 to 4.05 with an average score of 3.46. The highest score was for Watershed and Ecosystem Management and the lowest score was for Seawater Desalination. The Quality of Life /Recreation scores were all neutral or greater, indicating that no Concepts have an overall negative impact on Quality of Life or Recreation.

Table 32. Quality of Life/Recreation Performance Measure and Evaluation Objective Scores

Concept	Green Space/Open Space Performance Measure Scores	Recreation Opportunities Performance Measure Scores	Quality of Life/Recreation Evaluation Objective Unweighted Scores
Conveyance Improvement	3.29	3.98	3.63
Enhanced Conservation	NA	NA	NA
Gray Water Use	3.34	3.00	3.17
Groundwater	3.10	2.95	3.02
Imported Water	3.06	2.97	3.02
Potable Reuse	3.38	3.54	3.46
Recycled Water	4.07	3.40	3.74
Seawater Desalination	3.15	2.88	3.02
Stormwater BMPs	4.41	3.45	3.93
Stormwater Capture	3.44	3.03	3.24
Urban & Agricultural Water Use Efficiency	4.27	3.27	3.77
Watershed & Ecosystem Management	4.64	3.47	4.05

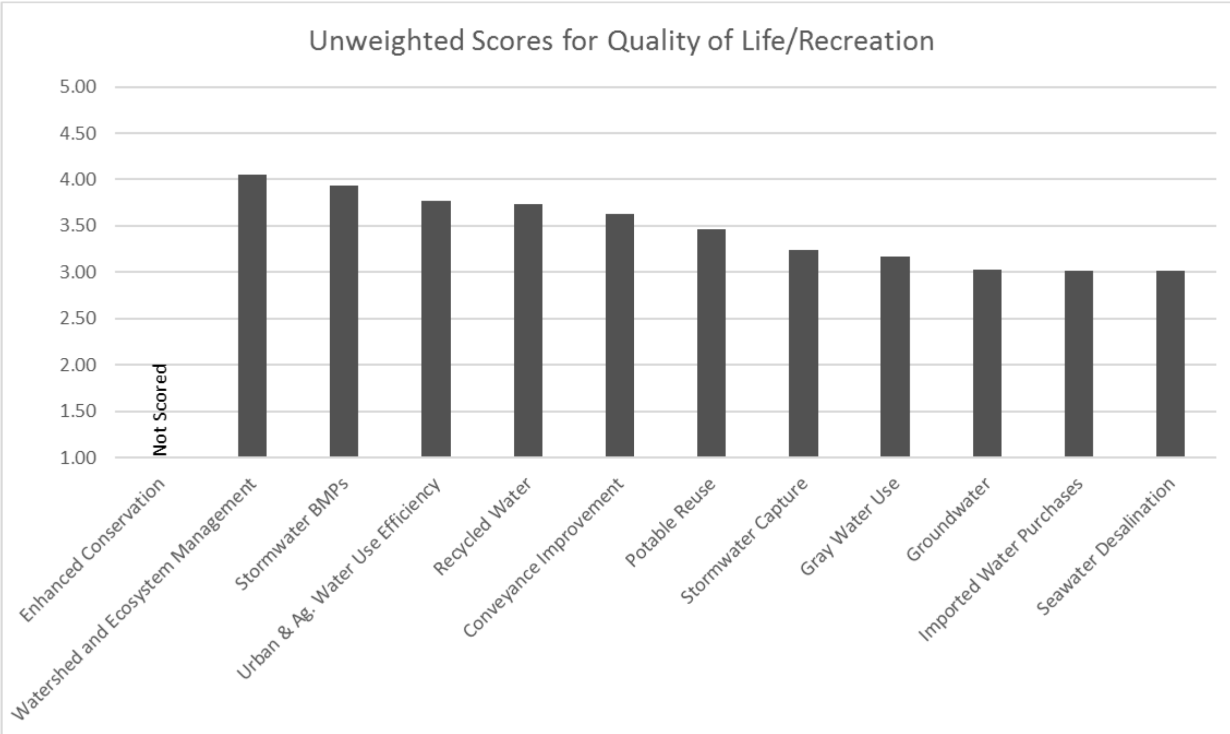


Figure 47. Quality of Life/Recreation Evaluation Objective unweighted scores.

8.1.10 Regional Economic Impact

The Regional Economic Impact Evaluation Objective included one Performance Measure, Regional Economic Impact. The Regional Economic Impact Performance Measure was calculated from a combination of project-level survey responses and responses from a panel of regional economic experts. Survey and panel responses evaluated projects and concepts for their ability to provide regional economic impacts, such as job creation beyond the lifetime of the project. The Regional Economic Impact Performance Measure was scored on a scale of 1 to 5, with scores of 1 and 2 indicating negative impacts to the regional economy, a score of 3 representing no or unknown impact, and scores of 4 and 5 indicating positive impacts to the regional economy.

The Regional Economic Impact results are summarized in Table 33 and Figure 48. Enhanced Conservation was given a score of NA for the project-level surveys because it was not included in the surveys. However, it was included in the questionnaire for regional economic experts, so it was scored at the Concept-level. The Overall Regional Economic Impact scores ranged from 2.60 to 4.80 with an average of 3.79. The highest score was for Recycled Water and the lowest score was for Enhanced Conservation.

Table 33. Regional Economic Impact Performance Measure and Evaluation Objective Scores

Concept	Regional Economic Impact Performance Measure and Evaluation Objective Unweighted Scores
Conveyance Improvement	4.05
Enhanced Conservation	2.60
Gray Water Use	3.50
Groundwater	4.36
Imported Water	2.83
Potable Reuse	4.80
Recycled Water	4.65
Seawater Desalination	3.64
Stormwater BMPs	3.25
Stormwater Capture	4.00
Urban & Agricultural Water Use Efficiency	4.20
Watershed & Ecosystem Management	3.61

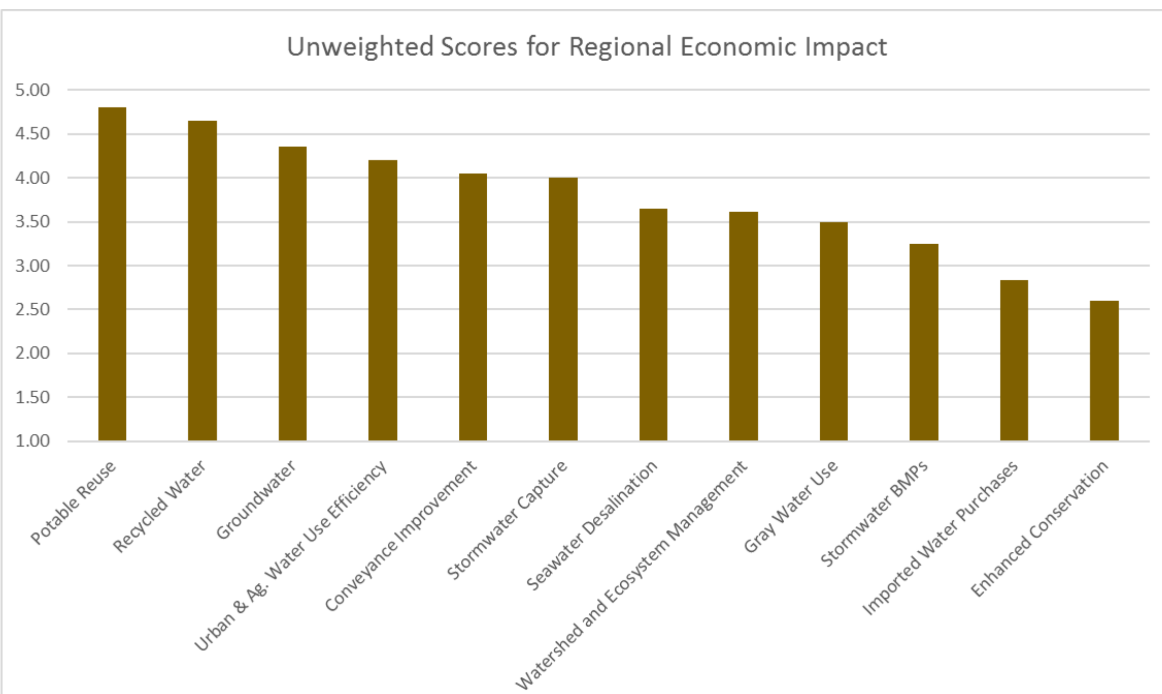


Figure 48. Regional Economic Impact Evaluation Objective unweighted scores.

8.1.11 Regional Integration and Coordination

The Regional Integration and Coordination score was based on two Performance Measures: Coordination, and Education and Outreach, which are both based entirely on project-level and Concept-level survey responses. The Coordination Performance Measure had two sub-scores. The first sub-score, Integration, quantified the level of integration or coordination with other projects or entities that is required to implement a project within a Concept. The second sub-score, Leveraging, quantified the need for leveraging assets or building off existing projects. The Coordination Performance Measure was scored on a scale of 1 to 5, with scores of 1 or 2 indicating that the project/Concept involved no or limited coordination and leveraging, scores of 3 indicating unknown coordination and leveraging, and scores of 4 and 5 indicating that the project/Concept involved integration or leveraging. The Evaluation Objective unweighted score was an average of the two Performance Measures. The Education and Outreach Performance Measure was based on project-level and Concept-level survey responses. The Education and Outreach Performance Measure was scored on a scale of 1 to 5. No education and outreach resulted in a score of 1, very limited education and outreach resulted in a score of 2, limited education and outreach resulted in a score of 3, moderate education and outreach had a score of 4, and significant education and outreach had a score of 5.

The Regional Integration and Coordination Evaluation Objective unweighted scores are presented in Table 34 and Figure 49. The Overall Regional Integration scores ranged from 2.54 to 4.20 with an average of 3.39. The highest score was for Potable Reuse and the lowest score was for Imported Water Purchases. All but two Concepts scored above 3.0, and only one scored above 4.0, indicating that most Concepts require moderate integration or coordination, sometimes require leveraging, and provide limited education and outreach opportunities. Enhanced Conservation was given a score of NA because it could not be scored for either of the two Performance Measures that make up the Evaluation Objective.

Table 34. Regional Integration and Coordination Evaluation Objective and Associated Performance Measures Scores

Concept	Coordination Performance Measure Scores	Education and Outreach Performance Measure Scores	Regional Integration and Coordination Evaluation Objective Unweighted Scores
Conveyance Improvement	3.18	2.43	2.81
Enhanced Conservation	NA	NA	NA
Gray Water Use	2.16	4.20	3.18
Groundwater	3.75	3.35	3.55
Imported Water	3.14	1.93	2.54

Concept	Coordination Performance Measure Scores	Education and Outreach Performance Measure Scores	Regional Integration and Coordination Evaluation Objective Unweighted Scores
Potable Reuse	4.01	4.39	4.20
Recycled Water	3.62	3.65	3.63
Seawater Desalination	3.74	3.88	3.81
Stormwater BMPs	2.58	3.58	3.08
Stormwater Capture	3.25	4.00	3.63
Urban & Agricultural Water Use Efficiency	2.74	4.71	3.73
Watershed & Ecosystem Management	2.39	3.82	3.10

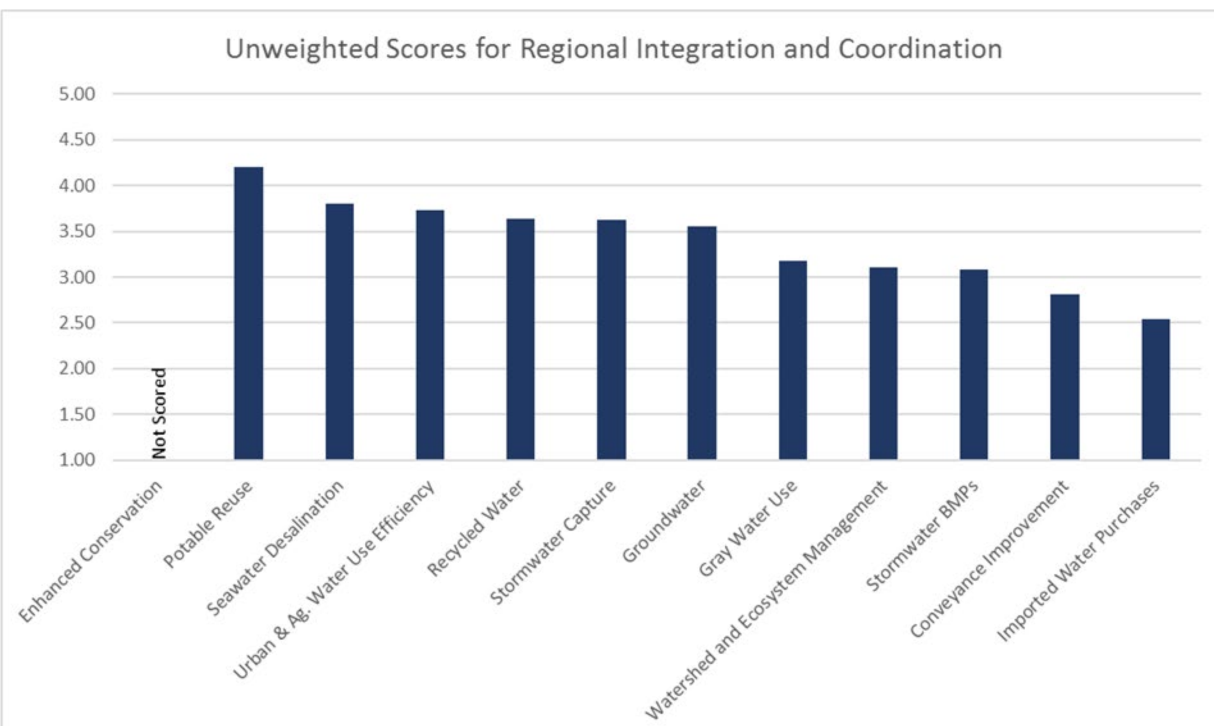


Figure 49. Regional Integration and Coordination Evaluation Objective unweighted scores.

8.1.12 Reliability and Robustness

The Reliability and Robustness Evaluation Objective included three Performance Measures: Water Shortage Volume, Vulnerability of Water Supply Facilities and Infrastructure, and Carryover Storage & Reservoir Augmentation. The Water Shortage Volume Performance Measure was based on modeling results for water shortage volume. It was scored on a scale of 1 to 5, with 1 assigned to the largest relative shortage volume, 3 assigned to a relative shortage volume of zero, 5 assigned to the largest reduction in relative shortage volume, and other values linearly interpolated between 1 and 3 or 3 and 5. The Vulnerability of Water Supply Facilities and Infrastructure was based on responses to four survey questions regarding the ability of a project or Concept to impact the diversity of water supply, impacts on resilience of the conveyance system, impacts on aging infrastructure, and impacts on wastewater flows. Scores of 1 and 2 indicated negative impacts, a score of 3 indicated neutral or unknown impacts, and scores of 4 and 5 indicated positive impacts. The Carryover Storage & Reservoir Augmentation Performance Measure was based on responses to a survey question regarding the impact of a project or Concept on the ability to use the reservoir storage capacity. It was scored on a scale of 1 to 5, with scores of 1 and 2 indicating negative impacts, a score of 3 indicating neutral or unknown impacts, and scores of 4 and 5 indicating positive impacts.

The Reliability and Robustness Evaluation Objective scores, as well as the three Performance Measure scores used to calculate the final overall scores, are shown in Table 35 and Figure 50. All the Reliability and Robustness scores were above a neutral score of 3.0, indicating that none of the Concepts were anticipated to reduce Reliability and Robustness. The average score was 3.60 and the highest-scoring Concept was Potable Reuse, which may be attributed to this Concept having the highest Water Shortage Volume Performance Measure score, in addition to high scores for the other Performance Measures. The lowest-scoring Concepts were Gray Water Use, Imported Water Purchases, and Urban and Agricultural Water Use Efficiency. Enhanced Conservation received a score of NA because it could only be scored on one of the three Performance Measures. However, it should be noted that Enhanced Conservation had the highest Water Shortage Volume Performance Measure score, implying that if the other Performance Measure scores for Reliability and Robustness had been available for this Concept, it would have received a high overall score. The major driving Performance Measure for the Reliability and Robustness Evaluation Objective was the Water Shortage Volume measure. The Imported Water Purchases, Recycled Water, Stormwater BMPs, Stormwater Capture, and Urban and Agricultural Water Use Efficiency Concepts all had very low shortage volume scores which resulted in the low overall scores.

Table 35. Reliability and Robustness Evaluation Objective and Associated Performance Measures Scores

Concept	Water Shortage Volume Performance Measure Scores	Vulnerability of Water Supply Facilities and Infrastructure Performance Measure Scores	Carryover Storage and Reservoir Augmentation Performance Measure Scores	Reliability and Robustness Evaluation Objective Unweighted Scores
Conveyance Improvement	3.10	4.18	4.05	3.78
Enhanced Conservation	5.00	NA	NA	NA
Gray Water Use	3.17	3.39	3.06	3.20
Groundwater	3.81	3.68	3.84	3.78
Imported Water	3.15	2.88	3.59	3.20
Potable Reuse	4.35	3.96	4.26	4.19
Recycled Water	3.88	3.96	3.88	3.90
Seawater Desalination	4.17	3.78	3.78	3.91
Stormwater BMPs	3.01	3.50	3.36	3.29
Stormwater Capture	3.04	3.74	4.11	3.63
Urban & Agricultural Water Use Efficiency	3.14	3.21	3.25	3.20
Watershed & Ecosystem Management	3.12	3.52	3.82	3.49

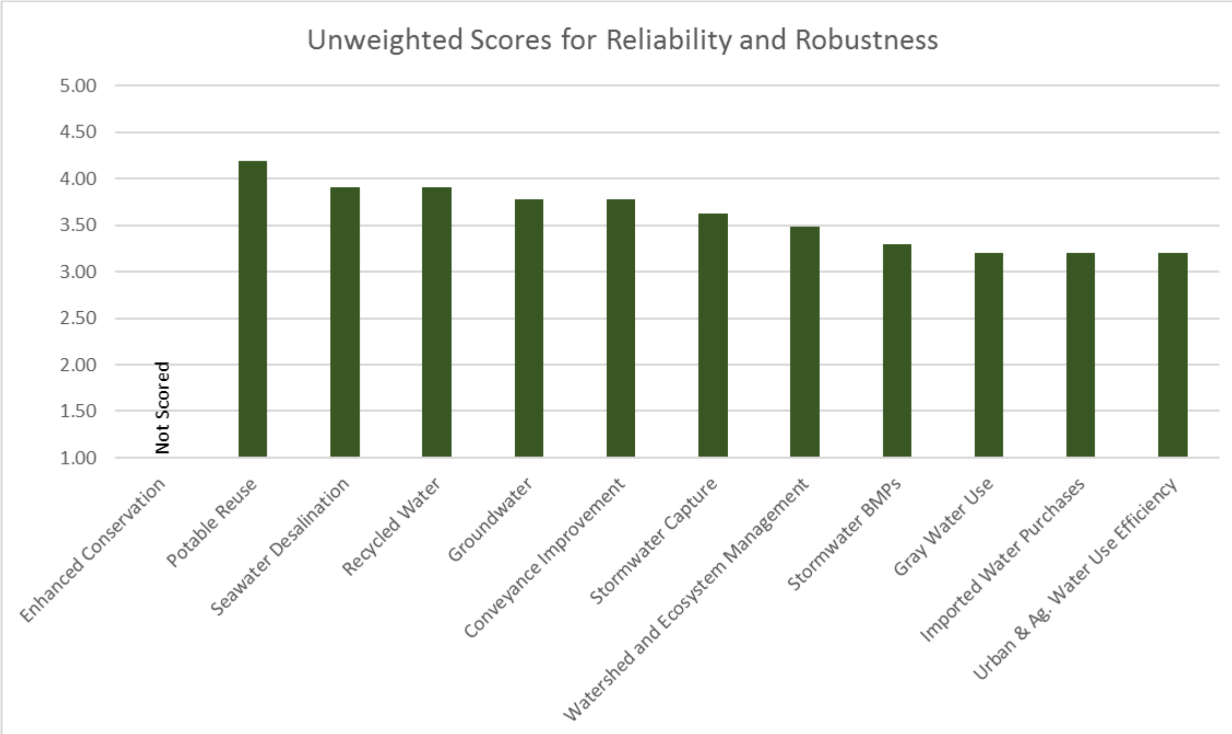


Figure 50. Reliability and Robustness Evaluation Objective unweighted scores.

8.1.13 Water Quality and Watersheds

The Water Quality and Watersheds Evaluation Objective was based on three Performance Measures, Stormwater and Wastewater Discharges, Surface Water Quality, and Groundwater Quality. The Stormwater and Wastewater Discharges Performance Measure was calculated based on two sub-scores: Discharges to Freshwater or Estuarine Water Bodies and Discharges to Marine Water Bodies, which determined whether concepts had a negative, neutral or positive impact on the volume and/or quality of discharge to water bodies. The Performance Measure was scored on a scale of 1 to 5, with scores of 1 and 2 indicating negative impacts, a score of 3 indicating no or unknown impacts, and scores of 4 and 5 indicating positive impacts. The Surface Water Quality and Groundwater Quality Performance Measure scores were based on a combination of project-level survey data and GIS data which evaluated projects/concepts based upon their impact to impaired surface or groundwater bodies identified by CalEnviroScreen Tool. These Performance Measures were also scored on a scale of 1 to 5, with scores of 1 and 2 indicating negative impacts, a score of 3 indicating no or unknown impacts, and scores of 4 and 5 indicating positive impacts.

The scores for each of the three Performance Measures were averaged to derive the Water Quality and Watersheds Evaluation Objective unweighted scores. The scores are summarized in Table 36 and Figure 51 below. The average Water Quality and Watersheds Evaluation Objective unweighted score was 3.45. The highest scoring Concepts were Potable Reuse with a score of 3.98 and Stormwater BMPs with a score of 3.86. The lowest scoring Concept was Seawater Desalination with a score of 2.83. Enhanced Conservation and Imported Water Purchases received scores of NA because they could not be scored for some or all Performance Measures.

Table 36. Water Quality and Watersheds Evaluation Objective and Associated Performance Measures Scores

Concept	Stormwater and Wastewater Discharges Performance Measure Scores	Surface Water Quality Performance Measure Scores	Groundwater Quality Performance Measure Scores	Water Quality and Watersheds Evaluation Objective Unweighted Scores
Conveyance Improvement	3.22	3.00	3.50	3.24
Enhanced Conservation	NA	NA	NA	NA
Gray Water Use	3.56	3.00	3.00	3.19
Groundwater	3.31	3.00	3.78	3.36
Imported Water	2.78	NA	NA	NA
Potable Reuse	3.57	4.25	4.13	3.98
Recycled Water	3.78	3.00	3.00	3.26
Seawater Desalination	2.50	3.00	3.00	2.83
Stormwater BMPs	4.28	4.11	3.21	3.86
Stormwater Capture	4.56	3.00	3.00	3.52
Urban & Agricultural Water Use Efficiency	4.08	3.50	3.00	3.53
Watershed & Ecosystem Management	3.91	4.07	3.21	3.73

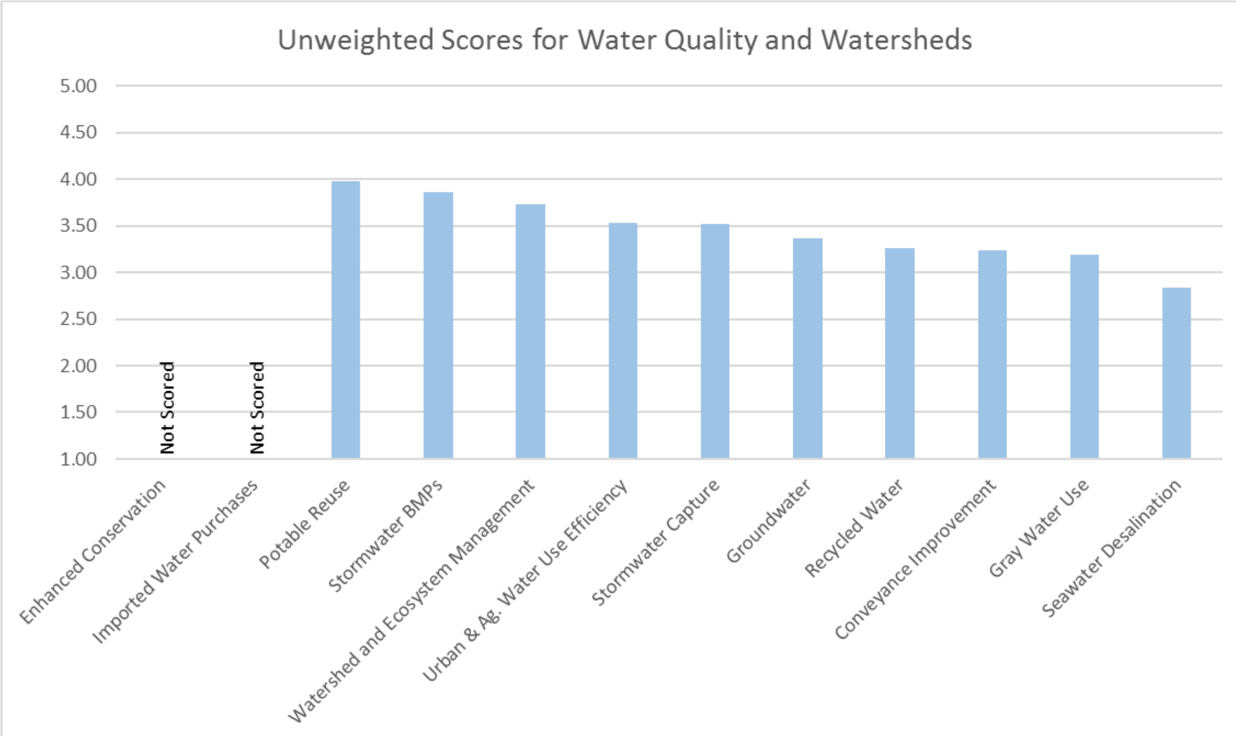


Figure 51. Water Quality and Watersheds Evaluation Objective unweighted scores.

8.2 Trade-Off Analysis Scores Including All Evaluation Objectives and Weighted for Importance

The individual Evaluation Objective analysis results can be used to compare Concepts within a single Evaluation Objective, but the individual results do not provide a comprehensive comparison across all Evaluation Objectives. Multiple Evaluation Objectives can be considered in a trade-off analysis by combining individual scores into a single multi-criterion total score. The total score provides a unit-less comparison of effects summed across Evaluation Objective categories.

An evaluation of multiple Evaluation Objective trade-offs requires the calculated Evaluation Objective unweighted scores to be combined with the Evaluation Objective weights described in Section 7.2.1. These weights are multiplied by the individual Evaluation Objective unweighted scores and divided by 10 (the highest possible importance weight) to derive a final weighted score that accounts for the importance of each Evaluation Objective (Table 37). The Evaluation Objective weights used in this analysis are from survey data collected as part of the Basin Study. However, new or updated weights could be used if additional information was found for a project or area of interest as project planning progresses or the public becomes more aware of and interested in projects under consideration. If it had been determined that each Evaluation Objective had the same level of importance, then weighting could have been skipped.

Table 37. Weighted Evaluation Objective Scores based on Mean Survey Results by Concept

Concept	Address Climate Change through Greenhouse Gas (GHG) Reduction	Climate Resilience	Cost Effectiveness	Environmental Justice	Optimize Local Supplies	Project Complexity	Protect Habitats, Wildlife, and Ecosystems	Provide for Scalability of Implementation	Quality of Life/Recreation	Regional Economic Impact	Regional Integration and Coordination	Reliability and Robustness	Water Quality and Watersheds
Conveyance Improvement	2.61	2.47	1.88	2.61	3.57	2.15	2.76	2.52	2.69	3.16	2.39	3.78	3.24
Enhanced Conservation	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.03	NA	NA	NA
Gray Water Use	2.67	4.80	3.12	NA	3.98	2.23	2.76	2.77	2.35	2.73	2.70	3.20	3.19
Groundwater	2.48	3.57	1.82	2.68	4.67	1.47	2.82	2.36	2.24	3.40	3.02	3.78	3.36
Imported Water Purchases	1.95	NA	2.62	NA	2.64	2.38	2.76	2.16	2.23	2.21	2.16	3.20	NA
Potable Reuse	2.61	2.54	1.62	2.72	4.55	1.28	2.76	2.91	2.56	3.74	3.57	4.19	3.98
Recycled Water	2.88	2.70	2.13	2.65	4.61	2.28	2.76	2.96	2.77	3.63	3.09	3.90	3.26
Seawater Desalination	1.93	4.80	1.39	NA	4.70	1.07	2.76	1.95	2.23	2.84	3.23	3.91	2.83
Stormwater BMPs	2.75	4.17	2.44	2.85	3.31	2.27	2.94	2.48	2.91	2.54	2.62	3.29	3.86
Stormwater Capture	2.60	4.80	2.27	2.61	4.49	1.80	2.76	2.60	2.39	3.12	3.08	3.63	3.52
Urban & Ag. Water Use Efficiency	3.08	3.60	3.49	3.05	4.00	3.02	2.84	3.14	2.79	3.28	3.17	3.20	3.53
Watershed and Ecosystem Management	2.97	3.82	2.48	3.30	3.62	2.07	3.08	2.70	3.00	2.82	2.64	3.49	3.73

The Trade-off Analysis results for all the Evaluation Objectives (see Sections 7.4.1 through 7.4.13) using the Evaluation Objective weights are presented in Table 38 and Figure 52. Only eight of the 13 Concepts can be directly compared with the Trade-off Analysis because some Concepts were not scored for all Evaluation Objectives, so the total possible points differs for those Concepts. In addition to the total weighted scores, the scores are converted to a relative point scale where a 100 corresponds to the Concept with the highest point total, and the percent difference from the highest-scoring Concepts is also tabulated. The purpose of this information is to provide a more intuitive indicator of the relative position of each Concept.

