Using Future Climate Projections to Support Water Resources Decision Making in California

Advanced Climate modeling and Decision-Making Support of Climate Services

20 September -24 September in Aspen, Colorado

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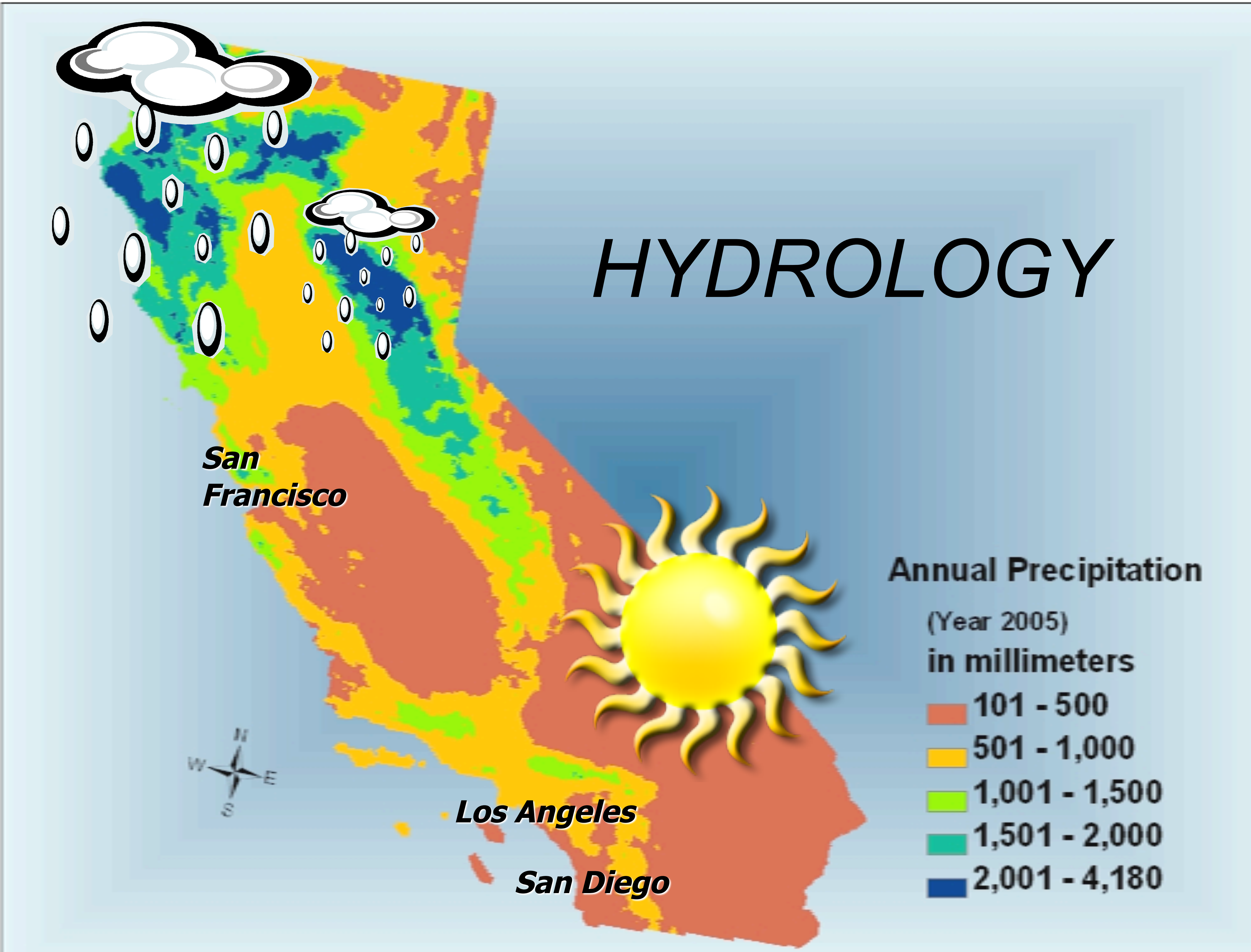
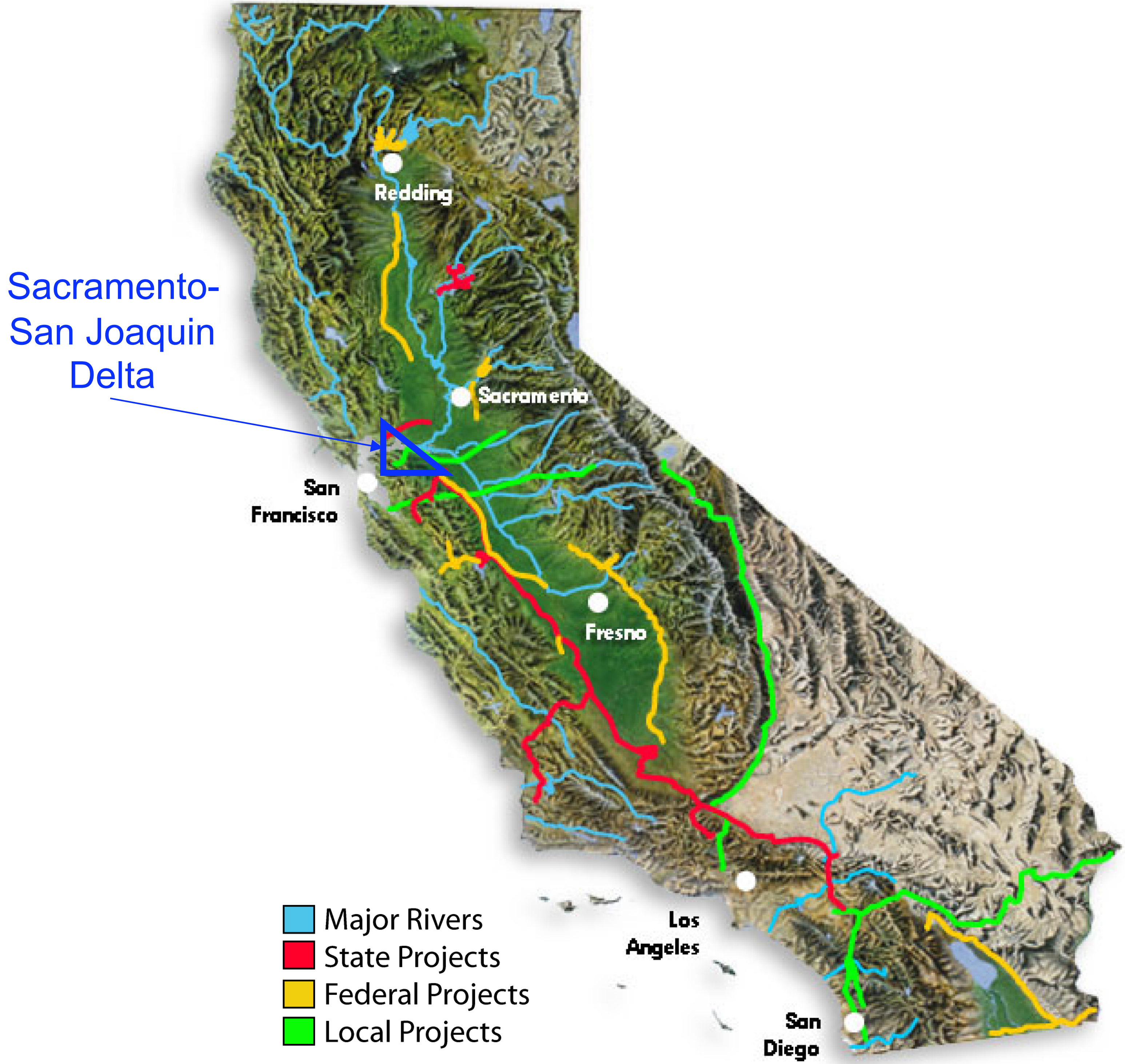
California Department of Water Resources

Department of Water Resources
Modeling Support Branch
Bay-Delta Office

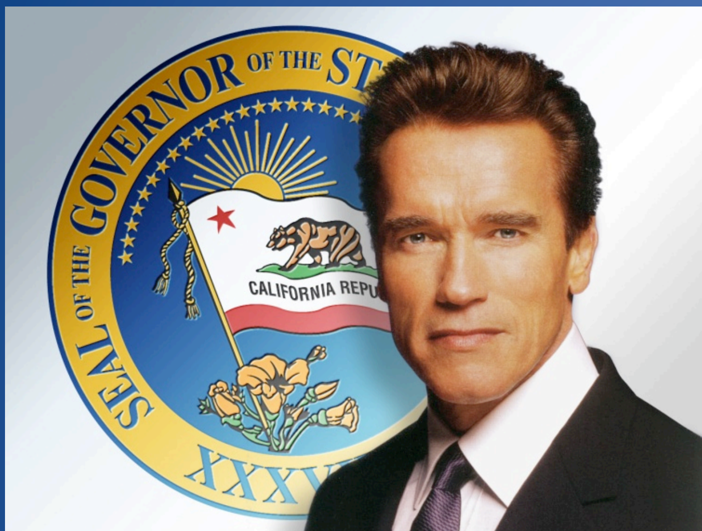


HYDROLOGY
San Francisco
Los Angeles
San Diego
N
W
E
S
Annual Precipitation
(Year 2005)
in millimeters
101 - 500
501 - 1,000
1,001 - 1,500
1,501 - 2,000
2,001 - 4,180



Sacramento-
San Joaquin
Delta
Redding
Sacramento
San
Francisco
Fresno
Los
Angeles
San
Diego
Major Rivers
State Projects
Federal Projects
Local Projects

Governor's Executive Order S-3-05



CALIFORNIA
Climate
ACTION TEAM

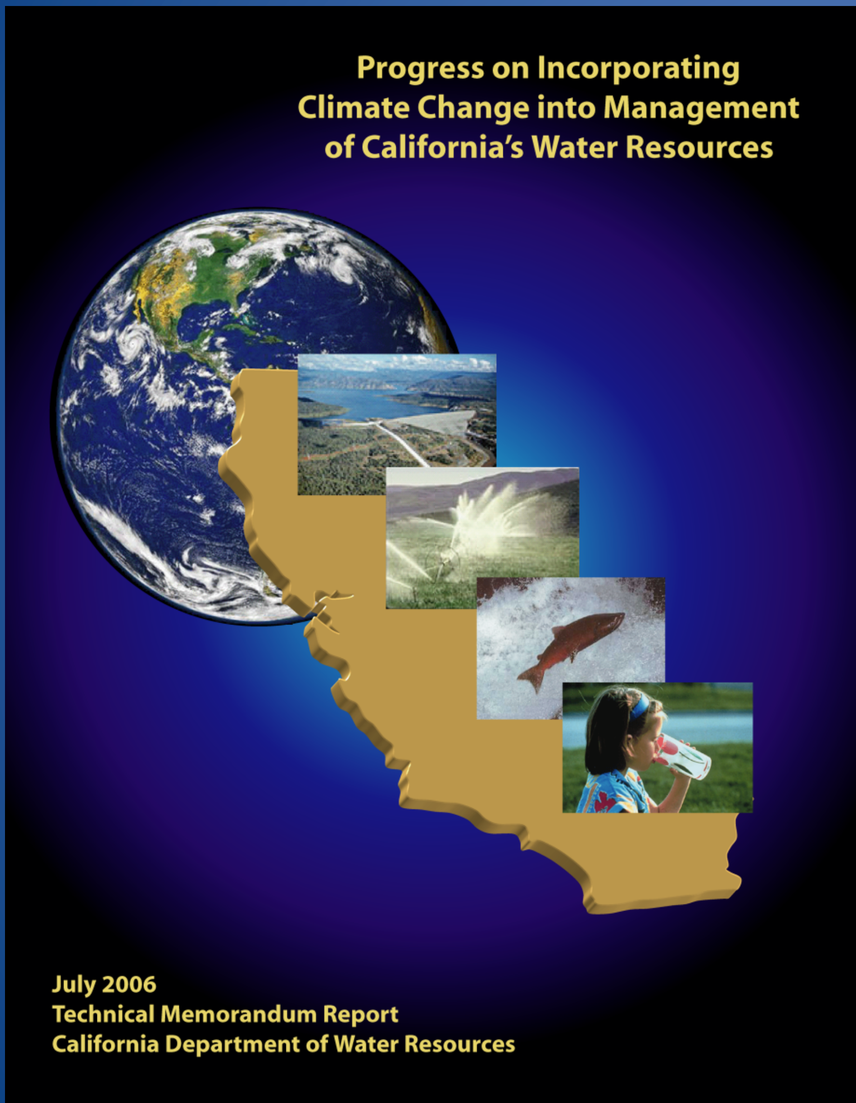
- Signed June 1, 2005
- Targets to reduce emission levels of greenhouse gases
- Required biennial reports starting January 2006
  - Water supply
  - Public health
  - Agriculture
  - CA coastline
  - Forestry
- Formed Climate Action Team

