CLIMATE CHANGE MODELING FOR THE BDCP / WATERFIX

Figure 1. Hierarchy of models

Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4 p. 43.

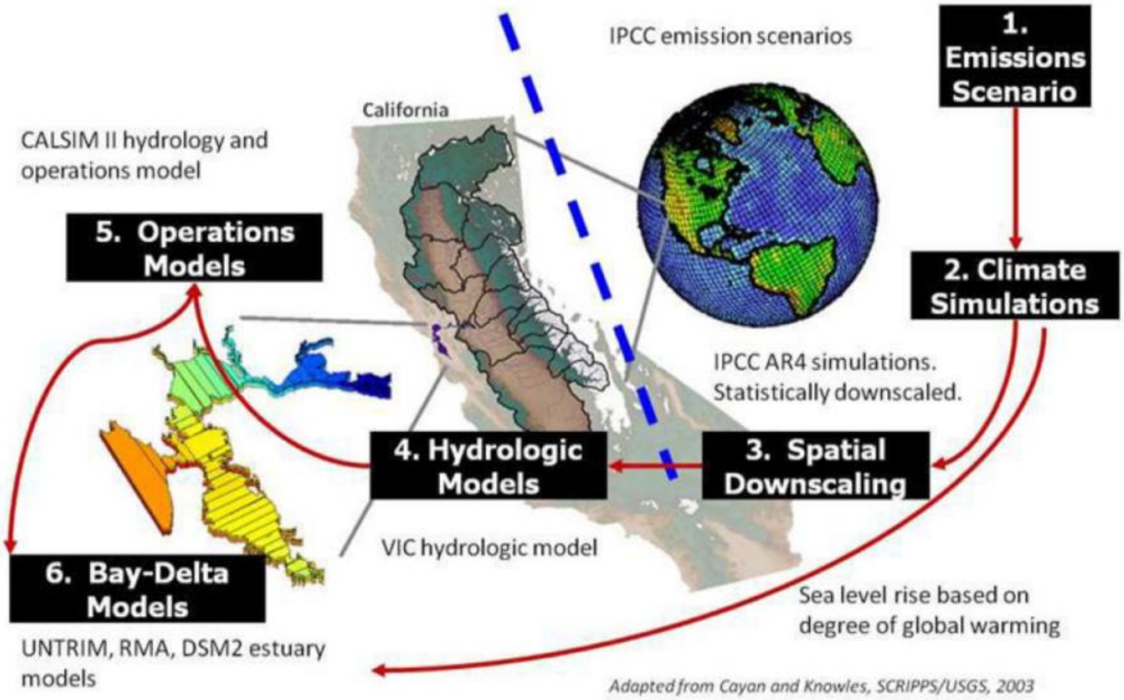


Figure 20. Graphical depiction of the analytical process for incorporating climate change into water planning.

SEA LEVEL RISE ESTIMATES

Figure 2. From the 2009 Climate Action Team, using the method of Rahmstorf

BDCP EIR/EIS Appendix 5A-D, SWRCB-4, p. 17.

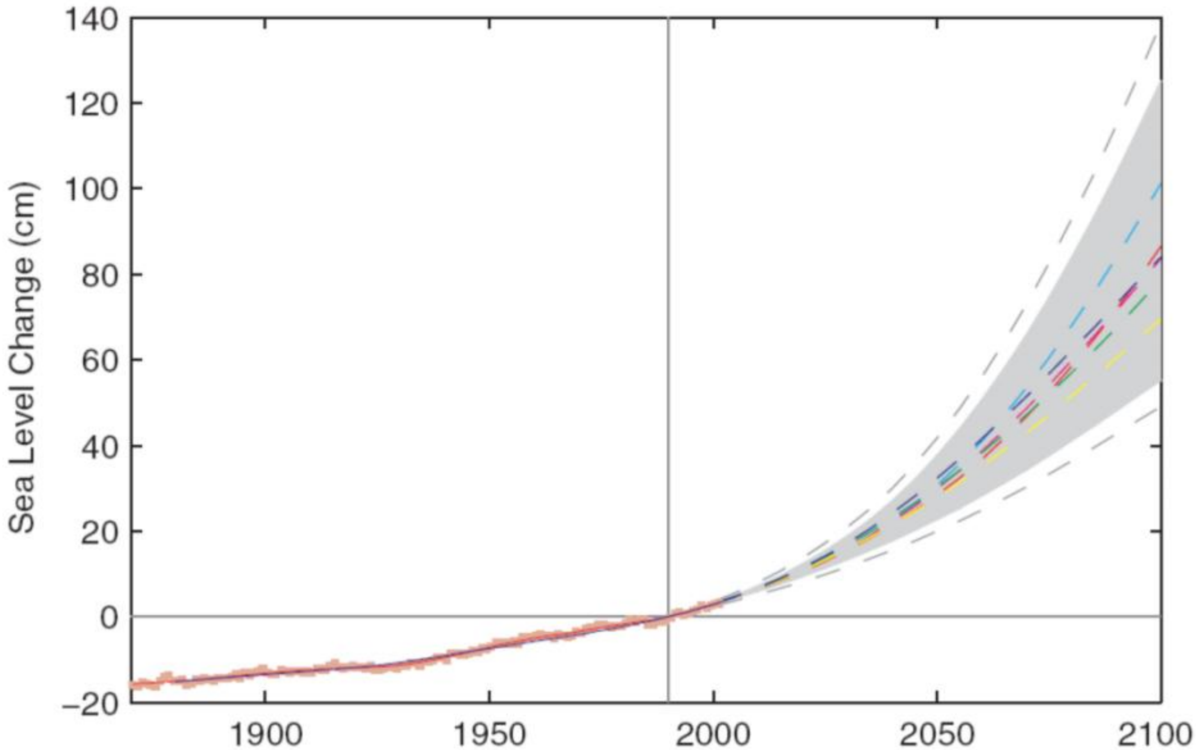


Figure 11. Past global mean sea level and future mean sea level based on global mean temperature projections (Ramsdorf 2007).

1 meter = 100 cm = 39 inches, 3.25 feet

1.4 meters = 140 cm = 55 inches, 4.6 feet

SEA LEVEL RISE ESTIMATES

Figure 3. Department of Water Resources 2009 Sea Level Rise Projections for the Bay Delta

BDCP EIR/EIS Appendix 5A-D, SWRCB-4, p.18.

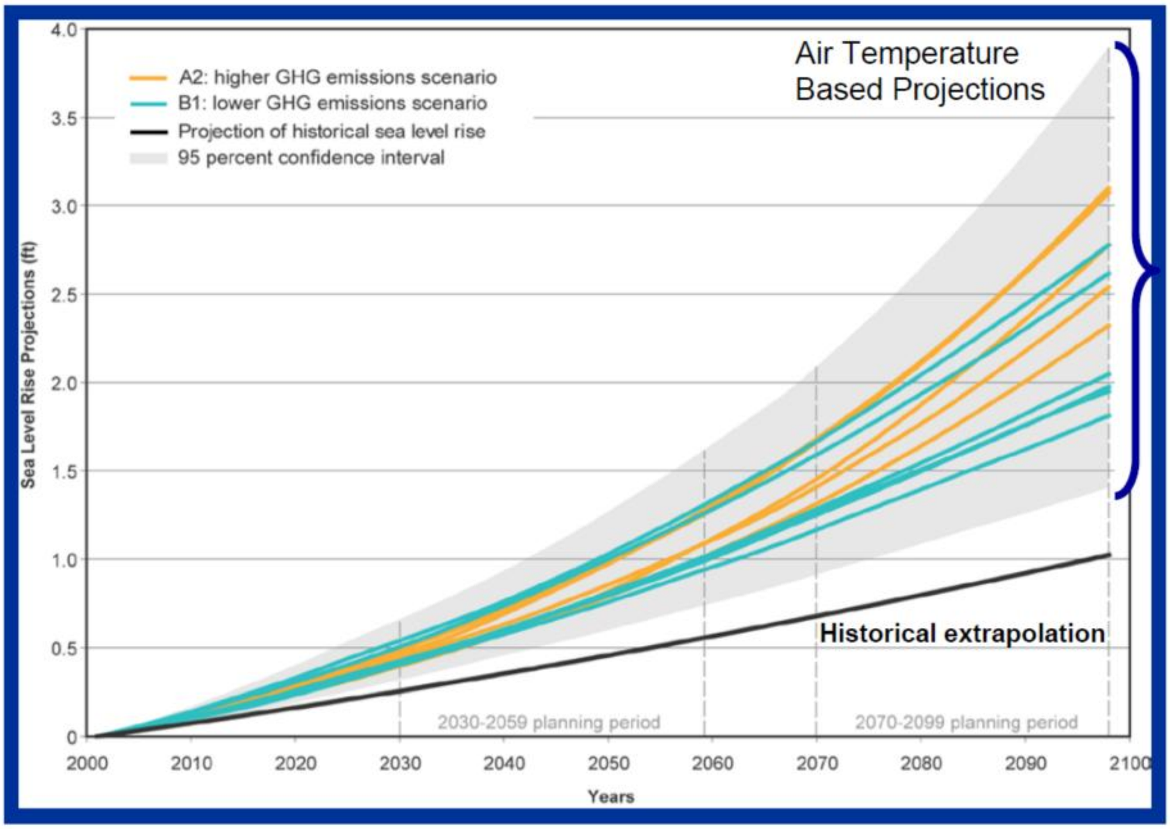


Figure 12. DWR-generated future sea level rise projections based on 12 CAT scenario projections using Ramsdorf method (Chung et al 2009).

