A wide river flows through a lush, green landscape. The water is a deep blue-green color, reflecting the sky. The banks are lined with dense vegetation, including trees and shrubs. On the right bank, there is a small wooden structure with a solar panel mounted on it. The sky is a clear, pale blue.

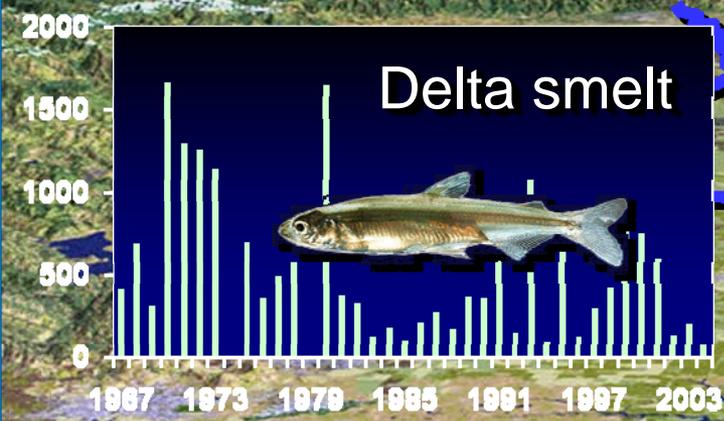
Climate Scenarios and Climate Sensitivity for the Bay Delta Conservation Plan

Armin Munévar, CH2M HILL
CWEMF Annual Meeting
Asilomar, CA
March 1, 2011

Presentation Focus

- Key Research/Application Questions
 - Which climate projections should be selected for long-range water planning impact analyses when the entire ensemble cannot be simulated?
 - What balance of climate projection versus observed variability should be incorporated in planning?
 - How can climate change uncertainty be presented as scenarios of the future?
- Scenarios based on these research/application questions were developed for use in the Bay Delta Conservation Plan
- Summary of Projected Changes to System

Sacramento-San Joaquin Delta supports a vital ecosystem and serves as a major hub for water exports



Sacramento

Stockton

Recent export restrictions under biological opinions

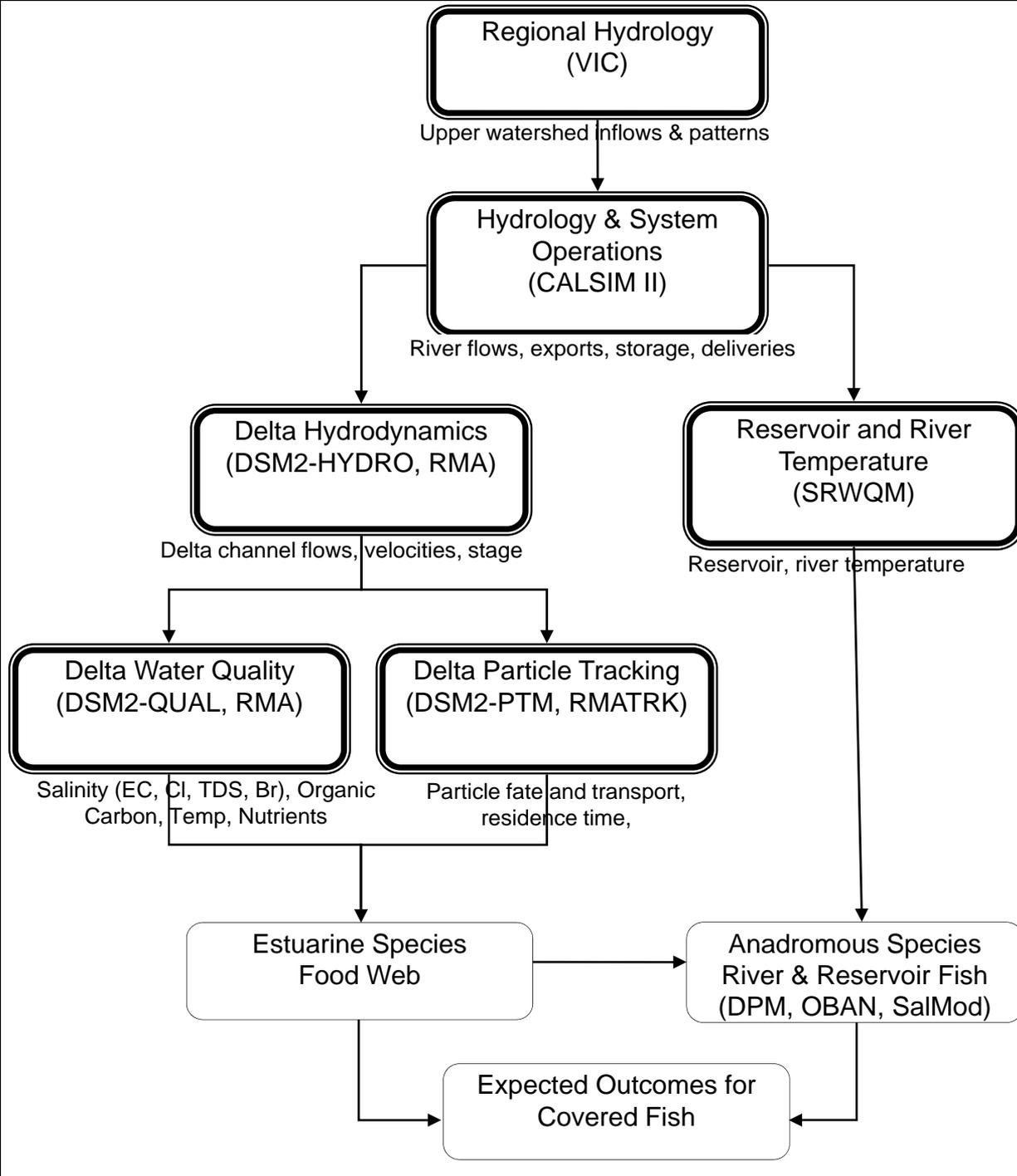
SWP Pumps
CVP Pumps

Bay Delta Conservation Plan (BDCP)

- Collaborative approach to restore the Sacramento-San Joaquin Delta's ecosystem and protect water supplies
- Conservation measures being considered by the BDCP
 - tidal marsh restoration,
 - floodplain restoration,
 - alternative ways for conveying water for exports,
 - changes to operations of current facilities, and
 - control of toxic pollutants, invasive species, and other impairments to water quality



Integrated & Cascading Set of Analyses

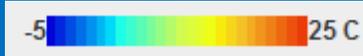
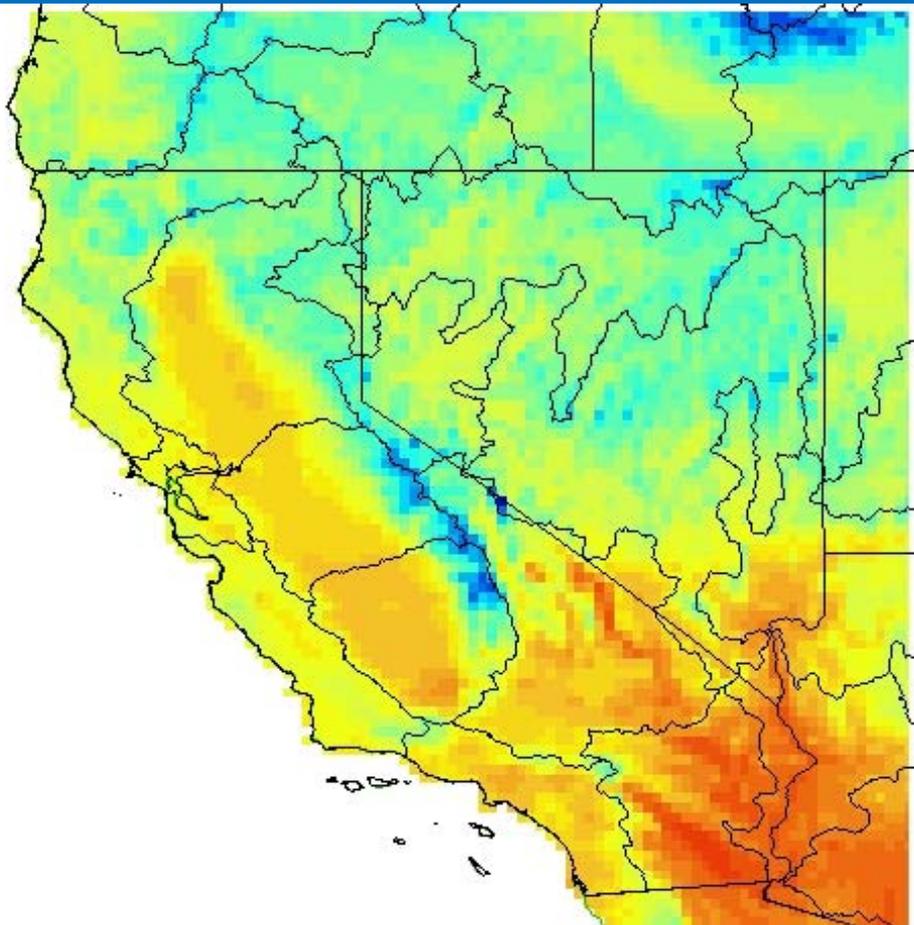


- Process seeks permit for a 50-yr period
- Quantitative analysis being prepared for disclosure of impacts/ effects at three points in time
- Approximately 2015, 2025, and 2060

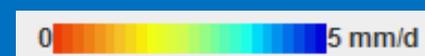
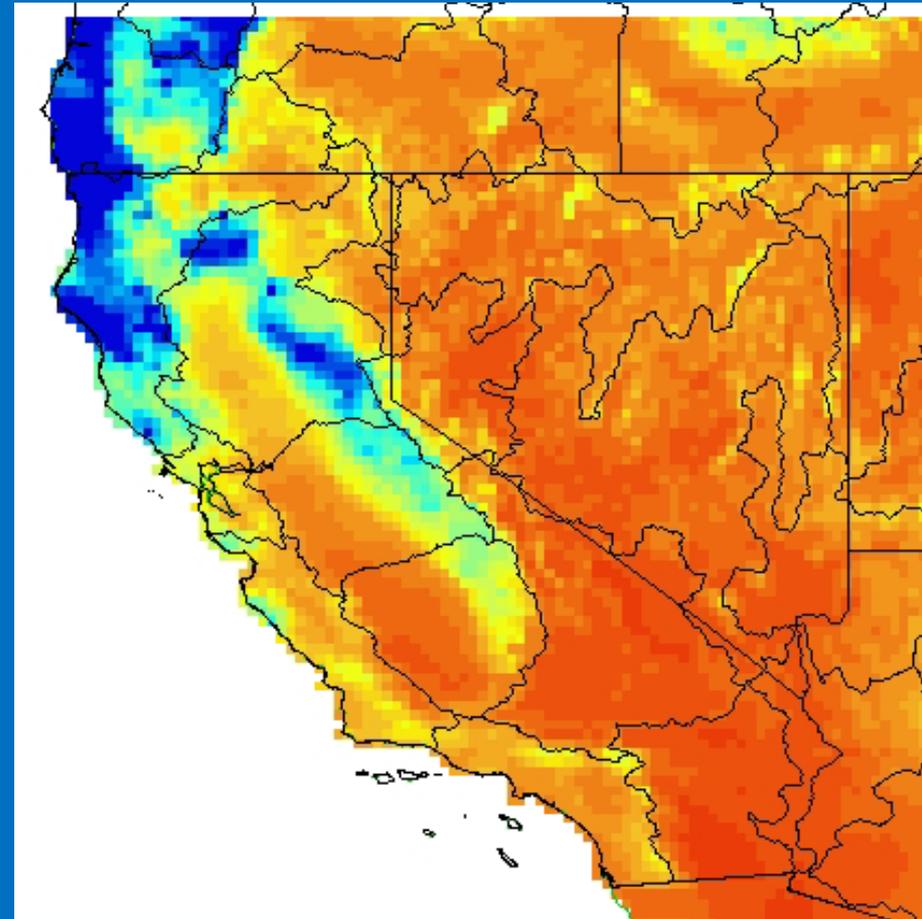
Observed Climate

1950-1999 (Maurer et al 2002)

