RECLAMATION

Managing Water in the West

Draft – For Review

San Diego Watershed Basin Study

Task 2.2 - Climate Change Impacts and Hydrologic Modeling

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center

February 2016

Mission Statements

The mission of the City of San Diego Public Utilities Department is to ensure the quality, reliability, and sustainability of water, wastewater and recycled water services for the benefit of the ratepayers and citizens served.

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

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San Diego Watershed Basin Study

Task 2.2 - Climate Change Impacts and Hydrologic Modeling

February 2016

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Table of Contents

Executive Summary 3
1.0 Introduction 5
1.1 Study Purpose and Objectives 5
1.2 Description of Basin Study Area 6
2.0 Climate Impacts 10
2.1 Methodology 10
2.1.1 Climate Change Projections 10
2.1.2 Hydrologic Modeling 10
2.1.3 Surface Water 10
2.1.4 Groundwater 11
2.1.5 Imported Water Analyses 11
2.2 Imported Water Supply 12
2.2.1 Legal Allocation Structure 12
2.2.2 Colorado River 13
2.2.3 State Water Project 21
2.3 Surface Water Supply 21
2.4 Groundwater Supply 28
2.4.1 Representative Groundwater Locations 29
2.5 Next Steps 32
3.0 References 32
4.0 Appendix A – Surface Water Figures 34

List of Figures

Figure 1. San Diego County Watershed Basin Study Area 7
Figure 2: San Diego Watershed Basin Study Management Agencies 8
Figure 3: San Diego Watershed Basin Study Water Resource Features 9
Figure 4 CMIP3 and CMIP5 Climate Projection Scenarios (Knutti and Sedláček 2012) 12
Figure 5: Lower Basin Shortages > 1MAF in three years 17
Figure 6: Lower Basin Shortages > 1.5maf in five years 18
Figure 7: Mean Lower Basin Shortage 19
Figure 8: Lake Mead Pool Elevations <1000ft 20
Figure 9. San Diego County Surface Water Identified Locations 22
Figure 10: San Vicente Barona Valley Inflow Change 24
Figure 11: San Vicente Foster Canyon Inflow Change 25
Figure 12: San Vicente Kimball Valley Inflow Change 25
Figure 13: San Vicente Dam Streamflow Change 26
Figure 14: HDe climate change scenarios 28
Figure 15: San Vicente Reservoir HDe Monthly Streamflow Changes 28
Figure 16: San Pasqual Groundwater Basin Guejito Creek Streamflow Recharge 30
Figure 17: San Diego River Groundwater Basin Forester Creek Streamflow Recharge 30
Figure 18: San Diego River Groundwater Basin Sycamore Canyon Streamflow Recharge 31
Figure 19: Mission Valley Groundwater Basin San Diego River Streamflow Recharge 31

List of Tables

Table 1. Historic and Future Periods 11
Table 2. Colorado River Basin Study Demand Scenarios 13
Table 3: Lake Mead Shortage Measures 14
Table 4: Lake Mead Level Thresholds 15
Table 5: SWP Deliveries (from Sacramento-San Joaquin Climate Impacts Assessment) 21
Table 6: Surface Water Identified Locations 22
Table 7: HDe Scenario Definitions 26
Table 8: Representative Groundwater Selected Locations 29

Acronyms and Abbreviations

BCSD	Bias-Correction Spatial Disaggregation
cfs	cubic feet per second
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
DWR	California Department of Water Resources
EIS	Environmental Impact Statement
HDe	Ensemble-informed hybrid delta method
IID	Imperial Irrigation District
IPCC	Intergovernmental Panel on Climate Change
IRWM	Integrated Regional Water Management
MAF	million acre-feet
MWD	Metropolitan Water District of Southern California
QSA	Quantification Settlement Agreement
RCP	Representative Concentration Pathways
Reclamation	United States Department of the Interior, Bureau of Reclamation
SDCWA	San Diego County Water Authority
SDPUD	San Diego Public Utilities Department
SWP	State Water Project
SWRCB	California State Water Resources Control Board
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity Model

Executive Summary

The analysis for Task 2.2 of the San Diego Watershed Basin Study examined climate change impacts on water supply sources in the San Diego region. Climate change scenarios were based on CMIP5 climate model projections used in the 5th Intergovernmental Panel on Climate Change Assessment. These projections have been downscaled to capture local impacts, and the Variable Infiltration Capacity (VIC) hydrologic model was used to obtain streamflow values. Imported water measures for both the Colorado River and the State Water Project (SWP) were identified in past Basin Studies and Climate Impact Assessments. For the Colorado River, shortages of greater than 1.0 MAF in two years and 1.5 MAF in five years were used. Multiple hydrologic sequences were run, with the percent of these sequences or traces with shortages exceeding used as a measure. Across demand scenarios and management alternatives, the numbers of traces with shortages in excess of these thresholds were fairly consistent in the 2020s future period. They ranged from 25% to 32% for the 1.5MAF and 33% to 37% for the 1.0MAF. The number of traces exceeding in the 2050s were higher under the no-action alternative, ranging from 72.6% under demand scenario B to 81.4% under scenario D2. Under the interim guidelines, the range of exceedance was 53.2% under demand scenario D1 to 60.3% under demand scenario C1. Mean shortages to Lower Basin states followed this same pattern. The numbers of traces showing Lake Mead levels below 1,000 ft were comparable across demand scenarios and management alternatives for the 2020s future period. In the 2050s future period, increases were seen in the frequency over the 2020s, with higher values under the interim guidelines than the no-action alternative. SWP deliveries saw little change in the 2012-2040 future period under the two climate change scenarios. There was a 6-10% reduction in deliveries as compared to the historic period for the 2041-2070 future period. Future changes in streamflows were examined using modeled naturalized flows for key locations across San Diego County. These included reservoir inflows, reservoir outflows, and river outlets. For all locations, similar changes in streamflow were observed. Results show moderate increases of 5% to 15% annually by the 2020s under a moderate warming scenario, RCP4.5. For the same period, the high warming scenario, RCP8.5, has increases in streamflow of 20% to 25%. By the 2050s, increases in streamflow are higher under RCP4.5, ranging from 10% to 20% with RCP8.5 showing slight decreases to increases of 5%. For both the 2020s and 2050s higher annual flows come primarily from increases in December to March winter streamflow. April to July spring streamflow has little trend, with changes of +/- 15%. Groundwater recharge is dominated by streamflow infiltration, so the same analysis was performed at locations where streams enter groundwater basins. These locations show the same changes in streamflow as seen for surface water.

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1.0 Introduction

The San Diego Watershed Basin Study (SDWBS) currently ongoing is examining the impact of climate change on water supply and demand within San Diego County. These impacts are being evaluated according to key measures of system performance and used to identify structural and non-structural alternatives to ensure acceptable system performance. This study is broken into several tasks as shown below:

1 Project Management
2.1 Water Supply and Water Demand Projections
2.2 Downscaled Climate Change and Hydrologic Modeling
2.3 Existing Structural Response and Operations Guidelines Analysis
2.4 Structural and Operations Concepts
2.5 Trade-Off Analysis and Recommendations
2.6 Final Report

This interim report presents the results for Task 2.2, evaluating the impact of climate change on water supply using climate change projections and hydrologic modeling. The San Diego County Water Authority (SDCWA) provides wholesale water to 24 member agencies in San Diego County The region is dependent on imported water to supply 80% of existing demand (City of San Diego, County of San Diego, and San Diego County Water Authority 2013); (Bureau of Reclamation and City of San Diego 2014)). Local surface water, groundwater, and recycled water, along with desalination comprise the remainder. This report examines the impact of climate on these water supply sources and offers information for planning future water supply system development, and for examining alternative water supply sources to water resource managers in the San Diego region. There is specific interest in SDCWA member agencies developing local water supply sources to reduce demand for imported water.

1.1 Study Purpose and Objectives

Task 2.2 of the SDWBS examines the impact of climate and climate change on water supply and demand in the San Diego region. It considers specifically:

a. How might climate change impact the reliability and volumes of imported water supplies to the region?
b. How will changes in local weather patterns impact the ability to capture and use local surface supplies?
c. How will changes in local weather patterns impact the ability to capture and use local groundwater supplies?
d. Which watersheds will be impacted the most by climate change and what is the magnitude of water supply fluctuations?

1.2 Description of Basin Study Area

The SDWBS study area is shown in Figure 1 and contains a majority of San Diego County. This study region matches the one used in for San Diego Integrated Regional Water Management planning. Eleven major watersheds comprise this study region. SDCWA provides wholesale water to local water agencies as shown in Figure 2, with water resource features including delivery network and storage shown in Figure 3.

The scope of the SDWBS includes the entire SDCWA service area. The analysis of climate impacts on water supply a is focused on locally available water supply within the study area and the two major sources of imported water: the Colorado River and the SWP.

Local supply analysis examined surface water impacts at major storage reservoirs that included Barrett, El Capitan Hodges, Loveland, Lower Otay, Mirimar, Morena, Murray, San Vicente, Sutherland, and Sweetwater. Groundwater impacts were examined for San Pasqual, San Diego River, and Mission Valley groundwater basins.

Figure 1. San Diego County Watershed Basin Study Area

Management Agency Boundaries

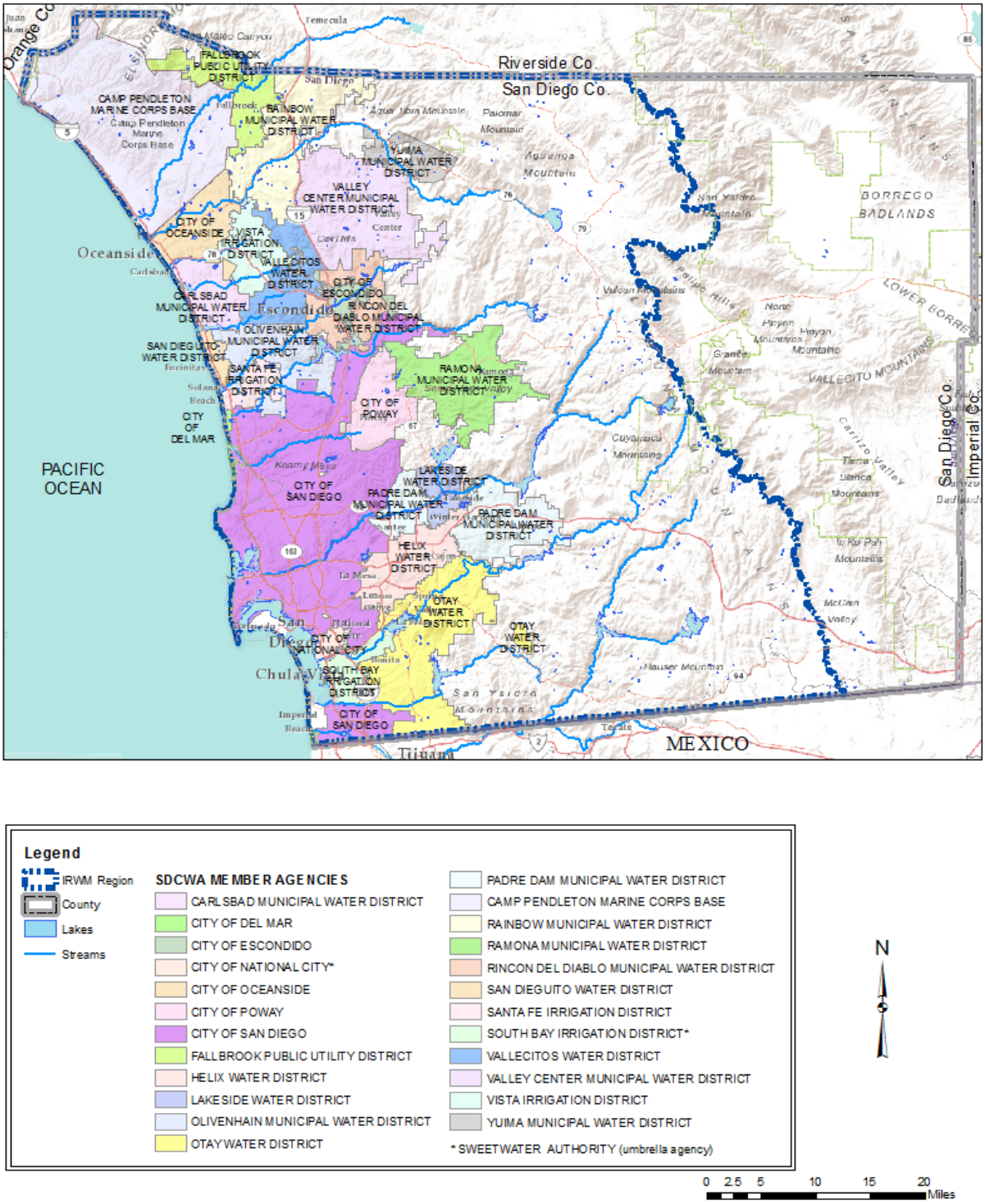


Figure 2: San Diego Watershed Basin Study Management Agencies

Water Resources Features

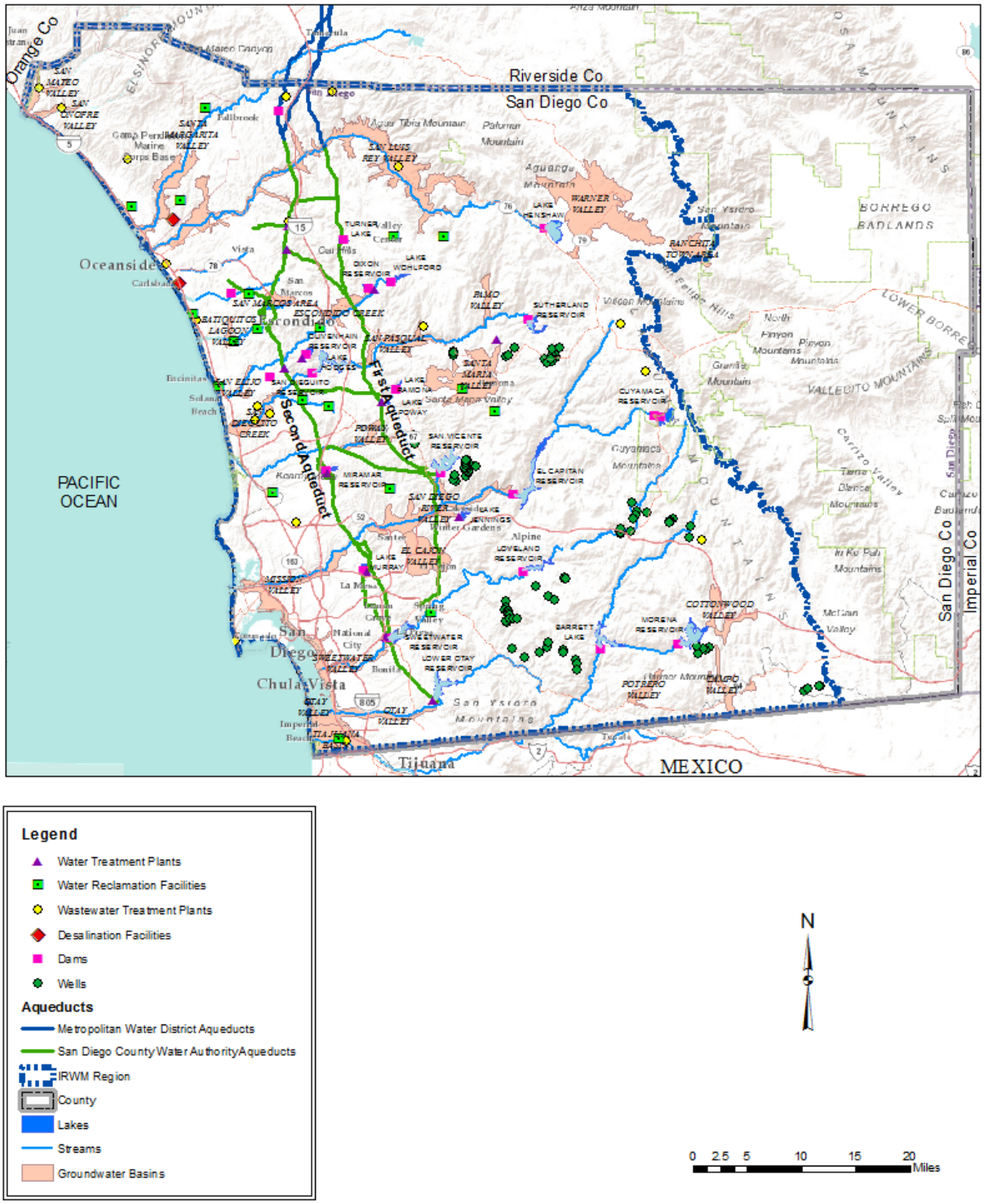


Figure 3: San Diego Watershed Basin Study Water Resource Features

2.0 Climate Impacts

Section 2 describes the methodology used and presents the results for climate impact assessments performed addressing the questions in Section 1.1.