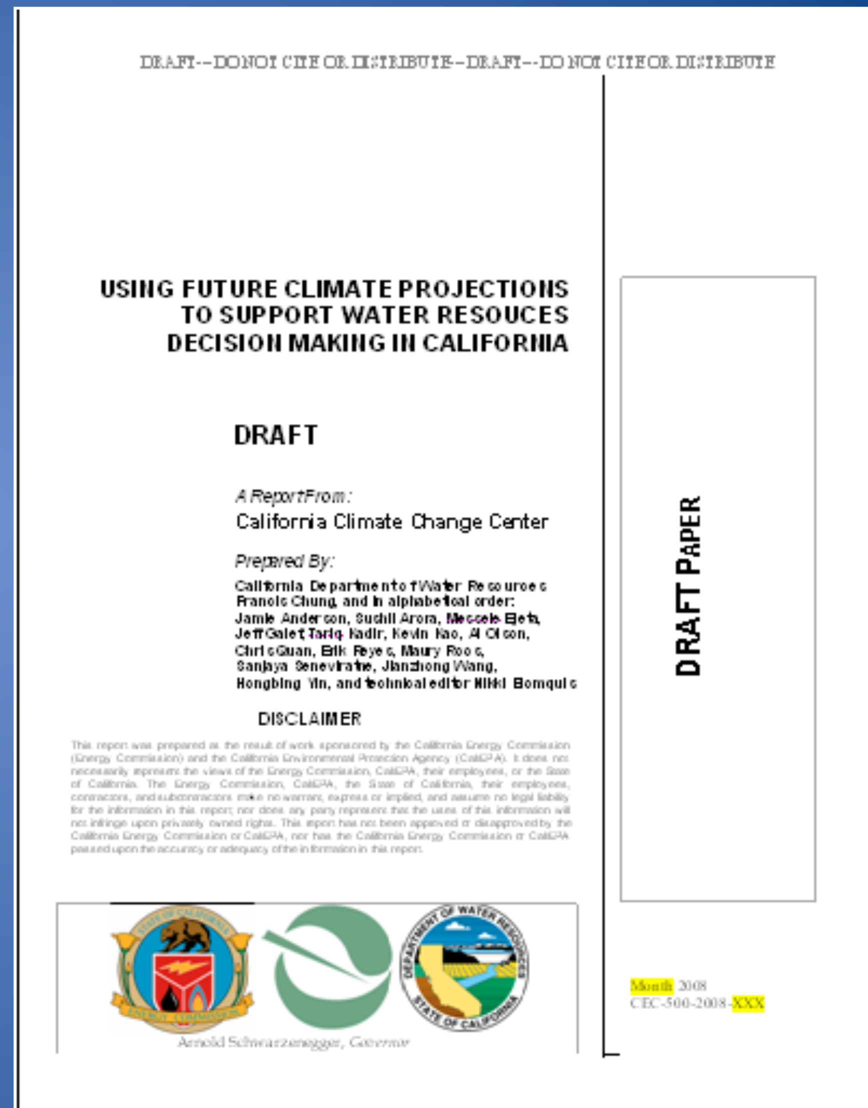
2006 Report

4 Scenarios (2 GCM x2 GHG)

2009 Report

12 Scenarios (6 GCM x2 GHG)





DRAFT--DO NOT CITE OR DISTRIBUTE--DRAFT--DO NOT CITE OR DISTRIBUTE

USING FUTURE CLIMATE PROJECTIONS
TO SUPPORT WATER RESOUCES
DECISION MAKING IN CALIFORNIA

DRAFT

A Report From:
California Climate Change Center

Prepared By:
California Department of Water Resources
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Arnold Schwarzenegger, Governor

DRAFT PAPER

Month 2008
CEC-500-2008-XXX

2009 CAT Future Climate Scenarios

6 Global Climate Models

- GFDL-CM2.1 (USA)
- NCAR-PCM1 (USA)
- CNRM-CM3 (France)
- MPI-ECHAM5 (Germany)
- MIROC3.2med (Japan)
- NCAR-CCSM3 (USA)

2 GHG Emissions Scenarios

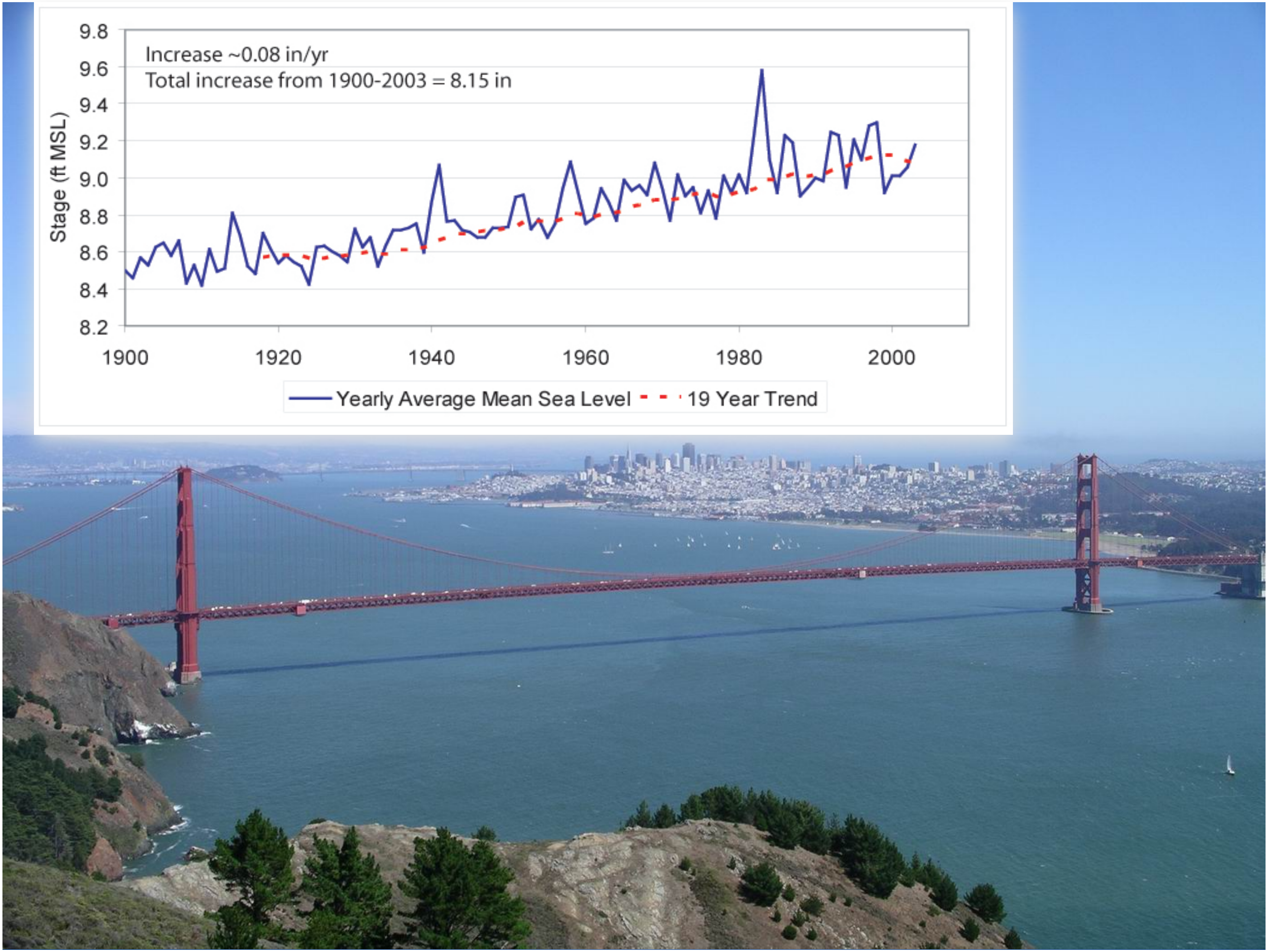
- A2 (higher GHG emissions)
  - high population growth
  - regional economic growth
  - fragmented technological changes
- B1 (lower GHG emissions)
  - low population growth
  - rapid economic growth
  - sustainable technology

12 Total Scenarios = 6 GCM x 2 GHG Emissions Scenarios

Using Future Climate Projections in Decision Making

- Sea level rise
- Effects of increasing air temperature on the upper Feather Basin
- Climate change impacts on water supply reliability

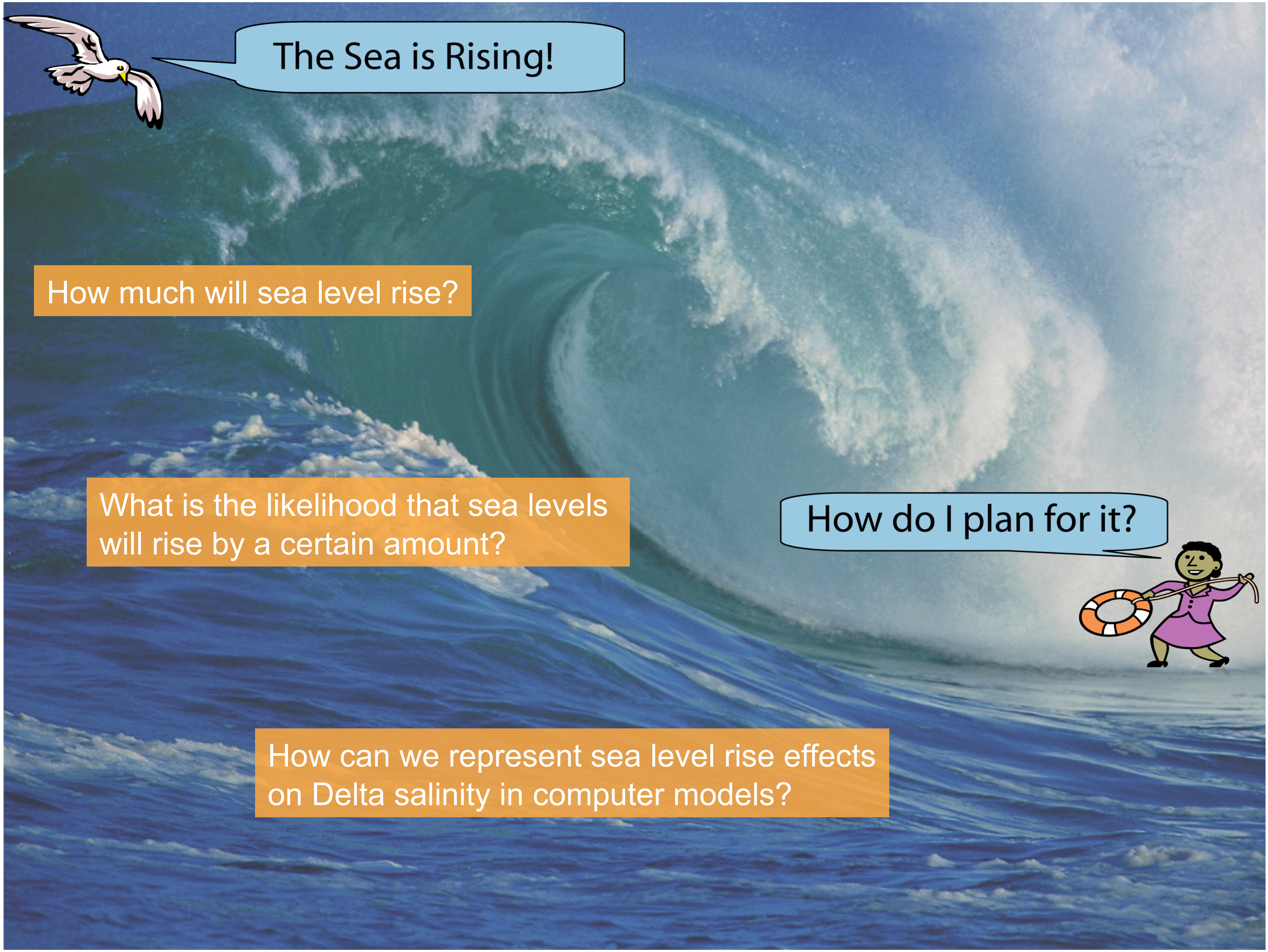
Sea Level Rise


Increase ~0.08 in/yr
Total increase from 1900-2003 = 8.15 in
Stage (ft MSL)
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
8.2
1900
1920
1940
1960
1980
2000
Yearly Average Mean Sea Level
19 Year Trend

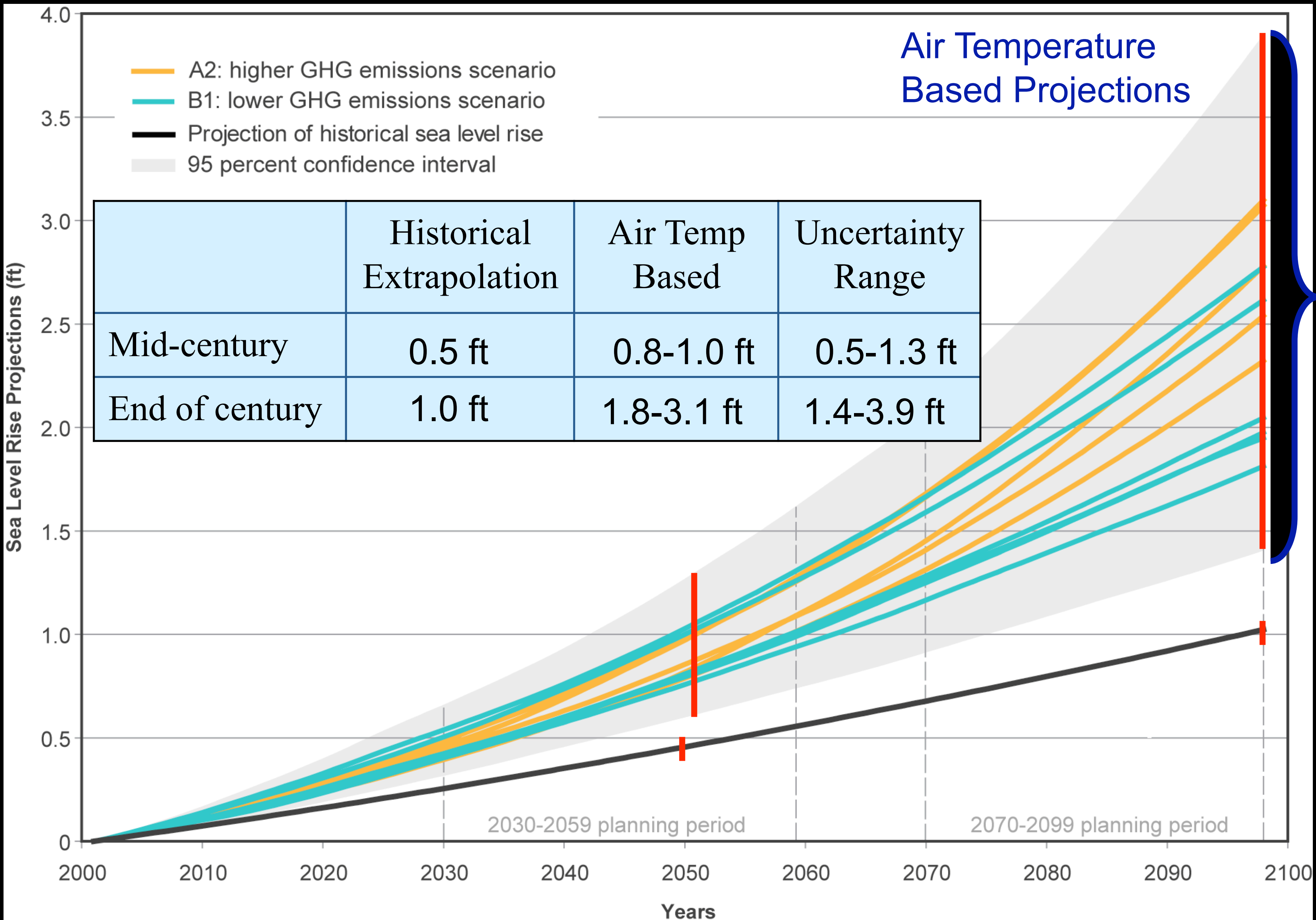
Sea Level Trends in California

CO-OPS Gauge Number - Name	Sea Level Trend (feet/century)
9419750 - Crescent City	-0.16
9414750 - Alameda	0.29
9414290 - San Francisco	0.70
9412110 - Port San Luis	0.30
9410840 - Santa Monica	0.52
9410660 - Los Angeles	0.28
9410230 - La Jolla	0.73
9410170 - San Diego	0.71

