Climate Change Projections in the WaterFix

DEIRDRE DES JARDINS
CALIFORNIA WATER RESEARCH

Independent Science Board, 2014

The potential effects of climate change and sea-level rise are underestimated. . . . The potential direct effects of climate change and sea-level rise on the effectiveness of actions, including operations involving new water conveyance facilities, are not adequately considered. . . .

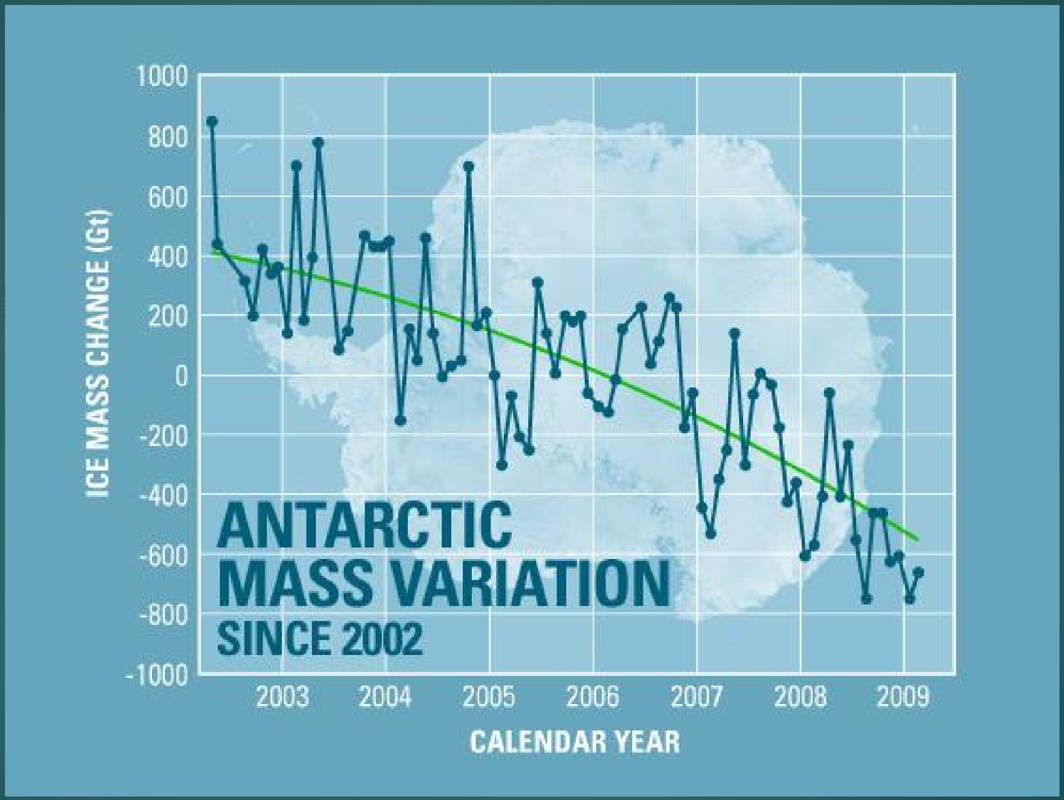
In their response to our preliminary draft review, the Department of Water Resources noted that "the scope of an EIR/EIS is to consider the effects of the project on the environment, and not the environment on the project". If the effects of major environmental disruptions such as climate change, sea-level rise, levee breaches, floods, and the like are not considered, however, one must assume that the actions will have the stated outcomes. We believe this is dangerously unrealistic. CEQA requires impacts to be assessed "in order to provide decision makers enough information to make a reasoned choice about the project and its alternatives".

Sea level rise is underestimated

- Independent Science Board estimated in 2007 that DWR could use estimates of 1 meter (3.25 feet) of sea level rise by 2100, but cautioned that melting of ice sheets could cause up to 2 meters (6.6 feet)
- NOAA 2012 guidelines – use high estimates of 2 meters for new infrastructure with a long expected lifetime
- Satellite observations show dramatic increase in rate of ice sheet melting

- DWR's 2009 projections for water supply planning – 1.8 to 3.1 feet by 2100.
- BDCP sea level rise assumptions were based on this projection.

NASA: Antarctic ice sheet loss



Source: http://www.nasa.gov/images/content/416685main_20100108_Climate_1.jpg

Sea Level Rise – Cayan et. al. California Climate Action Team

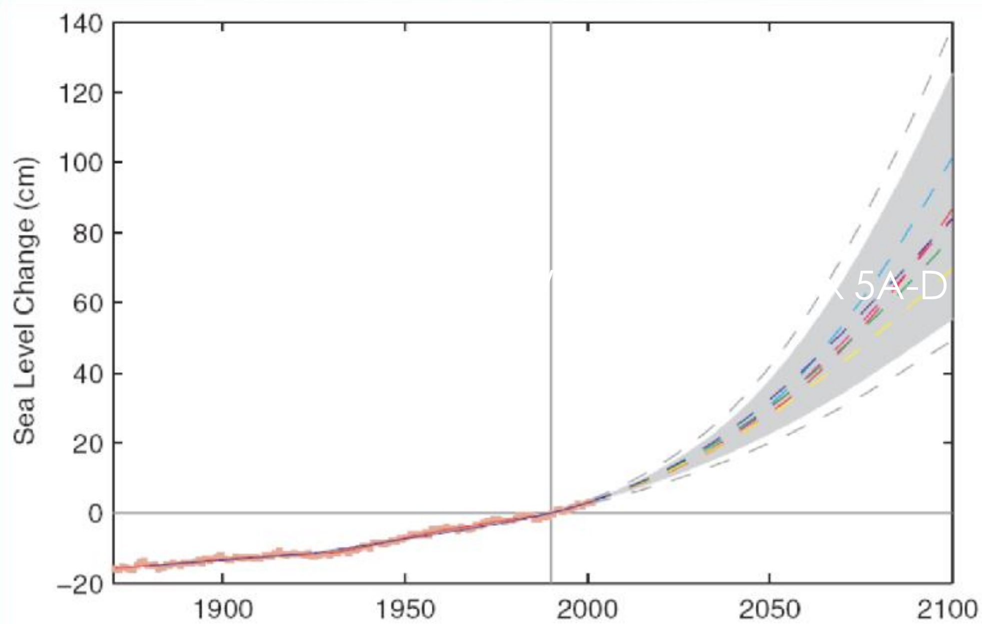
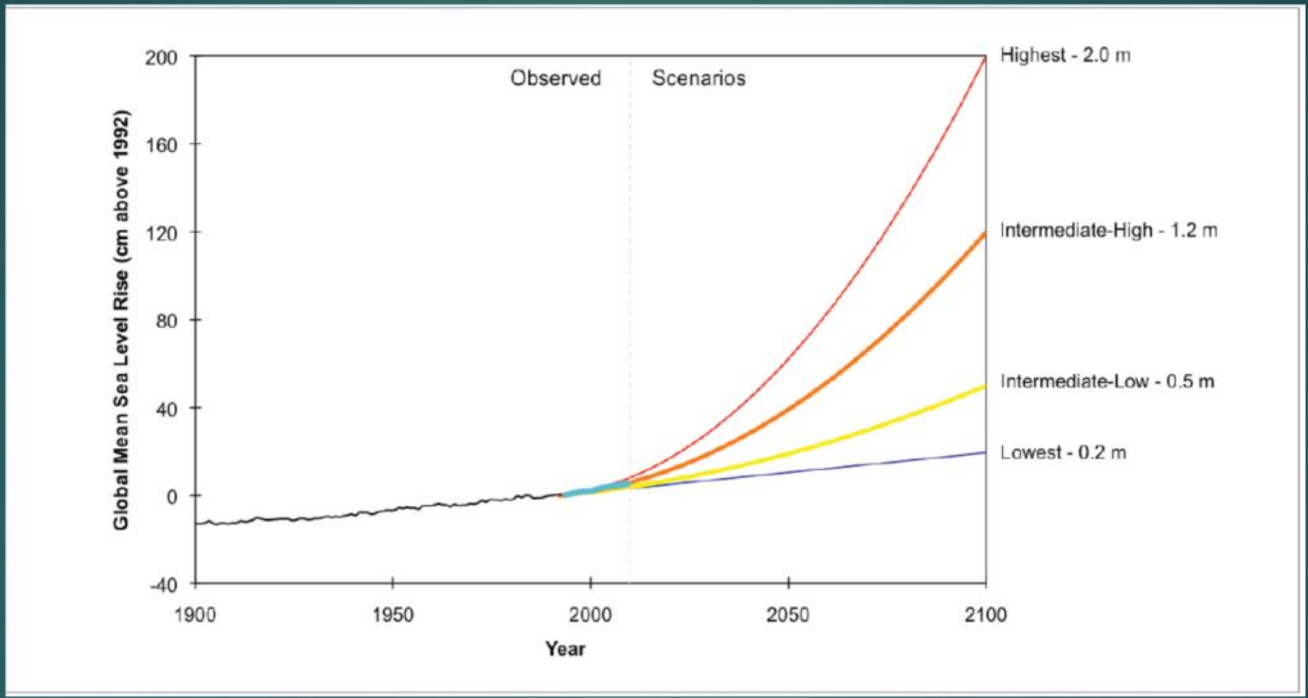


Figure 11. Past global mean sea level and future mean sea level based on global mean temperature projections (Ramsdorf 2007).