Temperature



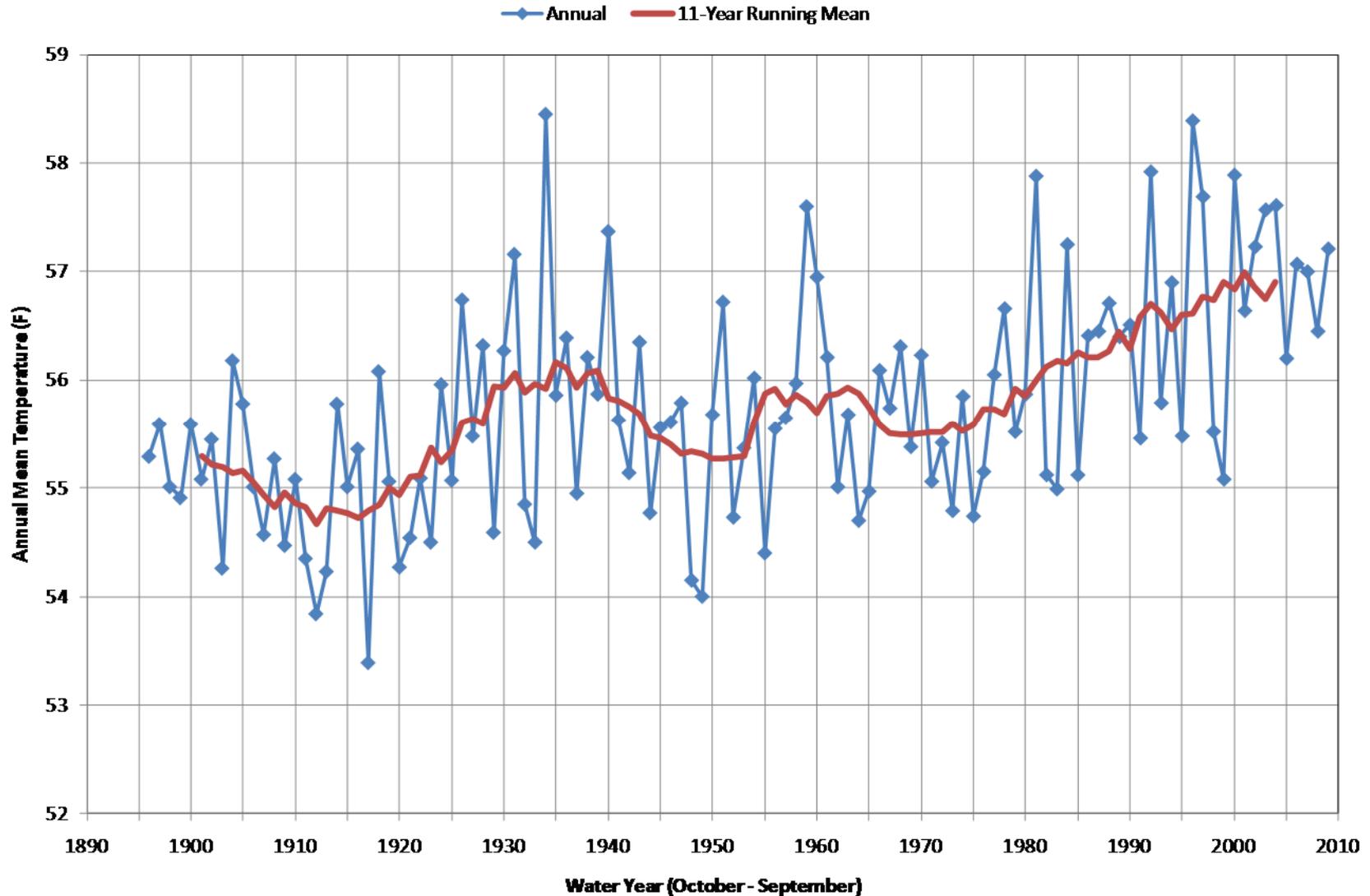
Precipitation



Observed Statewide Temperature Trends

1896-2009

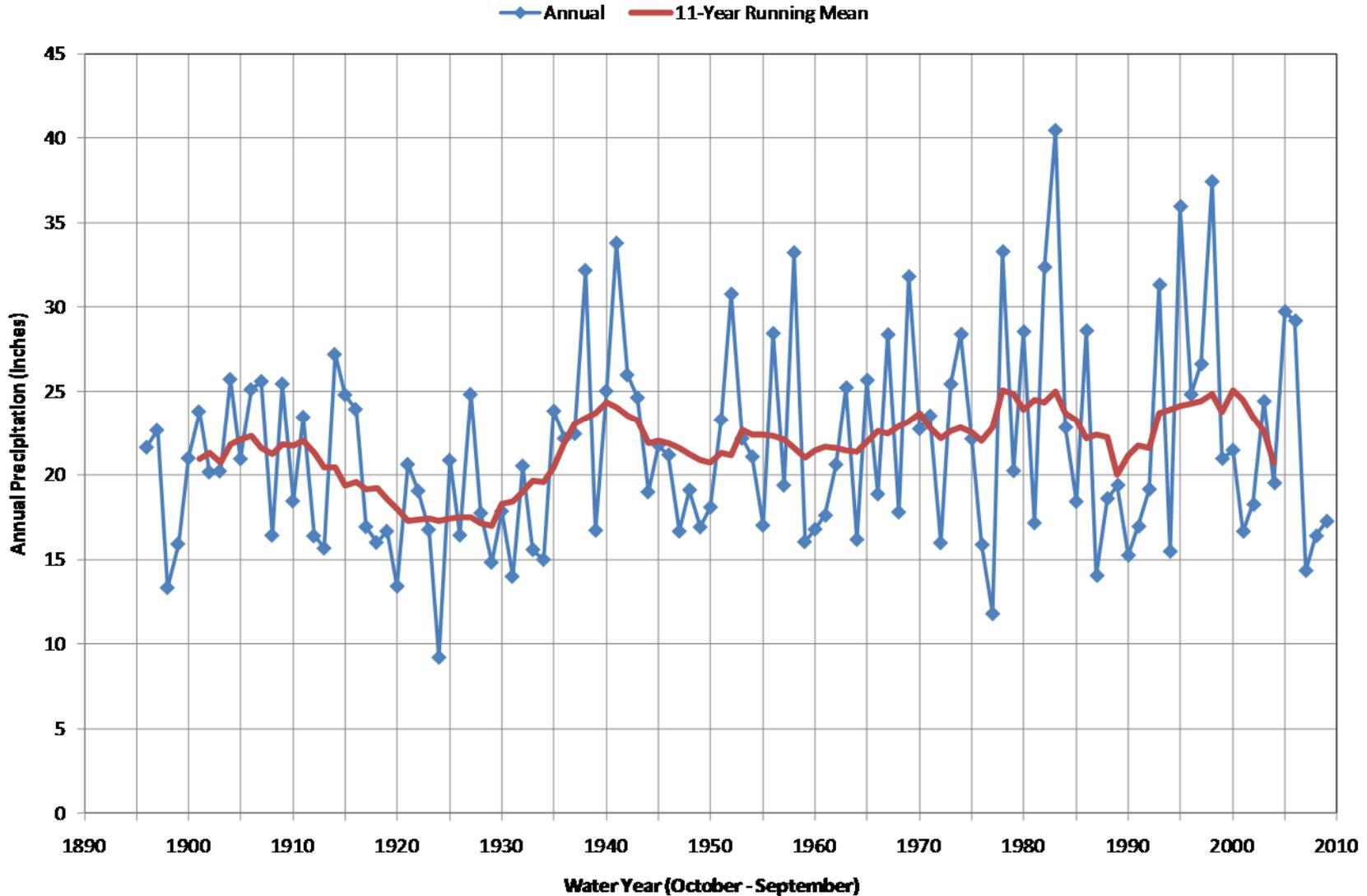
California Statewide Annual Mean Temperature



Observed Statewide Precipitation Trends

1896-2009

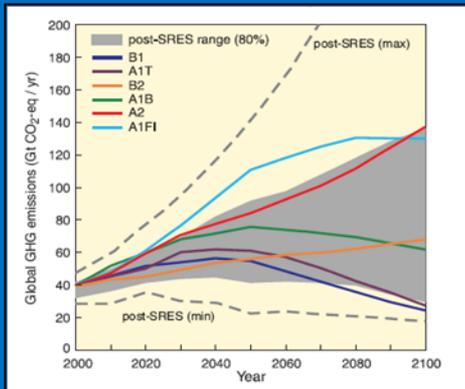
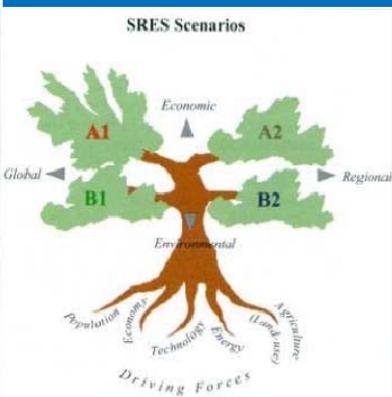
California Statewide Annual Precipitation



Downscaled Climate Projections

112 downscaled climate projections

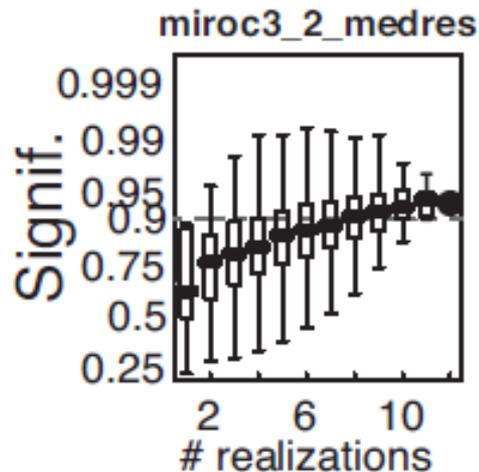
- PCMDI CMIP3 DCP archive
- BCSD downscaling method
- 16 GCMs included in IPCC AR4
- SRES A2, A1b, and B1 scenarios to bracket range
- Multiple realizations



