State of California
Natural Resources Agency
Department of Water Resources

Climate Change Characterization and Analysis in California Water Resources Planning Studies

Final Report

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Governor
State of California

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Secretary for Resources
Natural Resources Agency

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Abstract

California's water resources and the hydraulic systems that have been built to manage those resources are acutely vulnerable to the impacts of climate change. Historical planning practices that assume that past observations of climate and hydrology are reasonable predictors of future conditions have been called into question because of climate change. As a result, recent water resources planning in California, as in other places around the world, involves the development of new approaches to consider possible changes in future climate and hydrology. This type of analysis is a field of study that is evolving rapidly. The California Department of Water Resources (DWR) has been one of the early leaders in including climate change analysis in its planning studies and reports; however, DWR does not currently have a standard framework or a set of recommended approaches for considering climate change in its planning studies. A variety of approaches to characterize and analyze future climate have been used in various DWR planning studies. This paper surveys and summarizes the approaches and methodologies that have been used over the last four years. It is the first comprehensive comparative look at the different approaches, their strengths and weaknesses, and how they have been used in past studies. This work is anticipated to lay the groundwork for a future DWR study aimed at developing a standard framework and a consistent set of approaches to be used for characterizing and analyzing climate change in future DWR planning studies and which may provide guidance for DWR partners and grantees.

This paper surveys planning studies in which DWR was the sole conducting agency and studies in which DWR participated with other agencies to develop joint documents. In the studies under way or completed since 2006, DWR generally considered future climate and hydrology change by following one of four approaches: (1) a scenario approach based on selection of a limited number of Global Climate Models simulations; (2) an ensemble-informed approach based on 112 available downscaled simulations from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007); (3) relative change approaches that apply perturbations to historical data to simulate the potential impacts of climate change; or (4) qualitative approaches.

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Acronyms and Abbreviations

ANNs	Artificial Neural Networks
AR4	IPCC Fourth Assessment Report
BA	biological assessment
BCSD	bias correction and spatial downscaling
BDCP	Bay Delta Conservation Plan
CA	constructed analogue
CalLite	screening model (see Glossary)
CALSIM II	water resources planning model jointly developed by DWR and USBR to simulate SWP and CVP operations
CAT	California Climate Action Team
CCSM	Community Climate System Model
CCWD	Contra Costa Water District
CDF	cumulative distribution function
CEQA	California Environmental Quality Act
CVFPP	Central Valley Flood Protection Plan
CVP	Central Valley Project
cm	centimeter
CMIP3	Coupled Model Intercomparison Project, Phase 3
CNRM-CM3	GCM developed by Centre National de Recherché Météorologiques, France
Delta	Sacramento-San Joaquin Delta
DHCCP	Delta Habitat Conservation and Conveyance Program
DOI	US Department of Interior
DOI/LLNL data set	Data set of GCM simulations downscaled over United States developed jointly by the DOI/USBR, Lawrence Livermore National Laboratory, and Santa Clara University
DRMS	Delta Risk Management Strategy
DSC	Delta Stewardship Council
DSM2	Delta Simulation Model II (see Glossary)
DWR	California Department of Water Resources
ECHAM5 / MPI-OM	GCM developed by Max Plank Institute, Germany; same as MPI ECHAM5.
EIR	environmental impact report
EIS	environmental impact statement
GFDL CM2.1	GCM (model version 2.1) developed by Geophysical Dynamics Laboratory, NOAA
GHG	greenhouse gas
GIS	geographical information system
GCMs	Global Climate Model(s) or General Circulation Model(s)
HR model	Statewide Hydrologic Region model
in	inch
IPCC	Intergovernmental Panel on Climate Change
IRP	integrated resource plan
ISB	(CALFED) Independent Science Board
km	kilometers
LAWS	Land Atmosphere Water Simulator (model)
LLNL	Lawrence Livermore National Laboratory
MAGICC	see Glossary
MIROC 3.2	GCM medium-resolution model (see Glossary)
mmhos	millimhos per centimeter (a measure of electrical conductivity)
MPI ECHAM5	Same as ECHAM5 / MPI-OM
NCAR	National Center for Atmospheric Research
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODOS	North-of-the-Delta Offstream Storage
NRDC	Natural Resources Defense Council

OCAP	Operations Criteria and Plan
OCAP BA	2008 Biological Assessment for the Continued Long-Term Operations of the Central Valley Project and State Water Project (see Glossary)
PA model	Planning Area model
PEIR	programmatic environmental impact report
PCM	Parallel Climate Model
PPIC	Public Policy Institute of California
RegCM3	fine-resolution limited-domain climate model (see Glossary)
SacSMA/Snow17	hydrologic model (see Glossary)
SALSA	Salton Sea Analysis (model)
SJRRP	San Joaquin River Restoration Program
SLR	sea level rise
SRES	Special Report on Emissions Scenarios
SSERP	Salton Sea Ecosystem Restoration Program
State Water Board	State Water Resources Control Board
SWAP	State Wide Agricultural Production (model)
SWP	State Water Project
TAF	thousand acre-feet
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USFWS	US Fish and Wildlife Service
VIC	Variable Infiltration Capacity (model)
Water Plan	California Water Plan, Bulletin 160
WCRP	World Climate Research Programme
WEAP	Water Evaluation and Planning (model)
X2	Delta salinity standard (see Glossary)

Metric Conversion Table

Quantity	*To convert from metric unit*	*To customary unit*	*Multiply metric unit by*	*To convert to metric units, multiply customary unit by*
Length	millimeters (mm)	inches (in)*	0.03937	25.4
	centimeters (cm) for snow depth	inches (in)	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Area	square millimeters (mm^2)	square inches (in^2)	0.00155	645.16
	square meters (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometers (km^2)	square miles (mi^2)	0.3861	2.590
Volume	liters (L)	gallons (gal)	0.26417	3.7854
	megaliters	million gallons (10*)	0.26417	3.7854
	cubic meters (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic meters (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekameters (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic meters per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	liters per minute (L/mn)	gallons per minute (gal/mn)	0.26417	3.7854
	liters per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megaliters per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekameters per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lbs)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb.)	1.1023	0.90718
Velocity	meters per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	liters per minute per meter drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per liter (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimeter (µS/cm)	micromhos per centimeter (µmhos/cm)	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(9/5 x °C)+32	(°F - 32) x 5/9

Executive Summary

Introduction

California's water resources and the hydraulic systems that have been built to manage those resources are acutely vulnerable to the impacts of climate change. From diminishing Sierra snowpack and changing hydrology to rising sea levels that will place additional stress on the Sacramento-San Joaquin Delta, climate change poses significant challenges for current and future water resources management in California. The California Department of Water Resources (DWR) has been one of the early leaders to include climate change analysis in planning studies and reports. A variety of approaches to characterize and analyze future climate have been used in various DWR planning studies. This report surveys and summarizes the approaches and methodologies that have been used over the last four years. It provides the first comprehensive comparative look at the different approaches, their strengths and weaknesses, and how they have been used in past studies. This work is anticipated to lay the groundwork for a future DWR study aimed at developing a standard framework and a consistent set of approaches to be used for characterizing and analyzing climate change in future DWR planning studies.

The planning studies reviewed in this report include studies where DWR is the sole agency conducting the study and studies where DWR participates with other agencies to develop joint documents. The studies range from DWR's flagship planning process, update of the California Water Plan, which provides strategic information about California water resources, to environmental impact reports for specific water management projects. All of these planning studies require an analysis of future conditions including climate and hydrology. Historical planning practices that assumed past observations of climate and hydrology were reasonable predictors of future conditions have been called into question because of climate change. As a result, recent water resources planning in California, as in other parts of the world, involves the development of new approaches to include possible changes in future climate and hydrology. The simulation of future climate and hydrology for the purpose of future planning is a field of study that is evolving rapidly. DWR does not have a standard approach or a set of recommended approaches for considering climate change in its planning studies.

The information in this report is intended for use by DWR to consider how to include climate change analyses in planning studies. The information may also be useful for other water resource planners. This report is the first step toward identifying opportunities for developing common climate change analysis approaches for studies with similar purposes and assumptions.

This report is a comprehensive survey of all DWR planning studies that have addressed the impact of climate change in predicting future climate conditions and impact on water resources. Thirteen ongoing and past planning studies are reviewed in detail. Seventeen different analysis characteristics are highlighted for each study including planning horizon, spatial coverage, climate analysis approach, number of Global Climate Models (GCMs) used, scenario selection, sea level rise, hydrologic simulation period, and streamflow sequence for operations modeling. Of the 13 projects, more than half were completed solely by DWR; the rest were completed in partnership with DWR, often with multiple State and federal agencies. Table ES 1 1ists the 13 projects and provides a comparison of the projects based on the 17 different analysis characteristics.

Findings

The projects highlight a major distinction among the types of planning studies that are done by DWR. This distinction is between general planning studies and project level analyses. General planning studies include any study that describes future conditions but does not propose an individual project or a series of related projects for implementation. Project level analyses are studies conducted for an individual project or a series of related projects that are being proposed for implementation. In many cases, project level analyses will be done for federal feasibility reports or environmental documentation pursuant to the National Environmental Policy Act or California Environmental Quality Act. General planning studies cover a much wider range of analyses than that for project level analyses.

Significant differences exist between studies that focus on specific projects versus studies that consider future conditions or impacts more generally. Both types of studies often involve multiple linked models. However, project level analyses focus on the impacts of a specific project and alternatives. General planning studies tend to stay at a much higher—i.e., coarser—level of analyses that assess general trends and often provide more generalized strategies or a menu of potential strategies for addressing anticipated problems. The type of planning study, general or project level, has important ramifications on the feasibility of using some climate change analysis approaches.

The surveyed projects highlight four general approaches to analyzing climate change in the planning studies. These approaches include (1) a scenario approach based on selection of a limited number of GCM simulations as used by the California Climate Action Team (CAT); (2) an ensemble-informed approach based on 112 available downscaled simulations from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007); (3) relative change approaches that apply perturbations to historical data to simulate the potential impacts of climate change; or (4) qualitative approaches. In addition, two supplementary analysis approaches—paleoclimate data and sensitivity analysis—have been used by DWR and others to help improve the climate change analyses.

The report identifies planning time horizon, spatial scale, and type of planning study as important issues in determining the need for or the type of climate change analysis used. In relation to planning time horizon, only studies with planning horizons exceeding 15 years completed a climate change analysis. However, planning horizon appeared to have little impact on the type of climate change analysis undertaken. Spatial scale, on the other hand, did not influence whether a climate change analysis was done, but was very important in influencing the type of analysis completed. Studies with smaller spatial coverage, typically project level analyses, tended to employ fewer technical approaches. General planning studies tended to cover large spatial areas and generally longer planning horizons. For general planning studies, a scenario approach (approach number 1 above) was used almost exclusively.

In general, the projects indicate an evolution in sophistication toward more quantitative and analytical approaches. Specifically, the database of 112 downscaled GCM simulations cooperatively developed by the US Department of Interior and Lawrence Livermore National Laboratory is increasingly being used as the basis for climate change characterization and analysis in planning studies. The simulations in the database were developed using a downscaling technique called bias correction and spatial downscaling. Use of the database varies from developing climate scenarios from all 112 simulations to selection of just a few simulations or just one simulation from the database. This report highlights how some projects have used the downscaled simulations directly (i.e., using the climate variables of interest directly from the simulation outputs) or indirectly (i.e., using an ensemble of simulations to generate new scenarios that represent the aggregated characteristics of the ensemble). For example, the CAT has used the simulations directly in its 2006 and 2009 assessment reports, while the Bay Delta Conservation Plan is using the simulations indirectly to develop five new climate scenarios for their planning analyses.

Characterization of future climate conditions including temperature, precipitation, and humidity was only the first step in the analysis of climate change impacts in the planning studies. Most of the studies proceed to use future climate scenarios to analyze expected future hydrology. This step typically involved using the downscaled GCM data to generate projection of future streamflow. The studies surveyed for this report used two general methods for developing streamflow projections: adjusted observed hydrologic sequences and unadjusted model generated sequences. Adjusted observed hydrologic sequences use the observed record of streamflows as a baseline to which adjustments are made to reflect potential climate changes. Unadjusted model generated sequences use climate models to generate input parameters for a hydrologic model which generates streamflow sequences that are used without adjustment.

Data Gaps, Needs Assessment, and Next Steps

The survey and descriptions of projects for this report will serve as a primary resource for DWR as it works to develop a standard framework and a set of consistent approaches for incorporating climate change in its planning studies. The list of past projects illustrates the types of activities in which DWR generally engages. However, it does not necessarily provide a comprehensive picture of all the different types of projects that DWR may be involved with in the future. For instance, no flood protection projects are highlighted, rather the studies focus on water supply and ecological restoration. Flood protection projects differ significantly from water supply and ecological restoration projects in their purpose, scope, analysis time-step, and the resulting impact assessment. Water supply and restoration projects generally focus on average long-term conditions, while flood protection projects focus on extreme climate events that result in short-term high runoff events. A large amount of uncertainty still exists in how climate change will influence the magnitude and frequency of extreme climate events in the future. As a result, developing climate characterization and analysis approaches for flood protection projects presents a unique challenge.

In addition, there is a lack of analysis of potential drought conditions that are more extreme than have been seen in our relatively short hydrologic record. There is significant evidence to suggest that California has historically been subject to very severe droughts and that climate change could result in droughts being more common, longer, or more severe. However, most current DWR approaches rely on an 82-year historical hydrologic record (1922–2003) on which GCM-generated future climate changed-hydrologic conditions are superposed. This record is likely too short to incorporate the possibility of a low frequency, but extreme, drought.

As DWR develops its standard framework and a set of approaches to addressing climate change, it will have to balance consistency across time and purpose with flexibility to incorporate continual improvements in scientific understanding of climate change as well as the state of the practice for analyzing impacts.

Thirteen large-scale planning studies that will include climate change analysis, but that have not yet developed a specific methodology for conducting that analysis, are already on the horizon. These projects further highlight the need for a coordinated set of approaches for characterizing and analyzing climate change across DWR activities.

Summary

Scientific advancements will continue to improve our understanding of the Earth's climate system and our confidence and accuracy in predicting future changes to the system. Technical advances will continue to improve the methods we have for incorporating climate model data into our planning processes. As these advances occur, DWR must endeavor to employ the best science and the most robust analytical methods while maintaining consistency in the way that climate change is characterized and analyzed across its many programs.

We recommend a multi-step process for developing a DWR climate change approach: (1) Formation of a workgroup of DWR experts to develop the approach; (2) Development of a suite of probable approaches for climate change characterization based on project purpose, planning horizon, and spatial coverage of projects; (3) Transparent development of a draft methodology document including a standard framework and a set of consistent approaches for review by DWR management as well as peer review by experts from within and outside of DWR.

The workgroup will also work on issues associated with the implementation of the recommended approaches in the methodology document, including ongoing communication and coordination. A plan and process for periodic review and revisions to the framework and the approaches in light of scientific and technical advances will also be included.

Summary of Planning Studies Surveyed and Type of Climate Change Analysis Conducted

Study Aspect	1	2	3	4	5	6	7	8	9	10	11	12	13
Planning Study Name	**CWP Update 2009 - B160**	**2006 SWP/CVP Impacts Report**	**2009 SWP/CVP Impacts Report**	**SWP Delivery Reliability Report 2009**	**Management Response Status Report**	**DRMS Phase 1 Report**	**Monterey Plus FEIR 2010**	**Salton Sea Ecosystem Restoration Program**	**Oroville Facilities Relicensing**	**BDCP and DHCCP Operations and Planning**	**CVP/SWP OCAP BA**	**Los Vaqueros Reservoir Expansion EIR/EIS**	**CVP IRP**
Publication/Analysis Completion Date	March 2010	July 2006	April 2009	December 2009	February 2010	December 2008	February 2010	2007	July 2008	In progress.	August 2008	March 2010	In progress
Project/General Study	General Study	General Study	General Study	General Study	General Study	General Study	Project	Project	Project	Project	Project	Project	Project
DWR's Role	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Participant	DWR Participant	DWR Participant	Other Related
Section Reference	Section III.B.1.i	Section III.B.1.ii	Section III.B.1.ii	Section III.B.1.iii	Section III.B.1.iv	Section III.B.1.v	Section III.B.2.i	Section III.B.2.ii	Section III.B.2.iii	Section III.C.2.i	Section III.C.2.ii	Section III.C.2.iii	Section III.D.1
Planning Horizon	2050	2050 (mid-century).	2045 (mid-century); 2085 (end of	2029	2045	50-, 100-, and 200- years from the	2020	2078	2058	2015; 2025; and 2060.	2025 and 2050.	2030	2030, 2060, and 2085.
Spatial Coverage	Statewide	Central Valley and SWP/CVP service areas.	Central Valley and SWP/CVP service areas.	Central Valley and SWP service areas.	Statewide	Central Valley and the Delta.	Central Valley and SWP service areas.	Salton Sea area	Central Valley and SWP service areas.	Central Valley, SWP/CVP service areas, and the Delta.	Central Valley, SWP/CVP service areas, and the Delta.	The Delta and the Bay area.	Central Valley and CVP service areas.
Climate Analysis Approach	CAT 2009 Approach (Scenario Analysis)	CAT 2006 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	A Monte Carlo sensitivity analysis approach based on results from the CAT 2006 study and others.	Relative change ("Delta") approach based on results from the 2006 SWP/CVP Impacts Report	A Monte Carlo sensitivity analysis approach based on results from the CAT 2006 study.	Qualitative approach.	Ensemble informed approach.	Bracketing scenario analysis approach.	Qualitative approach based on results from the 2006 SWP/CVP Impacts Report and OCAP BA.	Ensemble informed approach.
Number of GCMs Considered	6	2	6	6	6	13	2	2	Not applicable.	16	16	2	16
Emission Scenarios Considered	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A1b, A2, and B1	SRES A2 and B1	SRES A2 and B1	Not applicable.	SRES A2, B1, and A1b.	SRES A2, B1, and A1b.	SRES A2 and B1	SRES A2, B1, and A1b.
Number of Projections Considered	12	4	12	12	12	4 from CAT 2006 plus others.	4	4	Not applicable.	112	112	4	112
Regional Downscaling	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Not applicable.	Not applicable.	Not applicable.	Bias Correction Spatial Downscaling (BCSD).	Bias Correction Spatial Downscaling (BCSD)	Not applicable.	Bias Correction Spatial Downscaling (BCSD)
Scenario Selection	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 12 scenarios.	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 4 scenarios.	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 12 scenarios.	A single representative median scenario (MPI ECHAM5 with higher emissions SRES A2) based on a set of climatology, hydrology, and related effects metrics.	A single representative scenario (GFDL CM2.1 with higher emissions SRES A2) based on producing average water delivery impacts. Also for sensitivity analysis, all 12 CAT 2009 scenarios.	A total of 84 scenarios using a probabilistic, Monte Carlo approach, based on data from 4 CAT 2006 scenarios.	Results from a single scenario (GFDL CM2.1 with higher emissions SRES A2) from the 2006 SWP/CVP Impacts Report, based on producing largest average annual impact on SWP deliveries.	A total of 1000 scenarios using a probabilistic, Monte Carlo approach, based on data from 4 CAT 2006 scenarios.	Not applicable.	Ensemble-informed scenarios, based on joint ΔT-ΔP distributions as partitioned into statistical regions representing range of all 112 projections; done for each downscaled grid cell (1/8th degree). A central tendency scenario: by aggregating all projections falling within the inner-quartiles, 25th to 75th percentile. Four additional scenarios: by aggregating the ten projections based on normalized distance from joint ΔT-ΔP distributions (closest to the 90th/10th	Climate change scenarios based on individual projections based on 10^{th} and 90^{th} percentile of period average ΔT and ΔP. A total of 4 scenarios.	Not applicable.	BDCP approach (ensemble informed)
Climate Variables Adjusted	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed), and wind velocity.	Not applicable.	Not applicable.	Not applicable.	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg change, wind speed not changed)	Not applicable.	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).

Study Aspect	1	2	3	4	5	6	7	8	9	10	11	12	13
Planning Study Name	**CWP Update 2009 - B160**	**2006 SWP/CVP Impacts Report**	**2009 SWP/CVP Impacts Report**	**SWP Delivery Reliability Report 2009**	**Management Response Status Report**	**DRMS Phase 1 Report**	**Monterey Plus FEIR 2010**	**Salton Sea Ecosystem Restoration Program**	**Oroville Facilities Relicensing**	**BDCP and DHCCP Operations and Planning**	**CVP/SWP OCAP BA**	**Los Vaqueros Reservoir Expansion EIR/EIS**	**CVP IRP**
Climate Variability Adjustment	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Not applicable.	Not applicable.	Not applicable.	Statistically-mapped onto historic climate. Reflects observed sequence with monthly variability adjustments based on statistical shifts from climate scenarios (quantile mapping).	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Not applicable.	CAT 2009 and BDCP approaches.
Sea Level Rise Projection[1]	None	1-foot at 2050.	1-foot at 2045; 2-feet at 2085.	1-foot at 2029.	1-foot at 2050.	Time series reflecting short-term variations, in addition to long-term variations (11 - 41 cm for year 2050;	Not considered.	Not applicable.	Not applicable.	6″ at 2025 and 18″ at 2060.	1-foot sea level rise at 2030, coupled with a 10% increase in tidal amplitude.	Not applicable.	Results from BDCP will be used.
Hydrologic Model	WEAP	VIC	VIC	VIC	VIC	VIC	Not applicable.	Not applicable.	Not applicable.	VIC	VIC and Sac-SMA/Snow 17.	Not applicable.	WEAP
Hydrologic Simulation Period	Reliance on projection period and sequence: 45-year simulations aligned with future period 2006-2050.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2035-2064 for 2050.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2030-2059, and 2070-2099.	Reliance on projection period and sequence: 30-year simulations aligned with future periods, based on 2009 SWP/CVP Impacts Report.	Reliance on projection period and sequence: 30-year simulations aligned with future periods, based on 2009 SWP/CVP Impacts Report.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2035-2064 for 2050, and 2070–2100 for 2085.	Not applicable.	Not applicable.	Not applicable.	Reliance on observed sequences with adjustments based on statistical shifts aligned with future period: 50-year simulations 1950-1999	Reliance on projection period and sequence: 30-year simulations aligned with future period 2011-2040 for 2025; 2036-2065 for 2050	Not applicable.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2011-2050 for 2030, 2051-2070 for 2060, and 2071-2100 for 2085.
Streamflow Adjustment	None.	A single step perturbation based on average monthly ΔQ % from historical data (i.e., all Octobers perturbed by same %). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Not applicable.	Not applicable.	Not applicable.	Time series of monthly ΔQ % from hydrologic model (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Perturbations based on average monthly ΔQ % from hydrologic model (i.e. all Octobers perturbed by same %). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Not applicable.	None.
Streamflow Sequence for Operations Modeling	Reliance on projection period and sequence: 45-year simulations aligned with future period 2006-2050.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 73-year simulations 1922-1994.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 73-year simulations 1922-1994.	Reliance on projection period and sequence: 72-year simulations aligned with future period 2005-2078, based on data from historical period 1950-2002.	Not applicable.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Not applicable.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2011-2050 for 2030, 2051-2070 for 2060, and 2071-2100 for 2085.

[1]Most of the recent studies reported herein use sea-level rise estimates based on a methodology that relates observed global mean sea level rise to global mean surface air temperature (Rahmstorf, 2007). This methodology allows estimations of global sea level rise using the surface air temperature projected by the GCM simulations. An important assumption implicit in the use of this methodology for California is that sea level rise along the California coast will mirror estimates of global sea level rise.

xx Table ES-1 Summary of studies and analysis

Section I Introduction

I.A Climate Change and the California Department of Water Resources Planning Activities

California's water resources and the hydraulic systems that have been built to manage those resources are acutely vulnerable to the impacts of climate change. From diminishing Sierra snowpack and changing hydrology to rising sea levels that will place additional stress on the Sacramento-San Joaquin Delta (the Delta), climate change poses significant challenges for current and future water resources management in California. The California Department of Water Resources (DWR) has been one of the early leaders in including climate change analysis in its planning documents. A variety of approaches to characterize and analyze future climate have been used in various DWR planning studies. The planning studies reviewed in this report include studies where DWR is the sole agency conducting the study and studies where DWR participates with other agencies to develop joint documents. The studies range from DWR's flagship planning process, update of the California Water Plan, which provides strategic information about California water resources, to environmental impact reports (EIRs) for specific water management projects. All of these planning studies require an analysis of future conditions including climate and hydrology. Historical planning practices that assume that past observations of climate and hydrology were reasonable predictors of future conditions have been called into question because of climate change. As a result, recent water resources planning in California, as in other parts of the world, involves the development of new approaches to include possible changes in future climate and hydrology.

I.B The Need for this Report

The simulation of future climate and hydrology for the purpose of future planning is evolving rapidly. DWR's planning studies do not have a standard framework or a set of recommended approaches for considering climate change. Of the studies under way, DWR generally follows one of four approaches: (1) a scenario approach based on selection of a limited number of Global Climate Models (GCM) simulations; (2) an ensemble-informed approach based on 112 available downscaled simulations from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007); (3) relative change approaches that apply perturbations to historical data to simulate the potential impacts of climate change; or (4) qualitative approaches. In addition, two supplementary analysis approaches—paleoclimate data and sensitivity analysis—have been used by DWR and others to help improve the analyses.

This report surveys and summarizes the climate change characterization approaches and methodologies that have been used in recent planning studies conducted by DWR and its partner agencies. It is the first comprehensive comparative look at the different approaches, their strengths and weaknesses, and how they have been used in past studies.

The information is intended for use by DWR to consider how to include climate change analyses in planning studies. The information may also be useful for other water resource planners. This report is the first step toward identifying opportunities for developing common climate change analysis approaches for studies with similar purposes and assumptions. This work is envisioned to lay the groundwork for a future DWR study aimed at developing a standard framework and a consistent set of approaches to be used for characterizing and analyzing climate change in future DWR planning studies.

I.C Expected Climate Change-related Impacts

California is uniquely vulnerable to climate change. Our water supply system is dependent on snowpack storage in the Sierra Nevada, which is predicted to diminish by 25 percent by 2050 (DWR, 2008). California also relies on the Delta as a conveyance route for water delivered to 25 million Californians and millions of acres of prime farmland. Sea level rise increases salinity intrusion into the Delta, making it more difficult to maintain the freshness of the water pumped out of the Delta. The 1,100 miles of earthen levees that protect the Delta are also at increased risk of failure because of sea level rise as higher seas place more pressure on levees in the estuary. The risk of flooding in California, particularly in the Central Valley, may also increase as a result of climate change. Thousands of miles of river throughout the state are controlled by dams and reservoirs, and thousands of acres of land adjacent to those rivers are protected by levees and bypasses. Climate change is likely to increase storm frequency and severity with some increase in winter runoff in mountain basins due to higher-elevation snow levels during storms. Also, the snowpack will melt earlier in the season with less late-season runoff. All of these factors will further stress the state’s levees and reservoir operations.

In addition to the above mentioned impacts, climate change will make deliveries from the already stressed Colorado River system, an important source of water for California, more uncertain in the future.

I.D Need for More Advanced Approaches

Assessing the impacts of climate change on California’s water resources is a crucial aspect of water planning, as the state faces serious risk from climate-induced changes. Effectively analyzing the impacts of these changes on California’s water resources is critical to successfully executing DWR’s mission. Improving DWR’s capacity to address the impacts of climate change will improve California’s ability to appropriately prepare for the future and adapt to changes. Advances in DWR’s ability to address climate change in water resources planning are also likely to improve water resources planning at the regional and local level as tools and information developed by DWR are made available through the California Water Plan, State Water Project Delivery Reliability Report, and various DWR programs.

I.E Report Preparation Process and Contents Summary

This report describes various planning studies conducted by DWR and its partner agencies. In order to ensure that all DWR planning activities were covered, a survey was developed and sent to all managers and supervisors as well as all members of DWR's Climate Change Matrix Team[1]. The survey asked a series of simple questions to identify water resources studies that had been completed or would be completed by the survey-taker that included a climate change analysis. The survey's responses generated the list of projects covered in this report.

The studies described in this report span a wide range of planning study types, from statewide analysis of future water conditions to local water management project implementation analyses, from very sophisticated modeling of expected conditions and system responses to generalized assessments of climate change impacts.

This report discusses how future climate conditions have been developed in each of the planning studies and how those conditions impact the water resources of interest for the study. This comprehensive survey not only summarizes the climate change characterization approaches used in these DWR studies, but also highlights the strengths and weaknesses of each approach, and articulates the roadmap and initial considerations for standardizing and improving the consistency of the approaches for incorporating climate change in planning studies.