SEA LEVEL RISE ESTIMATES

Figure 4. From NOAA *Climate Program Office*, *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (December 2012), Exhibit PCFFA-10, p. 3.

2 meters = 79 inches, 6.6 feet

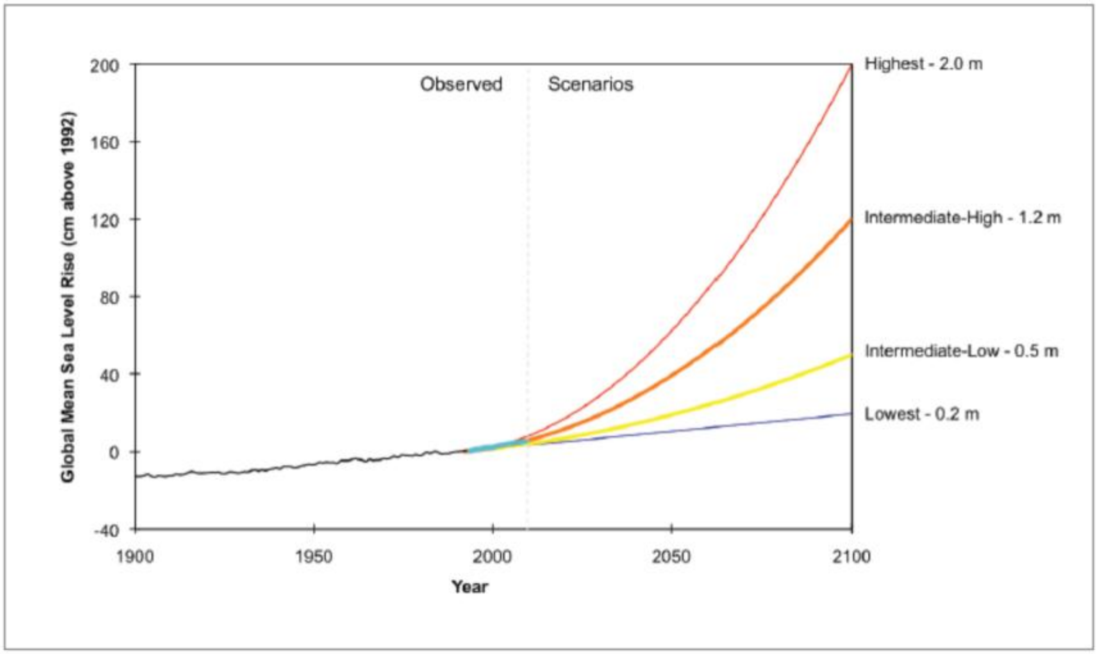
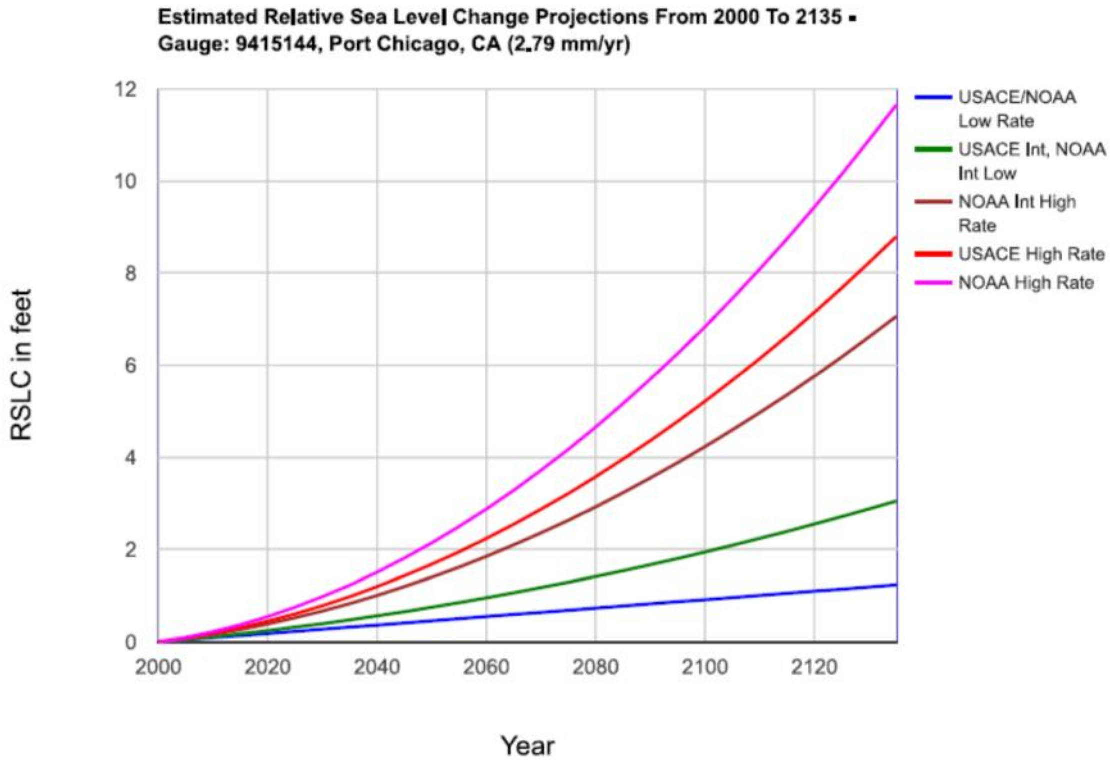


Figure ES 1. Global mean sea level rise scenarios. Present Mean Sea Level (MSL) for the US coasts is determined from the National Tidal Datum Epoch (NTDE) provided by NOAA. The NTDE is calculated using tide gauge observations from 1983 – 2001. Therefore, we use 1992, the mid-point of the NTDE, as a starting point for the projected curves. The Intermediate-High Scenario is an average of the high end of ranges of global mean SLR reported by several studies using semi-empirical approaches. The Intermediate Low Scenario is the global mean SLR projection from the IPCC AR4 at the 95% confidence interval.

SEA LEVEL RISE ESTIMATES

Figure 5. From the United States Army Corps of Engineers online calculator, regionally corrected sea level rise estimates for Port Chicago, accessed on August 16, 2016. Exhibit PCFFA-65.



Showing 100 year sea level rise estimates, the projected lifetime of the WaterFix

CMIP3 GLOBAL CIRCULATION MODEL DATABASE

Figure 6. From Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4, p. 34.

TABLE 2
General Circulation Models used in the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) Database

Modeling Group, Country	WCRP CMIP3 I.D.
Bjerknes Centre for Climate Research	BCCR-BCM2.0
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies, USA	GISS-ER
Institute for Numerical Mathematics, Russia	INM-CM3.0
Institut Pierre Simon Laplace, France	IPSL-CM4
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM
Meteorological Research Institute, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research, USA	CCSM3
National Center for Atmospheric Research, USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3

REGIONAL BIAS IN CMIP3 ENSEMBLE OF GLOBAL CLIMATE MODELS

Figure 7. From Flato et. al., Evaluation of Climate Models, Exhibit PCFFA-68, p. 812