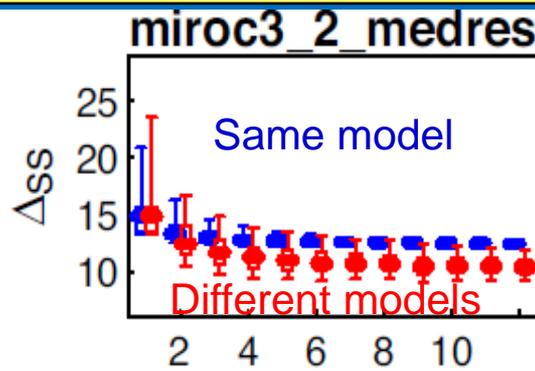
Source: IPCC 2007

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

Multi-model Ensemble is Superior to Any Individual Model Projection

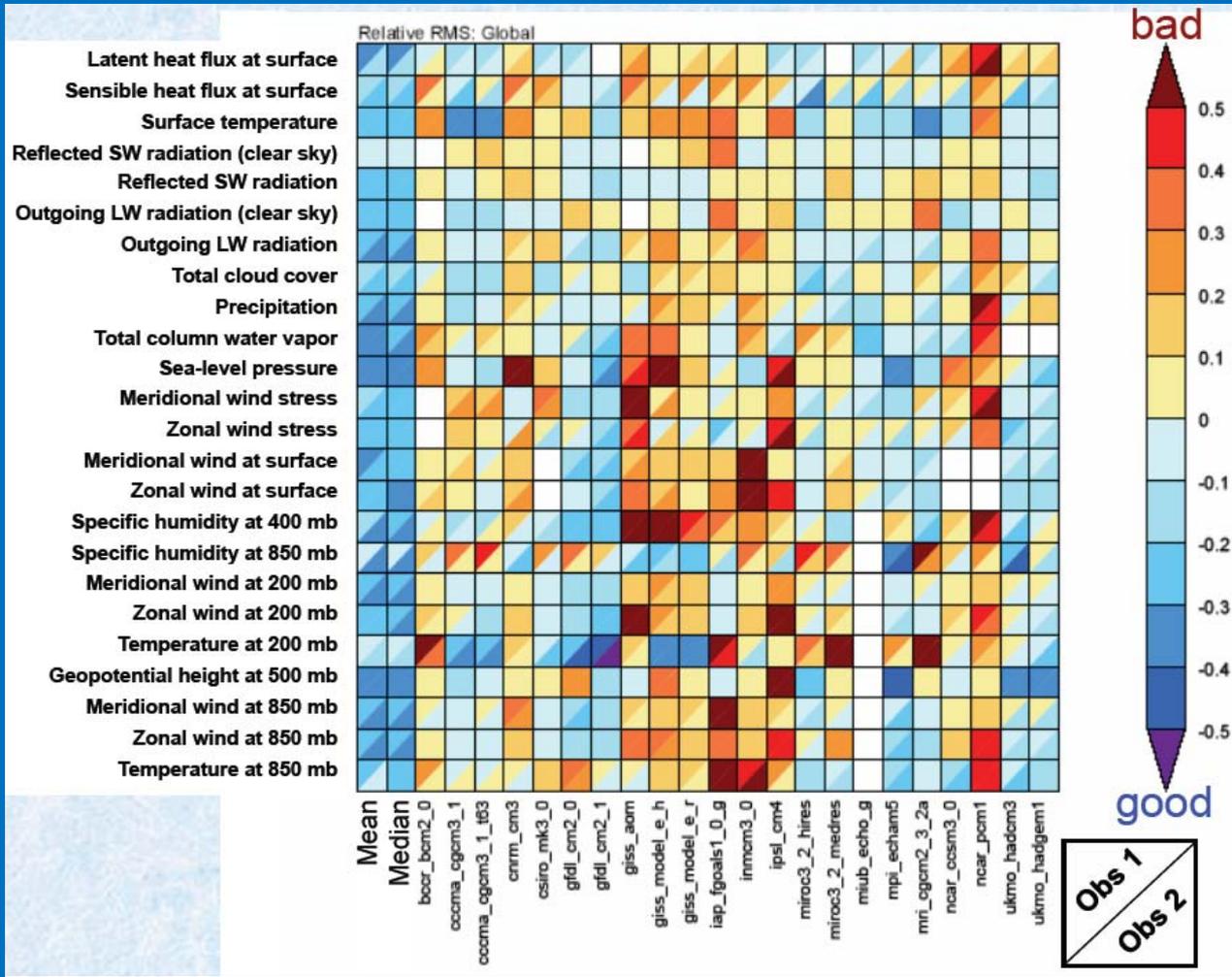


Statistical significance of model trend in JFM Tmin for western U.S. with increasing # of realizations



Change in model "skill score" with increasing # of realizations

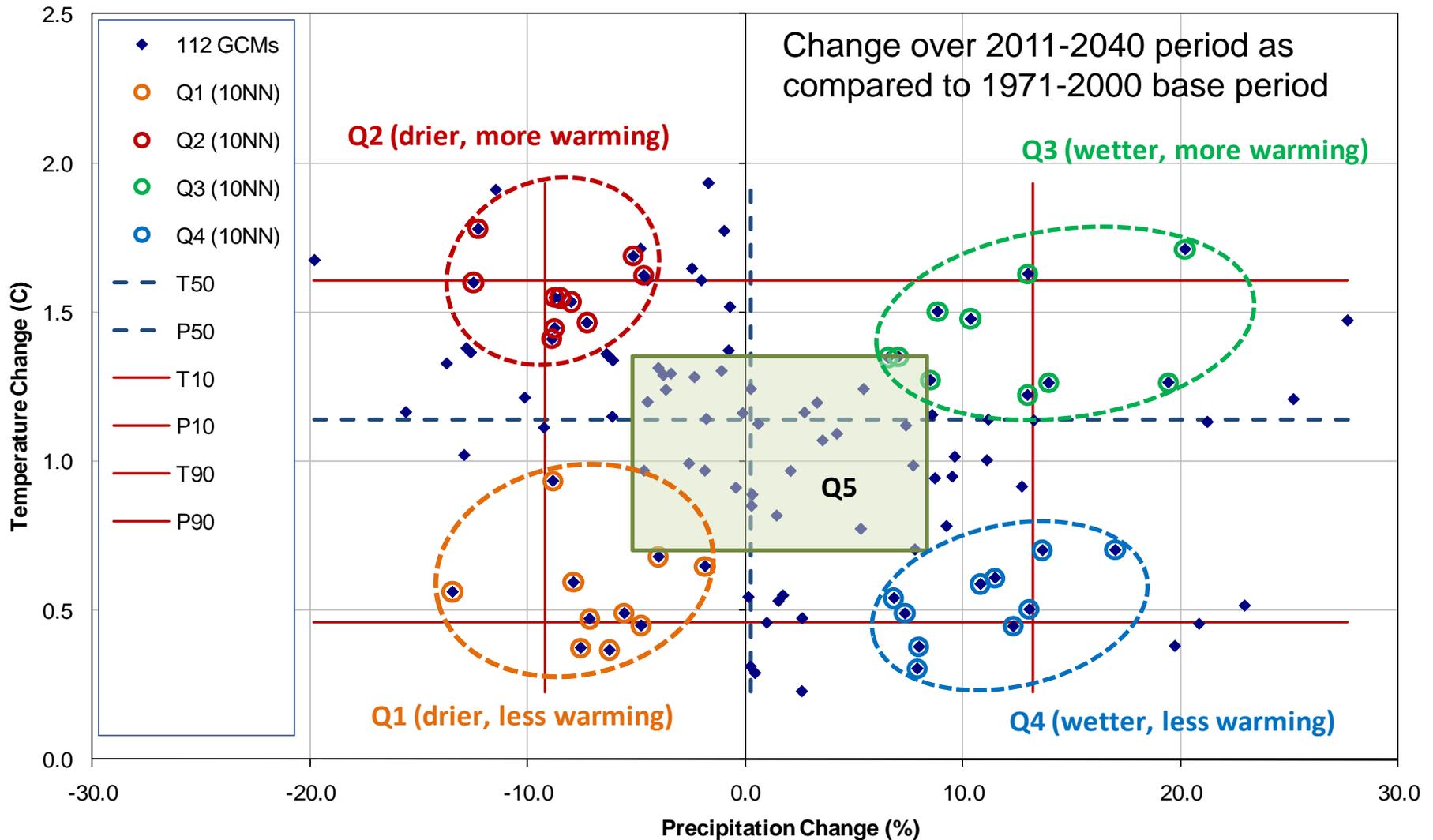
Source: Pierce et al, 2009



Source: Gleckler et al, 2008

Climate Scenarios – Nearest-Neighbor Method

Relationship Between Changes in Mean Annual Temperature and Precipitation
Scenarios - 10 NN Method
Feather River Basin (Example)

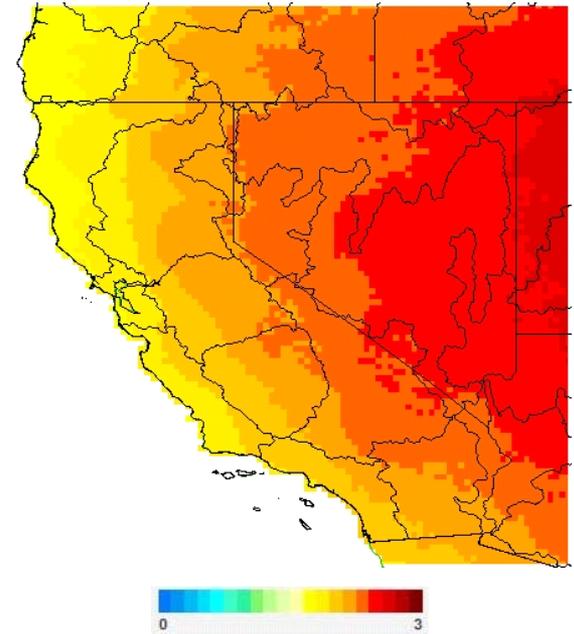


Projected Changes in Annual Temperature and Precipitation (Q5 Scenario)