2.1 Methodology

2.1.1 Climate Change Projections

Global Climate Model (GCM) projections provide estimates of precipitation and temperature from 1950 through 2099. Projections were obtained primarily from the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor, Stouffer, and Meehl 2011) which serves as the basis for the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5). The CMIP5 archive contains projections from 62 models developed by 29 modeling groups. For the historic period, models are constrained by observations of atmospheric conditions. Several alternative futures are reflected in the Representative Concentration Pathways (RCP) which vary future atmospheric conditions. In addition, many models provide projections initialized from multiple climate states in order represent uncertainties stemming from natural low frequency climate variability (Reclamation, 2013). For this analysis we used two RCPs: 4.5 reflecting a low-growth or strong emissions controls scenario, and 8.5, high-growth and limited emissions control scenario. Climate model projections were downscaled to a 1/8° x 1/8° (~54 square miles) using the Bias-Correction Spatial Disaggregation (BCSD) approach (Wood et al. 2002).

2.1.2 Hydrologic Modeling

Climate impacts were assessed separately for local surface water, local groundwater, and imported water. Downscaled CMIP5 climate projections were used as inputs to generate hydrologic projections using the Variable Infiltration Capacity (VIC) (Liang, Wood, and Lettenmaier 1996; Liang et al. 1994; Nijssen et al. 1997). VIC offers surface runoff and baseflow estimates for each grid cell which are then routed to stream channels. These data were produced west wide for use in West-wide Climate Risk Assessments and the Basin Studies Program. Additional information on this data set can be found on the project website, gdo-dcp.ucllnl.org/downscaled_cmip_projections. Critical hydrological points within the study area, including locations of reservoir inflows, reservoir outflows, river outlets, and representative groundwater recharge locations were identified and reflect important decision making locations. For each location, the upstream grid cells were identified using a digital elevation model, reflecting the watershed of that point, or all the upstream land where water would flow to that point. Summing the streamflow values available for each grid cell within the watershed gave an estimate of the naturalized streamflow at that location. This streamflow does not reflect any management or operation within the watershed. Using the hydrologic projections available from Reclamation's archive future streamflow were compared to a historic reference period to evaluate the impact of climate change.

2.1.3 Surface Water

For climate change projection, a reference historic period was selected and used to determine relative changes in two future periods. The reference and future periods selected are shown in Table 1.

Table 1. Historic and Future Periods

Historic Period	1990-1999	1990s
Future Period 1	2020-2029	2020s
Future Period 2	2050-2059	2050s

Change is streamflow were found for both selected climate change scenarios, RCP 4.5 and RCP 8.5. For the same surface water locations, the ensemble-informed hybrid delta (HDe) method was also employed. This method has been widely used by Reclamation in other studies including the St. Mary-Milk Basin Study, and the Climate Change Analysis for the Missouri River Basin (Bureau of Reclamation 2012a, 2012d).

2.1.4 Groundwater

In the San Diego region, local groundwater recharge occurs primarily along stream channels from streamflow infiltration. Representative groundwater recharge locations, where these channels enter the groundwater basin, were identified and used to examine climate impacts indirectly through changes in surface runoff.

2.1.5 Imported Water Analyses

The Colorado River Basin Water Supply and Demand Study and the Sacramento and San Joaquin Basins Climate Impact Assessment (Bureau of Reclamation 2012b, 2014), examining the impact of climate change on imported water supplies, were used to for the imported water analysis in this report. These studies relied on Coupled Model Intercomparison Project Phase 3 (CMIP3) (Meehl et al. 2007) projections, which used storylines of future development to describe alternative futures. These development storylines are reflected in the SRES scenarios, with B1, A1B, and A2 being the most commonly used in impacts studies (Nakicenovic et al. 2000). Figure 2 (Knutti and Sedláček 2012) shows the comparison between these three scenarios, and the CMIP5 RCP scenarios that were used for the analysis of local water supplies in the SDWBS Task 2.2 interim report. There is greater spread in future warming by 2100 in the CMIP5 scenarios, but for the SDWBS study horizon of 2050, the range is comparable to CMIP3. RCP4.5 and SRES A2 have similar warming by 2050, and RCP8.5 slightly higher than the mean of A2.

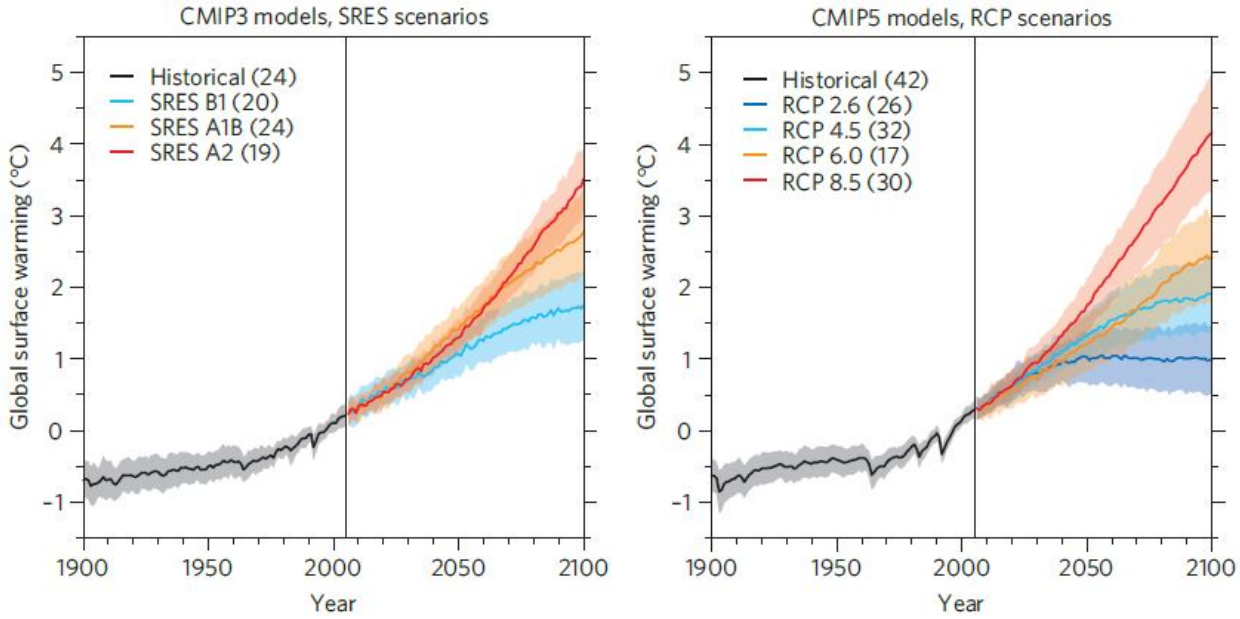


Figure 4 CMIP3 and CMIP5 Climate Projection Scenarios (Knutti and Sedláček 2012)

For the Colorado River, key measure data from the Colorado River Basin Supply and Demand Study were provided by Reclamation for use in this analysis. Comparable data were not available for the SWP.

2.2 Imported Water Supply

SDCWA currently relies on imported water to meet 80% of its demand. Imported water is delivered from two main sources: the Colorado River and SWP. In recent years, climate impact assessments have been conducted for both sources (Colorado River Basin Water Supply and Demand Report, 2013; Sacramento and San Joaquin Basins Study), evaluating their ability to deliver water using several selected performance measures. Lake Mead reservoir levels and shortages to Lower Basin states were used in the Colorado River Basin Water Supply and Demand Study (CRBWSDS) and relevant are to the SDWBS. Technical Report D – System Reliability Metrics (Bureau of Reclamation 2012c) describes the development and rational behind the selection of these measures. The Sacramento-San Joaquin Basin Climate Impacts Assessment (SSJBCIA) (Bureau of Reclamation 2014) uses the volume SWP exports to southern California as a measure to evaluate climate impacts . Given the legal structure and regulations used to allocate water from each of these sources, and periodic modification of the legal structure and regulations, it is difficult to determine exact future allocations to SDCWA. Using results from the CRBWSDS and SSJBCIA, the performance measures identified in each study and can be used to examine impacts on the imported water supply. To ensure consistency the imported water supply assessment results were recalculated for the future periods shown in Table 1.

2.2.1 Legal Allocation Structure

Imported water allocation follows a complex legal structure stemming from years of legal opinions, and interparty agreements. Increased environmental regulation on the Bay-Delta

system, and increased strain on the Colorado River have placed limits on present deliveries, and uncertainty surrounding future deliveries.

2.2.2 Colorado River

The 'Law of the River' apportions Colorado River water among the seven Colorado River Basin States, and the 'Seven Party Agreement' apportions California's Colorado River allocation among California water users. The Metropolitan Water District of Southern California (MWD), of which SDCWA is a member agency, has priority to 1,202,000 acre-feet per year of Colorado River water, including 112,000 acre-feet specifically identified for the City and County of San Diego. The State of California, in their Colorado River Water Use Plan, commonly referred to as the '4.4 Plan' (California 2000), along with the 2003 Colorado River Quantification Settlement Agreement (QSA) modified the Seven Party Agreement to ensure California remain within the 4,400,000 acre-feet specified in the Colorado River Compact, by setting new apportionments for irrigation districts. It also established water transfers from the Imperial Irrigation District (IID) to SDCWA. This water transferred from IID originates in the Colorado River, but given the agreement and mandate to supply water, should be considered separate from the Colorado River imported water. Also included in the QSA is the All-American and Coachella Valley Canal Linings Projects by which SDCWA paid for canal lining in exchange for the conserved water. SDCWA is guaranteed at least 77,000 acre-feet per year, and up to 4,850 acre-feet in addition based on water required for environmental use. As with the IID transfer, while this water originates in the Colorado River, it is guaranteed to SDCWA as part of the QSA.

The CRBWSDS was completed under the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) program with the final report issued in 2013. The impact of climate change, changing demand, and changing operations were considered and evaluated according to a set of performance measures which included reservoir levels, and deliveries to water right holders. The study region included the entire Colorado River basin watershed as well as adjacent areas receiving Colorado River water. The identified performance measures indicated how well the Colorado River system functioned under different future conditions and served as a basis for evaluating different structural and non-structural alternatives. For the SDWBS we selected five performance measures from the CRBWSDS performance measures that are relevant to the study region: two Lower Basin shortage volumes, two Lake Mead elevation thresholds, and mean annual shortages to Lower Basin states. These data were produced for the CRBWSDS; the only changes made were to match the two future periods selected for the SDWBS.

The performance measures were evaluated under six demand scenarios representing potential futures given sets of driving forces. The six scenarios are described in Table 2.

Table 2. Colorado River Basin Study Demand Scenarios

Scenario	Description
A	Continuation of growth, development patterns and institutions follow long-term trends
B	Slow growth with emphasis on economic efficiency
C1	Economic resurgence (population and energy) and

C2	current preference toward human and environmental values
D1	Expanded environmental awareness and stewardship with growing economy
D2	

Two sets of operations were also considered: continuing the 2007 Interim guidelines beyond 2026, and the no-action alternative from the interim guideline EIS. The 2007 interim guidelines establish coordinated operations in years when shortage conditions are declared for the Lower Basin States. Prior to the establishment of these guidelines, no detailed regulations and operations criteria existed for water supply shortages. This provides Lower Basin States with more certainty in annual water deliveries, especially in years of drought, and are currently in place until 2026. The no-action alternative reflects the operational guidelines in place prior to 2007. In 2012, Minute 319 updated the Colorado River treaty with Mexico, allowing for joint cooperative actions including altered operations when Lake Mead conditions are low and temporary storage of Mexico's water. These altered operations are not reflected in the CRBWSDS results.

Two shortage volumes: 1.5 MAF in five years and 1 MAF in two years, one Lake Mead elevation thresholds: 1,000ft, and the mean annual shortage to lower basin states were used as measures. Many sequences or traces of future hydrology were run for each demand and operations scenario, with the percent of traces exceeding the shortage thresholds, or showing reservoir levels below the threshold reported. The shortage volumes, 1.5 MAF and 1 MAF were chosen in the CRBWSDS through an iterative process with stakeholders. The 1,000ft Lake Mead level in addition there being less than 4.5 MAF remaining in storage, is directly tied to operations in the 2007 Interim Operating Guidelines. When Lake Mead is projected to fall below this level, the Secretary of the Interior consults with Lower Basin States to discuss further measures.

Table 3: Lake Mead Shortage Measures

hydrology	demand	operations	period	1 MAF in 2 Years (%)	1.5 MAF in 5 Years (%)	Shortage Volume (MAF)	scenario
VIC	C1	IG	2020s	26.85	34.65	0.23	Scenario C1
VIC	C1	NA	2020s	32.15	37.22	0.34	Scenario C1
VIC	C2	IG	2020s	27.25	34.57	0.23	Scenario C2
VIC	C2	NA	2020s	30.55	34.41	0.31	Scenario C2
VIC	CT	IG	2020s	26.21	33.92	0.22	Scenario A
VIC	CT	NA	2020s	30.47	35.21	0.32	Scenario A
VIC	D1	IG	2020s	26.45	34.57	0.22	Scenario D1
VIC	D1	NA	2020s	29.34	34.81	0.31	Scenario D1
VIC	D2	IG	2020s	27.09	33.92	0.22	Scenario D2
VIC	D2	NA	2020s	31.91	36.82	0.34	Scenario D2
VIC	ES	IG	2020s	25.32	33.52	0.21	Scenario B
VIC	ES	NA	2020s	29.26	34.65	0.33	Scenario B
VIC	C1	IG	2050s	60.29	68.01	0.43	Scenario C1

VIC	C1	NA	2050s	83.12	84.00	1.00	Scenario C1
VIC	C2	IG	2050s	57.40	65.03	0.41	Scenario C2
VIC	C2	NA	2050s	80.87	81.99	0.91	Scenario C2
VIC	CT	IG	2050s	56.43	64.23	0.40	Scenario A
VIC	CT	NA	2050s	77.97	78.94	0.91	Scenario A
VIC	D1	IG	2050s	53.22	61.66	0.38	Scenario D1
VIC	D1	NA	2050s	73.15	73.47	0.82	Scenario D1
VIC	D2	IG	2050s	58.92	65.84	0.42	Scenario D2
VIC	D2	NA	2050s	81.43	82.72	0.96	Scenario D2
VIC	ES	IG	2050s	54.18	63.75	0.39	Scenario B
VIC	ES	NA	2050s	72.67	74.52	0.94	Scenario B

Table 3 shows the Lake Mead shortage measures for all demand projections and operations strategies. These are also shown in Figure 3, Figure 4, and Figure 5. The percentage of traces exceeding 1 MAF at least once in any two year window or 1.5 MAF at least once in any five year window are shown. Percentage of traces exceeding 1 MAF in the 2020s under the interim guidelines, and for all demand scenarios, range between 25.3% and 29%. Under the no action alternative, the percentage of traces increases to between 29.3% and 32.1%. By the 2050s the percentage of traces under the interim guidelines range from 53.2% under demand scenario D1 to 60.3% under demand scenario C1. Under the no-action alternative, shortages range from 72.6% under demand scenario B to 81.4% under scenario D2. The percentage of traces with a shortage exceeding 1.5 MAF in five years range from 33.5% to 34.6% under the interim guidelines. Under the no-action alternative this increase to between 34.4% and 37.2%. The 2050s see a greater distinction between demand scenarios and operation strategies, with higher percent of traces exceeding the shortage under the no-action alternative. 61.7% to 68% of traces exceed 1.5 MAF under the interim guidelines and 73.5% to 82.7% of traces under the no-action alternative. Mean Lower Basin shortages are comparable in the 2020s across demand scenarios and management alternatives, from 0.22 to 0.229 MAF under the interim guidelines and from 0.314 to 0.34 MAF under the no-action alternative. There is a much larger difference between management alternatives by the 2050s, with the interim guidelines ranging between 0.381 and 0.433 MAF and the no-action alternative 0.8356 and 1.0 MAF.

Table 4: Lake Mead Level Thresholds

hydrology	demand	operations	period	<1,000ft (%)	scenario
VIC	C1	IG	2020s	24.74	Scenario C1
VIC	C1	NA	2020s	23.67	Scenario C1
VIC	C2	IG	2020s	25.72	Scenario C2
VIC	C2	NA	2020s	23.65	Scenario C2
VIC	CT	IG	2020s	25.21	Scenario A
VIC	CT	NA	2020s	25.37	Scenario A
VIC	D1	IG	2020s	23.37	Scenario D1

VIC	D1	NA	2020s	23.50	Scenario D1
VIC	D2	IG	2020s	25.05	Scenario D2
VIC	D2	NA	2020s	24.94	Scenario D2
VIC	ES	IG	2020s	23.81	Scenario B
VIC	ES	NA	2020s	22.32	Scenario B
VIC	C1	IG	2050s	55.56	Scenario C1
VIC	C1	NA	2050s	41.11	Scenario C1
VIC	C2	IG	2050s	54.26	Scenario C2
VIC	C2	NA	2050s	42.56	Scenario C2
VIC	CT	IG	2050s	53.55	Scenario A
VIC	CT	NA	2050s	38.09	Scenario A
VIC	D1	IG	2050s	49.33	Scenario D1
VIC	D1	NA	2050s	40.26	Scenario D1
VIC	D2	IG	2050s	56.27	Scenario D2
VIC	D2	NA	2050s	41.15	Scenario D2
VIC	ES	IG	2050s	51.45	Scenario B
VIC	ES	NA	2050s	32.09	Scenario B

Table 4 shows the frequency of Lake Mead levels falling below 1,000 ft.
For the 2020s, the percent of traces with Lake Mead levels below 1,000ft are comparable across demand scenarios and operations alternatives, ranging from 23.4.4% to 25.7% under the interim guidelines and from 22.3% to 25.6% under the no-action alternative. By the 2050s, percent of traces with reservoir levels below 1,000ft under the interim guidelines are higher than the no-action alternative, ranging from 49.3% to 55.6% as compared to 32.1% to 42.6%.