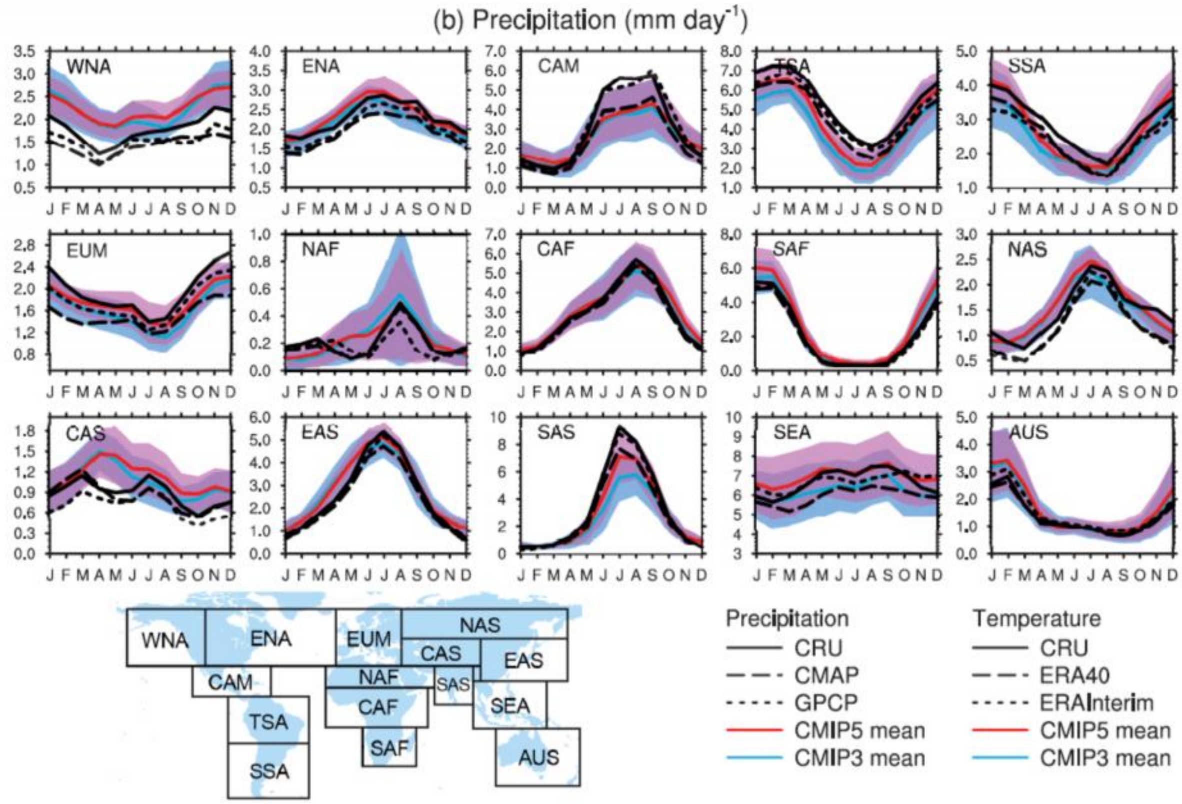
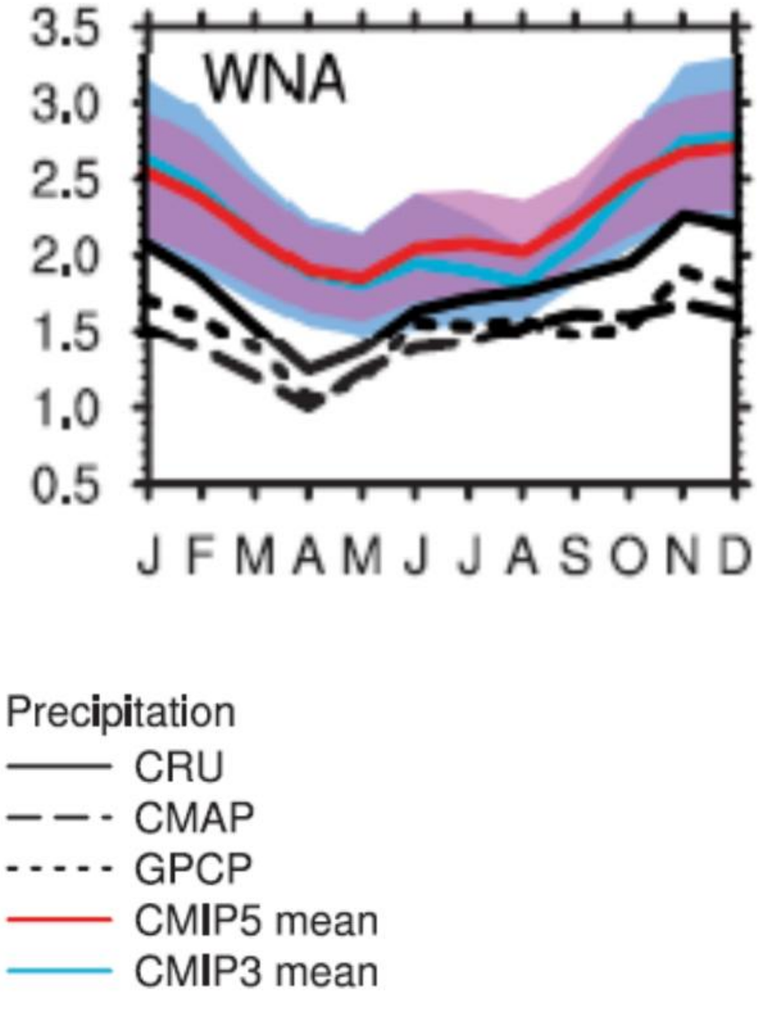


Figure 9.38 | Mean seasonal cycle of (a) temperature (°C) and (b) precipitation (mm day^{-1}). The average is taken over land areas within the indicated regions, and over the period 1980–1999. The red line is the average over 45 CMIP5 models; the blue line is the average over 22 CMIP3 models. The standard deviation of the respective data set is indicated with shading. The different line styles in black refer to observational and reanalysis data: Climatic Research Unit (CRU) TS3.10, ECMWF 40-year reanalysis (ERA40) and ERA-Interim for temperature; CRU TS3.10.1, Global Precipitation Climatology Project (GPCP), and CPC Merged Analysis of Precipitation (CMAP) for precipitation. Note the different axis-ranges for some of the sub-plots. The 15 regions shown are: Western North America (WNA), Eastern North America (ENA), Central America (CAM), Tropical South America (TSA), Southern South America (SSA), Europe and Mediterranean (EUM), North Africa (NAF), Central Africa (CAF), South Africa (SAF), North Asia (NAS), Central Asia (CAS), East Asia (EAS), South Asia (SAS), Southeast Asia (SEA) and Australia (AUS).

REGIONAL BIAS IN CMIP3 ENSEMBLE OF GLOBAL CLIMATE MODELS

Figure 8. From Flako et. al., Evaluation of Climate Models, Exhibit PCFFA-68, p. 812, closeup of Western North America (WNA).