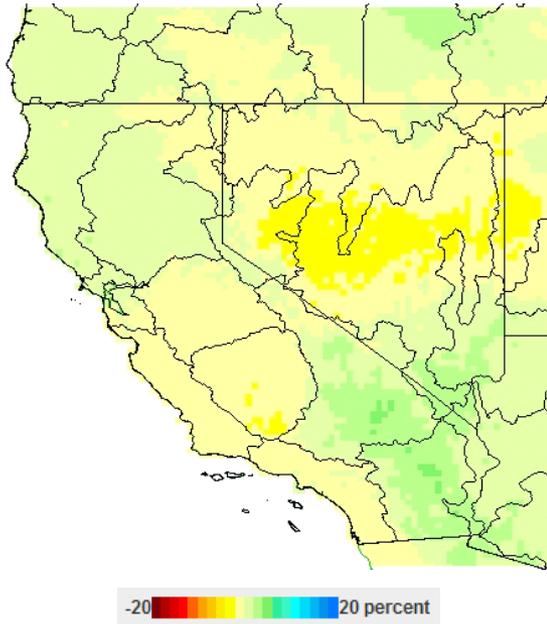
Temperature Change @ 2025



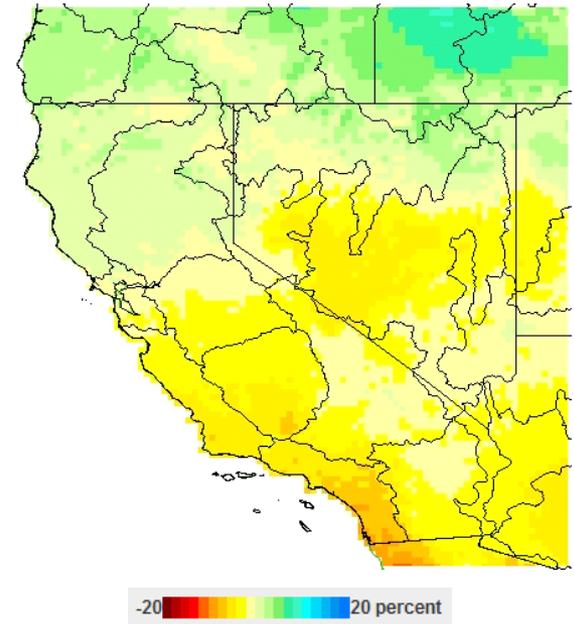
Temperature Change @ 2060



Precipitation Change @ 2025

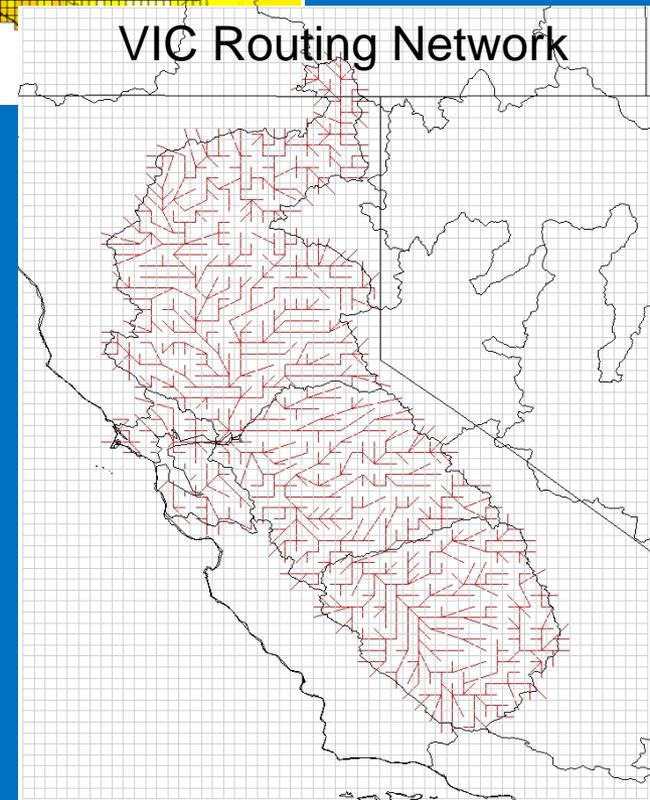
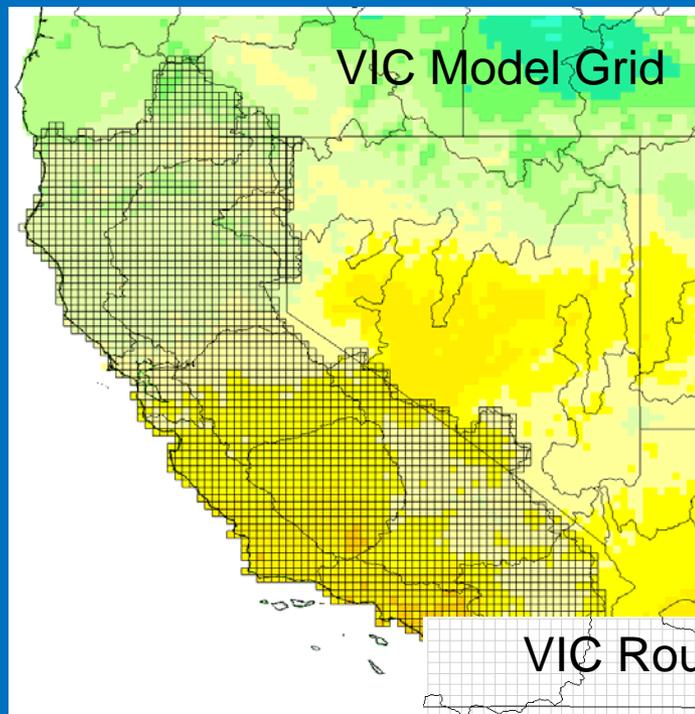
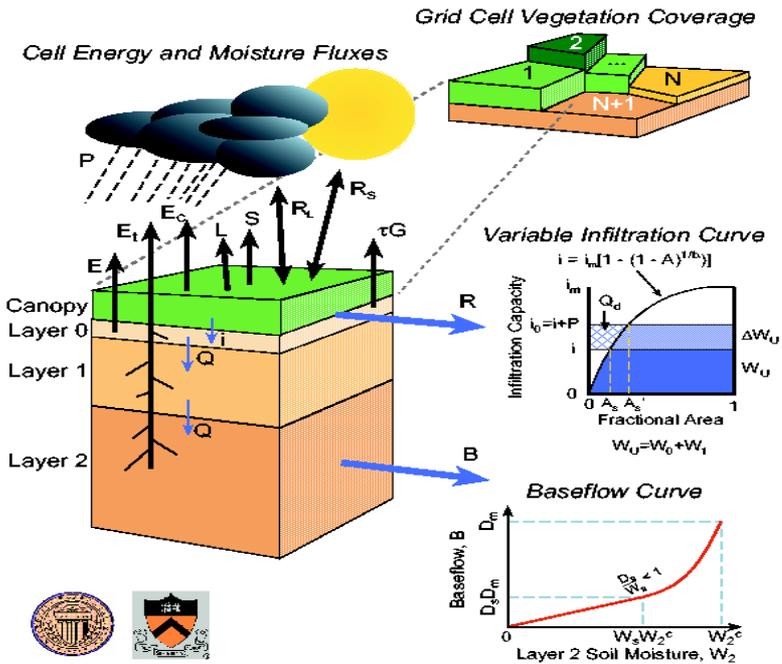


Precipitation Change @ 2060



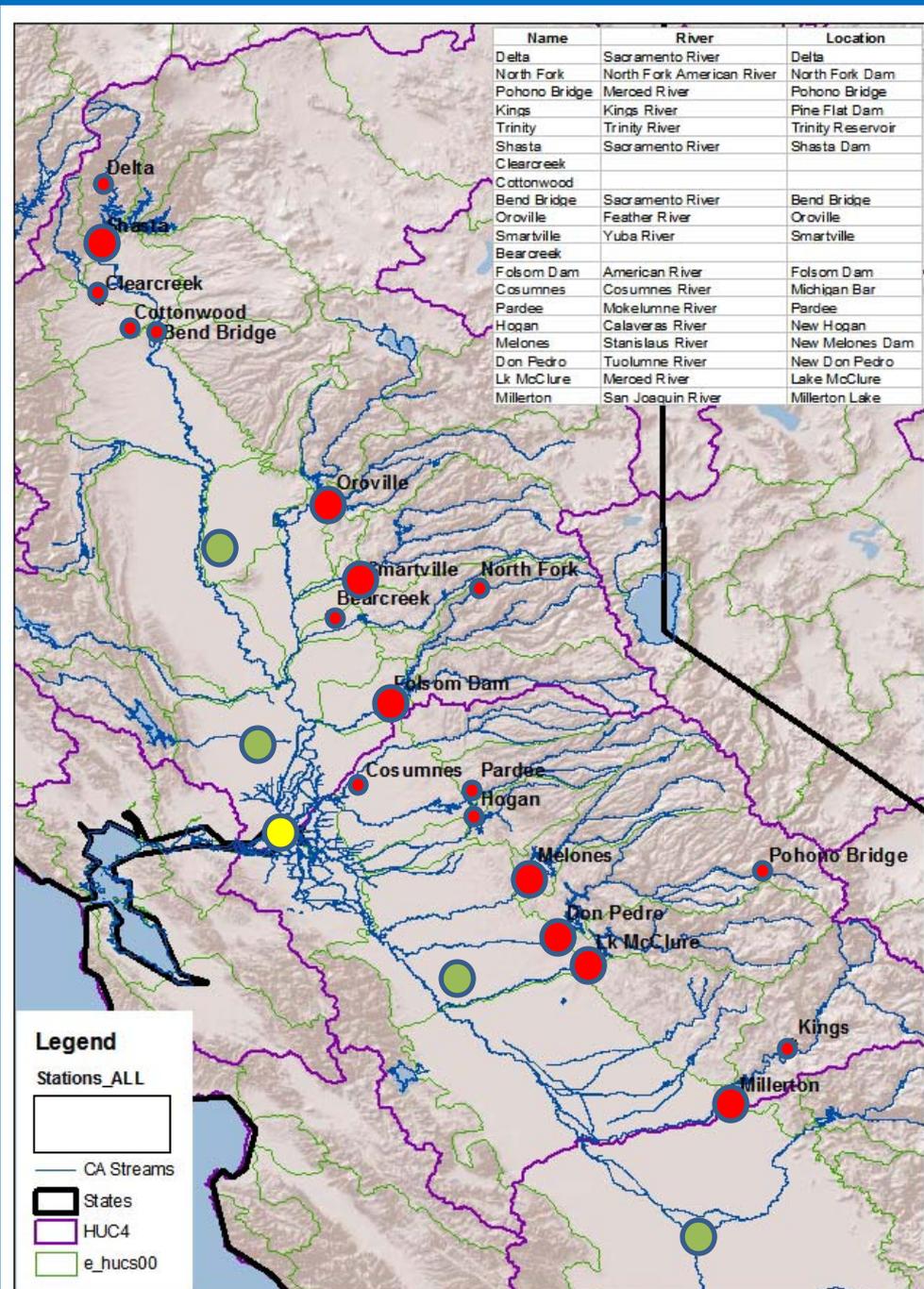
VIC Hydrologic Analysis

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model



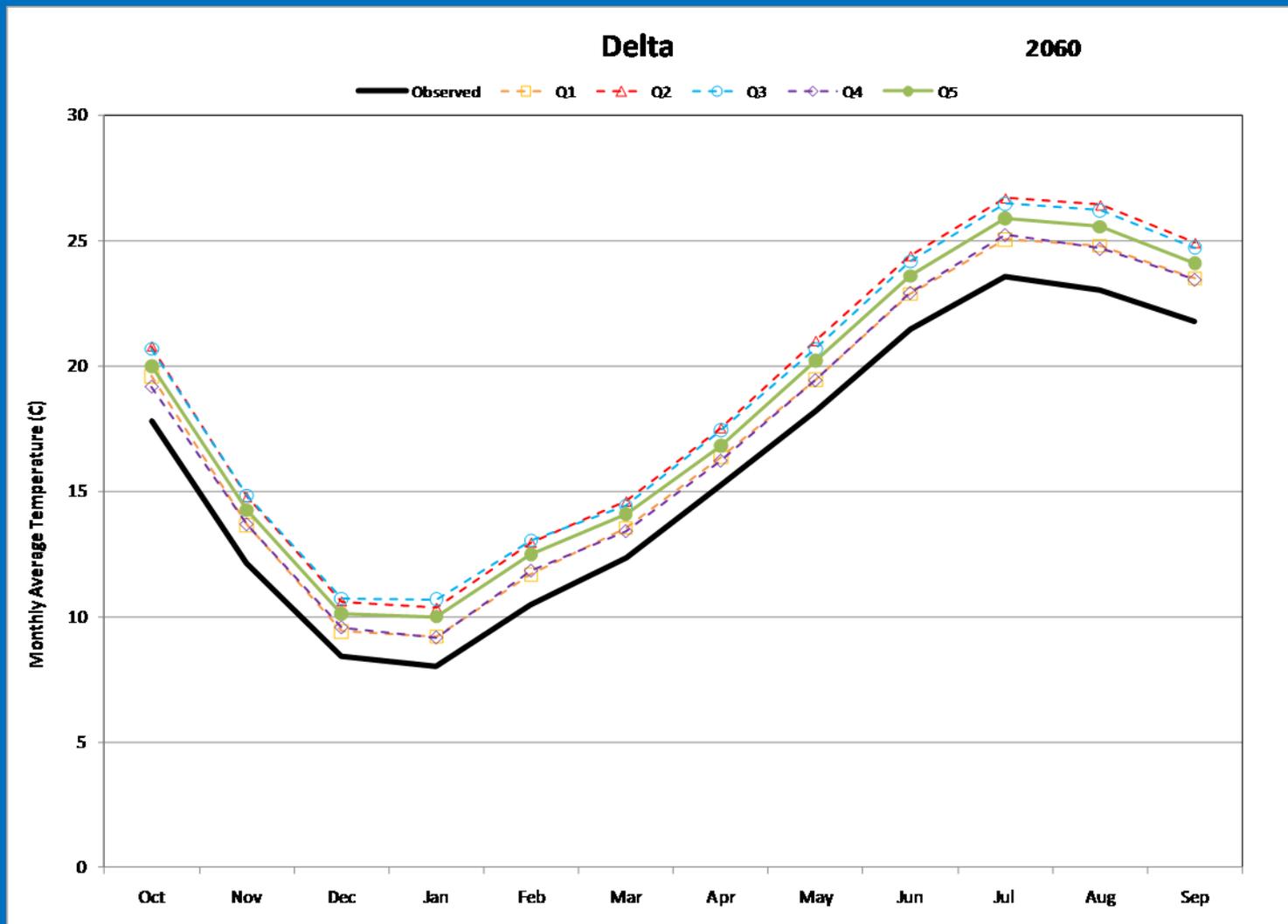
Climate interaction with the watershed characteristics matter immensely