Table 2-6 Relative Sea Level Trends for Eight Tide Gauges Along the Coast of California with 50 Years or More of Record



The Sea is Rising!
How much will sea level rise?
What is the likelihood that sea levels will rise by a certain amount?
How do I plan for it?
How can we represent sea level rise effects on Delta salinity in computer models?

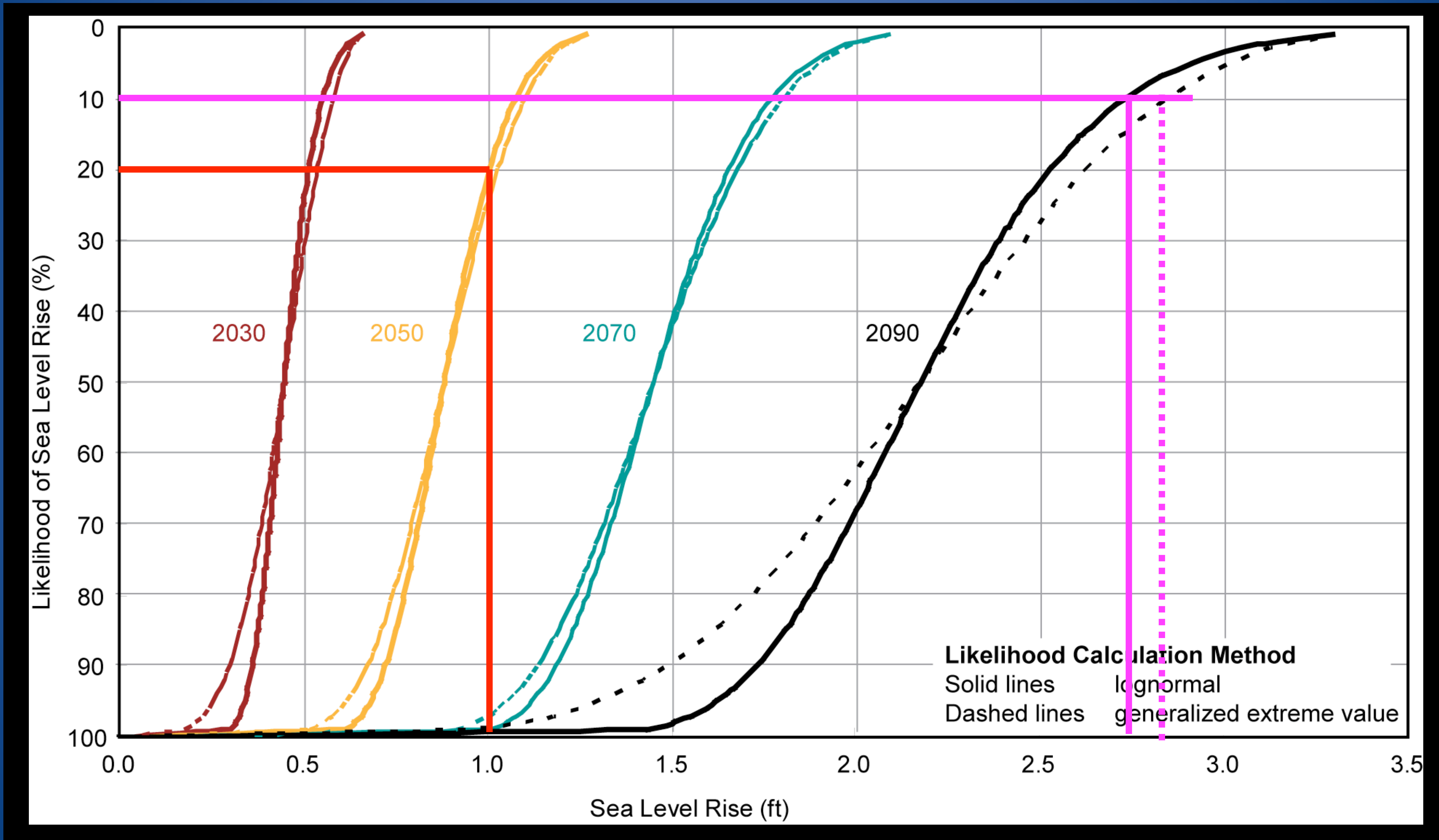


	Historical Extrapolation	Air Temp Based	Uncertainty Range
Mid-century	0.5 ft	0.8-1.0 ft	0.5-1.3 ft
End of century	1.0 ft	1.8-3.1 ft	1.4-3.9 ft

Relative Likelihood from 12 Scenarios

2050 20% chance 1ft SLR

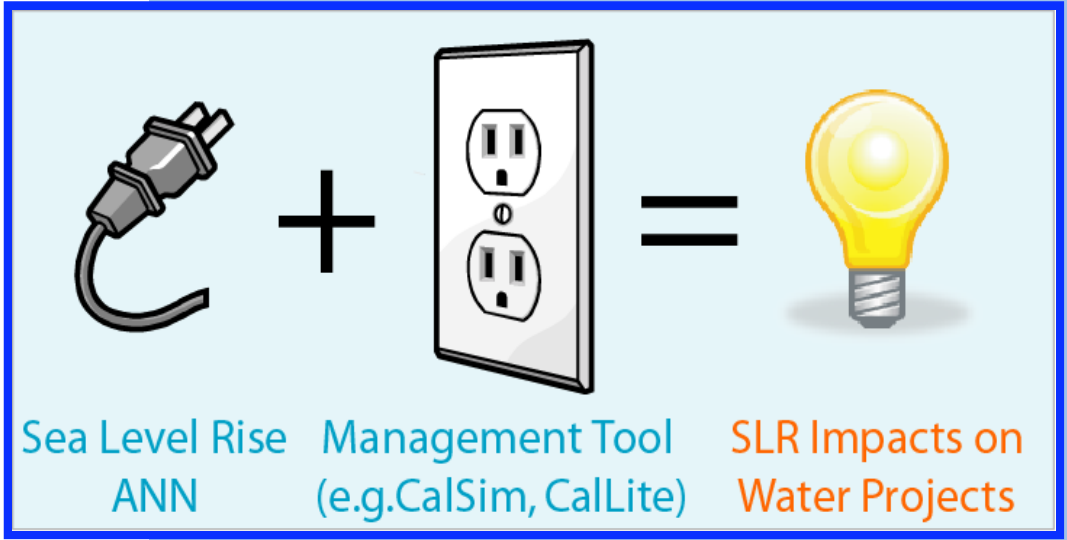
2090 10% chance SLR 2.75-2.80ft



Models of SWP and CVP Operations Need a Way to **Quickly** Represent Delta Water Quality Standard Compliance

Sacramento-San Joaquin Delta

Sea Level Rise Artificial Neural Networks

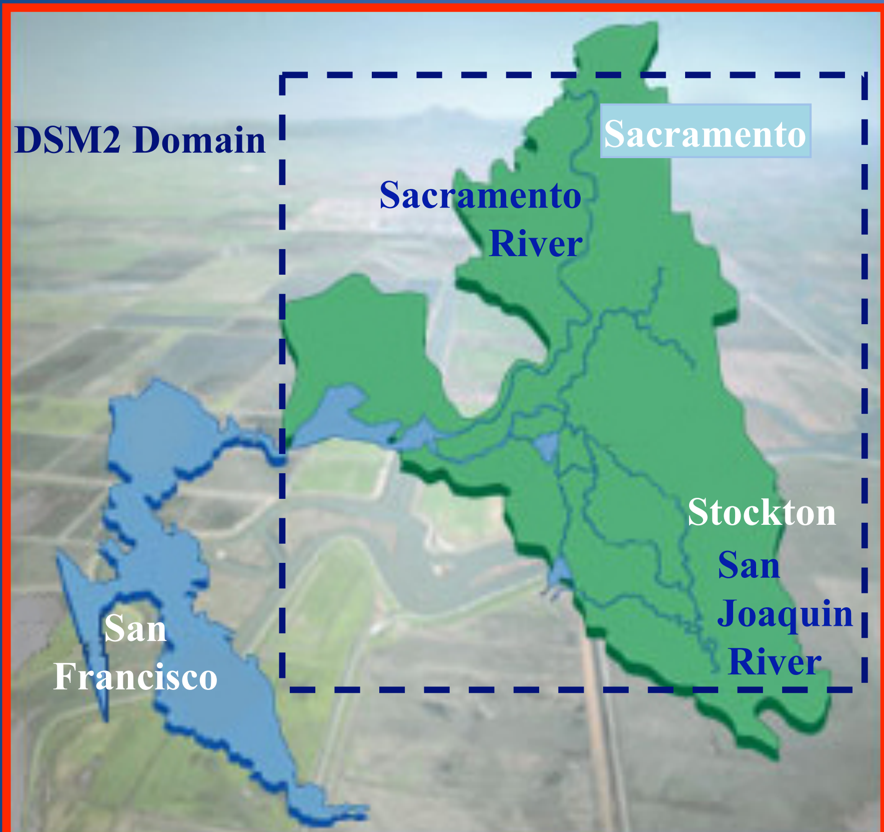


A Delta salinity ANN is a computer program that quickly estimates Delta salinity based on inflows and exports

An ANN can be used in management tools such as CalSim and CalLite to estimate sea level rise impacts

Developing Delta Salinity ANNs

1. Use DSM2 to simulate Delta Salinity for SLR scenarios



•Increase water level at Martinez

•Increase salinity at Martinez based on DRMS study by Ed Gross

2. Using DSM2 results, "train" SLR ANN to replicate Delta salinity based

INPUT
- Northern Delta inflows
- San Joaquin River flows
- Delta exports
- Delta consumptive use
- Cross Channel gate operations
- Tidal energy

↓

Sea Level Rise ANN

↓

OUTPUT Salinity at:

▪Collinsville	▪Old R at Rock Sl.
▪Emmaton	▪Los Vaqueros
▪Jersey Pt	▪Victoria Canal (center)
▪Antioch	▪Victoria Canal-Middle R
▪Chipps Is.	▪Clifton Court Forebay (SWP)
	▪Jones Pumping Plant (CVP)

ANN=Artificial Neural Network

Non-stationarity
in
Changing Climate

Stationarity is Dead

Milly et al, SCIENCE, 2006

Finding a suitable successor is crucial for human adaptation to changing climate.

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$[illegible] billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

[1]U.S. Geological Survey (USGS), c/o National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA. [2]USGS, Tucson, AZ 85745, USA. [3]Stockholm International Water Institute, SE 11151 Stockholm, Sweden. [4]USGS, Reston, VA 20192, USA. [5]Research Centre for Agriculture and Forest Environment, Polish Academy of Sciences, Poznań, Poland, and Potsdam Institute for Climate Impact Research, Potsdam, Germany. [6]University of Washington, Seattle, WA 98195, USA. [7]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA.

*Author for correspondence. E-mail: cmilly@usgs.gov.