Of those Concepts that could be directly compared, the highest-scoring Concept was Urban and Agricultural Water Use Efficiency, with a score of 42.16 points out of a possible 56.15 points. This Concept scored more than two points higher than any other Concept, and was the only Concept that scored above 40 points. All Concepts that could be directly compared scored within 15% of the highest-scoring Concept. No Concepts scored within 5% of the highest-scoring Concept. Five Concepts scored within 10% of the highest-scoring Concept: Watershed and Ecosystem Management, Stormwater Capture, Recycled Water, Potable Reuse, and Stormwater BMPs. The other two directly comparable Concepts, Groundwater and Conveyance Improvement, scored within 15% of the highest-scoring Concept.

Enhanced Conservation was scored only for one of the 13 Evaluation Objectives (Regional Economic Impact). Imported Water Purchases was not scored for three Evaluation Objectives (Climate Resilience; Environmental Justice; and Water Quality and Watersheds). Seawater Desalination and Gray Water Use were not scored for Environmental Justice.

Table 38. Total and Relative Points by Concept including All Evaluation Objectives and Using Mean Survey Scores

Concept	Rank	Total Scores Weighted by Importance	Total Possible Weighted Points	Relative Points on a 1 to 100 scale	Percent Difference from Highest Score
Concepts Scored for ALL Evaluation Objectives					
Urban & Ag. Water Use Efficiency	1	42.16	56.15	100.00	0%
Watershed and Ecosystem Management	2	39.72	56.15	94.21	6%
Stormwater Capture	3	39.67	56.15	94.10	6%
Recycled Water	4	39.62	56.15	93.97	6%
Potable Reuse	5	39.03	56.15	92.58	7%
Stormwater BMPs	7	38.42	56.15	91.12	9%
Groundwater	8	37.66	56.15	89.34	11%
Conveyance Improvement	9	35.82	56.15	84.96	15%
Concepts NOT Scored for All Evaluation Objectives					
Gray Water Use[a]	NA	36.50	51.80	NA	NA
Seawater Desalination[b]	NA	33.64	51.80	NA	NA
Imported Water Purchases[c]	NA	24.30	42.00	NA	NA
Enhanced Conservation[d]	NA	2.03	3.90	NA	NA

[a] Not Scored for Environmental Justice (maximum weighted score 51.80 points)

[b] Not Scored for Environmental Justice (maximum weighted score 51.80 points)

[c] Not scored for Climate Resilience, Environmental Justice, and Water Quality and Watersheds (maximum weighted score 42.00 points)

[d] Scored only on Regional Economic Impact (maximum weighted score 3.90 points)

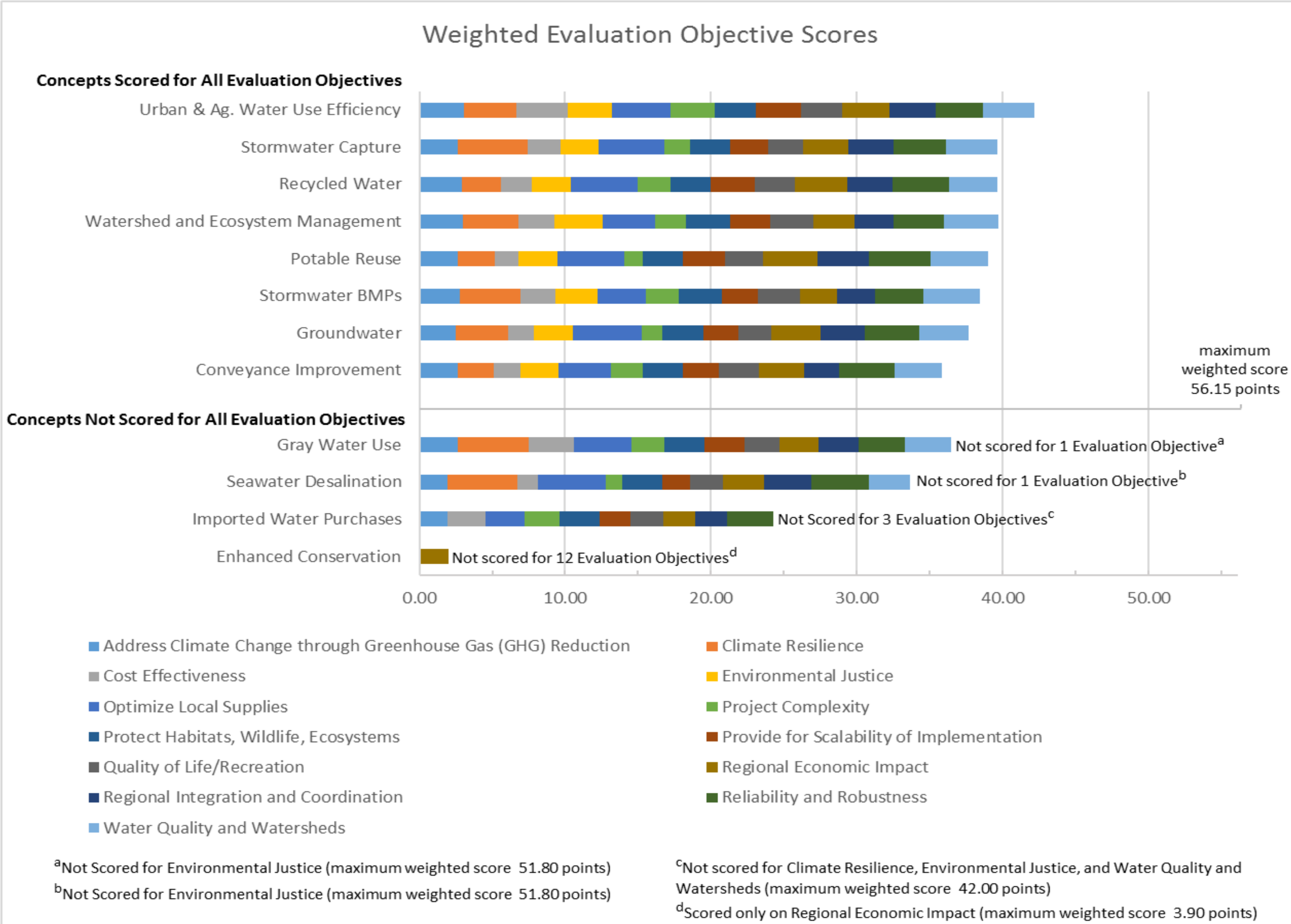


Figure 52. Trade-off analysis results for each Concept by Evaluation Objective, excluding Imported Water Purchases and Enhanced Conservation.

8.2.1 Analysis of the Statistical Difference in Unweighted Evaluation Objective Scores between Concepts

The scores reported in the previous section were based in part on mean (average) responses from the project- and Concept-level surveys (scoring inputs were also obtained from GIS and modeling data). Mean responses were used to represent the central tendency of individual survey responses for use in estimating various performance measures. The mean value is an appropriate representative measure when the data set does not have outlying values that would skew the mean. If there are outliers, then the median (middle) value may be a better representation of central tendency. However, the survey responses did not exhibit a large number of outliers, so the use of mean values was appropriate.

Although use of the mean was appropriate based on lack of outliers, another potential issue related to the use of mean values to estimate performance measure and Evaluation Objective scores is the statistical significance of the differences in means between Concepts. The accuracy of trade-off analysis results is contingent upon accurate measurement of differences in the performance of various Concepts. In some cases, differences in mean values may not accurately represent differences in the central tendency of the value of those variables. This would primarily be the case if the median is a better representation of central tendency compared to the mean. Therefore, it was important to determine the significance of differences in the mean survey question responses.

The mean responses for each of the project- and Concept-level survey questions for the individual Concepts were compared to determine if there was a significant difference between the mean responses for each Concept. Significance is based on the application of a pooled t-test, which uses the variation of values around the means of two different groups to test for a significant difference between those means. The mean of a specific variable for two groups may be different, but depending on variability in the survey responses, the difference in means may not be statistically significant. A non-significant difference between the mean responses for a specific survey question for two Concepts does not signify that the survey responses are inaccurate, but instead, that the performance of the two Concepts for the specific measure represented by the question is essentially the same. Use of different calculated mean responses for each Concept when the difference is not significantly different could lead to biased relative scores. The amount of bias is likely to be small if the mean responses for two Concepts are very close, but it is important to understand the potential for bias and the possible magnitude of bias.

As an example, the Concept-level survey included a question that asked about the extent to which a Concept would increase the diversity of the water supply. The mean value for the Groundwater Concept was 4.8125 and the mean value for the Recycled Water Concept responses was 4.9375. A pooled t-test was used to determine if there was a significant difference in the mean value of responses to the diversity of water supply question. The calculated pooled t-test p-value was 0.41 compared to a statistically significant critical p-value of 0.05 (the 5% level of significance is the standard level used for determining significance). Since the p-value for the comparison of

Groundwater to Recycled Water (0.41) was higher than the critical p-value value (0.05), the mean diversity of water supply responses for the Groundwater Concept and the Recycled Water Concept were determined to not be significantly different (e.g., they increase the diversity of water supply equally). This approach was applied to all the project-level and Concept-level questions used to calculate Performance Measure Values.

Across the Concepts and survey questions that could be compared, approximately 76% of the pooled t-test results for the project-level survey responses indicated the mean values were significantly different between Concepts, and 79% of the Concept-level survey means were significantly different between Concepts. This is a relatively high percentage, indicating that the potential for bias from using mean scores is relatively low.

8.3 Scores for Sub-Sets of Evaluation Objectives

The Trade-off Analysis results presented above include all Evaluation Objectives. Trade-off analyses with subsets of Evaluation Objectives can also be completed to evaluate specific Evaluation Objectives of interest. As examples, two additional trade-off analyses were completed using two subsets of Evaluation Objectives. The first example subset includes Evaluation Objectives that evaluate cost and feasibility: Cost Effectiveness; Project Complexity; Provide for Scalability of Implementation; and Regional Integration and Coordination. The second example subset includes Evaluation Objectives that evaluate environmentally-related factors: Address Climate Change through GHG Reduction; Climate Resilience; Environmental Justice; Protect Habitats, Wildlife, and Ecosystems; and Water Quality and Watersheds. The results of these two example subset trade-off analyses are presented in Table 39 and Table 40 and in Figure 53 and Figure 54.

A comparison of results for the three different groups of Evaluation Objectives is shown in Table 41. For the cost and feasibility subset, 11 of the 12 Concepts had scores for all Evaluation Objectives included in the subset, but Enhanced Conservation did not receive scores for any of the Evaluation Objectives included in the subset. For the Environmentally-related subset, eight of the 12 Concepts had scores for all Evaluation Objectives included in the Subset, but Enhanced Conservation was not scored for any of the Evaluation Objectives, Imported Water Purchases was only scored for two of the five Evaluation Objectives, and Seawater Desalination and Gray Water Use were only scored for four of the five Evaluation Objectives included in the subset. The Concepts that were not scored on all Evaluation Objectives included in the subset are not directly comparable to the other Concepts.

Table 39. Total Scores and Relative Points by Concept including Cost- and Feasibility-related Evaluation Objectives

Concept	Rank	Total Scores	Maximum Possible Weighted Score	Relative Points on a 1 to 100 scale
Concepts Scored for ALL Evaluation Objectives				
Urban & Agricultural Water Use Efficiency	1	12.81	16.00	100.00
Gray Water Use	2	10.82	16.00	84.49
Recycled Water	3	10.46	16.00	81.64
Watershed and Ecosystem Management	4	9.89	16.00	77.17
Stormwater BMPs	5	9.80	16.00	76.53
Stormwater Capture	6	9.74	16.00	76.07
Potable Reuse	7	9.38	16.00	73.21
Imported Water Purchases	8	9.31	16.00	72.66
Conveyance Improvement	9	8.94	16.00	69.76
Groundwater	10	8.67	16.00	67.66
Seawater Desalination	11	7.64	16.00	59.65
Concepts NOT Scored for All Evaluation Objectives				
Enhanced Conservation	NA	0.00	0.00	NA

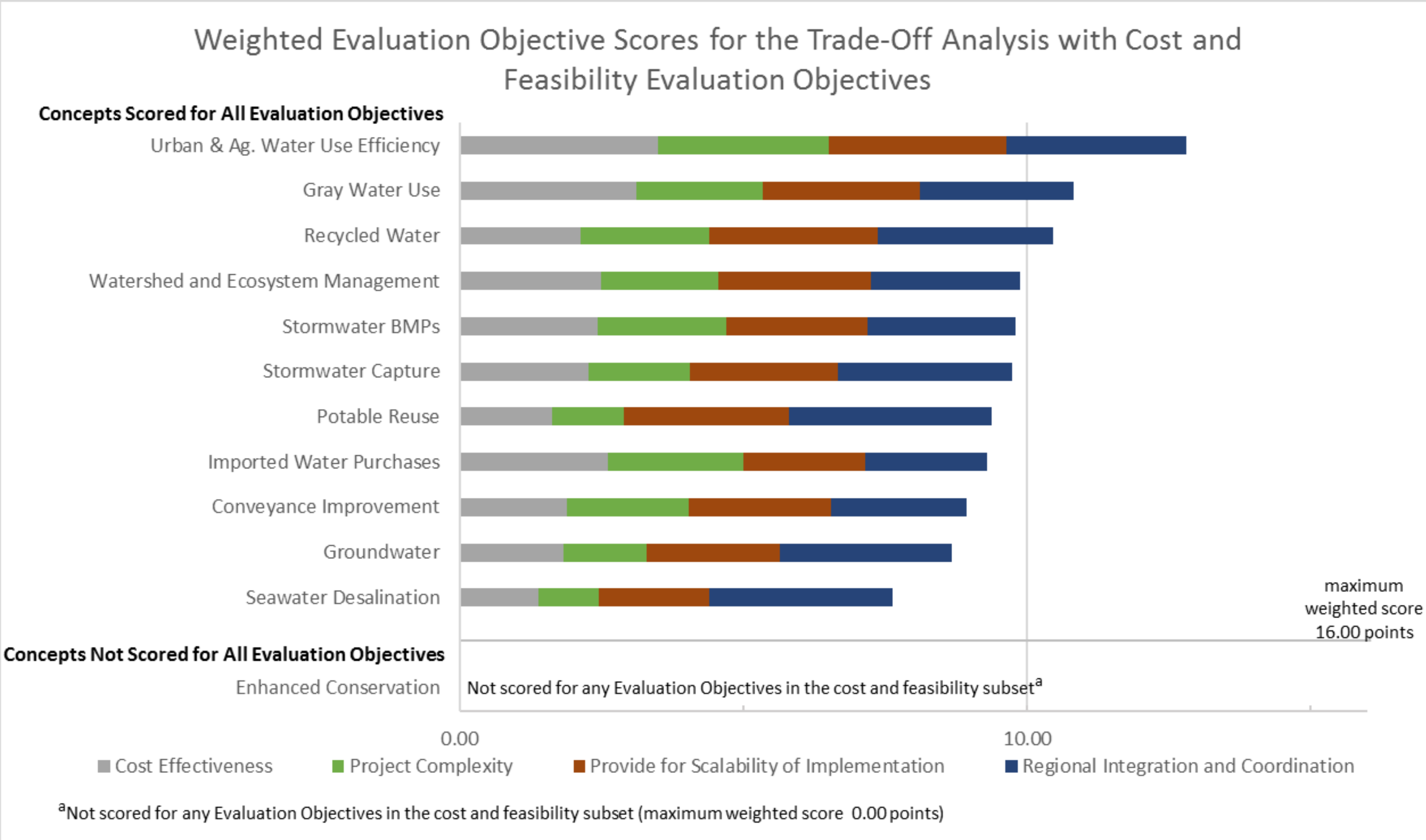


Figure 53. Trade-off analysis results using a subset of cost- and feasibility-related Evaluation Objectives.

Table 40. Total Scores and Relative Points by Concept including Environmentally-related Evaluation Objectives

Concept	Rank	Total Scores	Maximum Possible Weighted Score	Relative Points on a 1 to 100 scale
Concepts Scored for ALL Evaluation Objectives in the Subset				
Watershed and Ecosystem Management	1	16.91	22.85	100.00
Stormwater BMPs	2	16.56	22.85	97.98
Stormwater Capture	3	16.29	22.85	96.38
Urban & Ag. Water Use Efficiency	4	16.08	22.85	95.14
Groundwater	5	14.91	22.85	88.22
Potable Reuse	6	14.61	22.85	86.44
Recycled Water	7	14.25	22.85	84.31
Conveyance Improvement	8	13.69	22.85	80.98
Concepts NOT Scored for All Evaluation Objectives in the Subset				
Gray Water Use	NA	13.41	18.50	NA
Seawater Desalination	NA	12.32	18.50	NA
Imported Water Purchases	NA	4.71	8.70	NA
Enhanced Conservation	NA	0.00	0.00	NA

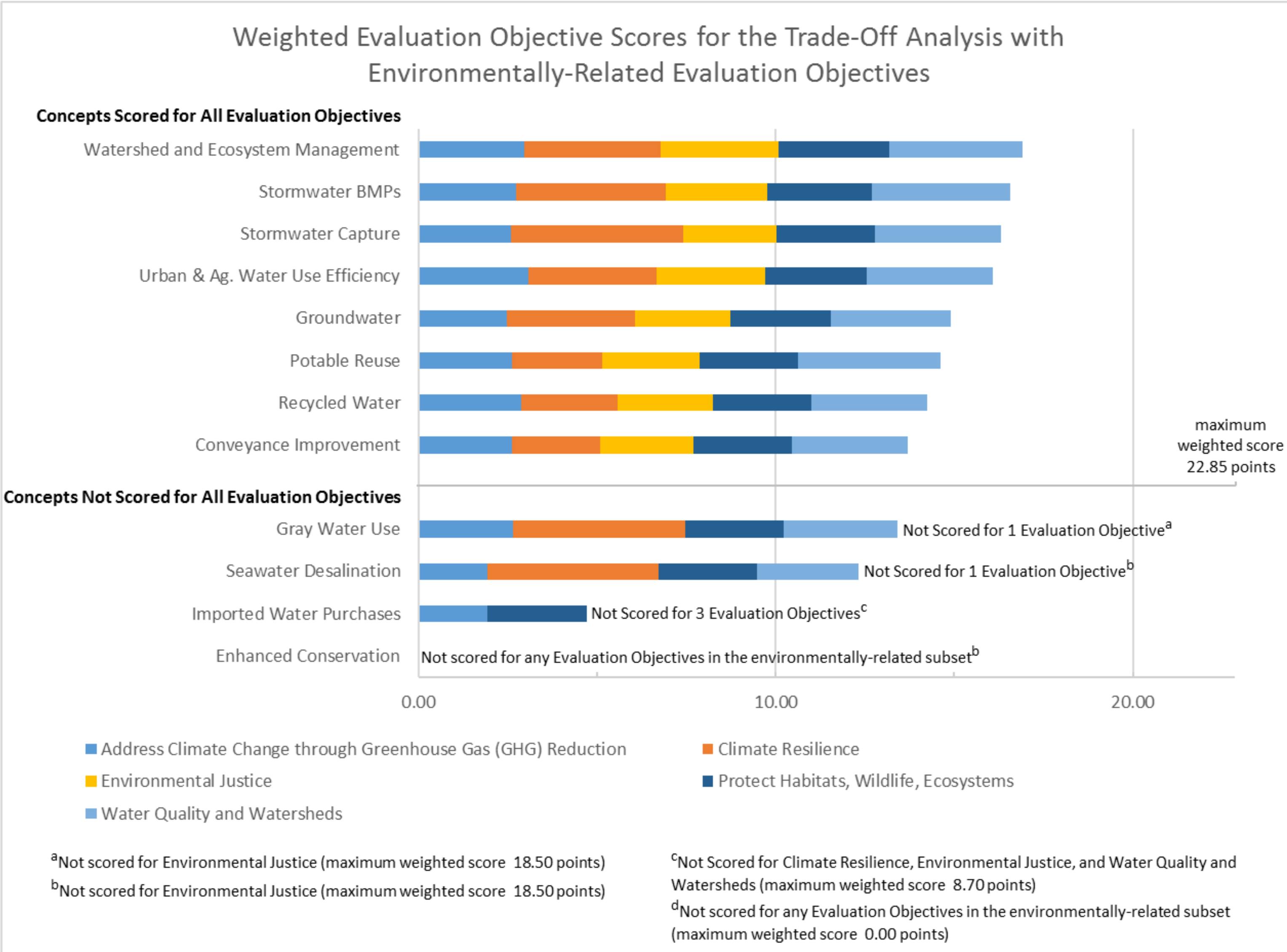


Figure 54. Trade-off analysis results for a subset of environmentally-related Evaluation Objectives.

Table 41. Trade-off Analysis Rankings based on All Evaluation Objectives, Environmentally-related Evaluation Objectives, and Cost/Feasibility Evaluation Objectives for Concepts that Received Scores for All Evaluation Objectives

Concept	Rank Based on All Evaluation Objectives	Rank for Cost and Feasibility Evaluation Objectives Subset	Rank for Environmentally-Related Evaluation Objectives Subset
Urban & Ag. Water Use Efficiency	1	1	4
Watershed and Ecosystem Management	2	4	1
Stormwater Capture	3	6	3
Recycled Water	4	3	7
Potable Reuse	5	7	6
Stormwater BMPs	6	5	2
Groundwater	7	10	5
Conveyance Improvement	8	9	8
Gray Water Use	NA	2	NA
Seawater Desalination	NA	11	NA
Imported Water Purchases	NA	8	NA
Enhanced Conservation	NA	NA	NA

Including only a sub-set of Evaluation Objectives clearly changed the ranking of the Concepts in the Trade-off Analysis results from the ranking using all Evaluation Objectives. For both the trade-off analysis including all Evaluation Objectives and the trade-off analysis using the cost/feasibility subset of Evaluation Objectives, the Urban and Agricultural Water Use Efficiency Concept had the greatest number of points, while the analysis including environmentally-related Evaluation Objectives dropped the Urban and Agricultural Water Use Efficiency Concept to fourth highest. Watershed and Ecosystem Management was raised to the highest ranking in the subset including environmentally-related Evaluation Objectives, from the second-ranked Concept including all Evaluation Objectives and fourth-ranked Concept using cost/feasibility related Evaluation Objectives. This demonstrates the potentially large influence that different perspectives on regional objectives, as reflected through the use of different subsets of Evaluation Objectives, can have on the Trade-off Analysis results.

There are many combinations of Evaluation Objectives that could be evaluated to reflect effects that are considered most important. In order to facilitate evaluation of different combinations of Evaluation Objectives, a customized trade-off analysis tool was published as part of the Task 2.5 Interim Report. This tool allows the user to choose the Evaluation Objectives included in the Trade-off Analysis, to choose the Concepts considered, and to modify the weights indicating the importance of different Evaluation Objectives.

9. Supplemental Economic Assessment

Although the primary mechanism of comparing Concepts for the Basin Study was to complete the Trade-Off Analysis, a Supplemental Economic Assessment was also completed to provide an estimation of quantifiable, monetized benefits to inform decision-makers. Although there are some crossovers between an economic assessment and a trade-off analysis (for example, the economic benefits from additional water supplies can be estimated as the volume in acre-feet multiplied by the value per acre-foot while a trade-off analysis can account for differences in water supply volumes by comparing differences in volumes for different Concepts), the Supplemental Economic Assessment performed here included a much smaller number of categories of benefits than the Trade-Off Analysis. The Supplemental Economic Assessment evaluated three categories of benefits that could be quantified and monetized relative to Baseline conditions: municipal and industrial water supply reliability (reduced shortages), recreation (reservoir visitation), and net energy usage.

9.1 Methods Used to Estimate Economic Benefits and Costs

Calculation of the economic benefits associated with water supply reliability, recreation, and energy usage relied on comparisons of model outputs for each single Concept model run relative to the Baseline model run (see Section 7.3.1.1) and data obtained from the literature as described below.

9.1.1 Municipal and Industrial Water Supply Reliability Benefits

The economic value of water supply reliability was calculated from the relative change in water supply shortages for each Concept and the value of avoided shortages compared to the Baseline. Based on a study by Koss and Khawaja, the avoided 1 in 10 year 10% shortage value was estimated to be approximately $12 per household per month (Koss & Khawaja, 2001). Using data on the average domestic water use in California (U.S. Geological Survey, 2014) and the average household size for California (U.S. Census Bureau, 2012), average annual water use was estimated to be 114,318 gallons per household (0.351 acre-feet per household) for California. Water reliability benefits were translated into a value per acre-foot by multiplying the average monthly water reliability values by 12 months, indexing the values to 2016 dollars using the Consumer Price Index for all urban consumers, and dividing the result by the estimated average annual water use in acre-feet. The water reliability benefit (value of avoided water supply shortage) was estimated to be $682 per acre-foot annually.

Annual total water supply shortage volumes from the Single Concept Portfolio model runs were used to evaluate the impact of different Concepts on water shortages relative to the Baseline model run.

9.1.2 The Economic Value of Recreation

The economic value of recreation was calculated from the relative change in reservoir visitation for each Concept and the value of recreation at reservoirs compared to the Baseline. A recreation value of $23.90 per day was used to evaluate recreation benefits for the San Diego Basin Study based on a California outdoor recreation economic study prepared for the California State Parks Department (BBC Research and Consulting, undated).

Average monthly reservoir elevations from the Single Concept Portfolio model runs were input into a recreation visitation model developed for the study. The recreation visitation modeling coefficients were used to estimate differences in visitation at the four recreation sites evaluated in the model.

9.1.3 Energy Usage Values

The economic value of energy usage was calculated from the relative change in annual net energy for each Concept and the avoided cost of power generation compared to the Baseline. Model metrics from the Task 2.5 single Concept model runs (Section 7.3.1.1) were used as the basis for estimating the change in annual net energy. The value of energy is based on the avoided cost of power generation, which assumes that the value of energy is equal to the cost of generating an extra unit of power for the Study Area. The avoided cost of power generation was calculated from the net energy usage of a Concept relative to the Baseline, and the Locational Marginal Price (LMP) for power in the San Diego area. The CWASim model output Net Energy was used to quantify net energy usage (see Table 18). The net energy usage for each Concept was then subtracted from the Baseline net energy usage to calculate the net energy usage relative to Baseline for each Concept. The California Independent System Operator website indicated the day-ahead market LMP for the San Diego area as of September 10, 2018 was about $34 per megawatt hour (MWh) (California ISO, 2018). Assuming that the current methods and costs of generating power will continue into the future, the value of energy was calculated by multiplying the LMP by the annual change in net energy usage for each Concept relative to the Baseline to obtain an annual value of change in net energy usage relative to the Baseline.

9.2 Economic Assessment Results

The results of the Economic Assessment are presented in Table 42 and Figure 55. All the Concepts generated positive benefits associated with reducing water shortages. Reduction in water supply shortages was an underlying goal of all Concepts because the purpose of the Concepts is to describe similar strategies or projects that could be used to meet the water demands of the region. Therefore, positive benefits associated with reduced water shortages would be expected for all Concepts. Enhanced Conservation generated the greatest reduced water shortage benefits 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. The Watershed and Ecosystem Management Concept had negative recreation benefits due to the inclusion of the Hodges Water Quality Improvement Program project in this Concept, which improves water quality, thereby allowing larger releases of stored water and resulting in lower reservoir elevations. Conveyance Improvement had the highest positive net value of recreation activities.

The reduction in net energy usage relative to the Baseline varied widely between Concepts. Two Concepts, Seawater Desalination and Conveyance Improvements, used more energy compared to the Baseline. The remaining Concepts used less energy compared to the Baseline. Enhanced Conservation had the largest net benefit of decreased energy usage, with a value that was more than three times the value of 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 water import, treatment, and conveyance. Potable Reuse, Recycled Water, and Groundwater also had net energy usage values that represented significant reductions compared to the Baseline.

The combined quantified and monetized economic effects for the three categories of benefits analyzed were positive relative to the Baseline for all Concepts except Seawater Desalination. Enhanced Conservation, Potable Reuse, and Recycled Water provided the greatest estimated quantifiable net benefit. Enhanced Conservation generated the greatest overall positive benefit relative to the Baseline for the three categories of benefits analyzed and had a net annual value more three times larger than any other Concept, primarily due to its large reduction in energy usage. The only Concept with a net negative benefit was Seawater Desalination, due to a high negative net energy value compared to the other Concepts. Recreation values played a comparatively small role in the Economic Assessment results.