Source: BDCP DEIR/DEIS, Appendix 5A-D

Sea Level Rise – NOAA 2012



Source: NOAA Climate Program Office, Global Sea Level Rise Scenarios for the United States National Climate Assessment

Sea Level Rise – DWR 2009

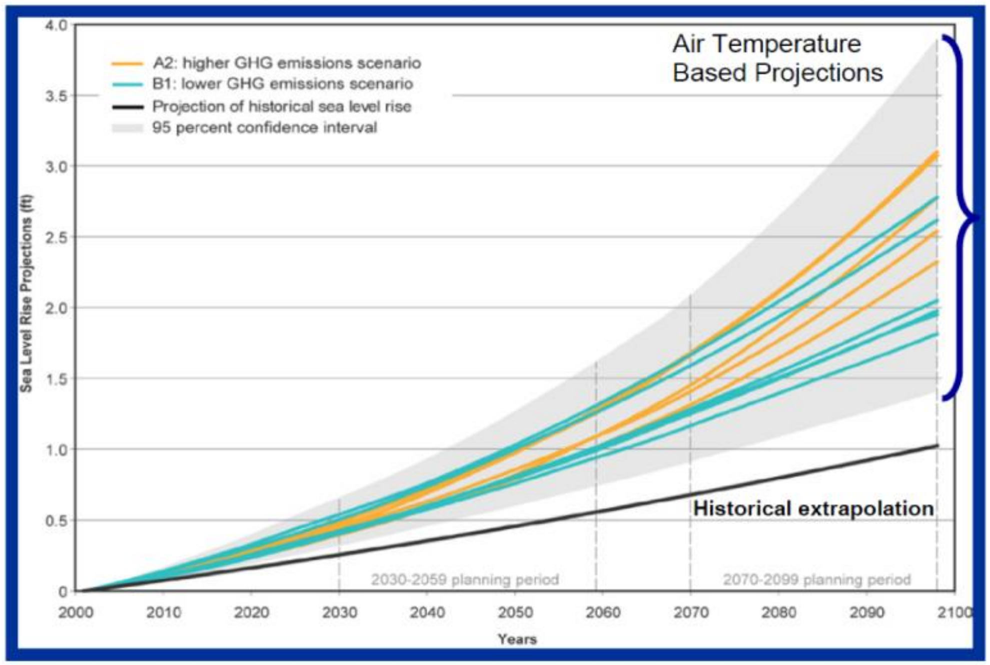
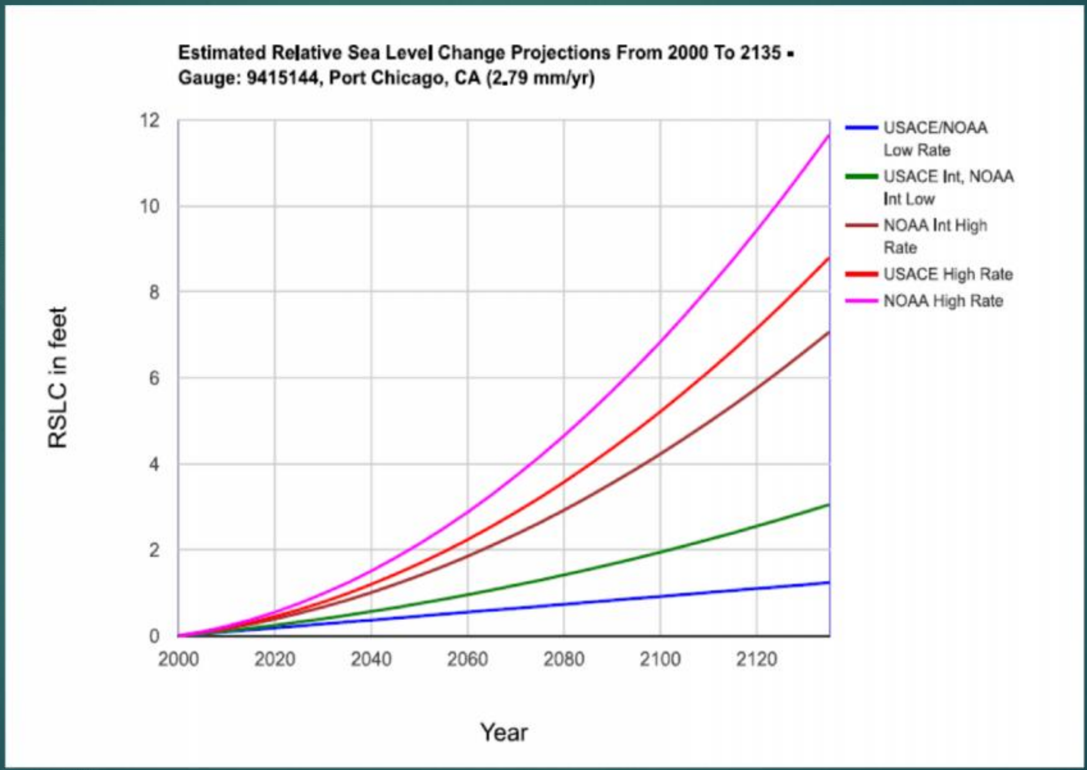


Figure 12. DWR-generated future sea level rise projections based on 12 CAT scenario projections using Ramsdorf method (Chung et al 2009).

Source: BDCP DEIR/DEIS, Appendix 5A-D

Sea Level Rise – NOAA and USACE, Port Chicago (to 2035)



Source: Army Corps of Engineers online calculator

Projected changes in runoff

- California's climate is unique
- Ensemble of global circulation models used for BDCP/WaterFix does well in Eastern North America and Europe, but a poor job in Western North America and California
- Still an active area of research
- Uncertainty of projections in future runoff needs to be addressed

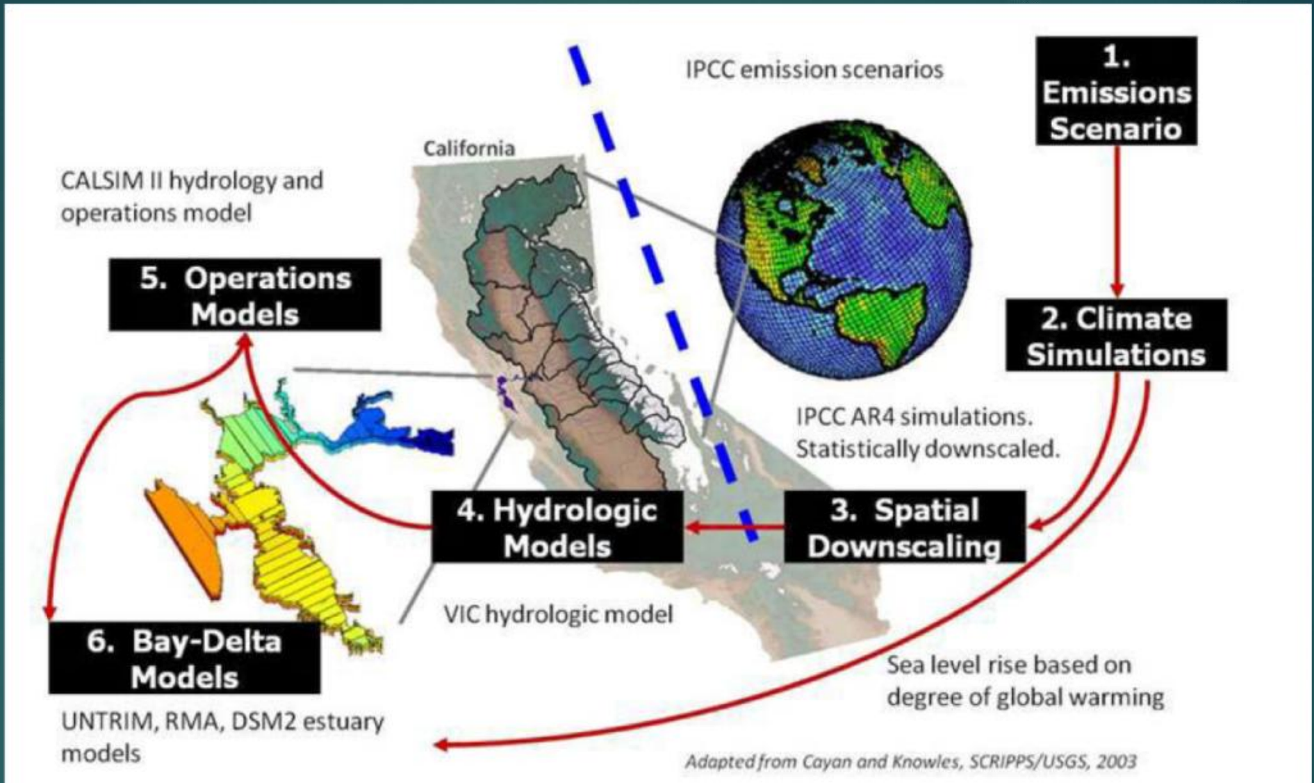


Figure 20. Graphical depiction of the analytical process for incorporating climate change into water planning.

Source: BDCP DEIR/DEIS, Appendix 5A-D

Greenhouse gas emissions scenarios

- Climate model forcing requires assumptions about growth in greenhouse gas emissions

- BDCP/WaterFix models use the Intergovernmental Panel on Climate Change (IPCC) 2007 SRES greenhouse gas emissions scenarios

- A2 – high -- some reduction in growth of emissions
- B2 – large reduction in growth of emission
- B1 – everybody drives a solar powered EV or rides a bicycle by 2060