Streamflow Routing and Climate Station Locations



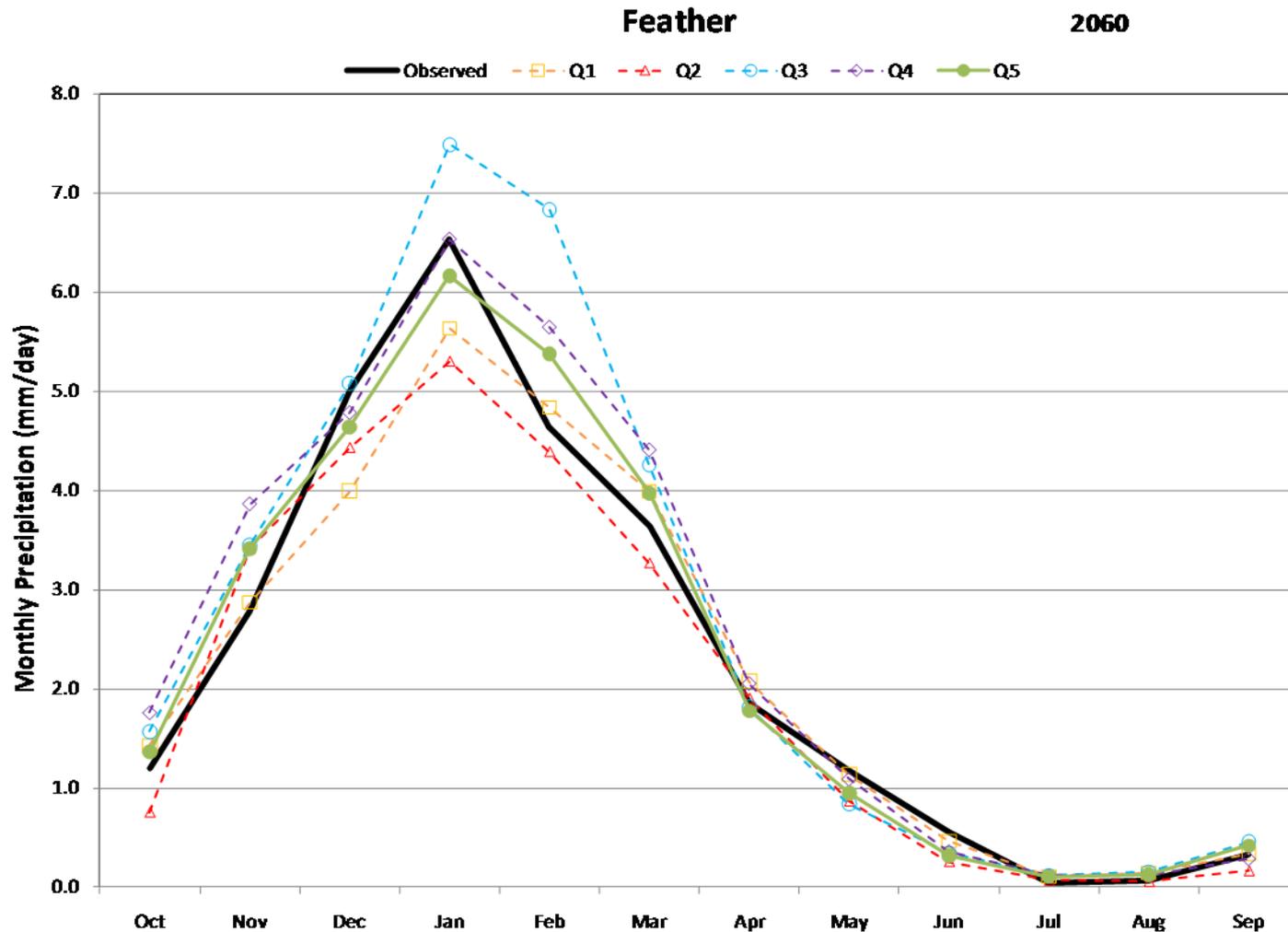
Temperature Projections

Delta Location @ 2060



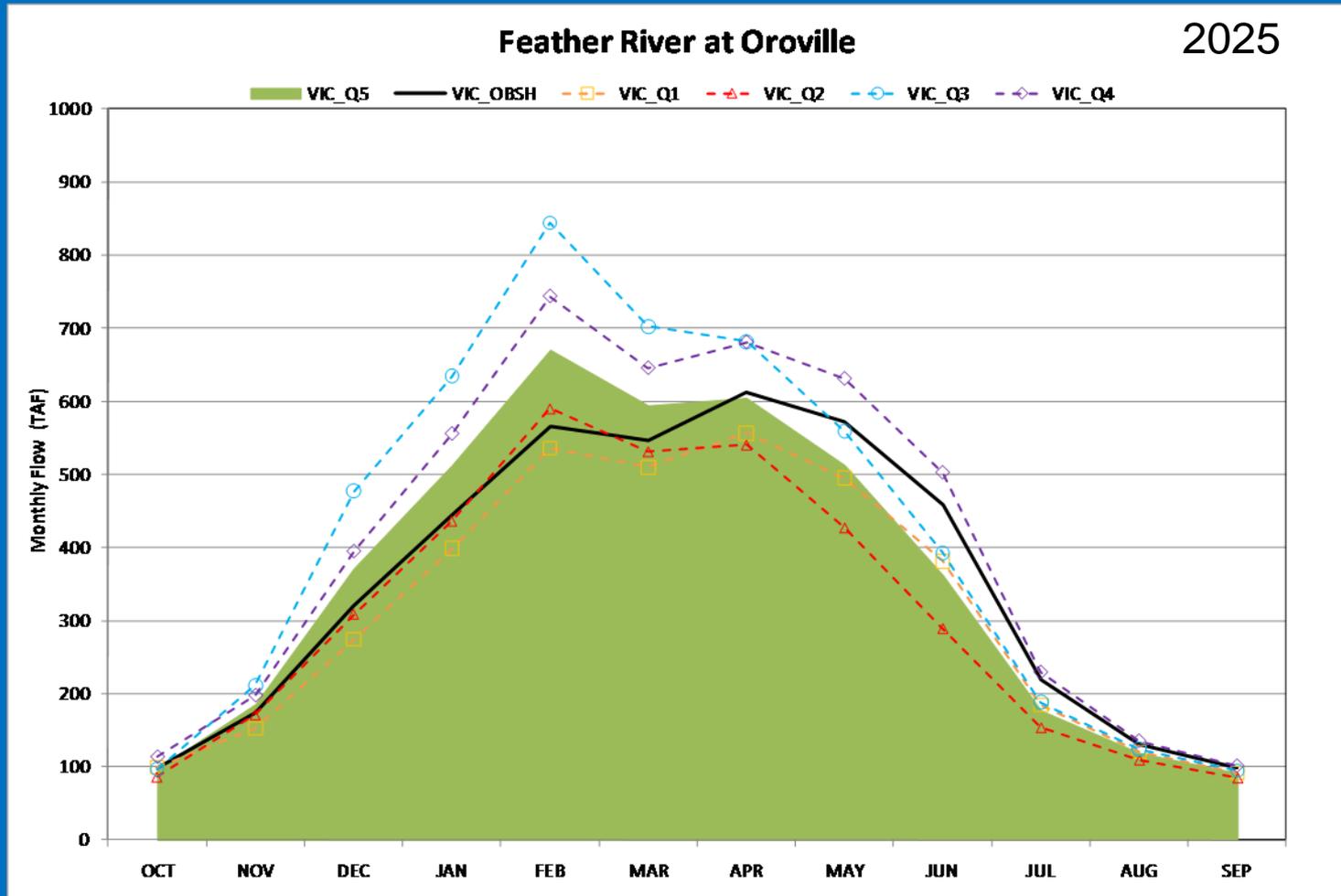
Precipitation Projections

Feather River location @ 2060



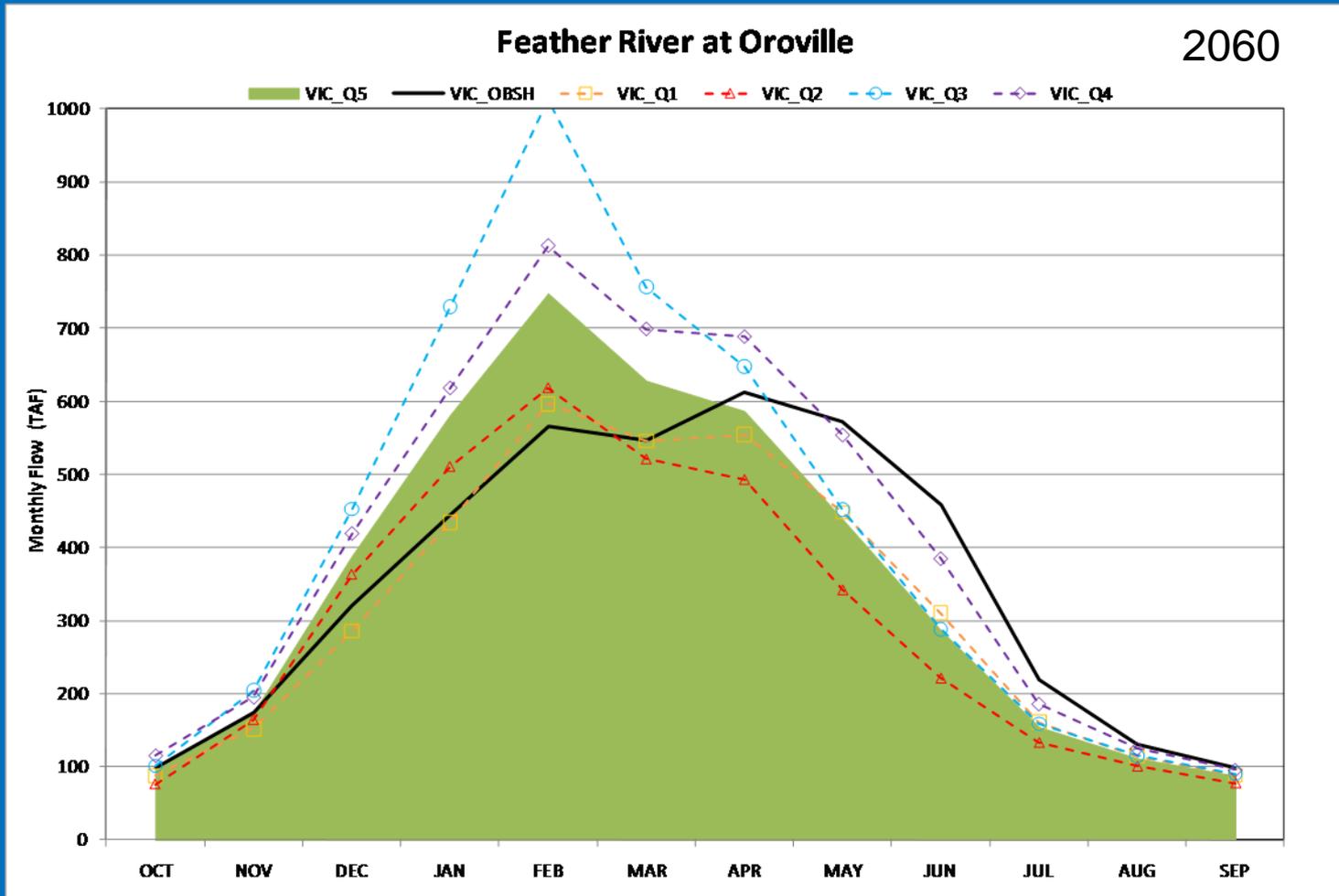
Projected Streamflow

Feather River at Oroville @ 2025



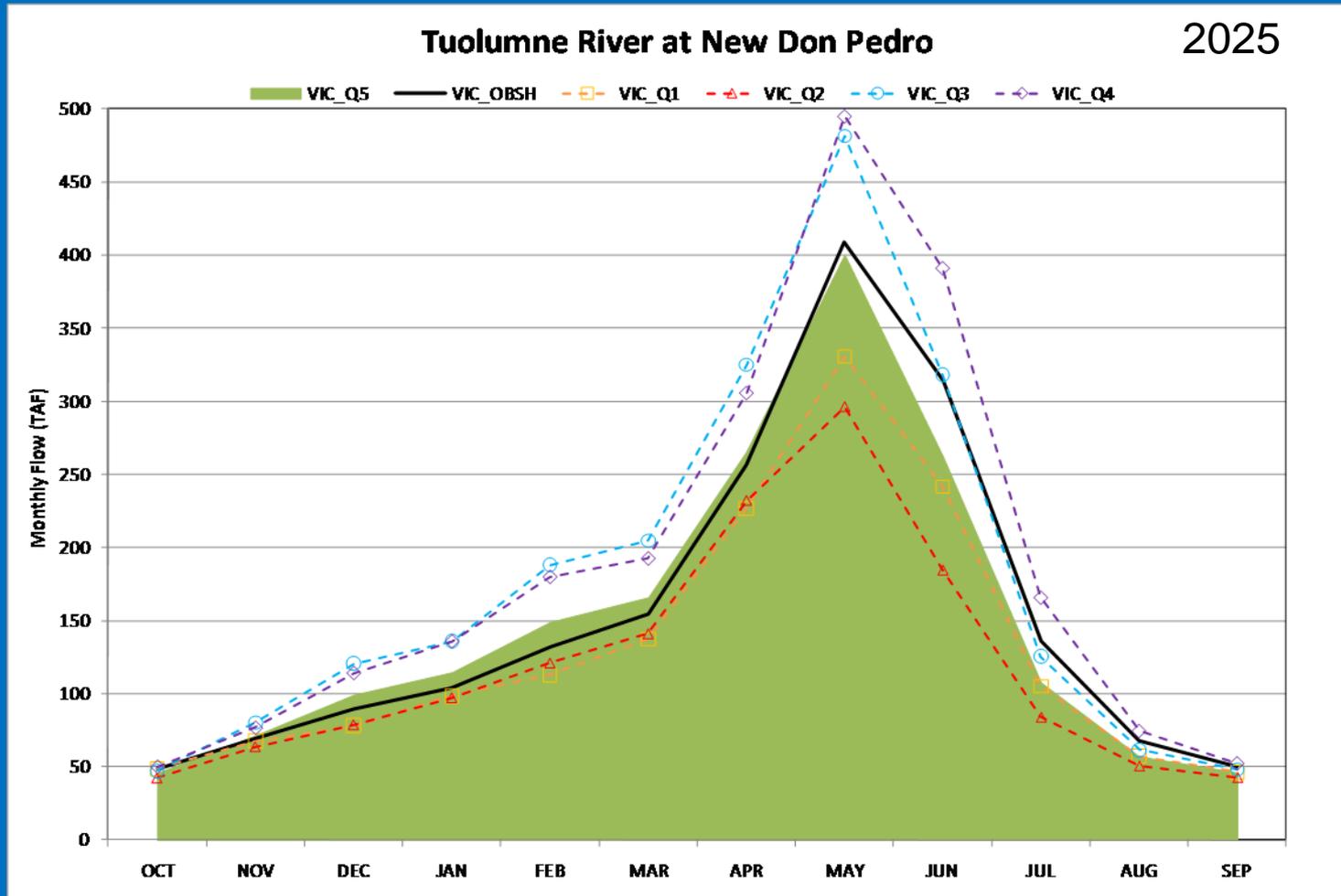
Projected Streamflow

Feather River at Oroville @ 2060



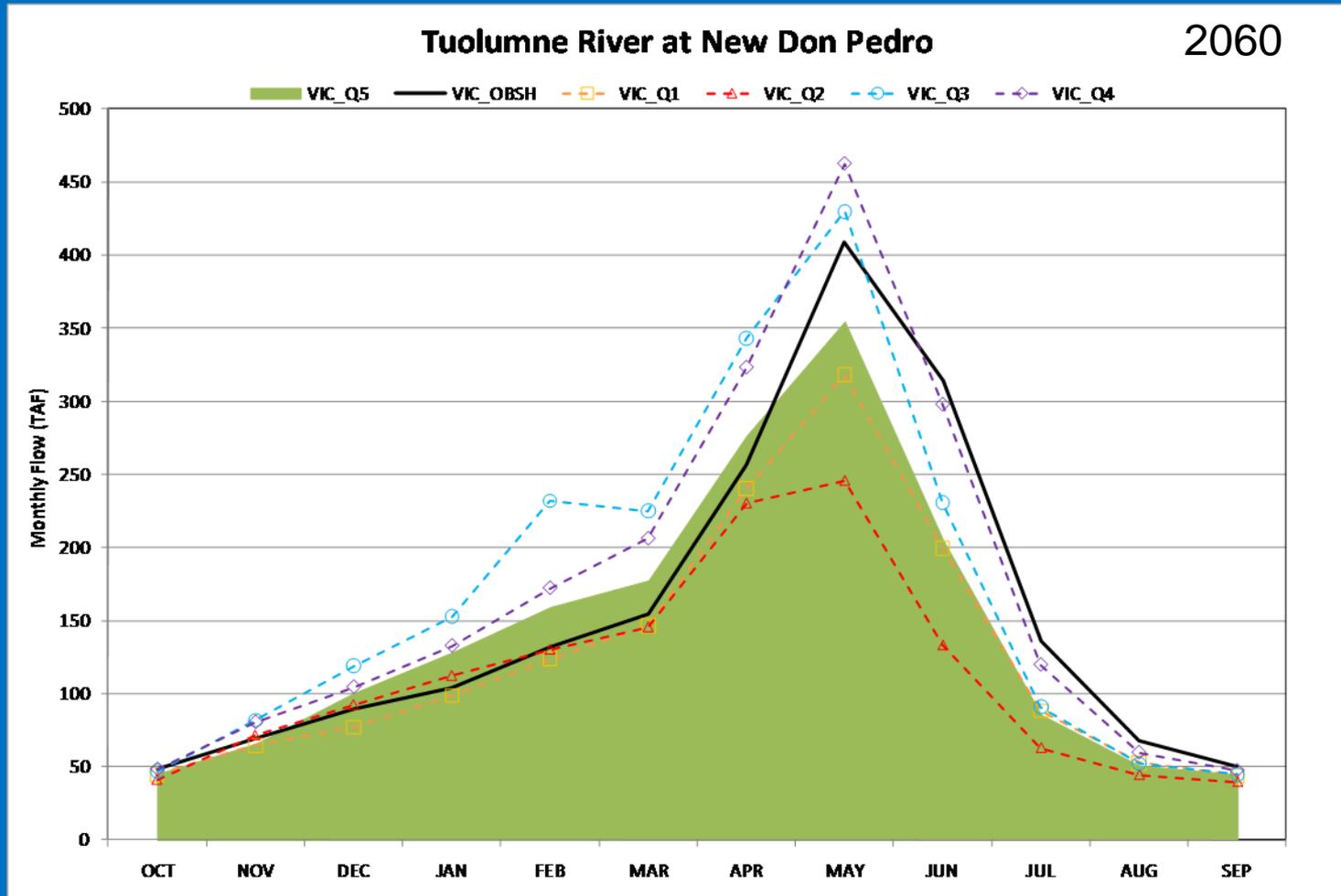
Projected Streamflow