Table 42. Estimated Value of Quantified and Monetized Effects Relative to Baseline

Concept	Annual Value of a Change in Water Shortages Relative to Baseline	Annual Change in the Value of Recreation Activities Relative to Baseline	Annual Value of a Change in Net Energy 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

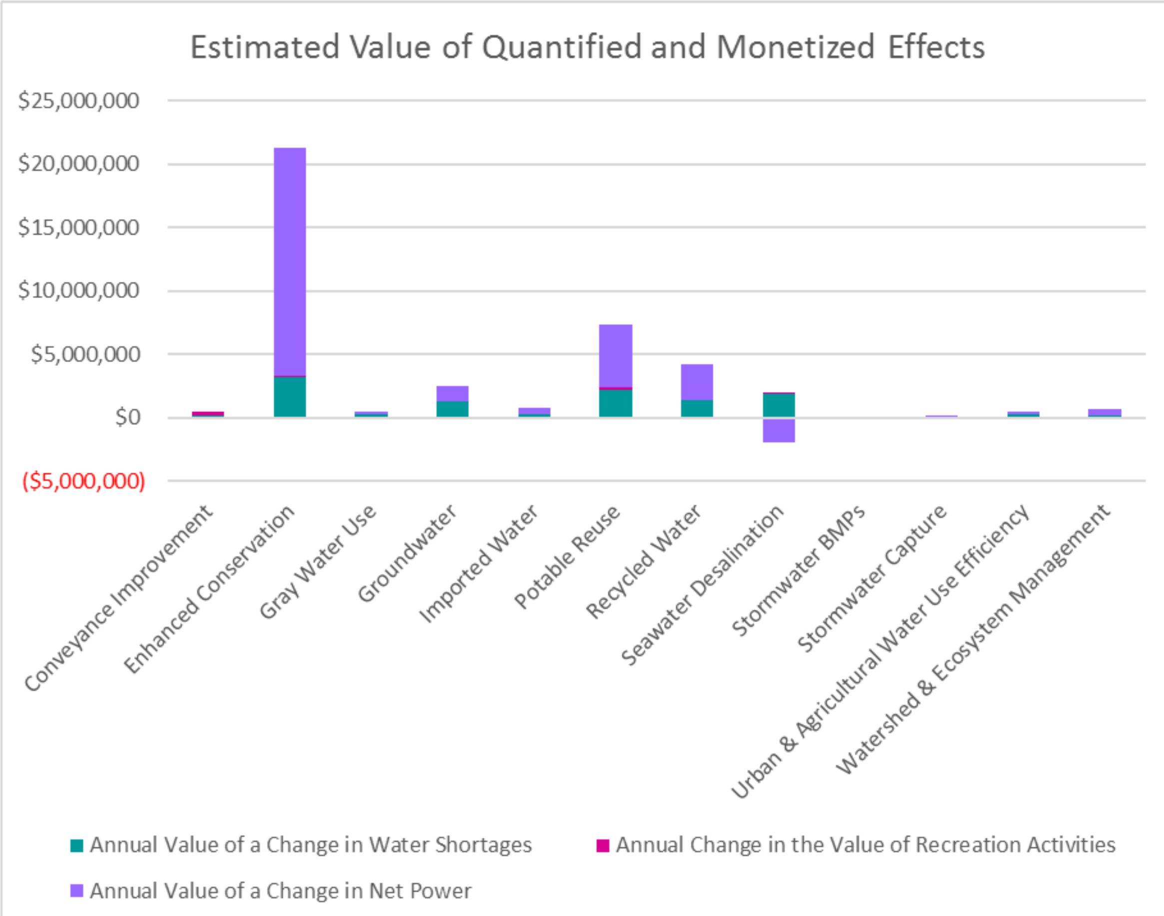


Figure 55. Estimated Annual Value of Quantified and Monetized Effects.

9.3 Comparison of Economic Assessment to Trade-Off Analysis Ranking

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 43. Since the Trade-off Analysis for Enhanced Conservation, Gray Water Use, Imported Water Purchases, and Seawater Desalination did not include all the Evaluation Objectives, the Trade-off Analysis and Economic Assessment results were not compared for these Concepts.

Table 43. Comparison of Concept Rankings for the Trade-off Analysis and Economic Assessment

Concept	Trade-Off Analysis Ranking based on all Evaluation Objectives	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 and 3rd in the Trade-off Analysis using means). There was also a fairly large difference between the ranking of Stormwater BMPs (6th in the Trade-off Analysis 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.

10. Results Discussion by Concept

The following sections provide a discussion of results by Concept, including results from the Impacts Assessment, Trade-Off Analysis, and Economic Assessment.

10.1 Conveyance Improvement

In the impact assessment, the Conveyance Improvement Concept was included in the Baseline, Baseline Plus, and Optimize Existing Facilities Portfolios. In the Baseline Portfolio, this Concept represented water treatment plants, pump stations, and pipelines as they existed in the Study Area in 2015. Two projects that modify conveyance facilities were included in the Baseline Plus Portfolio, and four additional projects were included in the Optimize Existing Facilities Portfolio. While Conveyance Improvement projects do not directly supply additional water to the region, they are able to increase the amount of water that can be delivered. As discussed in Section 6.1.4, some of the shortages observed can be attributed to conveyance restrictions caused by pipelines operating at their full capacity. Although pump station capacity did not appear to be a constraint during the model runs (Section 6.1.4.3), pipeline utilization appeared to be a constraint in the MWD Untreated pipeline (Section 6.1.4.2).

Conveyance Improvement projects can also affect the amount of water stored in reservoirs, which can impact water supply, recreation, and flood control. For example, Monthly Average Reservoir Storage in El Capitan appeared to be significantly higher in the Optimize Existing Facilities Portfolio for 2050 demands than in the Baseline Plus Portfolio for 2050 demands (see Figure 57). This increased storage was observed for all months of the year. This increased storage in the El Capitan is available due to the San Diego Reservoir Intertie project, which removed California Department of Water Resources, Division of Safety of Dams restrictions on reservoir storage. As seen in Figure 56, fewer flood outflows occur in the 2050 scenario in the Optimize Existing Facilities Portfolio when the San Diego Reservoir Intertie is implemented than in the Baseline Plus Portfolio, which indicates that implementation of this project would likely reduce water loss.

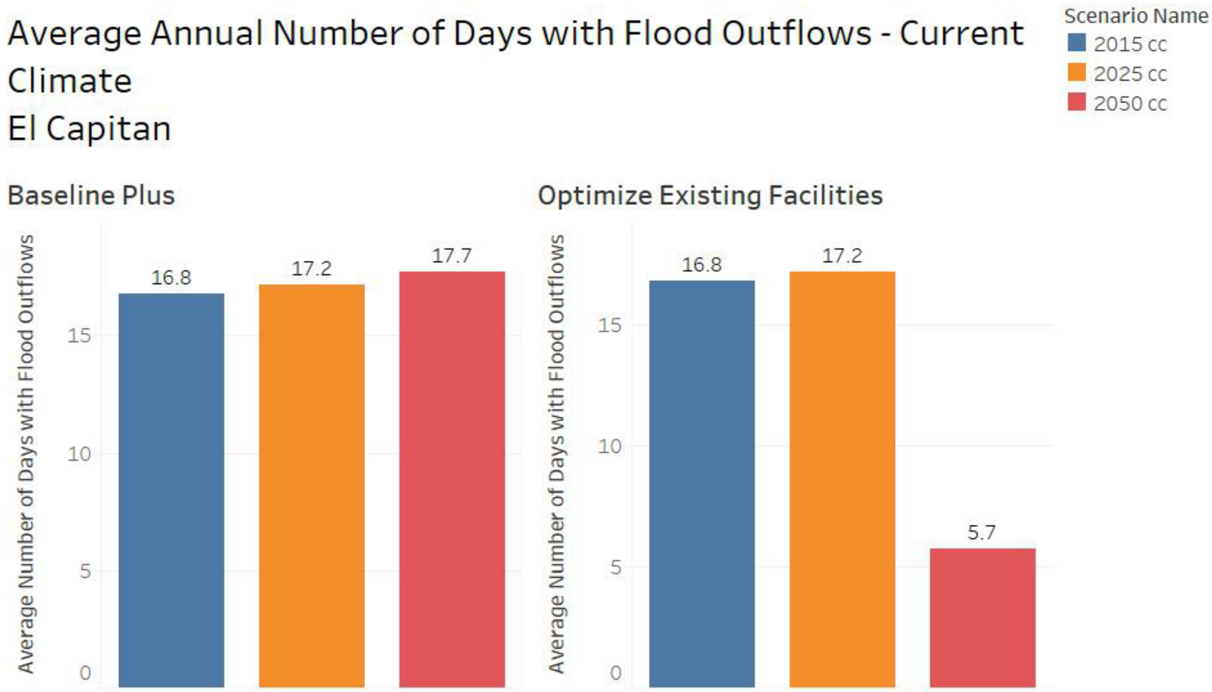


Figure 56. Number of Flood Outflows at El Capitan in the Baseline Plus and Optimize Existing Facilities Portfolios.

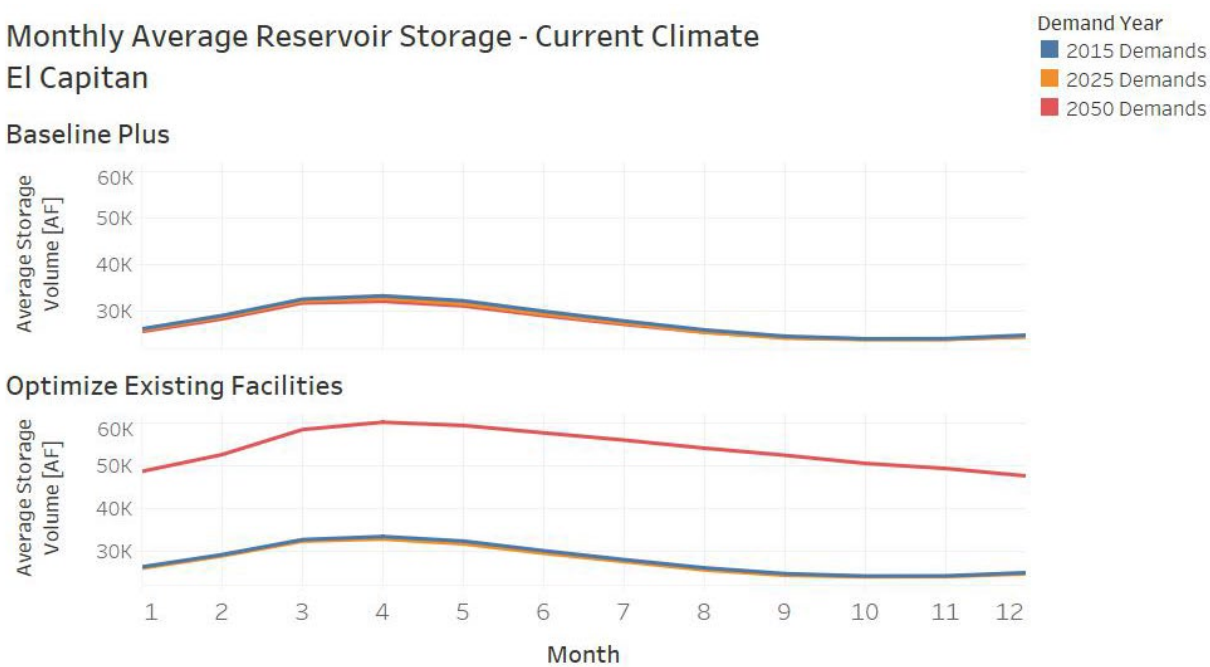


Figure 57. Monthly Average Reservoir Storage at El Capitan for the Baseline Plus and Optimize Existing Facilities Portfolios.

In the Trade-off Analysis, Conveyance Improvement scored best for the Regional Economic Impact, Optimize Local Supplies, and Reliability and Robustness Evaluation Objectives. Its lowest unweighted scores were for Cost Effectiveness and Climate Resilience. Six of the unweighted Evaluation Objective scores for Conveyance Improvement had scores less than or equal to a neutral 3.0 value. Individual Evaluation Objective scores for Conveyance Improvement are shown below in Figure 58.

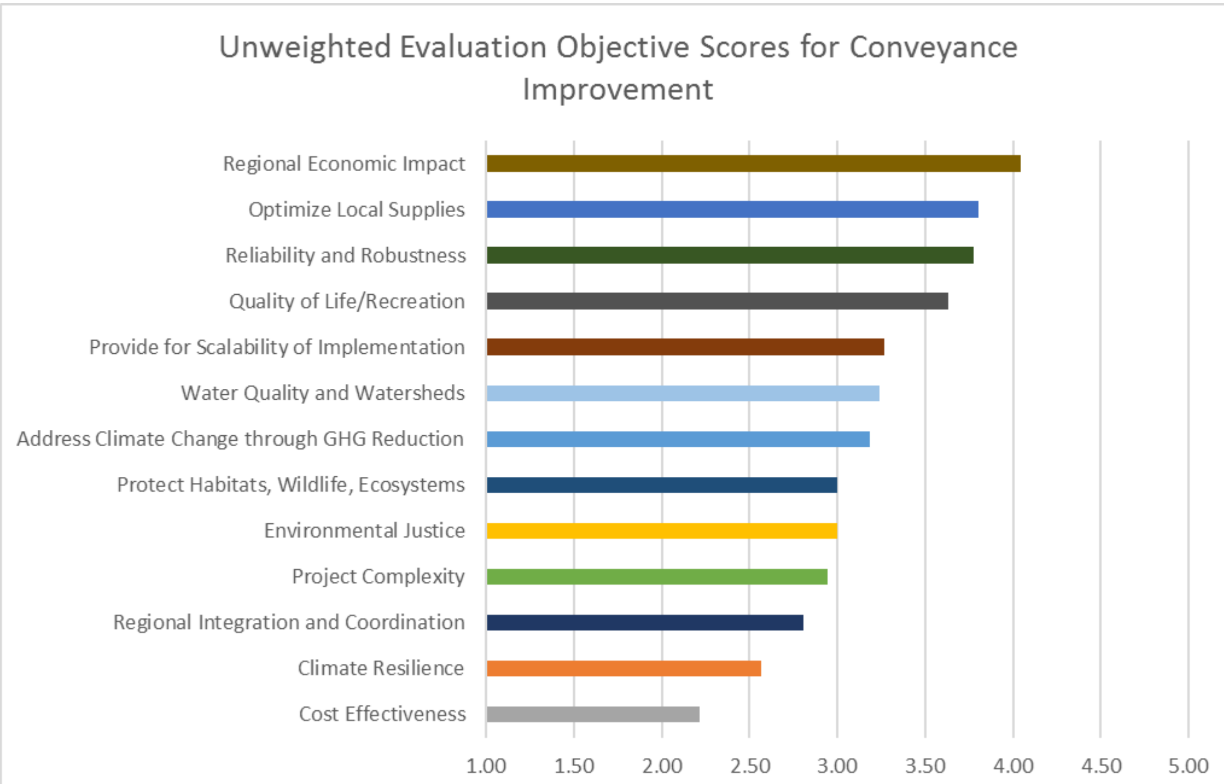


Figure 58. Unweighted Evaluation Objective scores for Conveyance Improvement.

In the Economic Assessment, Conveyance Improvement had the highest recreation benefits of all Concepts, but ranked near the bottom for water shortage and energy benefits, leading to an overall low net annual benefit relative to other Concepts.

10.2 Drought Restriction/Allocation

In the Impacts Assessment, the Drought Restriction/Allocation Concept was included in the Baseline Portfolio. The two projects included in this concept were Local Drought Restriction/Allocation and MWD Allocation. It was not modified in any subsequent portfolios. Since this Concept did not introduce new or modified projects to any portfolios, comparisons across the portfolios cannot be made.

Because the Drought Restriction/Allocation Concept was included in the Baseline Portfolio and was not modified in any other portfolios, it was not included in the Trade-Off Analysis or Economic Assessment.

10.3 Enhanced Conservation

In the Impacts Assessment, the Enhanced Conservation Concept was only included in the Enhanced Conservation Portfolio. It was also the only Concept included in the Enhanced Conservation Portfolio besides those in Baseline and Baseline Plus. Therefore, impacts to the system from this Concept were the same impacts as those to the system from the Enhanced Conservation Portfolio.

Water deliveries (not including Enhanced Conservation and Urban and Agricultural Water Use Efficiency) were significantly lower in the Enhanced Conservation Portfolio compared to the Baseline and Baseline Plus Portfolios. With the Enhanced Conservation Portfolio, deliveries were lower for 2050 demands than for 2025 demands (Figure 59). The decreased delivery volumes were due to the decreased demands after accounting for the Enhanced Conservation volume. The decreased demands had significant impacts on the system as can be observed in the model results discussed in Chapter 4, most notably for Shortage Volume, Pipeline Utilization, Treatment Plant Utilization, Reservoir Storage, and Energy.

For example, the Shortage Volume was zero for 2050 demands only in the Enhanced Conservation Portfolio due to the decreased demands on the system. Figure 60 and Figure 61 show that there are some realizations with shortages above the shortage threshold in the Baseline Plus Portfolio for central tendency climate, hot-dry climate, and warm-dry climate in the 2050 scenarios, while there are zero realizations above the shortage threshold in the Enhanced Conservation Portfolio. The only other portfolio to have zero shortages above the shortage threshold when considering the climate scenarios is the Increase Supplies Portfolio.

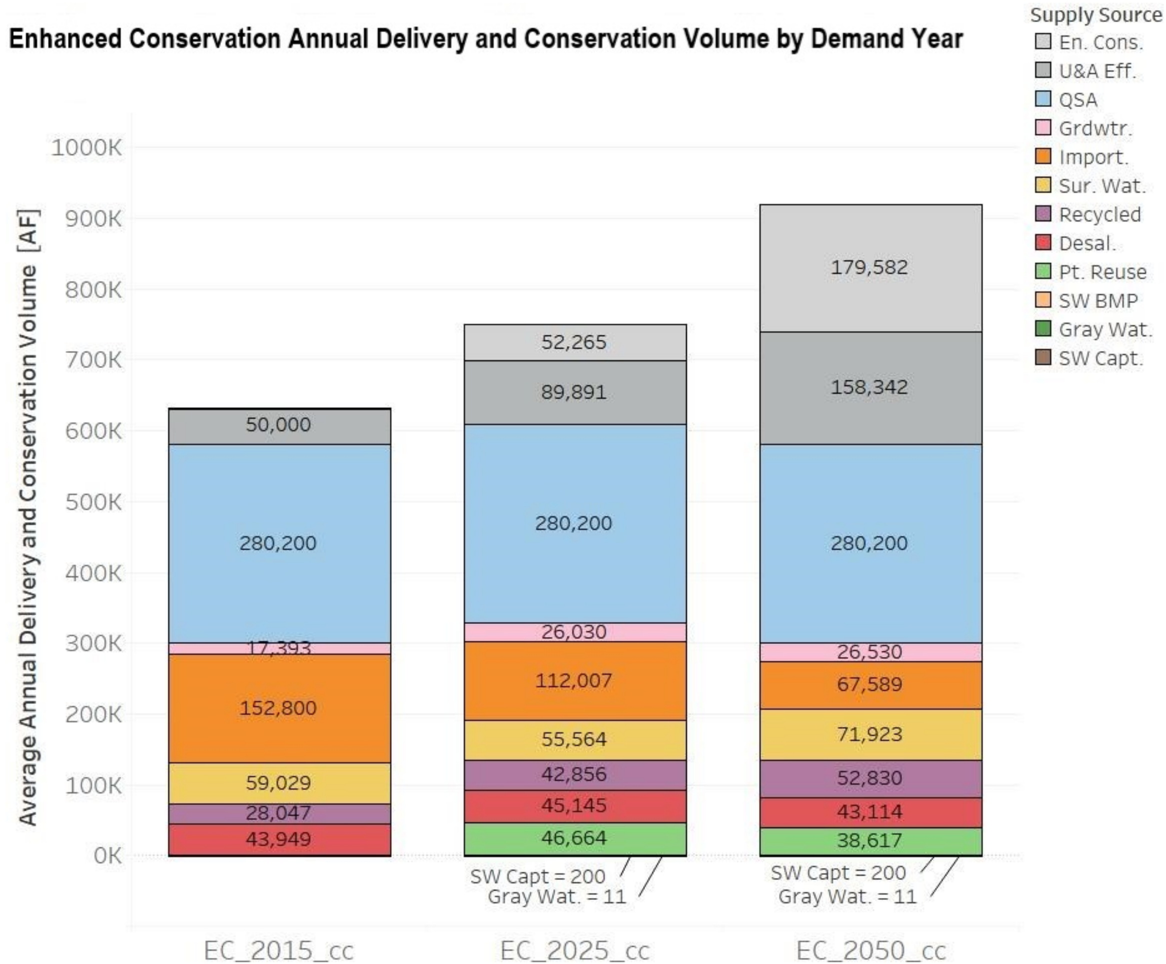


Figure 59. Annual Water Deliveries and Conservation Volumes for the Enhanced Conservation Portfolio.

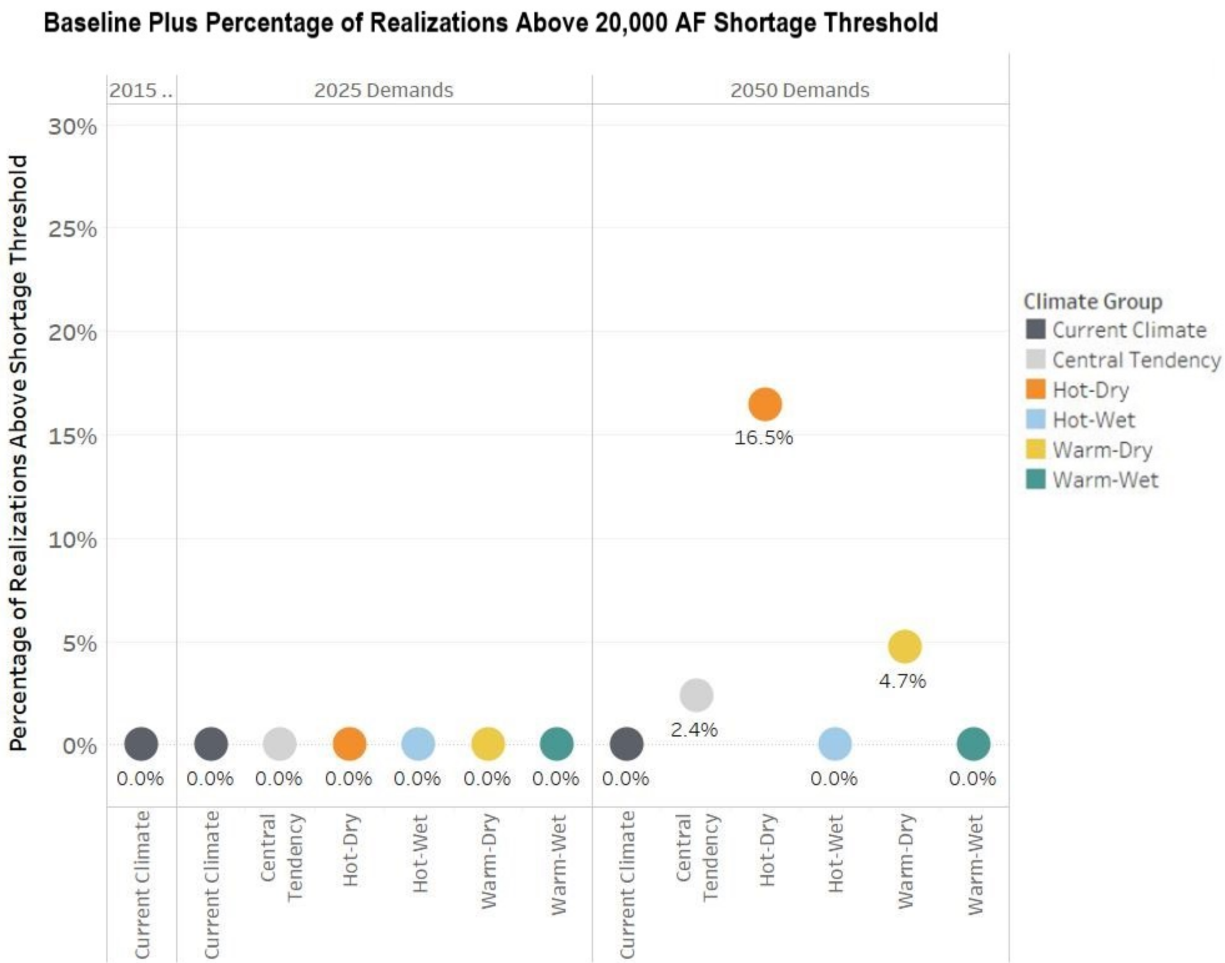


Figure 60. Percentage of Realizations above the 20,000 AF Shortage Threshold in the Baseline Plus (B+) Portfolio.

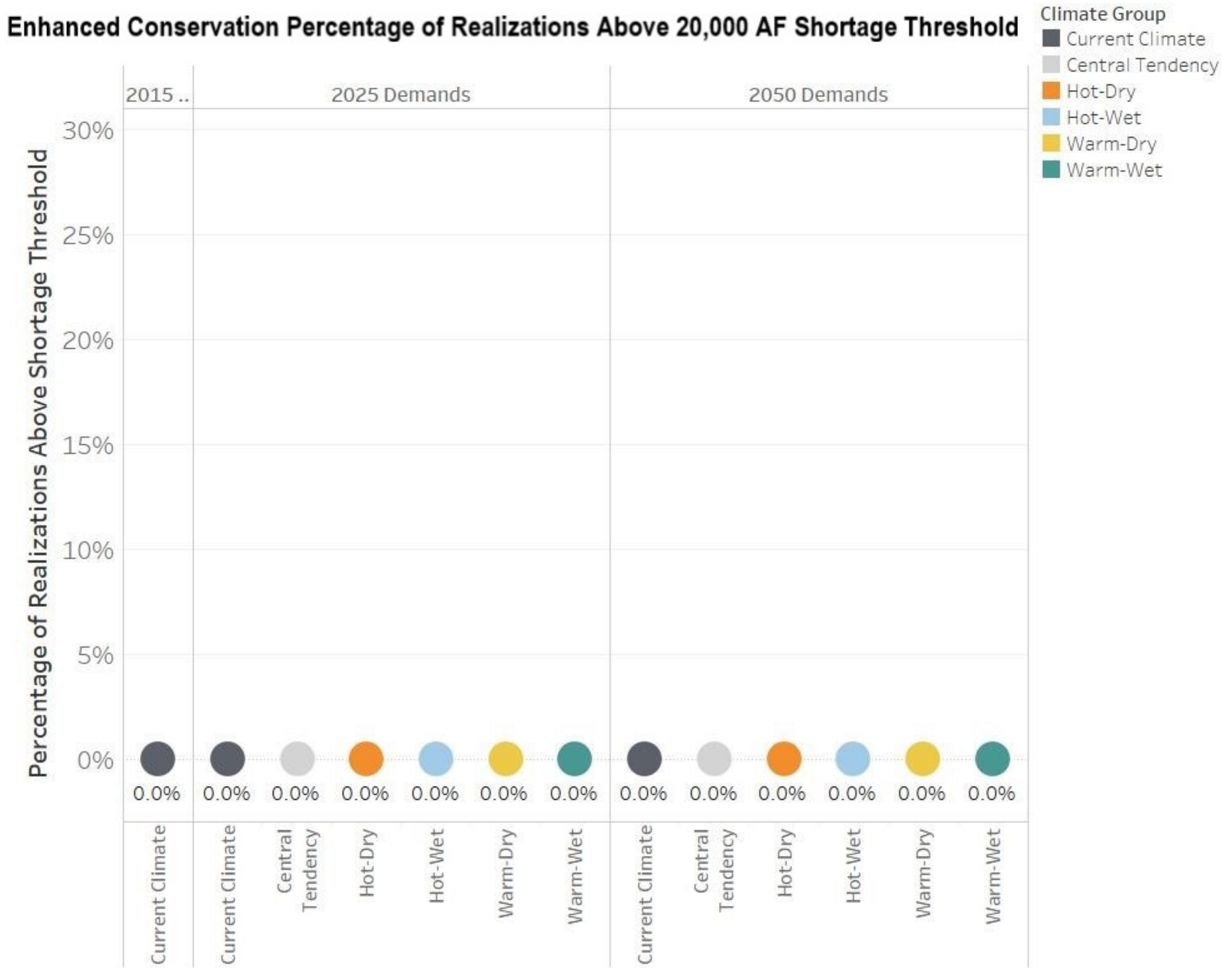


Figure 61. Percentage of Realizations above the 20,000 AF Shortage Threshold in the Enhanced Conservation Portfolio.

Pipeline Utilization was also impacted by the Enhanced Conservation Concept. Utilization of pipelines at the Untreated location and Crossover location was lower in the Enhanced Conservation Portfolio than in both the Baseline and Baseline Plus Portfolios (Figure 62). Similar to the case for Shortage Volume, the decreased Pipeline Utilization was a result of fewer demands on the system.