[1] DWR's Climate Change Matrix Team is an internal team comprising representatives from all divisions of DWR. The team meets regularly to share information, and coordinates on all climate change issues pertinent to DWR.

Section II Contemporary Approaches to Addressing Climate Change Used by the California Department of Water Resources

II.A IPCC GCMs and Downscaled Climate Projections

II.A.1 The IPCC

The IPCC was jointly established in 1988 by the World Meteorological Organization and the United Nations Environment Programme, with the mandate to:

- assess scientific information related to climate change,
- evaluate the environmental and socioeconomic consequences of climate change, and
- formulate realistic response strategies.

Since 1988, the IPCC has published four assessment reports (1990, 1995, 2001, and 2007) that bring together up-to-date policy-relevant scientific, technical, and socioeconomic information on climate change. The IPCC has also published several special reports, technical papers, and methodology reports, which have become standard works of reference, widely used by policymakers, scientists, other experts, and students.

The IPCC Fourth Assessment Report (AR4), published in 2007, is the current standard reference for worldwide climate change assessment information. As part of the IPCC AR4, an array of global coupled ocean atmospheric general circulation models was assembled to provide simulations of 20th and 21st century climate conditions. The array of simulations is known as the Coupled Model Intercomparison Project (CMIP3). The data set includes results from 25 different GCMs.

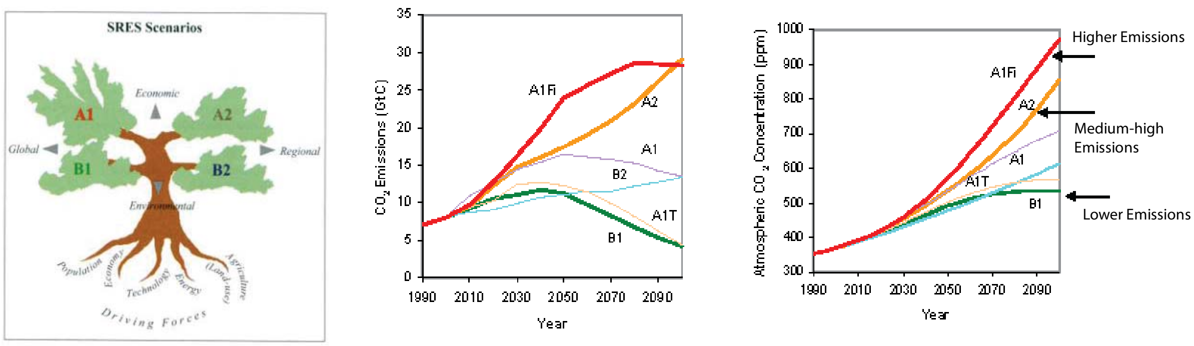
The IPCC AR4 builds on previous work by the IPCC to develop plausible future scenarios of anthropogenic emissions of all relevant greenhouse gases (GHGs) as well as other important climate-forcing compounds that are commonly emitted into the atmosphere. These scenarios consider a wide range of the major driving forces of future emissions, from demographic to technological and economic developments (IPCC, 2000).

The AR4 describes observed changes in climate and their effects, causes of change, projected climate change and its impacts, adaptation and mitigation options, and a long-term perspective climate change.

Water resource impacts are discussed in the report but are generally handled at a very high level. Although specific observed changes to precipitation and hydrology are noted in the report, detail projections of future impacts at local scales are not included.

II.A.2 Climate Storyline and Scenario Family

The approach used in the IPCC AR4 involved the development of a set of four alternative scenario "families." Each scenario family includes a coherent narrative called a "storyline" and a number of alternative interpretations and quantifications of each storyline developed by six different modeling approaches. Each storyline describes a demographic, social, economic, technological, environmental, and policy future (Figure 2–1). Brief descriptions of the four scenario families are provided below.



(a) Conceptual representation (b) Time-evolution of C0$_2$ emissions (c) Time-evolution of C0$_2$ concentrations

(CH2M Hill, 2010 and Cayan et al., 2006a)

Figure 2–1 IPCC SRES Emission Scenarios and resulting trends in CO_2 emissions and CO_2 concentrations

- The ***A1 storyline and scenario family*** represents a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. Several subsets of the A1 scenario family have also been commonly used and reported, including:
    - A1FI - projects continued heavy reliance on fossil-fuels.
    - A1B - projects reliance on a balanced mix of fossil and non-fossil fuel energy sources.
    - A1T - projects a decreased reliance on fossil energy sources and an increased reliance on non-fossil fuel energy sources.

- The ***A2 storyline and scenario family*** represents a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

- The ***B1 storyline and scenario family*** represents a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- The ***B2 storyline and scenario family*** represents a world in which the emphasis is on local solutions to attain economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.

The Special Report on Emissions Scenarios (SRES) (IPCC, 2000) states explicitly that “the scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold.” The scenarios are meant to assist researchers and policy-makers to explore potential long-term future conditions and the plausible ramifications of near-term activities and policy decisions.

The climate simulations in the IPCC AR4 made use of the above four emissions scenario families to generate climate projections for the next 100 years. These simulations were then used to analyze potential future conditions and develop global impact assessments and adaptation strategies.

II.A.3 Regional Downscaling

The IPCC AR4 does not provide detailed assessments of regional climate change impacts. The spatial scale of GCM outputs is too coarse for most regional impacts studies and decision-support purposes. The discrete global grid is too imprecise to adequately depict the complex structure of temperature and precipitation that characterizes most regional settings. To fill this need, the US Department of Interior's Bureau of Reclamation (Research and Development Office) and its Technical Service Center, Lawrence Livermore National Laboratory, Santa Clara University Civil Engineering Department, Climate Central, and The Institute for Research on Climate Change and its Societal Impacts have teamed up to develop a data set of GCM simulations downscaled over the entire United States. The data set is available as a public-access archive. This data set is hereafter referred to in this report as the DOI/LLNL data set. Downscaling is defined here as the process of deriving data at a finer resolution—in space or time—from a coarser resolution data set. For GCM outputs, this means, taking the large-scale signal from the GCM and translating it to the regional scale.

The DOI/LLNL data set includes 16 of the 25 models included in the CMIP3, run with three future GHG emissions scenarios (A2, B1, and A1B). The models included in the DOI/LLNL data set and the years of their development are furnished in Table 2–1. The data set contains a total of 112 downscaled climate projections (several of the models were run with multiple atmospheric and oceanic initial conditions for the same GHG emissions scenario). The downscaled projections increased the resolution from greater than 1 degree of latitude-longitude for GCM outputs to 1/8th degree of latitude-longitude (approximately 12 km by 12 km). Similar to GCM outputs, the downscaled outputs also cover the time period from 1950 to 2099 at monthly time steps and contain mean daily precipitation and mean monthly surface air temperature values. The data set is available at:
http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#About.

While multiple approaches exist for deriving regional climate data from coarse resolution model output, downscaling of the above data set was performed using a statistical method called bias correction and spatial downscaling (BCSD), described by Wood et al. (2004). This method is computationally efficient enough to be easily applied to ensembles of large number of projections (Maurer, 2007) and has been used in the study of potential climate change impacts on various resources systems, including watershed hydrology and reservoir systems.

A number of contemporary approaches have used the data set of 112 downscaled projections or individual projections from the data set to analyze climate change related impacts. Illustrative projects that make use of the data set, including more detailed description of the downscaling method utilized, are described below.

Table 2–1 GCMs with downscaled climate projections

No.	Modeling group, country	Model identification	Primary reference year
1	Bjerknes Centre for Climate Research (BCCR), Norway	BCCR-BCM2.0	2003
2	Canadian Centre for Climate Modeling and Analysis, Canada	CGCM3.1 (T47)	2001
3	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	CNRM-CM3	2005
4	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	CSIRO-MK3.0	2002
5	US Dept. of Commerce / National Oceanic and Atmospheric Administration (NOAA) / Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDL-CM2.0	2006
6	US Dept. of Commerce / National Oceanic and Atmospheric Administration (NOAA) / Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDL-CM2.1	2006
7	National Aeronautics and Space Administration (NASA) / Goddard Institute for Space Studies (GISS), USA	GISS-ER	2000
8	Institute for Numerical Mathematics (INM), Russia	INM-CM3.0	2002
9	Institut Pierre Simon Laplace (IPSL), France	IPSL-CM4	2005
10	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	2004
11	Meteorological Institute of the University of Bonn, Meteorological Research Institute of Korea Meteorological Administration (KMA), Germany/Korea	ECHO-G	1999
12	Max Planck Institute (MPI) for Meteorology, Germany	ECHAM5/ MPI-OM	2006
13	Meteorological Research Institute (MRI), Japan	MRI-CGCM2.3.2	2001
14	National Center for Atmospheric Research (NCAR), USA	CCSM3	2006
15	National Center for Atmospheric Research (NCAR), USA	PCM	2000
16	Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3	2000

Table note: The DOI/LLNL data set includes 16 of the 25 models in the CMIP3, run with three future GHG emissions scenarios (A2, B1, and A1B).

WCRP CMIP = World Climate Research Programme Coupled Model Intercomparison Project

Source: (Bias Corrected and Downscaled WRCP CMIP3 Climate Projections [Internet]. Santa Clara University. [Last modified Mar 21, 2010; Accessed Dec 8, 2010]. Available from: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#Aboutaccessed%2012/8/2010)

II.A.4 California Climate Action Team/California Climate Change Center Approach

II.A.4.i Approach Description

On June 1, 2005, Governor Arnold Schwarzenegger issued Executive Order S-3-05 establishing a Climate Action Team (CAT) and GHG emissions targets for California. The executive order charges the CAT with guiding the reporting efforts on meeting the targets and developing biennial reports on potential effects of climate change on California. In response to the executive order, the California Energy Commission and the California Environmental Protection Agency commissioned a series of studies/reports every two years to describe the potential impacts of climate change on key state resources. The regional focus of the impacts report required that issues related to uncertainties in future climate change projections from GCMs be addressed. Notable among these uncertainties was the differences between GCM projections in expected climate changes at regional scales. The scale, scope, and time frame of these studies barred an exhaustive analysis of all available GCM projections. Selection of a limited set of scenarios of possible climate change, targeted regionally to explore California's future climate, was determined to be the most effective way to prepare the biennial assessment reports. The biennial nature of the assessment reports provides the opportunity to build on and improve methodologies and analyses in each successive report.

II.A.4.ii Global Climate Models Used

Since 2005, CAT has issued two biennial assessment reports: one in 2006 and the other in 2009. For each report, the study team, on the basis of several criteria, selected a subset of the available GCM projections for inclusion in the assessment analysis.

In the 2006 study, the selection criteria stipulated that the GCM projections had to be freely coupled, non-flux-correcting formulation, with a horizontal resolution of 250 km (155 miles) or higher. Projections were also required to produce a realistic simulation of specific aspects of California's recent historical climate (particularly the distribution of temperature and the strong seasonal cycle of precipitation that exists in this region); contain realistic large-scale features, such as the spatial structure of precipitation; and include realistic variability at interdecadal and longer timescales during the historical simulations. Other criteria for GCM selection were the availability of climate model output data, the published track record of the modeling group, and model results exhibiting different levels of sensitivity to GHG forcing. All of these criteria yielded two GCMs: (1) Parallel Climate Model (PCM)—National Center for Atmospheric Research (NCAR)—and (2) Geophysical Dynamics Laboratory model version 2.1 (GFDL CM2.1)—National Oceanic and Atmospheric Administration (NOAA). These two models provided a reasonably wide variation in model sensitivity to global and regional temperature to GHG-forcing, with the NCAR PCM exhibiting relatively low sensitivity and GFDL CM2.1 exhibiting relatively high sensitivity (CAT, 2006).

In the 2009 study, GCMs were selected on the basis of providing a set of relevant monthly and, in some cases, daily data. Selected GCMs also had to produce historical simulations with reasonable representations of seasonal precipitation and temperature, the variability of annual precipitation, and El Niño/Southern Oscillation. These criteria yielded six GCMs: (1) PCM-NCAR; (2) GFDL CM2.1-NOAA; (3) Community Climate System Model (CCSM)–NCAR; (4) ECHAM5/MPI-OM—the Max Plank Institute; (5) MIROC 3.2 medium-resolution model—Center for Climate System Research of the University of Tokyo and collaborators; and (6) French Centre National de Recherché Météorologiques (CNRM) models (CAT, 2009). A list of these models and the years of their development is in Table 2–2.

Table 2–2 GCMs used in California Climate Action Team / California Climate Change Center Approach

No.	Model name; modeling group, country	Model identification	Primary reference year
1	Parallel Climate Model; National Center for Atmospheric Research (NCAR), USA	PCM	2000
2	Geophysical Dynamics Laboratory model version 2.1; US Dept. of Commerce / National Oceanic and Atmospheric Administration (NOAA) / Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDL-CM2.1	2006
3	Community Climate System Model; National Center for Atmospheric Research (NCAR), USA	CCSM3	2006
4	Max Planck Institute (MPI) for Meteorology, Germany	ECHAM5/ MPI-OM	2006
5	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	2004
6	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	CNRM-CM3	2005

(CAT, 2009 and Randall et al., 2007)

II.A.4.ii.a Emissions Scenarios

GHG emissions scenarios SRES A2 (medium-high emissions) and B1 (low emissions) were chosen for both studies based upon considerations discussed in the IPCC SRES and availability of outputs from model climate simulations (IPCC, 2000).

II.A.4.ii.b Starting/Initial Climate Conditions

Not discussed/Not Applicable.

II.A.4.ii.c Simulation/Forecast Time Period

The simulation/forecast time period for the 2006 study was from 2005 to 2099, and the historical period used as a climatological baseline was from 1961 to1990. The 2009 study simulated the period from 2000 to 2100 and used a historical period from 1950 to 1999 as the baseline climatological period.

II.A.4.iii Downscaling

The techniques used in each study for downscaling and bias correction differ slightly and are described separately for the respective studies.

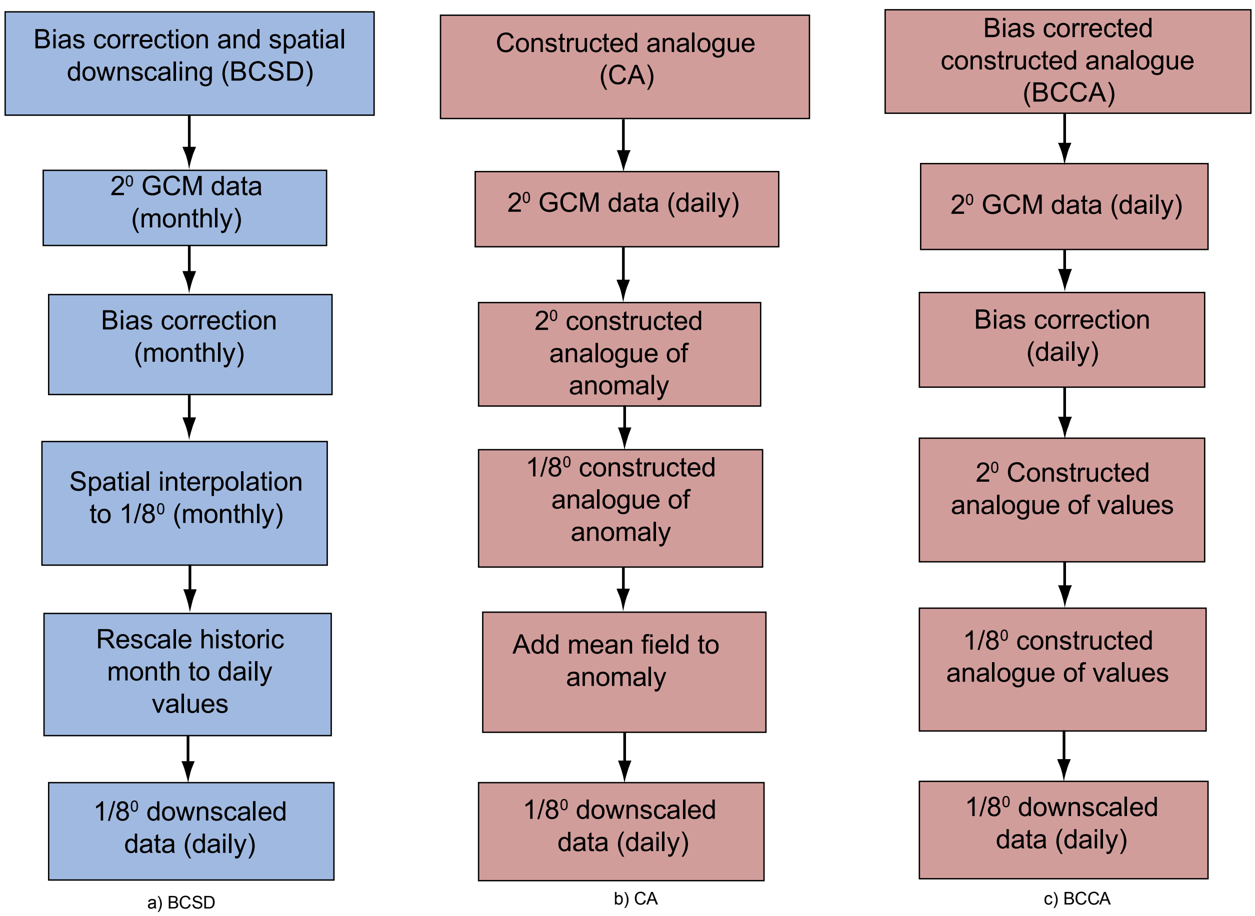
The CAT 2006 assessment report employed a statistical BCSD technique originally developed by Wood et al. (2002) for using global model forecast output for long-range streamflow forecasting. This technique was later adapted to downscale GCM output for use in studies examining the hydrologic impacts of climate change (Hayhoe et al., 2004; Maurer and Duffy, 2005; Payne et al., 2004; VanRheenen et al., 2004).

The BCSD approach first adjusts output from the GCMs to account for tendencies in the model to be too wet, dry, warm, or cool during the historical period (bias correction), and then the adjusted data are converted to regional data (spatial downscaling). Using this technique, the precipitation and temperature probabilities (at a monthly scale) during a simulated historical period (1950–1999) from the GCMs were mapped to the concurrent historical record. The historical observational data set used for this study was the gridded National Climatic Data Center Cooperative Observer station data (Maurer et al., 2002). This data set, developed at a spatial scale of 1/8th degree (about 7 miles = 12 km), was aggregated to a 2-degree latitude/longitude spatial resolution. For precipitation and temperature, cumulative distribution functions (CDFs) were developed for each month, at each of the 2 degree grid cells for both the gridded observations and each of the GCMs (raw GCM data were interpolated onto a common 2 degree grid for this purpose) for the historical period (1961–1990). The quantiles for monthly GCM-simulated precipitation and temperature were then mapped to the same quantiles for the observationally based CDFs. For temperature, the linear trend was removed prior to the bias correction and replaced afterward to avoid increasing sampling at the tails of the CDF as temperatures rose. In this way, the probability distribution of observations were reproduced by the bias-corrected climate model data for the overlapping climatological period, while both the mean and variability of future climate evolved according to GCM projections. The combined BCSD used in this study has been shown to compare favorably to different statistical and dynamic downscaling techniques (Wood et al., 2004) in the context of hydrologic impact studies. To obtain daily values using BCSD, the monthly values obtained are temporally disaggregated by re-sampling the historical data set based on pattern matching and identification of analogous historical months.

The CAT 2009 assessment report employed the same statistical BCSD technique used in the CAT 2006 assessment report, in addition to a direct, large-scale daily statistical downscaling method called constructed analogues (CA) (Hidalgo et al., 2008). The CA approach uses previously observed coarse-scale data and the corresponding fine-scale data to generate a relationship between the observed weather patterns and the daily GCM patterns (analogue) at a coarse scale; this relationship is then translated to a finer scale to produce regional information. The CA method is based on the notion that if one could find an exact analogue (in the historical record) to the weather field today, future weather should evolve similarly to weather conditions following the identified analogue. From a practical standpoint, finding an exact analogue in the historical record is not feasible so the CA method artificially constructs the analogues using linear combinations of past atmospheric patterns. The process involves developing linear regressions with the current weather or climate pattern as the dependent variable and selected historical patterns as independent variables. It is assumed that the same linear combination (using the same regression coefficients) of the future evolutions of each of the historical patterns that contributed to the constructed analogue would describe the evolution of weather or climate into the future (Van den Dool, 1994).

In brief, the CA method downscales daily large-scale data directly, and the BCSD method downscales monthly data, with a re-sampling of historical data to generate daily values. Each method demonstrates differing degrees of skill for producing downscaled results depending on particular variables: seasons, region of interest, or severity of temperature or precipitation event. In the CAT 2009 assessment report, the BCSD approach was applied to the output from of all six GCM simulations under both emission scenarios, resulting in 12 regional–scale climate change data sets. The CA approach was applied to the output from three GCMs—CNRM-CM3, GFDL-CM21, and NCAR-PCM1—under both emission scenarios, resulting in an additional six sets of regional-scale climate change data. Based on analysis conducted in the report, the CA method generally underestimated daily streamflows and did not adequately represent annual inflows to some of the major water supply reservoirs. Streamflow estimates based on CA method were, therefore, not used for further impacts analysis in the CAT 2009 assessment report.

Schematics of the BCSD and CA approaches and a third, very recent approach are shown in Figure 2–2. The new approach, known as the bias corrected constructed analogue technique, combines the strengths of both earlier approaches and is expected to be used widely in the future for downscaling GCM climate data (Maurer, 2009). Using this procedure, the daily GCM data are bias corrected prior to application of the constructed analogue approach.



(Maurer, 2009)

Figure 2–2 Schematics of GCM downscaling methods

II.A.4.iv Output Parameters of Interest

Of the large set of considerations in evaluating the GCM simulations, the CAT 2006 and 2009 studies focused on a few relatively simple model output parameters, mostly related to temperature and precipitation. After analyzing these output parameters for trends and expected levels of regional warming and precipitation change, the output parameters were used to drive a hydrologic model of the region.

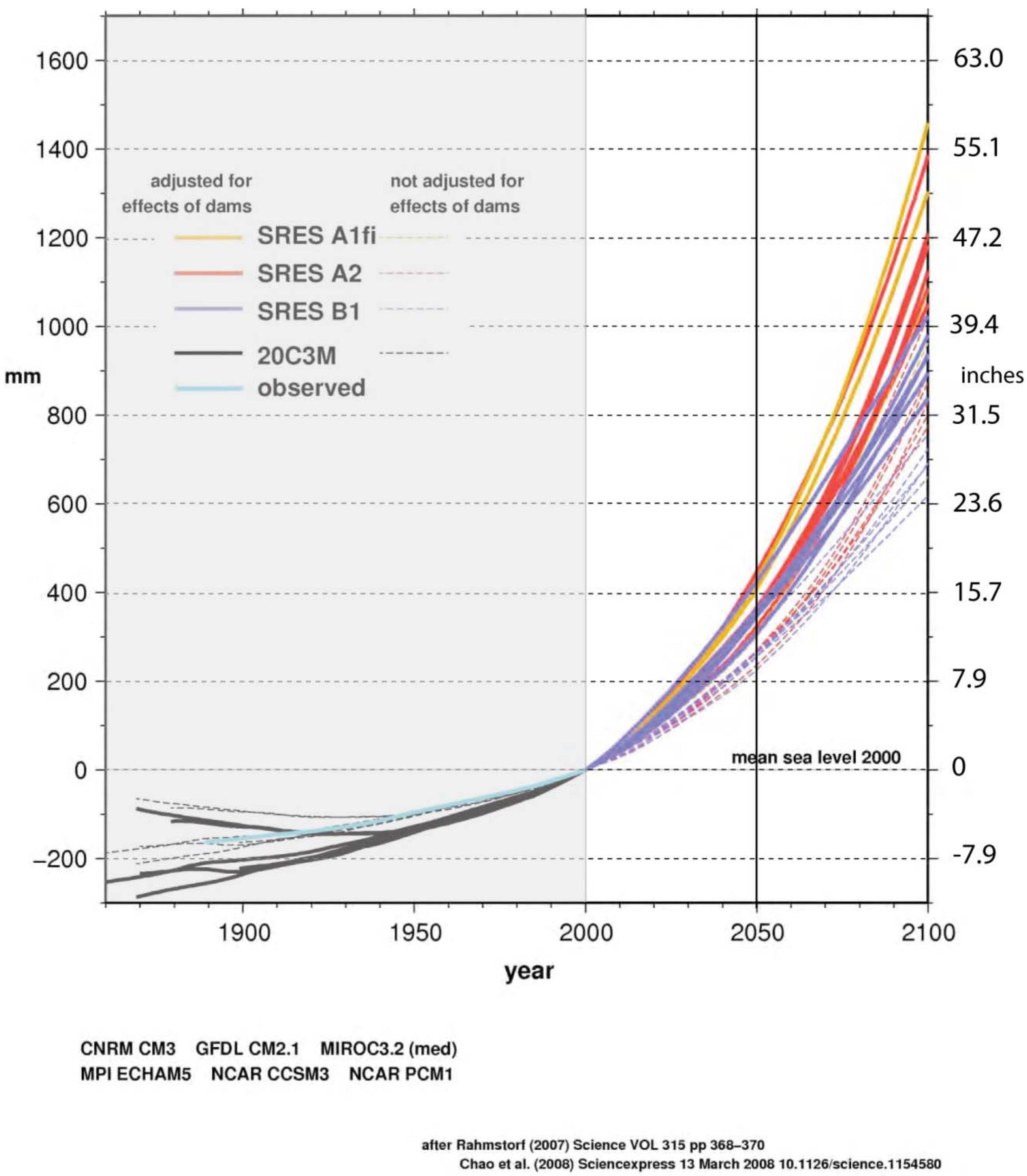
The Variable Infiltration Capacity (VIC) model (Liang et al., 1994; Liang et al., 1996) was used to derive land surface hydrologic variables consistent with the downscaled forcing data. VIC is a macro-scale, distributed, physically based hydrologic model that balances both surface energy and water over a grid mesh. The VIC model has been successfully applied at resolutions consistent with the resolution of downscaled climate data. A “mosaic” land surface scheme allows the VIC model to represent the subgrid scale spatial variability in topography and vegetation/land cover. This is especially important when simulating the hydrologic response in complex terrain and in snow-dominated regions. The VIC model also features a nonlinear mechanism for simulating slow (base flow) runoff response and explicit treatment of vegetation canopy on the surface energy balance. Following the simulation of the water and energy budgets by the VIC model, a second program within VIC is used to route the derived runoff through a defined river system to obtain streamflow at specified points. Outputs from the VIC model provide the necessary input data needed to run operational models of the state’s water system.

II.A.4.v Consideration of Sea Level Rise

The CAT 2006 report uses the relationship between projected global mean temperature change, sea level rise due to thermal expansion, and sea level rise due to ice melt to estimate total sea level rise projections for the study period. The MAGICC model (Hulme et al., 1995) was used to develop the relationship among the three variables.

By mid-century (2035–2064), projected global sea level rise ranges from 6 to 32 centimeters (2.4 to 12.6 inches) relative to 1990, with no discernable differences between A1, A1fi, and B2 scenarios. By end-of-century (2070–2100), however, sea level rise projections relative to 1990 range from 10 to 54 cm (3.9 to 21.3 inches) under lower emissions scenario (B1), 14 to 61 cm (5.5 to 24 inches) under medium-high emission scenario (A2), and 17 to 72 cm (6.7 to 28.3 inches) under higher emissions scenario (A1fi).

For the 2009 assessment report, CAT researchers used a methodology that relates observed global mean sea level rise to global mean surface air temperature (Rahmstorf, 2007). This methodology allows researchers to calculate estimates of global sea level rise using the surface air temperature projected by the GCM simulations. Rahmstorf ‘s method results in sea level rise estimates that are significantly higher than those produced by other recent estimates, including estimates from the IPCC AR4 (Cayan et al., 2008). An important assumption implicit in the CAT’s use of this methodology is that sea level rise along the California coast will mirror estimates of global sea level rise. In addition, CAT projections include a second set of sea level rise estimates that include modifications to account for the increase in the amount of water trapped behind dams and reservoirs during the historical period, which has artificially reduced surface runoff into the oceans (Chao et al., 2008). The estimates using global surface air temperature outputs from the 12 GCMs included in the CAT 2009 assessment indicate that potential sea level rise over the next century will be considerably higher than historical rates of increase (Figure 2–3). By 2050, sea level rise estimates (relative to the 2000 levels) range from 30 to 45 cm (12 to 18 inches) and by 2100, ranges from 82 to 140 cm (32 to 55 inches).