REGIONAL BIAS IN CMIP3 ENSEMBLE OF GLOBAL CLIMATE MODELS

Figure 9. Regional Temperature and Precipitation Bias

From Flato et. al., Evaluation of Climate Models, Exhibit PCFFA-68, p. 813

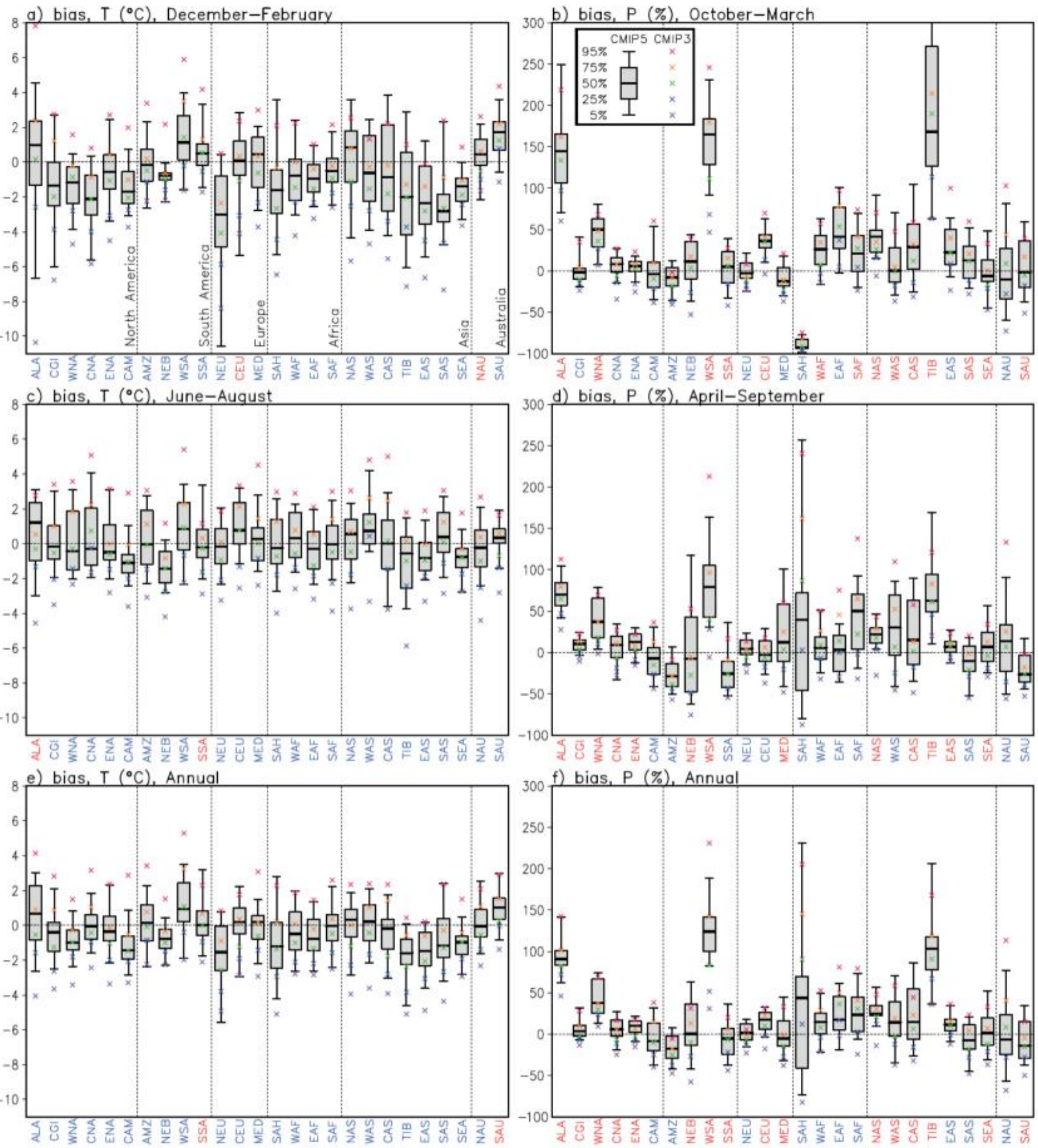
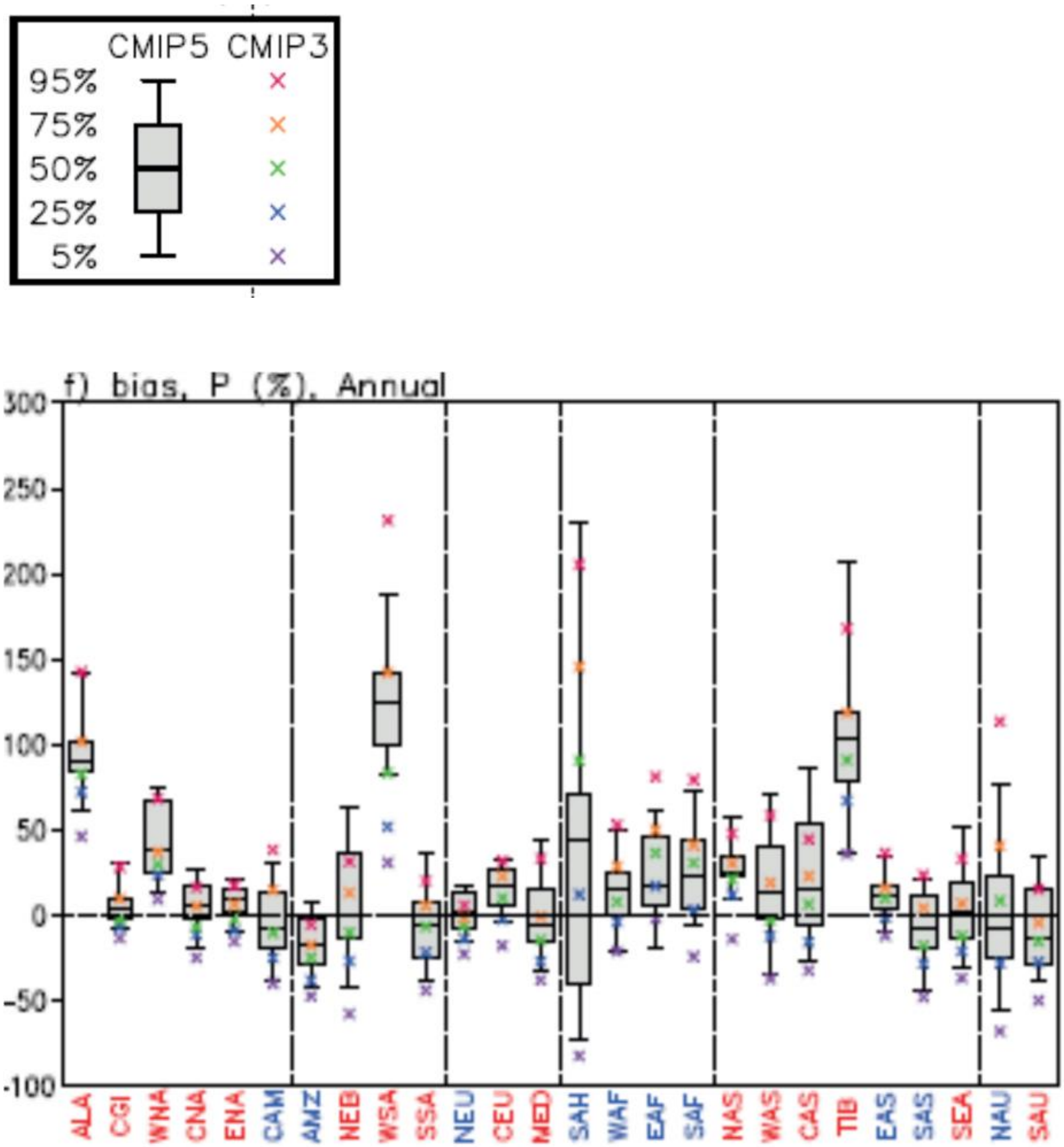


Figure 9.39 | Seasonal- and annual mean biases of (left) temperature (°C) and (right) precipitation (%) in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) land regions (cf. Seneviratne et al., 2012, p. 12. The region's coordinates can be found from their online Appendix 3.A). The 5th, 25th, 50th, 75th and 95th percentiles of the biases in 42 CMIP5 models are shown in box-and-whisker format, and corresponding values for 23 CMIP3 models with crosses. The CMIP3 20C3M simulations are complemented with the corresponding A1B runs for the 2001–2005 period. The biases are calculated over 1986–2005, using Climatic Research Unit (CRU) T3.10 as the reference for temperature and CRU TS 3.10.01 for precipitation. The regions are labelled with red when the root-mean-square error for the individual CMIP5 models is larger than that for CMIP3 and blue when it is smaller. The regions are: Alaska/NW Canada (ALA), Eastern Canada/Greenland/Iceland (CGI), Western North America (WNA), Central North America (CNA), Eastern North America (ENA), Central America/Mexico (CAM), Amazon (AMZ), NE Brazil (NEB), West Coast South America (WSA), South-Eastern South America (SSA), Northern Europe (NEU), Central Europe (CEU), Southern Europe/the Mediterranean (MED), Sahara (SAH), Western Africa (WAF), Eastern Africa (EAF), Southern Africa (SAF), Northern Asia (NAS), Western Asia (WAS), Central Asia (CAS), Tibetan Plateau (TIB), Eastern Asia (EAS), Southern Asia (SAS), Southeast Asia (SEA), Northern Australia (NAS) and Southern Australia/New Zealand (SAU). Note that the region WSA is poorly resolved in the models.

REGIONAL BIAS IN CMIP3 ENSEMBLE OF GLOBAL CLIMATE MODELS

Figure 10. Closeup of Western North America (WNA) annual precipitation bias,

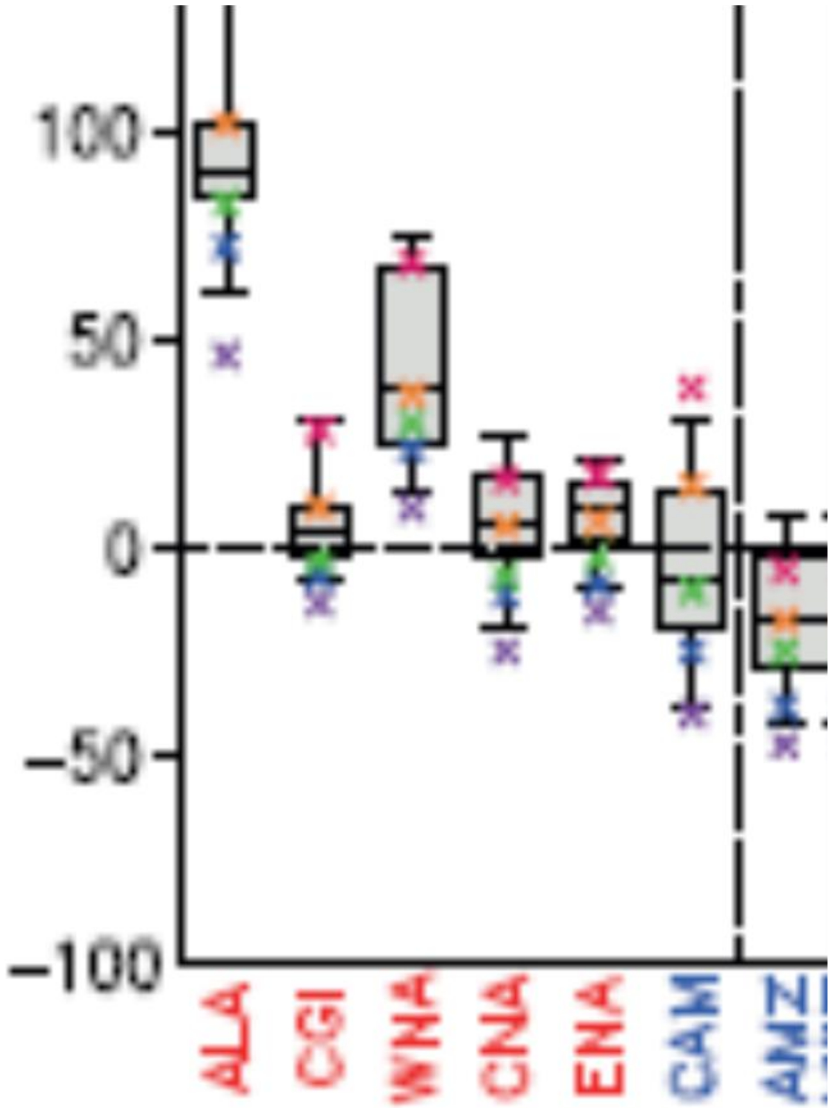
From Flato et. al., Evaluation of Climate Models, Exhibit PCFFA-68, p. 813



REGIONAL BIAS IN CMIP3 ENSEMBLE OF GLOBAL CLIMATE MODELS

Figure 11. Expanded closeup of Western North America (WNA) annual precipitation bias,

From Flato et. al., Evaluation of Climate Models, Exhibit PCFFA-68, p. 813



SELECTING GLOBAL CLIMATE MODELS

Figure 12. Recommendations of DWR's Climate Change Technical Advisory Group,

From DWR, Perspectives and Guidance for Climate Change Analysis, PCFFA-70, p.43.