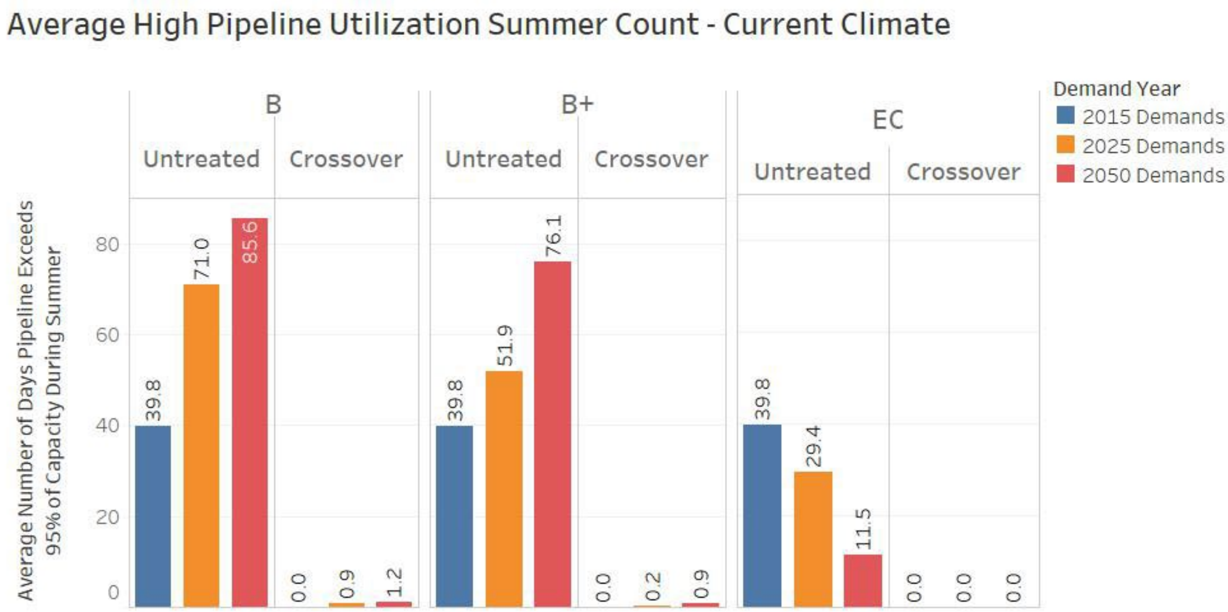


Figure 62. Average Number of Days Pipeline Exceeds 95% of Capacity during Summer for the Baseline, Baseline Plus, and Enhanced Conservation Portfolios.

Water Treatment Plant Utilization was significantly impacted by the Enhanced Conservation Concept. Utilization for all 11 water treatment plants was lower in the Enhanced Conservation Portfolio than in both the Baseline and Baseline Plus Portfolios in 2025 and 2050 demands for current climate, central tendency climate, and hot-dry climate. Figure 63 shows the system-wide Treatment Plant Utilization for the Baseline Plus and Enhanced Conservation Portfolios. In the 2050 scenarios, the treatment plant utilizations observed in the Enhanced Conservation Portfolio were at levels such that temporary shutdown of treatment plant operations could occur (or occur more often), resulting in operational challenges and/or potential water quality issues in the distribution system. The reduced Treatment Plant Utilization results are consistent with the result of lower energy consumption by Enhanced Conservation. The reduced Treatment Plant Utilization was a direct result of the decreased demands from the member agencies that the treatment plants serve.

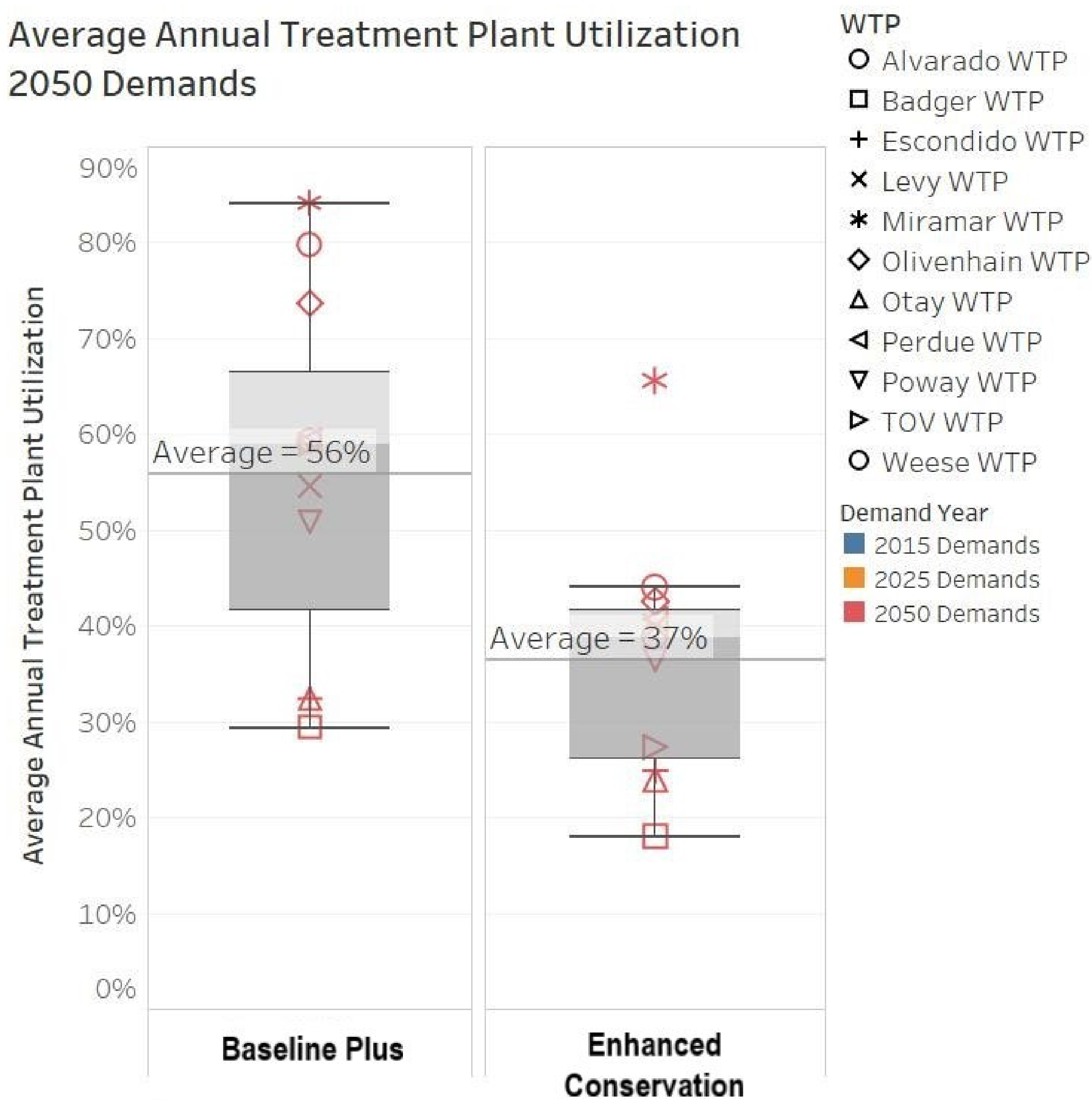


Figure 63. Average Treatment Plant Utilization for the 2050 Demand Scenario in the Baseline Plus and the Enhanced Conservation Portfolios.

The Enhanced Conservation Portfolio's lower demands also impacted Monthly Average Reservoir Storage, which was higher in the Enhanced Conservation Portfolio than in the Baseline and Baseline Plus Portfolios at Lower Otay and San Vicente for all months and at Olivenhain from June to October for the 2050 demand scenario (Figure 64 and Figure 65).

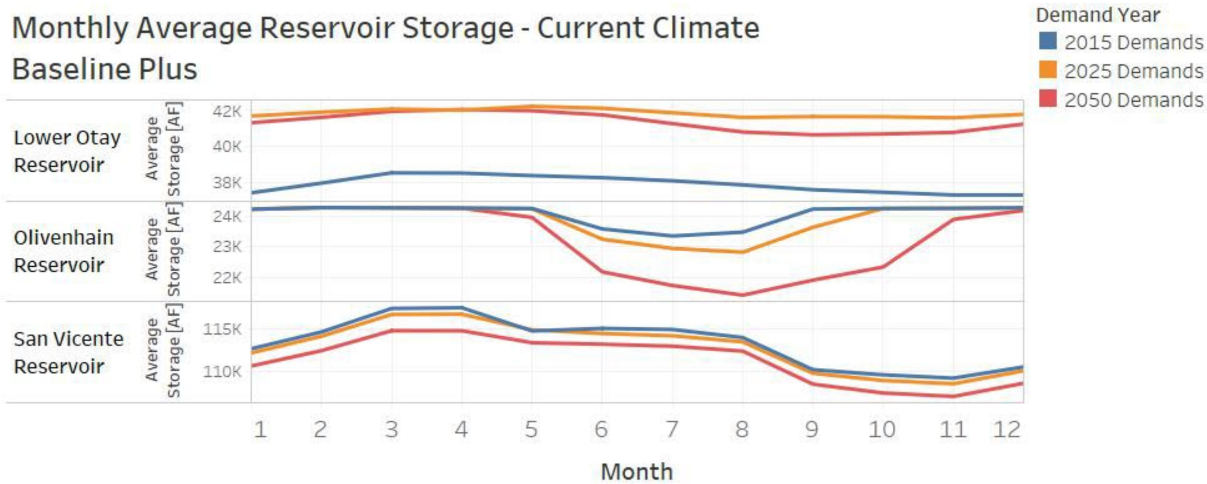


Figure 64. Monthly Average Reservoir Storage at Lower Otay, San Vicente, and Olivenhain for the Baseline Plus Portfolio.

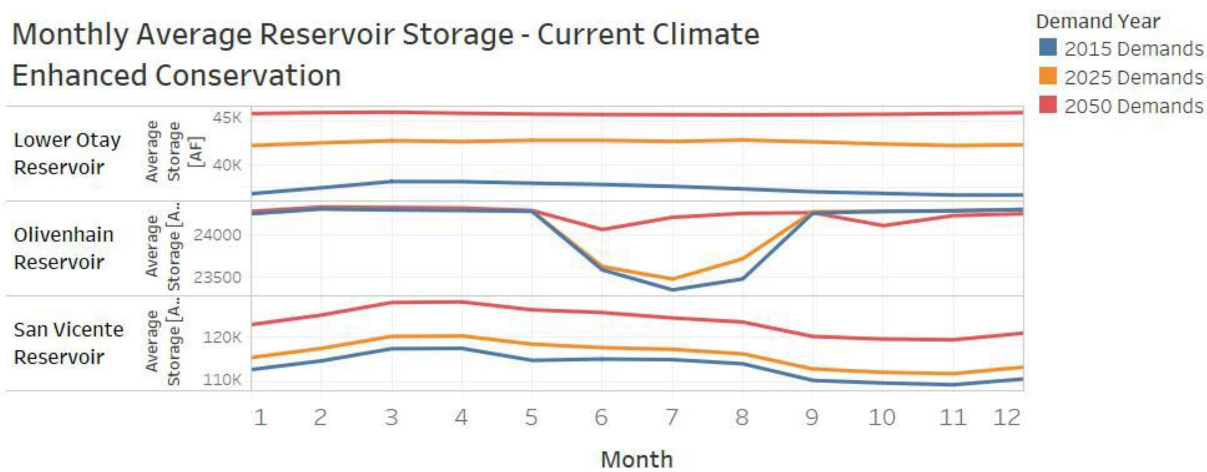


Figure 65. Monthly Average Reservoir Storage at Lower Otay, San Vicente, and Olivenhain for the Enhanced Conservation Portfolio.

Of the reservoirs analyzed in the End of September Storage analysis, the reservoir impacted the most from the Enhanced Conservation Concept was San Vicente (Figure 66). End of September Storage was higher at San Vicente in the Enhanced Conservation Portfolio than in the Baseline and Baseline Plus Portfolios for 2050 demands. The impact may be observed most at San Vicente compared to the other reservoirs because San Vicente storage is more dependent on imported supplies than local supplies (which average only 3% of the reservoir's capacity). Since local supplies take priority over imported water for meeting demands, the reservoirs that store more local supplies would take priority to meet the reduced demands of the Enhanced Conservation Portfolio, resulting in lower demands for San Vicente supply.

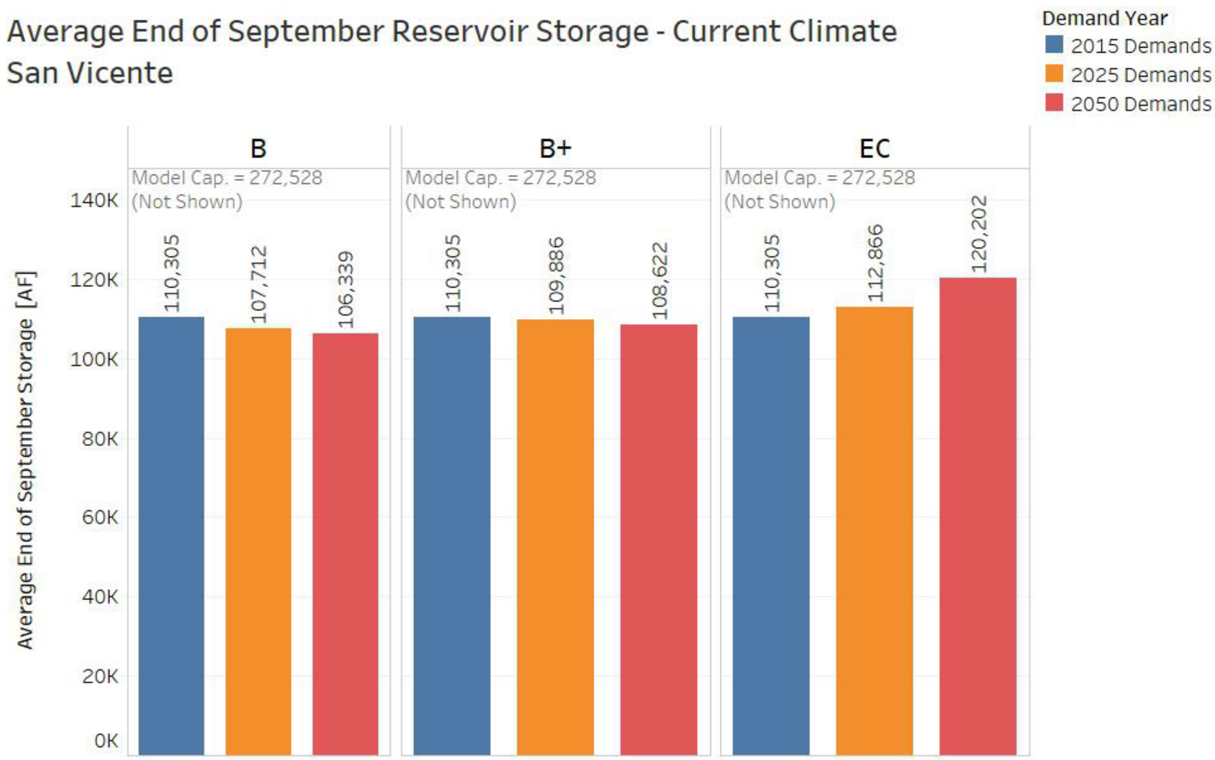


Figure 66. End of September Storage at San Vicente for the Baseline, Baseline Plus, and Enhanced Conservation Portfolios.

Energy Consumption in the Enhanced Conservation Portfolio was lower for both 2025 and 2050 demands than Energy Consumption in both the Baseline and Baseline Plus Portfolios. The lower energy consumption in the Enhanced Conservation Portfolio indicates that demand is a major driver of energy consumption; thus, when demands on the system are smaller due to the Enhanced Conservation project, energy consumption decreases. These results are consistent with the finding of reduced treatment plant utilization by Enhanced Conservation, indicating a link between demand, treatment plant and conveyance facility utilization, and energy consumption. Energy Consumption is shown for the three Portfolios in Figure 67.

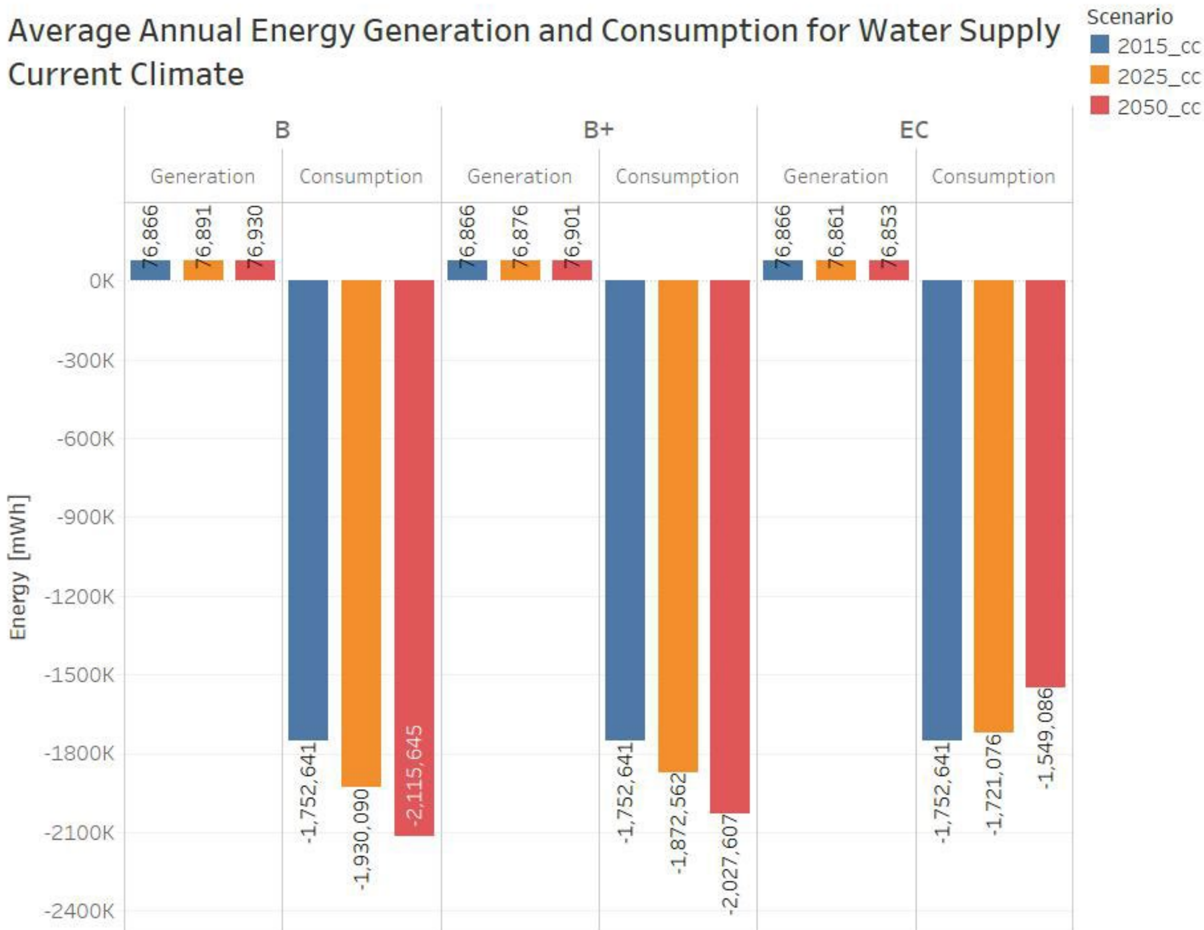


Figure 67. Energy Generation and Consumption for the Baseline, Baseline Plus, and Enhanced Conservation Portfolios.

Trade-off analysis results for Enhanced Conservation were available for only one Evaluation Objective, Regional Economic Impact. As a result, there was not enough data available to fully assess the relative strength of specific Evaluation Objectives within the Enhanced Conservation Concept. However, to the extent that there was similarity of projects within the Urban and Agricultural Water Use Efficiency Concept (such as the San Diego Water Conservation Program) and the Enhanced Conservation Concept, it is possible that some of the Trade-off Analysis results for Urban and Agricultural Water Use Efficiency could be applicable to Enhanced Conservation. The one available Evaluation Objective score for Enhanced Conservation is shown in Figure 68.

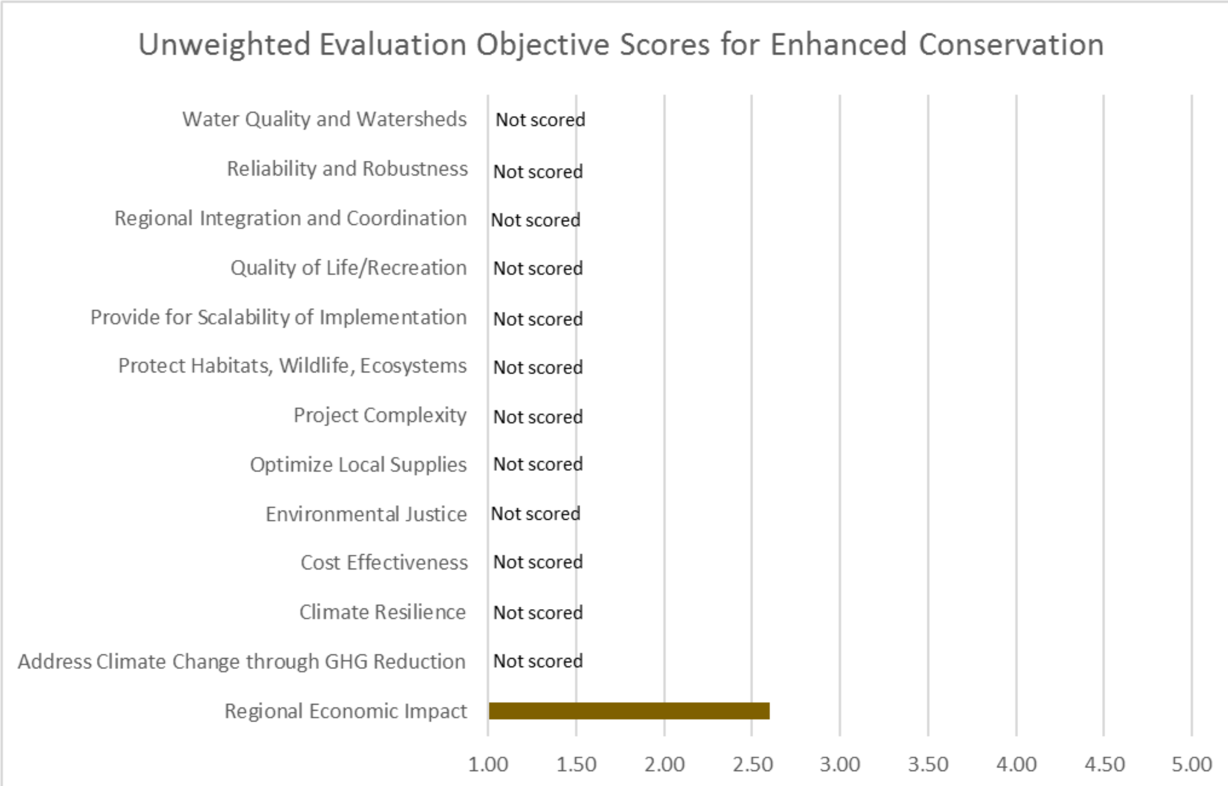


Figure 68. Unweighted Evaluation Objective scores for Enhanced Conservation.

In the Economic Assessment, Enhanced Conservation was the best performing Concept for both water shortage benefits and energy, and it was the third best Concept for recreation, leading to it having the highest net benefit of all Concepts on the overall Economic Assessment.

10.4 Firm Water Supply Agreements

In the impacts analysis, the Firm Water Supply Agreements concept was included in the Baseline Portfolio and was therefore included in all portfolios beyond Baseline. The only project associated with the Firm Water Supply Agreements concept was the QSA. The QSA available volume was assumed to be constant for all demand and climate scenarios and for all portfolios, and was modeled such that the full agreement volume was delivered every year. Therefore, the impact of the QSA and the Firm Water Supply Agreements Concept is the same across all portfolios, essentially acting as a demand reduction.

Because the Firm Water Supply Agreements Concept was included in the Baseline Portfolio and was not modified in any other portfolios, it was not included in the Trade-Off Analysis or Economic Assessment.

10.5 Gray Water Use

Two Gray Water Use projects were included in the Basin Study. These projects include Conservation Home Makeover in the Chollas Creek Watershed which was implemented in the Baseline Plus Portfolio, and the Gray Water Pilot Project which was implemented in the Increase Supplies Portfolio. These projects were implemented in the CWASim model as demand reductions. The Gray Water Pilot Project helped increase the amount of local water supply available in the 2050 demand scenario model runs for Increase Supplies Portfolio was. Although specific impacts from Gray Water Use are not directly observed, it contributes to the overall benefits of the Increase Supplies Portfolio, such as fewer shortages and less dependence on Imported Water than in the Baseline and Baseline Plus Portfolios (Figure 69).

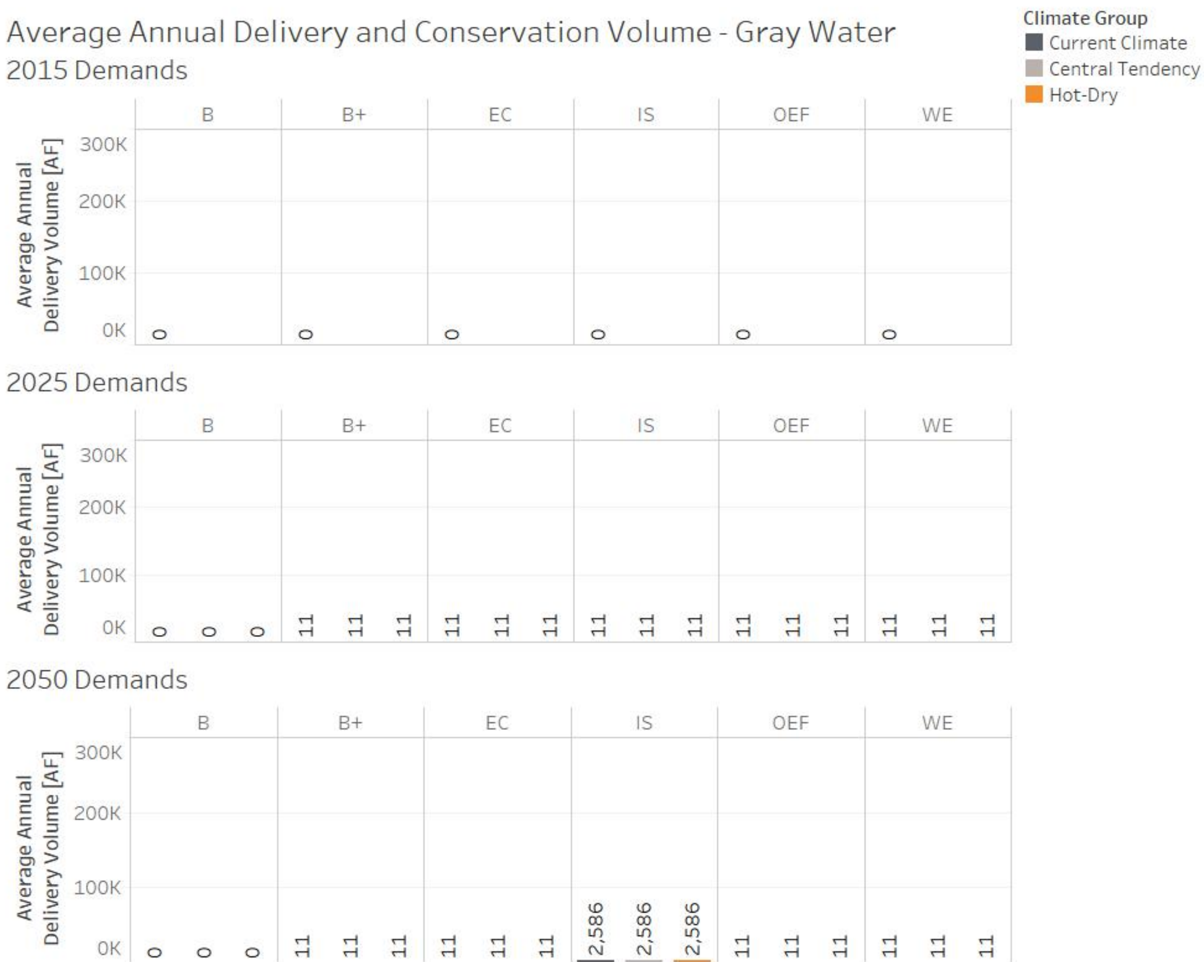


Figure 69. Annual Deliveries of Gray Water for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

In the Trade-off Analysis, Gray Water Use scored best for Climate Resilience, Optimize Local Supplies, and Cost Effectiveness. Its lowest unweighted scores were for Protect Habitats, Wildlife, and Ecosystems; Project Complexity; and Quality of Life/Recreation. Gray Water Use was not scored for Environmental Justice. All the unweighted Evaluation Objective scores for Gray Water Use had scores of 3.0 or higher. Individual Evaluation Objective scores for Gray Water Use are shown in Figure 70.