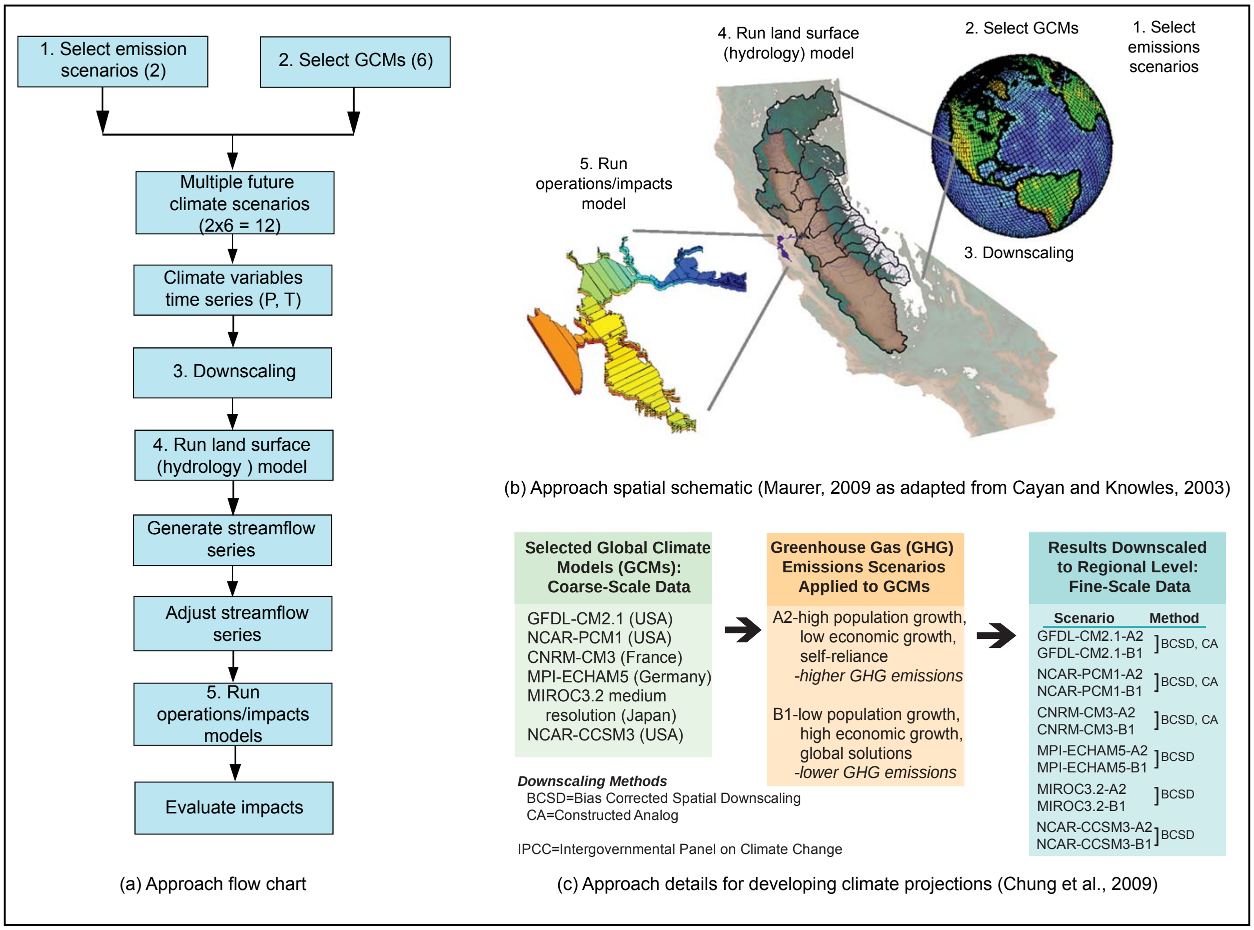
(Cayan et al., 2009)

Figure 2–3 Sea level rise projections based on air temperatures including those from 12 future climate scenarios used by the California Climate Action Team

As observed in the CAT 2006 assessment, different emissions scenarios produce little difference in temperature until about the middle of the 21st century; thereafter, the warming of the A2 scenario becomes increasingly distinct and larger than that of the B1 scenario. As temperatures rise, so do sea level and wave run-up along California beaches. Also, as temperatures rise, there is a substantial increase in the occurrence, magnitude, and duration of extremes including high sea level events.

II.A.4.vi Summary of Approach Strengths and Weaknesses

The CAT 2009 approach is depicted through a set of related figures—a flow chart, a spatial schematic, and an approach detail—in Figure 2–4. The CAT 2006 approach could be illustrated in a similar way.



(Chung et al., 2009)

Figure 2–4 Approach used by the California Climate Action Team/ California Climate Change Center

The CAT 2006 and 2009 approaches selected a subset of available GCM simulations based on a series of criteria related to the skill of GCMs in producing realistic simulations of specific aspects of California's recent historical climate (1950–1999) and model design parameters. The subset of GCMs was then analyzed in more detail. The CAT 2006 assessment used a subset of two GCMs, and the 2009 assessment used a subset of six GCMs. Each assessment focused on two (SRES A2 and B1) of the emissions scenarios described in the IPCC SRES (2000). This choice resulted in 4 and 12 scenarios of future climate change in the CAT 2006 assessment and the CAT 2009 assessment, respectively. The relatively small subsets of scenarios used in these reports allowed greater scrutiny of the GCMs and scenarios, their regional performance, and their outputs. The smaller subsets also allowed results to be reported for each scenario without aggregating or averaging the results of all of the scenario runs. This preserved the variability exhibited in each simulation, including extreme heat or precipitation conditions shown in the model outputs.

A limitation of the above approach is that the range of uncertainty as represented by the selected subset does not necessarily represent the range of uncertainty from the full set of GCM projections. This is apparent in the CAT 2009 assessments in which the 12 selected scenarios happen to be considerably drier than the full projection range of all 112 DOI/LLNL data set projections. The criteria used for selecting the subset of models and scenarios may also be considered a weakness because historical skill may not be reflective of future predictive performance (Pierce et al., 2009; Brekke et al., 2008).

II.A.5 Ensemble-Informed Approaches

II.A.5.i Approach Description

An ensemble-informed approach uses information from a larger array of future climate simulations rather than from a selected small subset of simulations. Simulation results from the full array of GCM simulations are aggregated using various statistical methods to develop a set of ensemble-informed simulations. Subensemble simulations may also be developed to highlight potential conditions represented by simulations that agree on one or more climate parameters, such as precipitation and temperature.

The Bay Delta Conservation Plan (BDCP) has developed an ensemble-informed approach that employs a procedure called quantile mapping, which maps the statistical properties of climate variables from an ensemble of GCM-generated data onto the time series of observed climatological data set. The approach thus allows the use of a shorter period to define the climate state, yet maintains the variability of the longer historical record. The ensemble-informed approach including the quantile mapping procedure, as used in the BDCP, is discussed in detail in Section III.C.2.i. The result of the ensemble-informed approach with quantile mapping procedure is a daily time series of temperature and precipitation that has the range of variability observed in the historical record, but that also contains the shift in climate properties (both mean and expanded variability) found in the downscaled climate projection. The extent of climate shifts may be different for each climate scenario, future period, spatial location, and month; therefore, it is important to consider a broad range of climate futures in order to characterize the projected effects of climate.

II.A.5.ii Summary of Approach Strengths and Weaknesses

The ensemble-informed approach allows analysis of a wider array of climate models and simulations than in other approaches thus incorporating a wider band of uncertainty, without necessarily expanding the complexity and scope of subsequent operational and impacts modeling. Multidecadal variability bias and spatial inconsistencies of individual projections are buffered by aggregating several projections. And the quantile mapping procedure preserves changes in climate variability across the entire probability curve, effectively showing shifts in magnitude or probability of extreme events.

A limitation of this approach is that it collapses the uncertainty of the multiple realizations into one or several representative ensemble-informed scenarios. Very rare extreme events projected by only a few simulations in the ensemble will be masked, reducing the extent of the uncertainty band present in the full range of projections.

II.B Relative Change Approaches

A limited number of studies have used a relative change approach. These approaches, as defined for this report, add or subtract a defined quantity or percentage quantity from the expected level of a parameter of interest to estimate the potential change due to climate change. Relative change approaches can be used for a wide array of resource evaluations. They rely on impact assessment results from other studies that indicate the general direction and order of magnitude of the expected changes due to climate change. For example, impact assessments of flooding in the Central Valley indicate that climate change will increase peak floodflows from levels that have historically occurred. The exact level of increase is unknown, and existing analytical methods are inadequate at simulating the extreme weather events that trigger flooding. Thus, a factor of safety or perturbation can be used to increase historical peak flows to model larger extreme flooding events that could occur in the future. The modified peak floodflow values can then be used in successive analyses to study impacts, flood risk, or design parameters.

II.C Qualitative Approaches

Several past studies have used qualitative approaches to analyze the potential impacts of climate change. Qualitative approaches, like relative change approaches, rely on impact assessment results from other studies that indicate the general direction and order of magnitude of the expected changes due to climate change. The study being conducted qualitatively analyzes and then describes how expected changes in climate, such as temperature, hydrology, precipitation, and humidity, could affect the resources of interest in the study. This approach does not use quantitative numbers to describe impacts, thus bypassing the need to address many of the challenges associated with the uncertainty of quantitative estimates of climate change. However, this approach provides only a generalized assessment of the potential impacts of climate change and may not provide a sufficient level of detail for some types of studies. This approach has been used in project level analyses and analyses that focus on local level impacts. The Los Vaqueros Reservoir Expansion EIR/Environmental Impact Statement (EIS) is one example that is described subsequently in Section III.

II.D Supplemental Approaches

Two supplemental approaches—paleoclimate data and sensitivity analysis—are important to mention here. Although not used as primary analysis approaches in past DWR planning studies, they have been used as important secondary approaches by DWR and its partner agencies.

II.D.1 Paleoclimate Data

Paleoclimate records are created using information from natural climate "proxies," such as tree rings, ice cores, corals, and ocean and lake sediments, that record variations in past climate. These proxies hold climate information that extend back far beyond the available observed climate record. Using sophisticated tools and procedures, paleoclimatologists are able to reconstruct records of temperature, streamflow, drought conditions, terrestrial environment characteristics, and other important historical conditions that incorporate additional climate variability and extremes into the extended data set.

Paleoclimate approaches do not predict or simulate future climate conditions but rather expand the amount of data we have about past climate conditions. For most areas, climatic and hydrologic records gathered from observed measurements extend back 100 or fewer years. Paleoclimate data can add hundreds of years of data, expanding the record significantly to include periods of higher or lower climate variability or continuous incremental change. This increased data set may provide additional insight into the potential variations in climate that can be expected in the future (with or without climate change.)

Paleoclimate approaches can be seen as a secondary (or supporting) climate change analysis for planning. Because they do not provide any prediction of future climate conditions, they cannot be considered a standalone analysis approach. However, paleoclimate data may provide important historical information not contained in the observed record or simulated future conditions.

Although no studies reviewed for this report have used a paleoclimate approach, it is being described here because interest appears to be growing for including these types of analysis in some planning studies. In 2007, the US Bureau of Reclamation (USBR) included extensive paleoclimate data and analysis in its EIS on the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead (Jerla and Prairie, 2009). As additional paleoclimatic flow records are developed for other river basins, it is expected that paleoclimate approaches for analyzing climate change in planning studies will become more widespread.

II.D.2 Sensitivity Analyses

Sensitivity analysis has not been used as a standalone analysis method in any DWR planning study. Instead, it has been used as a supplemental approach, in addition to a more robust analysis, to assess the sensitivity of a watershed to the expected impacts of climate change. Sensitivity analysis in mathematical modeling usually refers to apportioning the uncertainty of model outputs to variations in the input parameters. DWR has used a similar yet different type of sensitivity analysis to evaluate the risk associated with the uncertainty of climate simulations.

As part of the 2009 State Water Project/Central Valley Project (SWP/CVP) Impacts Report (Chung et al., 2009), DWR conducted a sensitivity analysis of temperature on runoff in the Feather River Basin. Future climate simulations differ greatly in direction and magnitude of changes in future precipitation patterns but show relatively high consistency in the direction of future changes in temperature. Therefore, in the 2009 SWP/CVP Impacts Report, DWR explored how temperature changes alone could affect runoff in the Feather River watershed. The analysis involved modeling the effect of temperature increases of 1 °C to 4 °C in 1 °C increments in the watershed without changing any other input parameter. The study yielded important results on the impacts of temperature on runoff in watersheds where some of the precipitation has historically fallen as snow.

II.E Summary of Climate Change Characterization Approaches

A summary of the contemporary approaches to addressing climate change used by DWR and discussed above is furnished in Table 2–3.

Table 2–3 Contemporary approaches to addressing climate change used by the California Department of Water Resources

No.	Approach	Approach summary
1	Scenario	A scenario approach uses outputs from a limited number of GCM simulations to analyze climate change impacts. For water resources planning studies in California, the Climate Action Team's (CAT's) scenario selection has commonly been used to analyze the impacts of climate change.[1]
2	Ensemble-informed	In an ensemble-informed approach, results from an array of GCM simulations are aggregated using various statistical methods to develop a set of ensemble-informed simulations.
3	Relative change	The relative change approach adds or subtracts a defined quantity or percentage quantity from the expected level of a parameter of interest to estimate the potential effects due to climate change. The approach relies on impact assessment results from other studies that indicate the general direction and order of magnitude of the expected effects due to climate change.
4	Qualitative	A qualitative approach relies on impact assessment data from other studies that indicate the general direction and order of magnitude of the expected changes due to climate change. Qualitative analyses describe how expected changes in climate such as temperature, hydrology, precipitation, and humidity could affect the resources of interest in the study.

Table note: In addition to these approaches, DWR and others have used supplementary analysis approaches, such as paleoclimate data and sensitivity analysis to help improve analyses.

- Paleoclimate approaches do not predict or simulate future climate conditions, but rather expand the amount of data about past climate conditions. Paleoclimate records are created using information from natural climate "proxies"—such as tree rings, ice cores, corals, and ocean and lake sediments—that record variations in past climate.
- Sensitivity analysis has not been used as a standalone analysis method by any DWR planning study. Sensitivity analysis in mathematical modeling usually refers to apportioning the uncertainty of model outputs to variations in the input parameters. A similar, yet different, type of sensitivity analysis has been used by DWR to look at the risk associated with the uncertainty of climate simulations. The purpose is to assess the sensitivity of a watershed to the expected impacts of climate change.

[1] Data from the IPCC GCMs (2007) are the current standard reference for worldwide climate change assessment information. The array of simulations for the 25 GCMs included is known as the Coupled Model Intercomparison Project (CMIP3) and provides simulations of 20th through 22nd century climate conditions. The associated 112 downscaled climate projections from 16 of the 25 GCMs are referred to in this report as the DOI/LLNL data set. The CAT used 12 of the 112 downscaled DOI/LLNL climate scenarios for its biennial impact assessment of the state's resources. The BDCP used all of the 112 downscaled DOI/LLNL climate scenarios for its analysis.

Section III Climate Change Analysis in California Water Resources Planning Studies

III.A Types of Planning Studies

The planning studies surveyed for this report are categorized into two types of studies:

- General planning studies, and
- Project-level analyses

General planning studies include any work of research or investigation that describes future conditions but does not propose an individual project or a series of related projects for implementation. Project level analyses are studies conducted for an individual project or a series of related projects that are being proposed for implementation. In many cases, project level analyses will be done for federal feasibility reports or environmental documentation pursuant to the National Environmental Policy Act or the California Environmental Quality Act (CEQA). General planning studies cover a much wider range of analyses than that for project level analyses. The distinction between these two types of analyses is made to acknowledge that significant differences exist between studies that focus on specific projects versus studies that consider more general future conditions or impacts. Both types of studies often involve multiple linked models. However, project level analyses focus on the impacts of a specific project and alternatives. General planning studies tend to stay at a much higher, i.e., coarser, level of analyses that assess general trends and often provide more generalized strategies or a menu of potential strategies for addressing anticipated problems.

Section III.B provides summaries as well as more detailed write-ups of DWR projects (DWR is sole agency responsible for study) reviewed in this report. Section III.C covers projects in which DWR is a participant, and Section III.D discusses other related projects. The summaries provide general background on the project and a brief description of the approach used to analyze climate change. The detailed write-up of each study provides a more comprehensive description of the approach used to analyze climate change. Each of the studies is summarized under the following topics:

a) Purpose and Synopsis of the Study
b) Planning Assumptions and Considerations
c) Climate Change Characterization
   Global Climate Models and Emission Scenarios
   Regional Downscaling
   Sea Level Rise Consideration
d) Streamflow Estimation
   Hydrologic Modeling
   Streamflow Adjustment
e) Planning Study/Model Results

The detailed project summaries below are taken from published, publicly available project documents. In most cases, the planning study title is the name of the document that was used as the primary reference. In cases where additional documents have been used as primary references, a note below the planning study title indicates the primary reference document or documents. Where appropriate, text in the detailed project summaries was taken verbatim from the reference documents.

III.B California Department of Water Resources Projects

III.B.1 General Planning Studies

III.B.1.i Study No. 1: California Water Plan Update 2009 - Bulletin 160

III.B.1.i.a Purpose and Synopsis of the Study

The purpose of the California Water Plan, Bulletin 160, (the Water Plan) is to provide a comprehensive statewide water resources management framework. The Water Plan is the state's strategic plan for developing and managing water resources statewide. Mandated to be completed and updated every five years by the California Water Code (Section 10005 et seq.), it provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future.

The Water Plan contains data and information about current and expected future water supplies and demands for California's water resources. California Water Plan Update 2009, referred to as Update 2009, (DWR, 2009a) includes projections of water resources conditions in 2050 and focuses on an analysis of three plausible future scenarios reflecting differing demographic growth and socioeconomic conditions: continuation of Current Trends, Slow & Strategic Growth, and Expansive Growth. In addition to water use changes driven by population and socioeconomic factors, Update 2009 analyzes how changes in temperature and precipitation patterns driven by climate change could affect water use in California by 2050. Sea level rise and climate change impacts on water supplies were not addressed in Update 2009 but will likely be addressed in future Water Plan updates.

Update 2009 adopted the approach developed for the CAT 2009 to establish climate change scenarios. The 12 climate-change scenarios used for the CAT 2009 were derived from six GCMs and two GHG emission scenarios. Each of the 12 future climate change scenarios was used to provide temperature and precipitation inputs to the Water Evaluation and Planning (WEAP) model to evaluate future water resources conditions. Based on WEAP model results, the range of potential changes in future water uses resulting from climate change were developed and reported.

A flow chart of the approach used in Water Plan Update 2009 is depicted in Figure 3–1. More details of the approach are provided in the subsections that follow.

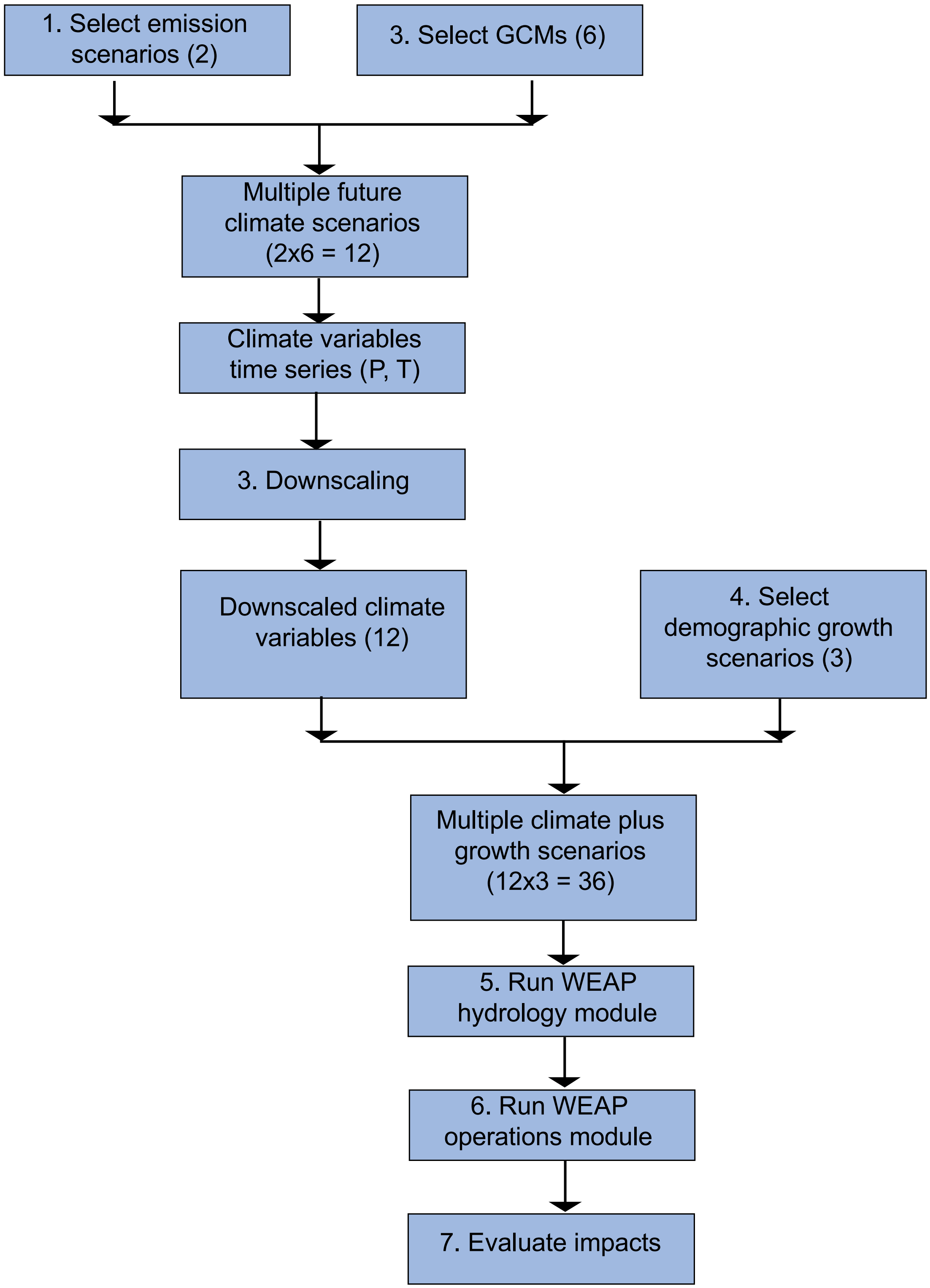


Figure 3–1 Approach used in the California Water Plan Update 2009, Bulletin 160

III.B.1.i.b Planning Assumptions and Considerations

California Water Plan Update 2009 developed three plausible future scenarios for 2050, reflecting differing demographic growth and socioeconomic conditions (DWR, 2009a):

- Current Trends—recent trends are assumed to continue into the future. In 2050, nearly 60 million people live in California. In some areas, where urban development and natural resources restoration have increased, irrigated crop land has decreased.
- Slow & Strategic Growth—less resource-intensive development than current conditions. Population growth is slower than currently projected. In 2050, about 45 million people live in the state. Conversion of agricultural land to urban development has slowed, and conversion occurs mostly for environmental restoration and flood protection.
- Expansive Growth—future conditions are more resource-intensive than current conditions. Population growth is faster than currently projected. In 2050, about 70 million people live in California. Irrigated cropland has decreased significantly where urban development and natural restoration have increased.

The planning horizon for the analysis was 2050, spanning an analysis period of 45 years (2006–2050). The land use and water demands used in the analyses represented a variable level of development that was assumed to change over the time horizon of analysis.

The climate data of interest for planning were temperature, precipitation, wind speed, and relative humidity. The outputs of interest for Update 2009 were agricultural water uses, urban (commercial and residential) outdoor water use, large landscape water use (golf courses), and environmental water use.

III.B.1.i.c Climate Change Characterization

Global Climate Models and Emission Scenarios. To be consistent with the ongoing work of the CAT, the Water Plan Update 2009 team chose to apply a similar approach to quantify the effects of future climate changes. As a result of the related coordination efforts, Update 2009 used the 12 CAT 2009 climate change projections (6 GCMs x 2 emissions scenarios) to provide a representative sample of GCM projections for future California climatic conditions. Each of the demographic growth scenarios selected for Update 2009 was evaluated under a set of monthly time sequences of weather derived from the 12 downscaled GCM simulations plus an additional scenario based on historical conditions projected into the future. The associated climate data include monthly temperature and precipitation on a $1/8^{th}$ degree grid (DWR, 2009a; SEI 2010).

Regional Downscaling. Data used for Water Plan Update 2009 were from the CAT 2009 data and approach.

Sea Level Rise Consideration. No sea level rise consideration was included in the scenario analysis conducted for Update 2009. It is anticipated that future Water Plan updates will evaluate sea level rise considerations that could potentially impact both water supplies and Delta water quality and water levels.

III.B.1.i.d Streamflow Estimation

Hydrologic Modeling. Update 2009 developed two water-planning models within the WEAP modeling framework. The first model, known as the Statewide Hydrologic Region (HR) model, is a low-resolution regional representation of monthly applied water use for each of the 10 hydrologic regions in California. For Update 2009, most of the scenario analysis was performed at this scale (DWR, 2009a; SEI, 2010).

The HR model used the BCSD GCM projections of temperature and precipitation to drive WEAP's built-in hydrology module. The HR model utilized the built-in hydrology module to estimate changes in agricultural and urban outdoor demands for each of the 10 hydrologic regions in California.

For Update 2009, a second higher resolution model called the Planning Area (PA) model was developed. The PA model was organized around DWR's planning areas. This model is a high resolution representation of monthly streamflows; comprehensive water use including agriculture and urban uses, and environmental flows; return flows; and groundwater use and storage for each planning area throughout two specific areas—the Sacramento River and San Joaquin River hydrologic regions. The PA model has been calibrated with historical supply and demand data. This model was not used for future projections of water supply and demand or any kind of scenario analysis in Update 2009 but will be used for scenario analysis in Water Plan Update 2013. The development of the PA model was envisioned as a pilot study to conduct more detailed analyses for the Sacramento River and San Joaquin River hydrologic regions. The higher resolution PA model can use the hydrology module—based on historical observed data or GCM output data—to estimate changes in agricultural and urban outdoor demand and can simulate snow accumulation/melt and runoff processes within each watershed throughout the region.

In relation to climate change, two sets of spatially averaged monthly temperature and precipitation sequences were developed for the HR model. One set corresponds to the urban areas and the other set corresponds to agricultural areas. Using a geographical information system (GIS), each of the 1/8th degree grid points was classified as urban, agricultural, or other land use. Subsequently, this classification was used to develop spatially averaged data by averaging the climate data of each grid cell that corresponded to one of three categories. This was possible because the location of agricultural land-use types within a hydrologic region was found to be consistent in that the majority of cells of any one type generally occurred together or resided within a similar climatic zone.

For the PA model of the Sacramento River and San Joaquin River hydrologic regions, a common but unique climate time series was used for both the urban and agricultural land uses for the 17 PAs that define the Central Valley floor catchments. However, the four planning areas at the higher elevations covering the southern Cascade range and northern and central Sierra Nevada were further disaggregated along watershed boundaries and elevation bands to reflect major reservoir operations and elevation-dependent hydrologic processes.

As a result, elevation bands had to be used to define climate for these banded catchments in the upper elevations. A banded catchment may be defined as the area that is contained within pre-defined elevation ranges (500 m). These catchments may not be contiguous units and so climate sequences from the downscaled 1/8th degree GCM grid data were selected based upon the proximity of grid points to the centroid (or center of mass) of each banded catchment.

Once the weather sequences were developed for the selected climate scenarios, urban and agricultural water demands were calculated based on each of the three future growth patterns. Indoor urban demand was assumed not to be affected by weather conditions and estimated through multiplying projections of the number of water-use entities (e.g., single-family households, multifamily households, commercial employees, industrial employees, and total population) by sector-specific water-use rates. Outdoor urban demand was estimated using the WEAP hydrology module as a function of irrigated landscape area, water-use rate factors, parameters defining soil and landscape characteristics, and monthly time series of weather sequences. Similarly, irrigated agricultural demand was estimated using the WEAP hydrology module as a function of the irrigated area of different crop types, parameters defining soil and land cover characteristics, and monthly time series of weather sequences (DWR, 2009a; SEI, 2010).

In addition to urban and agricultural water demand estimates, unmet environmental water demands were also estimated as surrogates for additional requirements in the future. These unmet demands may be deemed as instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or pending court decisions, but are not yet required by law. These future needs are supplemental to the current base environmental demands.