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was

Reduction in Spring Runoff

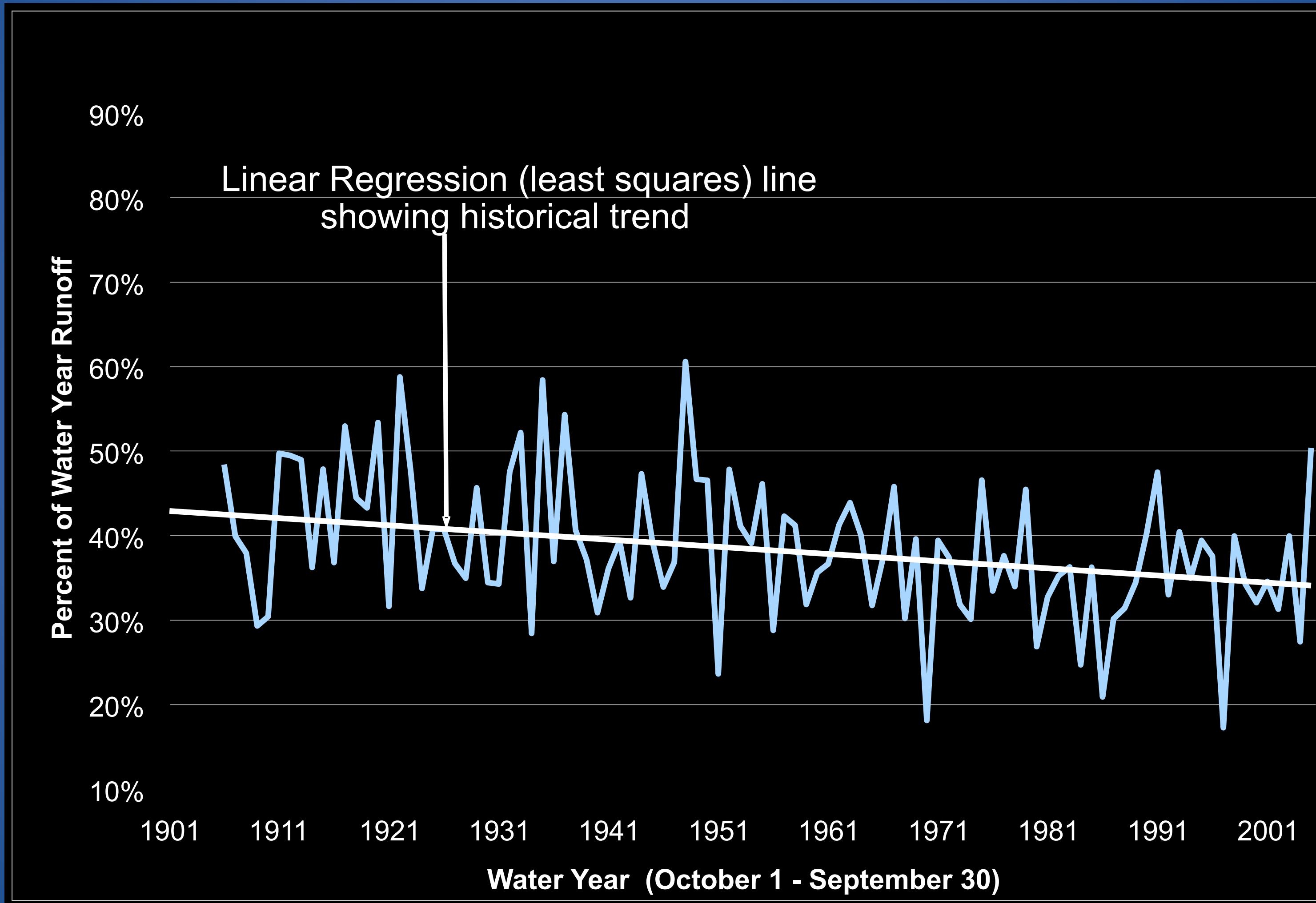


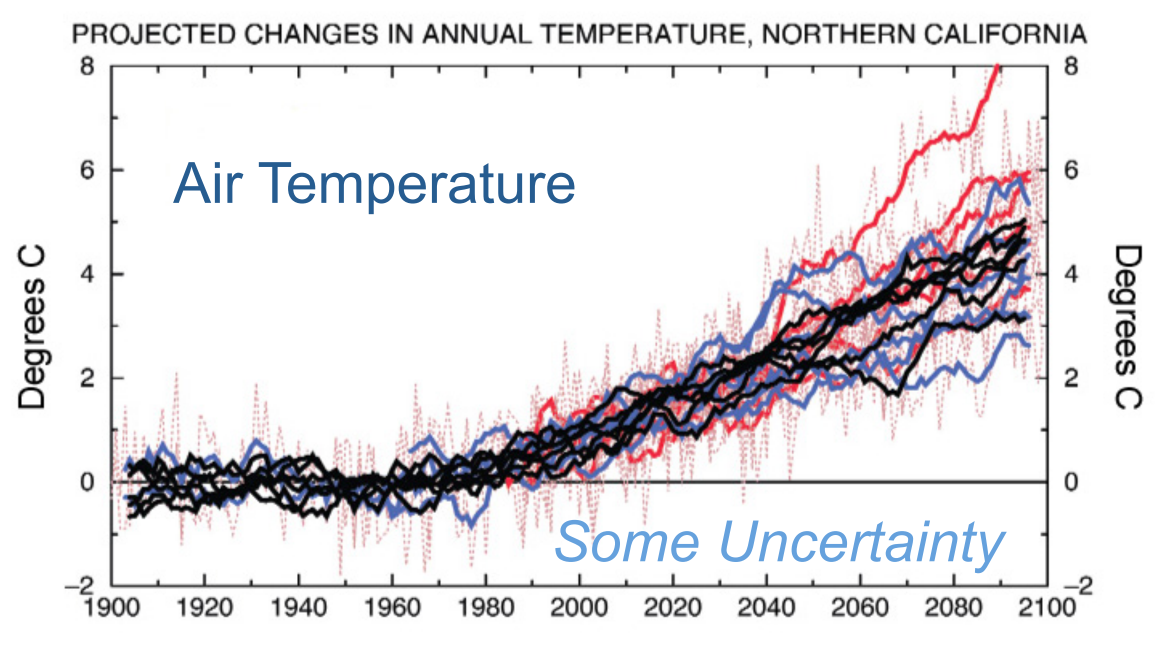
Figure 6-14 April-July Runoff as a percent of water year runoff for the Sacramento River

Changes in Annual Peak Runoff

Pre/Post 1955	Feather	Tuolumne	Eel
Mean	42/52	12/17	93/123
Standard Deviation	33/50	11/19	48/84
Range	145/232	52/91	165/489

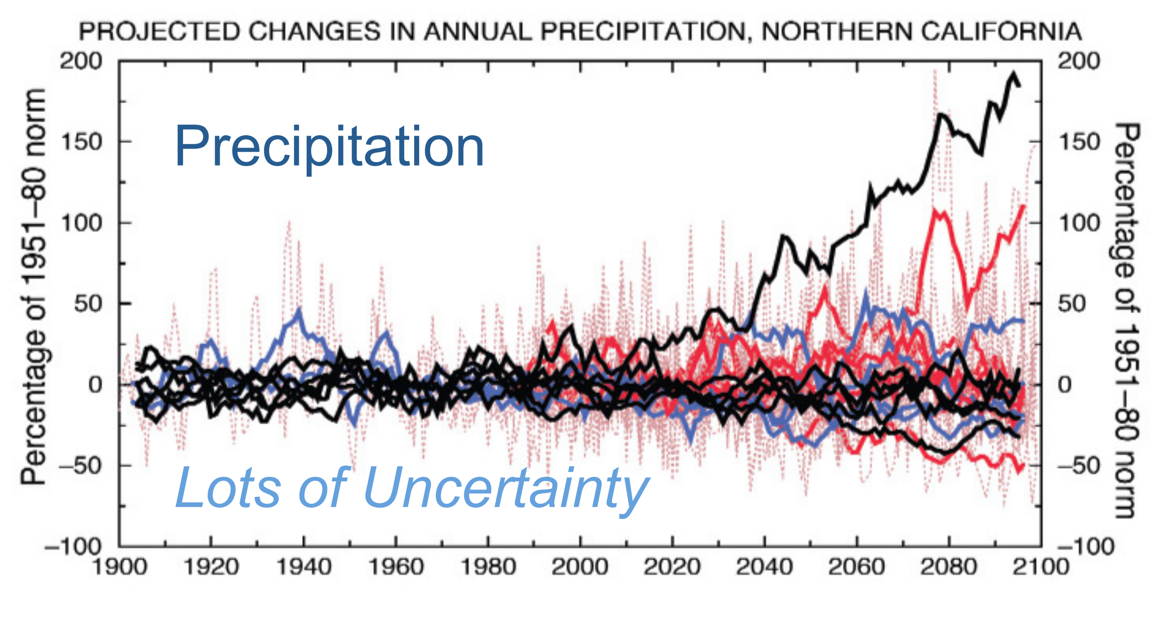
Values in 1000 cfs for annual peaks of 3-day average flows
1904-2004 data used for analysis
Range is maximum-minimum values for time period

Climate Projections for California



Temperature is increasing

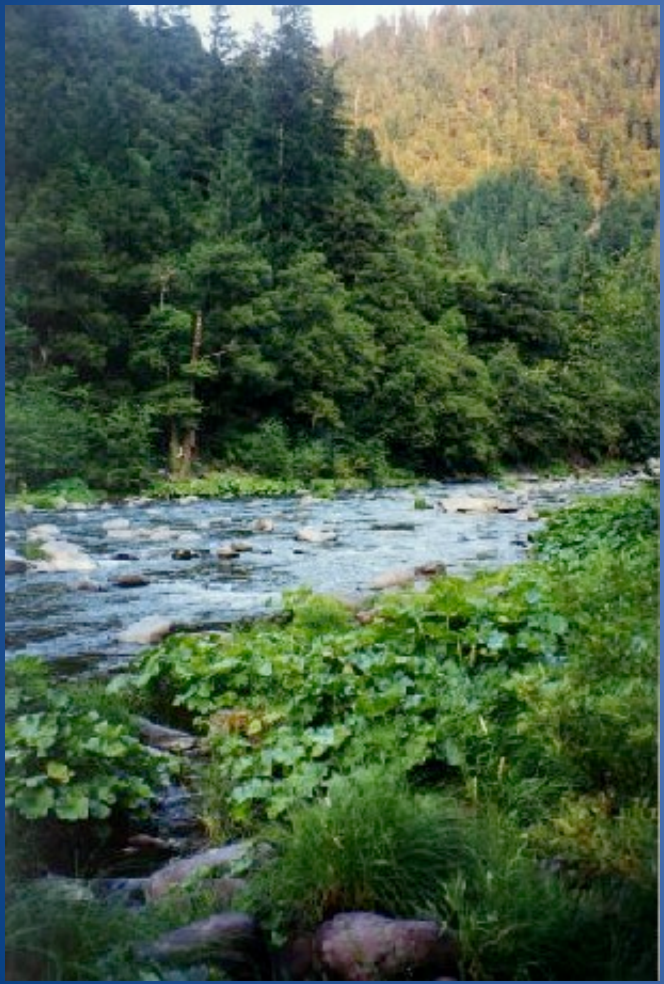
Precipitation patterns uncertain



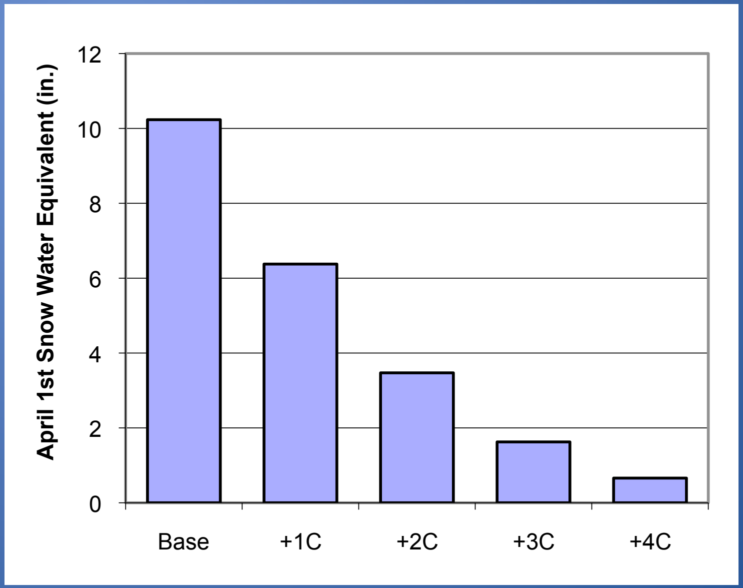
Based on IPCC Scenarios
From Dettinger, 2005

Feather River Basin: California's State Water Project Origin

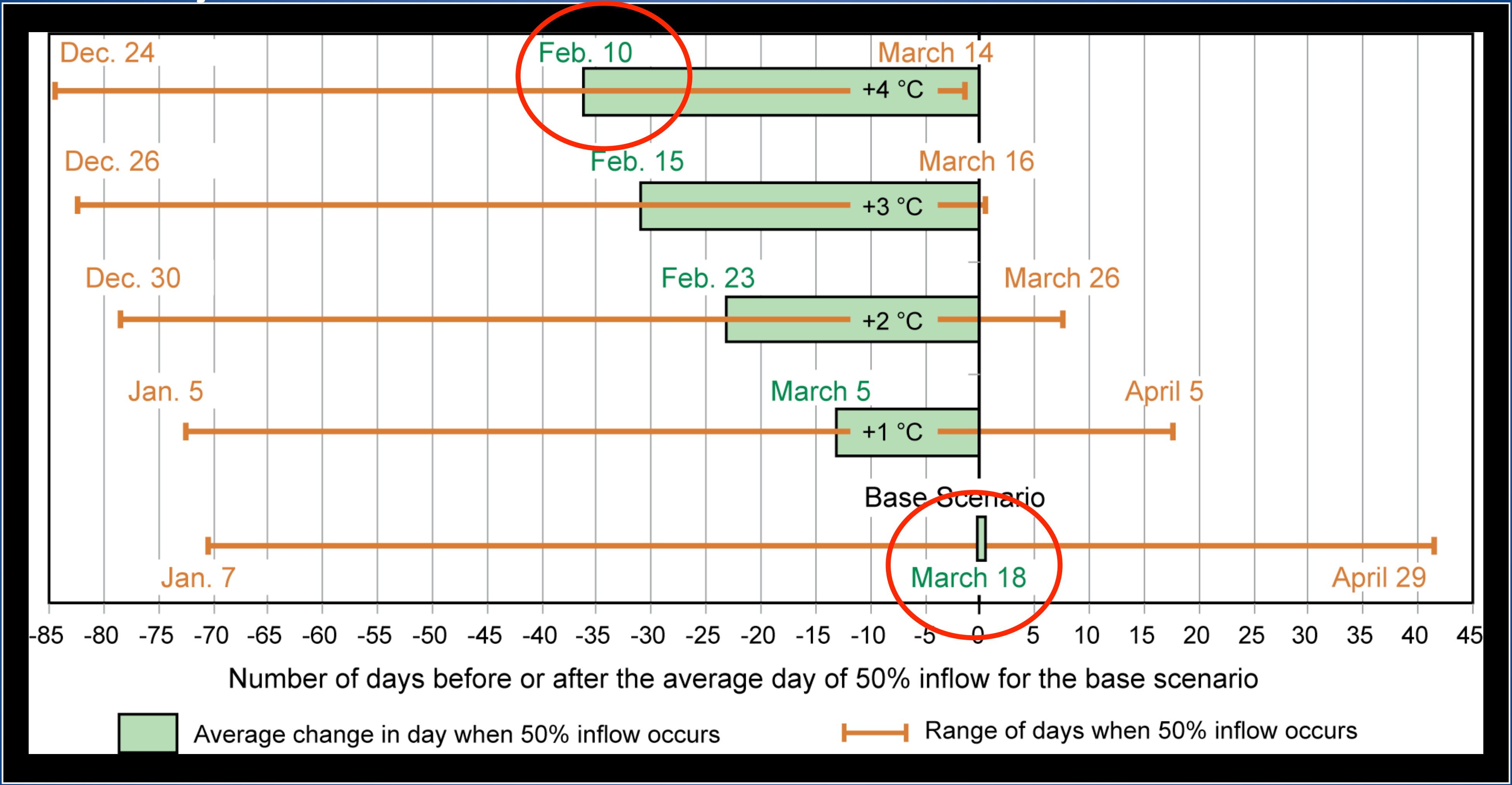
Upper Feather River Basin



- Inflow to Lake Oroville
- Effects of rising air temperature
  - Precipitation-runoff model PRMS
  - +1°C, +2°C, +3°C, +4°C