Tuolumne River at New Don Pedro @ 2025



Projected Streamflow

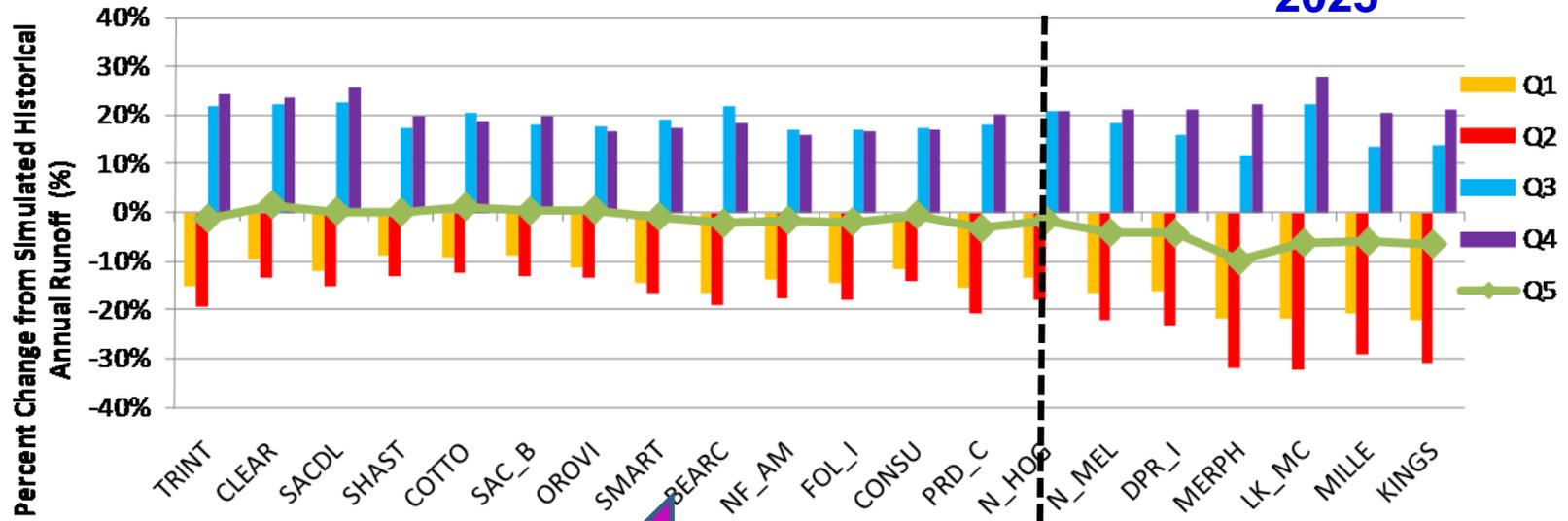
Tuolumne River at New Don Pedro @ 2060



Simulated
Changes
in Annual
Runoff

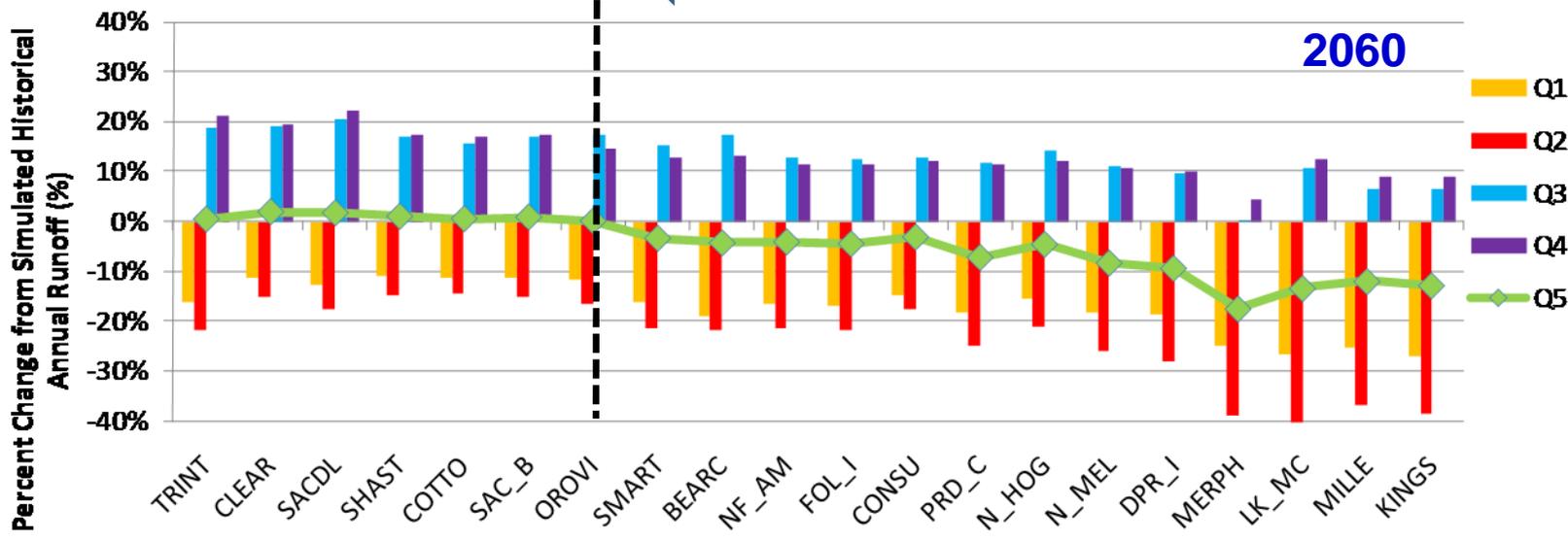
Change in Annual Runoff

2025



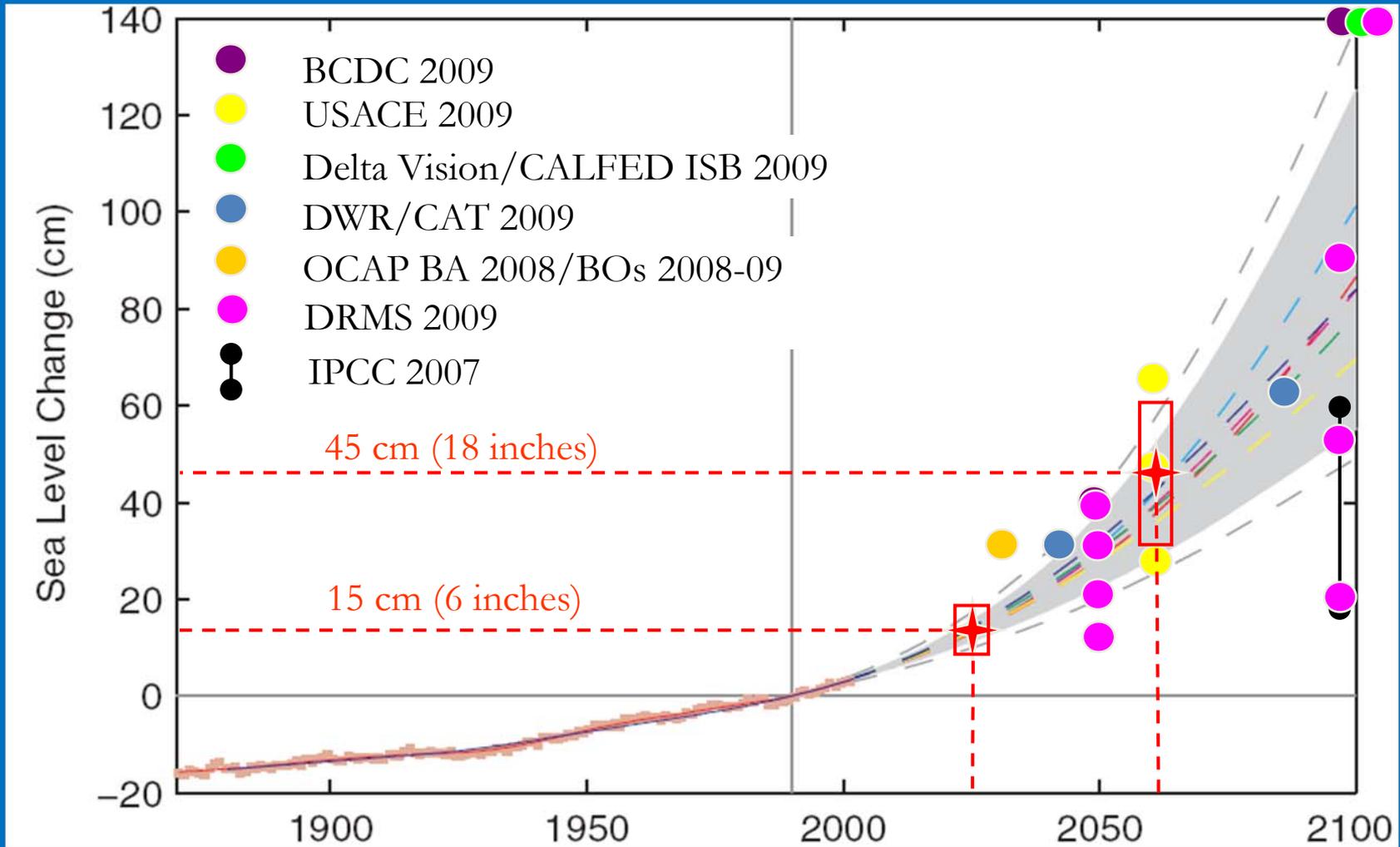
North-
South
Transect

2060



Basin

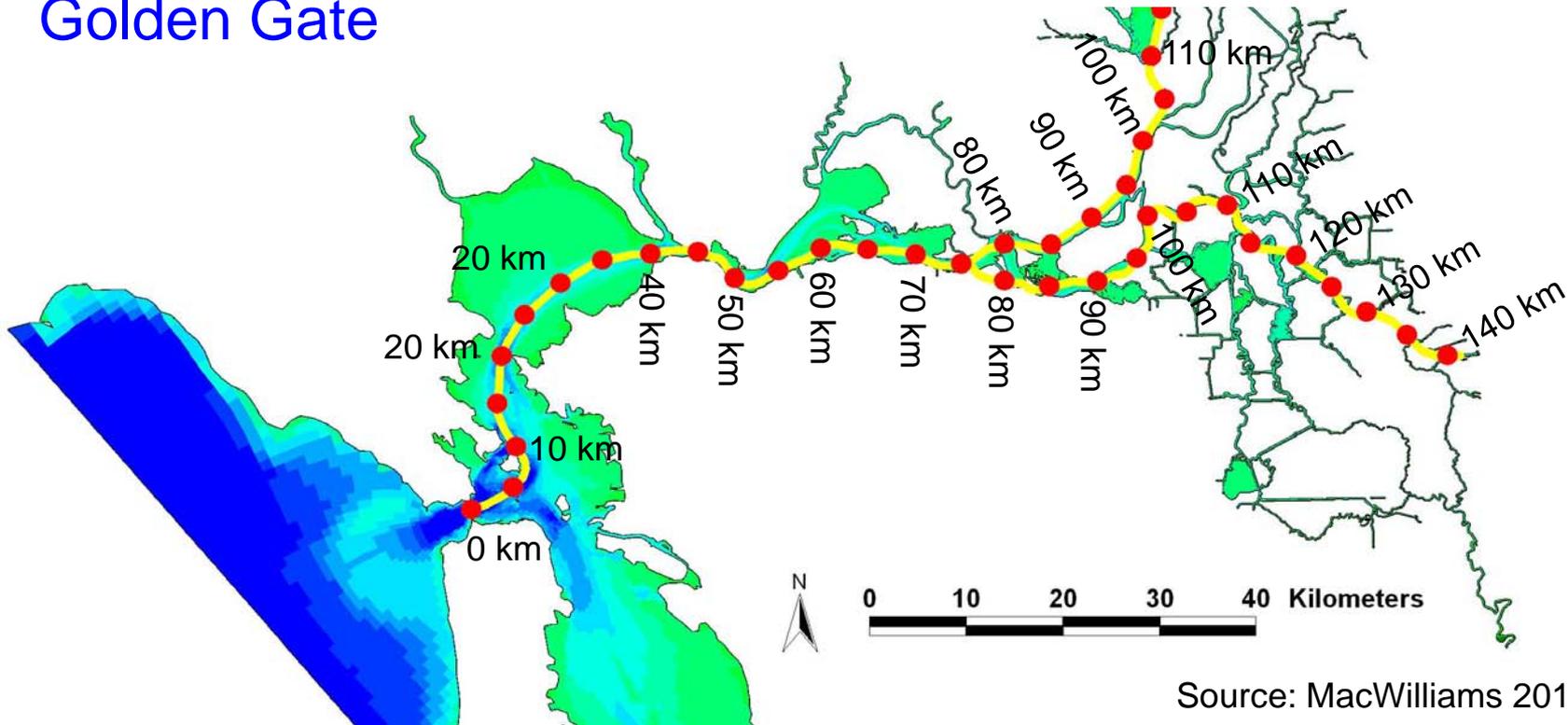
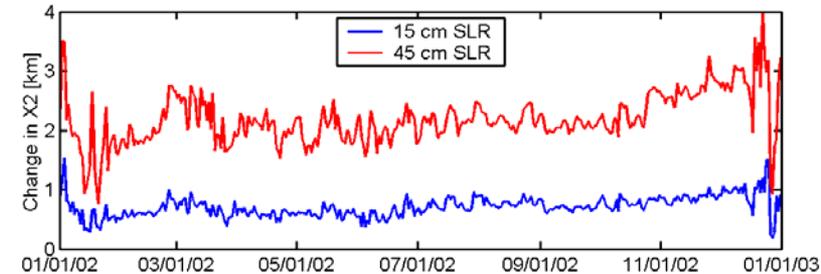
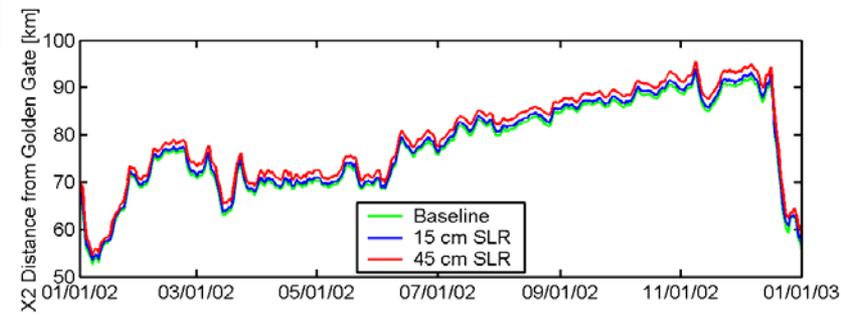
Navigating Sea Level Rise Uncertainty