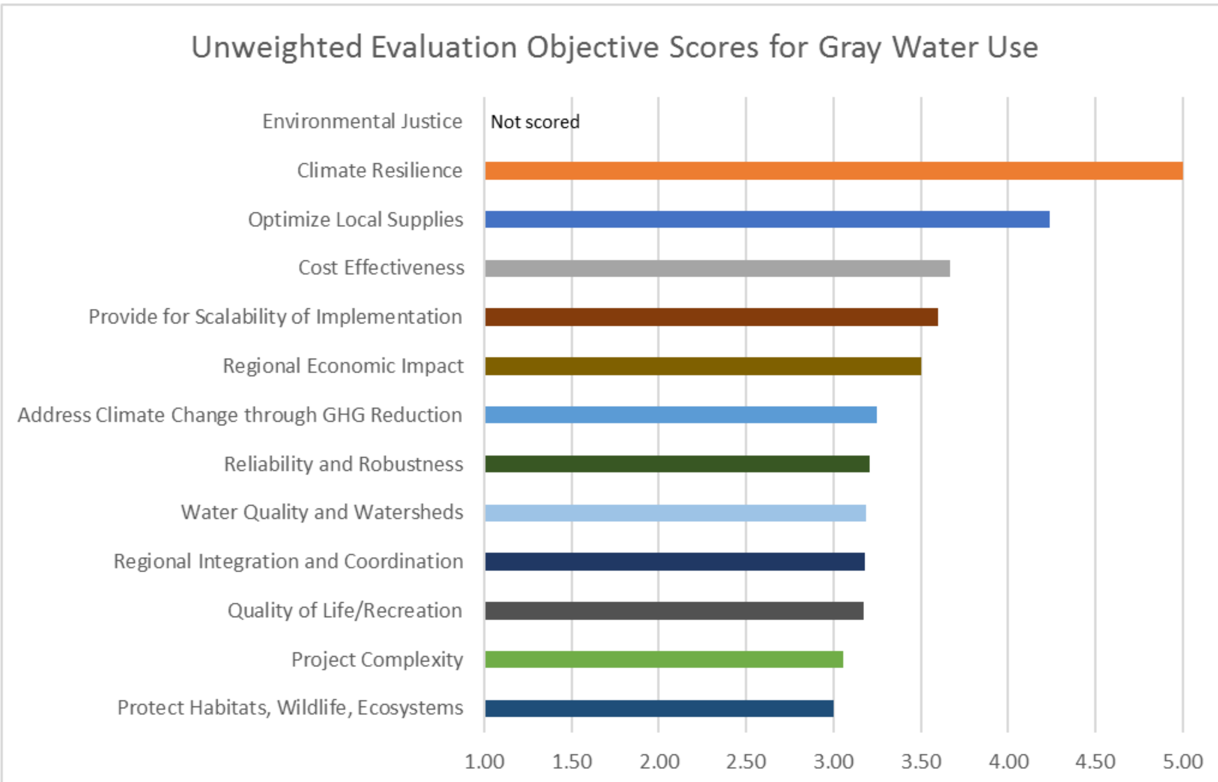


Figure 70. Unweighted Evaluation Objective scores for Gray Water Use.

In the Economic Assessment, Gray Water Use ranked near the middle of the net annual benefits relative to Baseline, but only had a net annual benefit value of approximately 2% of the best performing Concept (Enhanced Conservation). This is a result of the very large influence of the value of net energy benefits for Enhanced Conservation on the total net benefits.

10.6 Groundwater

In the Impacts Assessment, groundwater projects were included in the Baseline Portfolio, and additional projects were added as part of the Baseline Plus and Increase Supplies Portfolios, such as the San Dieguito River Basin Brackish Groundwater Recovery and Treatment project implemented in the Increase Supplies Portfolio for 2025 and 2050 demands. Groundwater projects were implemented as demand reductions. These projects help increase the amount of local water supply available in the Baseline Plus and Increase Supplies Portfolios, with a majority of the additional groundwater supply beyond the Baseline Portfolio in the Increase Supplies Portfolio. See Figure 71 for groundwater supply volumes included in the Increase Supplies Portfolio. Since Groundwater projects were implemented as demand reductions, the CWASim model results are not able to indicate impacts to a specific infrastructure component (such as a specific pipeline or reservoir). However, Groundwater projects contributed to the overall benefits of the Increase Supplies Portfolio, such as fewer shortages and less dependence on Imported Water.

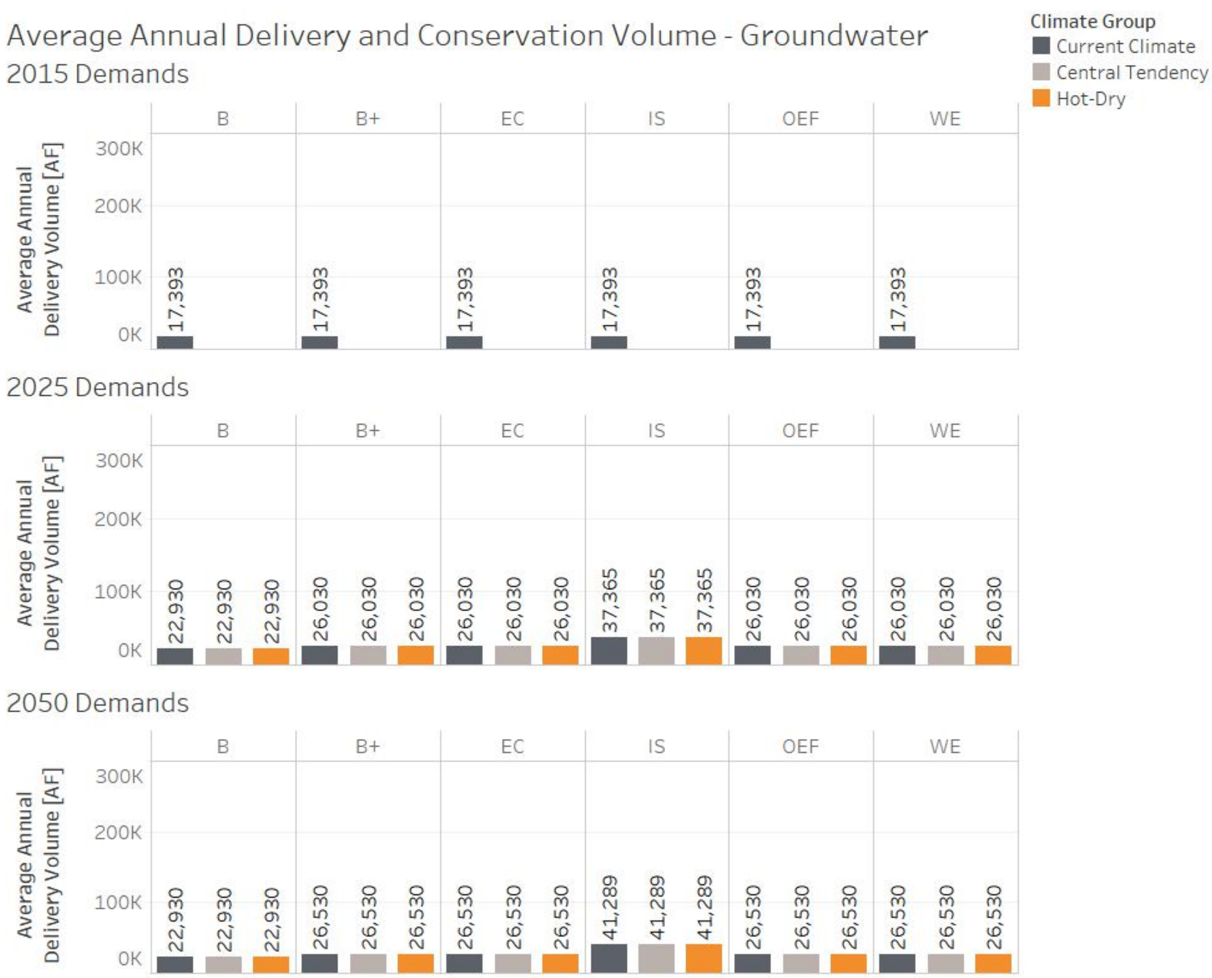


Figure 71. Annual Deliveries of Groundwater for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

In the Trade-off Analysis, the Groundwater Concept scored best for the Optimize Local Supplies, Regional Economic Impact, and Reliability and Robustness Evaluation Objectives, followed closely by Climate Resilience. Its lowest unweighted scores were for Project Complexity and Cost Effectiveness. These were the only two unweighted Evaluation Objectives for which Groundwater had scores lower than a neutral 3.0 score. Individual Evaluation Objective scores for Groundwater are shown in Figure 72.

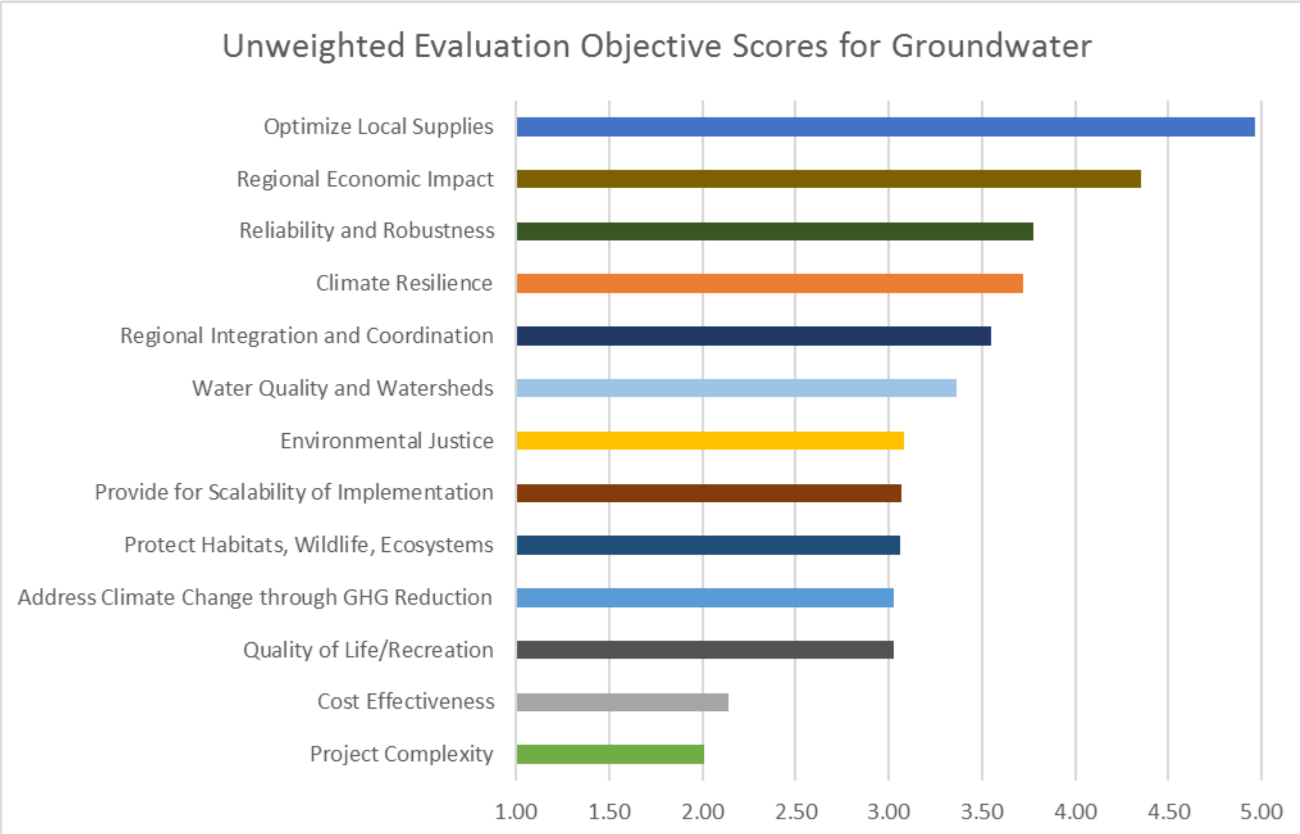


Figure 72. Unweighted Evaluation Objective scores for Groundwater.

In the Economic Assessment, Groundwater ranked in the top half of Concepts and its annual water shortage benefit was relatively close to the top performing Concept for water shortage benefits (Enhanced Conservation). However, its net benefits were low relative to the top performing Concept for recreation and energy.

10.7 Imported Water Purchases

The two Imported Water projects in the Basin Study were MWD Imported Water and Cadiz Additional Imported Supplies. In the Impacts Assessment, MWD Imported Water was included in the Baseline Portfolio and was not modified in any of the portfolios beyond the Baseline. The Cadiz Additional Imported Supplies project (5,000 AF/y) was included in the Increase Supplies Portfolio for the 2050 scenarios. As shown in in Figure 73, dependence on Imported Water in the 2050 demands scenario was lowest in the Enhanced Conservation and Increase Supplies Portfolios because less water supply was required from MWD. However, in all portfolios, Imported Water is still an important supply source.

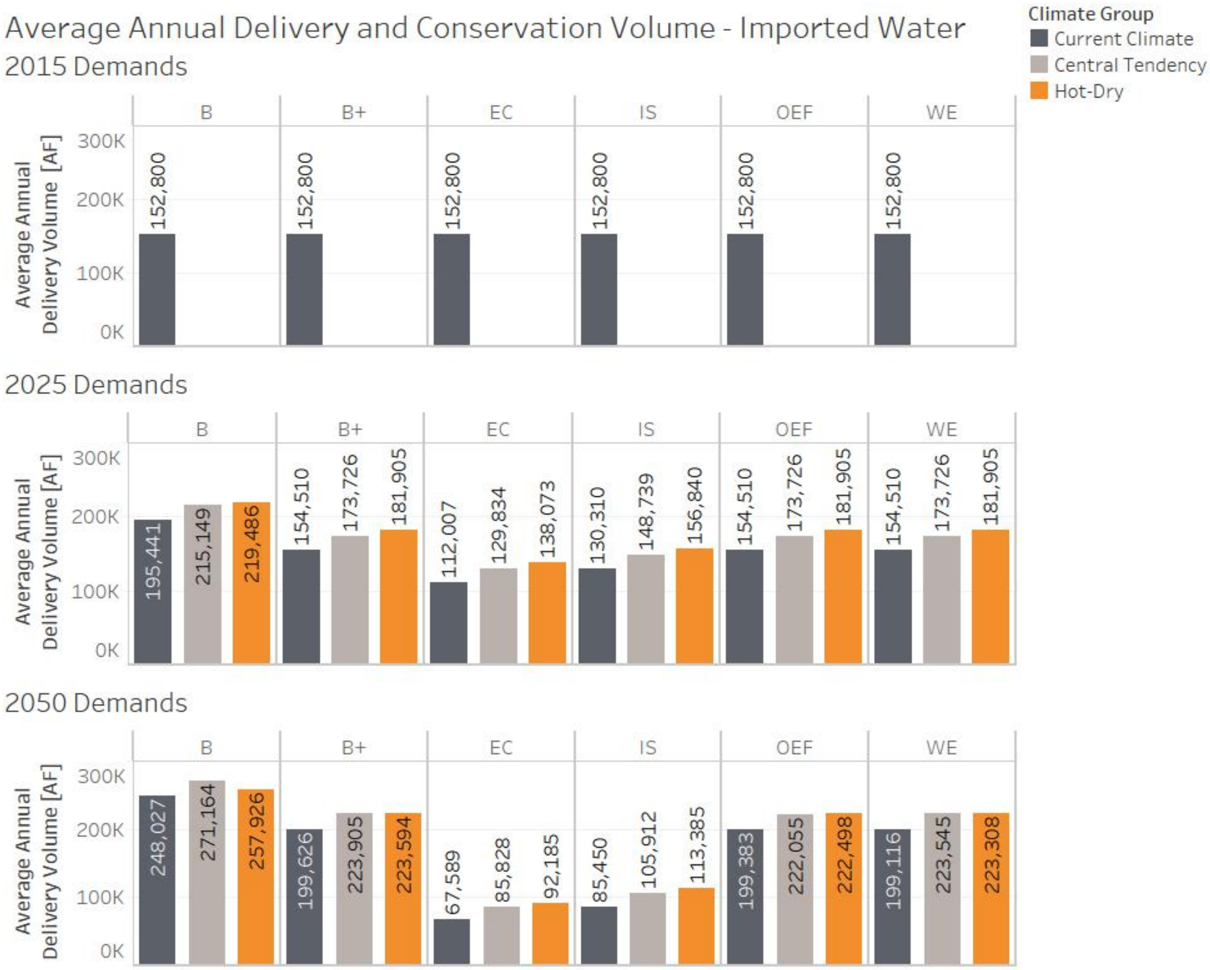


Figure 73. Average Annual Delivery Volume for Imported Water for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

In the Trade-off Analysis, Imported Water Purchases scored best for the Project Complexity, Reliability and Robustness, and Cost Effectiveness Evaluation Objectives. Its lowest unweighted scores were for Address Climate Change through GHG Mitigation and Regional Integration and Coordination. Imported Water Purchases was not scored for three Concepts (Climate Resilience, Environmental Justice, and Water Quality and Watersheds). Five of its unweighted Evaluation Objective scores were lower than a neutral 3.0 score. Individual Evaluation Objective scores for Imported Water Purchases are shown in Figure 74.

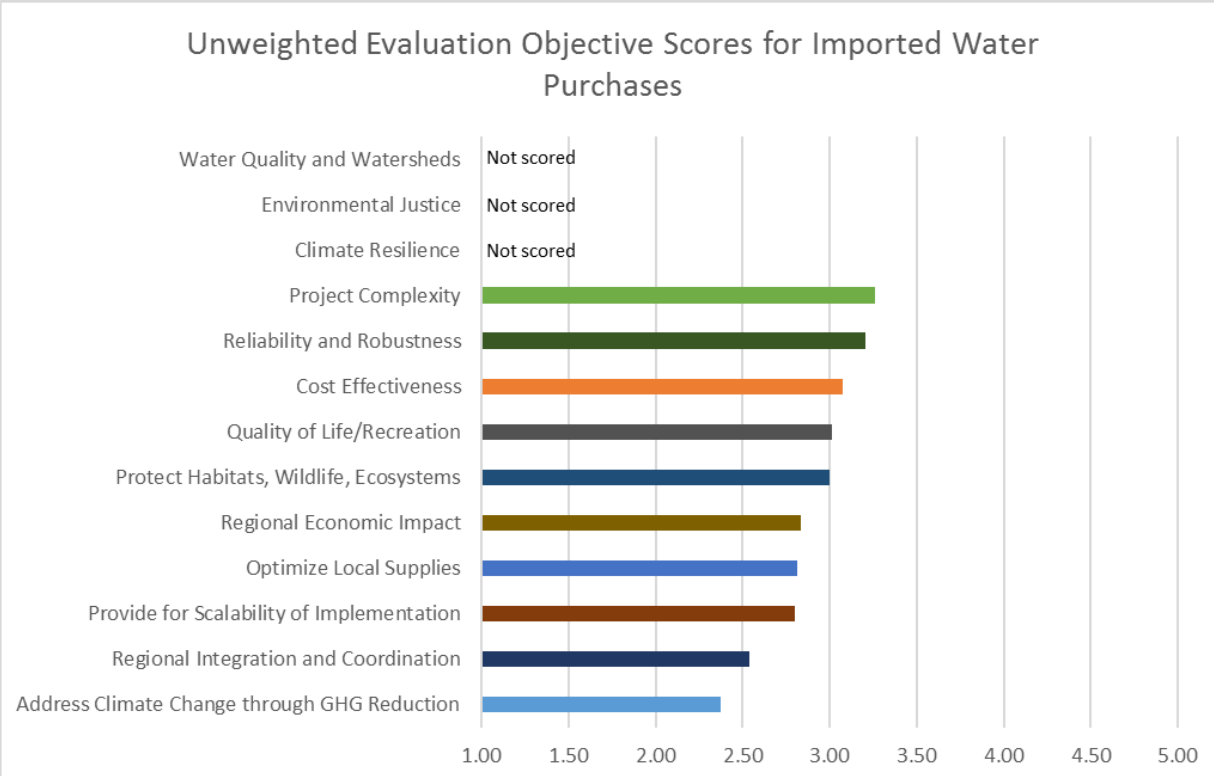


Figure 74. Unweighted Evaluation Objective scores for Imported Water Purchases.

In the Economic Assessment, Imported Water Purchases ranked near the middle of the Concepts, but its net annual benefits were only 4% of the best scoring Concept (Enhanced Conservation).

10.8 Local Surface Water Reservoirs

In the Impacts Assessment, the Local Surface Water Reservoirs Concept was included in the Baseline Portfolio and was therefore included in all portfolios beyond Baseline. This concept represented the reservoirs that were simulated in CWASim. Although modifications were made to reservoir systems by some projects, the changes were associated with other Concepts, not with the Local Surface Water Reservoirs concept, and this Concept was not modified in any subsequent portfolios. Therefore, no impacts to the system from Local Surface Water Reservoirs based on comparison of portfolio model results could be determined.

Because the Local Surface Water Reservoirs Concept was included in the Baseline Portfolio and was not modified in any other portfolios, it was not included in the Trade-Off Analysis or Economic Assessment.

10.9 Potable Reuse

In the Impacts Assessment, Potable Reuse Projects were included in the Baseline, Baseline Plus, and Increase Supplies Portfolios. One Potable Reuse project, the San Luis Rey WRF - Short/Long-Term Expansion project, was included in the Baseline Portfolio with a supply volume of 3,300 AF for 2025 and 2050 demands implemented as a demand reduction (Figure 75). In the Baseline Plus Portfolio, three additional Potable Reuse projects were included: East County Advanced Water Purification Program Phase 1 (implemented as demand reduction); East County Advanced Water Purification Program Phase 2 (implemented as demand reduction); and Pure Water Phase 1 (implemented through model logic). The Increase Supplies Portfolio included an additional nine Potable Reuse projects, with five implemented as demand reductions, one (Pure Water Phase 2) implemented through model logic, and three not implemented in the model. The Pure Water Phase 1 and other Baseline Plus Potable Reuse projects contributed to a large increase in Portable Reuse deliveries between the Baseline and Baseline Plus Portfolios. Potable Reuse deliveries in the Baseline Portfolio were 3,300 AF, and in the Baseline Plus Portfolio under current climate they were 46,704 AF in the 2025 demand scenario and 42,211 AF in the 2050 demand scenario for the Baseline Plus Portfolio. Potable Reuse deliveries were significantly higher in 2050 than in 2025 for the Increase Supplies Portfolio due to the implementation of Pure Water Phase 2 for the 2050 scenarios. In the Increase Supplies Portfolio under current climate, 47,254 AF of Potable Reuse water was delivered in the 2025 demand scenario and 128,555 AF was delivered in the 2050 demand scenario. In the Increase Supplies Portfolio for 2050 demands, Potable Reuse represented the third largest delivery volume, with only the QSA and Urban and Agricultural Water Use Efficiency delivery volumes larger than Potable Reuse deliveries, meaning that Potable Reuse surpassed Imported Water Purchases in delivery volume.

Surprisingly, Potable Reuse deliveries were lower in 2050 than in 2025 for all other portfolios besides Baseline and Increase Supplies. This may be due to the Hodges Water Quality Improvement Program, which was implemented in 2050 Baseline Plus and subsequent portfolios. Water from Hodges Reservoir can serve some of the same demands as water from Miramar Reservoir, which receives water from the Pure Water Phase 1 project. With the increase in supply availability from Hodges in the 2050 scenarios due to its increased release capacity, some of the demands that were met with Potable Reuse water in 2025 were likely met with Hodges water in the 2050 scenarios.

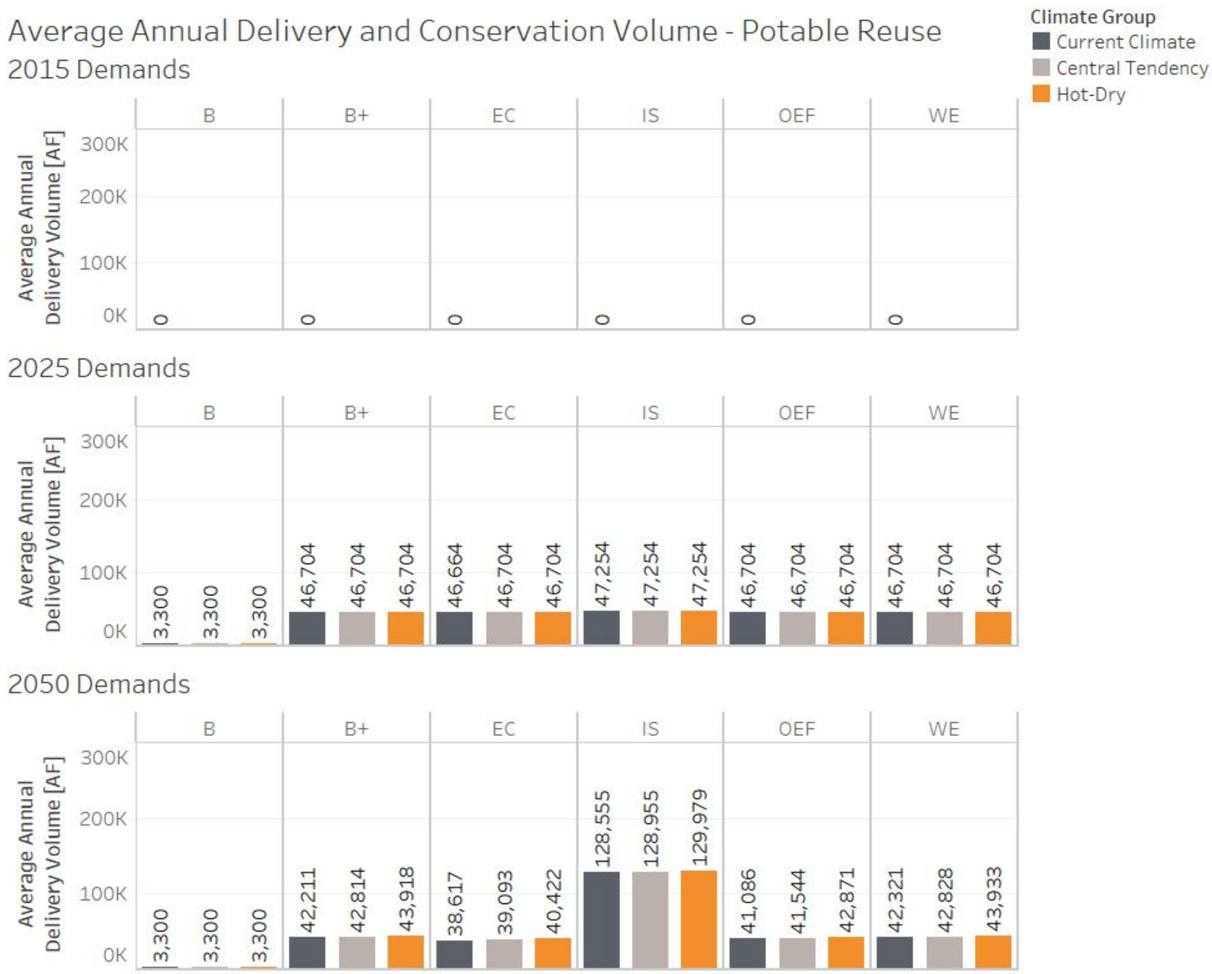


Figure 75. Average Annual Water Delivery Volume from Potable Reuse Projects for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

In the Trade-off Analysis, Potable Reuse scored best for the Optimize Local Supplies, Regional Economic Impact, and Regional Integration and Coordination Evaluation Objectives. Its score for Reliability and Robustness was very similar to its score for Regional Integration and Coordination (scores of 4.19 and 4.20, respectively). Its lowest unweighted scores were for Project Complexity and Cost Effectiveness. Three unweighted Evaluation Objective scores for Potable Reuse were lower than a neutral 3.0 score. Individual Evaluation Objective scores for Potable Reuse are shown in Figure 76.