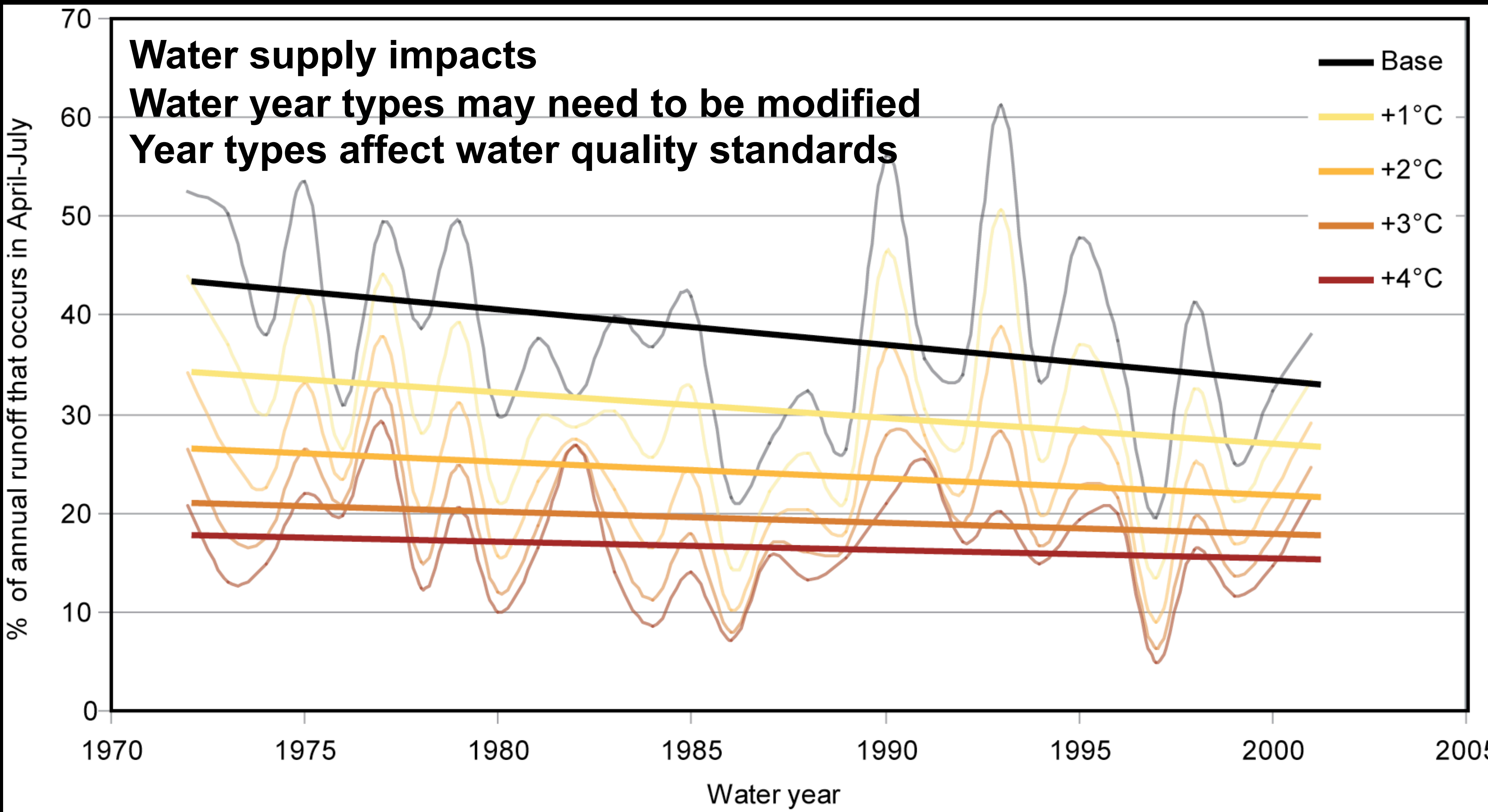


Day of 50% Annual Inflow at Oroville



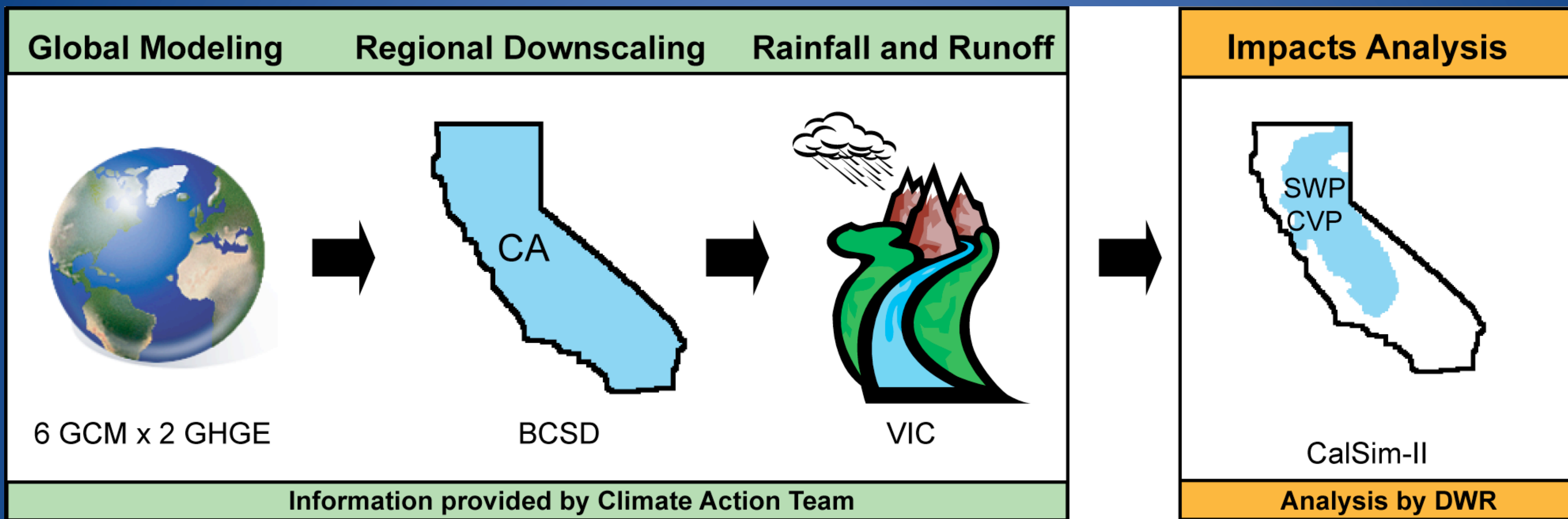
A 4°C increase in air temperature shifts 50% inflow from mid-March to mid-Feb

Runoff in April to July



SWP-CVP Impacts

SWP-CVP Impact Assessment Methodology



- Delta exports (supply)
- Carryover storage
- Groundwater pumping
- X2 location (environment)
- Vulnerability to System Interruption (reliability)