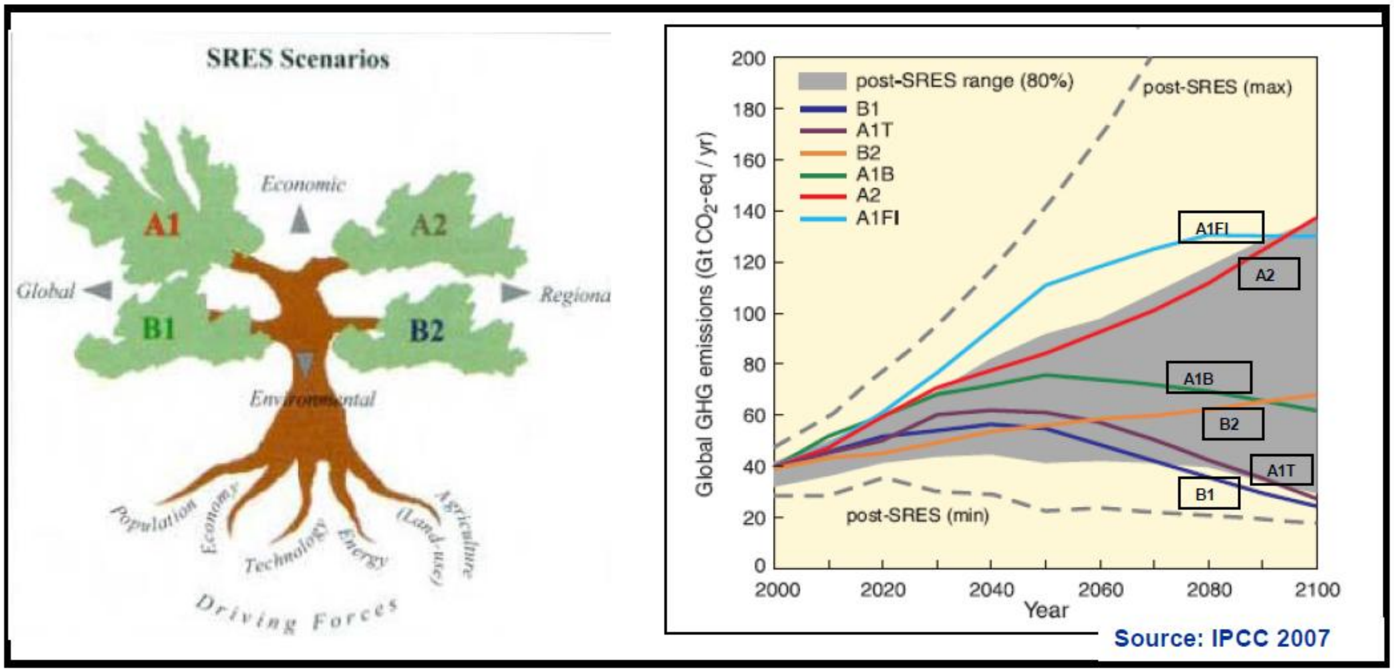


Figure 15. IPCC SRES emission scenarios storylines and future global greenhouse gas emissions.

Source: BDCP DEIR/DEIS, Appendix 5A-D, p. 29

Climate Models CMIP3 Database

General Circulation Models from climate research centers around the world

BDCP / WaterFix uses entire ensemble

California's Climate Action Team used subset selected for representation of California's climate

Source: BDCP DEIR/DEIS,

Appendix 5A-D

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 Models

From: *Evaluation of Climate Models*, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the IPCC, Flato et. al.

Estimation of regional bias in precipitation (mm/day)

BLUE LINE – CMIP3 mean

BLACK LINES – Observed data

WNA is Western North America

ENA is Eastern North America

EUM is Europe and the Mediterranean

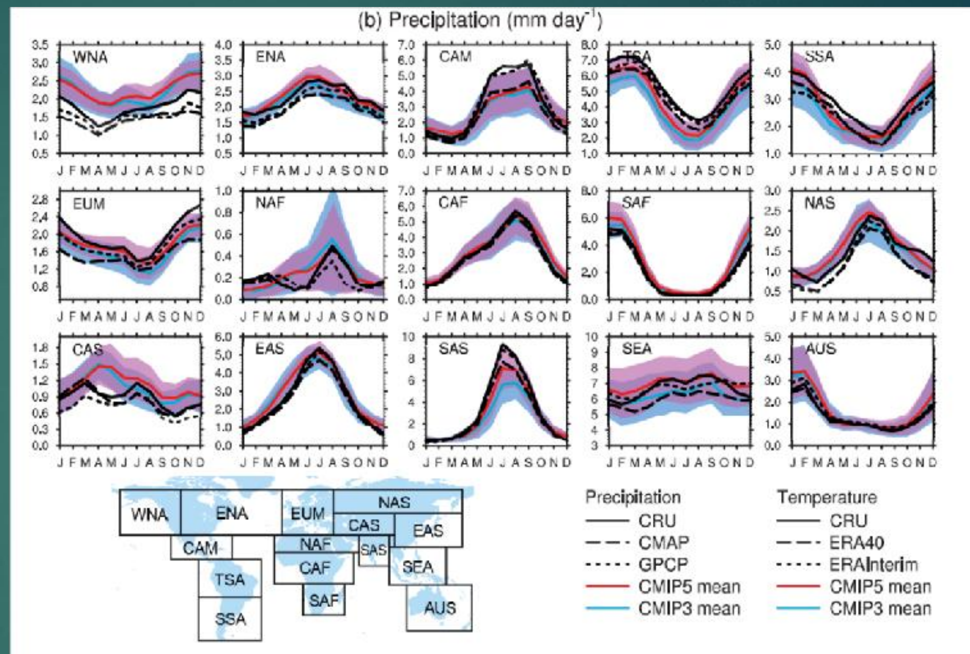


Figure 9.38 | Mean seasonal cycle of (a) temperature (°C) and (b) precipitation (mm day^{-1}). The average is taken over land areas within the indicated regions, and over the period 1980–1999. The red line is the average over 45 CMIP5 models; the blue line is the average over 22 CMIP3 models. The standard 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 Models

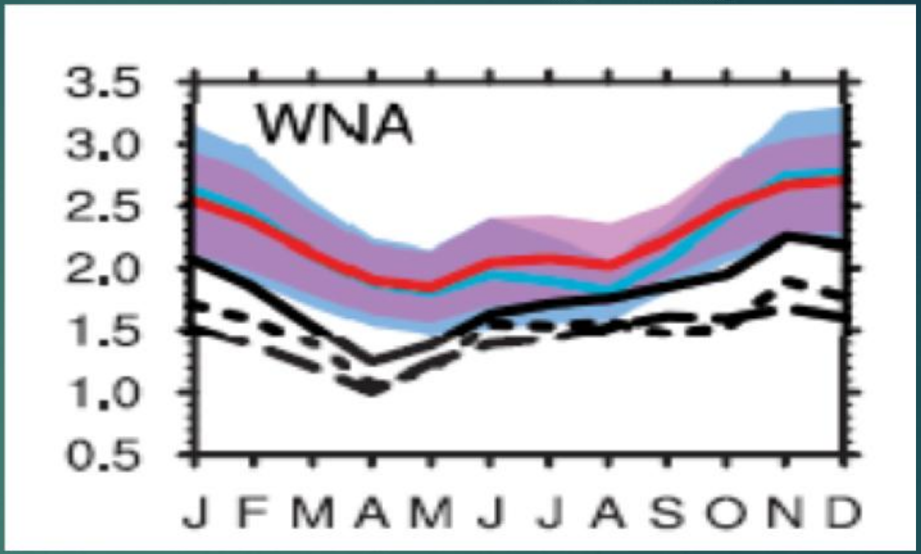
From: *Evaluation of Climate Models*, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the IPCC, Flato et. al.

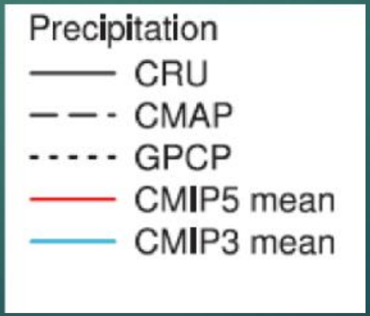
Closeup of Western North America (WNA)

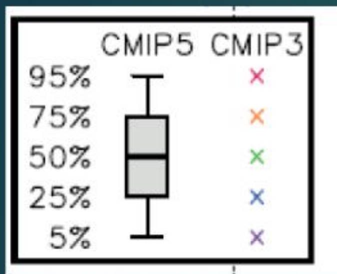
(mm/day)

BLUE LINE – CMIP3 mean

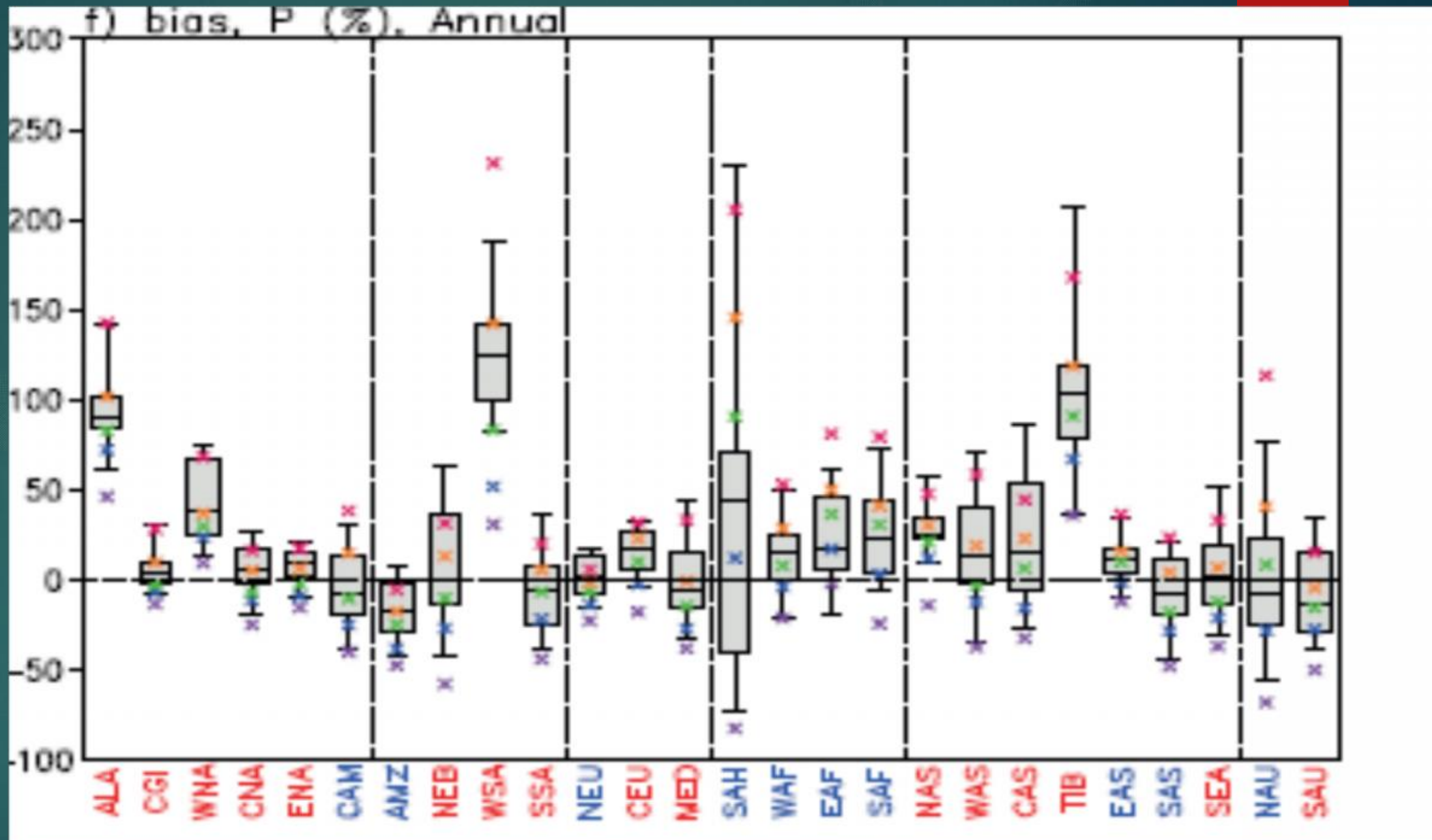
BLACK LINES – Observed data







- % Bias in annual precipitation
- Colored x s are CMIP3
- Green is 50% exceedance
- Red is 95% exceedance