Streamflow Adjustment. For California Water Plan Update 2009, streamflows were not adjusted to incorporate the expected impacts of climate change on future conditions. WEAP's built-in hydrology module generates streamflow outputs from temperature and precipitation data (as well as watershed properties).

III.B.1.i.e Planning Study/Model Results

The integrated framework available in WEAP can be used both as a hydrologic model and a planning model. For Update 2009, WEAP was used primarily for rainfall-runoff simulation and water use estimation. It was also used to develop and report the range of potential changes in future water uses resulting from climate change.

Without considering climate change, annual combined statewide water demand for applied water showed a decrease of about 2.5 million acre-feet relative to historical average conditions under the Slow & Strategic Growth scenario. However, under the Expansive Growth scenario, estimates indicated an increase in demand of about 6 million acre-feet per year over historical average conditions. The Current Trends scenario fell in between these two with an increase of about 2 million acre-feet per year over historical average conditions. When climate change was factored in, all scenarios showed higher annual water demands than under historical climate. For example, with climate change, the range of annual water demand for the Expansive Growth scenario was from about 6.5 to more than 9 million acre-feet per year, between 0.5 and 3 million acre-feet higher than under historical climate. The results reflect changes in water demand for future climate scenarios that are either warmer or drier, or both warmer and drier.

Climate change appeared to have a smaller impact on future annual urban water demands compared to the effects of future population growth, but could still result in increased annual water demands of up to 750 thousand acre-feet per year. In contrast, climate change could significantly offset the reduction in future agricultural annual water demands. For example, in the Current Trends scenario, statewide annual water demands for agriculture declined by about 5 million acre-feet per year without climate change; with climate change, this decline ranged from 3 to 4.5 million acre-feet per year.

As noted earlier, Update 2009 scenarios use currently unmet environmental objectives as a surrogate to estimate new requirements that may be enacted in the future to protect the environment. The changes in environmental water demand presented in Update 2009 were coarse estimates and not based on detailed hydrologic modeling of future instream flows. Under the three scenarios, the increase in annual water dedicated to environmental purposes could increase between 0.5 and 1.5 million acre-feet per year. Climate change could further increase these amounts by up to 10 percent.

The three baseline growth scenarios for 2050 would play out differently in different hydrologic regions. Hydrologic regions expecting higher population growth under the Current Trends and Expansive Growth scenarios, like South Coast and Sacramento River, showed higher changes in water demands. Population growth also tended to drive urbanization of agricultural lands, reducing irrigated crop acreage. Precipitation and temperature heavily influenced water demand for outdoor landscaping and irrigated agriculture. Less precipitation falling during the growing season increased the need to apply more irrigation water. Warmer temperatures increased crop evapotranspiration, which then increased water demand. The results showed that water demand remained the same or decreased in the San Joaquin River and Tulare Lake hydrologic regions when climate change was not considered because of less irrigated crop area from urbanization and more background water conservation (e.g., due to plumbing code changes, natural placement, actions water users implement on their own). Water demand changes in Central Valley agricultural areas were most sensitive to the warmer and drier climate change scenarios. This was particularly evident in the Sacramento River Hydrologic Region where the variation in potential change in water demand was quite large across the 12 climate change scenarios (DWR, 2009a).

III.B.1.ii Studies No. 2 and 3: 2006/2009 State Water Project/Central Valley Project Impacts Report

III.B.1.ii.a Purpose and Synopsis of the Study

In response to Governor's Executive Order S-3-05[2], DWR published "Progress on Incorporating Climate Change into Management of California's Water Resources" (DWR, 2006a). The 2006 SWP/CVP Impacts Report describes progress made toward incorporating climate change analysis into the tools and methodologies used by DWR for water resources planning and management. The purpose of the 2006 SWP/CVP Impacts Report was to provide a preliminary assessment of climate change impacts on California's main water supply projects, SWP and CVP operations and deliveries, and Delta water quality and water levels.

The 2006 SWP/CVP Impacts Report was updated in 2009 with a follow-up report titled "Using Future Climate Projections to Support Water Resources Decision Making in California" (Chung et al., 2009), and is anticipated to be updated every two years. The 2009 SWP/CVP Impacts Report presents an overview of advances in analyses that DWR has made since the 2006 SWP/CVP Impacts Report toward

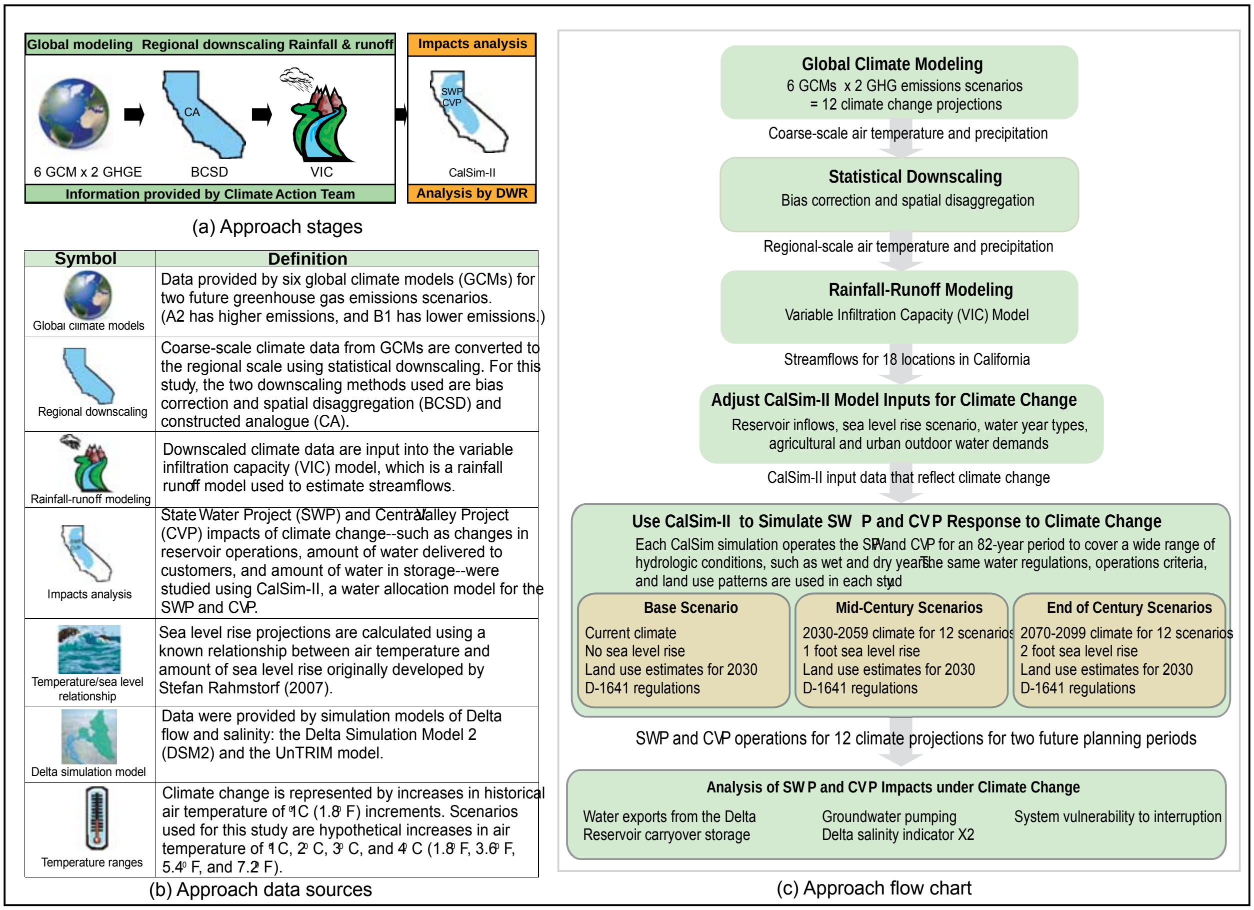
[2] Known as S-3-05: "… the following greenhouse gas emission reduction targets are hereby established for California: by 2010, reduce GHG emissions to 2000 levels; by 2020, reduce GHG emissions to 1990 levels; by 2050, reduce GHG emissions to 80 percent below 1990 levels;…"

using future climate projection information to support decision-making by quantifying possible impacts to water resources for a range of future climate scenarios.

The 2006 SWP/CVP Impacts Report used the CAT 2006 climate characterization approach for conducting its impact study (4 climate projections = 2 GCMs x 2 emissions scenarios). The effects on runoff were analyzed for one climate change future period, the period centering around 2050 (2035–2064). In order to translate the climate change characterizations to stream inflows that can be used as inputs to the CALSIM II operations and planning model (a water resources planning model jointly developed by DWR and USBR to simulate SWP and CVP operations), the 2006 SWP/CVP Impacts Report used the VIC rainfall-runoff model in tandem with a single step perturbation approach for streamflow adjustment (Miller et al., 2001). CALSIM II was used to simulate SWP and CVP operations and evaluate potential impacts on water deliveries due to climate change. The Delta inflows and exports generated by CALSIM II were fed into the Delta Simulation Model (DSM2) to simulate the flows, water levels, and water quality in the Delta. A sea level rise of 1 foot was assumed in the analysis using DSM2, but no sea level rise assumption was incorporated into the statewide analysis.

The 2009 SWP/CVP Impacts Report used the updated CAT 2009 climate analysis approach (12 climate projections = 6 GCMs x 2 emission scenarios) to assess the future reliability of SWP and CVP at mid century and end of century. The effects on runoff were analyzed for two climate change future periods, the first period centered around 2045 (2030–2059) and the second period centered around 2085 (2070–2099). In order to translate the climate change characterizations to stream inflows that can be used as inputs to the CALSIM II model, the 2009 SWP/CVP Impacts Report also used the VIC rainfall-runoff model. But streamflow adjustment was performed with a new three-step procedure (Wang et al., submitted for publication), in contrast to the single step perturbation approach used in the 2006 study. The 2009 SWP/CVP Impacts Report documents several advances over the 2006 impacts study in the use of future climate projection information in water resources planning for California. The resulting improvements in the analysis include improved understanding of how well selected climate models represent historical climate conditions and refined methodologies for representing streamflows, outdoor urban and agricultural water demands, and sea level rise.

The approach used in the 2009 SWP/CVP Impacts Report is depicted through a set of related figures—approach stages, approach data sources, and flow chart—as illustrated in Figure 3–2. Although not included in this report, the approach used in the 2006 SWP/CVP Impacts Report could also be illustrated in a similar way. More details of the approaches used in the 2006 and 2009 studies are provided below.



(Chung et al., 2009)

Figure 3–2 Approach used in 2009 State Water Project/Central Valley Project impact reports

III.B.1.ii.b Planning Assumptions and Considerations

The purpose of the 2006 SWP/CVP Impacts Report was to provide a preliminary assessment of climate change impacts on SWP and CVP operations. To that end, analyses were conducted to evaluate impacts at mid century under a set of monthly time sequences of temperature and precipitation data derived from four downscaled GCM simulations. Each of the four climate projections considered was assumed equally likely (DWR, 2006a). For the 2009 SWP/CVP Impacts Report, analyses were conducted to assess the future reliability of SWP and CVP at both mid century and end of century. The set of monthly time sequences of temperature and precipitation data under which the evaluations were performed was extended to 12 downscaled GCM simulations. Similar to that in the 2006 study, each of the 12 climate projections considered in the 2009 study was also assumed equally likely (Chung et al., 2009).

For both the 2006 and 2009 SWP/CVP Impacts Reports, the analyses did not assume any changes in the way water was conveyed across the Delta. Existing system infrastructure and existing regulatory and management practices including State Water Resources Control Board D1641 regulations (State Water Board, 2000) were assumed to be in place; operations guidelines that are subject to change, such as restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009), were not included.

For the 2006 SWP/CVP Impacts Report, preliminary impacts assessments were conducted for combined climate change and 1-foot sea level rise scenarios. Reservoir operations were changed to reflect shifts in runoff patterns for climate change, but changes in operations to maintain Delta water quality as a result of sea level rise was not accounted for. The analyses conducted for the 2009 study did consider Delta salinity intrusion due to sea level rise along with resulting changes in reservoir operations to maintain Delta water quality.

For the 2006 SWP/CVP Impacts Report, agricultural crop and urban outdoor water demands were not adjusted to reflect changes in future precipitation. Land use and water demands used in the analyses represented a constant 2020 level of development (USBR, 2004), and the level of development was assumed not to change over the time horizon of analysis. For the 2009 SWP/CVP Impacts Report, however, agricultural crop and urban outdoor water demands were adjusted to reflect changes in future precipitation.

For the 2006 SWP/CVP Impacts Report, the hydrologic time series used for the analysis was the 73-year historical record of 1922–1994, adjusted for future climate-induced changes. The planning horizon was the future period 2035–2064, centered around 2050. For the 2009 SWP/CVP Impacts Report, the hydrologic time series was the 82-year historical record of 1922–2003, adjusted for future climate-induced changes. The planning horizons for the analyses were two future periods: 2030–2059, centered around 2045; and 2070–2099, centered around 2085. The two periods covering the middle and the end of the 21st century, were selected for mid-term and long-term climate change impact analysis.

The climate data of interest for planning for both the 2006 and 2009 SWP/CVP Impacts Reports were temperature, precipitation, and relative humidity. Similarly, the outputs of interest from the planning model suite for both studies were streamflow, water uses, water supplies, SWP and CVP deliveries, and Delta water quality conditions.

III.B.1.ii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. For the 2006 SWP/CVP Impacts Report, CAT 2006 climate scenarios were used; for the 2009 SWP/CVP Impacts Report, the CAT 2009 climate scenarios were used.

Regional Downscaling. Data used for the 2006 SWP/CVP Impacts Report were from the CAT 2006 data and approach; data used for the 2009 SWP/CVP Impacts Report, were from the CAT 2009 data and approach.

Sea Level Rise Consideration. For the 2006 SWP/CVP Impacts Report, a sea level rise estimate of 1 foot at mid century was used. For the 2009 SWP/CVP Impacts Report, future sea level rise projections were estimated using a relationship between projected air temperatures and sea level rise (Rahmstorf, 2007). Although there is a wide range of uncertainty in sea level rise projections, sea level rise estimates used were 1 foot at mid century (same as that used in the 2006 SWP/CVP Impacts Report) and 2 feet at end of the century.

III.B.1.ii.d Streamflow Estimation

Hydrologic Modeling. Increases in air temperature and changes in precipitation patterns due to climate change would affect snowpack and runoff, which in turn would affect the timing and amount of flow in the streams that provide California's water supply.

For the 2006 SWP/CVP Impacts Report, estimates of stream inflows to the major SWP and CVP reservoirs under the four GCM projections were obtained based on available analysis from the VIC rainfall-runoff model that utilized GCM temperature and precipitation projections to generate the climate change-induced streamflows. As noted previously, one future period, 2035–2064 (centered around 2050), covering the middle of this century was selected for the climate change impact analysis (DWR, 2006a).

For the 2009 SWP/CVP Impacts Report, downscaled climate data from GCMs were also used as input data for the VIC model (Liang et al., 1994; Cayan et al., 2008) to generate regional estimates for snowpack, snowmelt timing, soil moisture content, and runoff (Maurer, 2007; Maurer and Duffy, 2005). The runoff estimates were then routed through the VIC model to obtain daily and monthly stream inflows to the SWP and CVP reservoirs (Maurer et al., 2007; Cayan et al., 2008). As noted previously, two future periods, 2030–2059 (centered around 2045) and 2070–2099 (centered around 2085), covering the middle and the end of this century were selected for mid-term and long-term climate change impact analysis. For the 2009 study, a three-step method, similar to that used to adjust streamflow estimates as discussed below, was used to adjust precipitation estimates derived from the GCM simulations. Agricultural crop and urban outdoor water demands were adjusted to reflect the resulting changes in precipitation (Chung et al., 2009).

Streamflow Adjustment. Streamflows estimated from downscaled future climate projections were not considered sufficient to use directly in climate change impacts analyses for SWP and CVP operations. However, these projections did offer reasonable estimates of how streamflows might change in the future relative to the past.

For the 2006 SWP/CVP Impacts Report (DWR, 2006a), a perturbation ratio method (Miller et al., 2001) was used to modify the historical sequence of SWP and CVP reservoir inflows to reflect future climate projections. Using estimated stream inflows from the VIC model, monthly average changes in reservoir inflows were determined by comparing predicted stream inflows in tributary basins during a 30-year future period relative to a 30-year historical period (an accepted climatological time-scale). The ratio between future and historical stream inflows is termed a perturbation ratio because it represents how much future conditions changed (were perturbed) relative to historical conditions. First, historical and projected time references were selected—1976 for the 1961–1990 period and 2050 for the 2035–2064 period. Monthly stream inflows were generated by VIC for each of the four climate simulations for both the historical period (1961–1990) and future mid-century period (2035–2064). The monthly perturbation ratios for mid-century projections were then calculated by dividing the mid-century average monthly stream inflows (generated by VIC) by their respective historical period average monthly stream inflows (also generated by VIC). Four new climate change projections of future reservoir inflow were then developed by multiplying the monthly perturbation ratios (for each of the four future climate projections) by the monthly reservoir inflows in the 73-year observed record (1922–1994).

Because the monthly perturbation ratios repeated themselves on an annual basis, the annual hydrology of both base and climate change scenarios maintained the same pattern of wet years and droughts. The significant change in inflows between the base and climate change scenarios was in the seasonal distribution of runoff only. Thus, using the monthly perturbation ratio method to estimate future streamflows did not preserve the climate-induced projected trends in annual streamflows. Because of this limitation in the simplified approach used in the 2006 SWP/CVP Impacts Report, a new three-step flow adjustment method (Wang et al., submitted for publication) was used in the 2009 SWP/CVP Impacts

Report to estimate future reservoir inflows that reflected both seasonal and annual trends from future climate projections.

The first step in the new three-step method used for the 2009 SWP/CVP Impacts Report is identical to the perturbation ratio method used in the 2006 SWP/CVP Impacts Report, as discussed above. First, historical and projected time references were selected for the 2009 SWP/CVP Impacts Report—1976 for the 1961–1990 period, 2045 for the 2030–2059 period, and 2085 for the 2070–2099 period. Monthly stream inflows generated by VIC were averaged around these years. The 1976 average monthly stream inflows were calculated using the 1961–1990 VIC data. The 2045 average monthly stream inflows were calculated using the 2030–2059 VIC data; and the 2085 average monthly stream inflows were calculated using the 2070–2099 VIC data. The perturbation ratios for 2045 were then calculated by dividing the 2045 VIC average monthly stream inflows by their respective 1976 VIC average monthly stream inflows, and the perturbation ratios for 2085 were calculated by dividing the 2085 VIC average monthly stream inflows by their respective 1976 VIC average monthly stream inflows

In the second step used in the 2009 SWP/CVP Impacts Report, the stream inflows simulated by VIC were adjusted to reflect projected seasonal shifts in runoff while preserving historical annual runoff volumes.

In the third step, the stream inflows were further adjusted to reflect projected changes in the annual runoff volume.

Using the above three steps, an 82-year sequence of reservoir inflows (water years 1922–2003) that reflected a wide range of hydrologic variability was developed for each of the 12 future climate projections for both the mid-century and end-of-century analysis periods. Because some water allocation and water quality regulations are based on water year type designations (for example, wet or dry years), these designations were modified as necessary to reflect the future climate projections.

III.B.1.ii.e Planning Study/Model Results

To quantify impacts on the SWP and CVP systems, for both the 2006 and 2009 SWP/CVP Impacts Reports, CALSIM II simulations were used with hydrologic sequences reflecting the different scenarios of climate change.

For the 2006 SWP/CVP Impacts Report, CALSIM II simulations provided estimates of reservoir releases and Delta exports for each climate change scenario. The resulting Delta inflows and exports were fed into DSM2 to simulate the flows, water levels, and water quality in the Delta. A sea level rise of 1 foot was considered in the DSM2 modeling of Delta hydrodynamics and water quality. However, these effects of sea level rise were not integrated into the CALSIM II system operations modeling (DWR, 2006a).

For the 2009 SWP/CVP Impacts Report, new sea level rise Artificial Neural Networks (SLR-ANNs) were developed using data derived from two Delta flow and salinity models, DSM2 and the UnTRIM model (Chung et al., 2009; Gross, 2007). DSM2 was used to generate detailed descriptions of potential Delta flow and salinity conditions for sea level rise scenarios. However, the DSM2 does not fully represent the complex mixing that is important for representing salt movement into the Delta under sea level rise. Consequently, results from modeling studies that do represent those processes were used to improve DSM2's representation. Thus salinity concentrations at the mouth of the Delta near Martinez were based on results from modeling studies by the 3-dimensional UnTRIM model (Gross, 2007). In addition, to increase the amount of salinity intrusion into the Delta, adjustments were made in the DSM2 studies (Chung and Seneviratne, 2009) to match salinity changes from recent Public Policy Institute of California (PPIC) studies using the Water Analysis Module (PPIC, 2008; URS, 2007). After incorporating these necessary modifications for sea level rise conditions, the DSM2 data for Delta flows and salinity were used to develop SLR-ANNs for both 1-foot and 2-foot sea level rise scenarios. The resulting SLR-ANNs were used in CALSIM II to represent sea level rise impacts on Delta salinity. The combination of CALSIM II and an SLR-ANN represented the effects of changes in inflows and exports due to changing air temperature and precipitation patterns and to sea level rise. The 1-foot SLR-ANN was used for the mid-century assessments and the 2-foot SLR-ANN was used for the end-of-the century assessments (Chung et al., 2009).

For the 2006 SWP/CVP Impacts Report, impacts were estimated for Delta exports, reservoir carryover storage, and the frequency of reservoir dead storage. The analysis showed that the reservoir system was at dead storage for a significant number of months under the various climate change scenarios. During these months, streamflow requirements were also not met on the Sacramento and American rivers (DWR, 2006a). For the 2009 SWP/CVP Impacts Report, impacts were estimated for Delta exports, reservoir carryover storage, Sacramento Valley groundwater pumping, power supply, Delta salinity standard (X2), and the frequency and extent of system vulnerability to operational interruption. The analysis showed that for the range of future climate projections, the reliability of the SWP and CVP water supply systems would be reduced. A water shortage worse than the one during the 1977 drought could occur in 1 out of every 6 to 8 years by mid century and 1 out of every 3 to 4 years at the end of the century. The range of impacts presented indicates the need for adaptation measures to improve the reliability of future water supplies in California (Chung et al., 2009).

III.B.1.iii Study No. 4: State Water Project Delivery Reliability Report

III.B.1.iii.a Purpose and Synopsis of the Study

The SWP Delivery Reliability Report is produced every two years as part of a settlement agreement signed in 2003. The latest report (DWR, 2009c) provides updates on current (2009) and future (2029) SWP water supply conditions and delivery reliability.

For the SWP, changes in climate have the potential to simultaneously affect the availability of source water, the ability to convey water, and users' demands for water. To better understand how the future reliability of the SWP may be affected by climate change, Delivery Reliability Report 2009 includes an analysis to assess potential climate change effects to SWP water deliveries in 2029.

The climate change analysis included in Delivery Reliability Report 2009 is based on DWR's 2009 SWP/CVP Impacts Report. Delivery Reliability Report 2009 uses a single climate change scenario from the 12 CAT 2009 scenarios. The scenario is representative of the expected median SWP/CVP effects, based on a set of climatology, hydrology, and related effects metrics. The delivery reliability study also incorporated Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality.

III.B.1.iii.b Planning Assumptions and Considerations

Delivery Reliability Report 2009 does not assume any changes in the way water is or will be conveyed across the Delta. Existing system infrastructure and existing regulatory and management practices including State Water Board D1641 regulations (State Water Board, 2000) were assumed to be in place; operations guidelines that are subject to change, such as restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009), were included. The delivery reliability study noted that these assumptions were not a prediction of the future but an assessment of the future if these factors did not change (DWR, 2009c).

The delivery reliability study also incorporated Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality.

For current (2009) SWP delivery reliability assessment, the hydrologic time series used for the analysis conducted was the 82-year historical record of 1922–2003. The land use and water demands used in the analyses represented a constant 2009 level of development, and the level of development was assumed not to change over the simulation period.

For future SWP delivery reliability assessment, the hydrologic time series used for the analysis conducted was also the 82-year historical record of 1922–2003, but adjusted for future climate induced changes. The planning horizon for the analyses was 20 years (2029). The land use and water demands used in the analyses represented a constant 2029 level of development, and the level of development was assumed not to change over the simulation period. Because 2029 climate change projections are not readily available, an interpolation scheme was used to estimate 2029 SWP deliveries under climate changed conditions. Annual SWP deliveries were interpolated between deliveries from the CALSIM II simulation with the climate change scenario (2050) and deliveries from the CALSIM II simulation which assumes no climate change.

The climate data of interest for planning were temperature, precipitation, and relative humidity. The outputs of interest from the planning model suite were streamflow, water uses, water supplies, SWP and CVP deliveries, and Delta water quality conditions.

III.B.1.iii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. DWR conducted the climate change analysis for the Delivery Reliability Report 2009 to better understand how the future reliability of the SWP and CVP may be affected by climate change. Potential 2029 SWP/CVP deliveries were estimated using a single median future climate projection based on results from the 12 projections used in the 2009 SWP/CVP impacts study (Chung et al., 2009).

To identify the median projection, an analysis was conducted of the 12 mid-century climate projections used in the 2009 SWP/CVP Impacts Report, and their resulting water supply effects. The metrics used for comparison consisted of projected climate and hydrology variables and their effects on SWP/CVP system exports; namely, temperature, precipitation, total inflow to major reservoirs, shifts in timing of run-off, and Delta exports. On the basis of this set of metrics pertaining to climatology, hydrology, and related SWP/CVP effects, the future climate projection from the ECHAM5/MPI-OM GCM run for the higher GHG emissions scenario (SRES A2 emissions scenario) was concluded to be representative of median SWP/CVP effects, and thus was used for the analyses presented in the 2009 delivery reliability study (DWR, 2009c).

Regional Downscaling. Regionally downscaled climate data used in the Delivery Reliability Report 2009 were from the CAT 2009.

Sea Level Rise Consideration. Future sea level rise projections were estimated using a relationship between projected air temperatures and sea level rise (Rahmstorf, 2007). Current sea level estimates and a 1-foot rise in sea level at mid-century were used to interpolate an estimate of sea level rise at 2029.

III.B.1.iii.d Streamflow Estimation

The delivery reliability analysis utilized results from work previously completed by DWR for the 2009 SWP/CVP Impacts Report. The projection of streamflow and reservoir inflows under the future climate change scenario used for the Delivery Reliability Report was developed as part of the 2009 SWP/CVP Impacts Report. A description of how streamflow and reservoir inflows were developed and adjusted for the impacts report can be found in Section III.B.1.ii, "Studies No. 2 and 3: 2006/2009 State Water Project/Central Valley Project Impacts Report."

III.B.1.iii.e Planning Study/Model Results

Estimates of SWP deliveries for Delivery Reliability Report 2009 were based upon operational simulations with DWR's CALSIM II model. The analysis incorporates several new and revised assumptions from the previous report (DWR, 2007a). Because of these changes, it is difficult to directly compare changes in projected reliability of the SWP from 2007 to 2009. Changes in supply projections reflect changes to hydrology driven by climate change as well as other factors including pumping restrictions in the Delta. In general, the analysis performed for the 2009 study, which includes climate change information, indicates that future water supplies are anticipated to be slightly less reliable. Estimates of SWP deliveries show that demand for Article 21 water may triple by 2029 and Table A demands will increase slightly to 100 percent due to increases in population, development, and climate conditions. The analysis also highlights that future SWP delivery reliability will be impacted by two limiting factors. The first is the significant restrictions on SWP and CVP Delta pumping required by the biological opinions issued by USFWS (2008) and NMFS (2009). The second is climate change, which is altering the hydrologic conditions in the state.

III.B.1.iv Study No. 5: Status Report on Preliminary Operations Simulations to Assess the Effects of Water Resources Challenges and Management Responses

III.B.1.iv.a Purpose and Synopsis of the Study

The 2009 Status Report on Preliminary Operations to Assess the Effects of Water Resource Challenges and Management Responses (Management Response Status Report) was completed in response to questions from the Governor's Office and DWR executives regarding the effectiveness of potential water management responses to current water resources challenges facing the State. The Management Response

Status Report was completed as an internal effort to answer these questions, and was included in the California Water Plan Update 2009, Volume 4, Reference Guide (DWR, 2009b). The study provided a preliminary assessment of the future performance of the SWP and CVP systems. It described and quantified the combined effects of increased environmental restrictions on water exports, climate change, and drought on SWP and CVP water deliveries. In addition, it evaluated the potential for three proposed management responses: construction of an alternative Delta conveyance system; construction of a new surface water reservoir at Sites, California; and implementation of an additional 5 million acre-feet of south-of-the-Delta groundwater storage.