SWP= State Water Project CVP=Central Valley Project

CALSIM II Grid

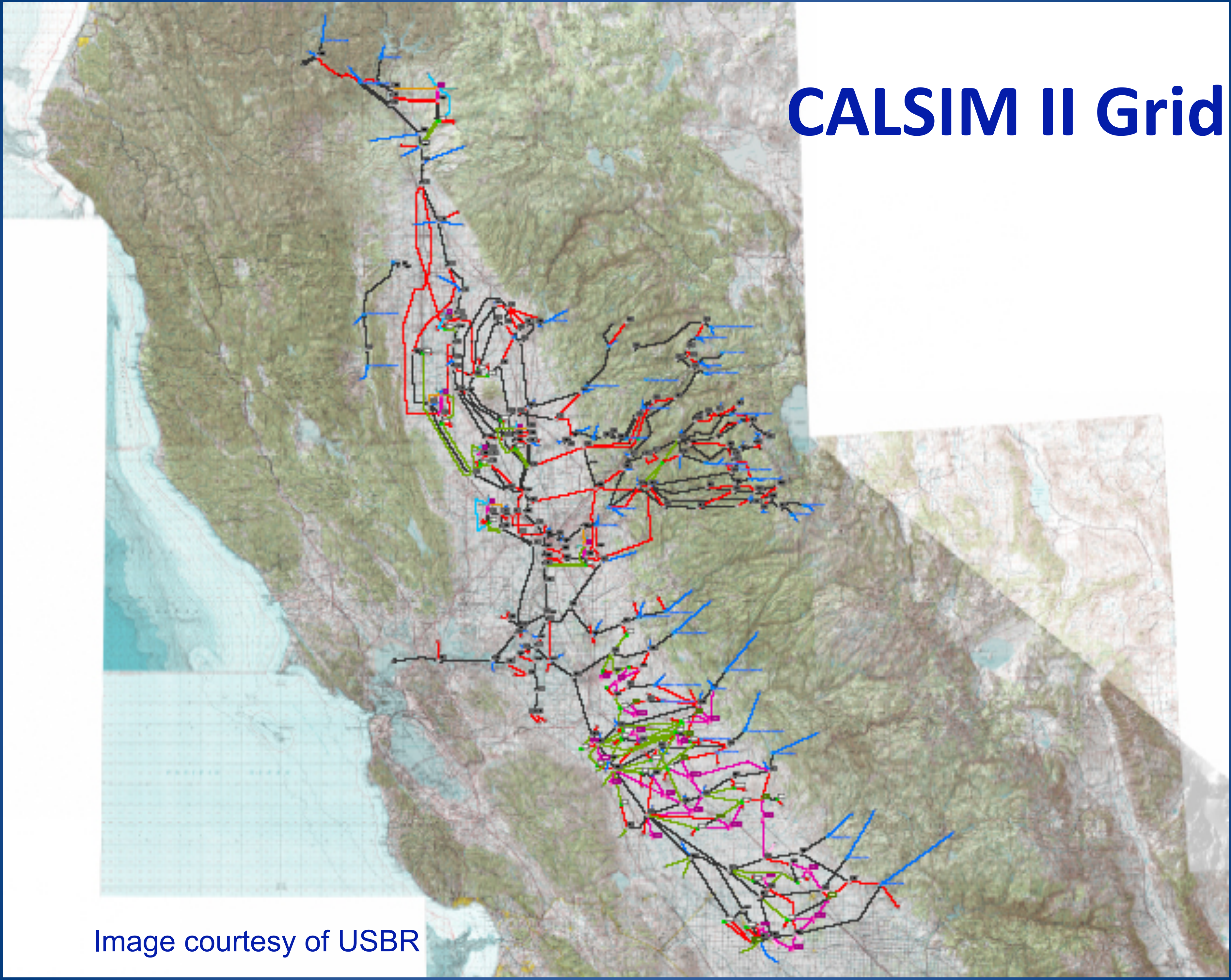


Image courtesy of USBR

DSM2 Grid

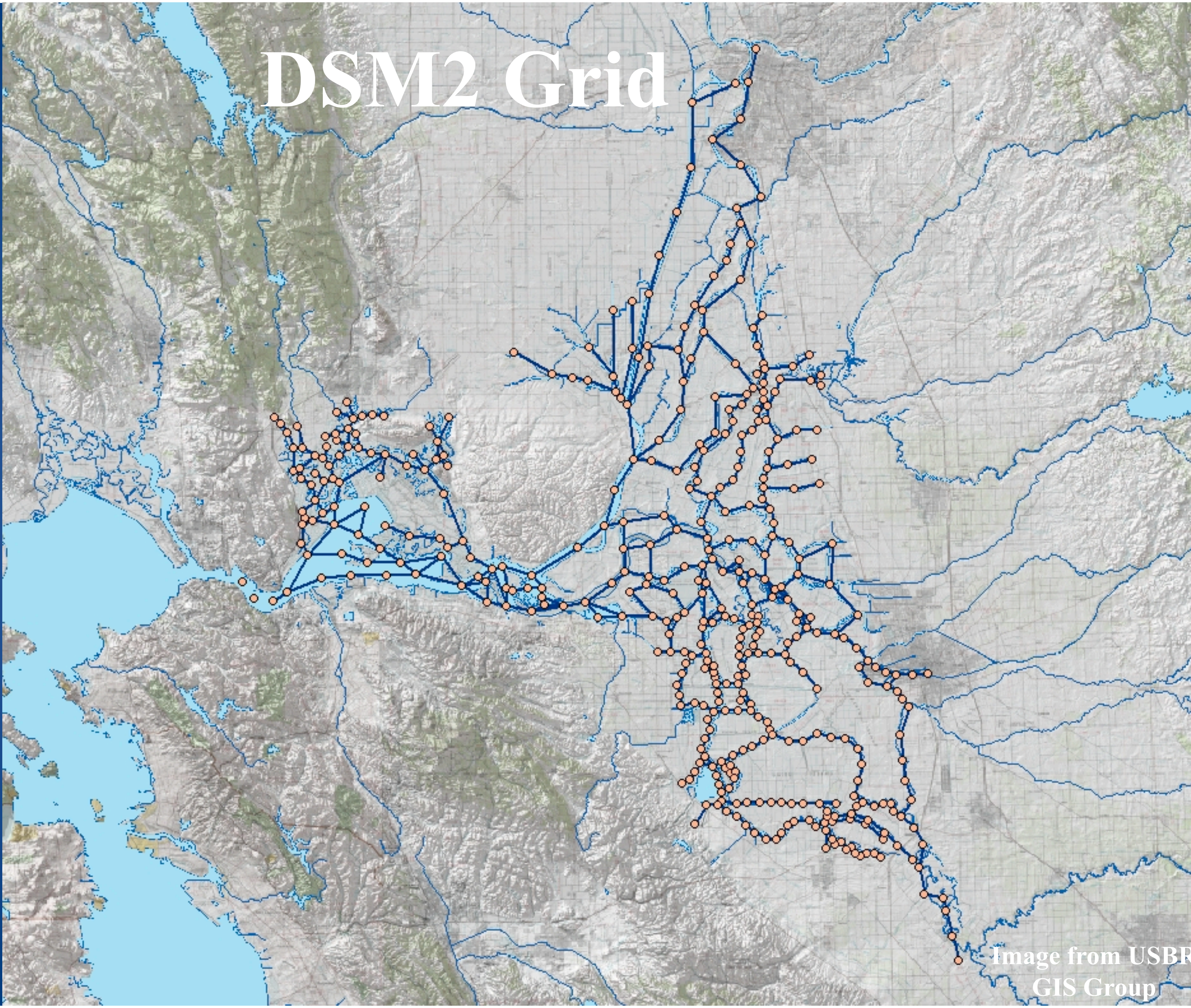
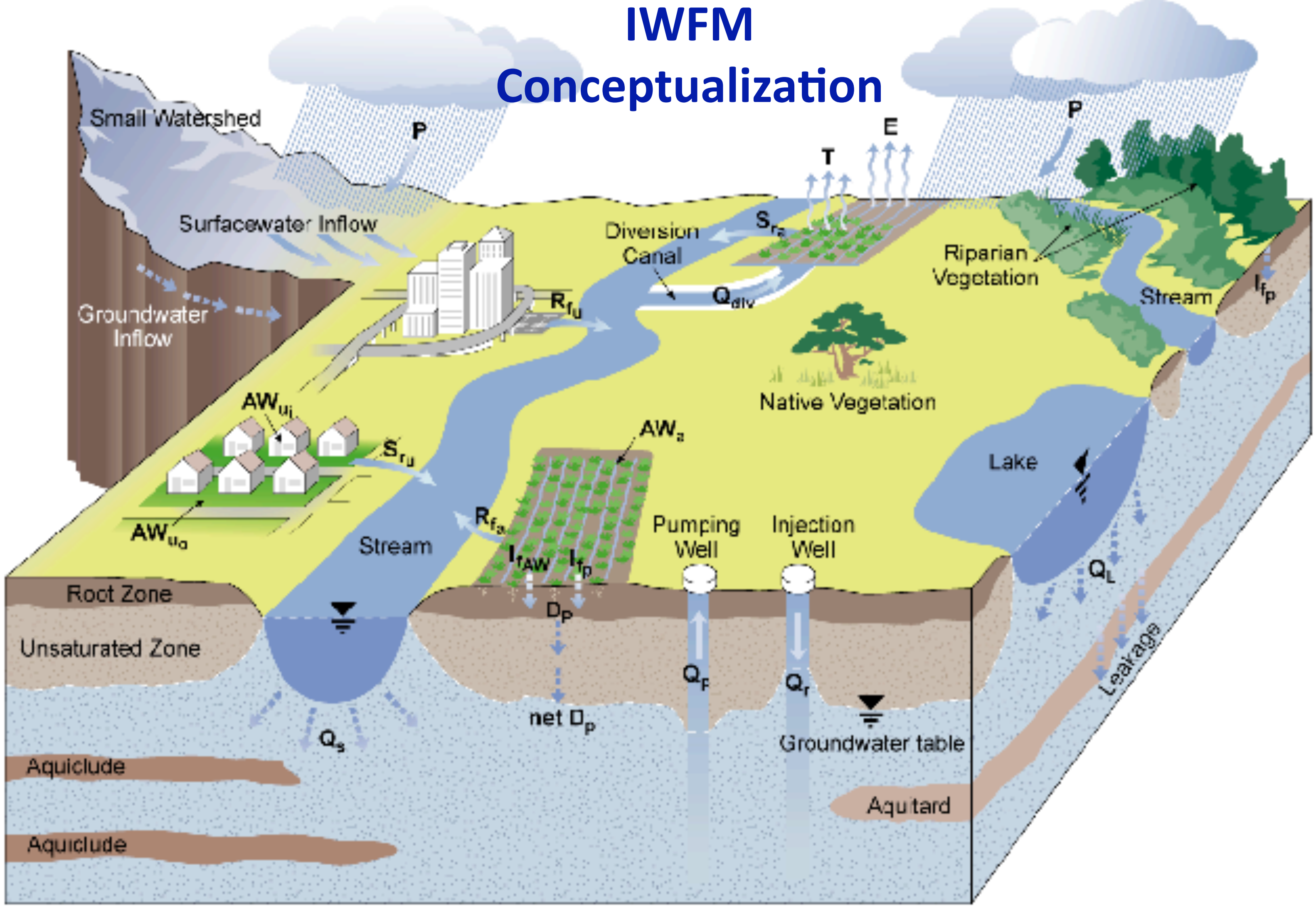


Image from USBR
GIS Group

IWFM Conceptualization

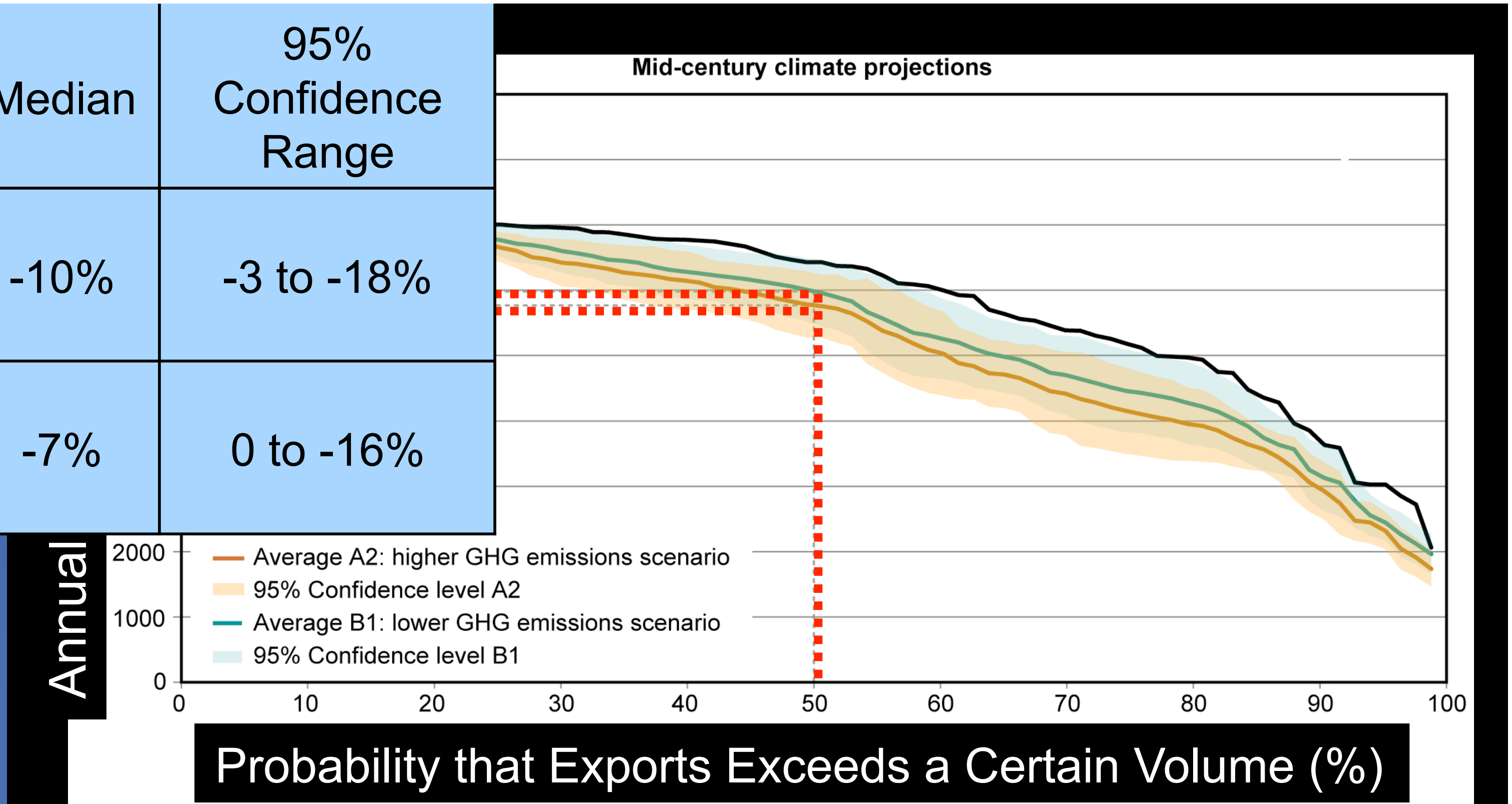


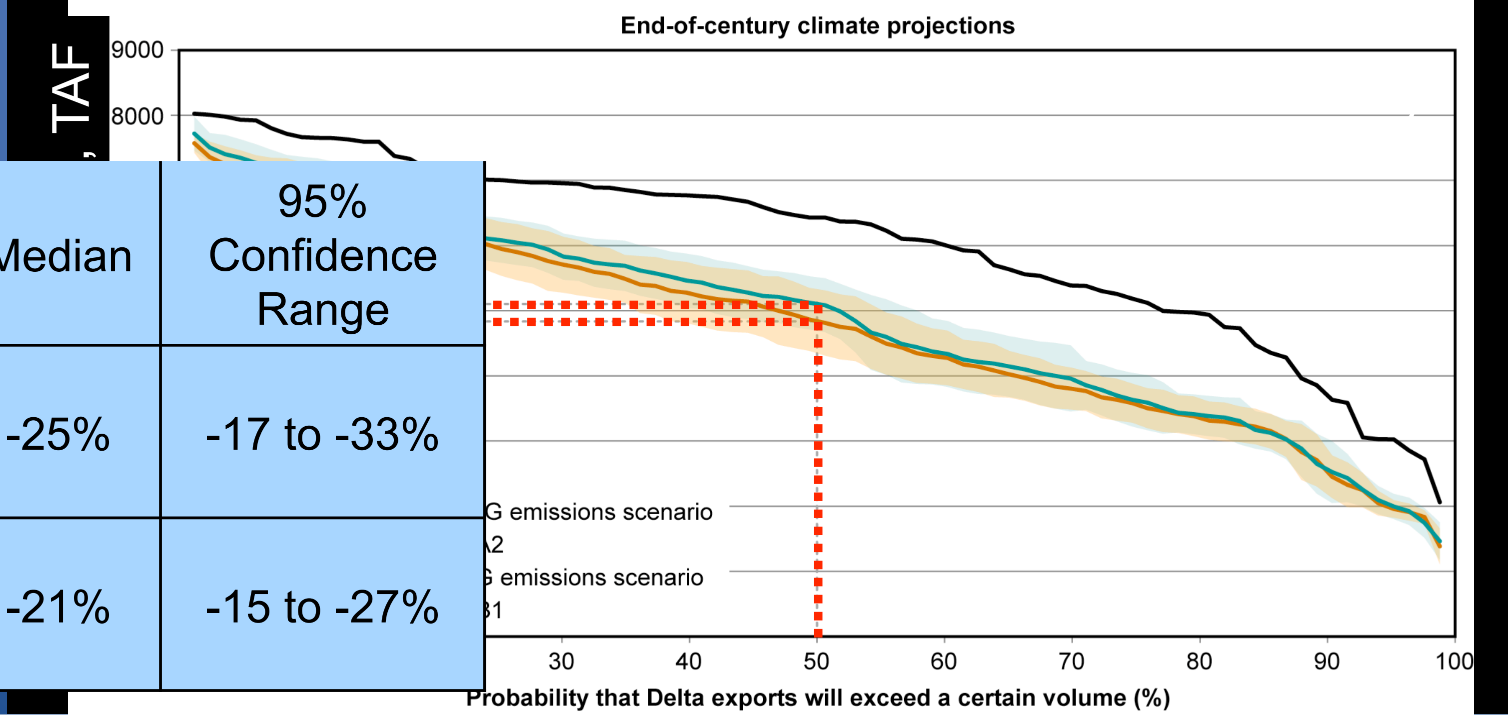
LEGEND

P .... *Precipitation*
AW_a .... *Water applied to agricultural lands*
AW_{u_i}.... *Water applied to indoor urban lands*
AW_{u_o}.... *Water applied to outdoor urban lands*
E .... *Evaporation*
T .... *Transpiration*
I_{f_p}......... *Infiltration of precipitation*
$I_{f_{AW}}$..... *Infiltration of applied water*
Q_{div}...... *Surface water diversion*
S_{r_a}......... *Agricultural runoff*
S_{r_u}. ..... *Urban runoff*
R_{f_a}......... *Agricultural return flow*
R_{f_u}. ...... *Urban return flow*
D_p......... *Deep percolation of water to the unsaturated zone*
net D_p.. *Recharge to the groundwater aquifer*
Q_p......... *Pumping from groundwater aquifer*
Q_r......... *Recharge to groundwater aquifer*
Q_s......... *Stream-groundwater interaction*
Q_L......... *Lake-groundwater interaction*