Regional Bias in Climate Models

Closeup of Western North America

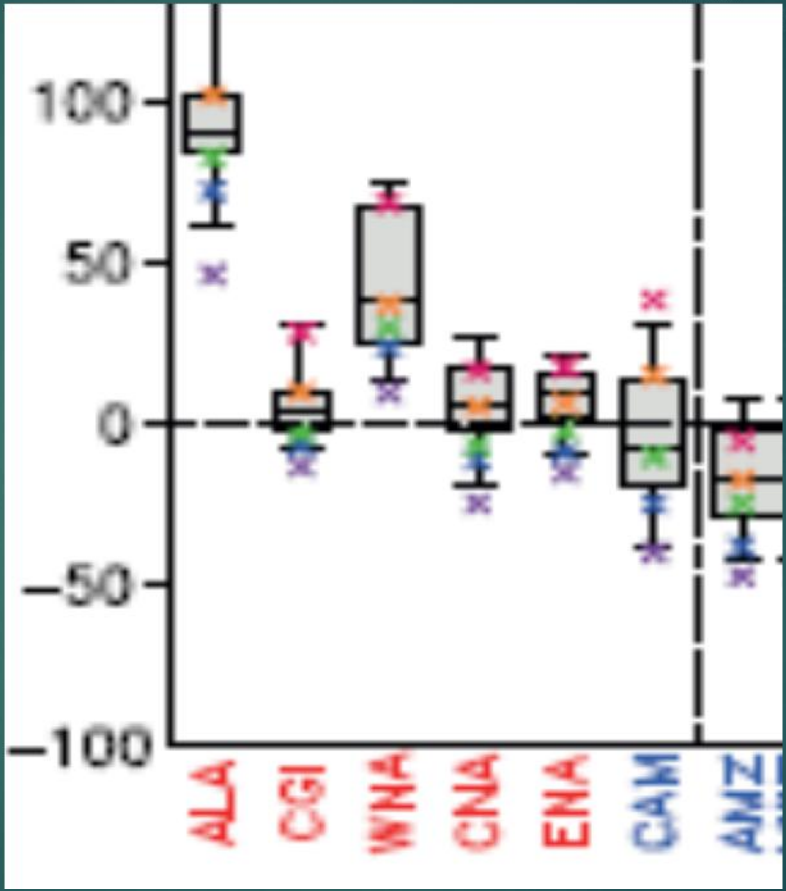
% Bias in annual precipitation

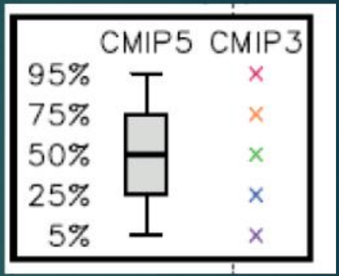
Colored x s are CMIP3

Green is 50% exceedance

Orange is 75% exceedance

Red is 95% exceedance



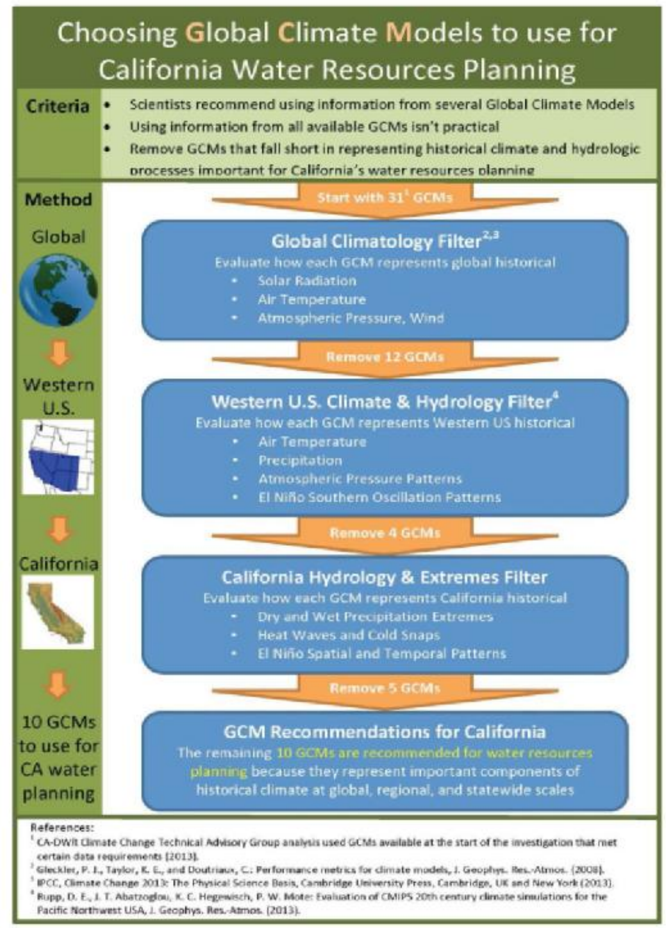


Recommendations of Climate Change Technical Advisory Group (CCTAG)

Approach used by Cayan et. al. for California Climate Change Assessments (2006, 2009, 2012)

Select climate models based on representation of historic hydrology in Western U.S. and California

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



2009 Climate Action Team – 6 GCMs

- Models selected for California by Cayan et. al.
- Shows significant drying for A2 emissions scenario, even in the near term

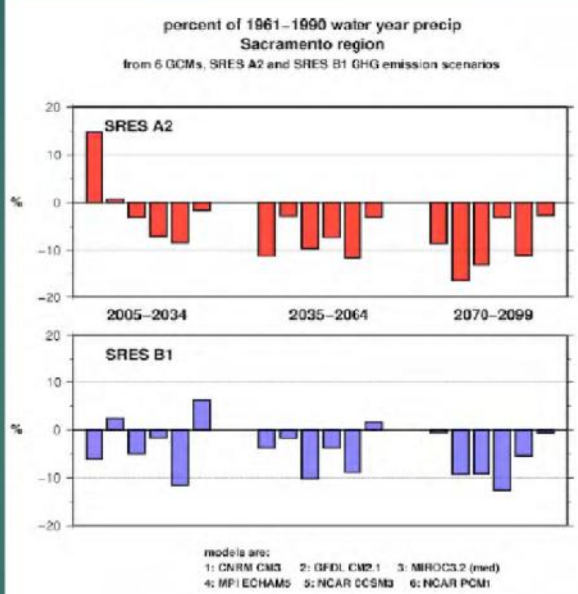


Figure 11. Differences in 30-year mean annual total precipitation of early (2005–2034), middle (2035–2064), and late (2070–2099) twenty-first century relative to 1961–1990 climatology for each of six GCMs, for SRES B1 (lower; blue) and SRES A2 (upper; red). Precipitation is taken directly from the GCMs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

Source: BDCP DEIR/DEIS, Appendix 5A-D

Nonstationarity

- Chung et. al., *Using Future Climate Projections to Support Water Resources Decision Making in California, Department of Water Resources, 2009.*

- In water resources planning, it is often assumed that future hydrologic variability will be similar to historical variability, which is an assumption of a statistically stationary hydrology. This assumption no longer holds true under climate change where the hydrological variability is non-stationary. Recent scientific research indicates that future hydrologic patterns are likely to be significantly different from historical patterns, which is also described as an assumption of a statistically non-stationary hydrology. In an article in *Science*, Milly et al. (2008) stated that "Stationarity is dead" and that "finding a suitable successor is crucial for human adaptation to changing climate."

Nonstationary runoff projections

- In *Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates* Null and Viers (2012)
- Used set of 6 GCMs selected for California by Cayan et. al.
- Did not map onto the historic 82 year sequence
- Showed dramatic increase in the frequency of dry and critically dry years by the end of the century

Null and Viers (2012)

Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates

Shifts in frequency of year types for the Sacramento Four River Index

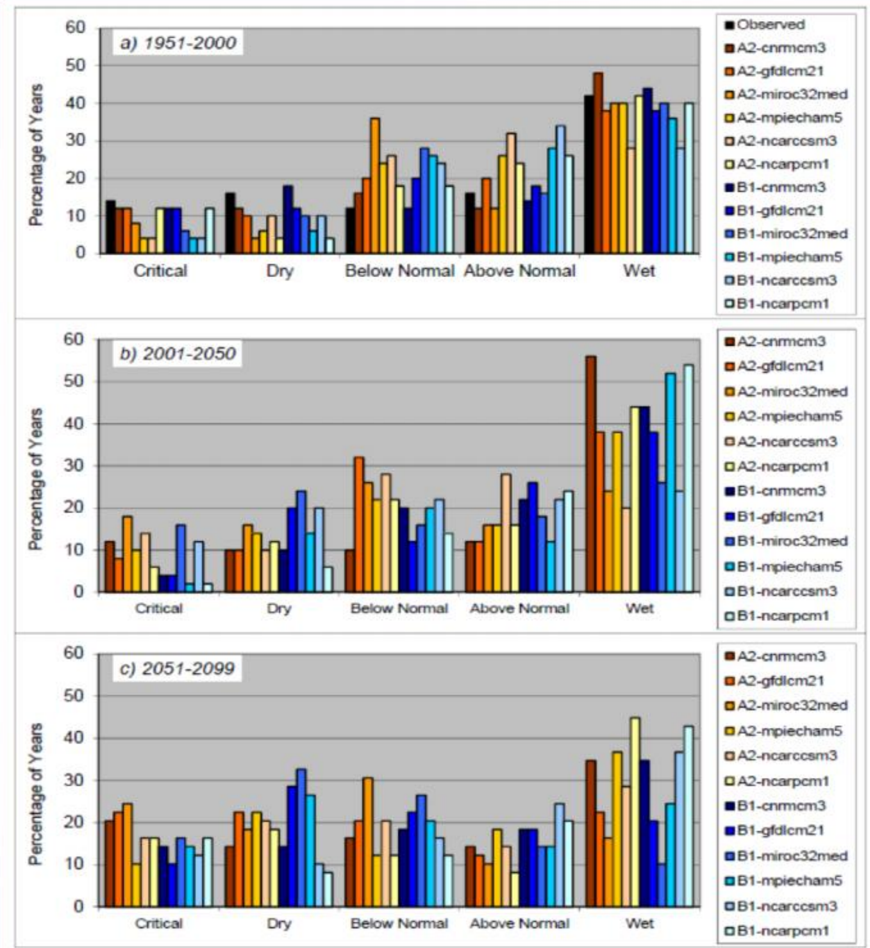
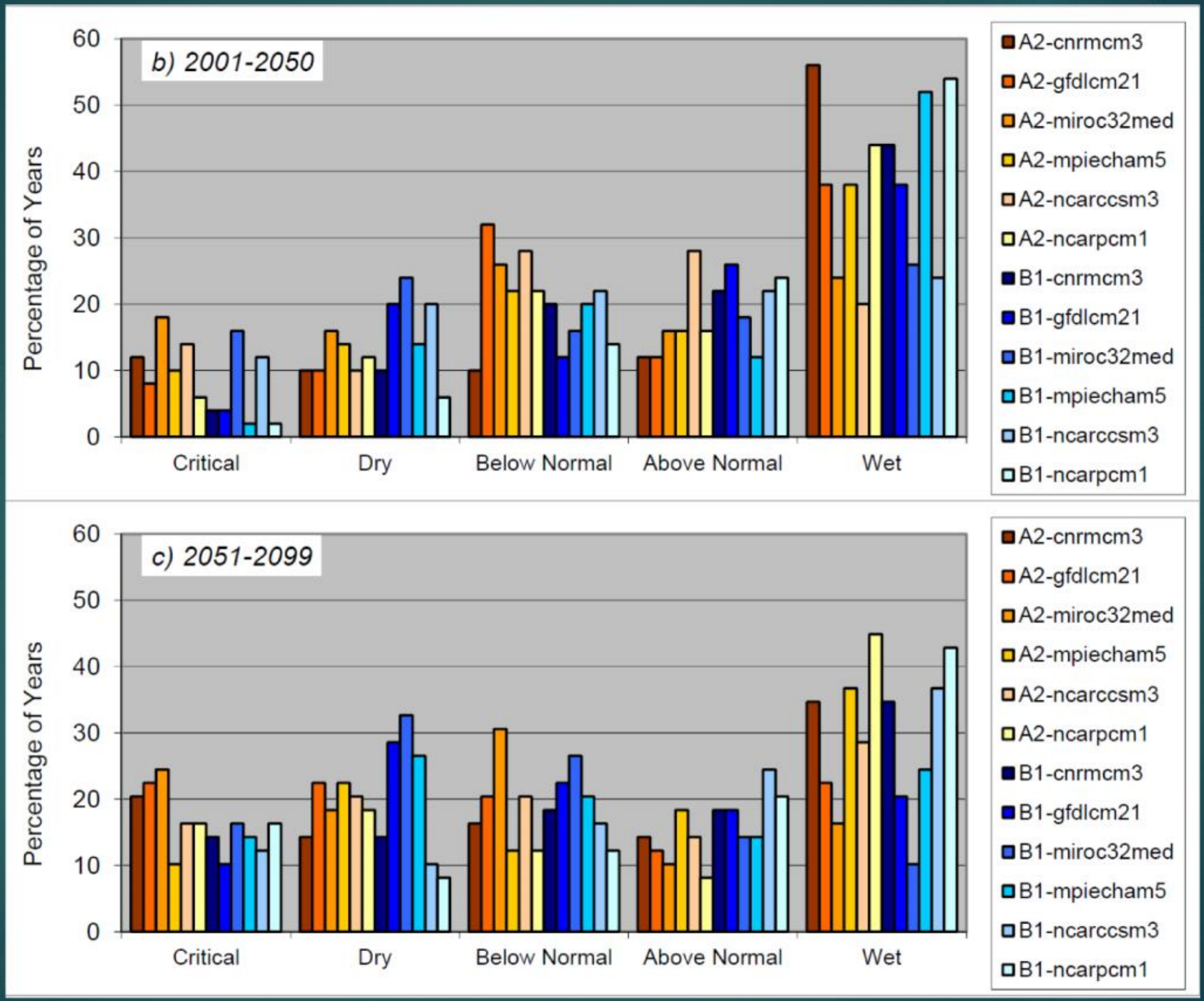


Figure 6. SVI Relative Frequency Histograms for (a) 1951–2000, (b) 2001–2050, and (c) 2051–2099


b) 2001-2050
Percentage of Years
60
50
40
30
20
10
0
Critical
Dry
Below Normal
Above Normal
Wet
A2-cnrmcm3
A2-gfdlcm21
A2-miroc32med
A2-mpiecham5
A2-ncarccsm3
A2-ncarpcm1
B1-cnrmcm3
B1-gfdlcm21
B1-miroc32med
B1-mpiecham5
B1-ncarccsm3
B1-ncarpcm1
c) 2051-2099
Percentage of Years
60
50
40
30
20
10
0
Critical
Dry
Below Normal
Above Normal
Wet
A2-cnrmcm3
A2-gfdlcm21
A2-miroc32med
A2-mpiecham5
A2-ncarccsm3
A2-ncarpcm1
B1-cnrmcm3
B1-gfdlcm21
B1-miroc32med
B1-mpiecham5
B1-ncarccsm3
B1-ncarpcm1

Null and Viers (2012)

Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates

Shifts in frequency of year types for the San Joaquin Valley Index

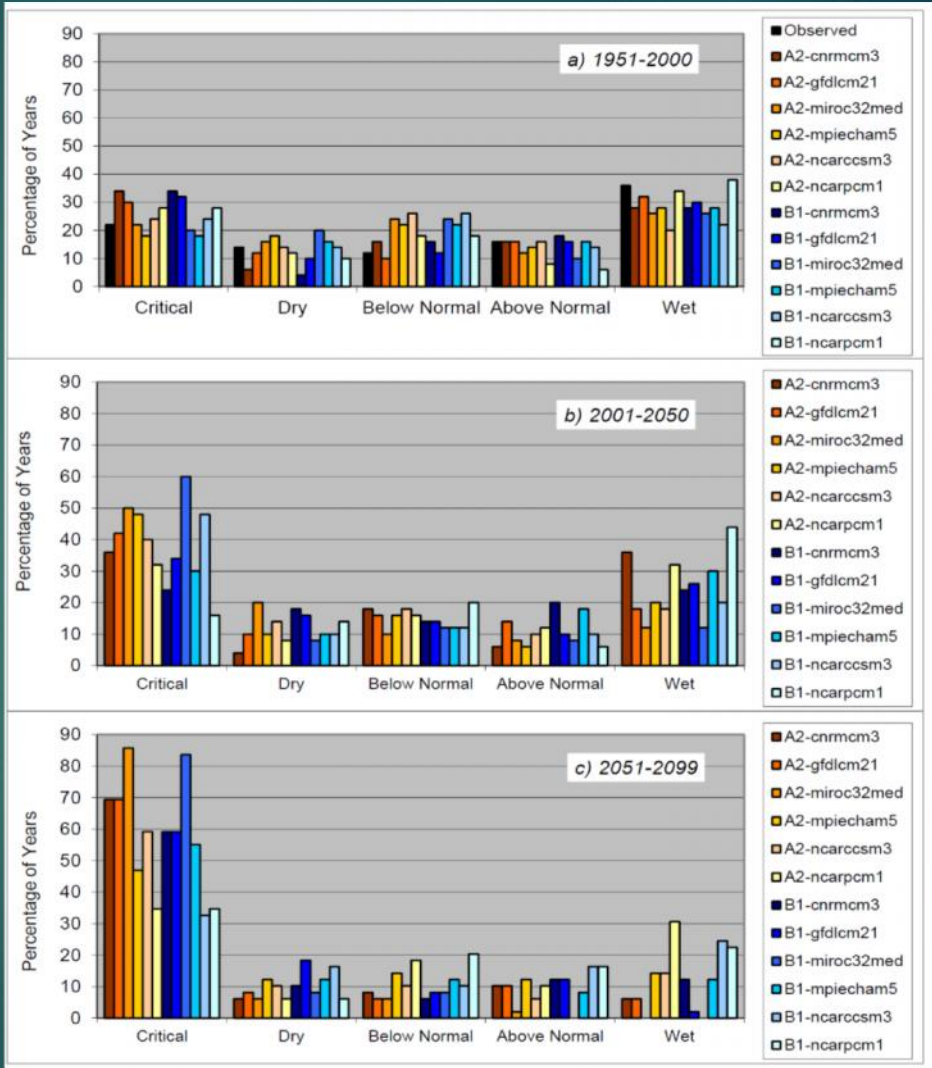
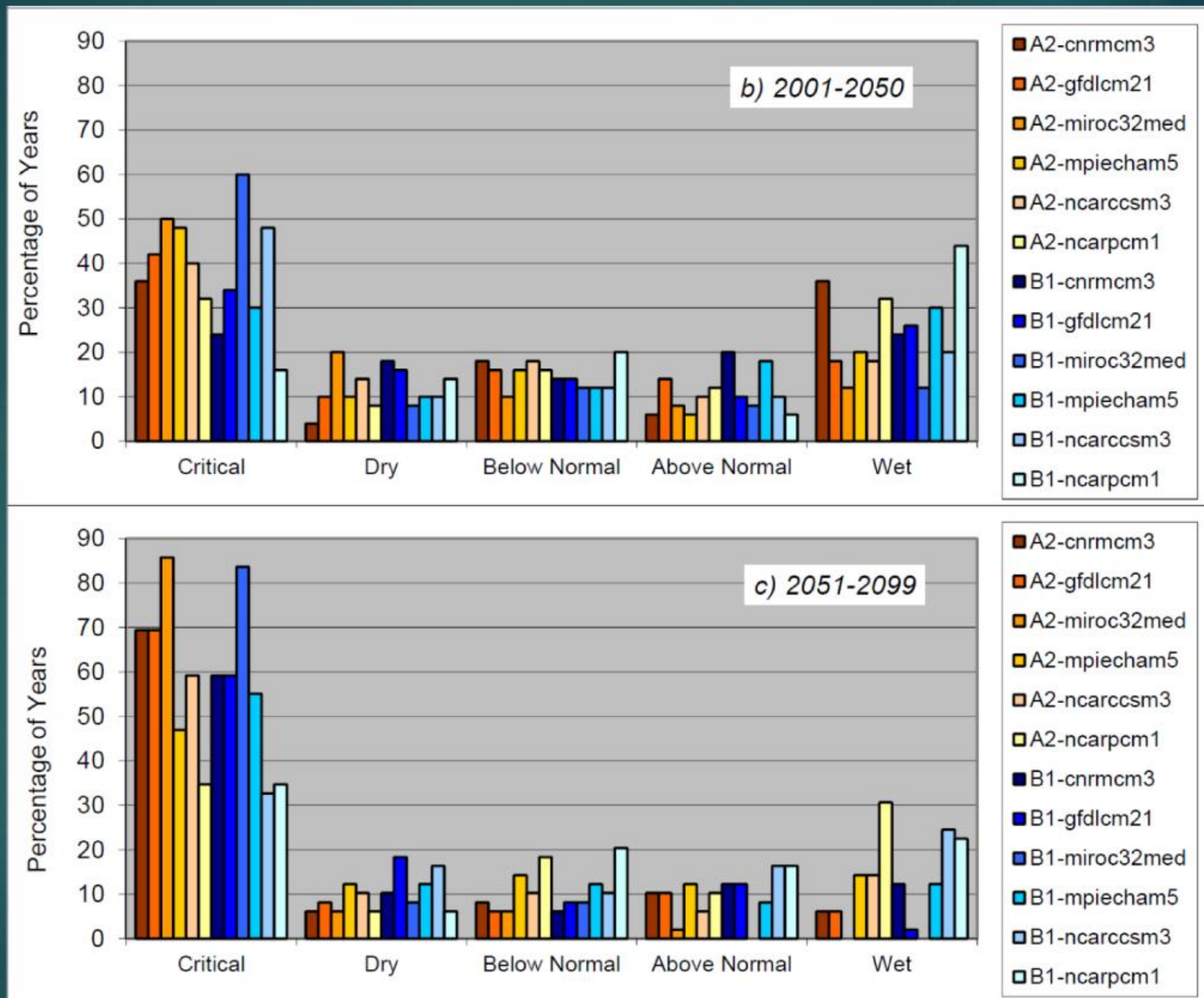