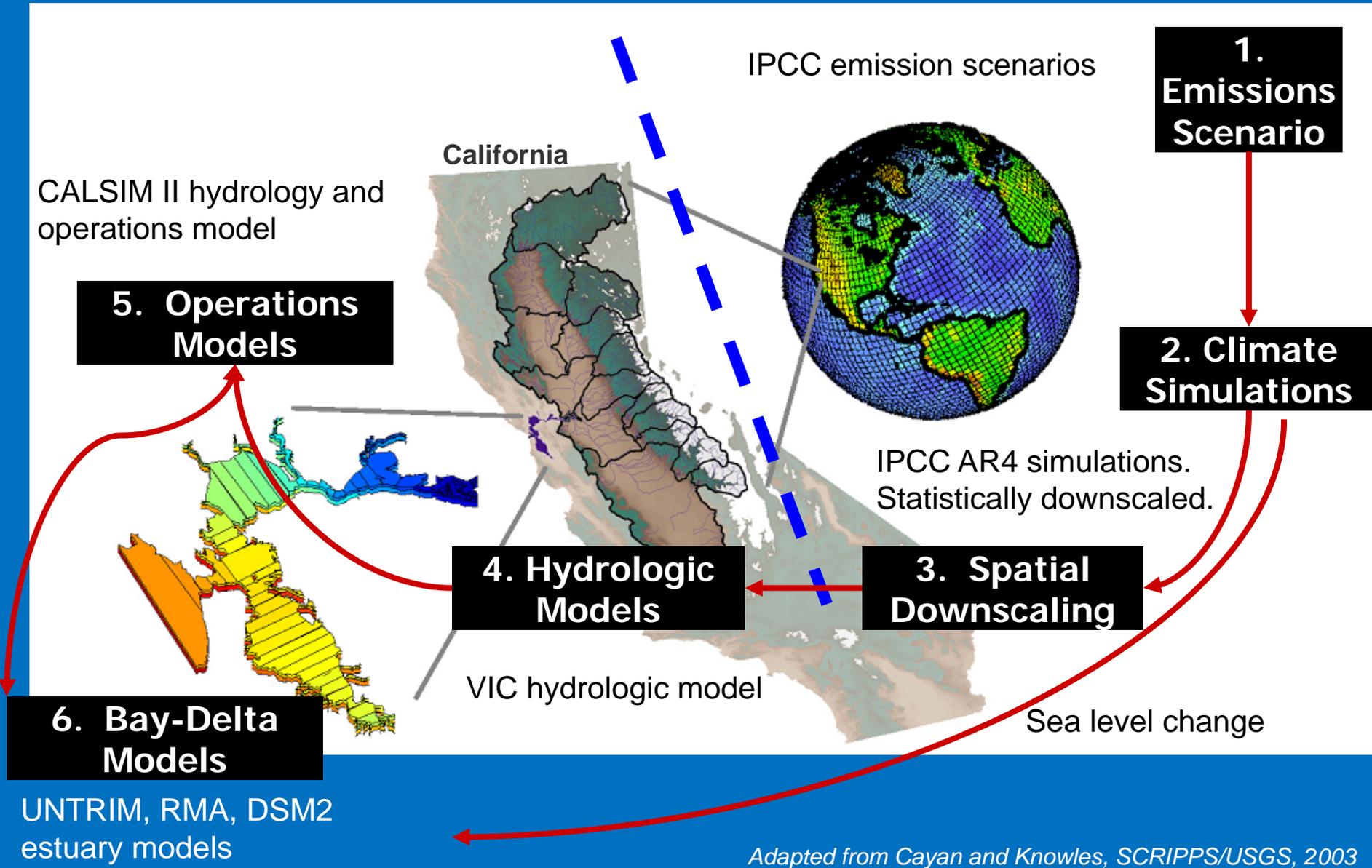
Source: Rahmstorf 2007

Effect of Sea Level Rise on Salinity Intrusion

X2 is defined as the position of the 2 psu bottom salinity value, and is measured along the axis of the estuary in km from the Golden Gate



Putting it Together ... system responds to climate forcings at both the watershed-scale and ocean boundary

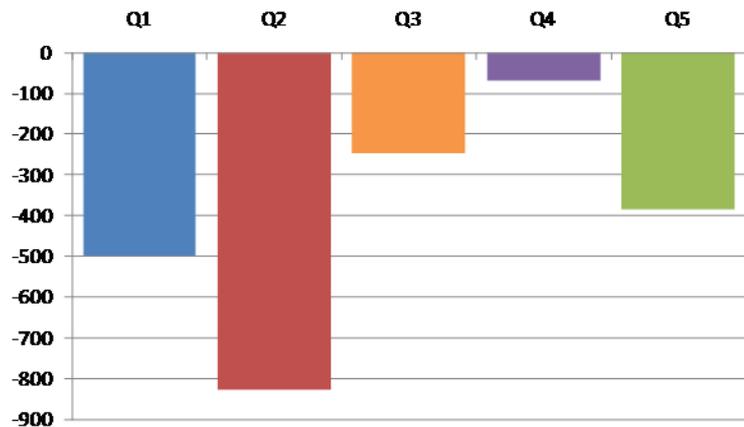


Summary of Changes to the Delta System

(Difference at 2060 from No Action, No Climate Change reference)