The Management Response Status Report described and analyzed five future scenarios in which water management challenges and response options were cumulatively analyzed to provide projections of the general effects of these challenges and responses (referred to as Future 1, Future 2, etc.). Each of the five future scenarios was analyzed under both average conditions and drought conditions. Each of these future scenarios was then analyzed with the added challenge of expected climate change impacts. For each scenario, the Management Response Status Report reported SWP and CVP deliveries (North of Delta, Delta, South of Delta, and total), X2 positions, and number of occurrences of dead storage at major SWP and CVP reservoirs.

Initially, a single GCM simulation (GFDL CM2.1 with the higher emissions SRES A2 scenario) was used to generate temperature and precipitation projections for future conditions with climate change. The Management Response Status Report also incorporated Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality. To illustrate the level of uncertainty in hydrologic changes associated with climate change, a sensitivity analysis was also completed using all 12 GCM simulations selected for the CAT 2009 Impacts Report. This analysis involved quantifying SWP and CVP deliveries for Future 5 (which included isolated Delta conveyance, Sites Reservoir in the north-of-Delta, and 5 million acre-feet of south-of-Delta groundwater storage) with and without climate change.

III.B.1.iv.b Planning Assumptions and Considerations

The Management Response Status Report analyzed five future scenarios in which water management challenges and response options were cumulatively analyzed to provide projections of the general effects of these challenges and responses, including those resulting from climate change. The Management Response Status Report assumed that all other existing system infrastructure and existing regulatory and management practices including State Water Board D1641 regulations (State Water Board, 2000) were in place. Among the five futures, Futures 5 was used for an additional sensitivity analysis under climate change. Futures 2, 3, 4, and 5 included Wanger-type regulation[3] of the Delta (Wanger, 2007; 2008), January 2009 BDCP planning assumptions with an isolated facility and mid-level criteria, Sites Reservoir, and 5 million acre-feet of additional groundwater storage south-of-the-Delta[4] . The analyses also considered Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality (DWR, 2009b).

The operations and hydrologic simulation used in this study were based upon methodology and assumptions associated with the CALSIM II planning, management, and operations model. The hydrologic and streamflow time series used for the analysis was the 82-year historical record of 1922–2003, but adjusted for future climate induced changes. The planning horizon for the analyses was 20 years (2030). The land use and water demands used in the analyses represented a constant 2030 level of development and the level of development was assumed not to change over the simulation period. The time frame for the climate change analyses was 2030–2059, centered around 2045.

The climate data of interest for planning were temperature, precipitation, and relative humidity. The outputs of interest from the planning model suite were streamflow, SWP and CVP deliveries (North of Delta, Delta, South of Delta, and total), X2 position, and number of occurrences of dead storage at major SWP and CVP reservoirs.

III.B.1.iv.c Climate Change Characterization

Global Climate Models and Emission Scenarios. For the Management Response Status Report analysis, a single representative climate change scenario from the 12 CAT 2009 scenarios (GFDL CM2.1 with higher emissions SRES A2 scenario at mid century) was used to generate temperature and precipitation projections for future conditions with climate change. This scenario, characterized by hotter and slightly wetter conditions, was selected because it produced average results for impacts to water deliveries from the Delta (Chung et al., 2009).

To demonstrate the sensitivity of the SWP/CVP system to hydrologic changes associated with climate change, all 12 CAT 2009 climate change scenarios were evaluated for one future scenario (Future 5). The purpose of this additional analysis was to generate a range of potential effects associated with climate change. Future 5 reflected an implementation of new facilities to improve and integrate statewide

[3] Wanger-type regulation narrows the time window of Delta pump operations and places additional restrictions on Delta exports during December through June to provide increased protection to delta smelt and Chinook salmon.
[4] Five million acre-feet was chosen as a conceptual level for the higher end of the range of the potential quantity of groundwater storage that could be developed south-of-the-Delta.

systems, including 5 million acre-feet of additional groundwater storage, construction of Sites Reservoir, and new Delta conveyance.

Regional Downscaling. Data used for the Management Response Status Report analysis were from the CAT 2009 data and approach.

Sea Level Rise Consideration. A 1-foot sea level rise at mid century was assumed for the Management Response Status Report analysis.

III.B.1.iv.d Streamflow Estimation

The Management Response Status Report analysis utilized results from work previously completed by DWR for the 2009 SWP/CVP Impacts Report for projections of streamflows and reservoir inflows under the future climate change scenarios selected for the Management Response Status Report study. A description of how streamflow and reservoir inflows were developed and adjusted for the impacts study is provided in Section III.B.1.ii, “Studies No. 2 and 3: 2006/2009 State Water Project/Central Valley Project Impacts Report.”

III.B.1.iv.e Planning Study/Model Results

The Management Response Status Report showed that under future conditions, even with implementation of water management strategies currently being considered, combined SWP and CVP deliveries would decrease in 11 of 12 climate change scenarios. Average reductions in deliveries ranged from 36,000 acre-feet per year to almost 1.5 million acre-feet per year. The sole climate change scenario that predicted an increase in deliveries showed a modest increase of 86,000 acre-feet per year (1 percent of projected non-climate changed deliveries).

The Management Response Status Report examined the frequency of major water supply reservoirs throughout the state being drawn down to dead storage conditions in the future. Under future conditions (assuming aggressive implementation of water management strategies currently being considered) without considering climate change, the dead storage occurrences over the 82-year simulation period totaled 38. Considering climate change, the number of occurrences of dead storage showed a decrease in 2 scenarios and an increase in 10 scenarios. The average number of occurrences of dead storage for all 12 climate scenarios was 153, representing a fourfold increase over future conditions that did not incorporate climate change.

III.B.1.v Study No. 6: Delta Risk Management Study Phase 1 Report

III.B.1.v.a Purpose and Synopsis of the Study

The Delta is one of the highest risk areas for flooding in the state. Climate change is anticipated to lead to sea level rise, more intense daily precipitation events, shifts in the seasonal timing of streamflows (DWR, 2008), and changes in wind speeds and directions in the Delta. All of these could contribute to increased flood risk and levee failure in the Delta. Flooding from projected climate change has not been studied as thoroughly as potential climate change impacts on water supply; however, many of the anticipated impacts of climate change are likely to further exacerbate flooding risks in California and in the Delta.

As part of the Delta Risk Management Strategy, DWR completed the DRMS Phase 1 study in 2009. The report documents estimated risks to the Delta under existing regulatory and management practices. The risk analysis considered the likely occurrence of earthquakes of varying magnitudes, future rates of subsidence, the likely magnitude and frequency of storms, and the potential effects associated with climate change.

DRMS Phase 1 analysis used several different methodologies to generate simulations of future conditions with anticipated climate change. Streamflow projections entering the Delta were based on results from the CAT 2006 study, although results from a total of 13 different GCMs (IPCC, 2007; Dettinger, 2006) were used for the overall analysis. Sea level rise was estimated using a range of sea level rise projections from Rahmstorf (2006), IPCC Third Assessment Report (2001), and linear extrapolation. Wind speed and direction were estimated using a third approach. The approximations of future conditions based on these multiple methodologies were aggregated to produce quantitative, probabilistic results for the potential risks of levee failure within the Delta.

III.B.1.v.b Planning Assumptions and Considerations

DRMS Phase 1 analysis was conducted to estimate risks to the Delta for planning horizons of 50 years, 100 years, and 200 years. The analyses did not assume any changes in the way water was conveyed across the Delta. Existing system infrastructure and existing regulatory and management practices including State Water Board D1641 regulations (State Water Board, 2000) were assumed to be in place; operations guidelines that are subject to change, such as restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009), were not included. The analyses also considered Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality (URS/JBA, 2008a).

The hydrologic time series used for the analysis conducted was the 82-year historical record of 1922–2003, but adjusted for future climate induced changes. The land use and water demands used in the analyses represented a constant 2030 level of development, and the level of development was assumed not to change over the simulation period. The planning horizon for the analysis to estimate risks to the Delta was 50 years, 100 years, and 200 years.

The climate data of interest for planning were temperature, precipitation, relative humidity, and wind velocity. The outputs of interest from the planning model suite were streamflow, water uses, water supplies, SWP and CVP deliveries, and Delta water quality conditions.

III.B.1.v.c Climate Change Characterization

Global Climate Models and Emission Scenarios. Climate change projections were needed for DRMS Phase 1 analysis for temperature and precipitation, daily streamflow, sea level rise (on timescales down to hourly), and in-Delta wind velocity. The projections of different variables resulting from climate change for DRMS Phase 1 analysis were made on the basis of available simulations and projections. As a result, in some cases for this study, different climate quantities were projected using different models and/or assumptions (URS/JBA, 2008a).

The temperature and precipitation projections were required as inputs to develop future water use projections. Probabilistic projections of statewide temperature and precipitation were developed on the basis of results from 13 different GCMs and 3 different GHG emissions scenarios (SRES A1b, A2, and B1 scenarios) (IPCC, 2000; IPCC, 2007) by methods described in Dettinger (2006). In developing the probabilistic projections, all models—not all simulations—were given equal weight. In all, 84 simulations were analyzed. Based on these 84 simulations, a large number of probabilistic projections sharing key statistical properties were developed using a mathematical “resampling” technique (URS/JBA, 2008a).

In-Delta wind velocities determine wind/wave action, which can be a significant factor in the erosion of levees. In the case of winds, the flows in the Delta region are driven by large-scale pressure gradients, which typically result from strong temperature gradients between the coast and the Central Valley, and are reasonably simulated by GCMs. However, local flows are influenced by small-scale topographic and meteorological features that are not resolved by typical GCMs. As a result, to simulate winds in the Delta, a global/nested model combination was used that had a fine-resolution limited-domain climate model nested within a coarser-resolution GCM. The GCM was used to capture the large-scale driving gradients, and the finer-resolution nested model was used to simulate the smaller-scale features and flows. The combination of the RegCM3 limited-domain climate model nested within the NCAR CCSM GCM was used, although the RegCM3 model significantly overestimated observed wind speeds. The RegCM3 model, however, had much greater success in reproducing observed wind directions. These evaluations were performed on the basis of statistical properties, such as means and standard deviations, of observed winds (URS/JBA, 2008a).

Regional Downscaling. The air temperature and precipitation from the GCM simulations were downscaled to reflect regional climate change projections using BCSD (Wood et al., 2002; Maurer and Duffy, 2005) for use in streamflow estimation. The precipitation and temperature probabilities (at a monthly scale) during a historical period (1950–1999) from the GCMs were mapped to the concurrent historical record. The historical observational data set used for this effort was the gridded National Climatic Data Center Cooperative Observer station data (Maurer et al., 2002) and aggregated up to a 2-degree latitude/longitude spatial resolution. The quantiles for monthly GCM-simulated precipitation and temperature were then mapped to the same quantiles for the observationally based CDF. For temperature, the linear trend was removed prior to the bias correction and replaced afterward, to avoid increasing sampling at the tails of the CDF as temperatures rose. In this way, the probability distribution of observations would be reproduced by the bias-corrected climate model data for the overlapping climatological period, while both the mean and variability of future climate would evolve according to GCM projections (URS/JBA, 2008a).

For spatially interpolating the monthly bias-corrected precipitation and temperature, the method of Wood et al. (2002, 2004) was applied, which for each month interpolated the bias-corrected GCM anomalies, expressed as a ratio (for precipitation) and shift (for temperature) relative to the climatological period at each 2-degree GCM grid cell to the centers of $1/8^{th}$ degree hydrologic model grid cells over California. These factors were then applied to the $1/8^{th}$ degree gridded precipitation and temperature, the resolution of the downscaled data.

Sea Level Rise Consideration. Sea-level projections developed for the DRMS Phase 1 study were based on extrapolation of observed increases during the 20^{th} century, and analyses conducted by Rahmstorf (2006) and IPCC (2001). The estimated ranges of mean sea level rise were from 11 cm to 41 cm for year 2050 and from 20 cm to 140 cm for year 2100. For short-term (hourly/daily) sea-level fluctuations, the results of Cayan et al. (2006b) were adopted. Risk of overtopping and other forms of levee failure are expected to be elevated when short-term increases in sea level combine with long-term sea level rise to produce unusually high water stands. To obtain projections of future sea levels in the Delta, projections of future sea levels at San Francisco—both slow trends and short-term variations—were obtained (Cayan et al., 2006c). While the long-term trends will be the same in the two locations, short-term sea-level variations are generally damped in inland waterways and estuaries, such as the Delta, because of friction and geometrical factors. A digital low-pass filter was developed that preferentially damped the higher-frequency variations and enabled projection of future variations in sea levels in the Delta (Mallard Island), based on projected variations at San Francisco. The filter was applied to the time series of predicted sea levels at San Francisco to generate the time series of predicted sea levels at different locations in the Delta.

III.B.1.v.d Streamflow Estimation

Hydrologic Modeling. Variations in streamflows, as opposed to sea-level variations, are the dominant contributor to short-timescale water-level variations in most areas of the Delta. These variations depend on hourly timescale precipitation, runoff, and streamflow as well as reservoir operations practices.

Although multiple projections of monthly timescale streamflows in California have been published, only one comprehensive set of published daily mean flows on major California streams is available (Cayan et al., 2006c). DRMS Phase 1 analysis required streamflows at an hourly timescale. Hourly streamflows were calculated using the VIC rainfall-runoff model using temperature and precipitation projections for the 21st century obtained from the same four climate scenarios (2 GCM X 2 GHG emissions scenario) used for the CAT 2006 report. The two emission scenarios were the SRES A2 and B1 scenarios. The VIC model required daily mean meteorological input. Daily timescale results of GCMs, however, are not always reliable. Therefore, VIC was driven with daily mean precipitation values estimated from monthly mean GCM results, adjusted on the basis of statistical relationships with observed data. This “temporal downscaling” process assumes that the relationship between monthly precipitation amounts and daily precipitation amounts is fixed as climate changes. In essence, this procedure assumes that the number of rainy days per month will remain fixed under climate change, and that any change in monthly precipitation amounts will come in the form of changes in precipitation amounts on days when significant precipitation occurs (URS/JBA, 2008a).

Streamflow Adjustment. For the DRMS Phase 1 analysis, no streamflow adjustment was undertaken because precipitation and temperature data were directly fed into the VIC model to simulate streamflows.

III.B.1.v.e Planning Study/Model Results

For the DRMS Phase 1 analysis, operation simulations of SWP and CVP were conducted with the DWR CALSIM II model using an extended record of adjusted historical precipitation and adjusted historical runoff under existing regulatory and management practices.

DRMS Phase 1 analysis concludes that under business-as-usual practices, the Delta region as it exists today is unsustainable. If a major earthquake occurs, levees would fail and as many as 20 islands could be flooded simultaneously. Under business-as-usual practices, high water conditions could cause about 140 levee failures in the Delta over the next 100 years. Multiple island failures caused by high water would likely be less severe than failures from a major earthquake, but could still be extensive. Dry-weather levee failures unrelated to earthquakes, such as from slumping or seepage, will continue to occur in the Delta about once every seven years. By the year 2100, Delta levee failure risks due to high water conditions will increase by 800 percent. The risk of levee failure from a major earthquake is projected to increase by 93 percent during the same period (URS/JBA, 2008b).

III.B.2 Project Level Analysis

III.B.2.i Study No. 7: Monterey Plus Final Environmental Impact Report 2010

III.B.2.i.a Purpose and Synopsis of the Study

Monterey Plus is a term used synonymously for “Monterey Amendment to the State Water Project Contracts (Including Kern Water Bank Transfer) and Associated Actions as Part of a Settlement Agreement.” In the final EIR for the Monterey Plus project (published in 2010), DWR analyzed, among other things the potential environmental impacts from modifications to the SWP long-term water supply contracts, according to the Monterey Amendment executed in 1995 and 1996. The final EIR includes analyses of a baseline, a proposed project, four different no project alternatives, and one action alternative.

The draft EIR (published in 2007) describes and presents analysis of the effects of the Monterey Amendment on operation of the SWP, including analyses of Table A deliveries in 2020. Analyses were performed with the CALSIM II model using historical hydrological data for the period 1922–1994. In preparing the draft EIR, a decision was made to not attempt to quantify in the CALSIM II operational modeling of the proposed project or alternatives the expected impacts of climate change on precipitation and temperature. That decision was based on the fact that, although previous modeling scenarios showed that there could be future decreases in Table A allocations in drier scenarios and fewer opportunities for delivery of Article 21 water, the degree to which these effects would be felt in 2020 had not been studied and remained unknown. Instead, a sensitivity analysis of the potential impacts of climate change on SWP deliveries was performed using data from DWR analyses. The results from the sensitivity analysis showed that long-term (2035–2064) average Table A supplies to SWP contractors could decrease up to 10 percent (assuming no changes in existing facilities and operations as a result of climate change). In addition, the draft EIR and final EIR discussed potential climate change impacts, including the effects of sea level rise, in a qualitative manner.

For the final EIR, DWR determined that, in light of the best scientific information currently available, the conclusions of the draft EIR were still valid. The final EIR also concluded that a longer period of analysis would not identify any new impacts or define any increase in the severity of those impacts already analyzed.

III.B.2.i.b Planning Assumptions and Considerations

The Monterey Plus final EIR includes analyses of a baseline, a proposed project, four different no-project alternatives, and one action alternative under existing regulatory and management practices. These analyses did not assume any changes in the way water was conveyed across the Delta. Existing system infrastructure and State Water Board D1641 regulations (State Water Board, 2000) were assumed to be in place; operations guidelines that are subject to change, such as restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009), were not included. The CALSIM II analyses also did not consider Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality, although the draft EIR does cite DWR climate change studies that included the effects of sea level rise on the ability of the SWP to meet Delta water quality standards as one factor in the up to 10 percent decrease in future (2035–2064) SWP Table A allocations. The post-processing routine for CALSIM II output did estimate impacts on SWP Table A deliveries after the 10 percent decrease (PBS&J, 2010a).

The hydrologic time series used for the analysis was the 73-year historical record of 1922–1994. The planning horizon for the analyses was 2020. The land use and water demands used in the analyses represented a constant 2020 level of development, and the level of development was assumed not to change over the simulation period. The climate change analysis considered the effects of declines of long-term (2035–2064) average Table A supplies to SWP contractors.

III.B.2.i.c Climate Change Characterization

Global Climate Models and Emission Scenarios. Project-specific climate change analyses were not conducted for the Monterey Plus final EIR. Climate change was not incorporated into the CALSIM II modeling for the final EIR, and significance findings for the proposed project were not based on scenarios that included climate change effects. The final EIR noted the difficulty of developing climate change methodologies and that DWR, among others, continues to work on developing methodologies for analyzing the effects of climate change.

Although the final EIR did not include the effects of climate change in the baseline, the proposed project, or any of the alternatives, a separate sensitivity analysis of the potential effects of climate change on SWP deliveries was included in the final EIR. The sensitivity analysis was conducted using results from one of the 2006 SWP/CVP Impacts Report scenarios (GFDL CM2.1 with emissions scenario SRES B1). This climate scenario was selected because it showed the largest average annual impact on SWP deliveries relative to the baseline scenario, as reported in the 2006 Impacts Report. Annual differences in SWP allocations under the climate change scenario and those under the baseline scenario for the 2006 Impacts Report were computed. These differences were then applied to the allocations computed for the final EIR Baseline and Proposed Project (PBS&J, 2007; 2010b).

On the basis of the above computations, revised operational time series results were entered into the Monterey Plus final EIR post-processing routine for CALSIM II outputs to calculate SWP deliveries to each SWP contractor for the final EIR baseline and proposed project, based on applicable allocation rules.

Regional Downscaling. Not applicable.

Sea Level Rise Consideration. Not considered.

III.B.2.i.d Streamflow Estimation

Hydrologic Modeling. Not applicable.

Streamflow Adjustment. Not applicable.

III.B.2.i.e Planning Study/Model Results

Estimates of SWP deliveries for the Monterey Plus final EIR were based upon operation simulations with DWR's CALSIM II model using historical hydrological data for the period 1922–1994. Because the Monterey Plus final EIR alternatives included differing SWP allocation procedures that were not modeled explicitly in the CALSIM II model, a post-processing routine was used to calculate the SWP deliveries to individual SWP contractor under each alternative.

On the basis of the analyses performed, the final EIR concluded that the differences between the baseline and the proposed project were negligible with respect to climate change, indicating that the Table A transfers and altered water allocation procedures as incorporated in the Monterey Amendment would have no effect on the SWP's vulnerability to climate change. The final EIR also concluded that "overall, given current SWP facilities, SWP water supplies will become less reliable under the trends that have been identified with climate change with or without the Monterey Amendment."

III.B.2.ii Study No. 8: Salton Sea Ecosystem Restoration Program

III.B.2.ii.a Purpose and Synopsis of the Study

The programmatic EIR for the Salton Sea Ecosystem Restoration Program (SSERP) was prepared in 2006 and finalized in 2007. The PEIR involved the development and evaluation of restoration alternatives for stabilizing water levels and salinity for a portion of the Salton Sea (DWR, 2007b).

The Salton Sea is almost solely dependent on agricultural return flows for its water supply and has no outlet other than evaporation. Thus in order to analyze future conditions, both agricultural return flows and evaporation had to be simulated. Two sets of no action alternatives were developed based on two different assumptions. The "No Action Alternative-CEQA Conditions" was governed by CEQA guidance that limited consideration to those projects and actions which might be reasonably expected to occur in the foreseeable future. However, due to the duration of the program, 72 years, the significant uncertainty regarding future water management within the drainage area, and the effects of climate change on the evaporation of the Salton Sea, an alternative future termed the "No Action Alternative-Variability Conditions" was also developed to represent a range of estimates of future hydrology. The "No Action Alternative-Variability Conditions" was based on an uncertainty analysis in which the range of factors affecting inflow and evaporation, including potential climate change effects, was considered. Due to the lack of water rights and flow guarantees to the Salton Sea, as well for the purposes of comparison, this more conservative inflow and evaporation scenario was used in developing the eight restoration alternatives considered for the PEIR. Thus in this case, climate change effects were incorporated directly into the development of the alternatives.

To approximate the range of possible future inflows to the Salton Sea and characterize quantitatively the associated uncertainty and variability over the 72-year planning horizon, a Monte Carlo-type uncertainty analysis was used. The approach utilized 1,000 random samplings of the return flows to generate 1,000 different 72-year traces of potential future conditions. The cumulative effect of all future inflow possibilities was evaluated through simultaneous sampling of all uncertainty probability distributions in the Monte Carlo simulation. In order to address the potential effects of climate change on evaporation (the other component of the Salton Sea water balance), a Monte Carlo uncertainty analysis similar to that for inflow was used. Uncertainty was incorporated by correlating changes in water surface evaporation to changes in forecasted temperature, and climate change effects on the sea were estimated through the use of the same four GCM climate projections used for the CAT 2006 report. The resulting mean of all traces sampled in the Monte Carlo simulation (considering possible future climate effects) showed considerable increase in evaporation by 2035 and even more by 2078, as compared to that for the "No Action Alternative-CEQA Conditions."

III.B.2.ii.b Planning Assumptions and Considerations

As with most terminal lakes, the Salton Sea is highly sensitive to changes in inflows and climate conditions. The Salton Sea is constantly adjusting to the external forces of inflows, evaporation, and precipitation. However, the hydrologic regime is not in static equilibrium; and this dynamic condition causes continual changes in water volume, surface area, and elevation. The numerous factors that affect the volume of water used within the basin and the volumes of incidental drainage that would be discharged to the Salton Sea create a considerable level of uncertainty in projecting future inflows. Water quality and biological resources at the Salton Sea are sensitive to changes in inflows and salt loads; therefore, it was imperative to consider a range of possible future conditions such that decisions regarding the future restoration of the Salton Sea and placement of major infrastructure elements accommodate uncertainty.

As a result, uncertainty in predicting changes in inflows to and evaporation from the Salton Sea over the 72-year analysis period was a major consideration in simulating the future conditions of the sea. The "No Action Alternative-CEQA Conditions" was governed by CEQA guidance that limited consideration to those projects and actions which might be reasonably expected to occur in the foreseeable future if the restoration project was not implemented. Thus the "No Action Alternative-CEQA Conditions" reflected existing conditions plus changes that were reasonably expected to occur in the foreseeable future in the absence of the restoration project. However, the "No Action Alternative-CEQA Conditions" might not accurately reflect future conditions driven by climate change or changes in water use upstream over the 72-year analysis period. Recognizing the significant uncertainty regarding future water management within the drainage area and effects of climate change on the inflow into and evaporation from the Salton Sea, an alternative future, termed the "No Action Alternative-Variability Conditions," was developed to represent a range of estimates of potential future hydrology that might occur over the next 72 years (DWR, 2006b).

The hydrologic analyses conducted for Salton Sea PEIR was over a 72-year planning horizon from 2005 to 2078. The historical period used in the analysis was calendar year 1950-2002. This period was selected because it represented the period of time in which most of the existing water infrastructure was in place, for which a reasonably complete data set could be developed, and which contained a varied hydrologic period.

The climate data of interest for planning was temperature. The outputs of interests from the planning model were water surface elevation, salinity, and Salton Sea surface area.

III.B.2.ii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. The uncertainties in future inflow estimates represented both the effects of climate change and future water management considerations. No GCM simulation results were used for the inflow estimates. Rather, a Monte Carlo approach was used to approximate the range of possible future inflows to the Salton Sea characterizing the uncertainty and variability over the 72-year planning horizon. The approach utilized 1,000 random samplings of the input distributions to generate 1,000 different 72-year simulations of possible future climate conditions. The cumulative effect of all future inflow possibilities was evaluated through simultaneous sampling of all uncertainty probability distributions in the Monte Carlo simulation. The result was a time line of the system response to a range of future conditions. No specific trace was considered a prediction of future conditions, but the suite of model results and associated range of future outcomes were used for the planning analysis conducted for the PEIR.

Because evaporation rates are sensitive to small changes in meteorological conditions, which are influenced by long-term climate trends, the potential effects of climate change on the future Salton Sea evaporation (the single largest component in the water budget equation) were addressed by using a Monte Carlo approach, applied in conjunction with selected GCM simulation results. Uncertainty was incorporated by correlating changes in water surface evaporation to changes in forecasted temperature projections from four GCMs (CAT, 2006).

Regional Downscaling. Not applicable.

Sea Level Rise Consideration. Not applicable.

III.B.2.ii.d Streamflow Estimation

Hydrologic Modeling. Projections of total inflow to the sea were disaggregated for individual streams/drains, and the average annual flows for individual streams/drains were downscaled to monthly values. Spatial disaggregation was performed based on historical percentages of individual flow component contribution to the total flow for each major source area. The spatially disaggregated annual inflow data, by individual source, was downscaled into a monthly time series based on a review of historical monthly flow patterns and groups of percentile allocation. The annual flows were multiplied by the appropriate percentage for each month to develop a monthly time series for use in hydrologic modeling. The evapotranspiration pattern was developed from measured evapotranspiration at Brawley, CA (approximately 20 miles south of the southern end of the Salton Sea). The associated pattern reflected the long period of summer heating that is present in the watershed. This pattern was used for both evaporation and evapotranspiration in the hydrologic modeling analyses.

The Salton Sea Analysis (SALSA) model was used to simulate the conditions of the Salton Sea for each of the possible Monte Carlo input simulations of future inflows and evaporation rates. The SALSA model incorporated approximations of key components included in the PEIR alternatives: open water storage elements, habitat wetlands, air quality management areas, and natural and mechanical treatment systems. Monthly input data and simulation time steps were used.

For the Monte Carlo analyses of future inflows and evaporation rates, selected results such as water surface elevation, salinity, and sea surface area were retained from each simulation and descriptive statistics were generated for end of year values based on the results of all simulations. The generated result was a time line of the system response under a range of future conditions (DWR 2006b).

Streamflow Adjustment. Not applicable.

III.B.2.ii.e Planning Study/Model Results

Incorporation of potential climate changes into the simulation of future water balances for the sea provided important information about potential future conditions. The mean of all inflow simulations in the Monte Carlo analysis was about 795,000 acre-feet per year for the 2005 to 2078 period and about 717,000 acre-feet per year for the 2018 to 2078 period. The range of inflows to the Salton Sea when considering future uncertainty enabled a relative assessment of the risk associated with various assumptions of future water availability.