Figure 7. SJI Relative Frequency Histograms for (a) 1951–2000, (b) 2001–2050, and (c) 2051–2099

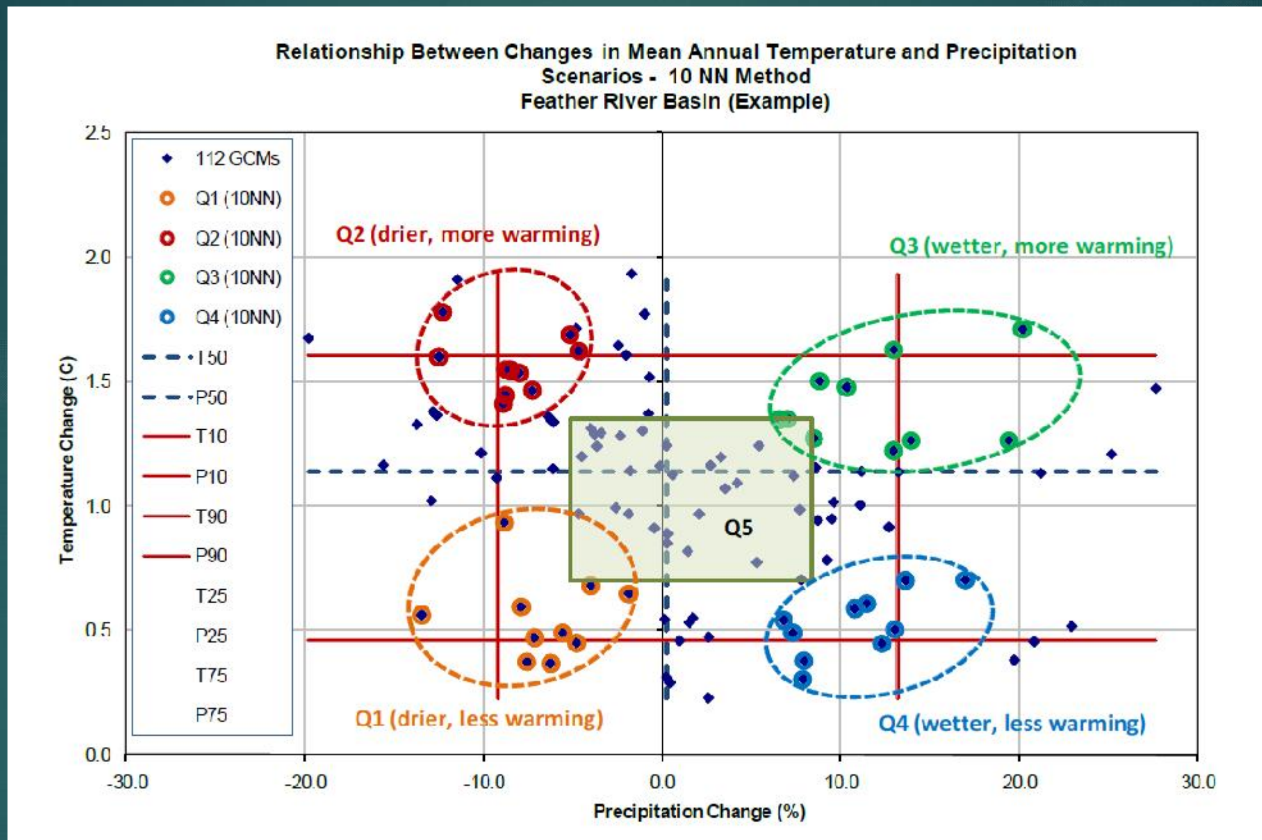

b) 2001-2050
Percentage of Years
90
80
70
60
50
40
30
20
10
0
Critical
Dry
Below Normal
Above Normal
Wet
A2-cnrmcm3
A2-gfdlcm21
A2-miroc32med
A2-mpiecham5
A2-ncarccsm3
A2-ncarpcm1
B1-cnrmcm3
B1-gfdlcm21
B1-miroc32med
B1-mpiecham5
B1-ncarccsm3
B1-ncarpcm1
c) 2051-2099
Percentage of Years
90
80
70
60
50
40
30
20
10
0
Critical
Dry
Below Normal
Above Normal
Wet
A2-cnrmcm3
A2-gfdlcm21
A2-miroc32med
A2-mpiecham5
A2-ncarccsm3
A2-ncarpcm1
B1-cnrmcm3
B1-gfdlcm21
B1-miroc32med
B1-mpiecham5
B1-ncarccsm3
B1-ncarpcm1

BDCP method for dealing with uncertainty in climate projections

- Divide set of 112 projections into four quartiles

- Drier, less warming
- Drier, more warming
- Wetter, less warming
- Wetter, more warming