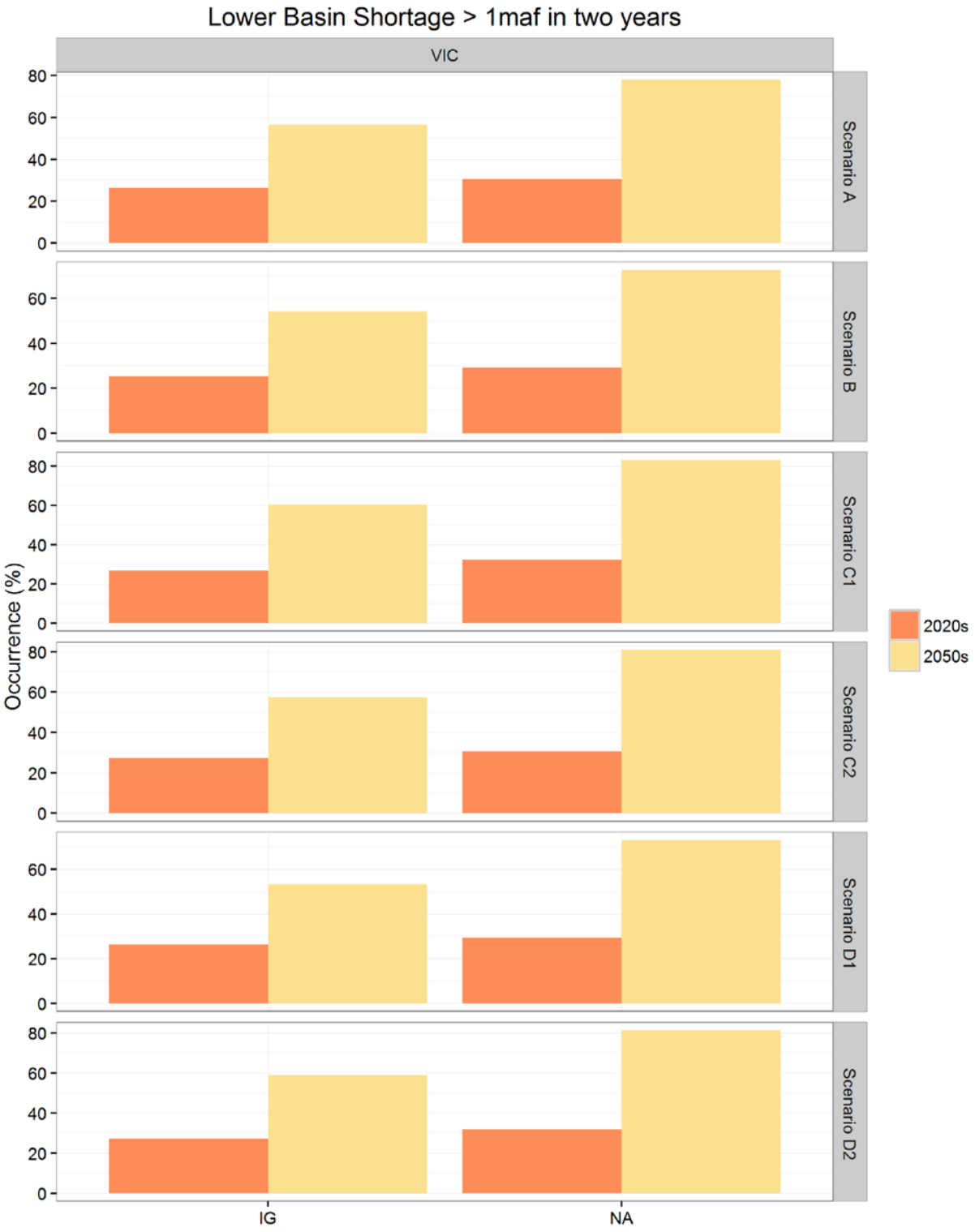


Figure 5: Lower Basin Shortages > 1MAF in three years

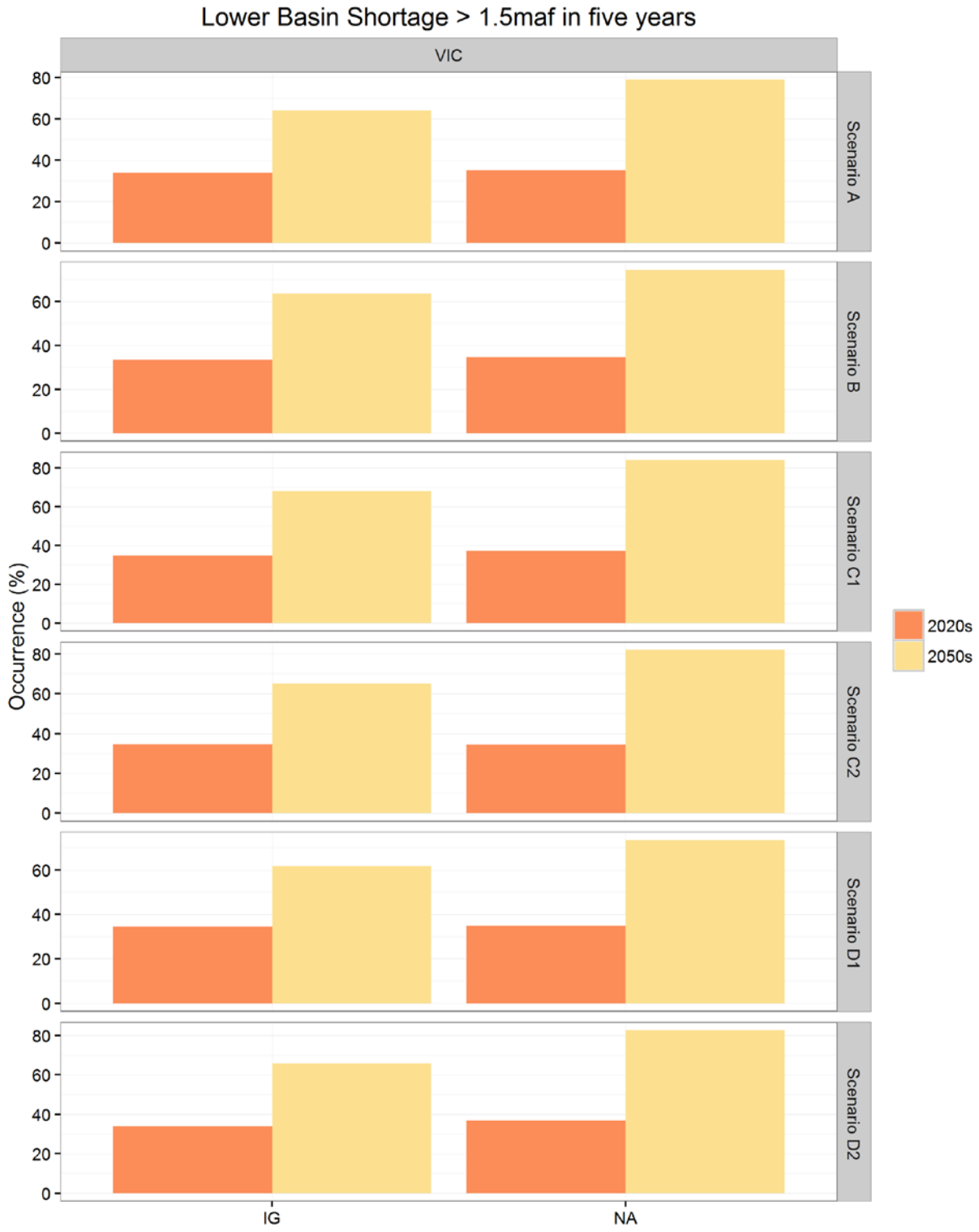


Figure 6: Lower Basin Shortages > 1.5maf in five years

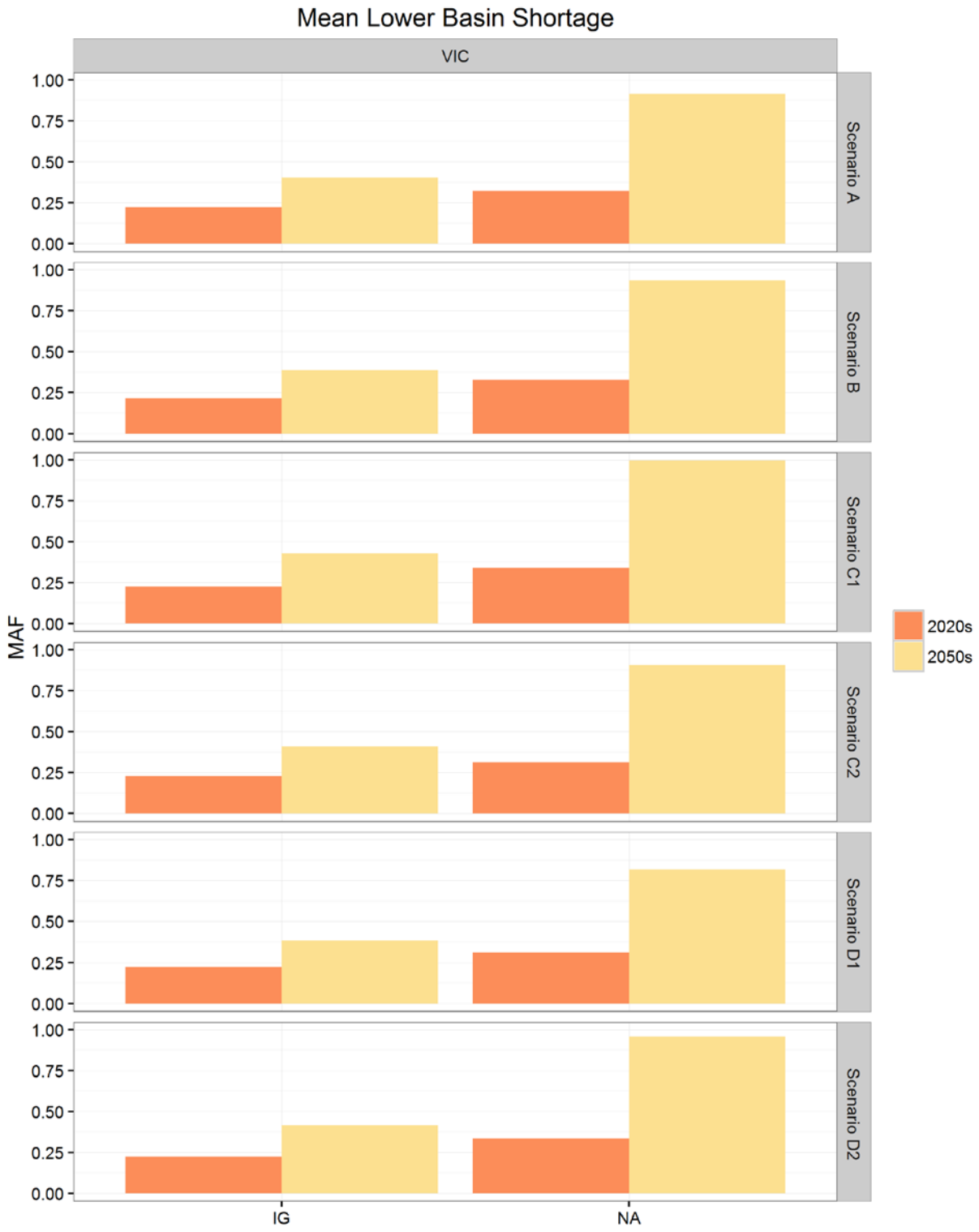


Figure 7: Mean Lower Basin Shortage

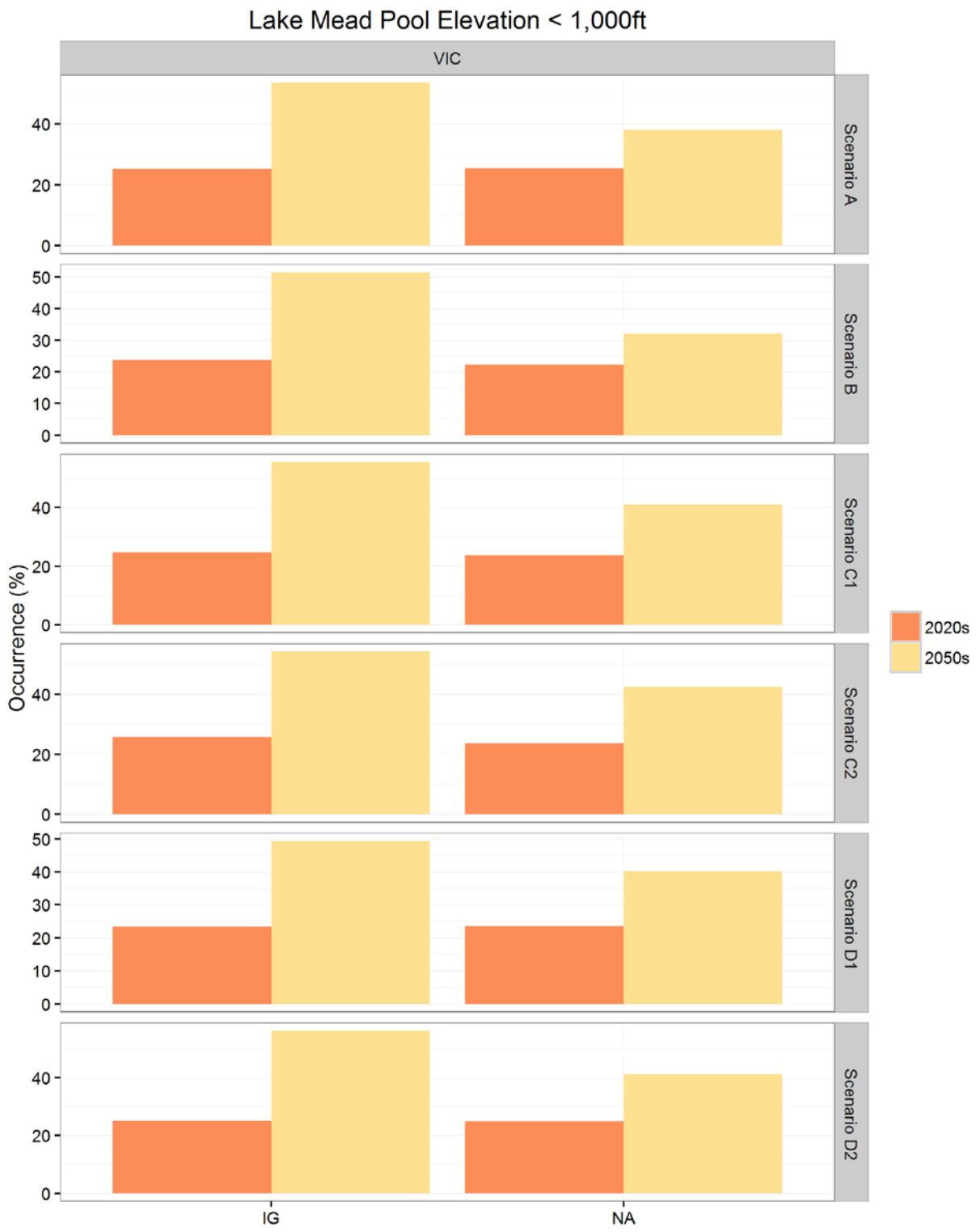


Figure 8: Lake Mead Pool Elevations <1000ft

2.2.3 State Water Project

The CA Department of Water Resources (DWR) sets allocations from the SWP based on operational studies that account for current and projected hydrologic conditions, reservoir storage, operational constraints including Biological Opinions for delta smelt, salmonids, and longfin smelt, and total contractor requests. Hydrologic conditions for the Sacramento and San Joaquin Rivers are determined using Water Supply Index (WSI) forecasts for each river. WSI are classified wet, above normal, below normal, dry, or critical based on thresholds established in the 1995 State Water Resources Control Board Water Quality Control Plan. MWD is currently entitled to a maximum of 1,911,500 acre-feet annually through 2035 in the 2005 contract with CA DWR. The SSJCIA evaluated the delivery reliability for SWP exports using a subset of 12 models from the CMIP3 climate model projections and selected by the State of California (CAT12). Volume of deliveries per year saw no change over the entire CMIP3 set and a 1% increase in the CAT12 set for 2012-2040. 2041-2070 saw decreases in volume of deliveries of 6% and 10% respectively, and decreases of 4% and 13% for 2071-2099.

Table 5: SWP Deliveries (from Sacramento-San Joaquin Climate Impacts Assessment)

					Percent Change from CT_NoCC	
Measure	**Period**	**CT_NoCC**	**CT_Q5**	**CAT12**	**CT_Q5**	**CAT12**
SWP Exports – Banks Pumping Plant (TAF / year)	2012-2040	2,663	2,653	2,680	0%	1%
	2041-2070	2,859	2,677	2,563	-6%	-10%
	2071-2099	2,982	2,780	2,594	-4%	-13%

The Sacramento-San Joaquin Basin Study (http://www.usbr.gov/mp/SSJBasinStudy) is currently ongoing and updating the SWP delivery reliability analysis using CMIP5. These results should offer an updated view of the impact of climate change on SWP deliveries.

2.3 Surface Water Supply

SDCWA member agencies maintain local storage and supply systems to ensure reliable delivery of water. Local surface water sources are primarily runoff from headwater catchments that are captured in storage reservoirs.