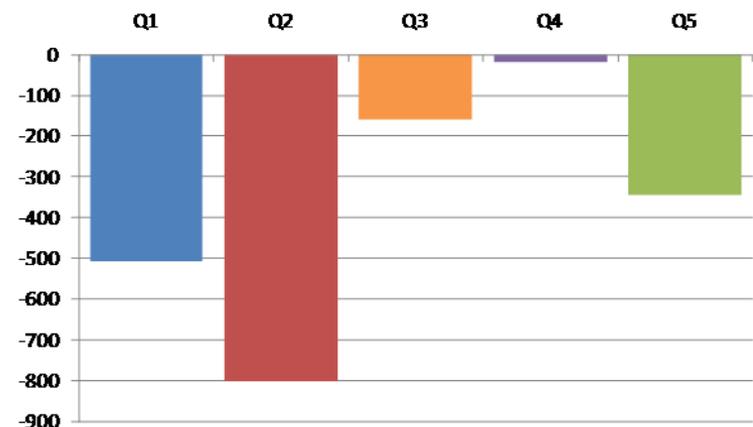
No Action

Shasta Carryover Storage (kaf)

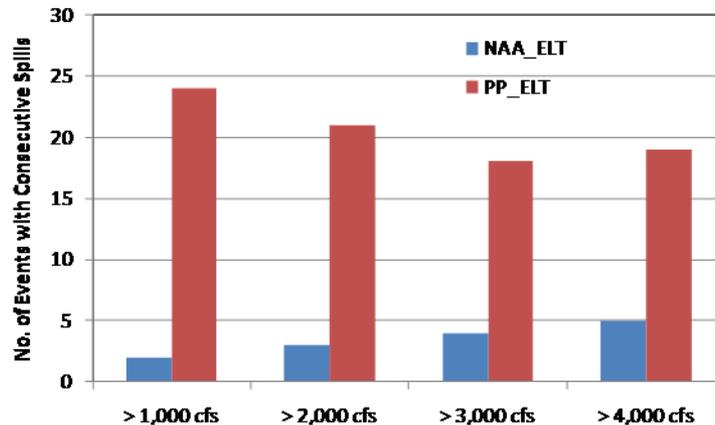


Proposed Project

Shasta Carryover Storage (kaf)



Increase in No. of Events Activating Floodplain (more than 7 consec. days)



DRAFT

Summary of Changes to the Delta System

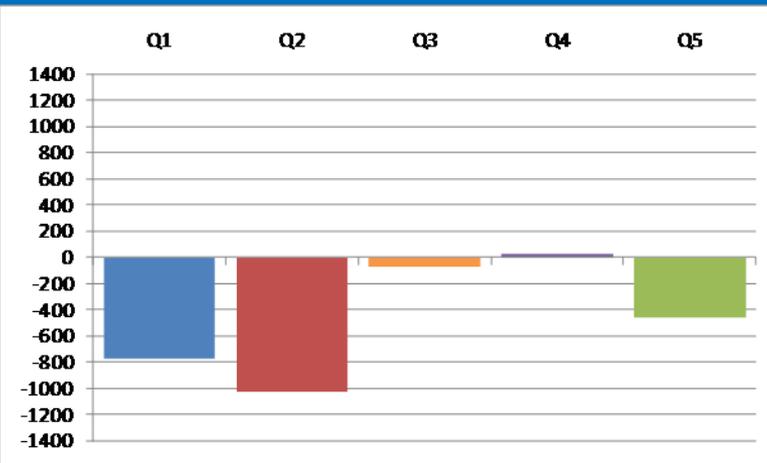
(Difference at 2060 from No Action, No Climate Change reference)

DRAFT

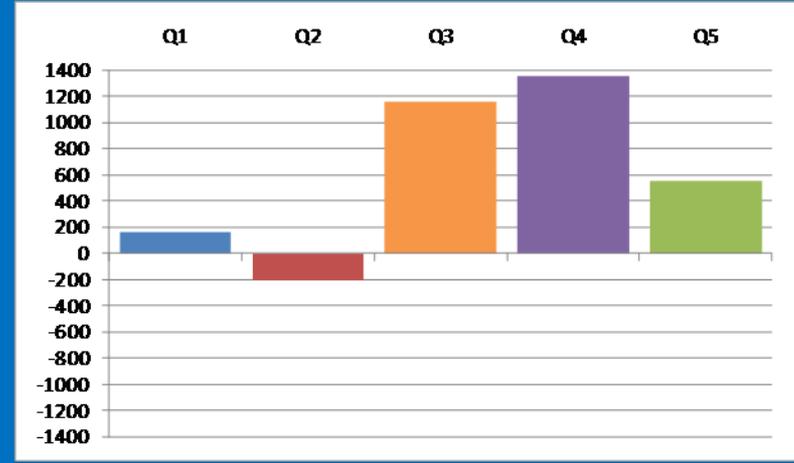
No Action

Proposed Project

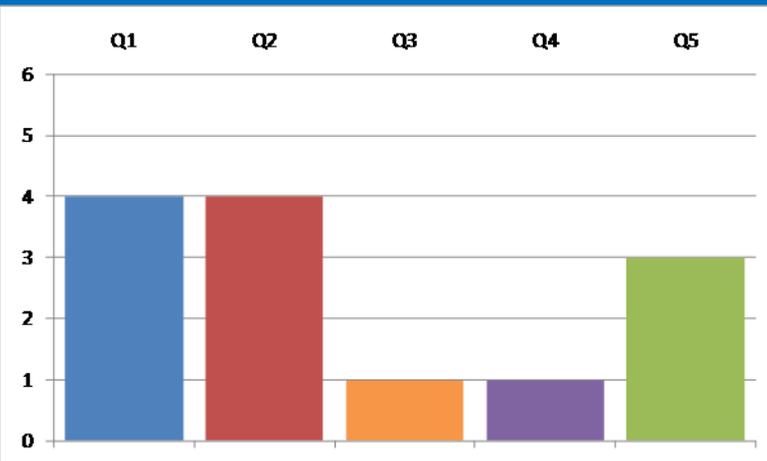
Delta Exports (kaf/yr)



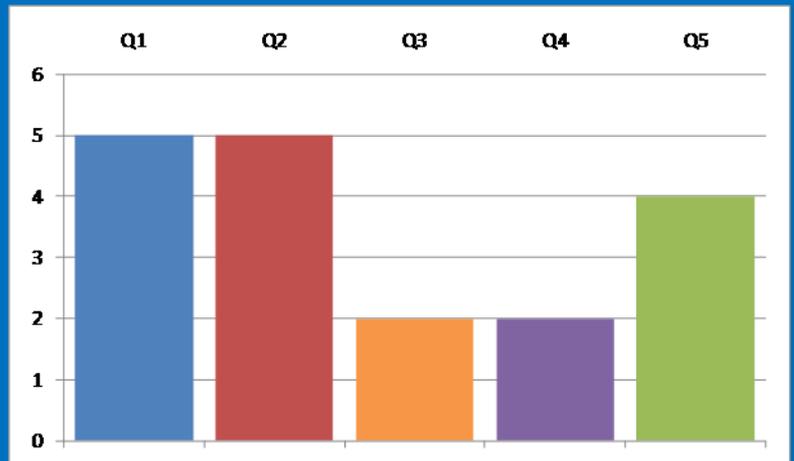
Delta Exports (kaf/yr)



Spring Delta X2 (km)



Spring Delta X2 (km)



Summary

- Long-range planning for programs such as the BDCP with cascading analyses and many alternatives require a manageable, yet informative set of climate scenarios for analysis
- Ensemble-informed climate scenarios have been developed for California for this long-range planning purpose
- Hydrologic and system responses to future climate change is substantial, but geographically/facility varied



Thank you!

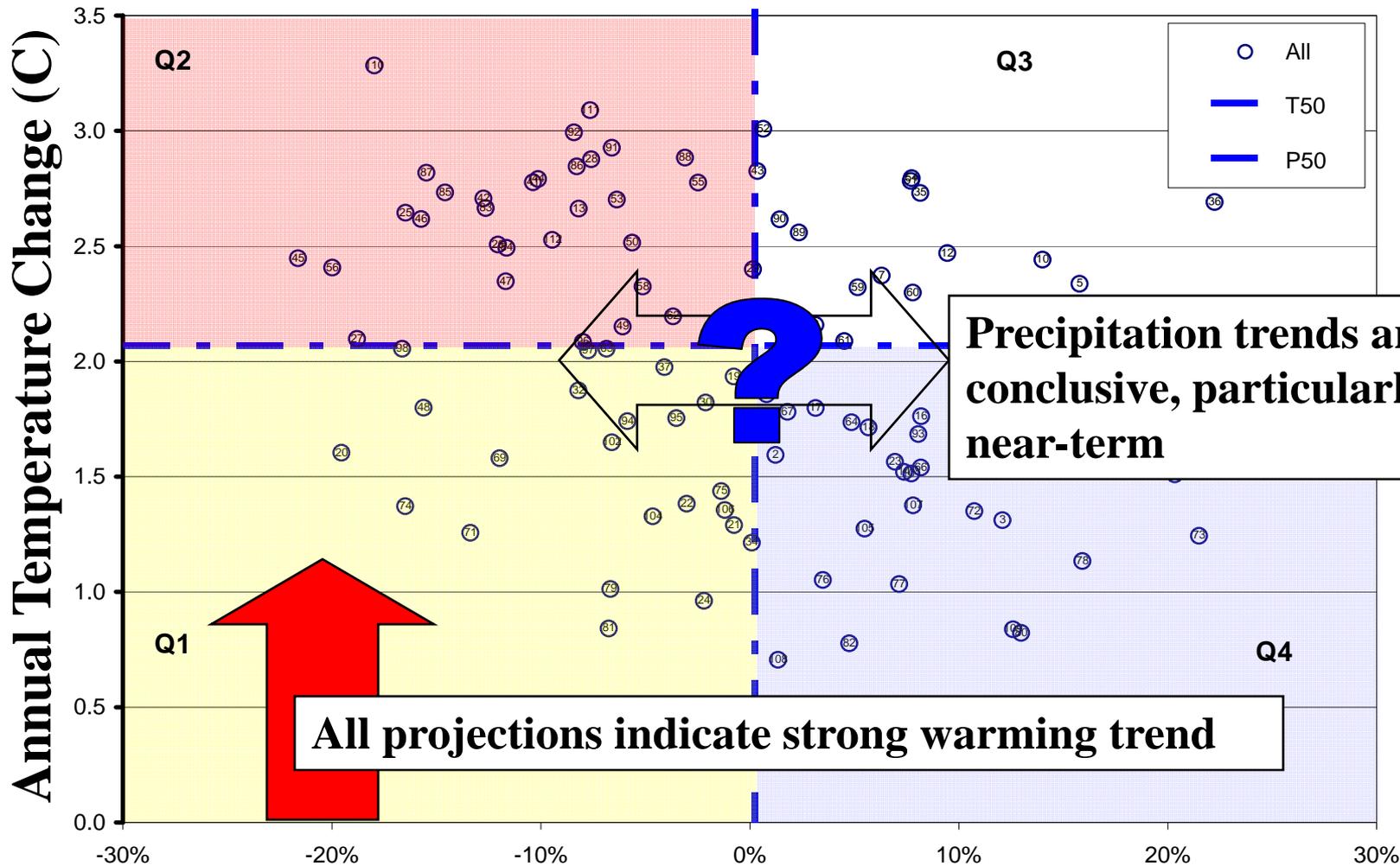
Armin Munévar, CH2M HILL
armin.munevar@ch2m.com

Sorting through Regional Climate Uncertainty

Relationship between Changes in Period-Mean Annual Precipitation and Temperature:

Folsom

(112 projections, evaluated at 2060 [2046-75] relative to 1971-2000)



Precipitation trends are less conclusive, particularly in near-term

All projections indicate strong warming trend

Annual Precipitation Change (%)