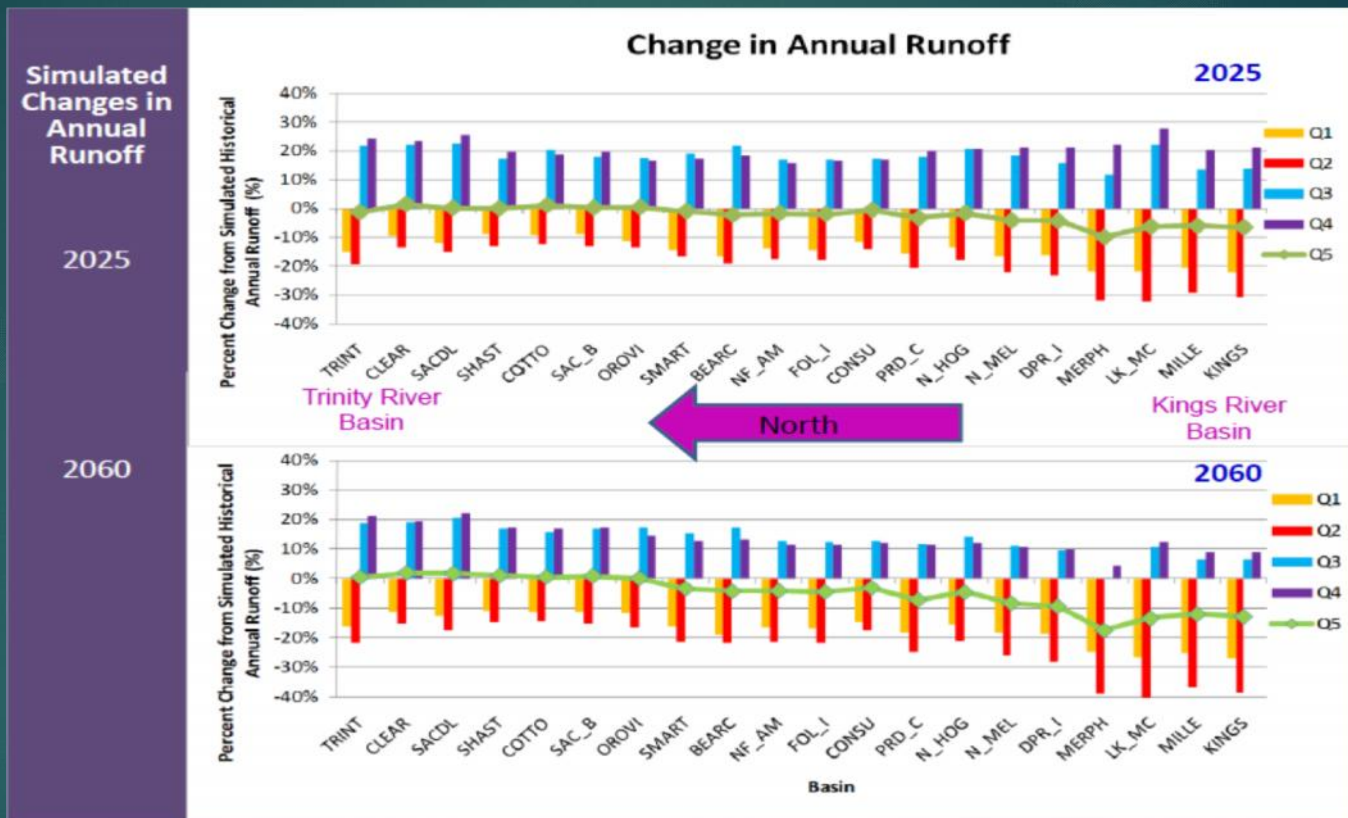
- Use quartiles to estimate uncertainty



Source: BDCP DEIR/DEIS, Appendix 5A-D, p. 36

Central Tendency Projection

- Clustered around mean change in precipitation and temperature
- Eliminates
  - 25% and less -- driest
  - 75% and more -- wettest
  - 25% and less warming
  - 75% and more warming
- Drier models were consistent with recent droughts in Southwest and California



Source: BDCP DEIR/DEIS, Appendix 5A-D

Central Tendency Projection

- Produces projections close to historical runoff patterns in the near term.
- Highest sensitivity (highest warming) models now appear most likely (Sherwood, *Spread in model climate sensitivity traced to atmospheric convective mixing,* Nature 2014.)
- These model projections were eliminated by 25%-75% pruning
- More warming generally means more drying

2010 Recommended Analysis for BDCP

- Do CALSIM runs for all quartiles (Q1-Q4) as well as Q5
- Sensitivity analyses only for highest sea level rise (1.4 m)

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

Source: BDCP DEIR/DEIS, Appendix 5A-D, p. 44

Recommendations

- There is significant uncertainty about shifts in runoff due to climate change
- Q2 drier, warmer scenario represents the greatest risk
- Strongly agree with the 2010 recommendations to use the Q1-Q4 projections for input into all CALSIM runs
- Needs to be explicitly considered in the CALSIM model results presented for the WaterFix Hearing

Draft Biological Assessment

- ESA required assessment of Q1-Q4 alternative runoff scenarios
- CALSIM runs were produced for both the No Action Alternative and the Preferred Alternative
- The No Action Alternative is the same as the WaterFix Hearing No Action Alternative
- This analysis should have also been done for the WaterFix Hearing CALSIM model runs

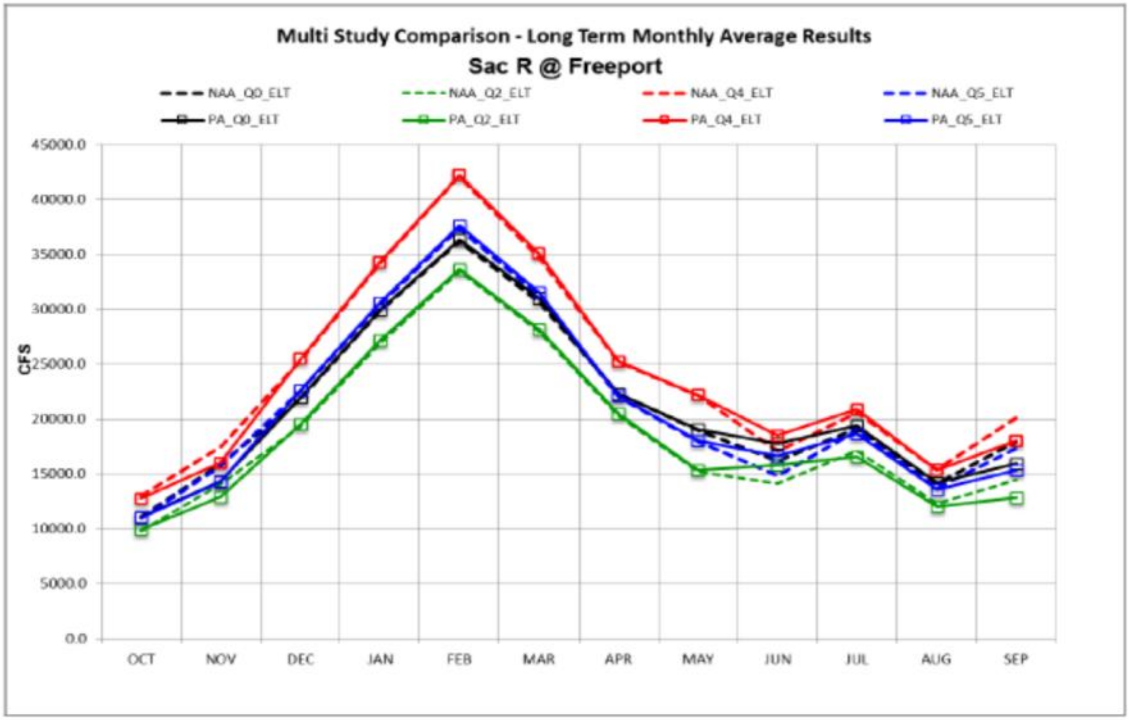


Figure 5.A.A.3-12 Sacramento River at Freeport Monthly Flow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

Source: Revised Draft BA, Appendix 5A

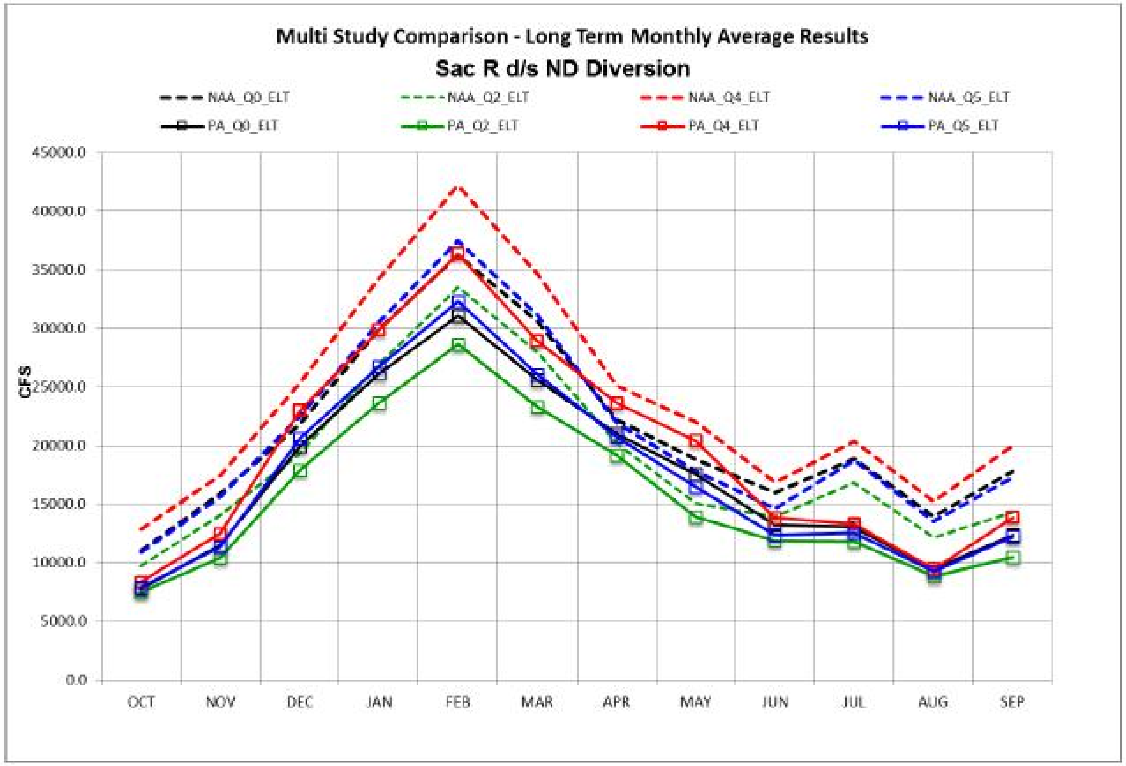


Figure 5.A.A.3-13 Sacramento River downstream of North Delta Diversion Monthly Flow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