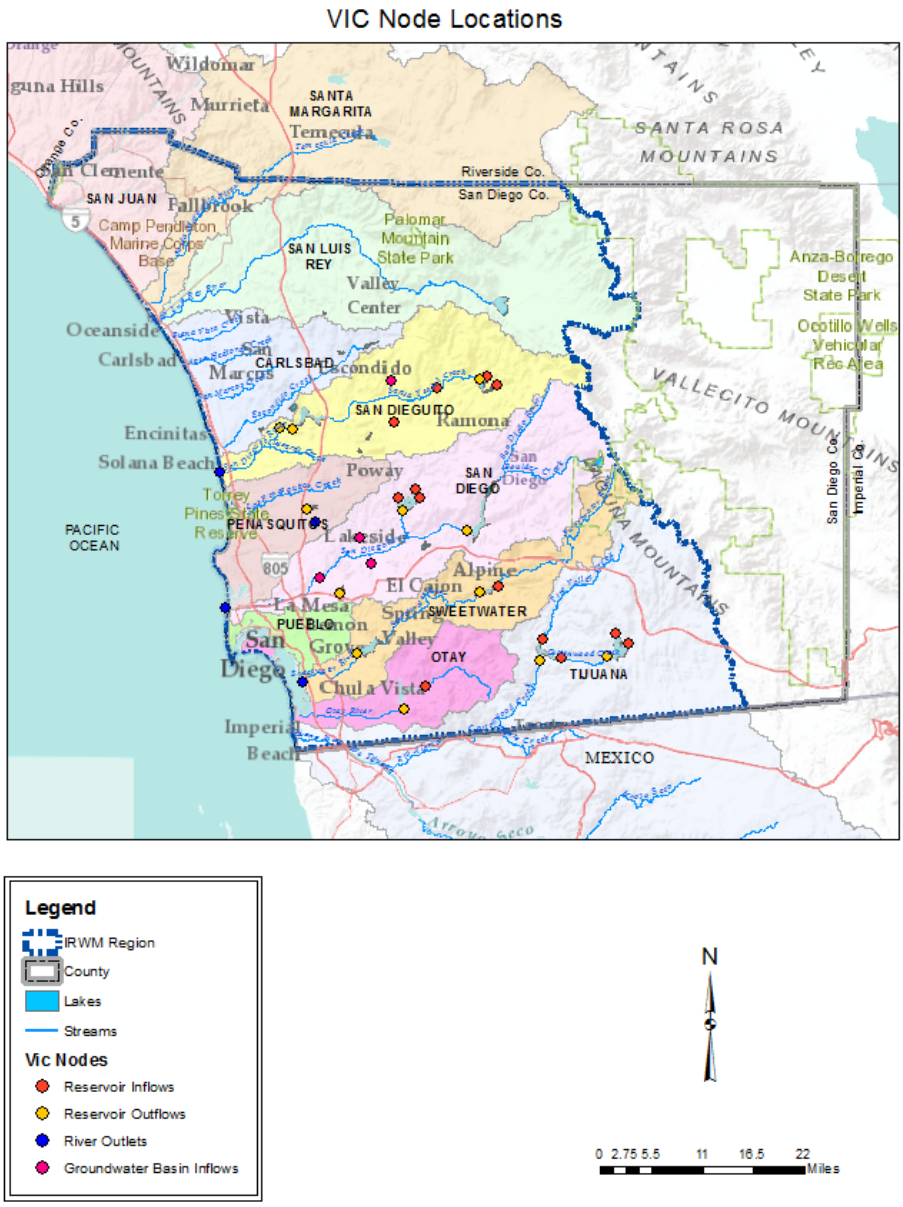


Figure 9. San Diego County Surface Water Identified Locations

Table 6: Surface Water Identified Locations

Longitude	Latitude	Name	Water Body	Description
-116.865	33.107	Santa Ysabel Creek Gauge (11025500)	San Ysabel Creek	Inflow to Hodges
-116.945	33.052	Santa Maria Creek Gauge (11028500)	Santa Maria Creek	Inflow to Hodges
-116.905	32.946	San Vicente Kimball Valley Inflow	San Vicente Reservoir	Inflow to San Vicente

-116.937	32.932	San Vicente Foster Canyon Inflow	San Vicente Reservoir	Inflow to San Vicente
-116.895	32.932	San Vicente Barona Valley Inflow	San Vicente Reservoir	Inflow to San Vicente
-116.883	32.638	Jamul Creek Gauge (11014000)	Jamal Creek	Inflow to Lower Otay
-116.632	32.683	Cottonwood Creek Inflow	Cottonwood Creek	Inflow to Barrett
-116.531	32.721	Morena Creek Inflow	Morena Creek	Inflow to Morena
-116.507	32.705	Cottonwood Creek Inflow	Cottonwood Creek	Inflow to Morena
-116.666	32.712	Pine Valley Inflow	Pine Valley	Inflow to Barrett
-116.750	32.794	Sweetwater River Inflow	Sweetwater River	Inflow to Loveland
-116.772	33.125	Bloomdale Creek Inflow	Bloomdale Creek	Inflow to Sutherland
-116.755	33.112	Santa Ysabel Creek Inflow	Santa Ysabel Creek	Inflow to Sutherland
-117.157	33.040	San Dieguito River Gauge	San Dieguito River	Downstream of Hodges
-117.135	33.040	Lake Hodges Dam Gauge	Hodges Reservoir	Outflow from Hodges
-116.671	32.679	Barrett Lake Dam	Cottonwood Creek	Outflow from Barrett
-116.547	32.686	Morena Dam	Cottonwood Creek	Outflow from Morena
-116.785	32.785	Sweetwater Falls Dam	Sweetwater River	Outflow from Loveland
-117.011	32.689	Sweetwater Dam	Sweetwater River	Outflow from Sweetwater
-116.924	32.602	Savage Dam	Otay River	Outflow from Lower Otay
-117.045	32.781	Murray Reservoir Dam	Murray Reservoir	Outflow from Murray Reservoir
-117.107	32.914	Miramar Lake Dam	Miramar Lake	Outflow from Miramar Lake
-116.787	33.119	Sutherland Lake Dam	Santa Ysabel Creek	Outflow from Sutherland
-117.255	32.757	San Diego River Outlet	San Diego River	Outlet to Ocean
-117.111	32.643	Sweetwater River Outlet	Sweetwater River	Outlet to Ocean
-117.090	32.893	Otay River Outlet	Otay River	Outlet to Ocean
-117.269	32.972	San Dieguito River Outlet	San Dieguito River	Outlet to Ocean
-116.927	32.913	San Vicente Dam (11022100)	San Vicente Reservoir	San Vicente Reservoir Level
-116.808	32.882	El Capitan Reservoir (11020600)	El Capitan Reservoir	El Capitan Reservoir Level

Changes in naturalized flows were calculated for selected critical points, including reservoir inflows, reservoir outflows, and river outlets and locations are shown in Table 6.Outlet locations for the major rivers in the study region, Otay, Sweetwater, San Diego, and San Dieguito were selected, along with inflows to major water supply reservoirs discussed in the IRWM plan and in a systems model developed for long-range planning. Outflows from these reservoirs as well as

USGS stream gauge locations were also included. Reservoir inflows offer a measure of how changes in climate may impact natural flows into the reservoir, reservoir outflows a measure of the change in total upstream flows. River outlets offer the total river basin change in natural flows. All of these locations exhibit similar behaviors given the small size of each of the basins.

Naturalized flow values were obtained from VIC modeling as described in 2.1.2. Results for selected locations are presented below. Additional figures can be found in Appendix A. Changes in streamflow for the three major inflows to San Vicente, Barona Valley, Foster Canyon, and Kimball Canyon are shown in Figure 9, Figure 10, and Figure 11. These three inflow locations see increases in annual streamflow of 7% to 9% under RCP4.5 and increases of 15% to 22% under RCP8.5 in the 2020s future period. These increases are also seen in the December to March streamflow, 11% to 12% under RCP4.5 and 25% to 26% under RCP8.5. April to July streamflows see more modest increases in the 2020s, 5% to 7% under RCP4.5 and 9% to 19% under RCP8.5. In the 2050s future period, these increases in streamflow are even greater under RCP4.5 for the annual and December to March periods, with smaller increases seen for the April to July period. Under RCP8.5 streamflow increases in the 2050s are smaller than the 2020s under RCP8.5 for the annual and December to March periods, with decreases seen in the April to July period. Naturalized streamflow changes at San Vicente Dam are comparable to the three inflow locations.