Calculations of evaporation from the sea were also extremely important and highlighted the potential impact of climate change on water volume in the sea. Climate simulations showed a considerable increase in evaporation by 2035 and even more by 2078, as compared to that for the “No Action Alternative-CEQA Conditions.” The mean of all climate simulations in the Monte Carlo analysis showed evaporation would increase by about 3.3 percent by 2035 and 7.7 percent by 2078. Using the 2078 mean annual evaporation rate, an additional 100,000 acre-feet per year would be lost from the sea (DWR, 2006b).

III.B.2.iii Study No. 9: Oroville Facilities Relicensing

III.B.2.iii.a Purpose and Synopsis of the Study

The Oroville Dam and associated facilities (Oroville Facilities) are operated in compliance with a license issued by Federal Energy Regulatory Commission. The original license for the Oroville Facilities, issued on February 11, 1957, expired on January 31, 2007. DWR is seeking a new federal license from the commission to continue generating hydroelectric power from two pumping-generating plants and one power plant in Oroville Facilities.

An EIR has been developed for the relicensing project to evaluate and disclose the potential impacts of the project and alternatives. As part of the analysis completed for the Oroville relicensing project, DWR completed a qualitative analysis of the potential impact of climate change on inflows to the reservoir and releases from the reservoir.

III.B.2.iii.b Planning Assumptions and Considerations

Not applicable.

III.B.2.iii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. Not applicable.

Regional Downscaling. Not applicable.

Sea Level Rise. Not applicable.

III.B.2.iii.d Streamflow Estimation

Hydrologic Modeling. Not applicable.

Streamflow Adjustment. Not applicable.

III.B.2.iii.e Planning Study/Model Results

Analyses conducted for the Oroville relicensing project EIR showed that climate change assumptions had little or no consequence on the environmental effects of alternatives, including the no-project alternative. None of the project alternatives, including the no-project alternative, appeared to alter the net amount of water released from the Oroville Facilities over the baseline conditions. Furthermore, the range of annual reservoir drawdown was nearly identical for all alternatives. Therefore, it was concluded that the effects of climate change on future project operations would be essentially the same under each alternative.

III.C Projects on Which California Department of Water Resources is a Participant

III.C.1 General Planning Studies

No projects to report.

III.C.2 Project Level Analysis

III.C.2.i Study No. 10: Bay-Delta Conservation Plan and Delta Habitat Conservation and Conveyance Program Operations and Planning

The following discussion pertaining to climate change analysis conducted for BDCP is based on "Draft Bay-Delta Conservation Plan–Methodology for Incorporating Climate Change" (CH2M Hill, 2010).

III.C.2.i.a Purpose and Synopsis of the Study

The BDCP is being developed to promote the recovery of endangered, threatened and sensitive fish and wildlife species, and their habitats in the Delta in a way that will also protect and restore water supplies. The Delta Habitat Conservation and Conveyance Program (DHCCP) is a partnership between DWR and USBR to evaluate the ecosystem restoration and water conveyance alternatives identified by the BDCP along with other conveyance alternatives. Analysis of the effects and impacts of the BDCP will be performed at three time lines: 2015, 2025, and 2060. These evaluations will culminate in the completion of a joint EIR/EIS.

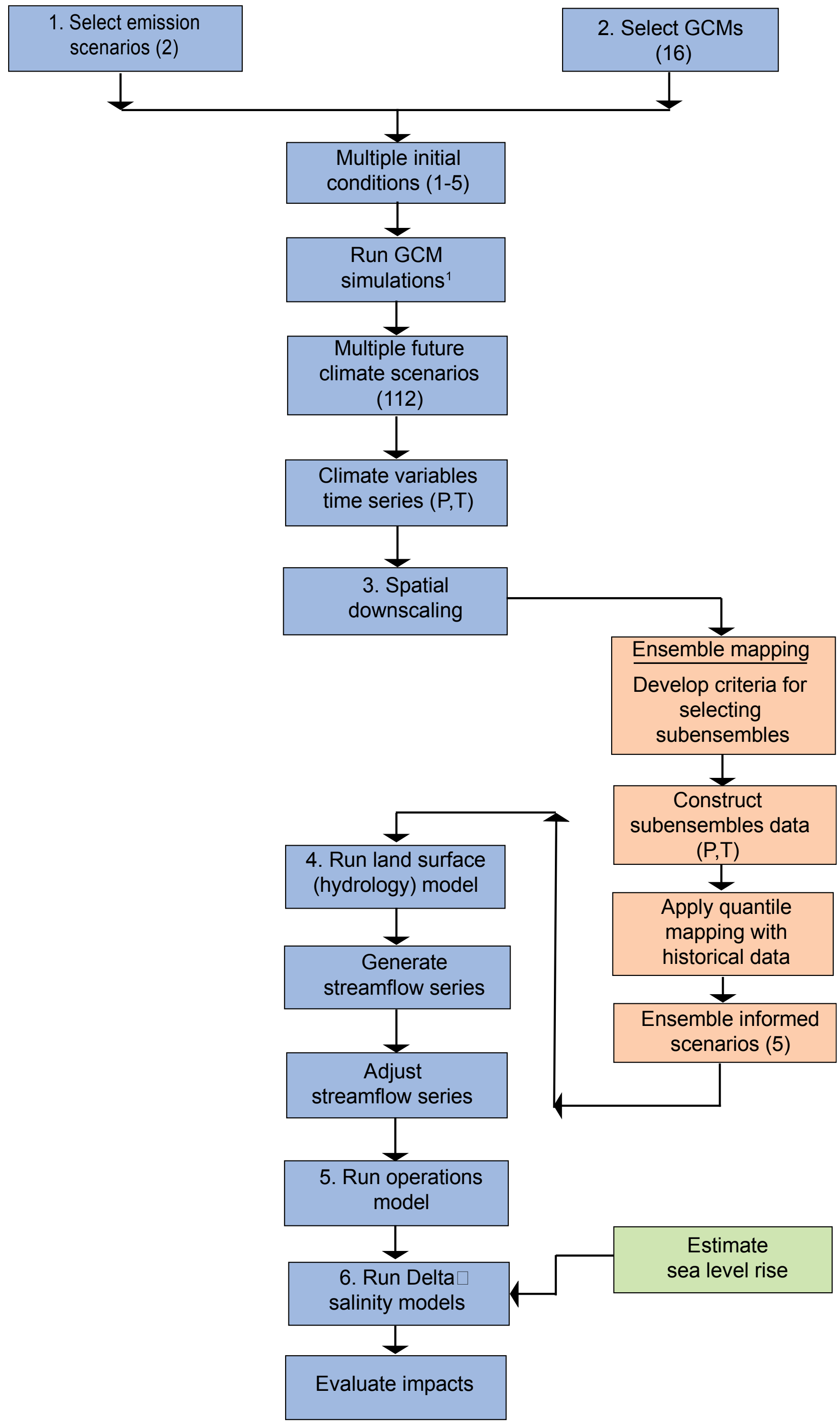
The approach used in the selection of climate scenarios for BDCP analysis consisted of choosing five ensemble-informed climate scenarios for each future time line (2025 and 2060). The recommended approach made use of all 112 available BCSD downscaled DOI/LLNL data set GCM projections. The five ensemble-informed climate scenarios were created by plotting normalized average change in temperature and precipitation (from historical conditions) for each GCM projection at each downscaled grid cell. A central tendency scenario was developed by aggregating all projections falling within the inner quartiles (25^{th} to 75^{th} percentile) of the ensemble. Four additional scenarios were developed to represent future conditions that are (1) drier with less warming, (2) drier with more warming, (3) wetter with more warming, and (4) wetter with less warming than the ensemble median. These additional scenarios were developed by aggregating the 10 projections closest to the 90^{th} /10^{th} percentile anchor points.

The five ensemble-informed climate scenarios were used to create modified temperature and precipitation inputs for the VIC rainfall-runoff model for generating reservoir inflow time series for the CALSIM II operations model. The CALSIM II model, in turn, provides monthly inflows to the Delta, as well as the Delta exports, for input to the DSM2, a hydrodynamic model.

DSM2 simulations will be developed for each habitat condition and sea level rise scenario that is coincident with the BDCP time line. Estimates of projected sea level rise for BDCP are based on work conducted by Rahmstorf (2007). For the early long-term time line (2025), Rahmstorf projects approximately 5 to 7 inches of sea level rise; BDCP is using 6 inches for analysis purposes. At the late long-term time line (2060), the projected sea level rise is estimated to be approximately 12 to 24 inches; BDCP is using 18 inches. In addition, sensitivity scenarios will be evaluated considering sea level rise of up to 24 inches by 2060. Additional sensitivity simulations using the 3-D UNTRIM model will be performed for sea level rise scenarios of 36 inches and 55 inches.

Based on the selected sea level rise estimates and DSM2 results, new ANNs will be developed based on the flow-salinity response simulated by DSM2. These sea level rise-habitat ANNs will be verified and subsequently included in the CALSIM II model. The CALSIM II model will then be simulated with each of the five climate change-induced hydrologic conditions in addition to the historical hydrologic conditions.

The approach used in the BDCP is summarized in the flow chart shown in Figure 3–3. More details of the approach used are provided below.



[1] Several GCMs were run multiple times with the same emissions s cenario but different initial clim ate conditions. Many of the model and emission s cenario combinations were run with as ma ny as five dif erent initial conditions.

Figure 3–3 Approach used in Bay-Delta Conservation Plan and DHCCP operations and planning

III.C.2.i.b Planning Assumptions and Considerations

The BDCP, if approved, would be implemented in phases over the next 50 years. To model the phased implementation of the project, analysis for BDCP was performed at three time lines—2015, 2025, and 2060. A set of monthly time sequences of temperature and precipitation data derived from downscaled GCM simulations has been developed for each of the time lines. Existing and recent regulatory and management practices including State Water Board D1641 regulations (State Water Board, 2000) are assumed to be in place; restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009) are included. Various combinations of an isolated facility, Fremont Weir modifications, and Delta habitat restoration are included. The analysis also considers Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality. Because additional conveyance facilities proposed as part of the BDCP would fundamentally change the way water is moved through and around the Delta, current regulatory and environmental restrictions on Delta operations could undergo significant changes. The BDCP has proposed new environmental restrictions based on the plan elements.

The hydrologic time series used for the BDCP analysis is the 82-year historical record of 1922-2003, adjusted for future climate induced changes. The planning horizons for the analyses are 2015, 2025, and 2065. Runoff patterns in the studies simulating 2015, 2025, and 2060 scenarios for the 82-year record are adjusted to reflect the current and future levels of development in the source areas by analyzing land use patterns and projecting future land and water use. Climate change scenarios and sea level rise estimates are included in the two long-term analysis time lines (2025 and 2060).

The climate data of interest for planning are temperature, precipitation, and relative humidity. The outputs of interest from the planning model suite are streamflow, water uses, water supplies, SWP and CVP deliveries, and Delta water quality conditions. Reservoir, river, and Delta water quality models have incorporated the effects of climate change through changes in input meteorology for projected warming at 2025 and 2060.

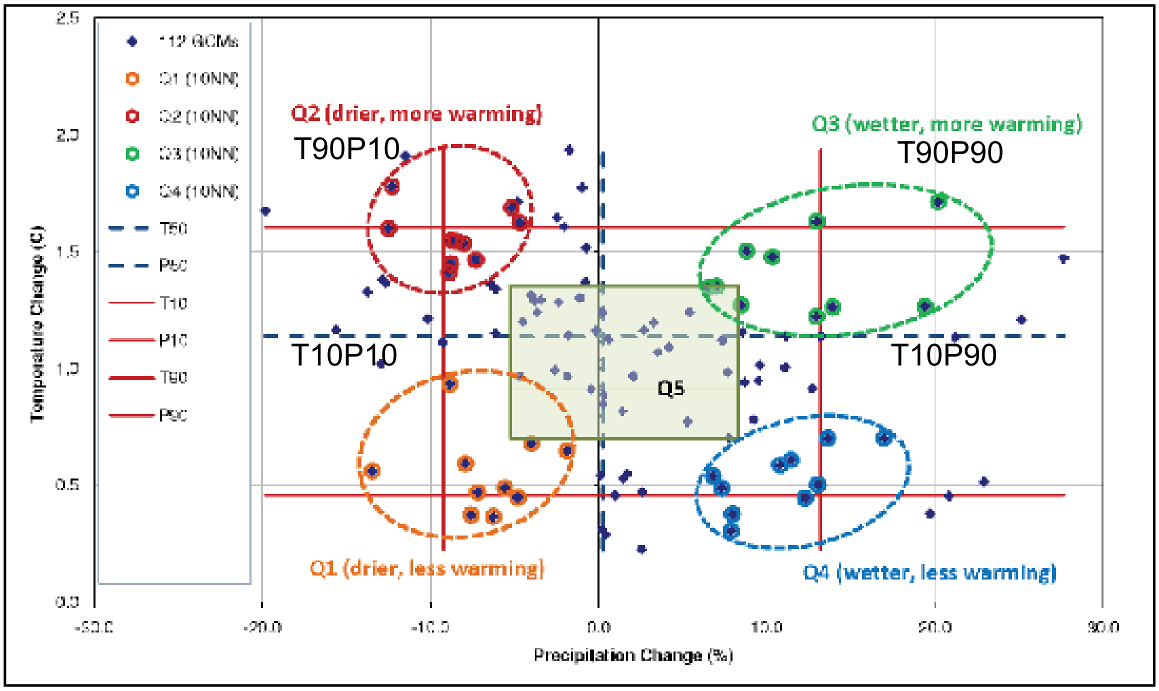
III.C.2.i.c Climate Change Characterization

Global Climate Models and Emission Scenarios. Because BDCP and DHCCP process operates under a cooperative framework, the related environmental processes entail a coordinated effort for incorporating and analyzing the effects of future climate change. To that end, a technical subgroup comprising key staff at DWR, USBR, US Fish and Wildlife Service, and National Marine Fisheries Service was formed to review the technical merits of potential approaches for incorporating climate change into the BDCP analytical processes. The technical subgroup recommended the following criteria to guide the selection of climate scenario:

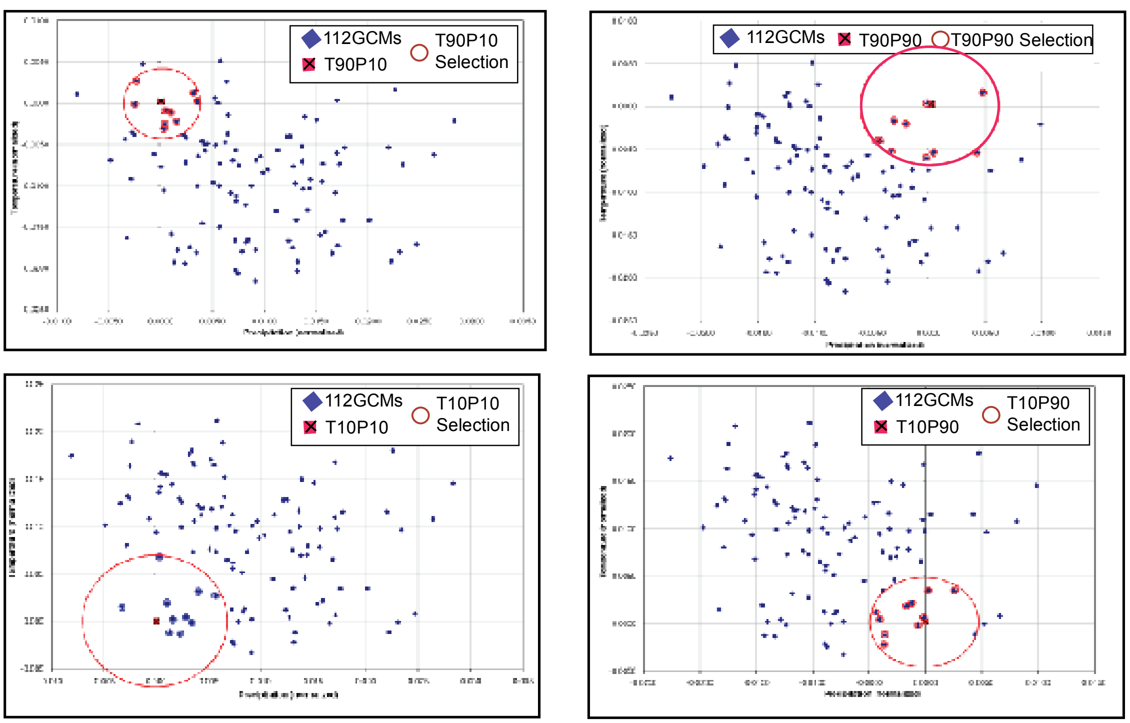
1) Select a limited range of scenarios broad enough to reflect the uncertainty with GCM projections and emission scenarios but limited enough to facilitate quantitative analysis of potential projects and alternatives;
2) Select scenarios that reduce the "noise" inherent with any particular GCM projection due to multidecadal variability that often does not preserve relative rank for different locations and time periods;
3) Select an approach that incorporates both the mean climate change trend and changes in variability; and
4) Select time periods that are consistent with the major phases used in the BDCP planning.

The approach used in the selection of climate scenario for BDCP analysis consisted of choosing five ensemble-informed climate scenarios for each future analysis period (2025 and 2060). The recommended approach made use of all 112 available downscaled DOI/LLNL data set GCM projections to characterize the range of future climate possibilities (CH2M Hill, 2010).

Five climate scenarios for each future analysis period (2025 and 2060) were developed. The five climate scenarios were created by developing ensembles of GCM projections that predicted similar future conditions. The members of the ensemble were then combined to generate an ensemble projection or scenario. The procedure involved plotting normalized average change in temperature and precipitation (from historical conditions) for each GCM projection at each downscaled grid cell ($1/8^{th}$ degree resolution). A central tendency scenario was developed by aggregating all projections falling within the inner quartiles, 25th to 75th percentile. Four additional scenarios were developed to represent future conditions that were (1) drier with less warming, (2) drier with more warming, (3) wetter with more warming, and (4) wetter with less warming than the ensemble median. These ensembles were developed by aggregating the 10 projections closest to the 90^{th} /10^{th} percentile anchor points. An automated process was used to identify the members of the subensembles for each scenario and to generate the five scenario projections for every $1/8^{th}$ degree grid cell. The ensemble mapping technique as used in the BDCP is illustrated in Figure 3–4.



(a) Scenario identification through relationship between changes in mean annual temperature and precipitation (Feather River Basin)



(b) 10 nearest neighbor GCM data mapping in normalized spaces: Feather River (63, 28)

Note: (b) charts: y-axis Temperature (normalized), x-axis Precipitation (normalized)

(CH2M Hill, 2010)

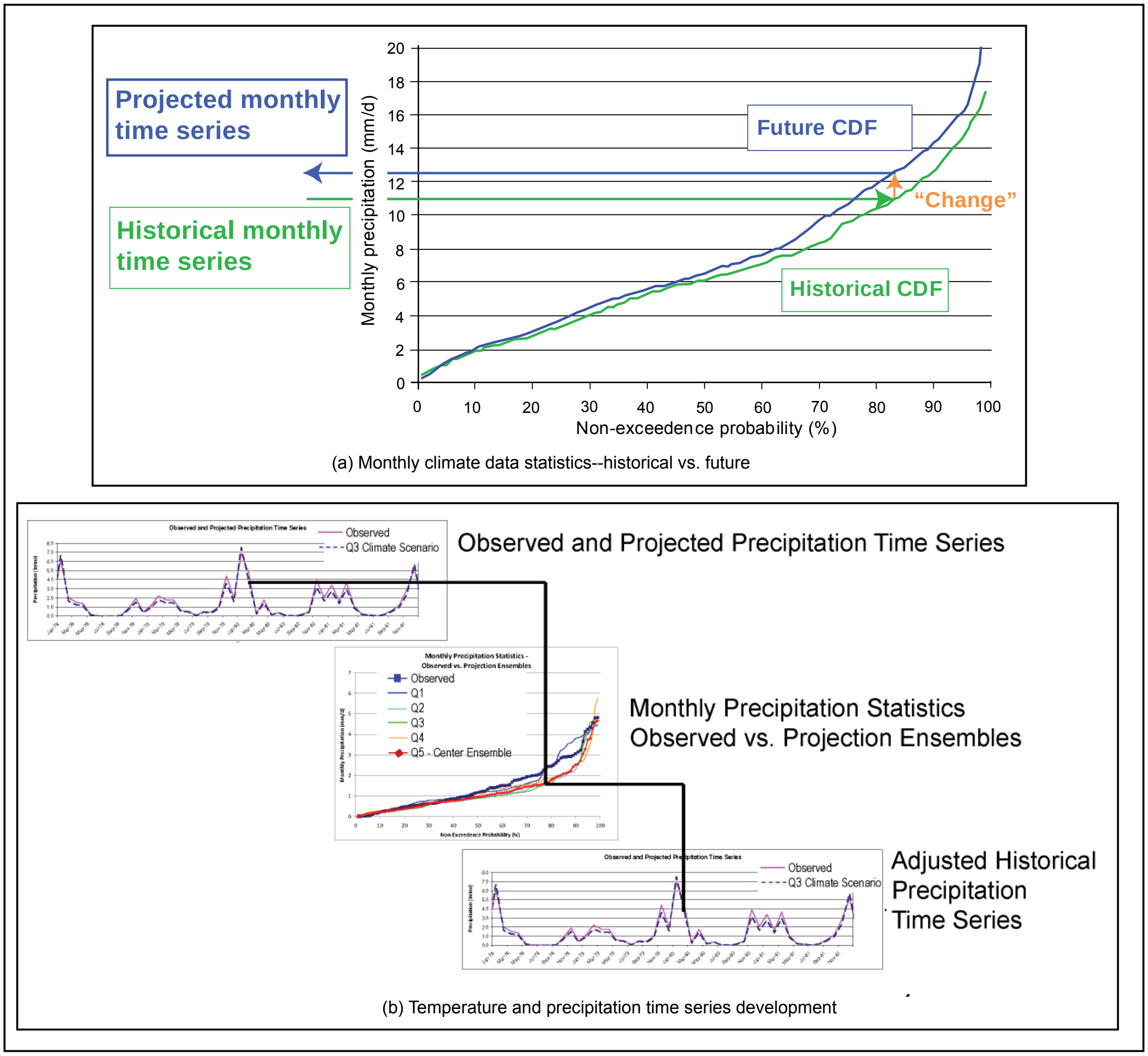
Figure 3–4 Ensemble mapping used in Bay-Delta Conservation Plan and DHCCP operations and planning

In order to incorporate both the climate change signal and the natural variability in the longer-term observed record, an expanded time series was created using a statistical technique called quantile mapping that makes use of the long-term observed records. The approach is similar to that applied by the Climate Impacts Group for development of hydrologic scenarios for water planning in the Pacific Northwest (Wood et al., 2002; Salathe et al., 2007) and applied in the Lower Colorado River, Texas studies (CH2M Hill, 2007). The quantile mapping approach maps the statistical properties of climate variables from one data subset with the time series of events from a different subset. The approach allows the use of a shorter period to define the climate state, while maintaining the variability of the longer historical record.

The quantile mapping approach involves six sequential steps:

1) Extract a 30-year slice of downscaled climate projections based on the ensemble subset for the quadrant of interest and centered on the year of investigation [e.g., 2025 (2011-2040) or 2060 (2046-2075)];
2) For each calendar month (e.g., January) of the future period, determine the statistical properties (cumulative distribution frequency or CDF) of temperature and precipitation at each downscaled grid cell;
3) For each calendar month of the historical period (1950–1999 for BDCP analysis), determine the CDF of temperature and precipitation at each grid cell;
4) Develop quantile maps between the historical observed CDFs and the future downscaled climate CDFs;
5) Using the quantile maps, redevelop a monthly time series of temperature and precipitation over the observed period (1950–1999) that incorporates the climate shift of the future period; and
6) Convert monthly time series to a daily time series by scaling monthly values to daily sequence found in the observed record.

The result of the quantile mapping approach is a daily time series of temperature and precipitation that not only exhibits the range of variability observed in the historic record, but also contains the shift in climate properties (both mean and expanded variability) found in the downscaled climate projection. The quantile mapping approach was used to generate daily time series of temperature and precipitation for 2025 and 2060 time lines considered in BDCP (CH2M Hill, 2010). The quantile mapping approach as used in the BDCP is illustrated in Figure 3–5.



(CH2M Hill, 2010)

Figure 3–5 Quantile mapping used in the Bay-Delta Conservation Plan and DHCCP operations and planning

Because the above procedure entailed deriving the scenarios from multiple projections, rather than a single GCM projection, the procedure is expected to reduce "noise" primarily associated with multidecadal variability and GCM sampling. Much of this noise arises because of the significant uncertainty inherent in the climate forecasts provided by the current generation of GCMs. By combining the climate change signal from GCM ensembles with the range of natural variability observed in the historical record, much of this noise can be overcome.

Regional Downscaling. Data used for BDCP were from the DOI/LLNL dataset and approach.

Sea Level Rise Consideration. Estimates of future sea level rise were developed for use in analyzing impacts and benefits of BDCP for the two future analyses time lines (2025 and 2060).

Due to the limitations with the current state of physical models for assessing future sea level rise, several scientific groups, including the CALFED Independent Science Board (ISB) (Healy 2007), recommended the use of empirical models to estimate sea level rise for short- to medium-term planning purposes. Both the CALFED ISB and CAT 2009 assessments have utilized the empirical approach developed by Rahmstorf (2007) that projects future sea level rise rates based on the degree of projected temperature change resulting from climate change. This method better reproduces historical sea levels and generally produces larger estimates of sea level rise than those indicated by the IPCC AR4 (2007). When evaluating all projections of global air temperature, Rahmstorf projects a mid-range sea level rise of 70 to 100 cm (28 to 40 inches) by the end of the century (2100); when the full range of uncertainty from the whole spectrum of available GCM simulations are considered, the projected rise is 50 cm to 140 cm (20 to 55 inches).

Based on the work conducted by Rahmstorf (2007), projected ranges of sea level rise for the BDCP analysis are 12 to 18 cm (5 to 7 inches) at the early long-term time line (2025) and 30 to 60 cm (12 to 24 inches) at the late long-term time line (2060). These sea level rise estimates are also consistent with those outlined in the recent US Army Corps of Engineers guidance circular for incorporating sea-level changes in civil works programs (USACE, 2009). Due to the considerable uncertainty in these projections and the state of sea level rise science, for each BDCP time line, the mid ranges of the estimates will be used: 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060. Sensitivity scenarios will also be prepared to evaluate impacts resulting from sea level rise of up to 24 inches by 2060.

III.C.2.i.d Streamflow Estimation

Hydrologic Modeling. The daily time sequences of precipitation and temperature developed through the process described above were used as inputs for the VIC rainfall-runoff model for generating reservoir inflow time series for the CALSIM II model. The VIC model simulates hydrologic processes on a $1/8^{th}$ degree scale to produce watershed runoff (and other hydrologic variables) for the major rivers and streams in the Central Valley.

Streamflow Adjustment. The changes in reservoir inflows and downstream accretions/depletions obtained from the VIC model were translated into modified input time series for the CALSIM II model.

III.C.2.i.e Planning Study/Model Results

Analysis and operational simulations for BDCP have not yet been conducted but will use DWR's CALSIM II model. At each long-term BDCP analysis time line (early long term, 2025, and late long term, 2060), the five ensemble climate change projections will be analyzed for the 30-year climatological period centered on the analysis year (e.g., 2011–2040 to represent 2025 time line). CALSIM II will simulate the response of the river-reservoir-conveyance system to the climate change derived hydrologic patterns and operations of a potential Delta conveyance system. Simulations will be developed for all alternatives as well as future no project/no action alternatives under the median climate change scenario. CALSIM II simulations will provide estimates of the change in operations, upstream storage and river flow conditions, and Delta facility and export operations associated with future climate change. The CALSIM II simulations will also provide monthly flows for all major inflow sources to the Delta, as well as the Delta exports, for input to DSM2. The four bracketing climate scenarios will be used in a sensitivity analysis to evaluate the full range of climate change impacts.

DSM2 simulations will be developed for each habitat condition and sea level rise scenario that is coincident with the BDCP time line. DSM2 simulations will be developed for the future no project/no action alternatives, with distinct simulations for each climate change-sea level rise scenario. These DSM2 simulations will provide information related to Delta system performance under changes to inflows (pattern and magnitudes), exports, and sea level rise. A sensitivity analysis of the Delta flow and salinity changes will be performed to determine the relative change associated with hydrology/exports as compared to sea level rise components of climate change. If it is determined that the climate changes to hydrology between the ensemble-informed scenarios are substantially less significant to Delta conditions than the sea level rise assumption, then only one hydrology scenario will be carried forward to the DSM2 modeling of the alternatives. New ANNs will be developed based on the flow-salinity response simulated by DSM2. These sea level rise-habitat ANNs will be verified and subsequently included in the CALSIM II model. The CALSIM II model will then be simulated with each of the five climate change induced hydrologic conditions in addition to the historical hydrologic conditions.