Figure 2-1 Three-Step Process for Selecting Global Climate Models to Use for California Water Resources

SACRAMENTO PRECIPITATION PROJECTIONS

Figure 13. From the Climate Action Team, 2009 Climate Change Scenarios Assessment, Cayan et al., PCFFA-69, p. 33.

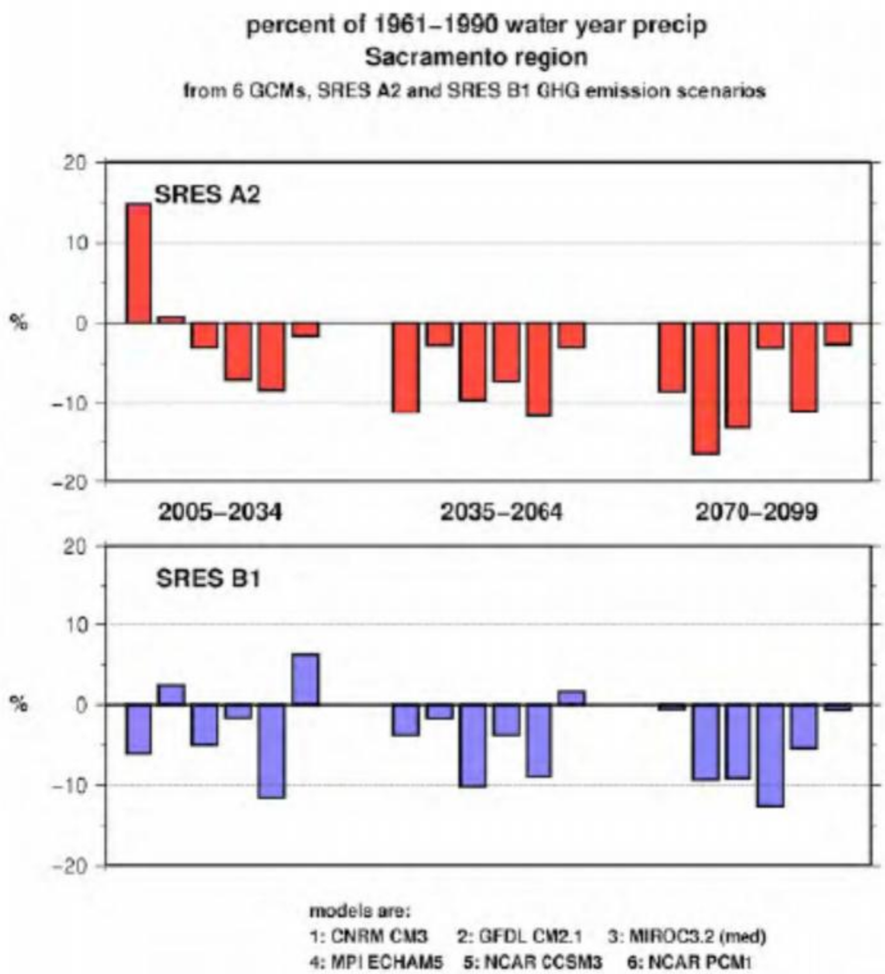


Figure 11. Differences in 30-year mean annual total precipitation of early (2005–2034), middle (2035–2064), and late (2070–2099) twenty-first century relative to 1961–1990 climatology for each of six GCMs, for SRES B1 (lower; blue) and SRES A2 (upper; red). Precipitation is taken directly from the GCMs from the grid point nearest to Sacramento.

PROJECTED INCREASE IN DRY AND CRITICALLY DRY YEARS

Figure 14. From Sarah Null et. al., Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates, Exhibit PCFFA 72, p. 15

Table 6. Percentage of Years in Each Water Type by Modeled Time Period and Emissions Scenario (italicized values are percent change from historical period)

	SVI					
	1951-2000 (%)		2001-2050 (%)		2051-2099 (%)	
	A2	B1	A2	B1	A2	B1
Critical	8.7	8.3	11.3 *(2.7)*	6.7 *(-1.7)*	18.4 *(9.7)*	14.0 *(5.6)*
Dry	7.7	10.0	12.0 *(4.3)*	15.7 *(5.7)*	19.4 *(11.7)*	20.1 *(10.1)*
Below Normal	23.3	21.3	23.3 *(0.0)*	17.3 *(-4.0)*	18.7 *(-4.6)*	19.4 *(-1.9)*
Above Normal	21.0	22.7	16.7 *(-4.3)*	20.7 *(-2.0)*	12.9 *(-8.1)*	18.4 *(-4.3)*
Wet	39.3	37.7	36.7 *(-2.7)*	39.7 *(2.0)*	30.6 *(-8.7)*	28.2 *(-9.4)*

Comments: The table shows water year types, averaged over all six GCM models in the study, for the two greenhouse gas emissions scenarios.

The medium-high emissions scenario (A2) projections showed dry and critically dry years in the Sacramento Valley increasing to 23% of all years between 2000 and 2050, and to 38% of all years in the latter half of the century. Under this scenario, the incidence of dry and critically dry years would more than double. The projections also showed a decrease in wet years.

In the Sacramento Valley, the A2 projections showed wet and above normal years decreased to 53% of all years in 2000-2050, and to 41.5% of years by the latter half of the century.

The lower greenhouse gas emissions scenario (B1) showed similar but less dramatic shifts.