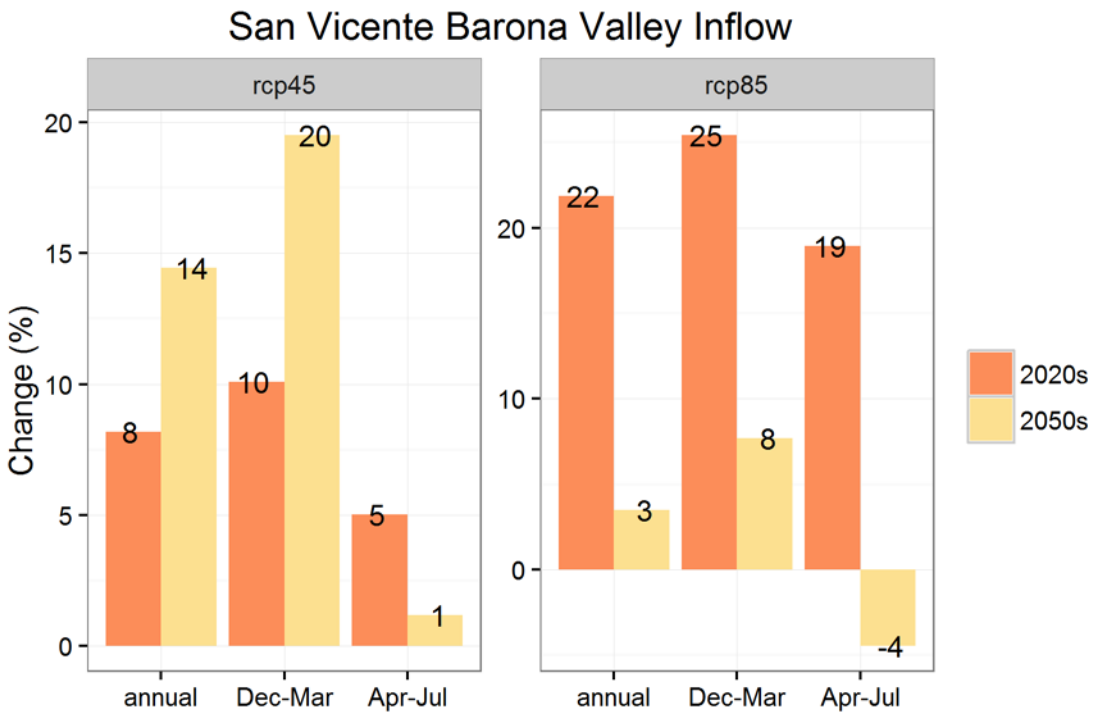


Figure 10: San Vicente Barona Valley Inflow Change

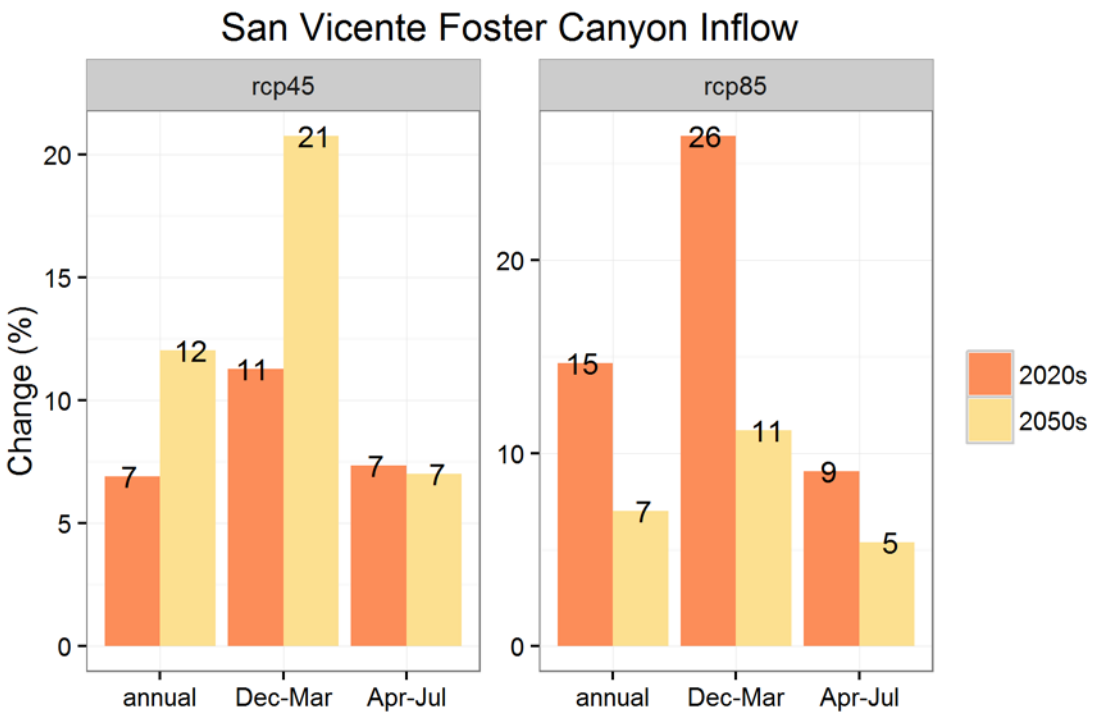


Figure 11: San Vicente Foster Canyon Inflow Change

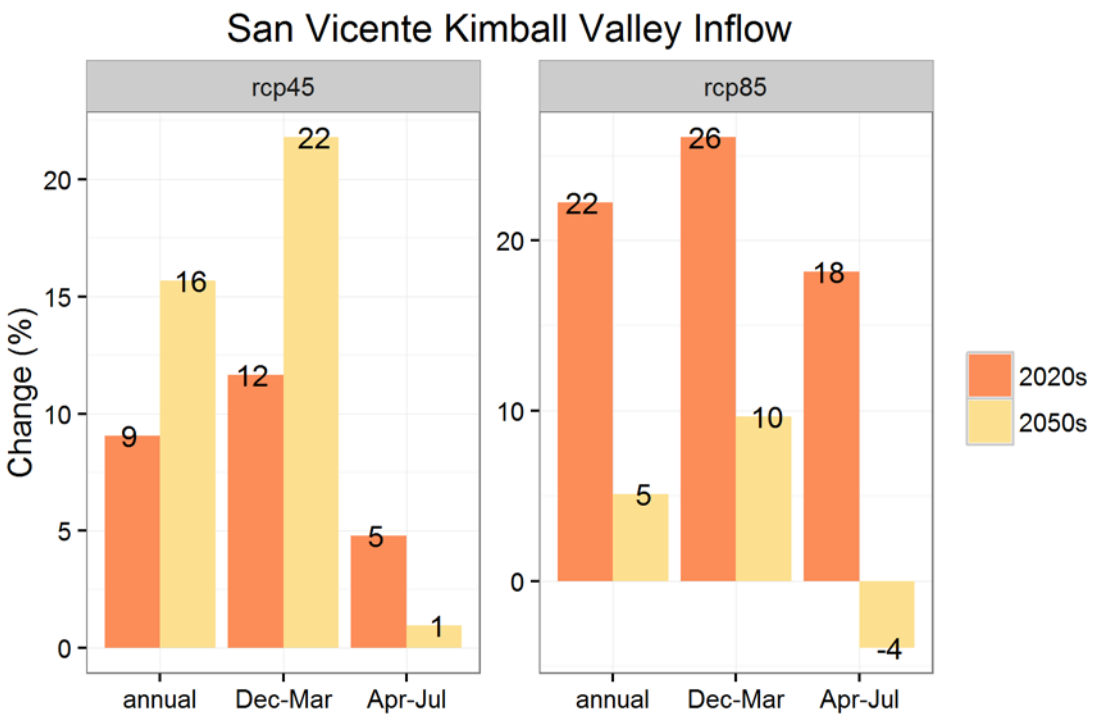


Figure 12: San Vicente Kimball Valley Inflow Change

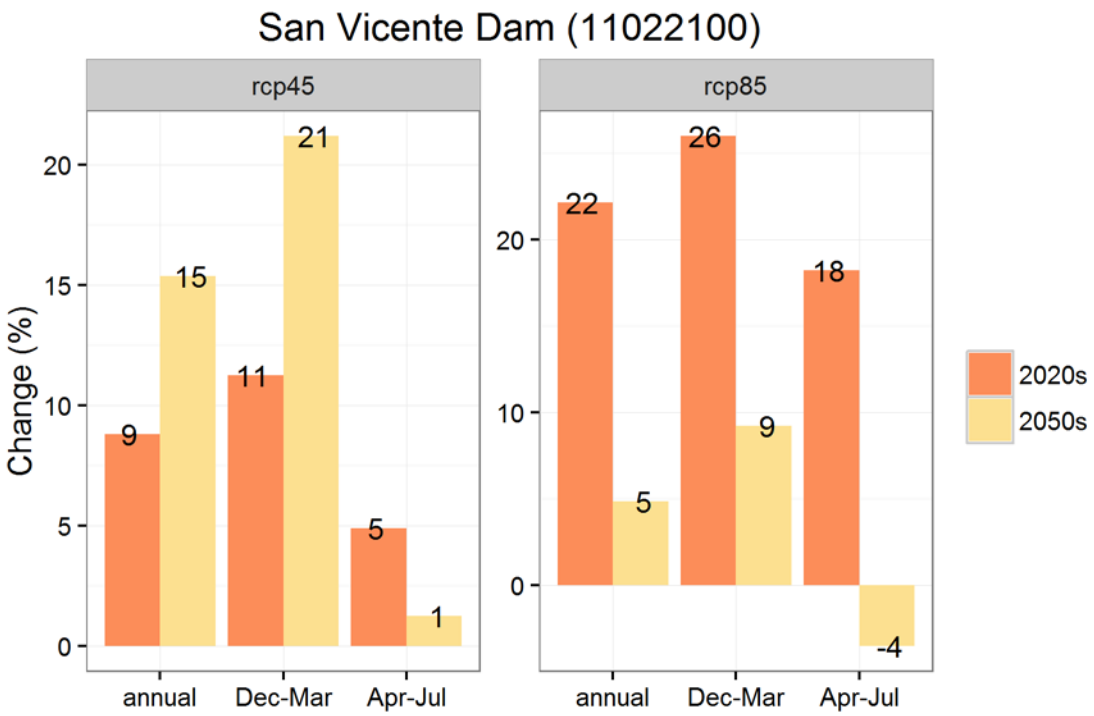
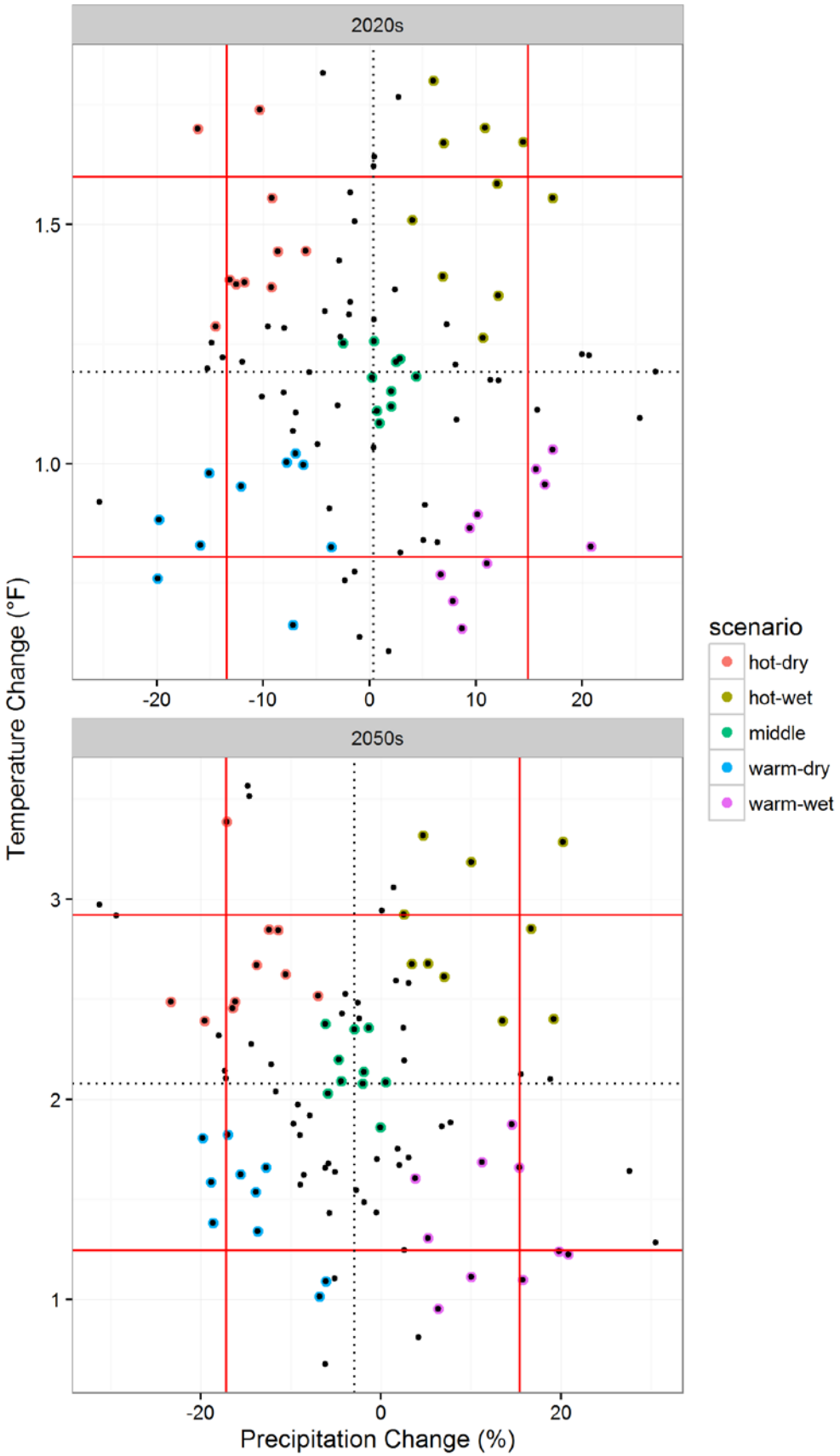


Figure 13: San Vicente Dam Streamflow Change

The HDe climate change scenarios are shown in Figure 14. The changes in precipitation (%) and temperature (°F), are calculated between a 1950-1999 historical period and the 2020s and 2050s future periods for all models and RCPs in the CMIP5 archive. The five scenarios are defined by these changes, and are shown in Table 7.

Table 7: HDe Scenario Definitions

Scenario	Temperature Change (°F)	Precipitation Change (%)
hot-dry	90th percentile	10th percentile
hot-wet	90th percentile	90th percentile
middle	50th percentile	50th percentile
warm-dry	10th percentile	10th percentile
warm-wet	10th percentile	90th percentile


2020s
2050s
Temperature Change (°F)
Precipitation Change (%)
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1.0
3
2
1
-20
-10
0
10
20
scenario
hot-dry
hot-wet
middle
warm-dry
warm-wet

Figure 14: HDe climate change scenarios

Ten model runs were selected for each HDe scenario and these model outputs were used to examine the impact of climate change on surface water by calculating the change in naturalized streamflows using the VIC streamflow data. The percent change in streamflow at the San Vicente Dam location are shown in Figure 15.

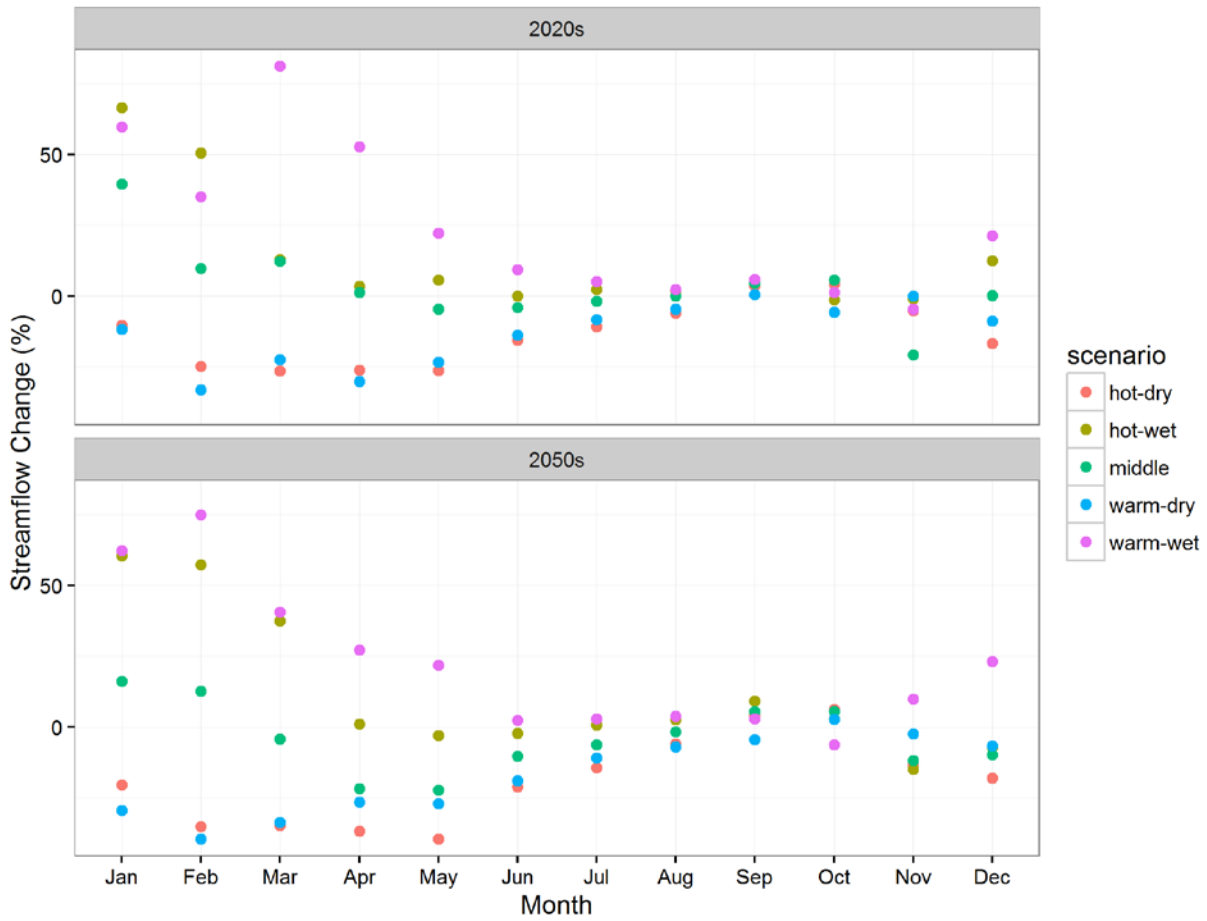


Figure 15: San Vicente Reservoir HDe Monthly Streamflow Changes

These monthly changes were calculated for all reservoir outflow locations and will be used to support future project tasks.

2.4 Groundwater Supply

Groundwater supplies are used to meet approximately 4% of total SDCWA member agencies' water demand. Groundwater basins identified by SDWBS partners as being of particular interest were the San Pasqual, the San Diego River, and Mission Valley basins. CA DWR Bulletin 118 provided background information on these three groundwater basins including composition and primary sources of recharge. San Pasqual Valley Groundwater Basin in central San Diego County is fed primarily by recharge from precipitation and ephemeral streams. Typical years see

no streamflow leave the valley and all infiltrate (Bulletin 118; Izbicki 1983). Recharge into the San Diego River Valley Groundwater Basin primarily comes from releases into San Vicente Creek and the San Diego River from San Vicente and El Capitan dams respectively, and reservoir underflow. Several smaller tributaries also contribute to recharge. Mission Valley Groundwater Basin adjacent to the San Diego River Valley Basin receives a majority of its recharge from the San Diego River. A smaller fraction of recharge comes from irrigation return flows (San Pasqual), wastewater discharge, and rainfall. All basins are unconfined and given streamflow and rainfall are primary sources of recharge, exhibit a strong connection with local climate conditions.

2.4.1 Representative Groundwater Locations

Streamflow is the primary source of groundwater recharge for basins in San Diego County, with additional recharge from precipitation, wastewater treatment outflows, and agricultural return flows. Given this strong relationship between streamflow and groundwater recharge, changes in streamflow where it enters the groundwater basin can be used to quantify the impact of climate on groundwater. The approach used is the same as surface water, and Table 7 shows the representative groundwater flow locations.

Table 8: Representative Groundwater Selected Locations

Longitude	Latitude	Name	Water Body	Description
-117.081	32.807	Mission Valley GW Basin San Diego River Inflow	San Diego River	Mission Valley GW Basin Inflow
-116.985	32.830	San Diego GW Basin Forester Creek Inflow	Forester Creek	San Diego GW Basin Inflow
-117.006	32.870	San Diego GW Basin Sycamore Canyon Inflow	Sycamore Canyon	San Diego GW Basin Inflow
-116.952	33.116	San Pasqual GW Basin Guejito Creek Inflow	Guejito Creek	San Pasqual GW Basin Inflow

We calculated mean streamflow at each location for the 1990s historic reference period and used these values to calculate the percent change for the two future periods of interest: 2020s and 2050s. This was done for annual values as well as December to March (winter), and April to July (spring) streamflow. For the three groundwater basins, similar future changes are observed. A similar pattern to the surface water locations is seen where annual increases for the 2020s are greater under RCP8.5 ranging from 16% to 24%. For the same period, annual increases under RCP4.5 range from 4% to 12%. By the 2050s this flips, with higher increases seen under RCP4.5, 10% to 19%, than under RCP8.5, 3% to 8%. December to March shows higher increases than annual flows for all locations, with slight increases or decreases in streamflow seen in the April to July period.