III.C.2.ii Study No. 11: Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment

III.C.2.ii.a Purpose and Synopsis of the Study

The 2008 Biological Assessment for the Continued Long-Term Operations of the Central Valley Project and State Water Project evaluates the effect of project operations on listed species and critical habitat. Although an obvious misnomer, this document is nevertheless customarily referred to as Operations

Criteria and Plan Biological Assessment (OCAP BA), The OCAP BA presented a sensitivity analysis of potential climate change and sea level rise implications to SWP/CVP operations and system conditions that may occur during the consultation horizon of the OCAP (i.e., 2030) (USBR, 2008). The analyses included in the OCAP BA were also utilized in the subsequent biological opinions for delta smelt (USFWS, 2008) and Chinook salmon (NMFS, 2009), and adopted as the relevant assessment of the future impacts of climate change for the purposes of the analysis in the respective biological opinions.

The climate change analyses were used to evaluate how fishery habitats will change and how fish populations will respond to the effects of climate change such as reduced streamflows, sea level rise, elevated air and water temperatures, reduced summer flows, increased and more frequent flooding, and more frequent and severe droughts.

The OCAP BA used a bracketing scenario analysis to select four climate change scenarios for the evaluation. The four selected scenarios were individual model runs that most closely represented the 10^{th} and 90^{th} percentile of period average changes in temperature and precipitation. These four scenarios were selected to bracket the range of possible future regional climate conditions as compared to historical climate.

Regional climate change projections of temperature and precipitation were used to estimate monthly changes in surface water runoff and CVP and SWP reservoir inflows using the VIC and Sac-SMA/Snow 17 rainfall-runoff models. A one-foot sea level rise at 2030 was considered with each of the four climate change scenarios used, based on recent projections of sea level rise by 2030 and on availability of existing DSM2 simulations. For the OCAP BA study, the assumption of a one-foot sea level rise was coupled with a 10 percent increase in tidal amplitude. Sea level rise was combined with water supply changes to determine changes in SWP and CVP operations, as well as Delta flows and velocities, and reservoir and river water temperatures.

III.C.2.ii.b Planning Assumptions and Considerations

The OCAP-BA analysis did not assume any changes in the way water was conveyed across the Delta. Existing system infrastructure and existing regulatory and management practices including State Water Board D1641 regulations (State Water Board, 2000) were assumed to be in place; restrictions on Delta exports contained in the recently published delta smelt and Chinook salmon biological opinions (USFWS, 2008; NMFS, 2009) were not included. The analyses also considered Delta salinity intrusion due to sea level rise and resulting changes in reservoir operations to maintain Delta water quality (USBR, 2008).

SWP/CVP water demands were not modified based on the assumption that district-level demand-management flexibility existed for both SWP and CVP water contractors (e.g., shifts in cropping choices, irrigation technology, etc.) so that district-level water demands would not necessarily change even though crop-specific water needs would be expected to increase with warming.

The hydrologic time series used for the analysis was the 82-year historical record of 1922-2003, adjusted for future climate induced changes. The planning horizon for the OCAP-BA was 2030. The land use and water demands used in the analyses represented a constant 2030 level of development, and the level of development was assumed not to change over the simulation period.

The climate data of interest for planning were temperature, precipitation, and relative humidity. The outputs of interest from the planning model suite were streamflow, water uses, water supplies, SWP and CVP deliveries, and Delta water quality conditions.

III.C.2.ii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. The OCAP BA presented a sensitivity analysis of potential climate change and sea level rise implications to SWP/CVP operations and system conditions that may occur during the consultation horizon (USBR, 2008). The analyses included in the OCAP BA were also utilized in the subsequent biological opinions for Delta smelt and Chinook salmon, and adopted as the relevant assessment of the future impacts of climate change for the purposes of the analysis in the respective biological opinions (USFWS, 2008; NMFS, 2009).

The DOI/LLNL dataset GCM projections were used to characterize the range of future climate possibilities. All 112 downscaled projections were plotted on a graph of normalized average change in temperature and precipitation (from historical conditions) at the downscaled grid cell (1/8th degree resolution) centered above Folsom Dam. Four GCMs were chosen that most closely represented the paired precipitation-temperature changes at the 10th and 90th percentile. These projections were selected to bracket the range of possible future climates. The resulting four scenarios were assumed collectively to span regional climate changes as compared to historical climate. The four scenarios represented futures that were less warming-wetter; more warming-wetter; less warming-drier; and more warming-drier.

Regional Downscaling. Data used for the OCAP BA were from the DOI/LLNL dataset and approach.

Sea Level Rise Consideration. A one-foot sea level rise at 2030 was considered with each of the four climate change scenarios, based on recent projections of sea level rise by 2030 and on availability of

DSM2 simulations. For the OCAP BA study, the assumption of a one-foot sea level rise was coupled with a 10 percent increase in tidal amplitude. This assumed amount of sea level rise by 2030 would seem to represent the high end of the rate of sea level rise (CAT, 2009).

III.C.2.ii.d Streamflow Estimation

Hydrologic Modeling. Regional climate change projections of temperature and precipitation were used to estimate monthly changes in surface water runoff and SWP and CVP reservoir inflows using VIC and Sac-SMA/Snow 17 rainfall-runoff models (USBR, 2008). SWP/CVP operations studies featured other adjustments dependent on changes to reservoir inflows: year-type classifications, water supply forecasts, and allocation rules based on foresight of reservoir inflows. The projection periods and sequences considered were 30-year simulations aligned with future period 2011–2040 for 2025 and 2036–2065 for 2050.

Streamflow Adjustment. Perturbations to adjust stream inflows were based on average monthly change in stream inflows from the hydrologic model, i.e., each month perturbed by same percent every year of simulation (Miller et al., 2001). The adjustments were based on annual change in stream inflow values. Results showed that for each headwater basin evaluated, the range of annual impacts was not very sensitive to choice of runoff model (SacSMA/Snow17 versus VIC). As a result, only SacSMA/Snow17 results were utilized for SWP and CVP operations analysis.

III.C.2.ii.e Planning Study/Model Results

Operations simulations of SWP and CVP were conducted with DWR’s CALSIM II model using an extended record of historical precipitation and adjusted historical runoff. SWP/CVP operations studies featured other adjustments dependent on changes to reservoir inflows: year-type classifications, water supply forecasts, and allocation rules based on foresight of reservoir inflows. For the OCAP BA study, sea level rise was combined with water supply changes to determine changes in SWP and CVP operations, as well as Delta flows and velocities, and reservoir and river water temperatures. The results quantified how SWP/CVP water supply, operations, and operations-dependent conditions might vary relative to a range of 2030 climate possibilities and associated sea level rise conditions.

Results show that climate change leading to future warming would be expected to cause a greater fraction of annual runoff to occur during winter and early spring and reduced fraction of annual runoff to occur during late spring and summer. Changes in both mean-annual deliveries and carryover storage were found to be more sensitive to changes in mean-annual precipitation, and relatively minor to changes in mean-annual air temperature. Sea level rise impacts on salt water intrusions resulted in a significant decrease in both SWP and CVP deliveries, without considering the effects of regional climate change. Sea level rise also led to greater salinity intrusion into the Delta, indicated by simulated X2 results. However, the wetter regional climate change scenarios showed that such sea level rise effects on salinity intrusion were offset by increased upstream runoff and Delta outflow.

Results also showed that spring flows at the head of Old River were most affected by the wetter-warmer climate change scenarios, which led to increased flows during wetter years and decreased flows during drier years. Negative Old and Middle River flows typically increased under climate change, especially during the winter. Changes in mean-annual air temperature had relatively more influence on changes in reservoir and river water temperature changes than they had with changes in SWP/CVP storage and delivery operations. Changes in mean-annual precipitation toward wetter or drier conditions acted to partially offset or reinforce air temperature warming effects on reservoir and river water temperatures.

III.C.2.iii Study No. 12: Los Vaqueros Reservoir Expansion EIR/EIS

III.C.2.iii.a Purpose and Synopsis of the Study

The Contra Costa Water District (CCWD) and USBR with DWR participation investigated and proposed a project to expand the existing Los Vaqueros Reservoir from 100 thousand acre-feet of storage to 275 TAF of storage (USBR and CCWD, 2010). The joint EIR/EIS qualitatively evaluates the potential effects of climate change on the proposed project. The evaluation uses the 2006 SWP/CVP Impacts Report (DWR, 2006a) and the “Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise, Appendix R of the OCAP-BA” (USBR, 2008) to provide quantitative projections of the future impacts to the SWP and CVP systems and the Delta.

III.C.2.iii.b Planning Assumptions and Considerations

Not applicable.

III.C.2.iii.c Climate Change Characterization

Global Climate Models and Emission Scenarios. Not applicable.

Regional Downscaling. Not applicable.

Sea Level Rise Consideration. Not applicable.

III.C.2.iii.d Streamflow Estimation

Hydrologic Modeling. Not applicable.

Streamflow Adjustment. Not applicable.

III.C.2.iii.e Planning Study/Model Results

The Los Vaqueros EIR/S found that planned operations on the project would not be significantly changed by expected climate changes. Flexibility of the project operations allows compensation for sea level rise and flow variations within the Delta. And the use of multiple intakes and increased storage would ensure project benefits under projected climate change conditions.

III.D Other Related Efforts

III.D.1 General Planning Studies

No projects to report.

III.D.2 Project Level Analysis

III.D.2.i Study No. 13: Central Valley Project Integrated Resources Plan

III.D.2.i.a Purpose and Synopsis of the Study

USBR is developing an integrated resource plan (IRP) for the CVP. The CVP IRP is intended to build upon previous studies conducted through the Central Valley Project Yield Feasibility Investigation Program by refining the evaluations of current and future water balances to the scale of the individual CVP divisions and extending the basis of these analyses from the historical supply/demands to include the effects of future changes in climate, socioeconomic, and environmental conditions. In addition to these evaluations, the CVP IRP will coordinate with stakeholders to assess the impacts of these factors on infrastructure and operations, develop adaptation strategies, and perform trade-off analyses to determine the effectiveness, efficiency, and acceptability of potential responses to socioeconomic-climate induced supply/demand imbalances (USBR, 2010).

The future water balance evaluation analysis of the CVP IRP will utilize a total of five climate change futures to evaluate future water balances. The climate change futures of the five ensemble-informed scenarios are being used in the BDCP.

III.D.2.i.b Planning Assumptions and Considerations

Analyses for the CVP IRP will be performed at years 2030, 2060, and 2085. The CVP IRP will utilize the three socioeconomic futures (Current Trends, Slow & Strategic Growth, and Expansive Growth) developed by California Water Plan Update 2009 to reflect potentially differing socioeconomic conditions in the future.

Future agricultural and urban outdoor demands will be based on datasets being developed using the Land Atmosphere Water Simulator (LAWS) model, The LAWS model has been modified to directly compute plant transpiration, growth, and yield based on meteorological factors (temperature, relative humidity, wind speed, net radiation, and carbon dioxide) and plant-specific growth parameters. The model will be applied to develop water demand data sets for representative Central Valley growing regions corresponding to the five climate futures at the early (2030), mid (2060) and late (2085) 21^{th} century analysis periods.

In addition, CVP IRP will perform assessments of the economic effects of climate change on Central Valley agriculture. These evaluations will be accomplished by developing a dynamic linkage between WEAP and the State Wide Agricultural Production (SWAP) models. This linkage will allow WEAP to inform SWAP of the available supply and SWAP in turn to inform WEAP of the delivery priorities based on economic factors. These results will be used by CVP IRP to provide an assessment of economic impacts of climate change as well as to evaluate the effectiveness and efficiency of potential adaptation strategies.

III.D.2.i.c Climate Change Characterization

Global Climate Models and Emission Scenarios. The CVP IRP will address climate change considerations through five climate change scenarios that follow the BDCP ensemble-informed approach. These five climate sequences shall be developed using statistical techniques that consider the full range of 112 downscaled climate change projections to develop statistically relevant scenarios for water planning. These climate change projections shall then be combined with historically observed climate variability to generate hydrology sequences that maintain important multiyear variability not always reproduced in direct climate projections, such as the CAT 2009. Five climate scenarios shall be developed using the same multimodel ensemble-informed approach as that being used by BDCP. A central tendency scenario shall be developed by aggregating all projections falling within the inner -quartiles, 25^{th} to 75^{th} percentile. Four additional scenarios shall be developed to represent future conditions that are (1) drier with less warming, (2) drier with more warming, (3) wetter with more warming, and (4) wetter with less warming than the ensemble median. These ensembles will be developed by aggregating the 10 projections closest to the 90th /10th percentile anchor points (CH2M Hill, 2010).

Regional Downscaling. Data used for the CVP IRP will be from the DOI/LLNL data set and approach.

Sea Level Rise Consideration. For the CVP IRP, the relationships of sea level rise to salinity intrusion will be developed from the existing BDCP UnTRIM or DSM2 modeling runs (CH2M Hill, 2010); no new sea level rise modeling is anticipated for the CVP IRP.

III.D.2.i.d Streamflow Estimation

Hydrologic Modeling. For hydrologic modeling, climate data (precipitation, temperature, and relative humidity) for the five climate change scenarios will be utilized. The WEAP model will be used to develop climate-based watershed runoff for the main watersheds of the Central Valley and climate-based demand estimates for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. The WEAP model will also be used to simulate reservoir inflow data for use in reservoir operations simulation by the CalLite model. CalLite is a screening model jointly developed by DWR and USBR for planning and management of SWP and CVP. CalLite is a simplified representation of CASLIM II, but it does maintain the hydrologic, operational, and institutional integrity of CALSIM II. And it is much easier to use and reduces runtime significantly.

Streamflow Adjustment. Projections of temperature and precipitation will be utilized directly in the WEAP hydrology model to develop rainfall-runoff simulations. WEAP allows for analysis of future climate scenarios that are not reliant on historical hydrologic patterns. That is, streamflows are derived directly from the future climate scenarios and not from a perturbation of the historical hydrology.

III.D.2.i.d Planning Study/Model Results

The modeling of alternatives for the CVP IRP will be performed using the CalLite and WEAP models in an integrated fashion. The climate-based watershed runoff and demand estimates, as well as reservoir inflow data generated by the WEAP model, will be used as input to run the CalLite model. The WEAP model will be run one time for each of the 15 scenarios (3 socioeconomic X 5 climate futures) for 30-year periods centered around 2030 (early 21^{st} century), 2060 (mid 21^{st} century), and 2085 (late 21^{st} century.

The WEAP model will be used to evaluate climate impacts on supplies/demands and the development and assessment of potential adaptation strategies at the basin scale (Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions). The results of WEAP simulations will also be used as inputs to the CalLite model that will simulate operations of the SWP/CVP facilities, Delta facilities and regulatory controls, and SWP/CVP contractor allocation decisions. The CalLite model will be used also to simulate changes to the system that occur due to the implementation of statewide water management actions. The CalLite model will be set up to perform simulations of the ensemble of 15 scenarios for selected CVP IRP adaptation alternatives. The CVP IRP is still in the development stages, and no model results are currently available.

Section IV Comparison, Challenges, and Future Directions

IV.A Similarities and Differences Among Approaches

As described in Section III of this report, DWR has used a wide range of approaches in different studies to characterize and analyze the impacts of climate change. The approaches varied based on a study's purpose, the time horizon, spatial scale, and the study area's level of vulnerability or sensitivity to potential impacts of climate change. The approaches also reveal an evolution in the sophistication of climate change characterizations and analyses over time. A summary table of the planning studies surveyed for this report and described in Section III, including the type of climate change analysis conducted, is in Table 4-1[5]. The table shows that more advanced methods, such as CAT 2006/2009 scenario analysis and ensemble-informed approaches, have been applied for general planning studies and for project level analyses typically with a longer planning horizon and larger spatial scales. The table also shows that for project level analyses with shorter planning horizons, simpler methods such as a "relative change" approach or qualitative approach have been used. However, in all analyses being conducted more recently, the trend increasingly is to utilize more quantitative and analytical approaches.

Irrespective of the approach used—whether a simple qualitative analysis or a complex ensemble-informed technique—a common thread can usually be found. All the approaches rely on data from the112 downscaled DOI/LLNL data set to provide information about future climate conditions. Even in the case of qualitative approaches, the relevant discussions rely on results based on data from the DOI/LLNL data set to provide generalized assessments of future climate.

Depending on the approach, the entire DOI/LNLL data set may be used or a subset of the 112 simulation data set may be developed. The subset in some cases, as in the SWP Delivery Reliability Study or Management Response Status Report, consists of only a single GCM projection.

In the projects reviewed for this report, GCM projections are used both directly and indirectly to define climate change scenarios for the planning studies. For example, 12 GCM projections are used in the CAT 2009 approach directly to define the same number (i.e., 12) of analysis scenarios (used in several planning studies reviewed). In contrast, in the BDCP study, 112 GCM projections are utilized indirectly to define a total of five analysis scenarios that represent a much broader range of climate change conditions. The DRMS Phase 1 Study and the SSERP Final PEIR also use GCMs from the DOI/LLNL dataset indirectly.

[5] Table 4-1 Summary of planning studies surveyed and type of climate change analysis conducted is in large format (11x17 inches) in back of this report and also presented in smaller format as Table ES-1 in the Executive Summary.

These studies use the GCM projections to generate probabilistic Monte Carlo simulations. This approach is used to significantly increase the number of analysis scenarios with the objective to capture a broader variability in climate change.

The projects surveyed for this report show that planning horizon is one of the most important factors in determining when a climate change analysis is included in a planning study. The planning horizons for all of the studies featured in this report are at least 15 years, and some extending to as long as 70 years. It is worth noting the absence of any study whose time horizon is shorter than 15 years, indicating that studies with shorter time horizons are not typically incorporating climate change analysis. The BDCP analysis is perhaps most illustrative, in that it has three different time horizons: early near-term (5 years), late near-term (15 years), and long-term (50 years). Climate change analysis is omitted for the early near-term horizon because the effects of climate change are not expected to be significant over the period, but climate change analysis is included in the late near-term and long-term horizons.

Planning horizon may determine the necessity of including a climate change analysis in the study, but it does not appear to have a strong effect on the particular climate change analysis approach used. California Water Plan Update 2009 and 2009 SWP/CVP Impacts Study both have a 2050 planning horizon and use the CAT 2009 approach. The BDCP with a 2060 planning horizon uses an ensemble-informed approach. DRMS Phase I, OCAP BA, and CVP IRP also have 50-year planning horizons, but each uses a different approach.

Not surprisingly, the projects surveyed also indicate that project level analysis often involve smaller spatial coverage areas. The SSERP Final PEIR and Los Vaqueros Reservoir Expansion EIR/EIS involve much smaller coverage areas and used more simplified, less technical approaches to climate change analysis. Most of the general planning studies have coverage areas spanning the Central Valley and SWP/CVP service areas or the entire state. In all cases, general planning studies use the CAT 2006/2009 approach or, in the case of DRMS Phase I, a Monte Carlo simulation based on the CAT 2006 scenarios.

All the studies use regionally downscaled data from GCM results accomplished by the BCSD technique. Similarly, primary climate variables used in all the studies are temperature, precipitation, and humidity. Only the DRMS Phase 1 Study uses an additional variable, wind velocity.

The method used to simulate future hydrology varies significantly between the studies. Two general methods are used: adjusted observed hydrologic sequences and unadjusted model generated sequences. Adjusted observed hydrologic sequences use the observed record of streamflows as a baseline to which adjustments are made to reflect potential climate changes. Unadjusted model generated sequences use climate models to generate input parameters for a hydrologic model that generates streamflow sequences that are used without adjustment. Water Plan Update 2009 and CVP IRP rely on unadjusted model generated sequences; and the 2006 and 2009 SWP/CVP Impacts Studies, SWP Reliability Report 2009, and the BDCP all use variations of adjusted observed hydrologic records. Unadjusted model generated sequences typically varied from 30 to 45 years (but could be extended to any length—albeit with increasing uncertainty). Observed sequences usually use the 82-year hydrologic record from1922–2003. For the BDCP however, the observed sequence used is the 50-year period, 1950–1999. Arguments exist for using each method. The surveyed studies indicate that studies that rely on CALSIM II for SWP/CVP operational analysis typically use adjusted observed hydrologic sequences; but more general studies, such as California Water Plan Update 2009 and CVP IRP, typically use unadjusted model generated sequences. As DWR develops a standard set of approaches for characterizing and analyzing climate change, establishing a consistent method of simulating future hydrology will be an important issue for consideration.

In terms of characterization of climate variability, the CAT 2006/2009 studies use data directly from downscaled climate projections that reflect monthly sequence and variability from individual downscaled climate projections. This approach is used in all studies except the BDCP, where climate variability is statistically mapped onto historical climate that reflects observed sequence with monthly variability adjustments based on statistical shifts from climate scenarios. The CVP IRP analyses will also make use of the BDCP approach for characterizing climate variability. For projects where results from other studies are used—such as Monterey Plus EIR, SSERP Final PEIR, and Oroville Facilities Relicensing—characterization of climate variability does not arise directly, but rather is embedded in the results used.

Sea level rise is not considered in several studies, e.g., Water Plan Update 2009 and Monterey Plus EIR, SSERP Final PEIR, and Oroville Facilities Relicensing. A one-foot sea level rise assumption is made for studies with a planning horizon ranging from 2029 to 2050 (2009 SWP/CVP Impacts Study, SWP Reliability Report 2009, Management Response Status Report, and OCAP BA); and a two-foot sea level rise assumption is made for studies with a planning horizon of 2085 or longer (2009 SWP/CVP Impacts Study and DRMS Phase 1 Study). For BDCP, a sea level rise of 6 inches is assumed for 2025 and a sea level rise of 18 inches is assumed for 2060.

In most studies, VIC is the hydrologic model used to simulate streamflows using climate variable inputs from downscaled GCM results. In more recent studies, such as California Water Plan Update 2009 and CVP IRP, WEAP’s embedded hydrologic model is used. For SSERP Final PEIR, a local model (SALSA), specifically developed for the Salton Sea area, is used. For OCAP BA, SacSMA/Snow17 model is used, in addition to VIC.

For California Water Plan Update 2009 and CVP IRP, no streamflow adjustment based on historical data is made. For 2006 SWP/CVP Impacts Study and OCAP BA, a single step perturbation method based on average monthly changes in flow from historical data is used. This method results in all Octobers being perturbed by the same percentage. For some of the more recent studies, such as 2009 SWP/CVP Impacts Study, SWP Reliability Report 2009, and Management Response Status Report, a three-step perturbation method based on time series of monthly changes in flow from historical data is used. This method, allows each October to have a different adjustment.

It is important to note that none of the studies explicitly addresses impacts to groundwater resources. In the future, groundwater levels may be affected by increased groundwater pumping to meet increased water demands, salinization of coastal aquifers from sea level rise, and decreased recharge due to changing hydrology and increased evaporation and transpiration. California State government and DWR have historically had little regulatory authority over groundwater resources; however, recent legislation has increased the emphasis on groundwater monitoring and future legislations may expand interest in future impact projections for groundwater.

IV.B Data Gaps and Other Challenges

This report has surveyed the approaches that DWR and its partner agencies have used to characterize and analyze future climate conditions in their planning studies. The survey includes a wide range of project types, project scales and scopes, and planning horizons. As DWR envisions the development of a standard framework and a set of consistent approaches for incorporating climate change in its planning studies, it intends to use these past projects as part of the basis for that development. The projects covered in this report, however, are likely not adequate to fully provide the basis for developing a standardized framework and a set of approaches. Other challenges, many of which are highlighted in the projects reviewed in Section III, further complicate the development of a standardized framework and a set of approaches to climate change.

The list of past projects illustrates the types of activities in which DWR generally engages. However, it does not necessarily provide a comprehensive picture of all the different types of projects that DWR may be involved with in the future. For instance, the list of projects in Section III does not contain any flood protection projects; rather it contains studies focused only on water supply and ecological restoration. Flood protection projects differ significantly from water supply and ecological restoration projects in their purpose, scope, analysis time-step, and the resulting impact assessment. Water supply and restoration projects generally focus on average long-term conditions. Flood protection projects, on the other hand, focus on extreme climate events—large winter storms or warm wet spring storms that result in short-term high runoff events. A large amount of uncertainty still exists in how climate change will influence the magnitude and frequency of extreme climate events in the future. As a result, developing climate characterization and analysis approaches for flood protection projects presents an additional challenge.

In addition, there is a lack of analysis of potential drought conditions that are more extreme than we have seen in our relatively short hydrologic record. There is significant evidence to suggest that California has historically been subject to very severe droughts (Meko, 2001) and that climate change could result in droughts being more common, longer, or more severe (IPCC, 2008). However, most current DWR approaches rely on at most an 82-year historical hydrologic record (1922–2003) on which GCM-generated future climate changed hydrologic conditions are superposed. This record is likely too short to incorporate a low frequency, but extreme, drought that may have occurred in the past.

Developing a standard DWR framework and a set of approaches for characterizing and analyzing climate change has significant challenges associated with it. Scientific understanding of climate change as well as the state of the practice for analyzing impacts is evolving rapidly. New approaches are being developed as new information and analysis are becoming available. Developing and setting a standardized framework and a set of approaches that can improve consistency across DWR while not restricting the incorporation of cutting edge information and techniques will likely be a delicate balancing process.

As DWR begins this development, the issue of characterizing uncertainty in climate change projections will need to be tackled adequately for the whole spectrum of projects with which DWR may be involved.

A final critical issue is whether developing an internal DWR policy to articulate a standardized framework and a consistent set of approaches to characterizing and analyzing climate change could potentially create conflict with other State level initiatives regarding climate change. A DWR climate change approach policy would be aimed at the technical analysis performed by DWR. The policy would ensure that all studies conducted by DWR use the same set of data, assumptions, models, and techniques to the extent feasible. This policy is not expected to influence how the technical information generated by the analysis is used to make decisions. Therefore, DWR expects that an internal policy recommending a consistent DWR approach to characterizing and analyzing climate change will not lead to conflicts or inconsistencies with other State laws, executive orders, or directives.

IV.C Needs Assessment for Upcoming Projects

Climate change characterization and analysis will continue to be an important planning topic in the future. Thirteen large-scale planning studies that will include climate change analysis—but that have not yet developed a specific methodology for conducting that analysis—are already on the horizon. Each of these studies is briefly summarized below. These projects further highlight the need for a standard framework and a set of consistent approaches for considering climate change in DWR planning studies.

IV.C.1 General Planning Studies

IV.C.1.i Central Valley Flood Protection Plan

The Central Valley Flood Protection Plan (CVFPP) will be a long-term plan for improving flood management in the Central Valley. This document will: describe current flood risk; define goals, objectives, and constraints important in the planning process; identify potential plan elements; and make recommendations for improvement of the State-federal flood management system aimed at reducing the risk of flooding in the Central Valley.

The CVFPP is legislatively mandated to be completed by January 1, 2012, and will be updated every five years after that. The plan will have a long planning horizon (30–50 years) and will cover the Central Valley, extending from Shasta Lake on the Sacramento River to the San Joaquin River in the south.

IV.C.1.ii Statewide Flood Management Planning Report

Statewide Integrated Flood Management Planning will produce a report titled "Recommendations for Improving and Sustaining Integrated Flood Management in California." The report will develop strategies to address flood risk statewide. For each of the state's regions, the report will (1) assess and characterize existing and future flood risk, (2) document the current state of flood management infrastructure, (3) identify and document challenges and opportunities to improve integrated flood management, (4) recommend approaches to managing existing and future flood risk, and (5) present a strategy for financing system improvements. The flood risk assessment will consider climate change effects, with a 50-year planning horizon. An initial report is anticipated in 2012, with a final report in 2014.

IV.C.1.iii National Research Council Sea-Level Rise Study

Pursuant to Executive Order S-13-08, DWR along with four other California State agencies, the states of Oregon and Washington, and three federal agencies have engaged the National Research Council in a contract for science review of sea level rise for the West Coast. Through this contract, a panel of experts will be assembled. The panel will assess sea level rise for California, Oregon, and Washington and will provide estimated values or a range of values for sea level rise for planning purposes for the years 2030, 2050 and 2100. The Sea-Level Rise Study is anticipated to be completed in 2012.