Annual Delta Exports

		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	-10%	-3 to -18%
	Lower GHGE (B1)	-7%	0 to -16%

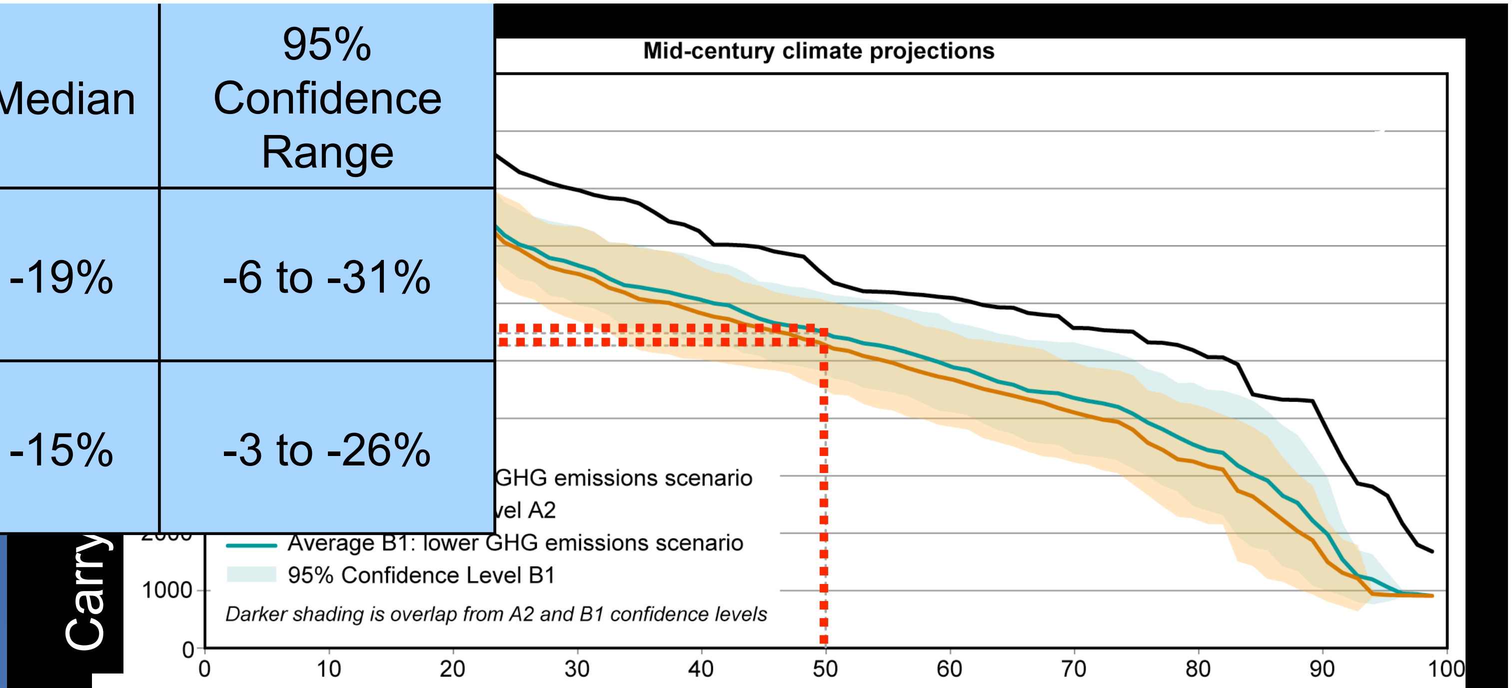


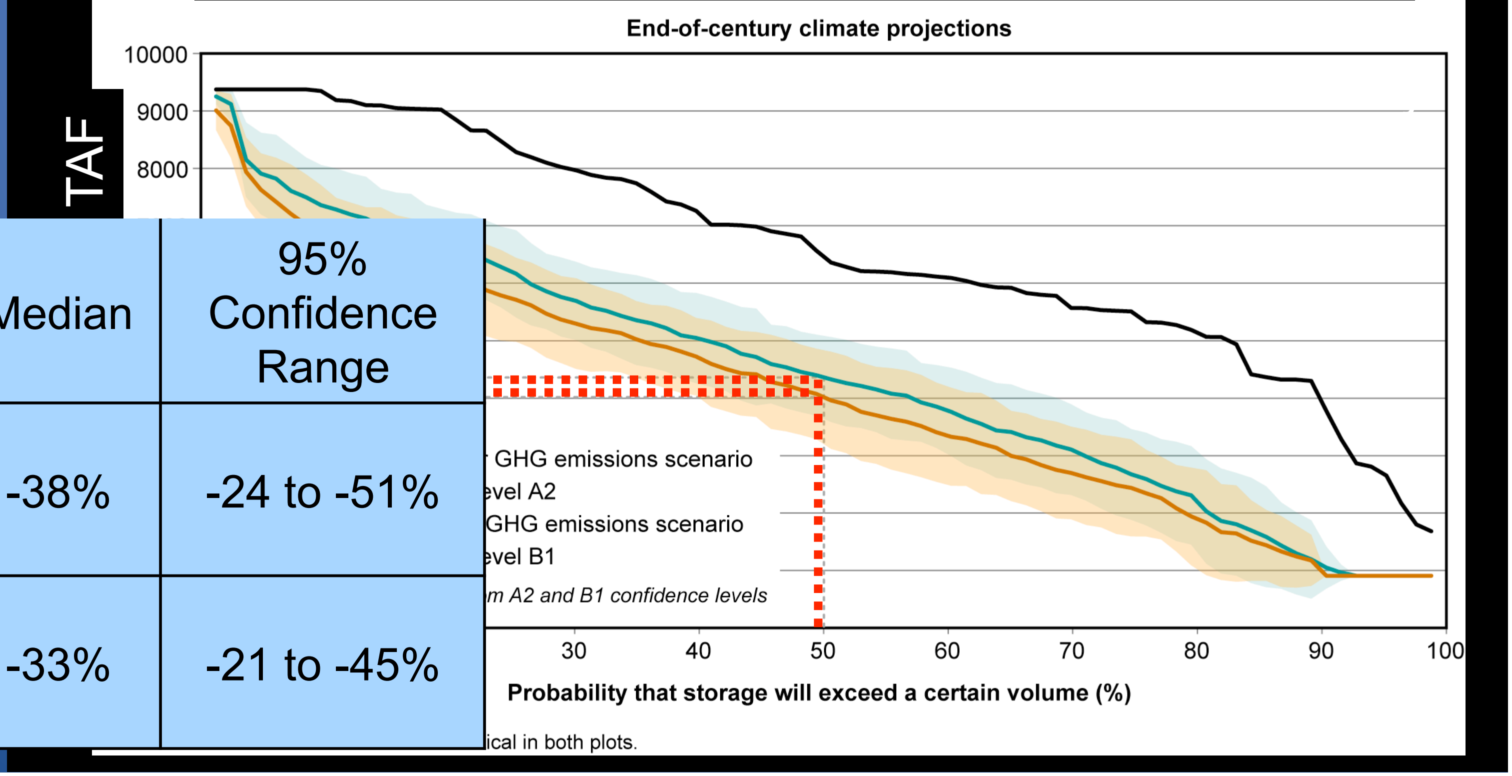


		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	-25%	-17 to -33%
	Lower GHGE (B1)	-21%	-15 to -27%

Reservoir Carryover Storage

		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	-19%	-6 to -31%
	Lower GHGE (B1)	-15%	-3 to -26%

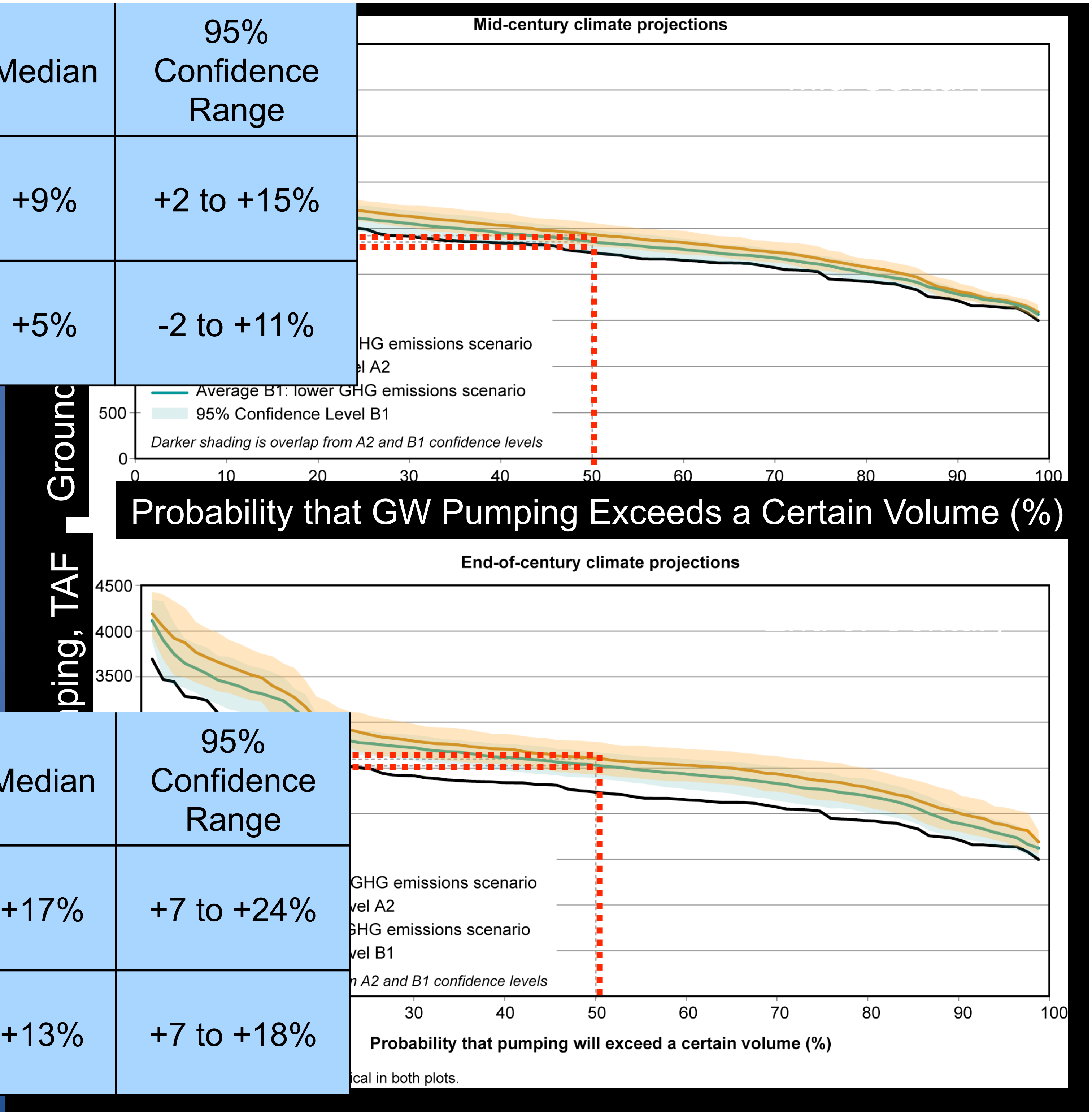




		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	-38%	-24 to -51%
	Lower GHGE (B1)	-33%	-21 to -45%

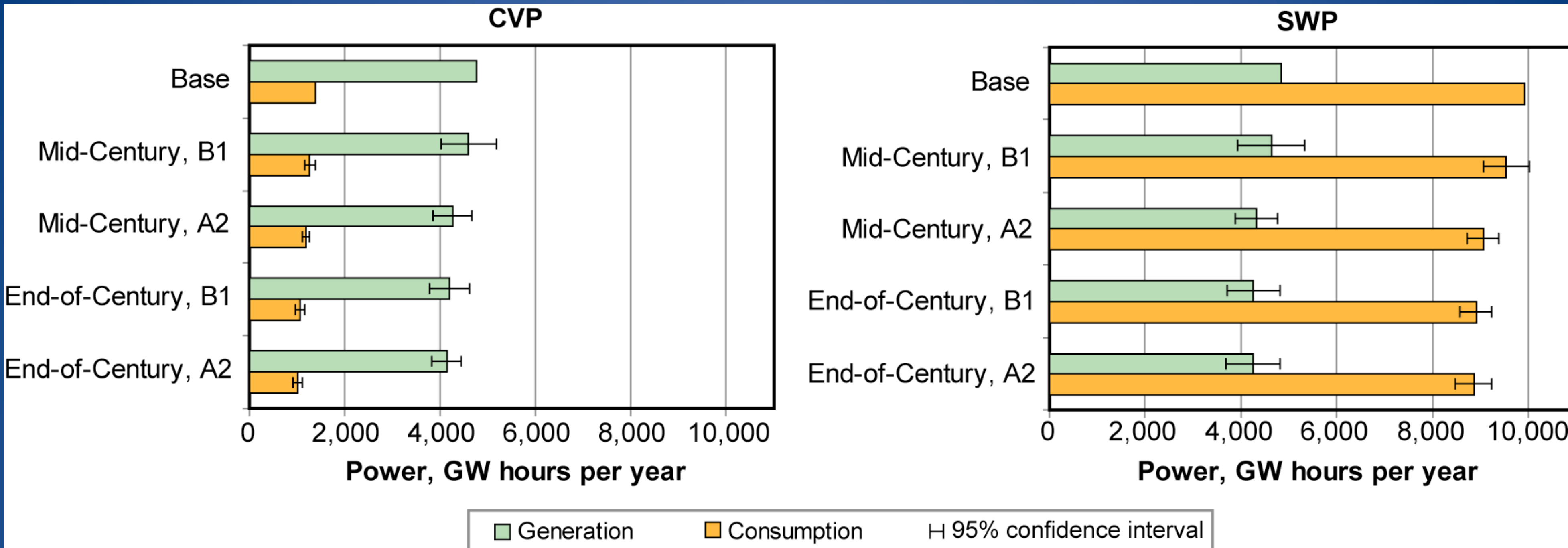
		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	+9%	+2 to +15%
	Lower GHGE (B1)	+5%	-2 to +11%