PROJECTED INCREASE IN DRY AND CRITICALLY DRY YEARS

Figure 15. From Sarah Null et. al., PCFFA 72, p. 19

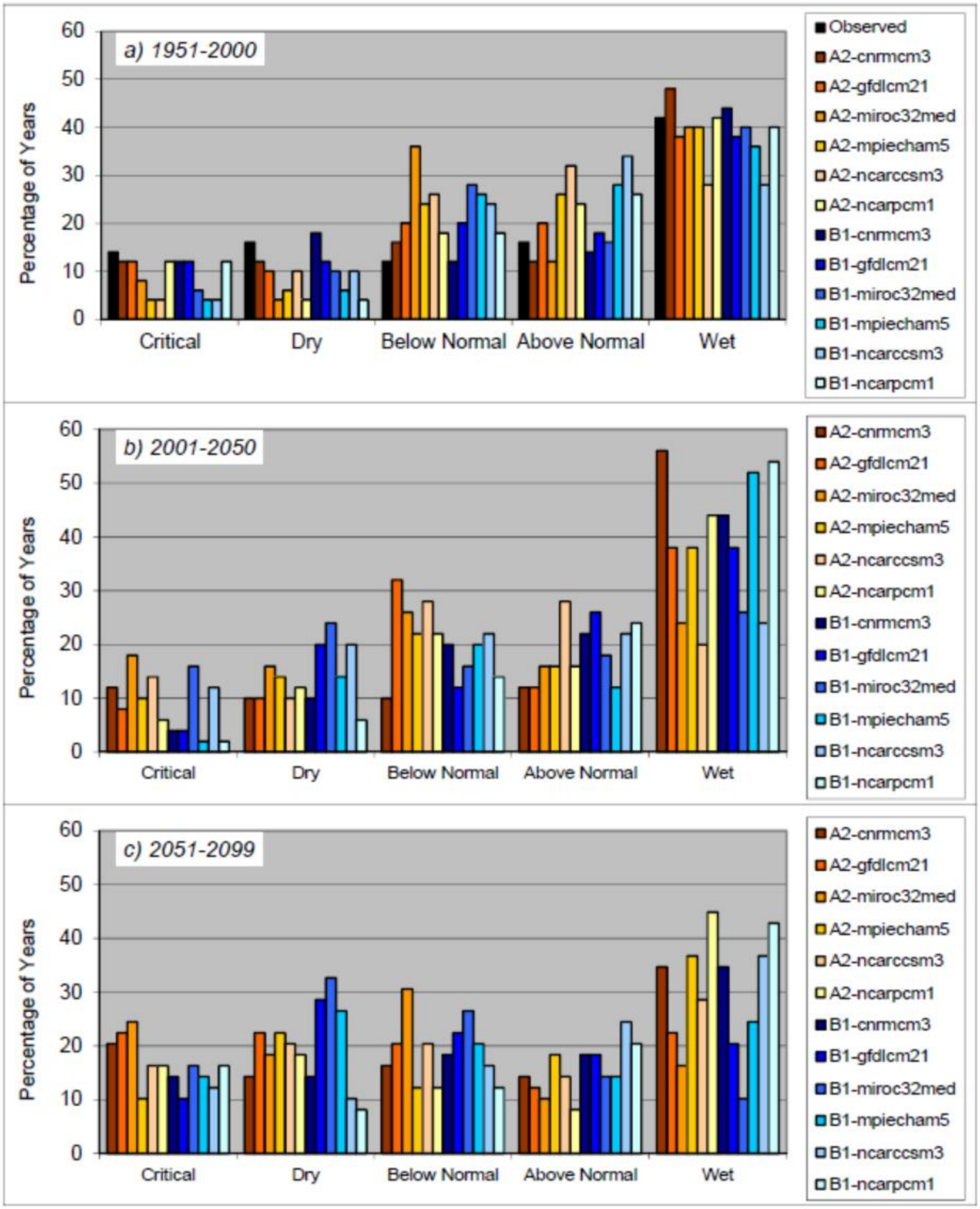


Figure 6. SVI Relative Frequency Histograms for (a) 1951-2000, (b) 2001-2050, and (c) 2051-2099

PROJECTED INCREASE IN DRY AND CRITICALLY DRY YEARS

Figure 16. From Sarah Null et. al., PCFFA 72, p. 20

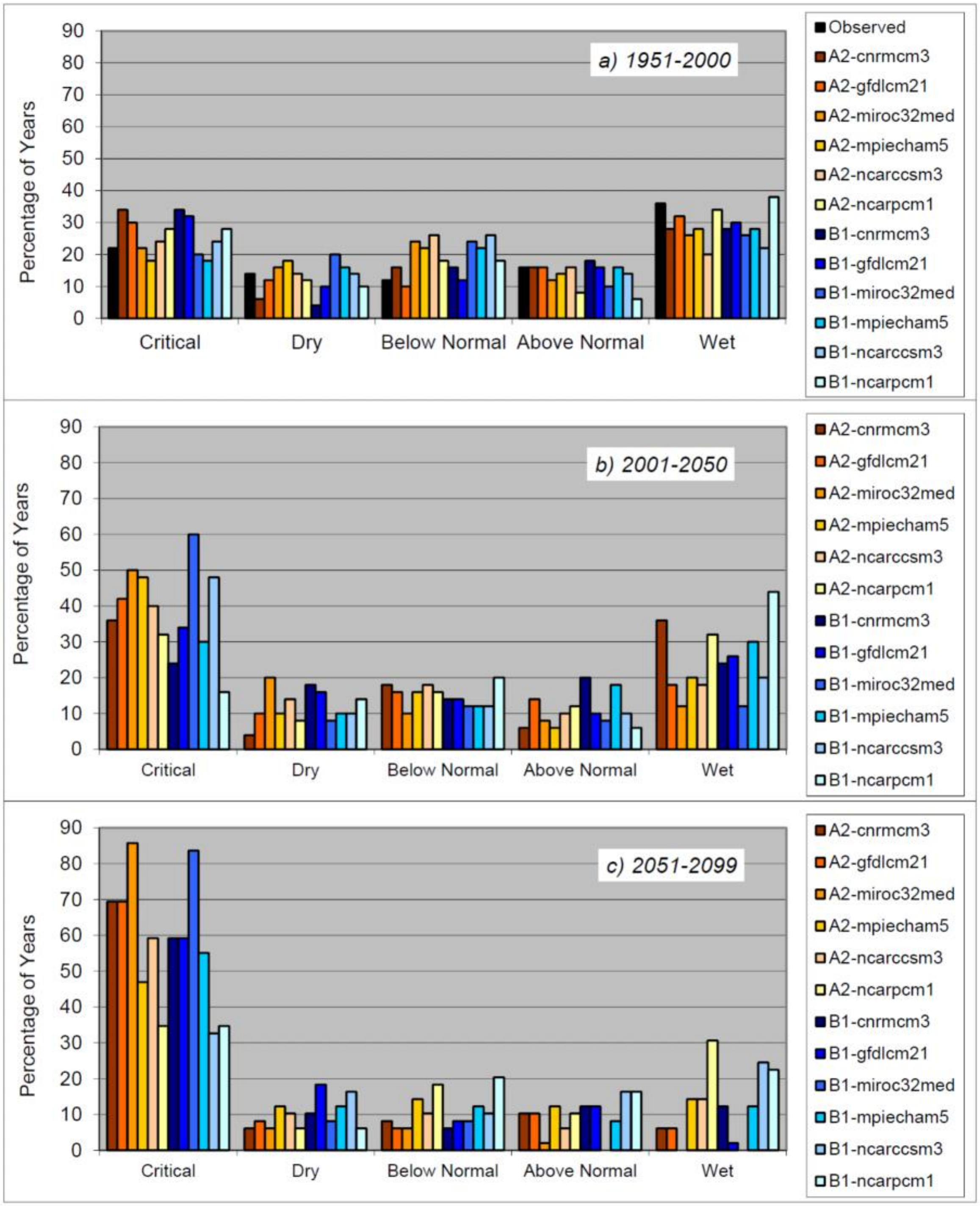
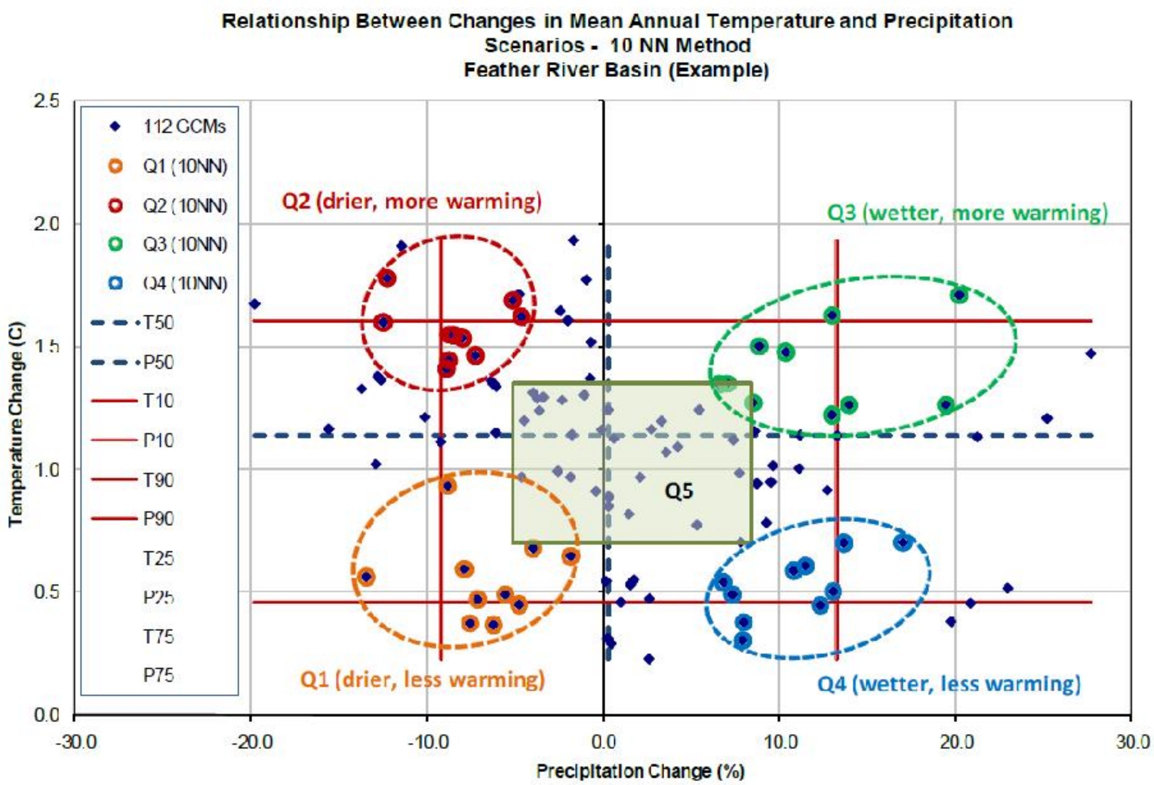


Figure 7. SJI Relative Frequency Histograms for (a) 1951–2000, (b) 2001–2050, and (c) 2051–2099

Figure 17. From Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4 p. 36.



BDCP APPROACH TO UNCERTAINTY IN CLIMATE CHANGE SCENARIOS

Figure 18. Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4 p. 44.