Source: Revised Draft BA, Appendix 5A

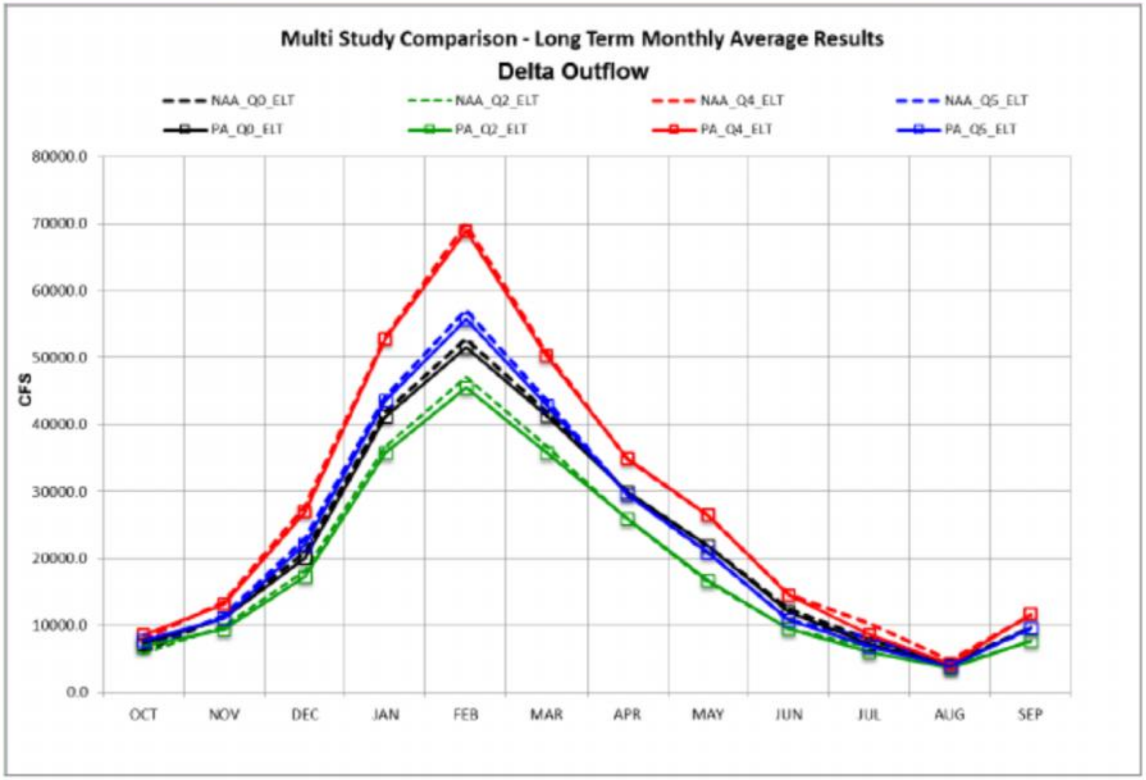


Figure 5.A.A.3-16 Monthly Delta Outflow for the NAA and PA under Q0, Q2, Q4 and Q5 climate scenarios at Year 2030

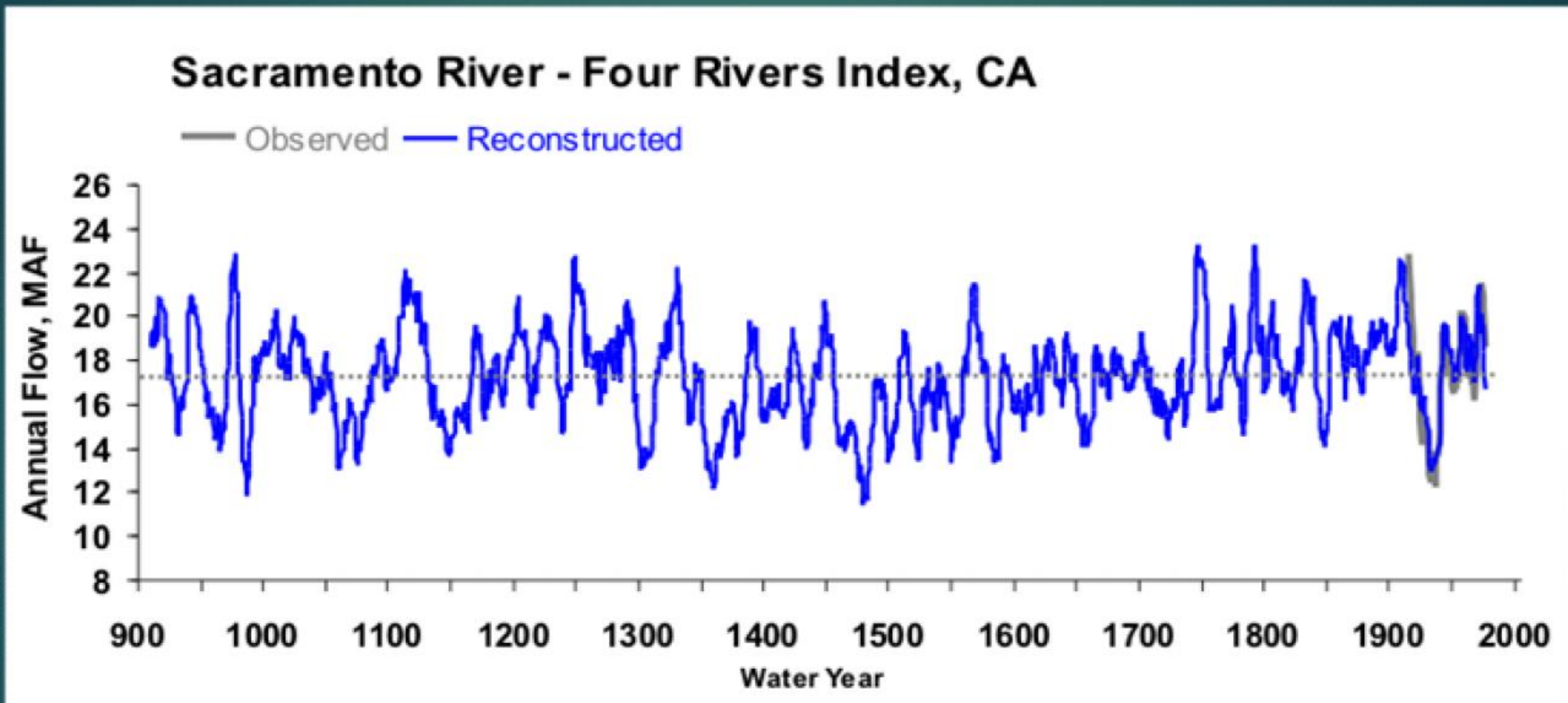
Source: Revised Draft BA, Appendix 5A

Paleoclimate and extreme droughts

- Khan et. al., *Climate Change Characterization and Analysis in California Water Resources Planning Studies, Department of Water Resources, 2010.*

- 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.

Tree Ring Reconstruction –Meko (2001)



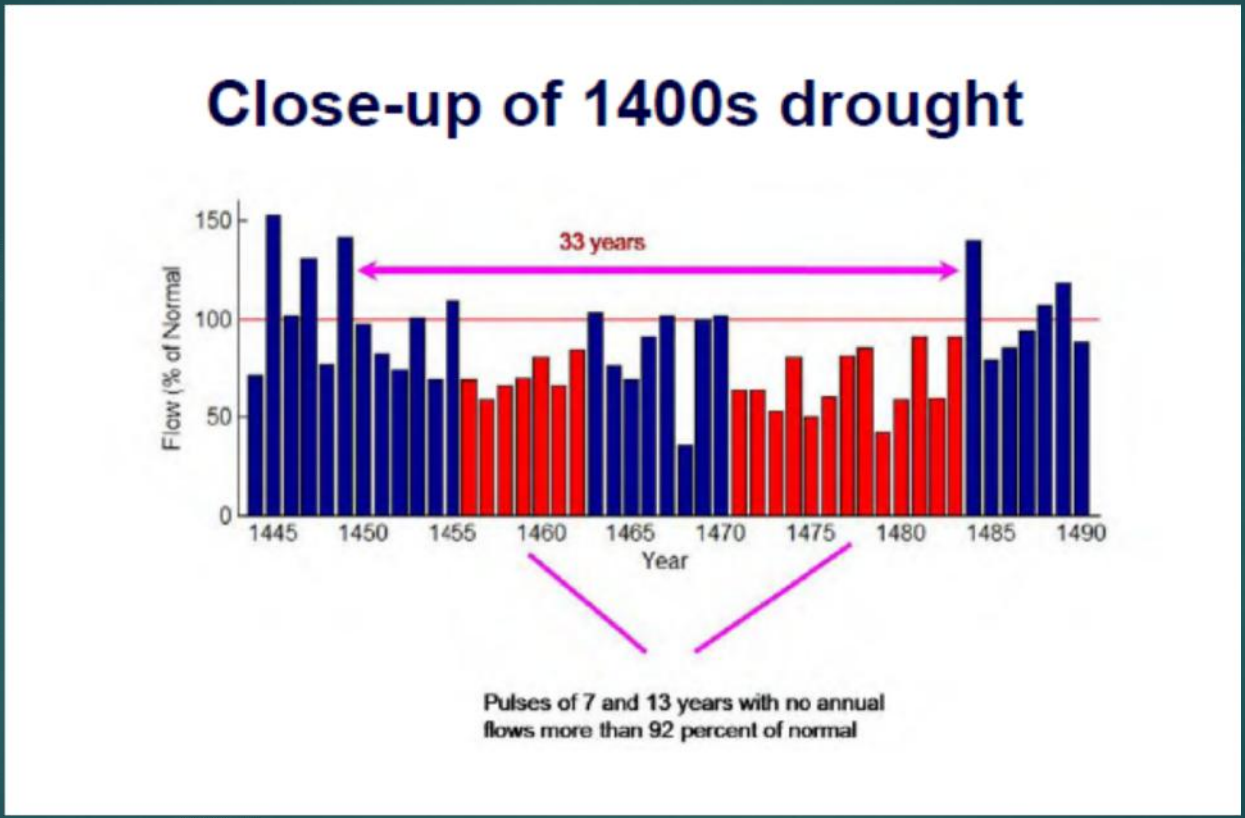
Source: http://www.treeflow.info/content/sacramento-river-four-rivers-index-ca

Tree Ring Reconstruction – Meko

- *David Meko, 2009 Extreme Precipitation Symposium,* Exhibit IFR-1, p.1.

- *…six-year droughts of the 1930s and 1980s-90s are as severe as any encountered in the tree-ring record. For longer running means the tree-ring record contains examples of drought severity and duration without analog since the start of the 20th century. For example, mean flow is reconstructed at 73 percent of normal (1906-2008 observed mean, 23.8x106 acre-feet) for the 25-year period ending in 1480.*

Tree Ring Reconstruction --Meko



Source: Meko, 2009 Extreme Precipitation Symposium, Exhibit IFR-1, p. 24

Summary and Recommendations

- Tree ring reconstructions show that California has experienced many episodes of severe drought, as well as climate shifts
- There needs to be an explicit analysis of water supply and water quality for a repeat of the severe six year droughts of 1928-34 and 1987-1992
- Because of long periods of below normal runoff in the tree ring reconstructions, this is the minimum that should be considered