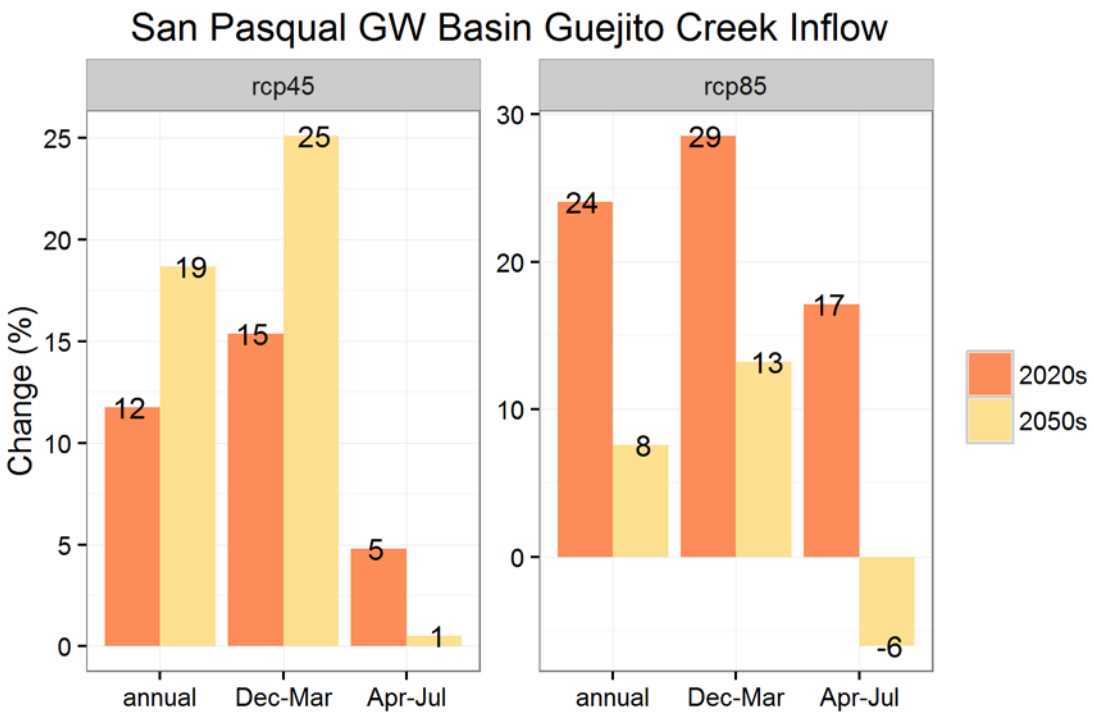


Figure 16: San Pasqual Groundwater Basin Guejito Creek Streamflow Recharge

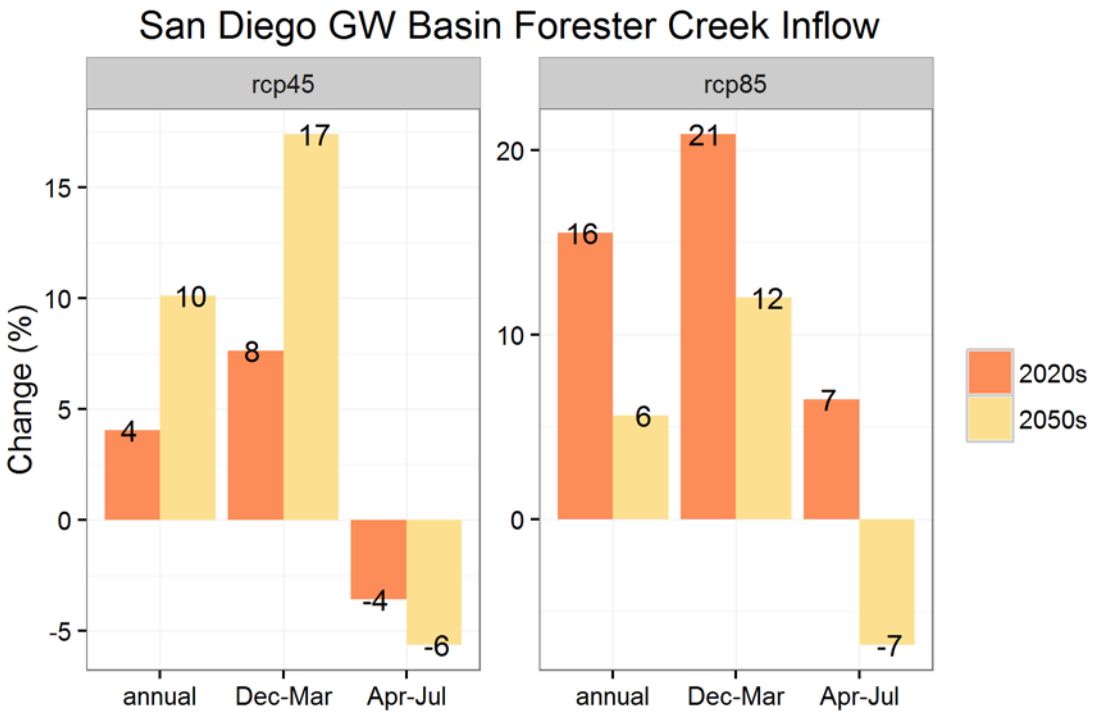


Figure 17: San Diego River Groundwater Basin Forester Creek Streamflow Recharge

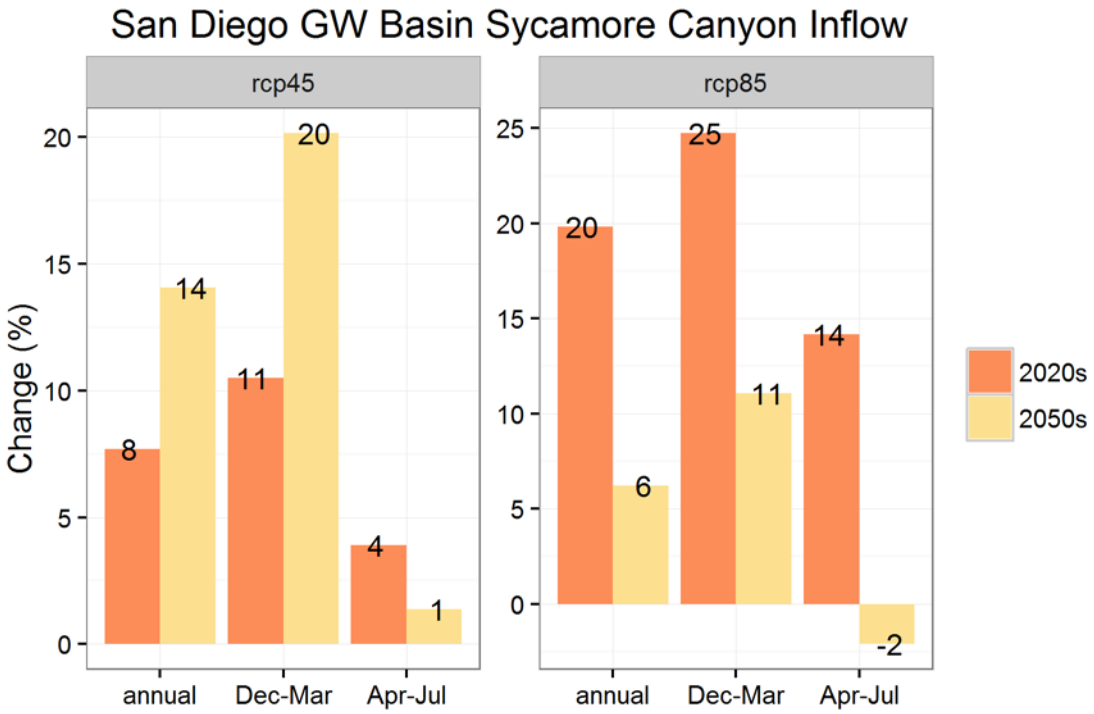


Figure 18: San Diego River Groundwater Basin Sycamore Canyon Streamflow Recharge

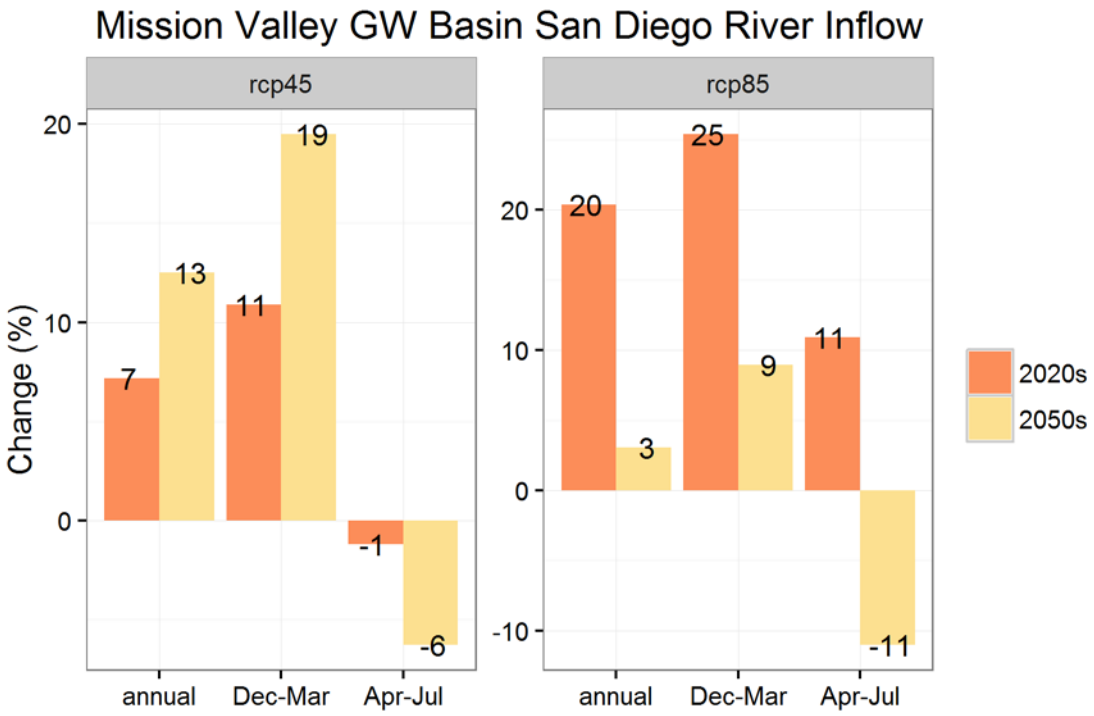


Figure 19: Mission Valley Groundwater Basin San Diego River Streamflow Recharge

2.5 Next Steps

Tasks 2.3 and 2.4 of the SDWBS will examine water supply and demand under current and future climate through modeling of the San Diego region's water supply system. A GoldSim model developed by SDCWA for long-range planning studies (CWASim) is currently being modified for this purpose. As the modifications of the model progresses, additional locations may need to be added to the set of representative surface water and groundwater locations evaluated in Task 2.2. Required CWASim model inputs for water supply include local reservoir inflows, were found for past studies through a mass balance approach using reservoir data. A comparison of these inputs to the reservoir inflows obtained in Task 2.2 of the SDWBS analysis will allow us to determine whether the Task 2.2 reservoir inflows are suitable to be used directly in the model. If not, one of two approaches could be taken. First, monthly change factors can be found for future periods and scenarios of interest and applied to the current historic data used by the model. Second, climate inputs obtained from the Task 2.2 analysis can be used in the same reservoir mass balance approach as the original CWASim model inputs to obtain new inputs reflective of the future periods and scenarios of interest.

The San Joaquin Basin Study is currently in progress and we hope to obtain additional information from that effort to better quantify climate impacts on the State Water Project as part of our imported water analysis. This would follow the same methodology as used with the Colorado River, where measures identified in the Basin Study were used and the time period of interest was shifted to match the rest of this analysis.

- Identify and calculate monthly change factors for all reservoir inflow locations required by CWASim
- Identify and provide precipitation and temperature inputs to water demand locations required by CWASim
- Provide a more detailed assessment of State Water Project climate impacts using onfoing basin study information

3.0 References

Bureau of Reclamation. 2012a. *Climate Change Analysis for the Missouri River Basin*.

———. 2012b. Colorado River Basin Water Supply and Demand Study *Colorado River Basin Water Supply and Demand Study*.

———. 2012c. *Colorado River Basin Water Supply and Demand Study: Technical Report D -*

Reliability Metrics.

———. 2012d. *St. Mary River and Milk River Basins Study Technical Report*.

———. 2014. *Sacramento and San Joaquin Basins Climate Impact Assessment*.

Bureau of Reclamation, and City of San Diego. 2014. *San Diego Watershed Basin Study Plan*.

California, State of. 2000. Water Supply *California's Colorado River Water Use Plan*.

City of San Diego, County of San Diego, and San Diego County Water Authority. 2013. *2013 San Diego Integrated Regional Water Management Plan*.

Knutti, Reto, and Jan Sedláček. 2012. "Robustness and Uncertainties in the New CMIP5 Climate Model Projections." *Nature Climate Change* 3(October): 1–5. http://dx.doi.org/10.1038/nclimate1716.

Liang, Xu, Dennis P Lettenmaier, Eric F Wood, and Stephen J. Burges. 1994. "A Simple Hydrologically Based Model of Land Surface Water and Energy Fluxes for General Circulation Models." *Journal of Geophysical Research* 99(D7): 14415.

Liang, Xu, Eric F Wood, and Dennis P Lettenmaier. 1996. "Surface Soil Moisture Parameterization of the VIC-2L Model: Evaluation and Modification." *Global and Planetary Change* 13(1-4): 195–206.

Meehl, Gerald A. et al. 2007. "The WCRP CMIP3 Multimodel Dataset: A New Era in Climatic Change Research." *Bulletin of the American Meteorological Society* 88(9): 1383–94.

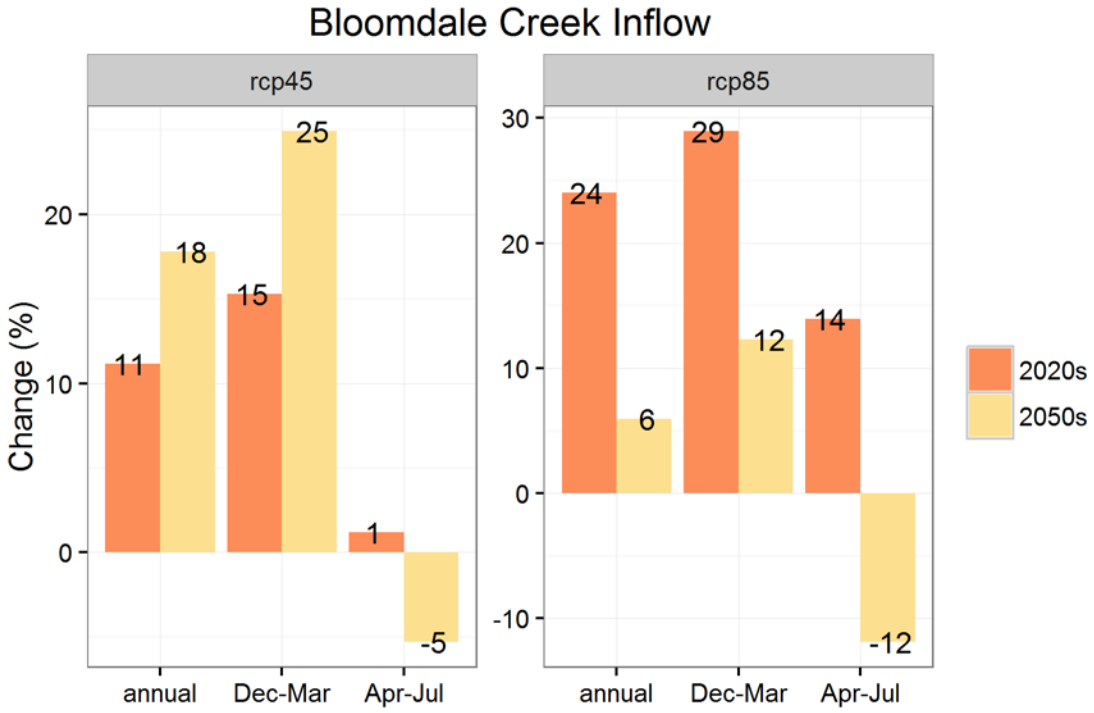
Nakicenovic, Nebojsa et al. 2000. *Emission Scenarios*.

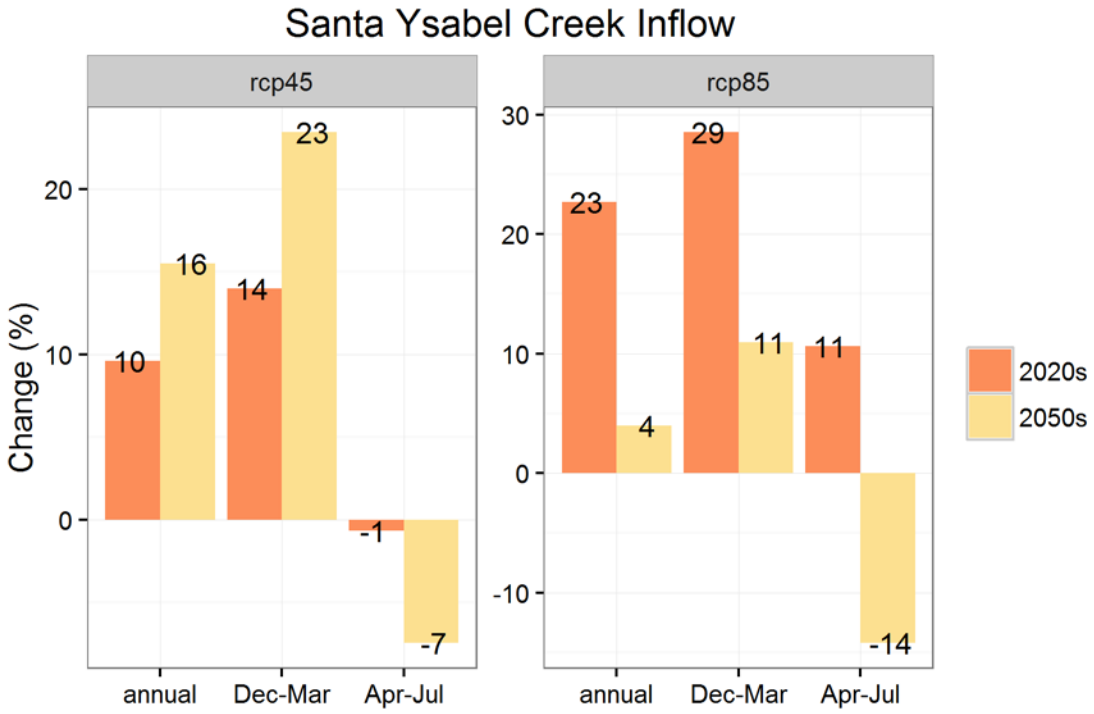
Nijssen, Bart et al. 1997. "Streamflow Simulation for Continental-Scale River Basins." *Water Resources Reserach* 33(4): 711–24.

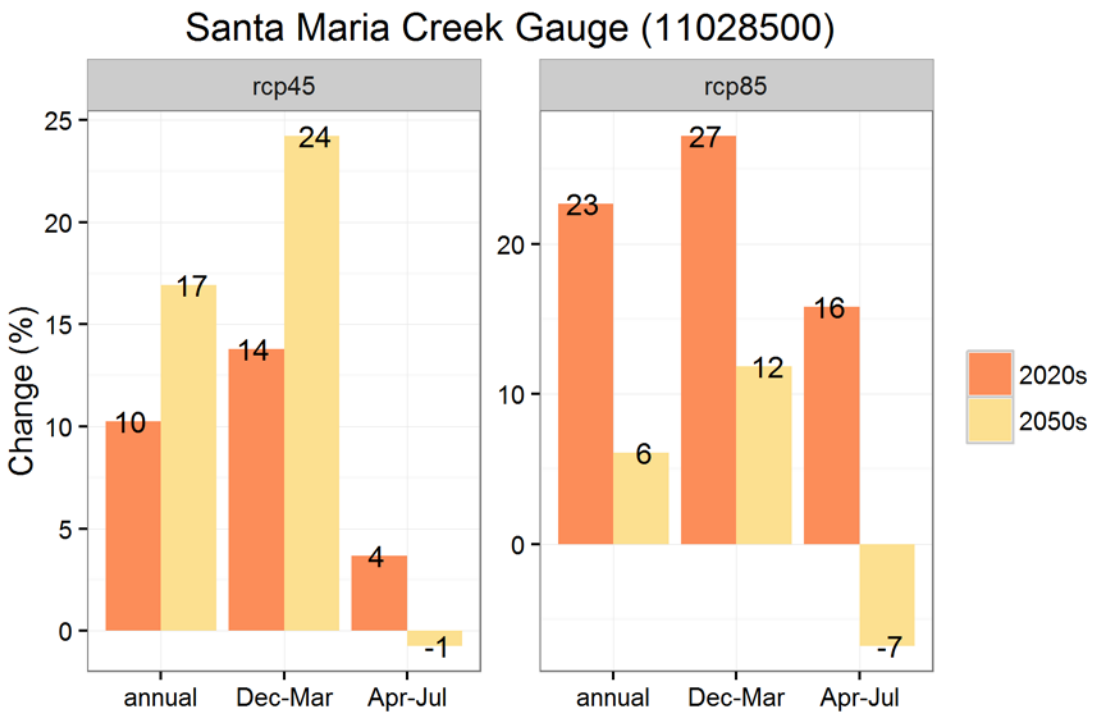
Taylor, Karl E., Ronald J. Stouffer, and Gerald A. Meehl. 2011. "An Overview of CMIP5 and the Experiment Design." *Bulletin of the American Meteorological Society* 93(4): 485–98.