Table 2. Recommended Analytical Tools and Timelines for Consideration of Climate Change Implications

		Uncertainty in Regional Climate Change: Scenarios (Quadrant Approach)					
Uncertainty in Sea Level Rise	**SLR (cm)**	**No Climate Change**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5 (central)**
	0	NT, ELT, LLT	S	S	S	S	S
	15 (central)	S	ELT	ELT	ELT	ELT	ELT
	30	S					
	45 (central)	S	LLT	LLT	LLT	LLT	LLT
	60	S					
	140	S					
	140 + 5% amplitude increase	S					

NT = Near-Term; ELT = Early Long-Term; LLT = Late Long-Term; S = Sensitivity analysis; FNA = Future No Action

CALSIM II & DSM2 (FNA + Alternatives)

CALSIM only (FNA + Alternatives bracketing analysis)

S Sensitivity Analysis (FNA only)

No modeling

BDCP APPROACH TO UNCERTAINTY IN REGIONAL CLIMATE CHANGE SCENARIOS

Figure 19. Appendix 5A-D of the BDCP DEIR/DEIS, SWRCB-4, p. 72.

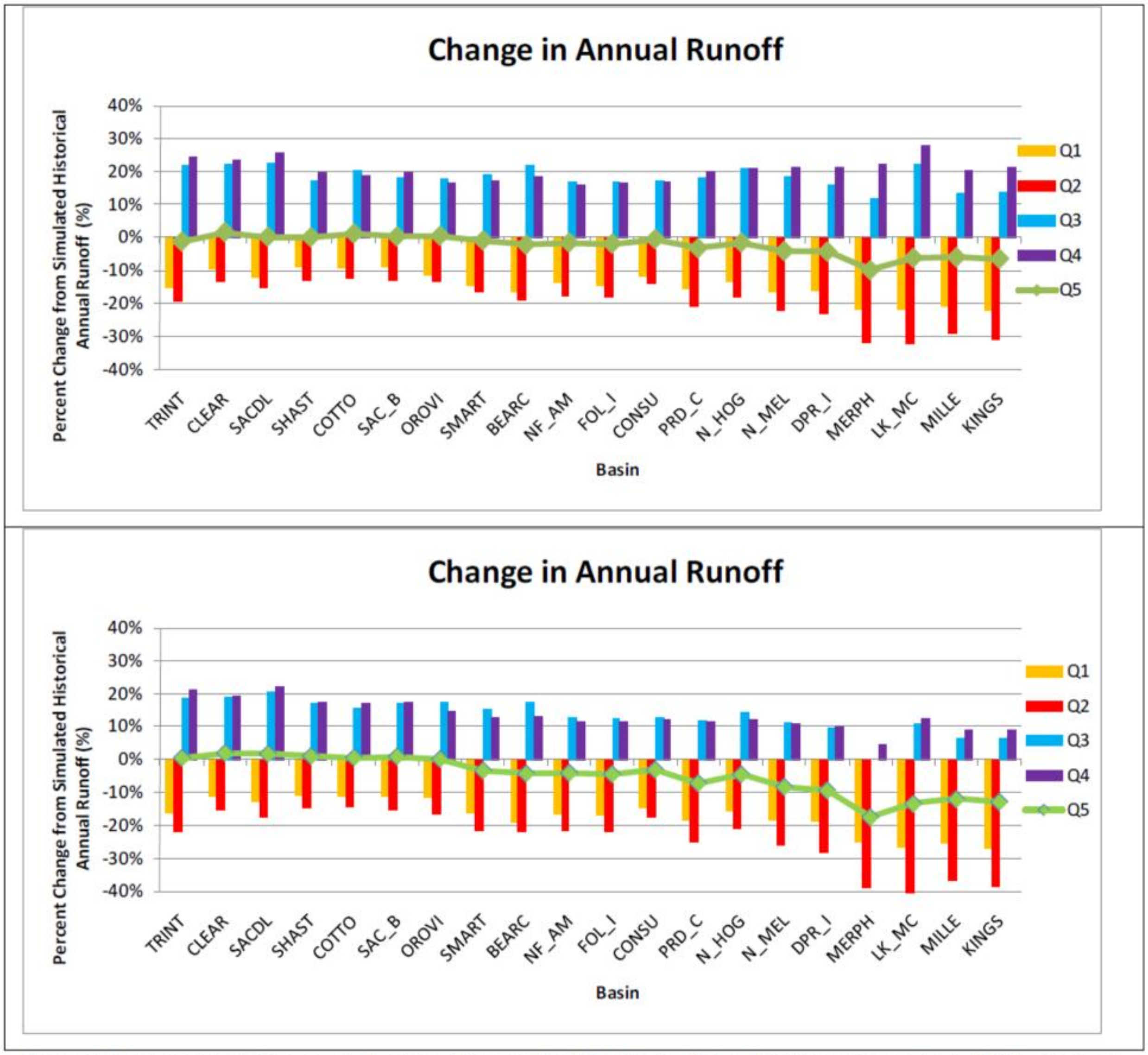


Figure 2-3: Simulated Changes in Natural Streamflow for Each of the VIC Simulations (top, 2025 changes; bottom, 2060 changes).

WATERFIX OPERATIONS SENSITIVITY TO CLIMATE CHANGE

Figure 20. SWRCB-104 (Appendix 5A), p. 120.

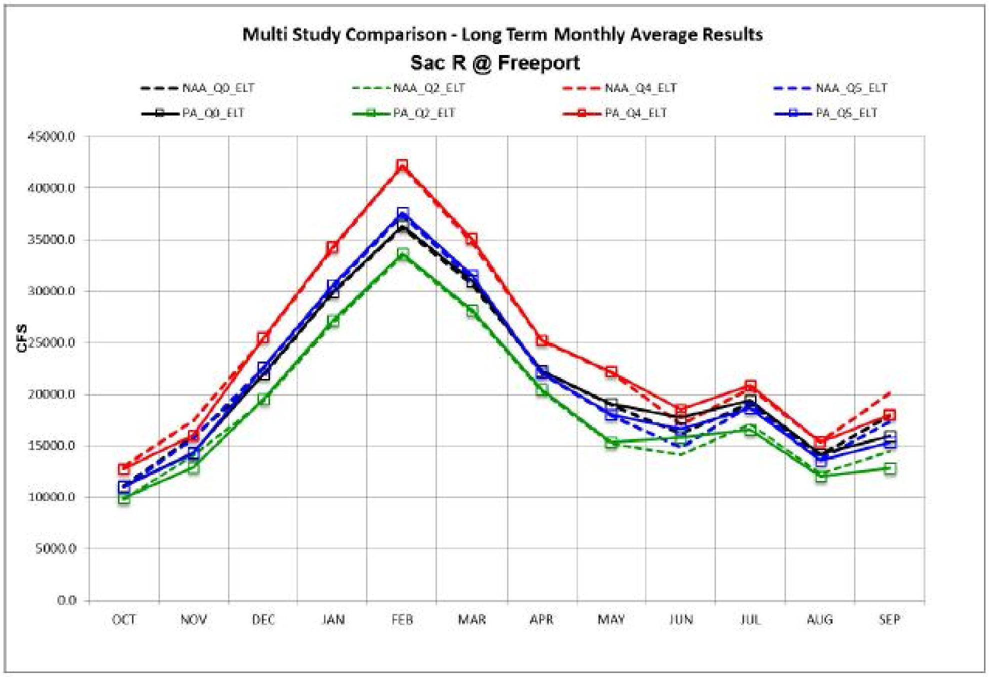


Figure 5.A.A.3-12 Sacramento River at Freeport Monthly Flow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

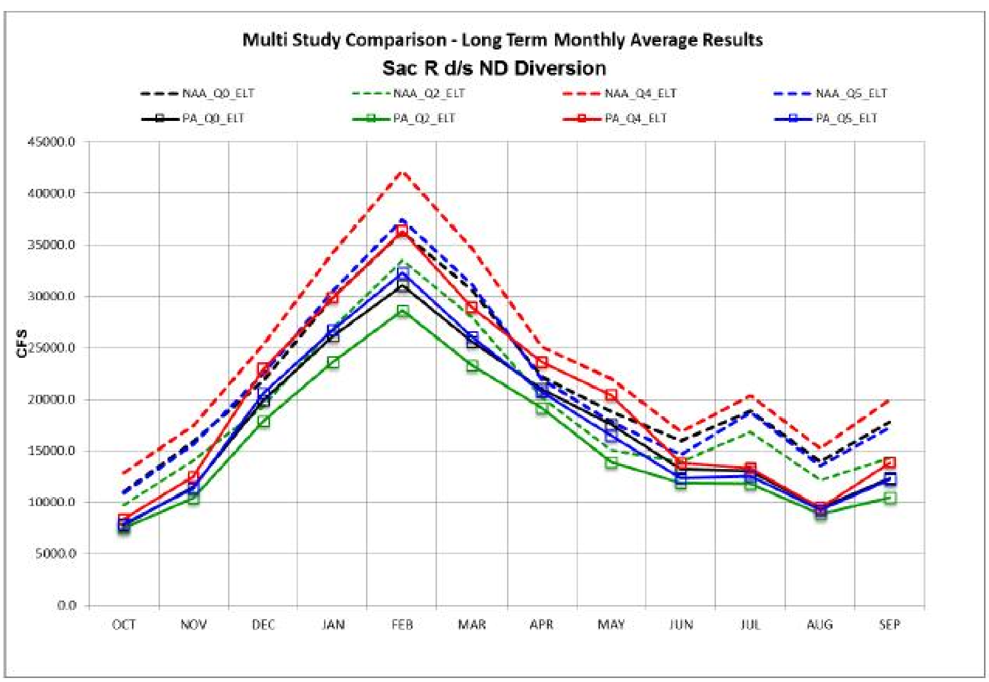


Figure 5.A.A.3-13 Sacramento River downstream of North Delta Diversion Monthly Flow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

Figure 21. SWRCB-104 (Appendix 5A), p. 122.