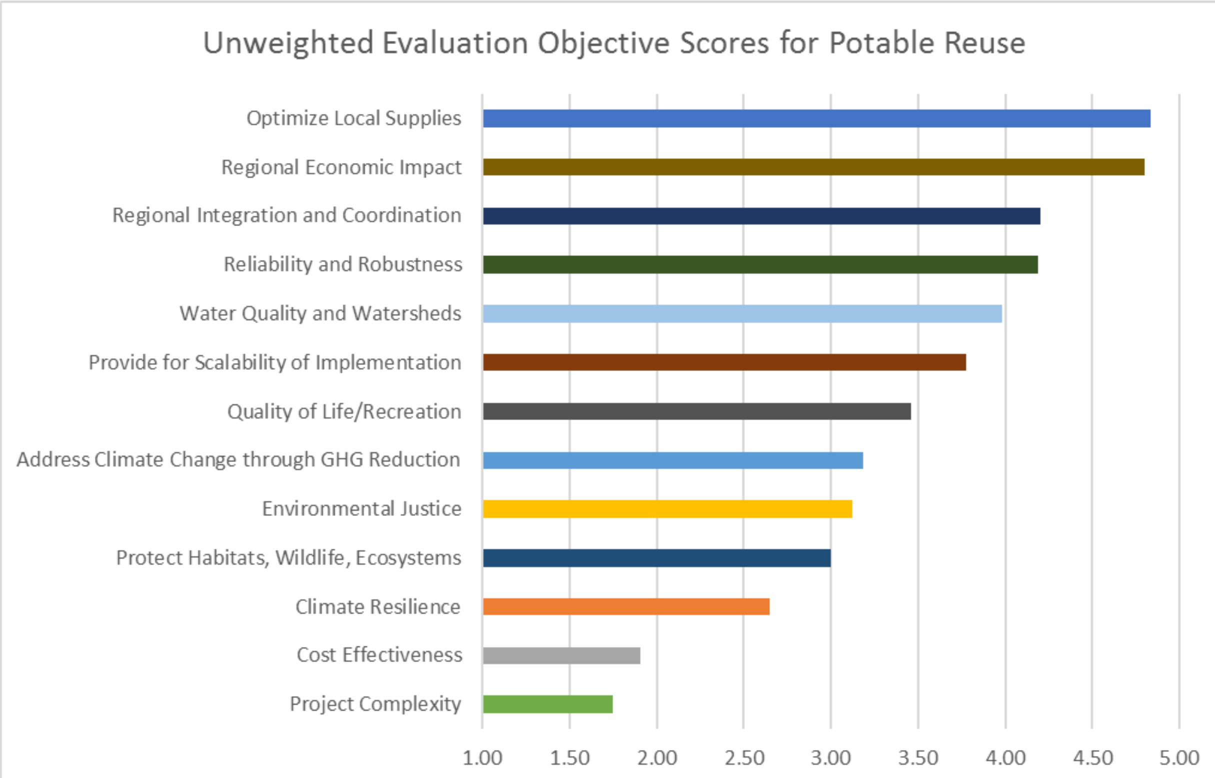


Figure 76. Unweighted Evaluation Objective scores for Potable Reuse.

In the Economic Assessment, Potable Reuse was the second-ranked Concept for water shortage, recreation, and energy benefits relative to Baseline, and ranked second overall. Its net annual value of monetized effects was relatively large, with a value that was 34% of the highest-ranking Concept (Enhanced Conservation).

10.10 Recycled Water

In the Impacts Assessment, Recycled Water projects were included in the Baseline, Baseline Plus, and Increase Supplies Portfolios. All Recycled Water projects were implemented as demand reductions. Figure 77 shows delivery volumes associated with the Recycled Water Concept when compared to other water supply sources for the Baseline, Baseline Plus, and Increase Supplies Portfolios. Since the Recycled Water projects were implemented as demand reductions, the CWASim model results are not able to indicate impacts to a specific infrastructure component (such as a specific pipeline or reservoir). Recycled Water, however, made up a large portion of the water supply in the Increase Supplies Portfolio for 2050 demands, and contributed to the overall benefit of the Increase Supplies Portfolio, such as fewer shortages and less dependence on Imported Water. Energy consumption in the Increase Supplies Portfolio was lower than in the Baseline Portfolio which indicates that the additional supply projects such as Recycled Water projects, which may increase energy needed for water treatment, do not necessarily increase regional energy consumption, and in fact may be significantly less energy intensive than some water supplies in the Baseline Portfolio, such as imported water deliveries.

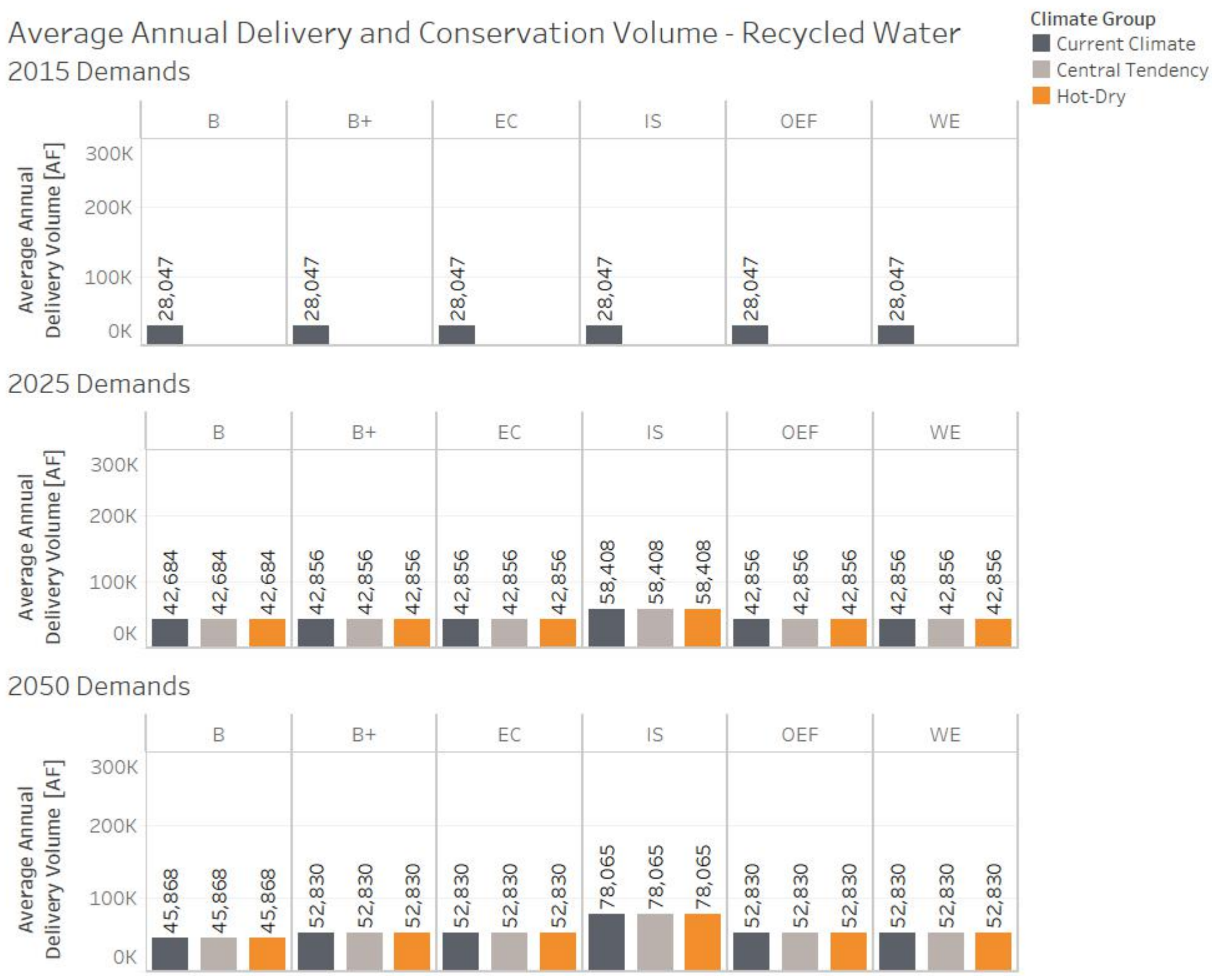


Figure 77. Annual water deliveries showing volumes associated with Recycled Water for each portfolio with current climate, central tendency climate, and hot-dry climate for the 2015 demand scenario, 2025 demand scenario, and 2050 demand scenario.

In the Trade-off Analysis, Recycled Water scored best for the Optimize Local Supplies and Regional Economic Impact Evaluation Objectives. Its scores for these two Evaluation Objectives were more than half a point higher than its third highest score (Reliability and Robustness). This indicates that the Recycled Water Concept is particularly good at providing positive regional economic impacts while increasing use of local supplies. Recycled Water's lowest unweighted scores were for Cost Effectiveness and Climate Resilience, both of which had scores lower than a neutral 3.0. Individual Evaluation Objective scores for Recycled Water Use are shown below in Figure 78.

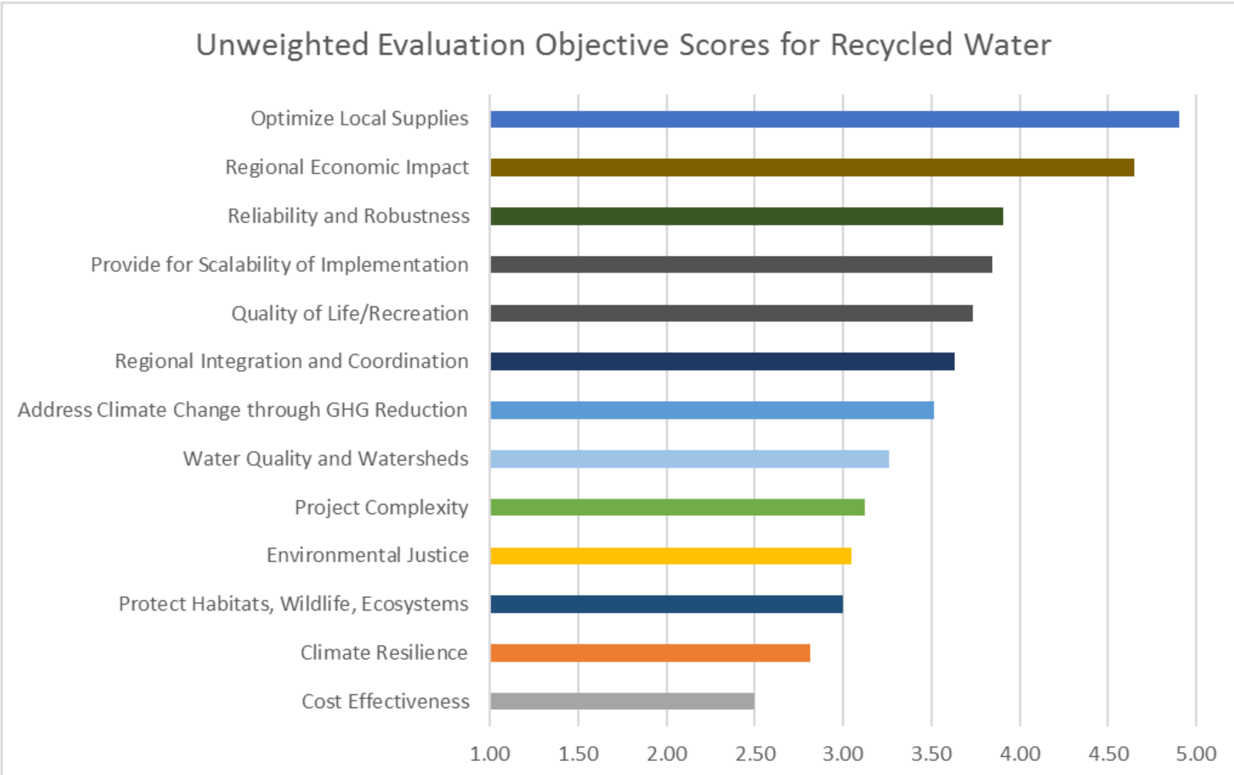


Figure 78. Unweighted Evaluation Objective scores for Recycled Water.

In the Economic Assessment, Recycled Water had a relatively high ranking for all three benefit categories, resulting in it being the Concept with the third highest overall net annual value of benefits and having a net value of about 20% of the best-performing Concept (Enhanced Conservation).

10.11 Seawater Desalination

In the Impacts Assessment, the Seawater Desalination Concept consisted of the Carlsbad Desalination Plant in the Baseline Portfolio, along with three additional projects (Re-rating of the Carlsbad Desalination Plant, the Camp Pendleton Desalination Plant, and the Rosarito Desalination Plant) introduced in the Increase Supplies Portfolio.

The delivery volume for Seawater Desalination increased by approximately 9,300 AF/y in 2050 from the Baseline Portfolio to the Increase Supplies Portfolio (Figure 79). Seawater Desalination made up a large portion of the water supply in the Increase Supplies Portfolio for 2050 demands and contributed to the overall benefit of the Increase Supplies Portfolio, such as fewer shortages and less dependence on Imported Water Purchases.

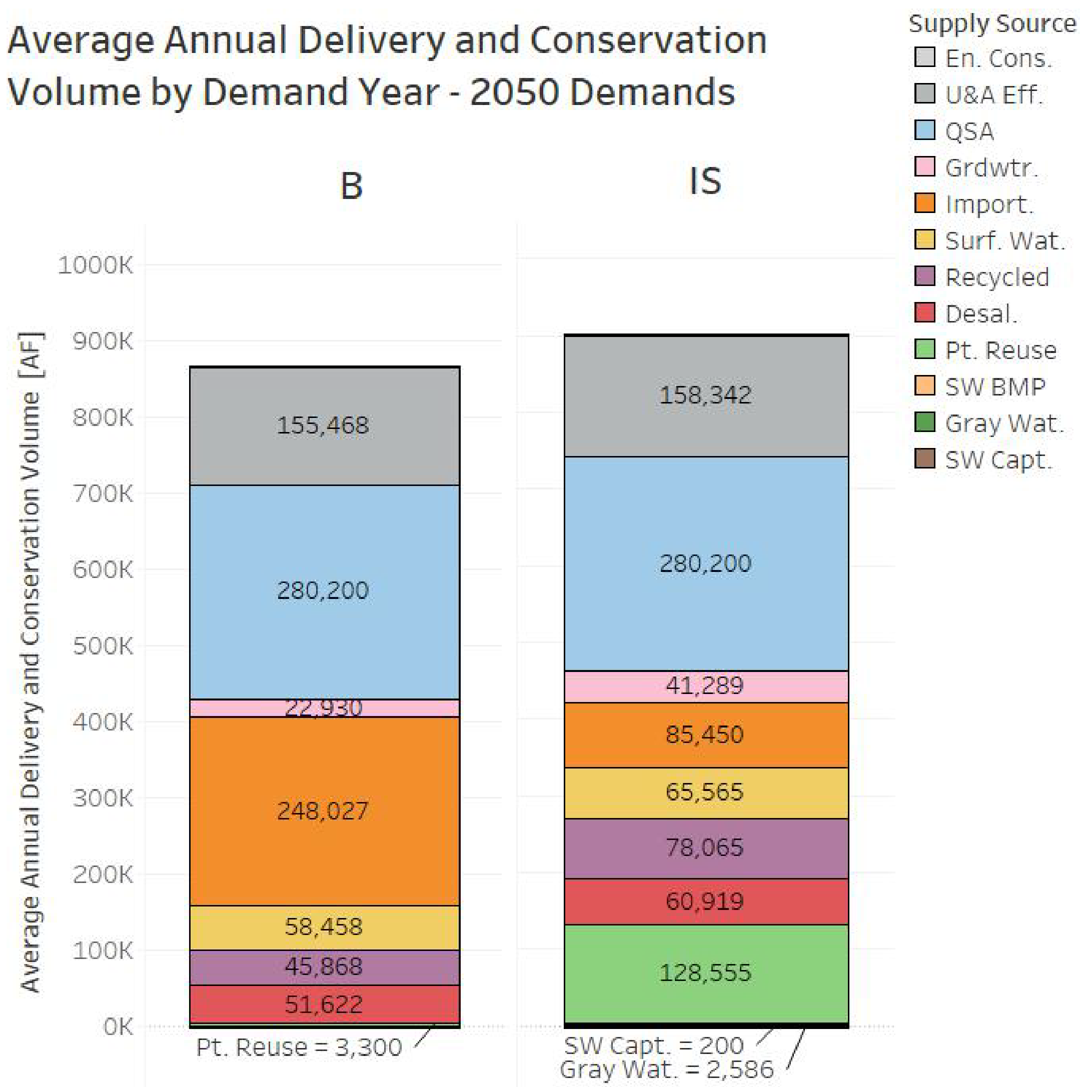


Figure 79. Annual water deliveries showing volumes associated with Seawater Desalination in the Baseline and the Increase Supplies Portfolios.

In general, Seawater Desalination is a more energy intensive supply source than traditional sources of potable water, and therefore, an increase in energy consumption was expected in the Increase Supplies Portfolio when the additional Seawater Desalination projects were implemented. Based on the analysis, however, there were minimal differences in energy consumption in the Increase Supplies Portfolio between demand scenarios, and the energy consumption in the Increase Supplies Portfolio was actually less than the energy consumption in the Baseline Portfolio for both 2025 and 2050 demands (Figure 80). The reason for this is that neither the Carlsbad Desalination Plan nor the Camp Pendleton Desalination Plant operated at full capacity during the model runs due to their low supply source priority in the CWASim model. Although the Camp Pendleton Desalination Plant was modeled at a plant capacity of 168,000 AF/y, Camp Pendleton Desalination only delivered approximately 7,300 AF/y in the Increase Supplies Portfolio 2050 current climate scenario. Deliveries from Carlsbad Desalination Facility were also approximately 14,900 AF/y lower in the

Increase Supplies Portfolio for the 2050 current climate scenario than in the Baseline Portfolio. If Carlsbad and Camp Pendleton Desalination Plants were to operate at full capacity, energy impacts would most likely differ from the results observed here. These results still indicate, however, that shifting from imported water to local water supply sources may have a net benefit to energy and reliability, even when the region's supply portfolio also includes more energy intensive supply sources such as Desalination.

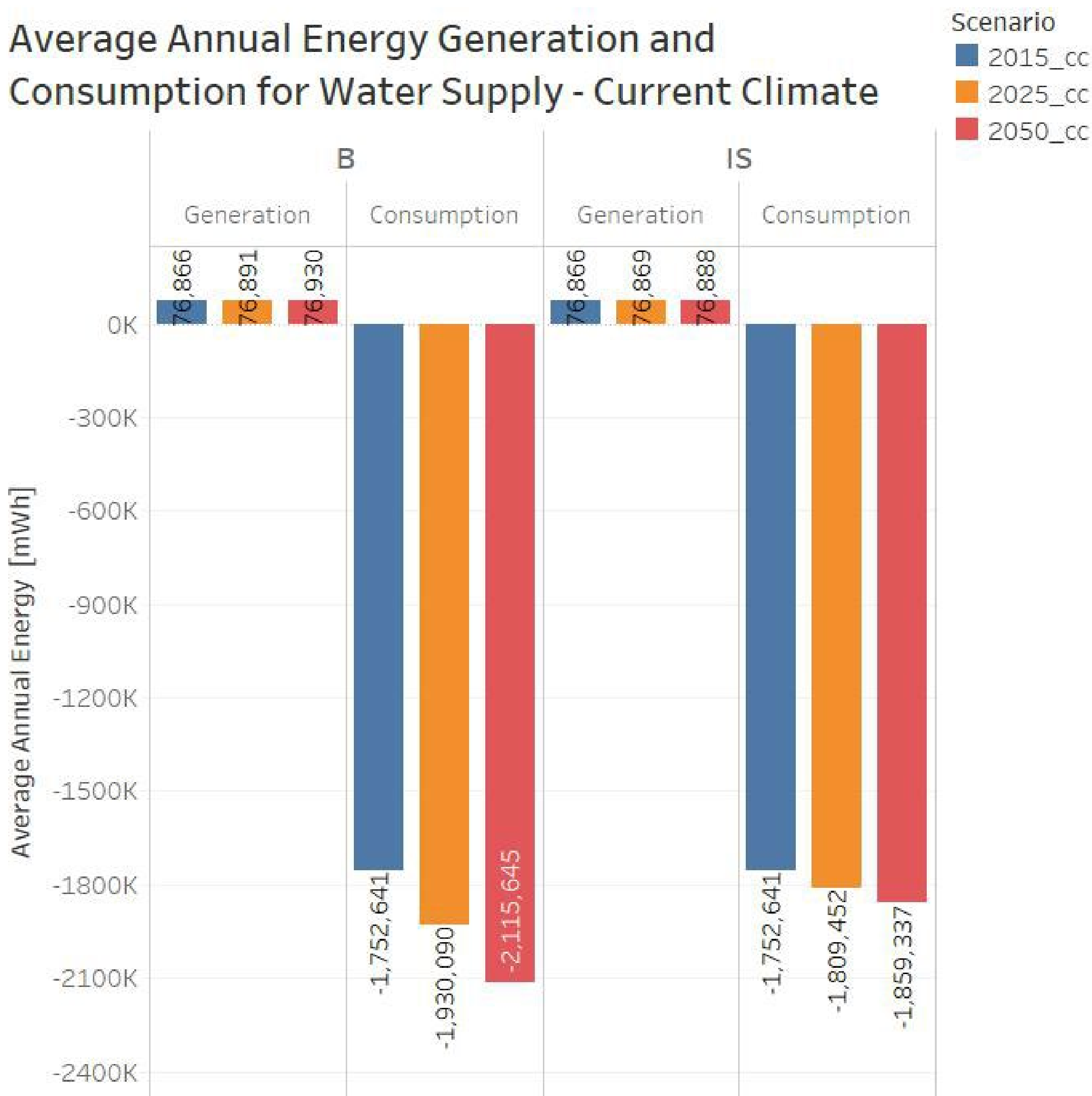


Figure 80. Energy Generation and Consumption in the Baseline Portfolio and the Increase Supplies Portfolio.

In the Trade-off Analysis, Seawater Desalination scored best for the Optimize Local Supplies and Climate Resilience Evaluation Objectives, with unweighted scores of 5.00 for both. Scores for these two Evaluation Objectives were more than one point higher than its third highest Evaluation

Objective score (Reliability and Robustness). This indicates that the Seawater Desalination Concept is particularly good at providing climate resilience while increasing the use of local supplies. Seawater Desalination's lowest unweighted scores were for Project Complexity and Cost Effectiveness, which both scored below a 2.0. Seawater Desalination had a high degree of variability for Evaluation Objective performance, with both some of the lowest and highest Evaluation Objectives scores. Five unweighted Evaluation Objective scores for Seawater Desalination were lower than a neutral score of 3.0. Individual Evaluation Objective scores for Seawater Desalination are shown below in Figure 81.

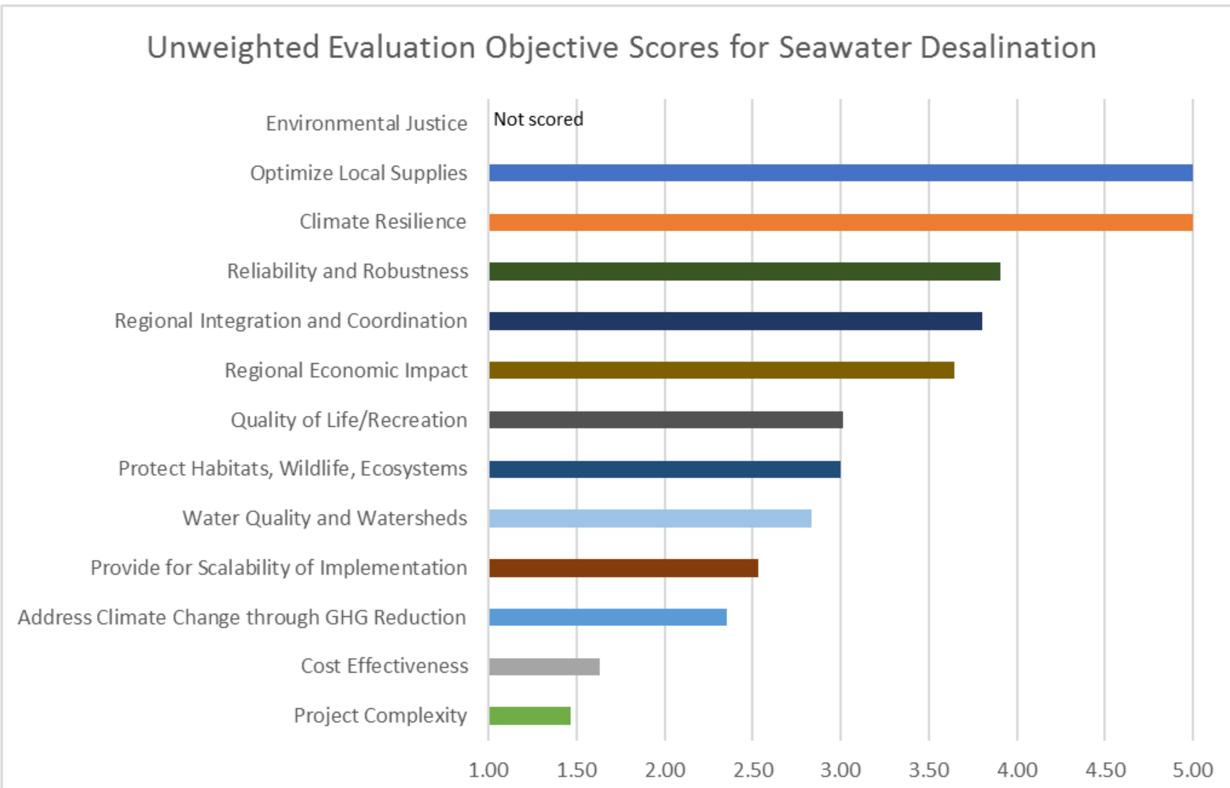


Figure 81. Unweighted Evaluation Objective scores for Seawater Desalination.

In the Economic Assessment, Seawater Desalination was one of only two Concepts that had a negative net energy benefit. It performed relatively well for water shortages and had a minimal effect on recreation. Overall, it was the worst-performing Concept in the Economic Assessment, with the only negative net annual value for the three categories of benefits.

10.12 Stormwater BMPs

In the Impacts Assessment, Stormwater BMP projects were only included in the Watershed Health and Ecosystem Restoration Portfolio. Of the 29 Stormwater BMP projects included in the Basin Study, eight were implemented in the CWASim model. The total water supply volume modeled from these eight projects was 98 AF/y, which is small relative to the other supply volumes, making it difficult to discern specific impacts from this supply type in the Impacts Assessment. The Trade-Off analysis provides more insight into the benefits of this Concept.

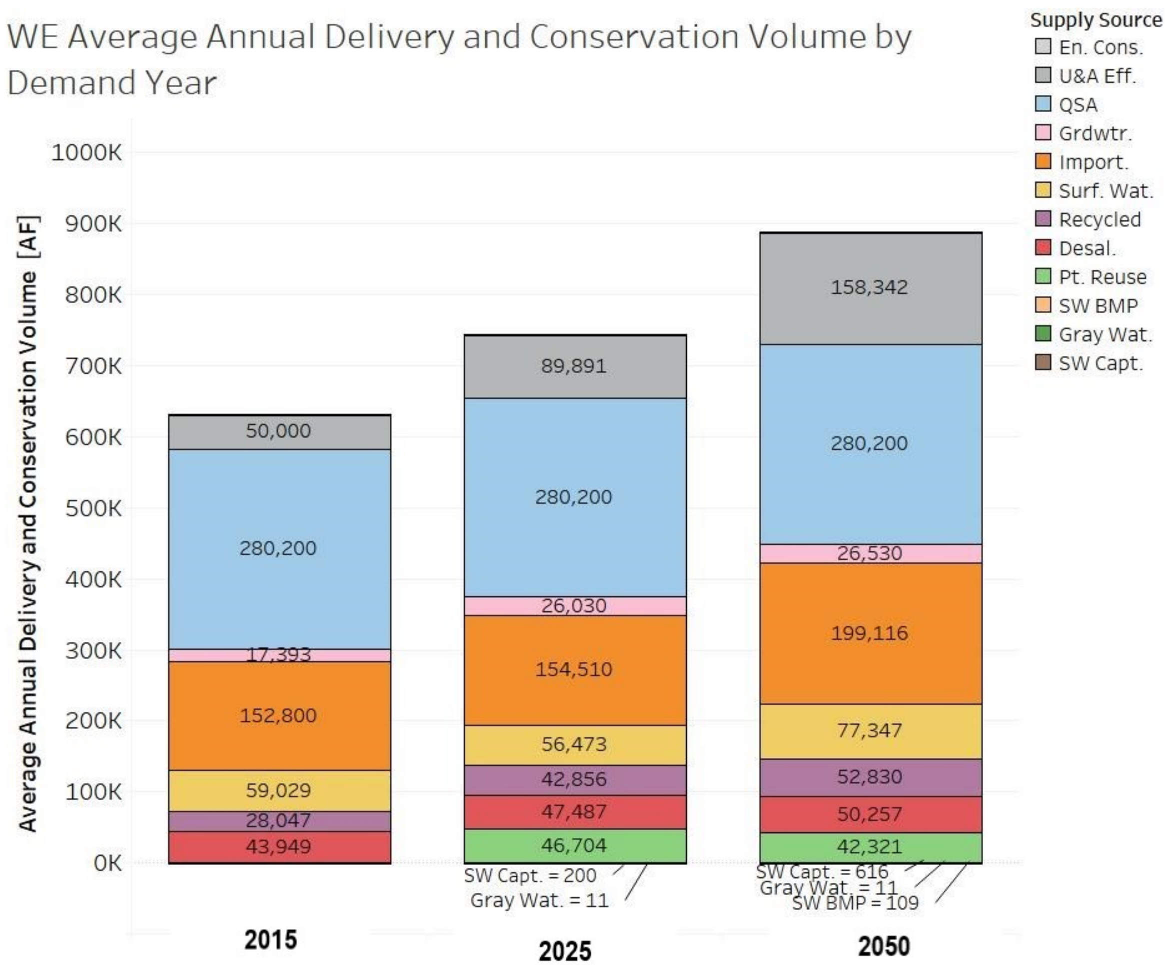


Figure 82. Annual water deliveries showing volumes associated with Stormwater BMP projects and Stormwater Capture projects in the Watershed Health and Ecosystem Restoration Portfolio.