Wood, Andrew W, Edwin P Maurer, Arun Kumar, and Dennis P Lettenmaier. 2002. "Long-Range Experimental Hydrologic Forecasting for the Eastern United States." *Journal of Geophysical Research D: Atmospheres* 107(20): 1–15.

4.0 Appendix A – Surface Water Figures



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rcp85
Change (%)
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10
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6
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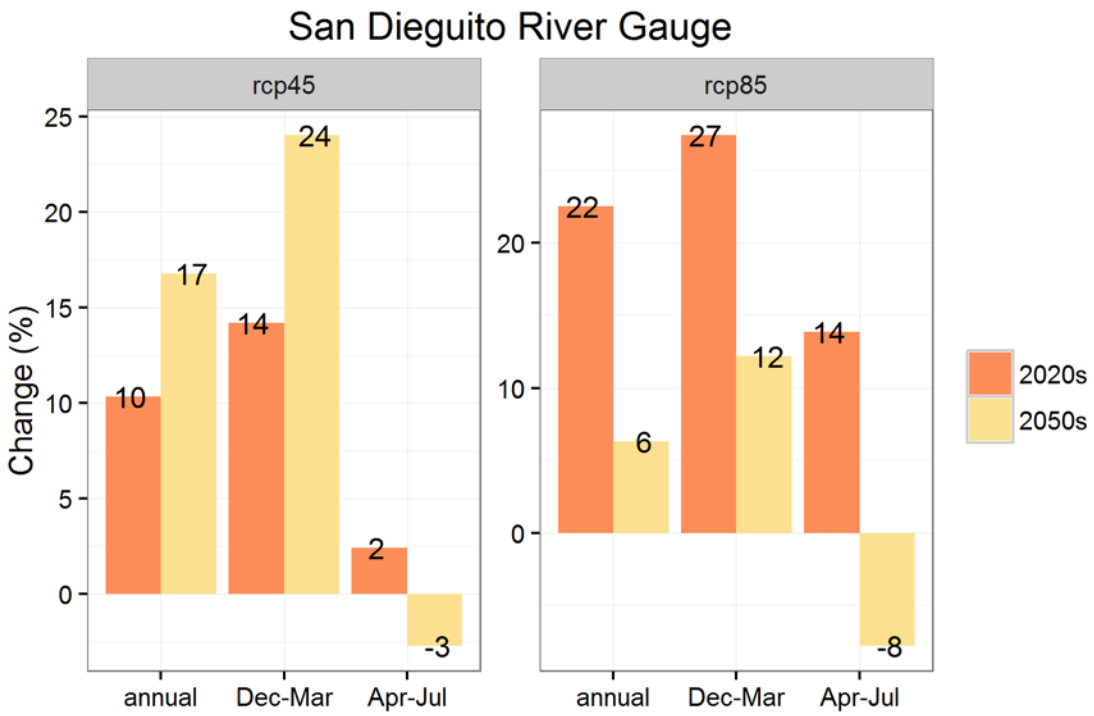
16
-7
annual
Dec-Mar
Apr-Jul
2020s
2050s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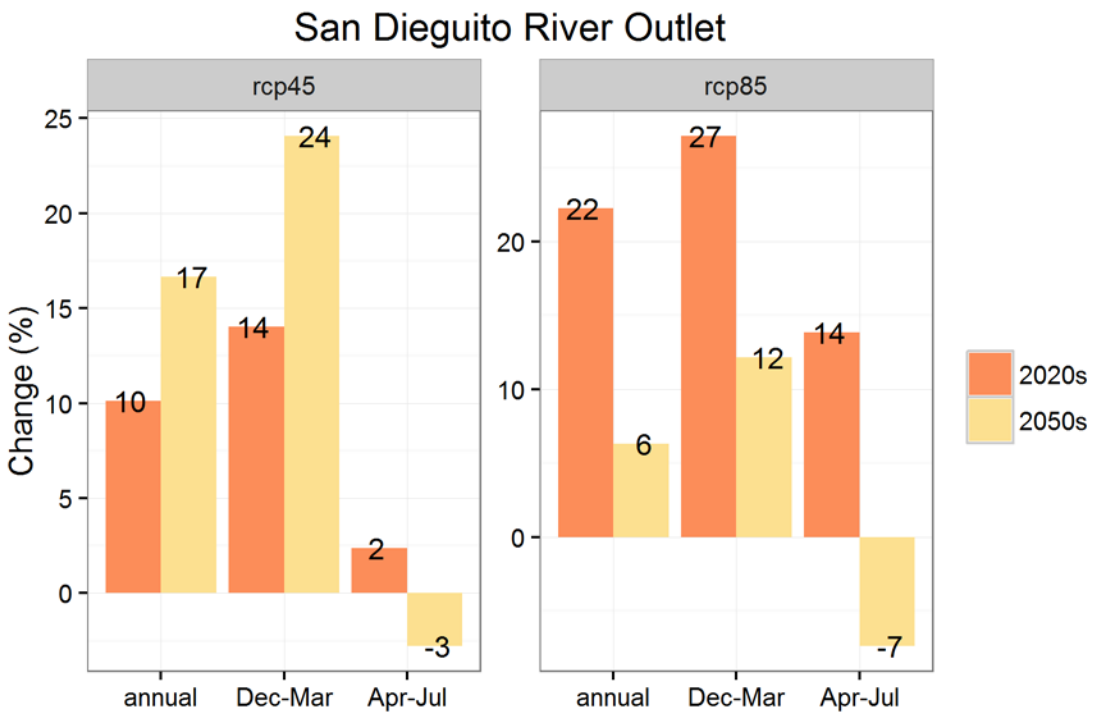
2050s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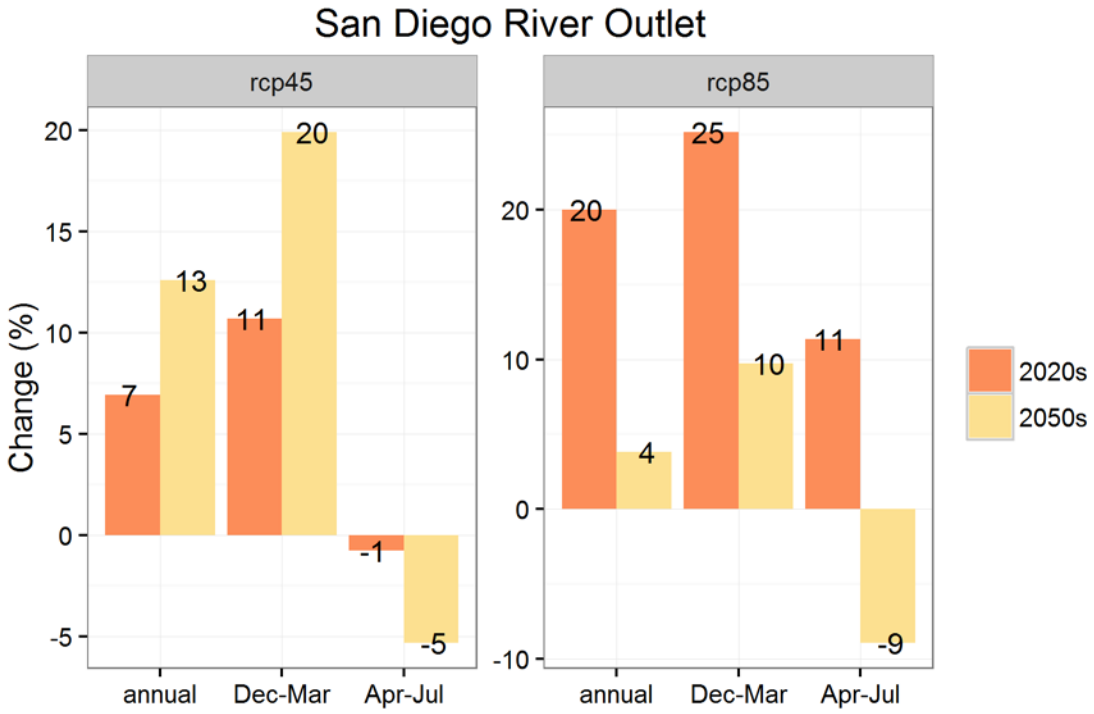
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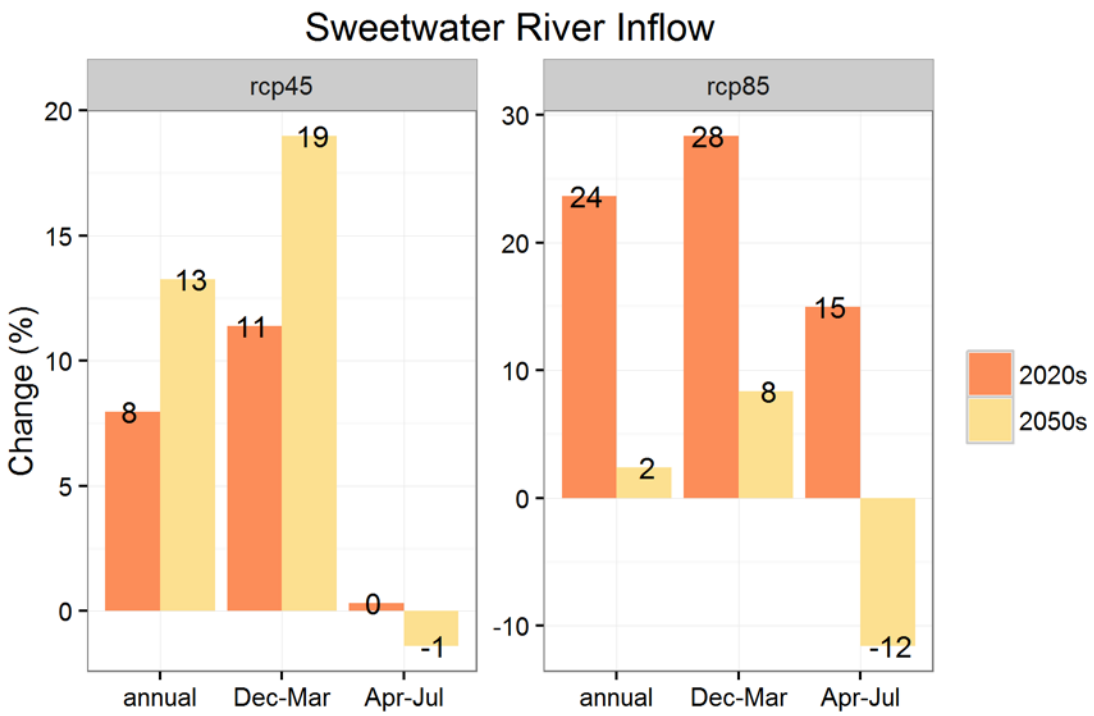
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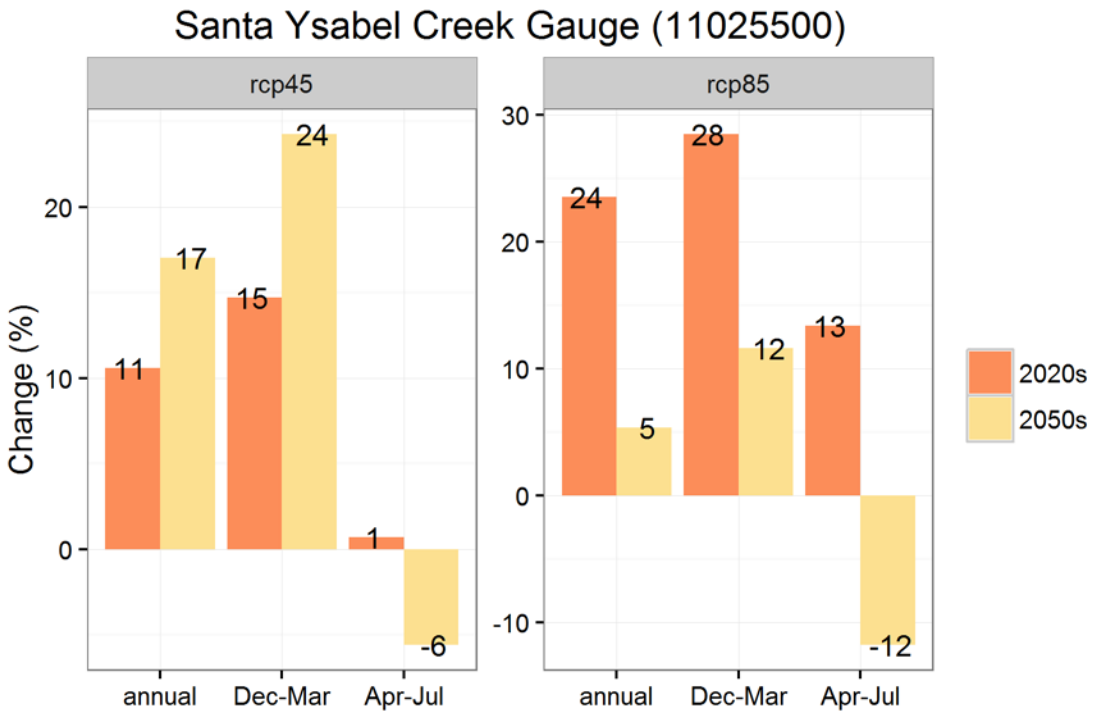
2020s
2050s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Change (%)
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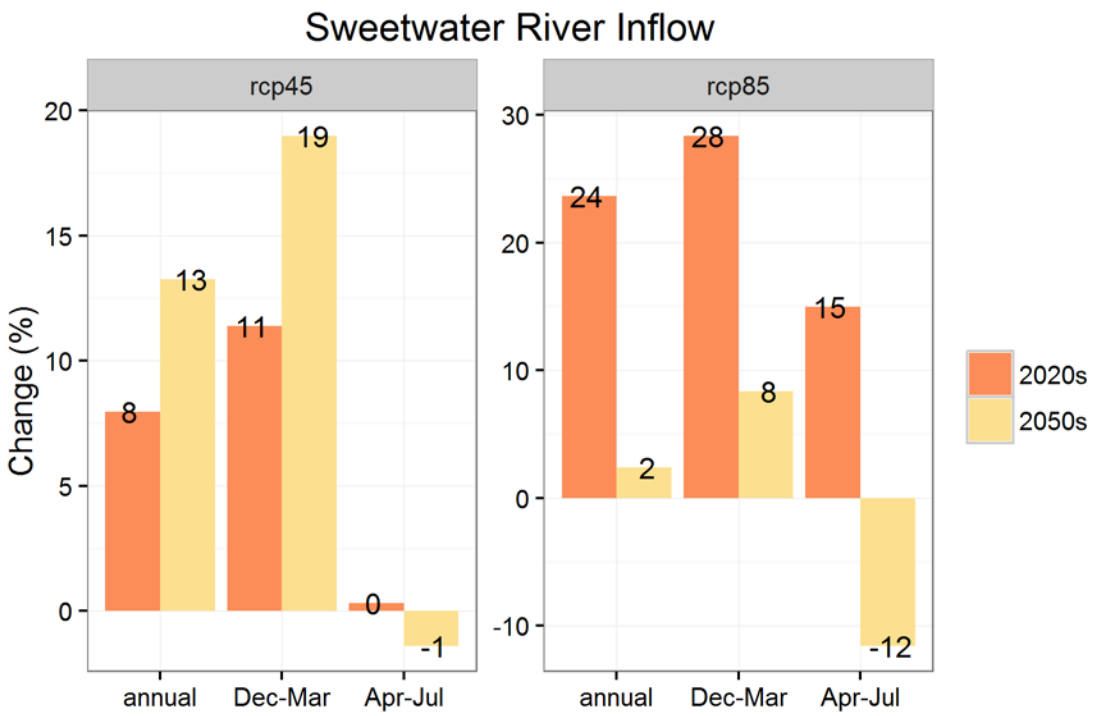
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Change (%)
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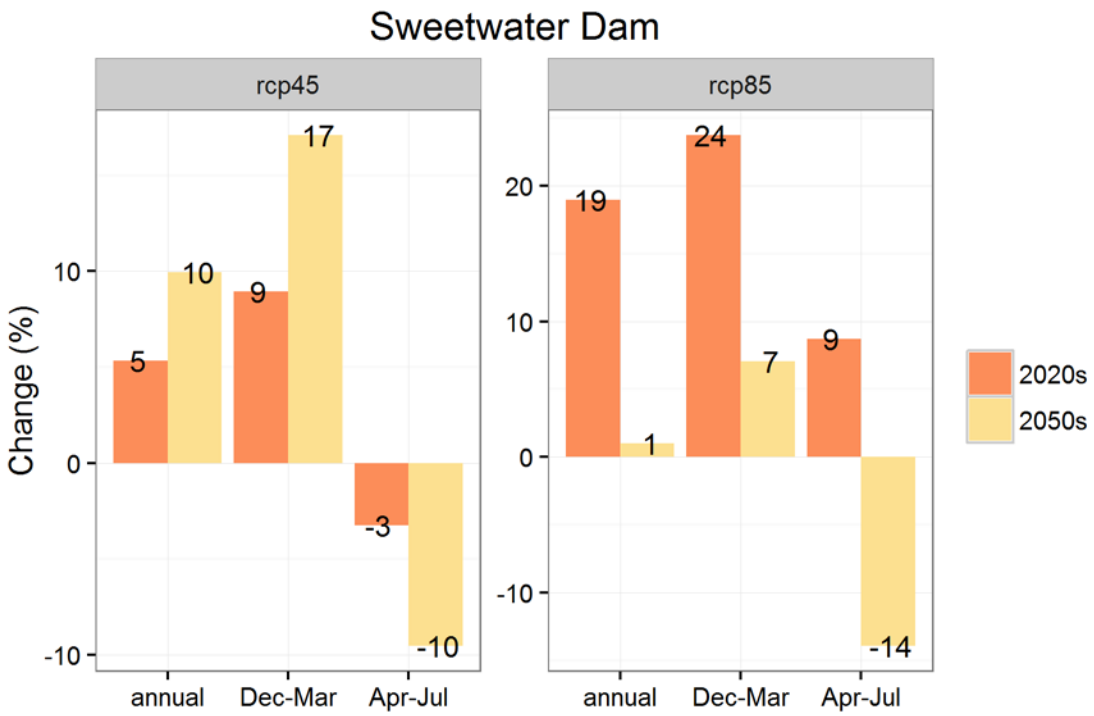
annual
Dec-Mar
Apr-Jul
2020s
2050s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Change (%)
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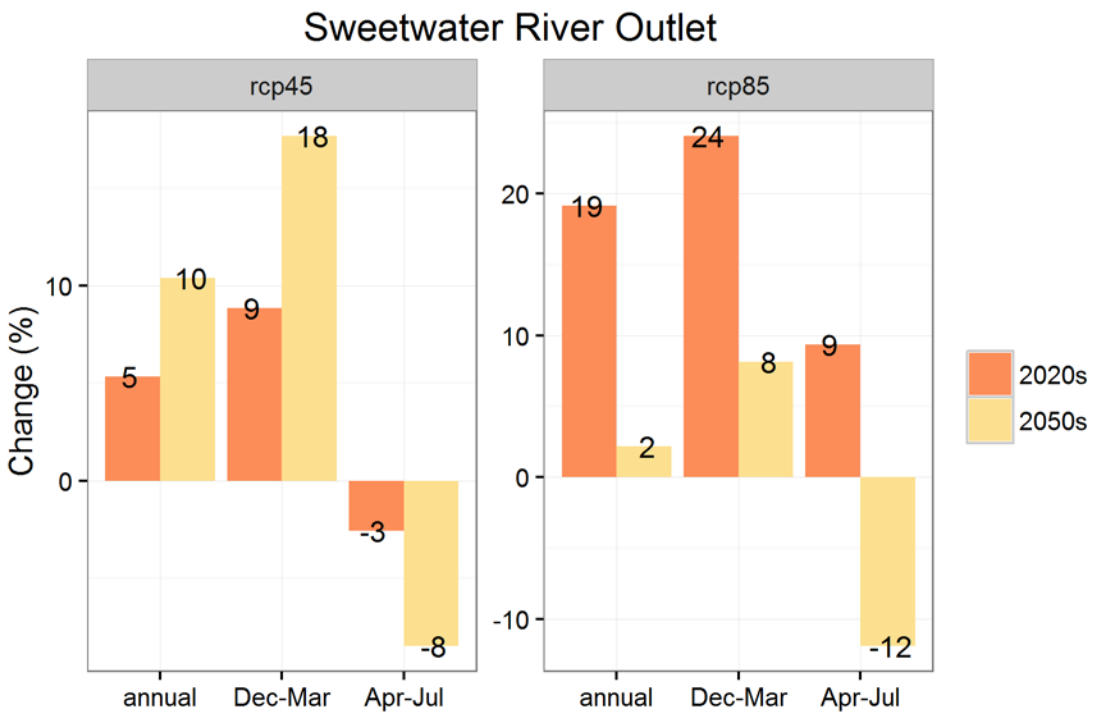
Dec-Mar
Apr-Jul
2020s
2050s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Change (%)
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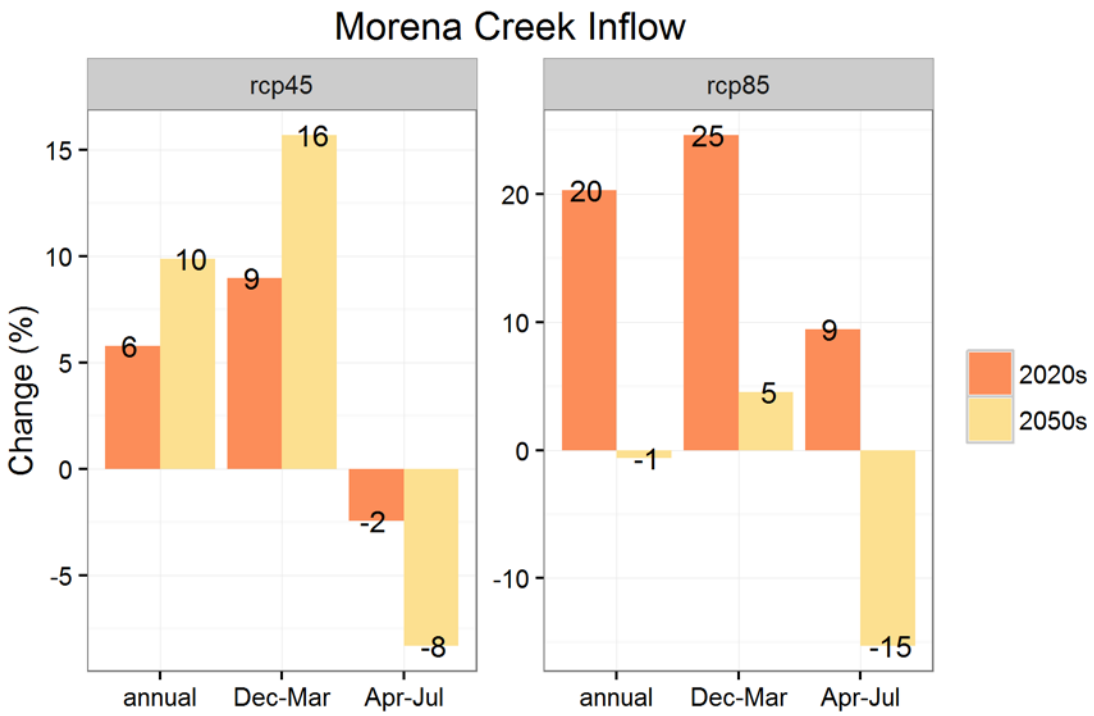
annual
Dec-Mar
Apr-Jul
2020s
2050s