Sac Valley Groundwater Pumping

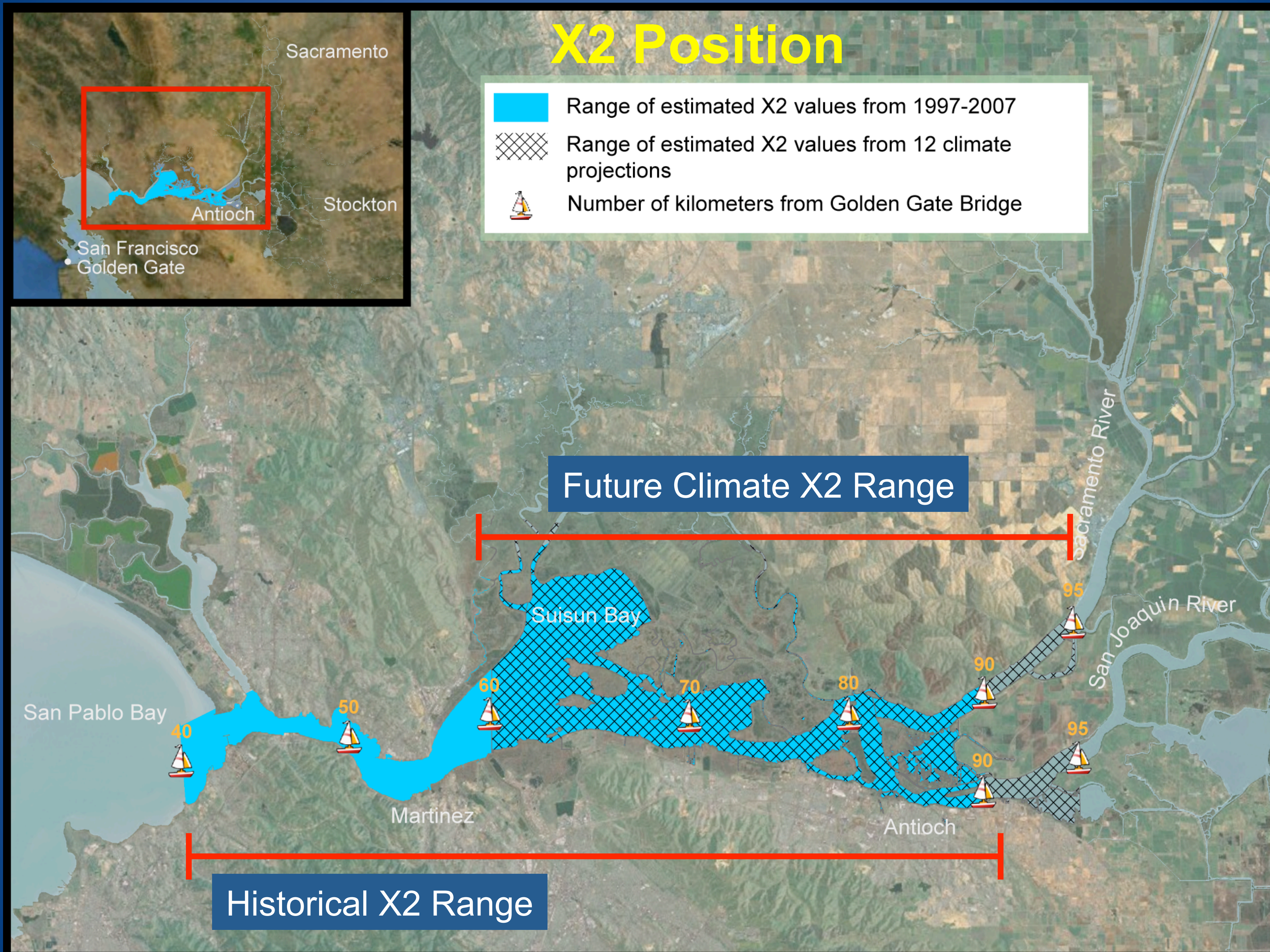


		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	+17%	+7 to +24%
	Lower GHGE (B1)	+13%	+7 to +18%

Power Supply



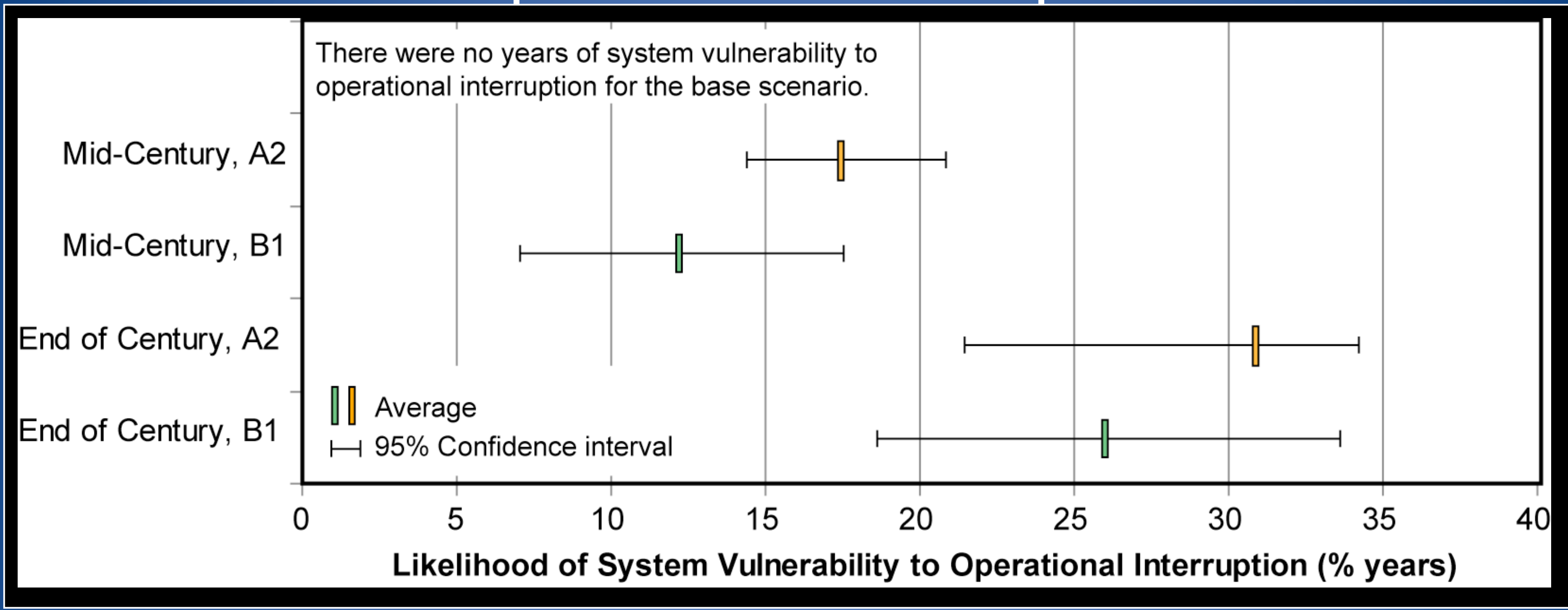
	Mid-Century		End of Century	
	Higher GHGE (A2)	Lower GHGE (B1)	Higher GHGE (A2)	Lower GHGE (B1)
CVP Gen.	-11%	-4%	-13%	-12%
CVP Use	-14%	-9%	-28%	-24%
SWP Gen.	-12%	-5%	-16%	-15%
SWP Use	-10%	-5%	-16%	-16%


X2 Position
Range of estimated X2 values from 1997-2007
Range of estimated X2 values from 12 climate projections
Number of kilometers from Golden Gate Bridge
Sacramento
Stockton
Antioch
San Francisco
Golden Gate
Future Climate X2 Range
Historical X2 Range
Suisun Bay
San Pablo Bay
Martinez
Antioch
Sacramento River
San Joaquin River
40
50
60
70
80
90
95
90
95

System Vulnerability to Operational Interruption

- The SWP-CVP system is vulnerable to operational interruption when water levels go below the lowest outlets (dead storage) in at least one of the main storage reservoirs
  - Trinity, Shasta, Oroville, and/or Folsom

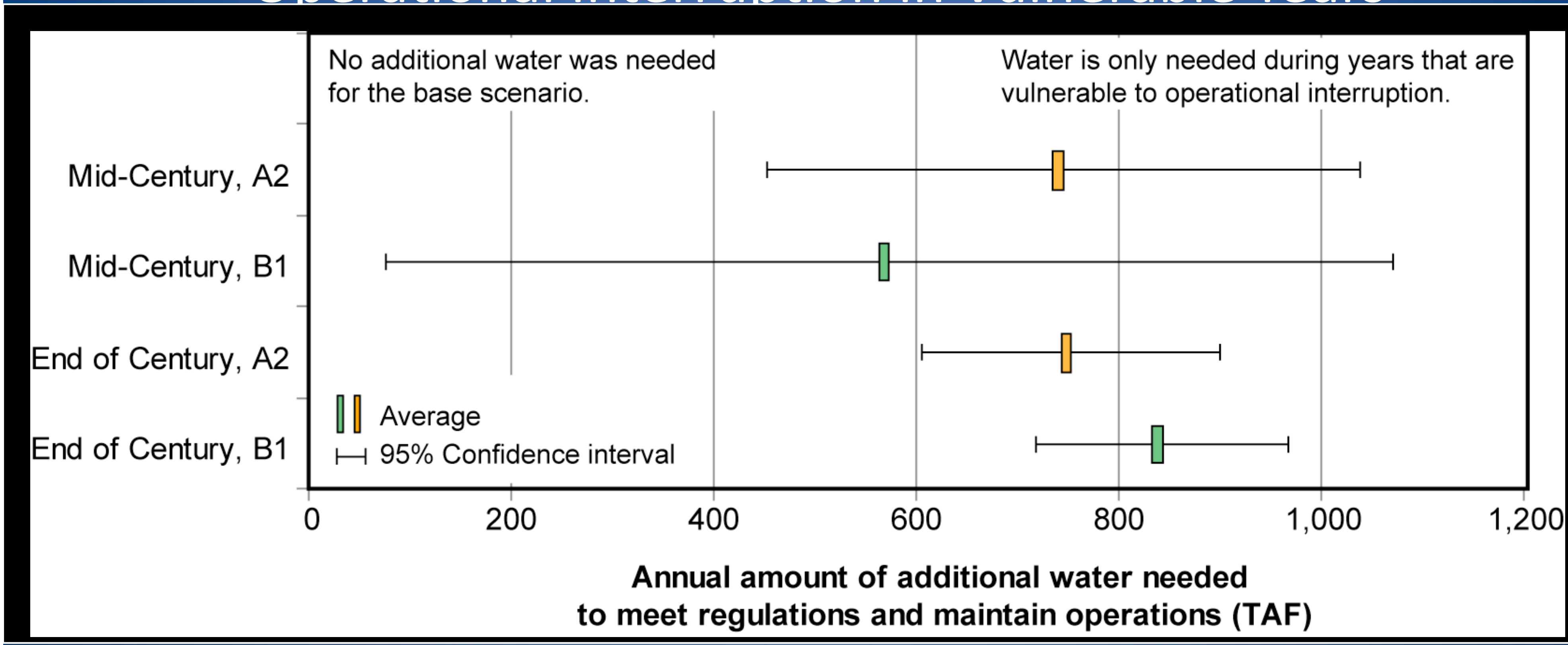
SWP-CVP Vulnerability to Operational Interruption



At mid-century 1 in 6 years is vulnerable for A2
1 in 8 years is vulnerable for B1

By the end of the century 1 in 3 years is vulnerable for A2
1 in 4years is vulnerable for B1

Amount of Additional Water Needed to Avoid Operational Interruption in Vulnerable Years



At mid-century 750 TAF is needed in vulnerable years for A2
575 TAF is needed in vulnerable years for B1

By the end of the century 750 TAF is needed in vulnerable years for A2
850 TAF is needed in vulnerable years for B1

Take Home Message

- Sea level rise
  - Amount, probability, Delta salinity ANNs
- Effects of increasing air temp on Feather basin
  - ↓ April snowpack, ↓ runoff in April-July
  - ←50% inflow to Oroville up to a month earlier
- Effects of climate change on SWP and CVP
  - ↓ annual Delta exports, ↓ reservoir carryover storage
  - ↑ annual groundwater pumping
  - → X2 range moves upstream, standard still met
  - ↓ Power supply
  - ↑ vulnerability to operational interruption

www.climatechange.ca.gov

www.water.ca.gov/climatechange/

chung@water.ca.gov