In the Trade-off Analysis, Stormwater BMPs scored best on the Climate Resilience, Quality of Life/Recreation, and Water Quality and Watersheds Evaluation Objectives. Its lowest unweighted scores were for Cost Effectiveness and Regional Integration and Coordination. Cost Effectiveness was the only Evaluation Objective for which the Stormwater BMPs Concept received an unweighted score below a neutral 3.0 score. Individual Evaluation Objective scores for Stormwater BMPs are shown below in Figure 83.

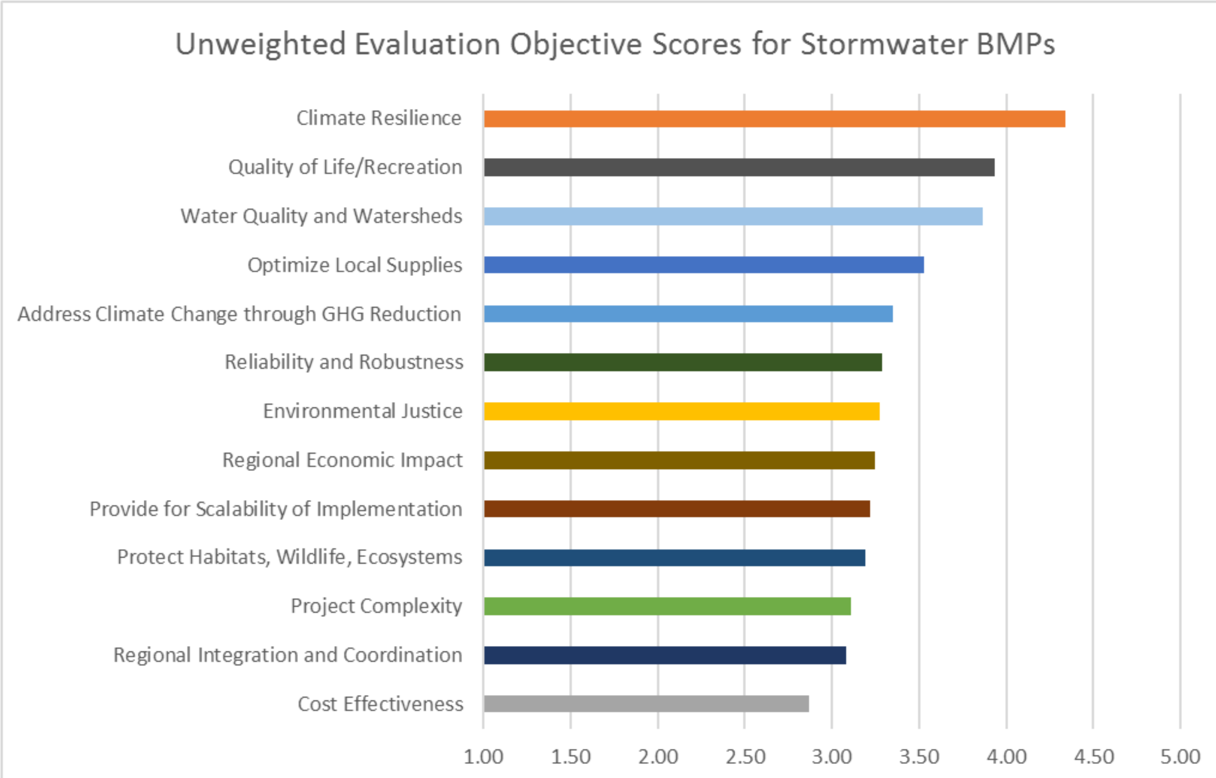


Figure 83. Unweighted Evaluation Objective scores for Stormwater BMPs.

In the Economic Assessment, Stormwater BMPs performed poorly relative to most other Concepts because it had little measurable effect on water shortages, recreation, or energy. This resulted in it having the second-worst rank in the Economic Assessment after Seawater Desalination.

10.13 Stormwater Capture

There were two Stormwater Capture projects in the Basin Study: Murray Urban Runoff Diversion System Capture and Rainwater Harvesting. For the Impacts Assessment, Murray Urban Runoff Diversion System Capture was included in the Baseline Plus Portfolio and implemented in the 2025 and 2050 demand scenarios, and Rainwater Harvesting was included in the Watershed Health and Ecosystem Restoration Portfolio and implemented only in the 2050 demand scenarios. Small water supply volumes were associated with these projects (200 AF/y and 416 AF/y, respectively). Similar to Stormwater BMPs, this volume is small relative to the other supply volumes, making it difficult to discern specific impacts from this supply type in the Impacts Assessment. The Trade-Off analysis provides more insight into the benefits of this Concept.

In the Trade-off Analysis, Stormwater Capture scored best on the Climate Resilience and Optimize Local Supplies Evaluation Objectives, both of which had unweighted scores that were more than half a point higher than the other 11 Evaluation Objectives. After the top two scores, Stormwater Capture had four Evaluation Objectives scores greater than a value of 3.5. Its lowest unweighted scores were for Project Complexity and Cost Effectiveness, which were both lower than a neutral 3.0 score. Individual Evaluation Objective scores for Stormwater Capture are shown in Figure 84.

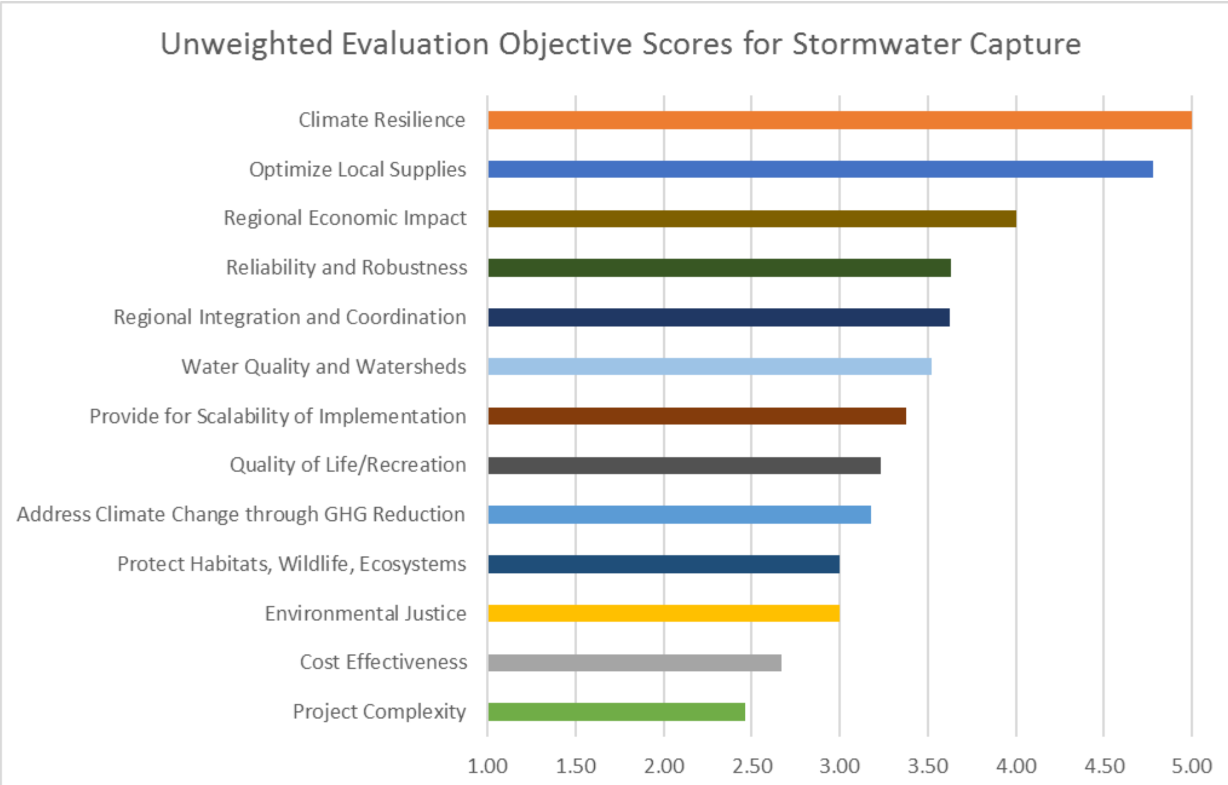


Figure 84. Unweighted Evaluation Objective scores for Stormwater Capture.

In the Economic Assessment, Stormwater Capture performed poorly relative to most other Concepts because it had only a small measurable effect on water shortages, recreation, or energy. This resulted in it having the third-worst rank in the Economic Assessment after Stormwater BMPs and Seawater Desalination.

10.14 Urban and Agricultural Water Use Efficiency

For the Impacts Assessment, the Urban and Agricultural Water Use Efficiency Concept was included in the Baseline Portfolio and expanded in the Baseline Plus Portfolio. Baseline conservation volume from this Concept was 50,000 AF/y in the 2015 demand scenarios, increasing to 89,110 AF/y in the 2025 demand scenarios and 155,468 AF/y in the 2050 demand scenarios. The additional annual conservation volume from this Concept in the Baseline Plus Portfolio was 781 AF/y for 2025 demands and 2,874 AF/y for 2050 demands (Figure 85 and Figure 86). Projects in this Concept are implemented as demand reductions, so the CWASim model results reflect reduced member agency demands, which decreases use of imported and local supplies.

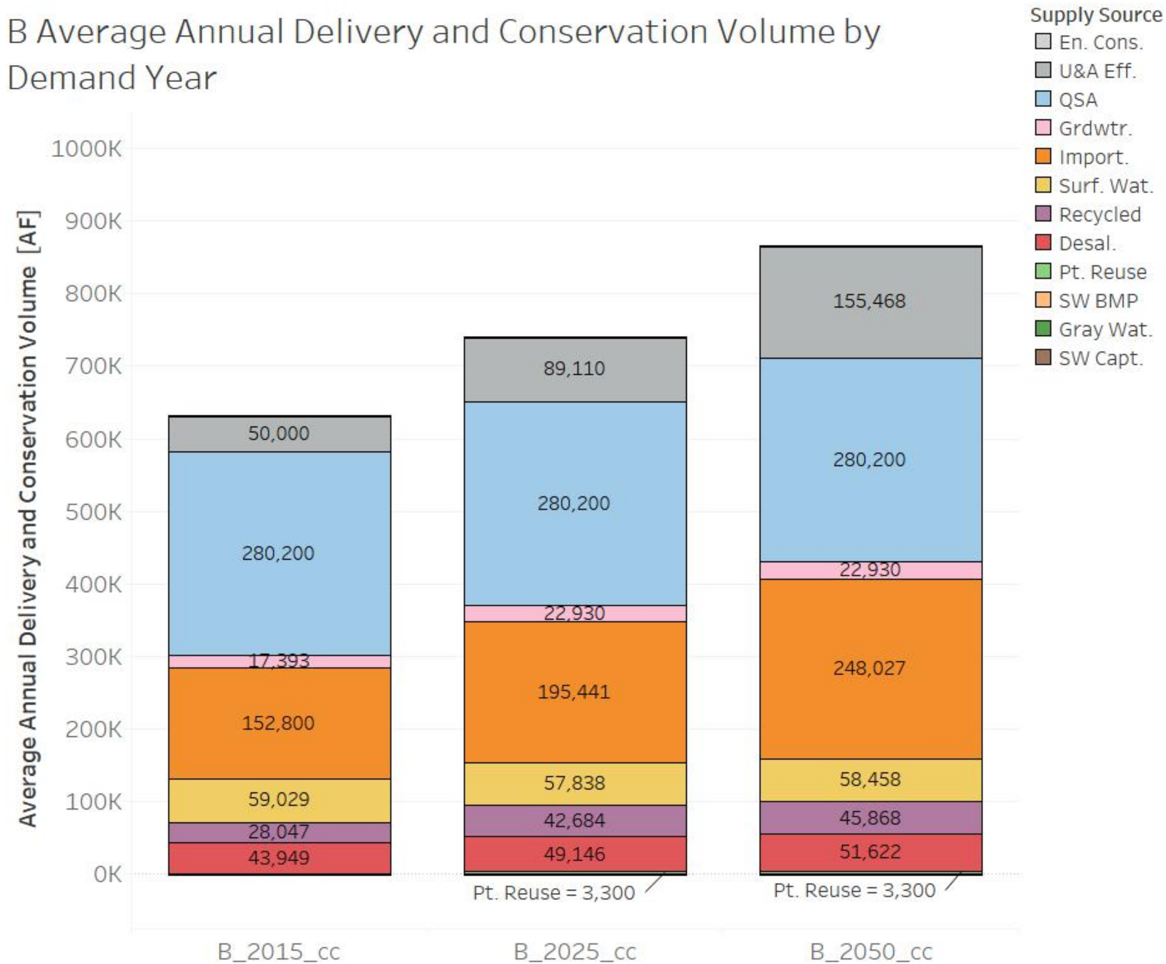


Figure 85. Annual Delivery Volumes showing the conservation volumes associated with Urban and Agricultural Water Use Efficiency in the Baseline Portfolio.

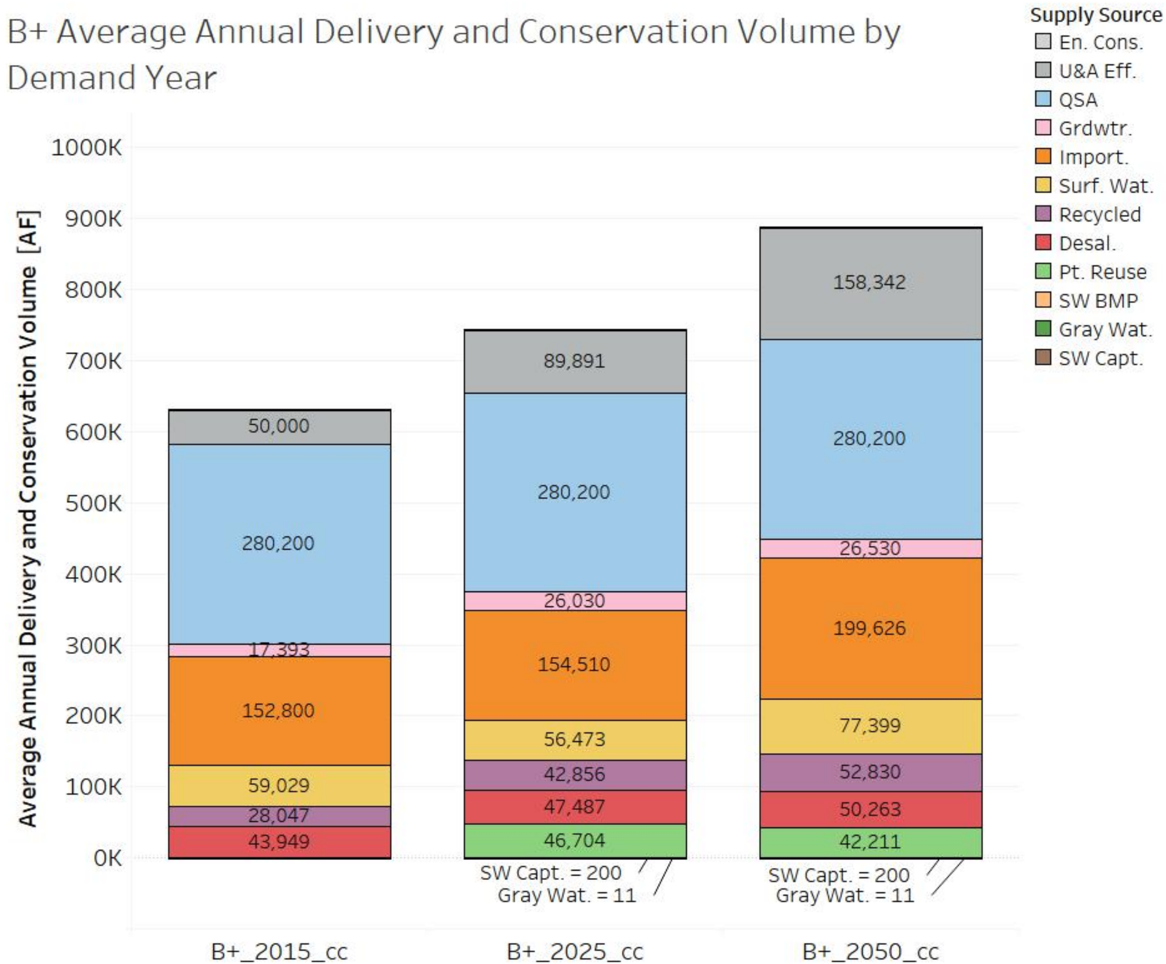


Figure 86. Annual Delivery Volumes showing the conservation volumes associated with Urban and Agricultural Water Use Efficiency in the Baseline Plus Portfolio.

In the Trade-off Analysis, Urban and Agricultural Water Use Efficiency scored best on the Optimize Local Supplies, Regional Economic Impact, and Project Complexity Evaluation Objectives, closely followed by Cost Effectiveness and Provide for Scalability of Implementation. All five of these Evaluation Objectives had unweighted scores higher than 4.00. Urban and Agricultural Water Use Efficiency scored lowest for Protect Habitats, Wildlife, and Ecosystems, and Reliability and Robustness. None of its unweighted Evaluation Objective scores were lower than a neutral 3.0, with the lowest unweighted score being a 3.08 for the Protect Habitats, Wildlife, and Ecosystems Evaluation Objective. Along with Gray Water Use, Urban and Agricultural Water Use Efficiency was one of the only Concepts that did not receive any unweighted scores below a 3.0 for any Evaluation Objective. The combination of no scores below 3.0 and six 4.0 or greater scores is why Urban and Agricultural Water Use Efficiency had the highest overall total score when considering all the Evaluation Objectives among all Concepts. Individual Evaluation Objective scores for Urban and Agricultural Water Use Efficiency are shown below in Figure 87.

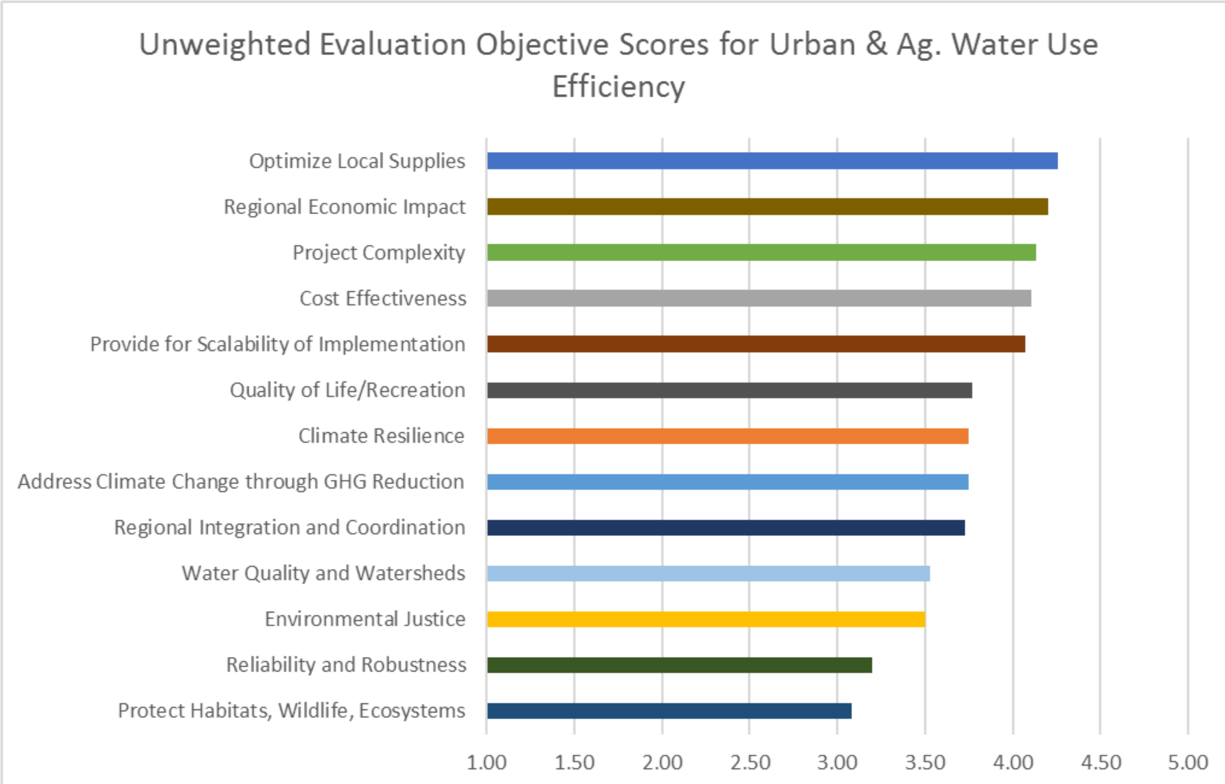


Figure 87. Unweighted Evaluation Objective scores for Urban and Agricultural Water Use Efficiency.

In the Economic Assessment, Urban and Agricultural Water Use Efficiency ranked in the lower half of Concepts and had an overall net annual value of economic effects that was approximately 2% of the value of the best-performing Concept (Enhanced Conservation).

10.15 Watershed and Ecosystem Management

For the Impacts Assessment, Watershed and Ecosystem Management projects were included in the Baseline Plus and Watershed Health and Ecosystem Restoration Portfolios. Of the four Watershed and Ecosystem Management projects included in the Baseline Plus Portfolio, two – Hodges Water Quality Improvement Program and Sweetwater Reservoir Wetlands Habitat Recovery – were implemented in the CWASim model. None of the Watershed and Ecosystem Management projects included in the Watershed Health and Ecosystem Restoration Portfolio were implemented in the CWASim model because they did not have a supply volume or operational impact associated with them that could be modeled.

The two Watershed Health and Ecosystem Management projects in the Baseline Plus Portfolio both impacted reservoir operations. The Sweetwater Reservoir Wetlands Habitat Recovery project was introduced in the Baseline Plus Portfolio 2025 scenarios and increased the available storage in Sweetwater Reservoir by 7,873 AF. The Hodges Water Quality Improvement Program project was introduced in the 2050 demand scenarios and allowed for increased use of Hodges Reservoir for water supply by improving its water quality, which currently does not meet the requirements to be conveyed to the regional aqueduct system. This project allowed higher releases of water from Hodges Reservoir to other parts of the regional water system, where it could then be used to meet demands.

Due to the improved water quality, more water could be used from Hodges Reservoir, causing the monthly average reservoir storage to decrease by approximately 5,000 AF each month (about a 30% decrease) and average reservoir releases (which are releases used to meet demands in the regional water system) to increase between 1,000 AF per month and 3,000 AF per month each month depending on the month (there are fewer releases from January to February and July to August) when this project is implemented. This amounts to an approximately 100% - 300% increase in the volume of reservoir releases from Hodges. Figure 88 and Figure 89 compare reservoir storage and releases between the Baseline and Baseline Plus Portfolios.

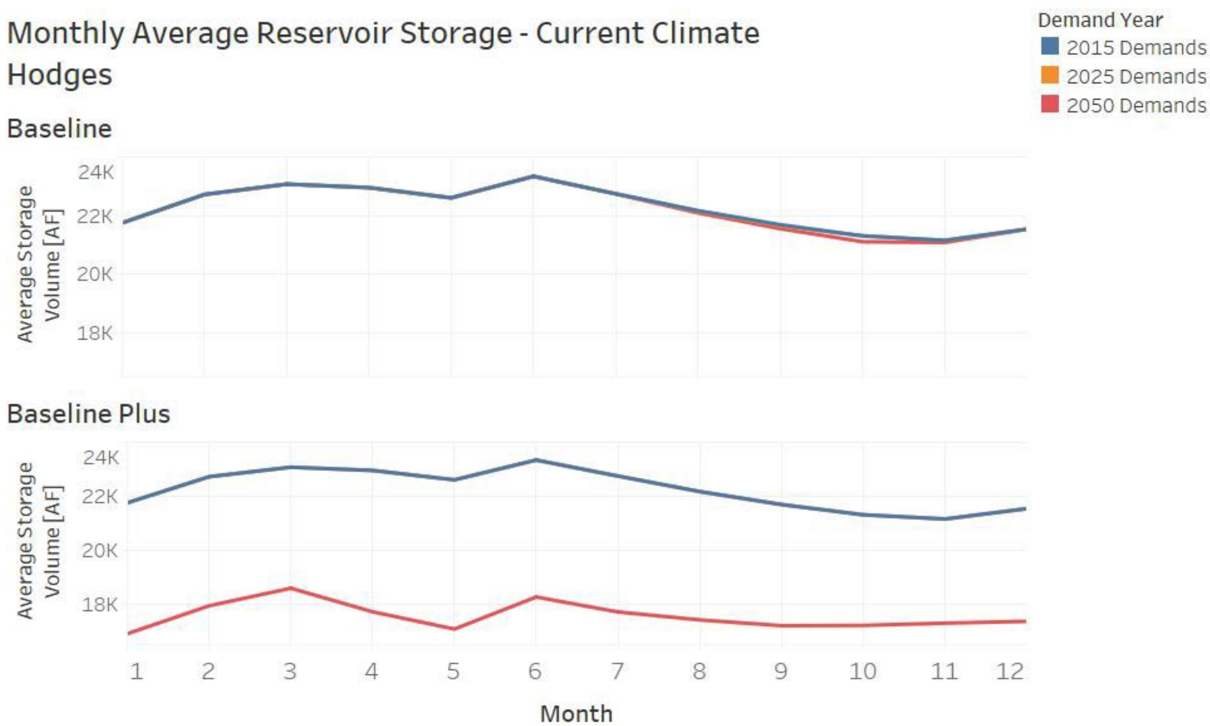


Figure 88. Reservoir Storage at Hodges for Baseline and Baseline Plus Portfolios.

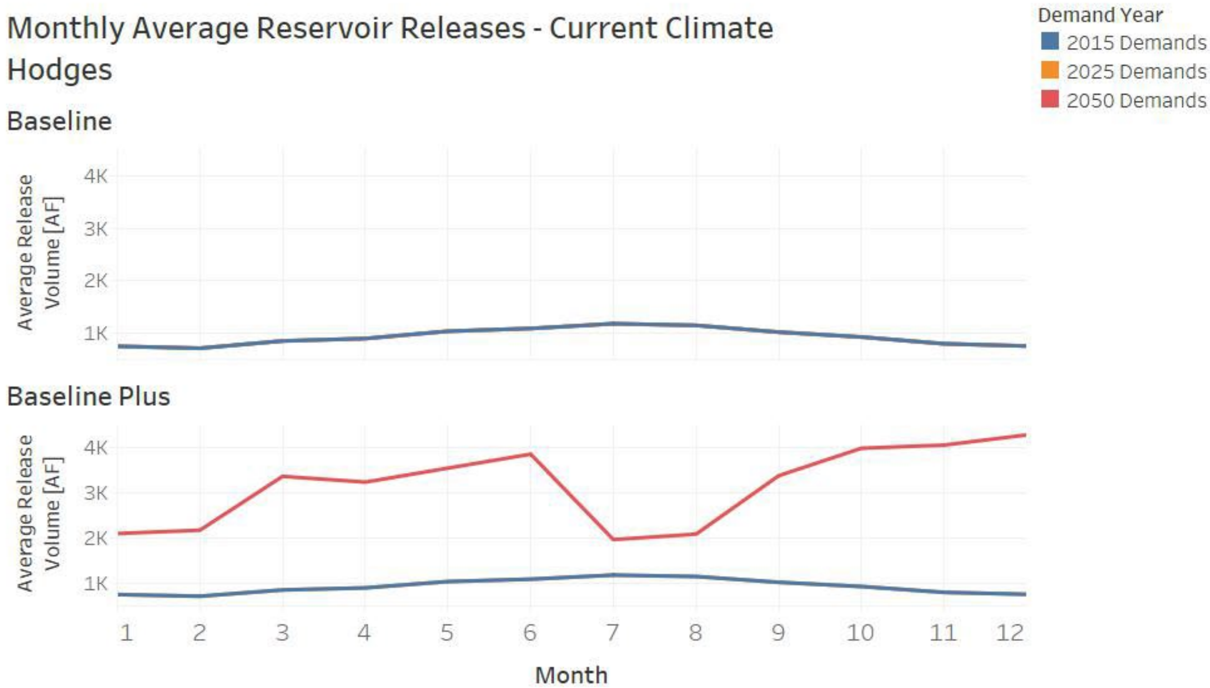
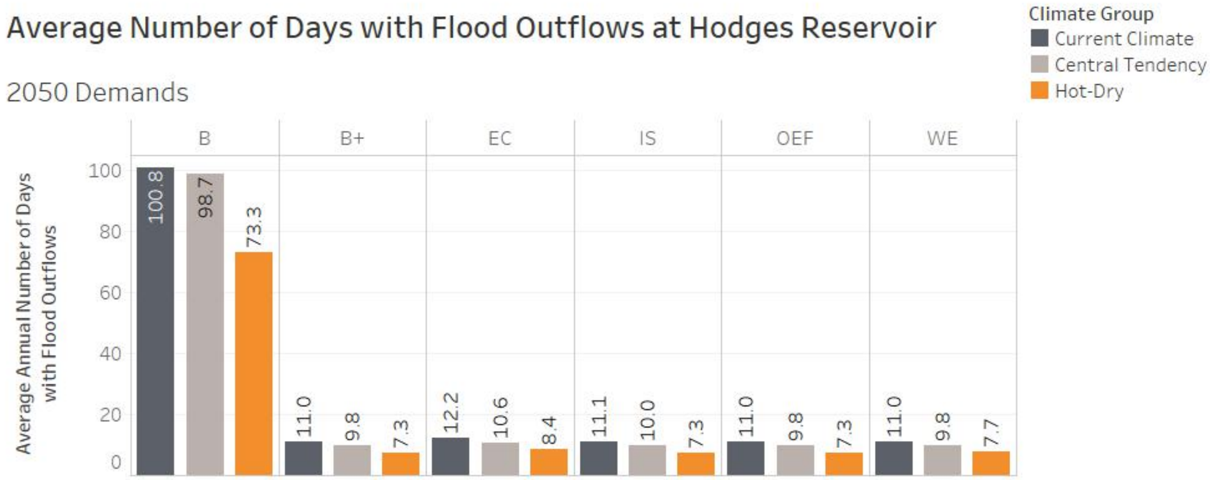


Figure 89. Reservoir Releases at Hodges for Baseline and Baseline Plus Portfolios.