IV.C.1.iv DWR Financial Assistance Grant Programs—Grant-making Guidelines and Considerations

DWR administers a number of financial assistance programs that provide funding for a wide range of water resource programs, including flood management programs, throughout California. DWR-administered grants programs have not previously required grantees to consider climate change in proposed projects. Recently, DWR started including climate change analysis considerations into some grant-making guidelines. It is expected that climate change analysis will increasingly become a part of the consideration of award of grants.

IV.C.1.v Urban Water Management Planning Guidelines

The Urban Water Management Planning Act requires all of California's urban water suppliers submit an Urban Water Management Plan to DWR every five years in order to be eligible for several types of State funding programs. Updated plans will be due in 2011 and will plan for the period 2010–2030. DWR is currently in the process of updating the Urban Water Management Plan Guidelines for 2010. For the first time, the guidelines will provide guidance on the inclusion of climate change analysis for urban water management planning purposes.

IV.C.1.vi Delta Risk Management Study (DRMS) Phase 2

The DRMS Phase 2 study builds on the work of the Phase 1 study described previously. The DRMS Phase 2 will develop four distinct scenarios to address the risks identified in the DRMS Phase I report. These scenarios aim to achieve multiple risk reduction objectives or benefits to the various assets and resources in the Delta and Suisun Marsh.

DWR is in the process of completing the review of the Phase 2 report; its release is scheduled for winter 2011. The report provides details of the scenarios and their risk reduction properties.

IV.C.1.vii Future California Landscape Water Demand and Climate Change Study

DWR will conduct a study of how climate change affects water demand in California's ecological and agricultural landscapes. The study will investigate how expected increases in evapotranspiration and water use efficiency will match up with ecophysiology and ecohydrology to drive changes in water demand for agriculture and native landscapes. The study will also investigate how projected increases in extreme weather (temperature and precipitation) will influence risk for California farmers. Physiology thresholds during the reproductive stage of several agricultural groups (woody-perennials and herbaceous) will be used to derive changes in risk for investment in water use.

Two planning horizons, 2050 and 2100, are being considered in the analysis with the study boundary being the entire state of California. The study is expected to be completed in 2011.

IV.C.1.viii State Water Project Operations-Power Impacts

DWR periodically evaluates conditions that could impact the power generation or power demand characteristics of the SWP. Changing temperatures, precipitation, and hydrology all have the potential to change current conditions. A consistent characterization of future climate change conditions could be used in future SWP power operations analyses.

IV.C.2 Project/Program Level Analyses

IV.C.2.i System Reoperation Studies

DWR has recently begun System Reoperation Studies to evaluate the potential benefits of re-operating the State’s water supply and flood protection system. The System Reoperation Studies will attempt to optimize the State’s water supply and flood protection system by balancing water supply reliability, flood protection, ecosystem stewardship, water quality, and groundwater overdraft.

The System Reoperations Studies will require modeling of future hydrology and water resource conditions in order to analyze the effects of alternative operational parameters.

IV.C.2.ii CALFED Surface Storage Investigations Progress Report

DWR and USBR in cooperation with other State and federal agencies and local partners are investigating four potential new surface storage projects originally proposed as part of the CALFED process: North-of-the-Delta Offstream Storage (NODOS) Investigation, Upper San Joaquin River Basin Storage Investigation, Los Vaqueros Expansion study, and Shasta Lake Water Resources Investigation. As an interim step toward completing federal feasibility reports and State and federal environmental impact documents for each project, DWR is preparing a progress report for the investigations. The progress report will provide basic information about the feasibility, costs, and benefits of the projects under existing and new Delta conveyance scenarios.

The CALFED Surface Storage Investigation Progress Report is scheduled to be published in late 2010.

IV.C.2.iii Sites Reservoir EIR/EIS and Feasibility Report

The Sites Reservoir Project is an ongoing investigation into the feasibility of constructing an offstream reservoir near Sites, California. Project formulations that are currently being investigated would divert water from the Sacramento River through existing and a potential new diversion point and through a series of existing canals and a potential new pipeline to a new reservoir. The proposed reservoir would provide additional water supplies to the SWP and CVP systems. Analysis of the project will cover the entire SWP and CVP service areas and future operations will be analyzed for a 50 year planning horizon.

IV.C.2.iv San Joaquin River Restoration Program Programmatic Environmental Impact Statement/ Environmental Impact Report

The San Joaquin River Restoration Program (SJRRP) was formed in response to a 2006 settlement of an 18-year-old lawsuit between the US Departments of the Interior and Commerce, the Natural Resources Defense Council (NRDC), and the Friant Water Users Authority. The goal of this comprehensive long-term program is to restore flows to the San Joaquin River from below Friant Dam to the confluence of the Merced River and restore a self-sustaining Chinook salmon and other fisheries in the river (the "Restoration Goal") while reducing or avoiding adverse water supply impacts to all of the Friant Division long-term contractors from restoration flows. The draft PEIS/PEIR for SJRRP is being developed. Climate change considerations are expected to be incorporated into the draft PEIR/PEIS using a bracketing scenario analysis approach, similar to that used in the OCAP BA.

IV.C.2.v Delta Stewardship Council Delta Plan

The Delta Stewardship Council (DSC) was established when the California Legislature enacted SBX7 1 as part of the 2009 Comprehensive Water Package in November 2009. Under this legislation, the DSC is required to develop and commence implementation of the Delta Plan, a long-term comprehensive management plan for the Delta, on or before January 1, 2012. The Delta Plan will be used to guide State and local actions in the Delta in a manner that furthers the co-equal goals of water supply reliability and Delta restoration. It is a major planning effort that may incorporate other significant ongoing planning efforts such as the BDCP and the CVFPP.

IV.D Next Steps

Scientific advancements will continue to improve our understanding of the Earth's climate system and our confidence and accuracy in predicting future changes to the system. Technical advances will continue to improve the methods we have for incorporating climate model data into our planning processes. As these advances occur, DWR must endeavor to employ the best science and the most robust analytical methods while maintaining consistency in the way that climate change is characterized and analyzed across its many programs. This paper has described several different approaches that have been used in past projects and documented the means and methods that have been used. This paper will provide a reference and a basis for research, discussion, and development of a standard framework and a consistent set of approaches for characterizing and analyzing climate change across DWR programs. We recommend a multi-step process for developing a DWR climate change approach. We envision a process that will be open, transparent, and collaborative. The first step will be to form a workgroup that will contribute to the development of the approach. DWR program staff will be identified to serve on the workgroup who have expertise in areas of climate change research, climate change policy, climate and hydrologic modeling, and data analysis. The workgroup will meet regularly during the development process to share additional research and resources on climate change characterization and analysis and develop goals, parameters, and limitations for the approach.

The workgroup will first develop a conceptual diagram of the development process that will schematically show the current set of approaches and their strengths and limitations. The schematic will also depict our envisioned future standard framework and a suite of probable approaches for climate change characterization based on project purpose, planning horizon, and spatial coverage of projects. This second part of the conceptual diagram will be an evolving portrayal of DWR's climate change analysis framework and approaches as the workgroup continues to build the final product resulting from this effort.

Based on the conceptual diagram, the workgroup will articulate a draft methodology document to be reviewed by DWR management as well as peer review from experts from within and outside of DWR. The methodology document will discuss the development of both a standard framework and a set of consistent approaches. The workgroup will solicit review and comments on the draft methodology document from within DWR through the Climate Change Matrix Team and CEQA Climate Change Committee and from outside of DWR through the California Water Plan Update - Climate Change Technical Advisory Group. After receiving feedback, the workgroup will work to develop a final methodology document.

The workgroup will also work on issues associated with the implementation of the recommended approaches in the methodology document, including ongoing communication and coordination. The workgroup will propose a process for facilitating the use of the standard framework on future projects while maintaining the flexibility needed to incorporate advances in scientific understanding and technical methods. A plan and process for periodic review and revisions to the framework and the approaches in light of scientific and technical advances will also be included.

DWR's efforts toward developing a standard suite of approaches for characterizing and analyzing climate change will likely have benefits that extend beyond DWR's own activities. The California Water Plan, SWP Reliability Report, and Biennial CAT Impacts Reports provide important information on water resource conditions that are used by planners throughout the state. Coordinating and standardizing the analysis procedures in these reports will make the information more consistent and will facilitate the use of these planning documents.

In addition, DWR through its various grant programs influences the development, conservation, and protection of water resources throughout the state. As DWR enhances its own methods for characterizing and analyzing climate change, these improvements will be shared with local water resource planning agencies. Use of the suite of standardized approaches are likely to be encouraged for use in Integrated Regional Water Management Planning activities and other grant funded water resource planning activities.

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Appendix 1 Glossary[6]

Adjusted observed hydrologic sequences are synthesized time sequences of simulated future hydrology, developed by using the observed record of streamflows as a baseline to which adjustments are made to reflect potential climate changes. (See also **unadjusted model generated sequences**).

A **banded catchment** is defined as the area that is contained within defined elevation ranges. The elevations bands are used to define climate in upper elevations of a watershed to reflect major reservoir operations and elevation-dependent hydrologic processes.

Bias corrected constructed analogue (BCCA) technique combines the strengths of both **bias corrected and spatial downscaling** and **constructed analogue** approaches and is expected to be used widely in the future for downscaling GCM climate data (Maurer, 2009). Using this procedure, the daily GCM data are bias corrected prior to application of the constructed analogue approach.

Bias corrected and spatial downscaling (BCSD) approach first adjusts output from the global climate models to account for tendencies in the model to be too wet, dry, warm, or cool as compared to the historical period (bias correction), and then the adjusted data are converted to regional data (spatial downscaling). Using this technique, the precipitation and temperature probabilities (at a monthly scale) during a simulated historical period from the GCMs are mapped to the concurrent historical record.

The historical observational data set used for this study is usually the gridded National Climatic Data Center Cooperative Observer station data. This data set, developed at a spatial scale of 1/8th degree (about 7 miles = 12 km), is aggregated to a 2 degree latitude-longitude spatial resolution. For precipitation and temperature, cumulative distribution functions (CDFs) for the historical period are developed for each month, at each of the 2 degree grid cells for both the gridded observations and the GCM data (raw GCM data are interpolated onto a common 2 degree grid for this purpose).

The quantiles for monthly GCM-simulated precipitation and temperature CDFs are then mapped to the same quantiles for the observationally based CDFs. For temperature, the linear trend is removed prior to the bias correction and replaced afterward to avoid increasing sampling at the tails of the CDF as temperatures rise. In this way, the probability distribution of observations are reproduced by the bias-corrected climate model data for the overlapping climatological period, while both the mean and variability of future climate evolves according to GCM projections. To obtain daily values using BCSD, the monthly values obtained are temporally disaggregated by re-sampling the historic data set based on

[6] Terms used in this report: Climate Change Characterization and Analysis in California Water Resources Planning Studies. Full citations of in-text references are in this report’s end references. See Section V References.

pattern matching and identification of analogous historical months. (see also **constructed analogue** approach)

CalLite is a screening model jointly developed by DWR and USBR for planning and management of SWP and CVP in California. CalLite is a simplified representation of CALSIM II, but it does maintain the hydrologic, operational, and institutional integrity of CALSIM II, and it is much easier to use and reduces runtime significantly. The screening tool is designed for use in a variety of stakeholder processes for improved understanding of water system operations and potential future management changes. CalLite can simulate observed hydrologic regimes or possible future climate change hydrologic regimes.

Constructed analogue (CA), a direct, large-scale daily statistical downscaling method, uses previously observed coarse-scale data and the corresponding fine-scale data to generate a relationship between observed weather patterns and daily patterns simulated by a GCM (analogues) at a coarser scale. This relationship is then translated to a finer scale to produce regional information. The CA method is based on the notion that if one could find an exact analogue (in the historical record) to the weather field today, future weather should evolve similarly to weather conditions following the identified analogue. From a practical standpoint, finding an exact analogue in the historical record is not feasible so the CA method artificially constructs the analogues using linear combinations of past atmospheric patterns. The process involves developing linear regressions with the current weather or climate pattern as the dependent variable and selected historical patterns as independent variables. It is assumed that the same linear combination (using the same regression coefficients) of the future evolutions of each of the historical patterns that contributed to the constructed analogue would describe the evolution of weather or climate into the future. (see also **bias corrected and spatial downscaling** approach)

Delta Simulation Model II (DSM2) is a mathematical model for simulation of one-dimensional hydrodynamics, water quality, and particle tracking in Sacramento-San Joaquin Delta. DSM2 is the primary model used by DWR to model salinity in the Sacramento-San Joaquin Delta.

Downscaling is defined in this report as the process of deriving data at a finer resolution—in space or time—from a coarser resolution data set. For GCM outputs, this means, taking the large-scale signal from the GCM and translating it to the regional scale.

Ensemble-informed approach uses information from a large array of future climate simulations rather than from a selected small subset of simulations.

General Circulation Models. See Global Climate Models.

GHG emissions scenarios. See IPCC emission scenarios.

Global Climate Models (GCMs) are a class of computer-driven models for weather forecasting, understanding climate, and projecting climate change. These computationally intensive numerical models are based on the integration of a variety of fluid dynamical, chemical, and sometimes biological equations.

IPCC emission scenarios “are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold.”

MAGICC is a model used to develop the relationship among projected global mean temperature change, sea level rise due to thermal expansion, and sea level rise due to ice melt to estimate total sea level rise projections (Hulme et al. 1995).

MIROC 3.2 is a global climate model (medium-resolution model) developed by Center for Climate System Research of the University of Tokyo and collaborators.

Monte Carlo simulation is a computerized mathematical technique that allows accounting for risk in quantitative analysis and decision making. Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities that will occur for any choice of action. It shows the extreme possibilities—the outcomes for the worst conditions and for the most conservative decision—along with consequences for intermediate decisions. Risk analysis is performed by building models of possible results by substituting a range of values—a probability distribution—for any factor that has uncertainty. The results are then calculated repeatedly, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of calculations. The end result is distributions of possible outcome values. Because of use of probability distributions, variables can have different probabilities of different outcomes occurring.

Monterey Plus is a term used synonymously with “Monterey Amendment to the State Water Project Contracts (Including Kern Water Bank Transfer) and Associated Actions as Part of a Settlement Agreement.”

Operations Criteria and Plan Biological Assessment (OCAP BA) refers to the 2008 Biological Assessment for the Continued Long-Term Operations of the Central Valley Project and State Water Project, which evaluates the effect of project operations on listed species and critical habitat.

Paleoclimate records are created using information from natural climate "proxies," such as tree rings, ice cores, corals, and ocean and lake sediments, that record variations in past climate. These proxies hold climate information that extend back far beyond the available observed climate record. Using sophisticated tools and procedures, paleoclimatologists are able to reconstruct records of temperature, streamflow, drought conditions, terrestrial environment characteristics, and other important historical conditions that incorporate additional climate variability and extremes into the extended data set. Paleoclimate approaches do not predict or simulate future climate conditions but rather expand the amount of data about past climate conditions.

Qualitative approaches, as defined for this report, refers to climate change characterization approaches that rely on impact assessment data from other studies that indicate the general direction and order of magnitude of the expected changes due to climate change. The study being conducted qualitatively analyzes and then describes how expected changes in climate such as temperature, hydrology, precipitation, and humidity could affect the resources of interest in the study. This approach does not use quantitative numbers to describe impacts, thus bypassing the need to address many of the challenges associated with the uncertainty of quantitative estimates of climate change. However, this approach provides only a generalized assessment of the potential impacts of climate change and may not provide a sufficient level of detail for some types of studies.

Quantile mapping maps the statistical properties of climate variables from an ensemble of GCM - generated data onto the time series of observed climatological data set. The approach allows the use of a shorter period to define the climate state, while maintaining the variability of the longer historical record.

RegCM3 is a fine-resolution limited domain climate model that is used as a nested model within a coarser-resolution GCM. The GCM is used to capture the large-scale phenomena, while the finer-resolution nested model, i.e., RegCM3 is used to simulate the smaller-scale features.

Relative change approaches, as defined for this report, refers to climate change characterization approaches that add or subtract a defined quantity or percentage quantity from the expected level of a parameter of interest to estimate the potential change due to climate change. Relative change approaches can be used for a wide array of resource evaluations. They rely on impact assessment results from other studies that indicate the general direction and order of magnitude of the expected changes due to climate change.

SacSMA/Snow17 is a hydrologic model, similar to VIC model, to simulate rainfall-runoff using climate variable inputs from downscaled GCM results.

Spatial resolution of 1/8th degree is the resolution at which GCM outputs are typically downscaled. The downscaled projections increase the resolution from greater than 1 degree of latitude-longitude (approximately 100 km by 100 km) for GCM outputs to 1/8th degree of latitude-longitude (approximately 12 km by 12 km). The 1/8th degree resolution is the same as the "7.5-minute grid" used in the USGS 1:24,000-scale topographic maps, also known as 7.5-minute "quadrangles," "topo quads," or "quad maps."

Special Report on Emissions Scenarios (SRES) (IPCC 2000) documents the work conducted by the IPCC to develop plausible future scenarios of anthropogenic emissions of all relevant greenhouse gases (GHGs) as well as other important climate-forcing compounds that are commonly emitted into the atmosphere. These scenarios consider a wide range of the major driving forces of future emissions, from demographic to technological and economic developments. The SRES report states explicitly that "the scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold." The scenarios are meant to assist researchers and policymakers to explore potential long-term future conditions and the plausible ramifications of near-term activities and policy decisions.

Sensitivity analysis usually refers to apportioning the uncertainty of model outputs to variations in the input parameters.

Statewide Hydrologic Region model is a low-resolution regional representation of monthly applied water use for each of the 10 hydrologic regions in California. For Update 2009, most of the scenario analysis was performed at this scale

Unadjusted model generated sequences are synthesized sequences of model simulated hydrology, developed by using climate models to generate the input parameters for a hydrologic model that then generates streamflow sequences that are used without adjustment for the analysis. (see also **adjusted observed hydrologic sequences**)

The **Variable Infiltration Capacity** (VIC) model (Liang et al., 1994; Liang et al., 1996) is a macro-scale, distributed, physically based hydrologic model that balances both surface energy and water over a grid mesh. A "mosaic" land surface scheme allows the VIC model to represent the subgrid scale spatial variability in topography and vegetation/land cover. This is especially important when simulating the hydrologic response in complex terrain and in snow-dominated regions. The VIC model also features a nonlinear mechanism for simulating slow (base flow) runoff response and explicit treatment of vegetation canopy on the surface energy balance. Following the simulation of the water and energy budgets by the

VIC model, a second program within VIC is used to route the derived runoff through a defined river system to obtain streamflow at specified points.

Wanger regulations (Wanger, 2007; 2008), named after Judge Oliver Wanger of the US Eastern District Court. Judge Wanger's ruling in *Natural Resources Defense Council v. Kempthorne* (E.D. California, Case No. 1:05-CV-1207) invalidated the US Fish and Wildlife Service's 2004 biological opinion that addressed impacts of DWR and USBR joint operations of the State Water Project and Central Valley Project on the delta smelt. The result of the ruling was a narrowing of the time window of Delta pump operations and placement of additional restrictions on Delta exports during December through June to provide increased protection for the delta smelt.

X2, a measure for Delta salinity standard, is the location of the 2 parts per thousand salinity contour (isohaline), one meter off the bottom of the estuary, as measured in kilometers upstream from the Golden Gate Bridge. An electrical conductivity value of 2.64 mmhos/cm is used to represent the X2 location (State Water Board, 2000).

Summary of Planning Studies Surveyed and Type of Climate Change Analysis Conducted

Study Aspect/Sl. No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Planning Study Name	**CWP Update 2009 - B160**	**2006 SWP/CVP Impacts Report**	**2009 SWP/CVP Impacts Report**	**SWP Delivery Reliability Report 2009**	**Management Response Status Report**	**DRMS Phase 1 Report**	**Monterey Plus FEIR 2010**	**Salton Sea Ecosystem Restoration Program**	**Oroville Facilities Relicensing**	**BDCP and DHCCP Operations and Planning**	**CVP/SWP OCAP BA**	**Los Vaqueros Reservoir Expansion EIR/EIS**	**CVP IRP**
Publication/Analysis Completion Date	March 2010	July 2006	April 2009	December 2009	February 2010	December 2008	February 2010	2007	July 2008	In progress.	August 2008	March 2010	In progress
Project/General Study	General Study	General Study	General Study	General Study	General Study	General Study	Project	Project	Project	Project	Project	Project	Project
DWR's Role	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Study	DWR Participant	DWR Participant	DWR Participant	Other Related
Section Reference	Section III.B.1.i	Section III.B.1.ii	Section III.B.1.ii	Section III.B.1.iii	Section III.B.1.iv	Section III.B.1.v	Section III.B.2.i	Section III.B.2.ii	Section III.B.2.iii	Section III.C.2.i	Section III.C.2.ii	Section III.C.2.iii	Section III.D.1
Planning Horizon	2050	2050 (mid-century).	2045 (mid-century); 2085 (end of	2029	2045	50-, 100-, and 200- years from the	2020	2078	2058	2015; 2025; and 2060.	2025 and 2050.	2030	2030, 2060, and 2085.
Spatial Coverage	Statewide	Central Valley and SWP/CVP service areas.	Central Valley and SWP/CVP service areas.	Central Valley and SWP service areas.	Statewide	Central Valley and the Delta.	Central Valley and SWP service areas.	Salton Sea area	Central Valley and SWP service areas.	Central Valley, SWP/CVP service areas, and the Delta.	Central Valley, SWP/CVP service areas, and the Delta.	The Delta and the Bay area.	Central Valley and CVP service areas.
Climate Analysis Approach	CAT 2009 Approach (Scenario Analysis)	CAT 2006 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	CAT 2009 Approach (Scenario Analysis)	A Monte Carlo sensitivity analysis approach based on results from the CAT 2006 study and others.	Relative change ("Delta") approach based on results from the 2006 SWP/CVP Impacts Report	A Monte Carlo sensitivity analysis approach based on results from the CAT 2006 study.	Qualitative approach.	Ensemble informed approach.	Bracketing scenario analysis approach.	Qualitative approach based on results from the 2006 SWP/CVP Impacts Report and OCAP BA.	Ensemble informed approach.
Number of GCMs Considered	6	2	6	6	6	13	2	2	Not applicable.	16	16	2	16
Emission Scenarios Considered	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A2 and B1	SRES A1b, A2, and B1	SRES A2 and B1	SRES A2 and B1	Not applicable.	SRES A2, B1, and A1b.	SRES A2, B1, and A1b.	SRES A2 and B1	SRES A2, B1, and A1b.
Number of Projections Considered	12	4	12	12	12	4 from CAT 2006 plus others.	4	4	Not applicable.	112	112	4	112
Regional Downscaling	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Bias Correction, Spatial Downscaling (BCSD).	Not applicable.	Not applicable.	Not applicable.	Bias Correction Spatial Downscaling (BCSD).	Bias Correction Spatial Downscaling (BCSD)	Not applicable.	Bias Correction Spatial Downscaling (BCSD)
Scenario Selection	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 12 scenarios.	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 4 scenarios.	Individual scenarios based on output availability, reasonable representation of historical climate, skewed to drier conditions. A total of 12 scenarios.	A single representative median scenario (MPI ECHAM5 with higher emissions SRES A2) based on a set of climatology, hydrology, and related effects metrics.	A single representative scenario (GFDL CM2.1 with higher emissions SRES A2) based on producing average water delivery impacts. Also for sensitivity analysis, all 12 CAT 2009 scenarios.	A total of 84 scenarios using a probabilistic, Monte Carlo approach, based on data from 4 CAT 2006 scenarios.	Results from a single scenario (GFDL CM2.1 with higher emissions SRES A2) from the 2006 SWP/CVP Impacts Report, based on producing largest average annual impact on SWP deliveries.	A total of 1000 scenarios using a probabilistic, Monte Carlo approach, based on data from 4 CAT 2006 scenarios.	Not applicable.	Ensemble-informed scenarios, based on joint ΔT-ΔP distributions as partitioned into statistical regions representing range of all 112 projections; done for each downscaled grid cell (1/8th degree). A central tendency scenario: by aggregating all projections falling within the inner-quartiles, 25th to 75th percentile. Four additional scenarios: by aggregating the ten projections based on normalized distance from joint ΔT-ΔP distributions	Climate change scenarios based on individual projections based on 10^{th} and 90^{th} percentile of period average ΔT and ΔP. A total of 4 scenarios.	Not applicable.	BDCP approach (ensemble informed)
Climate Variables Adjusted	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed)	P, Tavg, Tmin, Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed), and wind velocity	Not applicable.	Not applicable.	Not applicable.	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg change, wind speed not changed)	Not applicable.	P, Tavg, Tmin, and Tmax (Tmin and Tmax adjusted based on Tavg, wind speed not changed).

Study Aspect/Sl. No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Planning Study Name	**CWP Update 2009 - B160**	**2006 SWP/CVP Impacts Report**	**2009 SWP/CVP Impacts Report**	**SWP Delivery Reliability Report 2009**	**Management Response Status Report**	**DRMS Phase 1 Report**	**Monterey Plus FEIR 2010**	**Salton Sea Ecosystem Restoration Program**	**Oroville Facilities Relicensing**	**BDCP and DHCCP Operations and Planning**	**CVP/SWP OCAP BA**	**Los Vaqueros Reservoir Expansion EIR/EIS**	**CVP IRP**
Climate Variability Adjustment	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Not applicable.	Not applicable.	Not applicable.	Statistically-mapped onto historic climate. Reflects observed sequence with monthly variability adjustments based on statistical shifts from climate scenarios (quantile	Direct from downscaled climate projection. Reflects monthly sequence and variability from individual downscaled climate projection.	Not applicable.	CAT 2009 and BDCP approaches.
Sea Level Rise Projection[1]	None	1-foot at 2050.	1-foot at 2045; 2-feet at 2085.	1-foot at 2029.	1-foot at 2050.	Time series reflecting short-term variations, in addition to long-term variations (11 - 41 cm for year 2050;	Not considered.	Not applicable.	Not applicable.	6" at 2025 and 18" at 2060.	1-foot sea level rise at 2030, coupled with a 10% increase in tidal amplitude.	Not applicable.	Results from BDCP will be used.
Hydrologic Model	WEAP	VIC	VIC	VIC	VIC	VIC	Not applicable.	Not applicable.	Not applicable.	VIC	VIC and Sac-SMA/Snow 17.	Not applicable.	WEAP
Hydrologic Simulation Period	Reliance on projection period and sequence: 45-year simulations aligned with future period 2006-2050.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2035-2064 for 2050.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2030-2059, and 2070-2099.	Reliance on projection period and sequence: 30-year simulations aligned with future periods, based on 2009 SWP/CVP Impacts Report.	Reliance on projection period and sequence: 30-year simulations aligned with future periods, based on 2009 SWP/CVP Impacts Report.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2035-2064 for 2050, and 2070–2100 for 2085.	Not applicable.	Not applicable.	Not applicable.	Reliance on observed sequences with adjustments based on statistical shifts aligned with future period: 50-year simulations 1950-1999	Reliance on projection period and sequence: 30-year simulations aligned with future period 2011-2040 for 2025; 2036-2065 for 2050	Not applicable.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2011-2050 for 2030, 2051-2070 for 2060, and 2071-2100 for 2085.
Streamflow Adjustment	None.	A single step perturbation based on average monthly ΔQ % from historical data (i.e., all Octobers perturbed by same %). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	A three-step perturbation based on time series of monthly ΔQ % from historical data (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Not applicable.	Not applicable.	Not applicable.	Time series of monthly ΔQ % from hydrologic model (each October may have different adjustment). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Perturbations based on average monthly ΔQ % from hydrologic model (i.e. all Octobers perturbed by same %). Correction based on annual ΔQ. Historic time reference used is 1976 for the 1961-1990.	Not applicable.	None.
Streamflow Sequence for Operations Modeling	Reliance on projection period and sequence: 45-year simulations aligned with future period 2006-2050.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 73-year simulations 1922-1994.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 73-year simulations 1922-1994.	Reliance on projection period and sequence: 72-year simulations aligned with future period 2005-2078, based on data from historical period 1950-2002.	Not applicable.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Reliance on observed sequences, with adjustments for climate induced changes in the future period: 82-year simulations 1922-2003.	Not applicable.	Reliance on projection period and sequence: 30-year simulations aligned with future periods: 2011-2050 for 2030, 2051-2070 for 2060, and 2071-2100 for 2085.

[1]Most of the recent studies reported herein use sea-level rise estimates based on a methodology that relates observed global mean sea level rise to global mean surface air temperature (Rahmstorf, 2007). This methodology allows estimations of global sea level rise using the surface air temperature projected by the GCM simulations. An important assumption implicit in the use of this methodology for California is that sea level rise along the California coast will mirror estimates of global sea level rise.