Morena Creek Inflow
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rcp85
Change (%)
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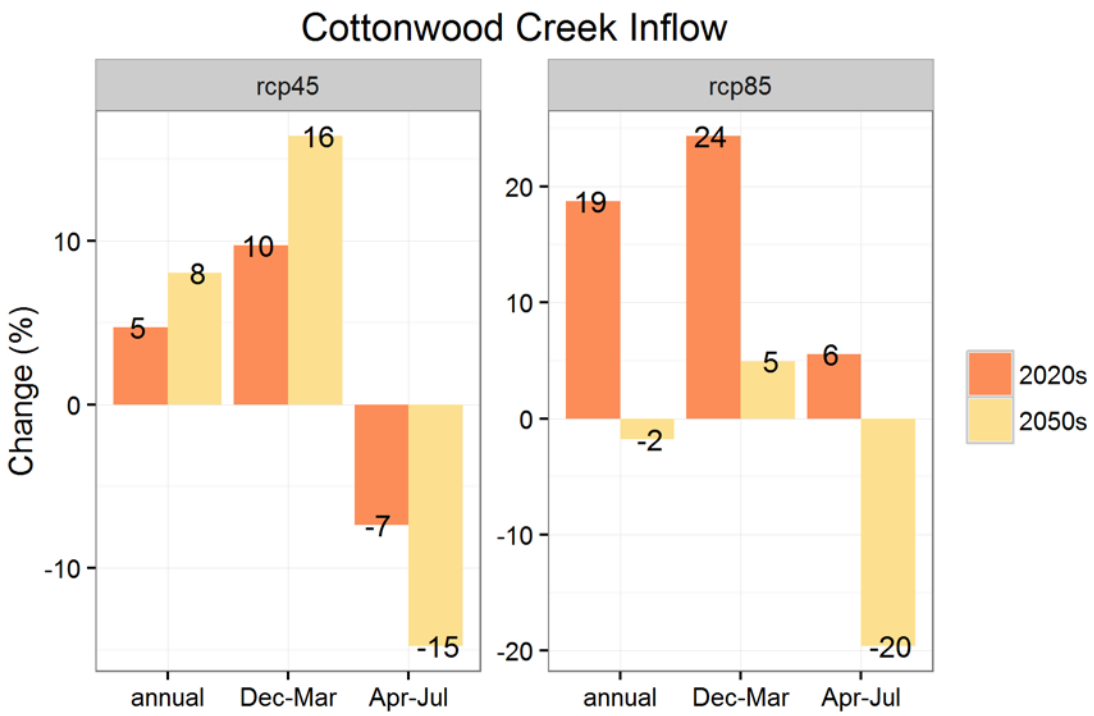
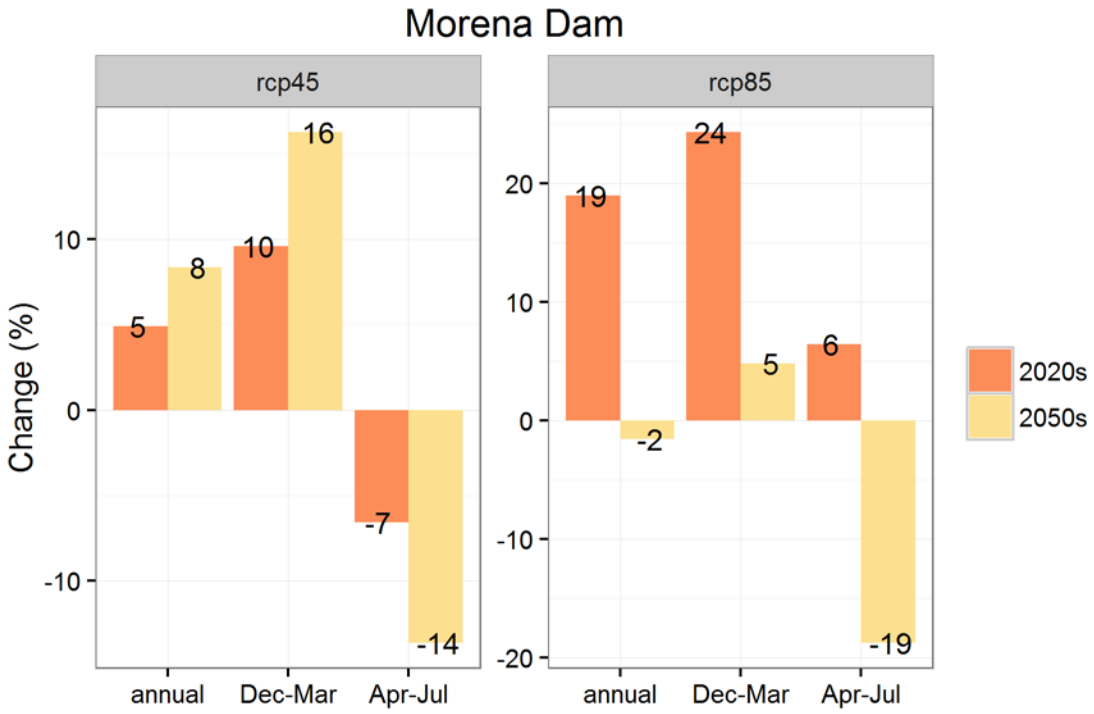
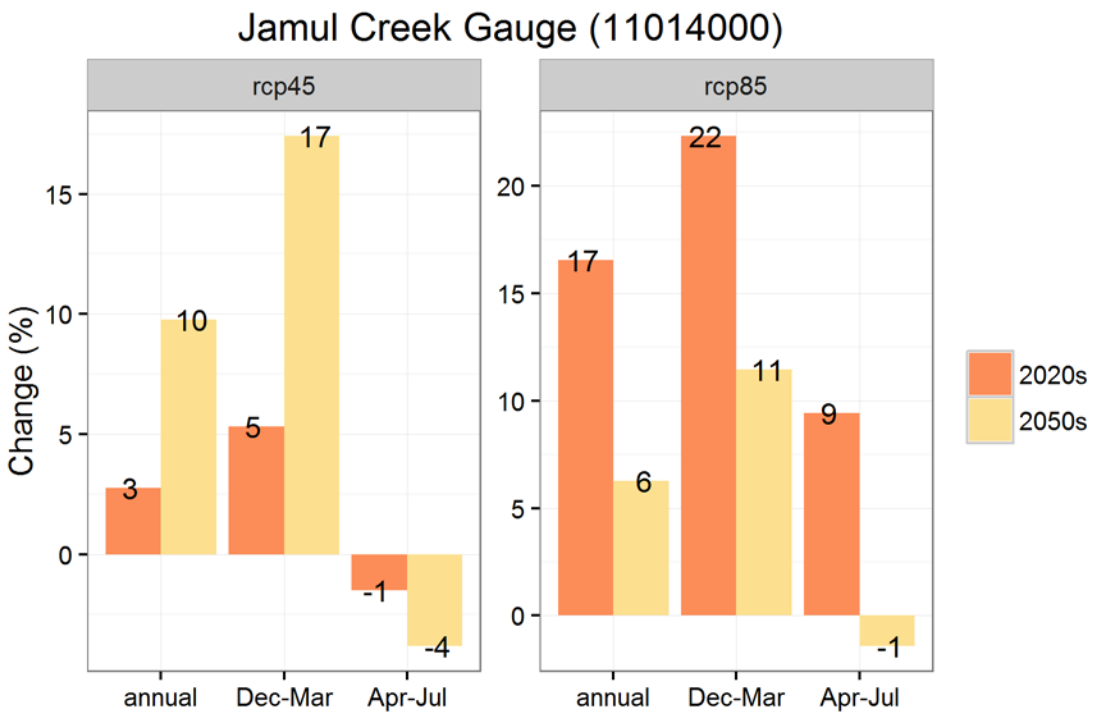
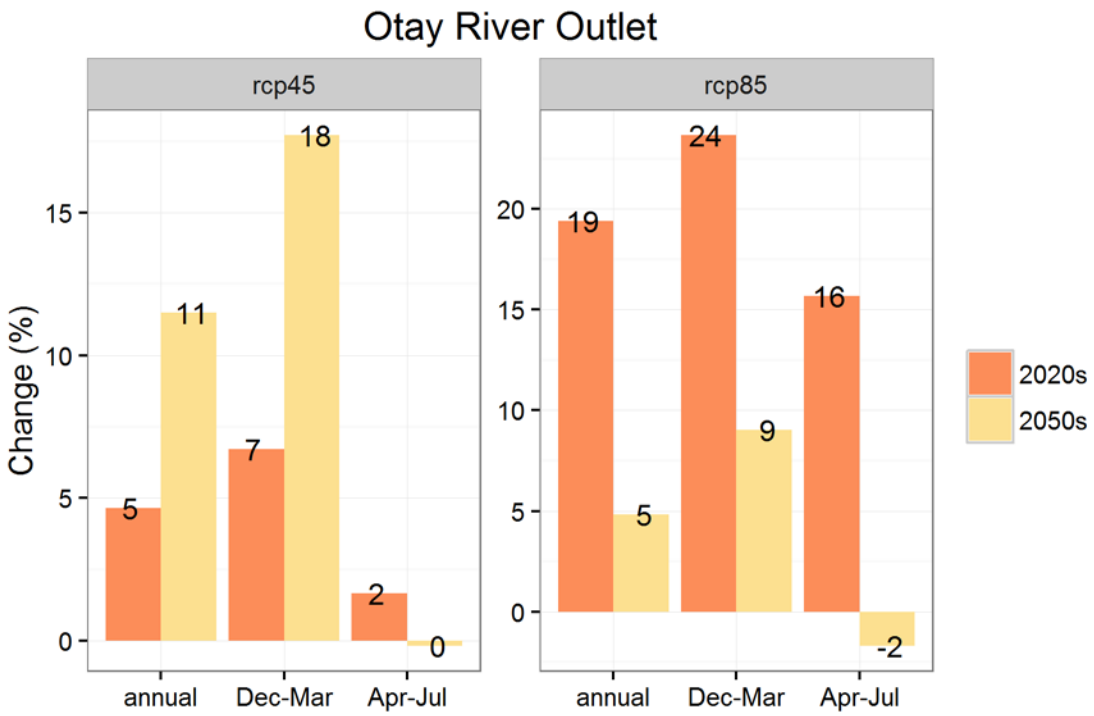
-5
20
-10
6
10
9
16
-2
-8
20
-1
25
5
9
-15
annual
Dec-Mar
Apr-Jul
2020s
2050s


Cottonwood Creek Inflow
rcp45
rcp85
Change (%)
10
0
-10
20
-20
5
8
10
16
-7
-15
19
-2
24
5
6
-20
annual
Dec-Mar
Apr-Jul
2020s
2050s


Morena Dam
rcp45
rcp85
Change (%)
10
0
-10
20
-20
5
8
10
16
-7
-14
19
-2
24
5
6
-19
annual
Dec-Mar
Apr-Jul
2020s
2050s


Jamul Creek Gauge (11014000)
rcp45
rcp85
Change (%)
annual
Dec-Mar
Apr-Jul
2020s
2050s
3
10
5
17
-1
-4
17
6
22
11
9
-1


Otay River Outlet
rcp45
rcp85
Change (%)
annual
Dec-Mar
Apr-Jul
2020s
2050s
5
11
7
18
2
0
19
5
24
9
16
-2