The Hodges Water Quality Improvement Program also had an impact on Flood Control. Based on the model results, this project is expected to create a 90% decrease in the Average Number of Days with Flood Outflows from the reservoir (from approximately 100 days in the Baseline Portfolio to 11 days in the Baseline Plus Portfolio with current climate, see Figure 90). The decreased frequency in flood outflows due to implementation of Hodges Water Quality Improvement Program is anticipated to result in a water savings of 2,900 to 5,700 AF/y, compared to the Baseline Portfolio, depending on the portfolio and climate scenario.



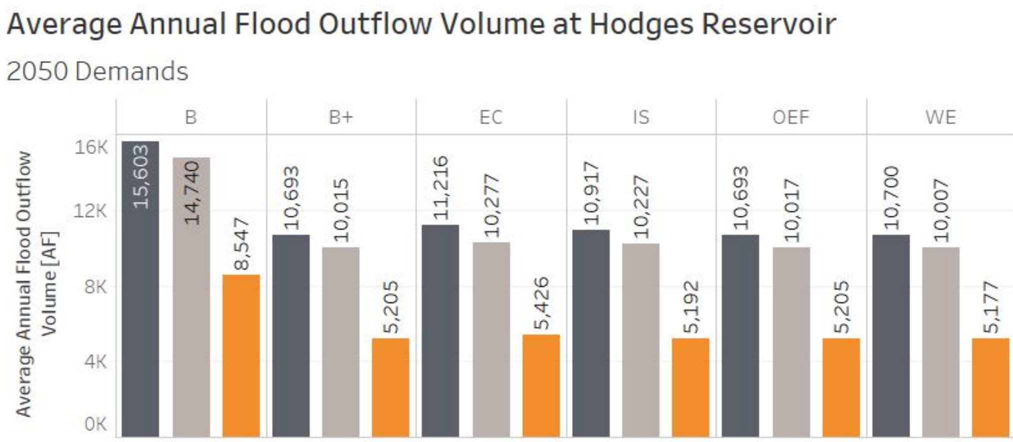


Figure 90. Hodges Flood Outflows and Flood Outflow Volume for Baseline and Baseline Plus Portfolios with current climate, central tendency climate, and hot-dry climate for the 2050 demand scenario.

In the Trade-off Analysis, Watershed and Ecosystem Management scored best for the Quality of Life/Recreation, Climate Resilience, and Optimize Local Supplies Evaluation Objectives. Its Quality of Life/Recreation Evaluation Objective score was above 4.0. Its lowest unweighted scores were for Project Complexity and Cost Effectiveness, both of which scored below a neutral 3.0 score. Individual Evaluation Objective scores for Watershed and Ecosystem Management are shown below in Figure 91.

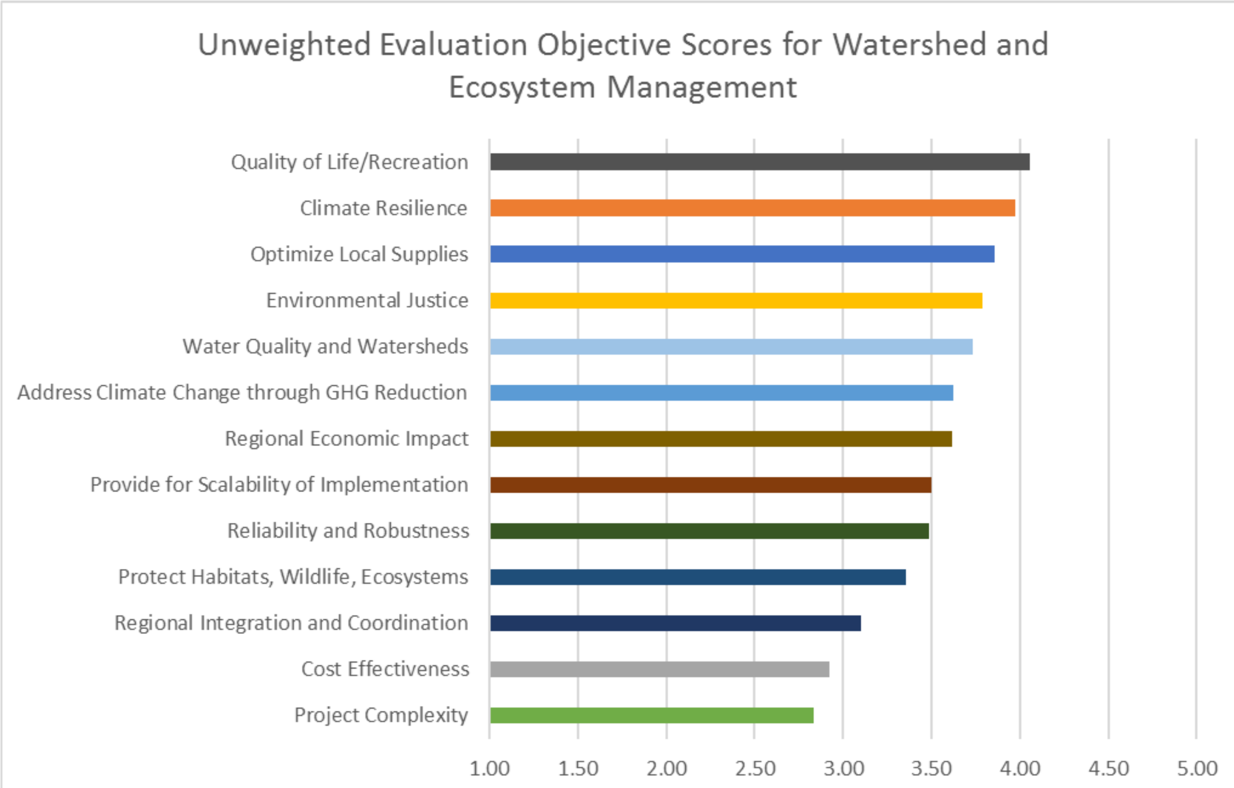


Figure 91. Unweighted Evaluation Objective scores for Watershed and Ecosystem Management.

In the Economic Assessment, Watershed and Ecosystem Management was the worst-performing Concept for recreation, with a negative value relative to the Baseline. It performed in the lower half of Concepts for water shortage benefits, and was the middle-ranked Concept for energy benefits, resulting in an overall middle ranking for net annual value of economic effects.

11. Summary and Conclusions

The purpose of the San Diego Basin Study was to explore the types and magnitudes of impacts of existing and potential future water management strategies on water delivery, energy, recreation, and flood control under a variety of climate and demand scenarios. This information is intended to help guide regional decision-makers in identification and selection of projects for design or further study.

Fifteen Concepts representing various water management strategies, including Seawater Desalination, Recycled Water, Urban and Agricultural Water Use Efficiency, Potable Reuse, and Groundwater were identified through a stakeholder process. Regional planning documents helped develop a list of 225 projects that were categorized by Concept.

Three types of analyses were used to evaluate the Concepts. In the Impacts Assessment, six portfolios of Concepts were modeled using a water system operations model. The results were and analyzed using metrics calculated from model outputs for four impact areas: Water Supply Energy, Recreation, and Flood Control. In the Trade-Off Analysis, 12 of the 15 Concepts (not including Baseline-only Concepts) were scored on 13 Evaluation Objectives. The scores were then combined into a final overall score for comparison. In the Supplemental Economic Assessment, the differences in economic value of each Concept were calculated relative to the Baseline for three categories of benefits; these values were then used to compare the Concepts.

Together, the results 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. These results could also 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.

11.1 Impacts Assessment Conclusions

If no additional adaptation strategies are employed in the region beyond the infrastructure and policies that were in place as of 2015 as represented by the Baseline Portfolio, the Impacts Assessment results indicate that increasing demand and changing climate may result in shortages within the region above the level that can generally be mitigated by short term drought response. If the region were to experience climate conditions similar to the hot-dry or warm-dry climate scenarios, the shortages could be further exacerbated. In addition to the increased possibility of shortages in the region, the Baseline Portfolio shows an increase in issues associated with high pipeline utilization for the untreated MWD pipeline, and higher energy consumption, which may be associated with increased operating and repair costs. The Baseline Portfolio was also associated with higher dependence on imported water.

By continuing to support the region’s active investments as simulated in the Baseline Plus Portfolio, improvements in water supply reliability are possible, as indicated by a decreased occurrence of shortages (although shortages may not be completely eliminated), while also having less dependence on imported water when compared to the Baseline. Analysis of results for the other portfolios beyond Baseline Plus demonstrates that there are promising options that the San Diego region may consider for future investments to further secure reliable water supplies. Results for the Enhanced Conservation Portfolio, which represents long-term or permanent restrictions in water use to decrease demand, demonstrate the direct benefits of conservation, as no shortages occurred in the model results. The Enhanced Conservation Portfolio also demonstrates indirect benefits of conservation, such as reduced energy consumption, fewer pipeline capacity issues due to high utilization, increased reservoir storage that provides a direct benefit to recreation, and less dependence on imported water. The Increase Supplies Portfolio addresses challenges such as water reliability and dependence on imported water while providing benefits such as decreased shortages, fewer issues associated with high pipeline utilization, and increased reservoir storage that provides a direct benefit to recreation, without implementation of the conservation associated with the Enhanced Conservation Portfolio. 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 provide benefits by maximizing the region's existing infrastructure and allowing for improved reservoir management that may provide flood control benefits that were not seen in other portfolios. Similar impacts were observed for the Watershed Health and Ecosystem Restoration Portfolio compared to the Baseline Plus Portfolio, since many of the environmental projects included in this Portfolio were unable to be simulated in the CWASim model due to the lack of available supply volumes. In addition to the benefits that were exhibited by the Baseline Plus Portfolio, this Portfolio would likely exhibit positive environmental impacts.

Key findings of the Impacts Assessment include:

- Water Delivery
  - The projected increase in population and changes in socioeconomic factors had a more significant impact on demand projections than the effect of climate change.
  - All portfolios except the Enhanced Conservation Portfolio aimed to increase water deliveries to meet increased demands, while the Enhanced Conservation Portfolio aimed to decrease demands.
  - All portfolios beyond Baseline showed a shift in water deliveries away from imported water to meet increasing demands. 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) may be effective at reducing dependence on imported water.
  - Surface Water deliveries appeared to have the greatest impact from climate change scenarios, with lower surface water deliveries (approximately 20% on average) for hot-dry climate and higher deliveries for warm-wet climate compared to central tendency climate, indicating that a hot-dry climate is likely to reduce the availability of local surface water.
  - Water delivery shortages were largest in the Baseline, lower in all other portfolios due to additional supply and conservation projects, and lowest in Enhanced Conservation due to the large reduction in demand.
  - Large shortage volumes are typically associated with supply shortages, while smaller shortage volumes are typically associated with conveyance limitations.
  - Overall, 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.

- Energy
    - There was an increase in energy consumption in all portfolios except Enhanced Conservation. The increase was smallest in Increase Supplies.
    - Energy consumption was slightly lower in the Baseline Plus, Optimize Existing Facilities, and Watershed Health and Ecosystem Restoration Portfolios than in the Baseline Portfolio, indicating that energy consumed by the additional projects in these Portfolios is offset in other areas of the system, most likely by the reduction of Imported Water usage compared to the Baseline Portfolio.
    - Energy consumption in the Enhanced Conservation Portfolio was significantly less than in the Baseline and Baseline Plus Portfolios due to the reduction in deliveries, and thus use of treatment plants and conveyance facilities, indicating that demands are a major driver of energy consumption (i.e., reduced demands lead to reduced energy consumption).
- Recreation impacts varied by reservoir and portfolio.
    - El Capitan boat ramps were frequently inaccessible except in Optimize Existing Facilities.
    - End of September elevation decreased in the Baseline Plus Portfolio for 2050 demands due to the implementation of the Hodges Water Quality Improvement Program, but there was no resulting impact on recreation.
    - Boat ramp accessibility improved at Lower Otay in all portfolios beyond Baseline, and lack of accessibility was completely eliminated in the Enhanced Conservation Portfolio.
    - Boat ramps remained accessible in all scenarios for San Vicente.
- Flood Control
    - At El Capitan, the number of days with flood outflows was larger in the Increase Supplies and Optimize Existing Facilities Portfolios than in the Baseline and Baseline Plus Portfolios, which can be attributed to the increased water supplies in the region, or operational flexibility.
    - Days with flood outflows decreased at Hodges Reservoir in portfolios beyond Baseline due to the implementation of the Hodges Water Quality Improvement Program.

- At Lower Otay the number of flood outflows was higher in the Enhanced Conservation Portfolio than in the Baseline Portfolio due to increased storage resulting from lower water demands.
- There were no flood outflows at San Vicente in any portfolios.

11.2 Trade-off Analysis Conclusions

The Trade-off Analysis performed with all Evaluation Objectives 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.

Key findings of the Trade-off Analysis include:

- Concepts can be divided into three groups based on the weighted scores for all Evaluation Objectives using mean survey scores, plus a fourth group that is not directly comparable to the other groups because the Concepts were not scored on all Evaluation Objectives.
  - Top Scoring Concept
    - Urban and Agricultural Water Use Efficiency
  - Concepts Scoring within 10% of the Top Scoring Concept
    - Watershed and Ecosystem Management
    - Stormwater Capture
    - Recycled Water
    - Potable Reuse
    - Stormwater BMPs
  - Concepts Scoring within 15% of the Top Scoring Concept
    - Groundwater
    - Conveyance Improvement
  - Concepts Not Scored on All Evaluation Objectives
    - Imported Water Purchases
    - Enhanced Conservation

  - Seawater Desalination
  - Gray Water Use

- Stakeholders identified Reliability and Robustness and Water Quality and Watersheds as the most important Evaluation Objectives in the survey that asked respondents to rank Evaluation Objectives on their relative importance. Climate Resilience was the next most important, followed by Optimize Local Supplies.

- 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. Gray Water Use scored highest for Climate Resilience, and Seawater Desalination scored highest for Optimize Local Supplies.

- Urban and Agricultural Water Use Efficiency, the highest scoring Concept for all Evaluation Objectives, scored higher than neutral for all Evaluation Objectives and did not receive an unweighted Evaluation Objective score below a neutral value of 3.00.

- The top overall scoring Concepts had individual Evaluation Objective scores that were consistently in the top tier of Concepts, although they were not necessarily the top scoring Concepts for every Evaluation Objective.

- Generally, most Concepts did not perform poorly for any particular Evaluation Objective, except Project Complexity and Cost Effectiveness. Most Concepts scored relatively poorly for Project Complexity, with an average unweighted score of 2.70, and Cost Effectiveness, with an average unweighted score of 2.74.

- No Concept received a less than neutral (3.00) score for Environmental Justice; Protect Habitats, Wildlife, and Ecosystems; Quality of Life/Recreation; or Reliability and Robustness.

- The Project Complexity Evaluation Objective had the largest range of unweighted scores, ranging from a low of 1.47 for Seawater Desalination to a high of 4.13 for Urban and Agricultural Water Use Efficiency.

- Protect Habitats, Wildlife, and Ecosystems had the smallest range of unweighted scores, ranging from 3.00 for seven Concepts to 3.35 for Watershed and Ecosystem Management.

- All Concepts had at least one Evaluation Objective with an unweighted score above 4.0 except for Imported Water and Enhanced Conservation. Imported Water received a maximum unweighted score of 3.26 (for Project Complexity) and was not scored for three Evaluation Objectives.

- Analysis of significant differences between Concepts using mean survey results indicated low potential for bias, and sensitivity analysis of overall Trade-off Analysis results using median scores indicated only minor changes in Concept ranking.

11.3 Supplemental Economic Assessment Conclusions

The Supplemental Economic Assessment evaluated three categories of benefits that could be quantified and monetized relative to Baseline conditions: municipal and industrial water supply reliability (reduced shortages), recreation (reservoir visitation), and net energy usage. These values were calculated from model outputs and economic values from literature. The Economic Assessment only includes a limited set of benefits that could be quantified and does not represent a full accounting of all economic effects that would be expected from each of the Concepts.

Key findings of the Economic Assessment include:

- Value of Water Supply Reliability
    - All the Concepts generated positive benefits associated with reducing water shortages.
    - Enhanced Conservation generated the greatest reduced water shortage benefits compared to the Baseline conditions, followed by Potable Reuse and Seawater Desalination.
- Value of Recreation
    - 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.
- Value of Energy
    - The difference in net energy usage relative to the Baseline was large and positive for Enhanced Conservation, Potable Reuse, Recycled Water, and Groundwater.
    - The reduction in net energy usage relative to the Baseline varied widely between Concepts. Enhanced Conservation had a reduction 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 water import, treatment, and conveyance.

- Net energy usage values relative to the Baseline were 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.

- Net Value of Water Supply Reliability, Recreation, and Energy
  - The combined quantified and monetized economic 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 for the three categories of benefits analyzed and had a net annual value more than three times larger than any other Concept, primarily due to its large reduction in energy usage.

11.4 Limitations

In any analysis, there are assumptions made and limitations in the available information that affect the results of the work. The assumptions made and limitations encountered in the Basin Study are summarized below. However, despite these assumptions and limitations, the Basin Study provides a depth and breadth of information about the potential impacts, costs, and benefits of a variety of strategies for addressing water supply and demand imbalances in the San Diego region.

11.4.1 Impacts Assessment Limitations

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. In order to perform simulation modeling, studies must also incorporate simplifications of system operations and assumptions about future conditions. The assumptions and simplifications that were made for the San Diego Basin Study have been documented above and in the Task 2.4 Interim Report; some key assumptions are highlighted here. Although these simplifications and assumptions were implemented, rigorous testing of the CWASim model was performed to ensure that results are representative of the conditions and trends that could be expected as a result of the scenarios examined in the Study.

Demands used in this Study were characterized by the 2015 SDCWA UWMP water supply and demand assumptions with minor modifications. Although SDCWA updated its demand forecast in 2018 to reflect changes in demand trends since the publication of the 2015 UWMP, the update occurred too late in the Basin Study process to be incorporated into the Study. Therefore, the Basin Study used demand projections from the 2015 UWMP, which are higher than the SDCWA 2018 demand forecast (San Diego County Water Authority, 2018a). Additionally, SDCWA will conduct a full re-estimation of demand forecast for the 2020 UWMP, which will most likely differ from demands used in the Basin Study.

It was assumed 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 the potential for renegotiation of the agreement and/or changes in water supply availability that could affect the supply volume. Other imported water supplies, such as MWD supplies from the SWP and CRA, were also assumed to remain available for the duration of the Study; however, reliability of imported water deliveries to the San Diego region is uncertain due to recurring droughts in northern California and the Colorado River Basin, regulatory restrictions related to endangered species in the Bay-Delta that limit SWP deliveries, the potential for catastrophic events such as earthquakes, and impacts of climate change. If the availability of one or both of these imported supplies was reduced, the region could experience greater shortage impacts than those observed in the Basin Study results.

Although supplies from projects modeled as demand reductions (e.g., recycled water, groundwater, some potable reuse, etc.) may need to be conveyed, treated, and/or stored within the San Diego system, the CWASim model is not able to simulate the potential effects of these projects on the conveyance system or reservoirs. Therefore, metrics for Pipeline Flow Volume, High Pipeline Utilization Summer Count, High Pump Station Utilization, Treatment Plant Utilization, Reservoir Storage, Reservoir Releases, End of September Storage, Energy Consumption and Generation, End of September Elevation, Number of Days with Flood Outflows, and Flood Outflow Volume do not include the effects of these projects. However, because most of these projects are local projects for single member agencies, the regional effects that are the primary focus of the CWASim model are likely to be limited in scope.

Projects were modeled based on the best available information about their capacities and water supply volumes at the time the model runs were performed. However, since many projects were at a very early stage of planning, there were changes to anticipated volumes or capacities for some projects after the model runs for the Study were completed. 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 interaction of Concepts and portfolios may also cause impacts that were not observed in the Basin Study, such as the interaction of conservation with Potable Reuse. While the results of the Enhanced Conservation Portfolio indicate that conservation is a promising option for addressing water delivery needs, the increase in conservation may decrease the amount or quality of wastewater available for Potable Reuse. This type of interaction could also possibly occur with Gray Water Use. However, projected volumes of Gray Water Use are orders of magnitude lower than levels that might have an appreciable impact to the wastewater available for Potable Reuse. In addition, temporary shutdown of treatment plant operations may occur (or occur more often) with Enhanced Conservation, resulting in operational challenges and/or potential water quality issues in the distribution system. These challenges were not reflected in the CWASim model results.

11.4.2 Trade-off Analysis Limitations

The Trade-off Analysis evaluated 12 Concepts using 13 Evaluation Objectives, which represents a very large number of potential outcomes. Given the level of analysis, this evaluation is essentially a screening analysis which can be used to identify promising Concepts based on the set of Evaluation Objectives and weights identified as part of the Study.

The use of survey results for scoring Evaluation Objectives has the potential to introduce bias or imprecision in the Trade-off Analysis results. The survey questions gathered qualitative information about the projects and Concepts rather than precise data. Survey respondents may have had different understandings of the projects or Concepts being scored, different interpretations of the meaning of terms in the survey, and/or may have been uncertain about what the effects of the projects or Concepts would be. The survey was sent to a large number of potential respondents (see Section 7.3.1.2) to lessen this potential bias.

The information available for the Enhanced Conservation, Imported Water Purchases, Seawater Desalination, and Gray Water Use Concepts was limited, resulting in these Concepts only receiving scores for a subset of the Evaluation Objectives. Because the projects in the Imported Water Purchases Concept could not be mapped, this Concept was only scored for Evaluation Objectives that did not require GIS data. Therefore, it excludes the Climate Resilience; Environmental Justice; Protect Habitats, Wildlife, and Ecosystems; and Water Quality and Watersheds Evaluation Objective scores. In addition, it was not scored for the Optimize Local Supplies Evaluation Objective because the survey response for the single Imported Water Purchases Concept was changed to NA due to misinterpretation of the question by the survey respondent. Therefore, Imported Water Purchases only had scores for 9 of the 13 Evaluation Objectives. Imported Water received a score of 21.58 out of a possible 37.40 points. The Enhanced Conservation Concept was split out from the Urban and Agricultural Water Use Efficiency Concept after the surveys were distributed and was a regional project that could not be mapped. Therefore, Enhanced Conservation only had a score for the Regional Economic Impact Evaluation Objective. Enhanced Conservation received a score of 2.03 out of a possible 3.90 points. Both Gray Water Use and Seawater Desalination had missing project-level survey data for Environmental Justice, so they received scores for only 12 of the 13 Evaluation Objectives and were not scored for the Environmental Justice Evaluation Objective.

Although Enhanced Conservation was not able to be scored for the majority of the Evaluation Objectives with the methods used for the other Concepts, it may be possible to gain insight into how Enhanced Conservation would score by its similarities to the Urban and Agricultural Water Use Efficiency Concept. Both Concepts relate to water conservation but Enhanced Conservation focuses on restrictions in water use imposed at the local, regional, or State level, while Urban and Agricultural Water Use Efficiency focuses on behavioral changes that encourage water efficiency.

The actual practices implemented to achieve an imposed level of Enhanced Conservation may be quite similar to the practices encouraged through Urban and Agricultural Water Use Efficiency projects. Therefore, despite some differences, the relative scores of Enhanced Conservation for some Evaluation Objectives may be quite similar to Urban and Agricultural Water Use Efficiency.

11.4.3 Economic Assessment Limitations

Due to limited data availability, the Economic Assessment completed as part of the Study was limited in scope and does not represent the full range of costs and benefits that would need to be considered in a full economic analysis.

11.5 Opportunities and Next Steps

Together, the results of the Impacts Assessment, Trade-off Analysis, and Supplemental Economic Assessment indicate that there are many promising options for addressing the water supply needs of the San Diego region through the 2050s. The three approaches are complementary, each with their own strengths and weakness. Synthesizing the results of the three analyses will provide decision-makers with the broadest range of information to guide decisions regarding which types of projects to target for further analysis, feasibility studies, or design.

For example, the impacts analysis indicated that Enhanced Conservation would have a number of positive benefits for the region, such as reduced energy consumption, fewer pipeline capacity issues due to high utilization, increased reservoir storage that provides a direct benefit to recreation, and less dependence on imported water. Although this Concept was only able to be analyzed for one Evaluation Objective in the Trade-off Analysis, it has many similarities to the highest-scoring Concept in the Trade-off Analysis, Urban and Agricultural Water Use Efficiency, and may therefore produce similar benefits for some Evaluation Objectives. Since Urban and Agricultural Water Use Efficiency was the top-scoring Concept in the Trade-off Analysis, it is likely that Enhanced Conservation would have scored well if more data had been available.

Similarly, the impacts analysis was only able to evaluate the impacts of some Concepts including Stormwater Capture, Watershed and Ecosystem Management, and Stormwater BMPs to a limited extent due to the dependency of the Impacts Assessment on the CWASim modeling tool, which is focused on water supply volume and water delivery. However, the Trade-Off Analysis results show that these Concepts perform well on many of the Evaluation Objectives, indicating that these Concepts may have significant benefits and would be worth considering for implementation as part of the overall water system in the San Diego region.

Potable Reuse and Recycled Water both scored well in the Trade-off Analysis, and were part of the Increase Supplies Portfolio in the Impacts Assessment, which had reduced shortage volumes, lower dependence on Imported Water, and lower energy consumption relative to the Baseline and Baseline Plus Portfolios. The strength of Potable Reuse in lowering dependence on imported supplies through optimizing local supplies was also identified in the Trade-off Analysis, where Optimize Local Supplies was the highest-scoring Evaluation Objective for Potable Reuse.

The results of the Basin Study can also help decision-makers understand the type of water supply mix that may be beneficial to work towards. Based on the results of the Impacts Assessment, the types of projects included in the Increase Supplies Portfolio may provide for more water reliability due to the increase of local supply sources and decreased dependence on imported water; however, those projects alone may not reduce the number of flood outflows from reservoirs. Implementing an intertie project, as was analyzed in the Optimize Existing Facilities Portfolio, may pair well with projects from the Increase Supplies 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. Although the Optimize Existing Facilities Portfolio did not reduce potential Shortage Volumes, its conveyance improvement did allow for increased storage for some reservoirs and fewer conveyance limitations. Since the Enhanced Conservation Portfolio only included the Concept of Enhanced Conservation, it may be beneficial to use the results to predict what may occur when this Portfolio is combined with Concepts like Potable Reuse and Recycled Water from the Increase Supplies Portfolio.

From the Trade-off Analysis, 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 be complementary. 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.

Concepts examined in the San Diego Basin Study represent a wide range of strategies that could be implemented individually or in combination to address the impacts of increasing demand and changing water supplies. The results of the Basin Study indicate that there are many promising Concepts and many possible combinations of Concepts that would have positive impacts and benefits for the San Diego region. As stakeholders and decision-makers consider the options for adapting to changing demands and climate, the above examples illustrate some of the numerous opportunities that could be adopted or explored further. The CWASim modeling tool and set of metrics used in the Impacts Assessment could be further applied to study specific combinations of interest, and the Customized Trade-off Analysis tool (published as part of the Task 2.5 Interim Report) can be used to perform comparisons of specific sets of Concepts for one or more objectives. The information and tools produced by the Basin Study can assist the San Diego region in adapting to the uncertainties associated with changing water supplies, as well as changes in water demands through the 2050s.

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