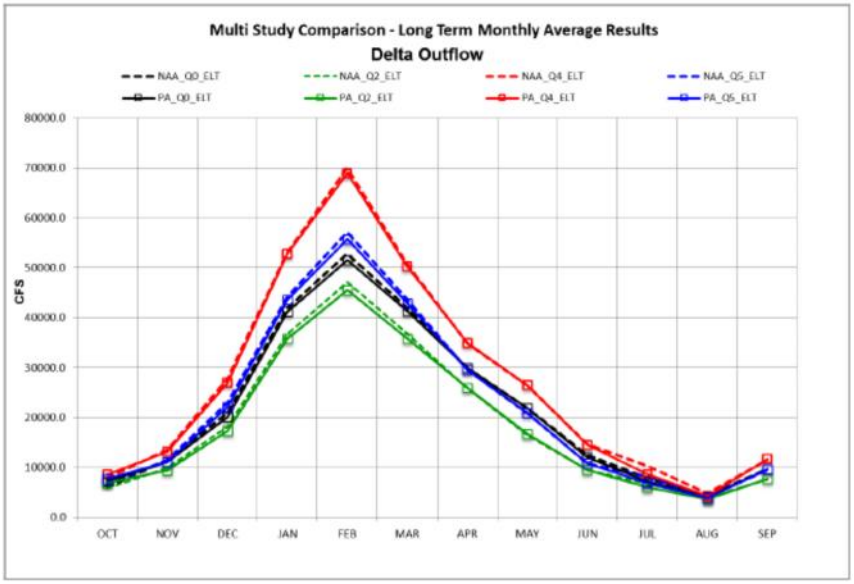


Figure 5.A.A.3-16 Monthly Delta Outflow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

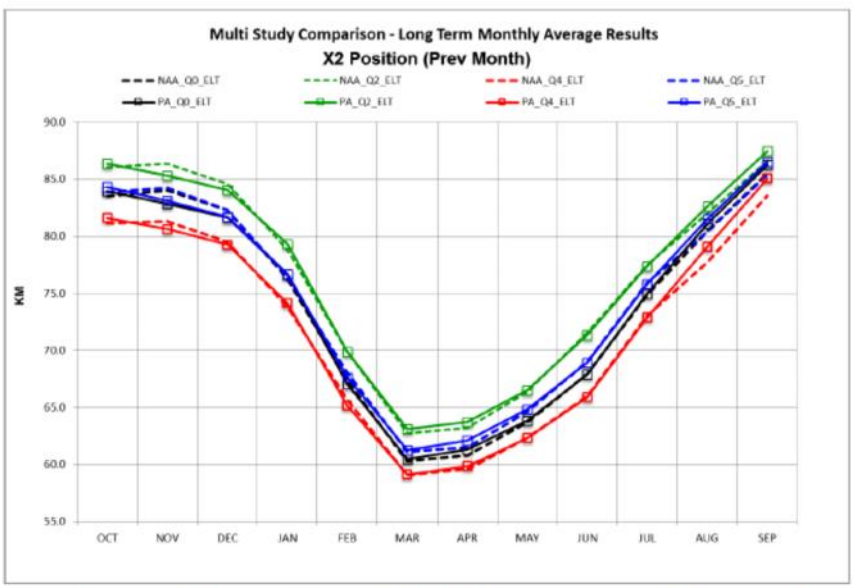


Figure 5.A.A.3-17 Previous Month X2 Position for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

Figure 21. TREE RING RECONSTRUCTION

David Meko (University of Arizona Laboratory of Tree-Ring Research) developed a reconstruction of the Sacramento River, Four Rivers Index (901-1977), for the California Department of Water Resources from 1999-2001. The dataset and graphs are available at http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca.   The following graphs are from that link.

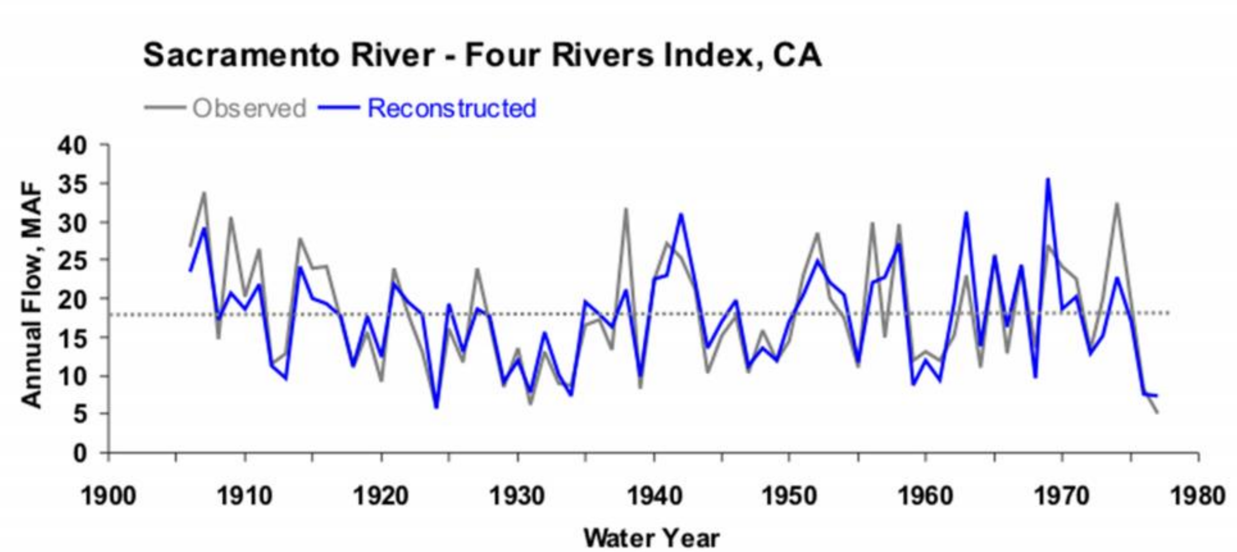


Figure 2. Observed (black) and reconstructed (blue) annual Sacramento River annual flow, 1906-1977. The observed mean is illustrated by the dashed line.

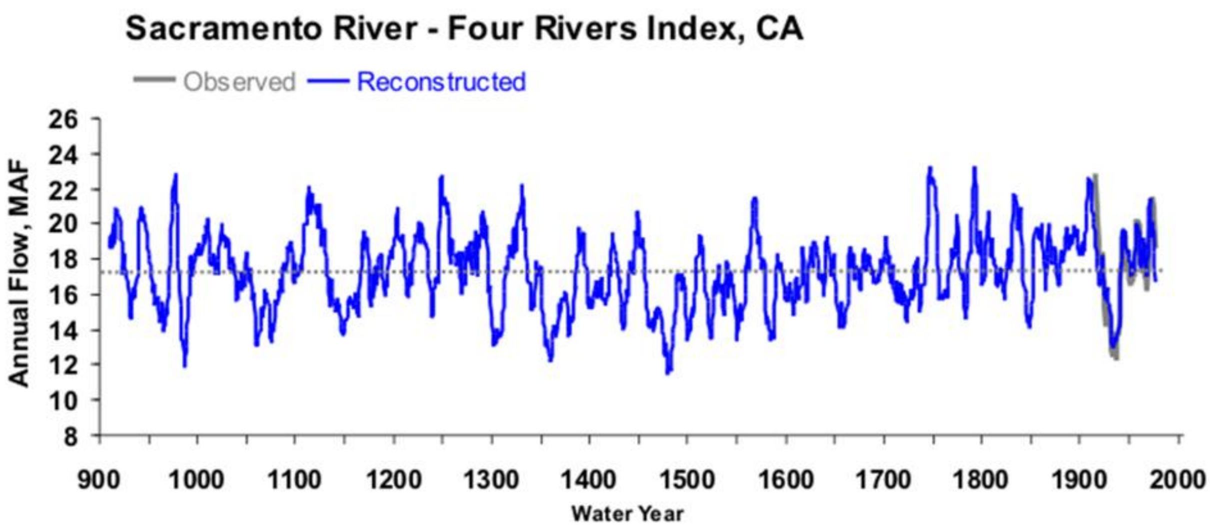


Figure 4. The 10-year running mean (plotted on final year) of reconstructed Sacramento River flow, 901-1977. Reconstructed values are shown in blue and observed values are shown in gray. The long-term reconstructed mean is shown by the dashed line