Investigating the Effects of Reduced Surface Water Deliveries on the Aquifers of California's Central Valley

Charles F. Brush

Bay-Delta Office
California Department of Water Resources
Sacramento, CA

AAAS Pacific Division, August 2009

Collaborators

Larry L. Dale, Energy Analysis Department, Lawrence Berkeley National Laboratory, Berkeley, CA

Norman L. Miller, Climate Science Department, Lawrence Berkeley National Laboratory, Berkeley, CA

Sebastian D. Vicuna, Civil and Environmental Engineering Department, University of California, Berkeley, CA

Emin C. Dogrul, Tariq N. Kadir, and **Francis I. Chung**, Bay-Delta Office, California Department of Water Resources, Sacramento, CA

Outline

- Water Storage and Delivery System
- C2VSIM Model
- Current Conditions
- Climate Change and California
- Simulating Drought Impacts on Groundwater
- Varying Crop Acreage
- Findings
- Future Work

California's Central Valley

- 55,000 sq. km. (20,000 sq. mi.)
- 25 MAF/yr surface water discharge
- Agricultural Production
  - 6.8 million acres (27,500 sq. km)
  - 10% of US crops value in 2002
- Population growth
  - 1970: 2.9 million
  - 2005: 6.4 million
- Pumping
  - ~9 MAF in 2002, or 13% if US pumping
  - Not measured or regulated

Water Storage and Delivery System

Supply in North and East

Demand in South and West

Moderately-sized reservoirs

Store winter precipitation as Sierra snowpack

Complex east-west and north-south distribution system combining rivers, canals and storage reservoirs

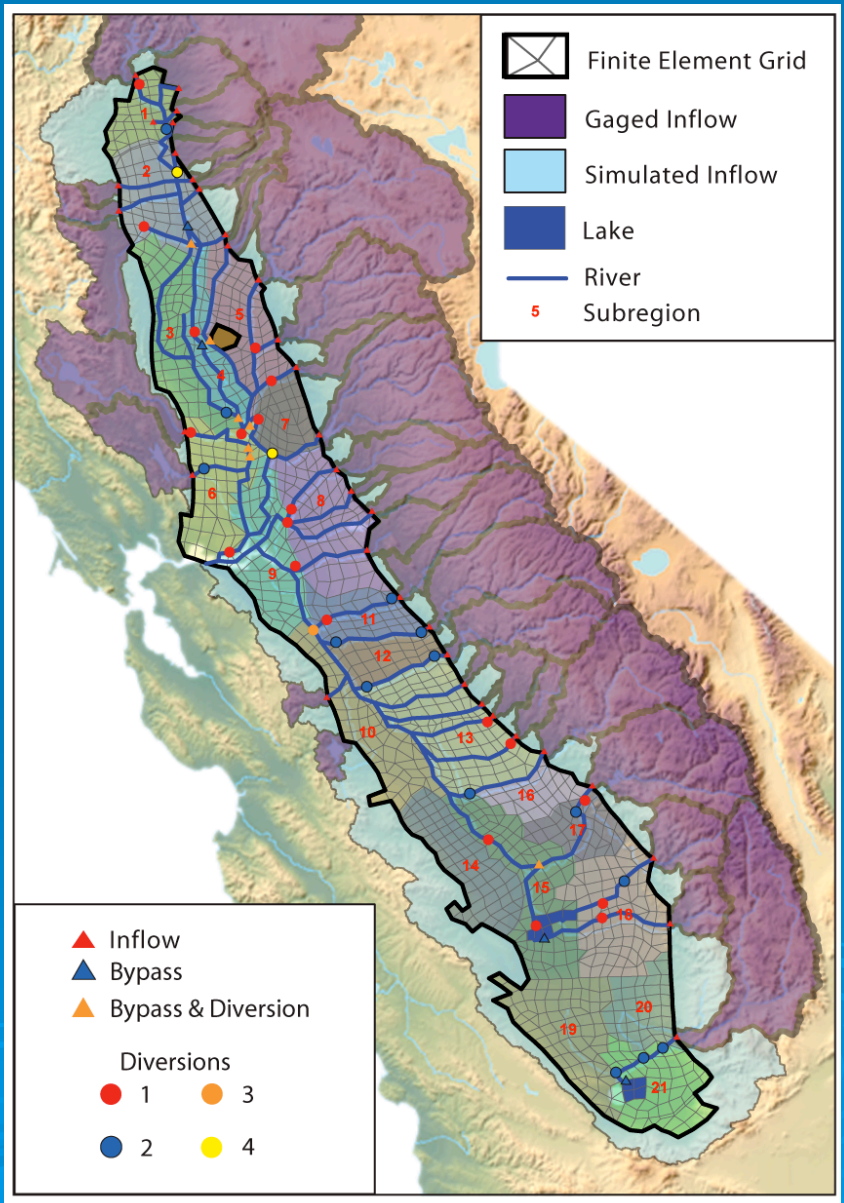
C2VSIM Model Grid

IWFM Application

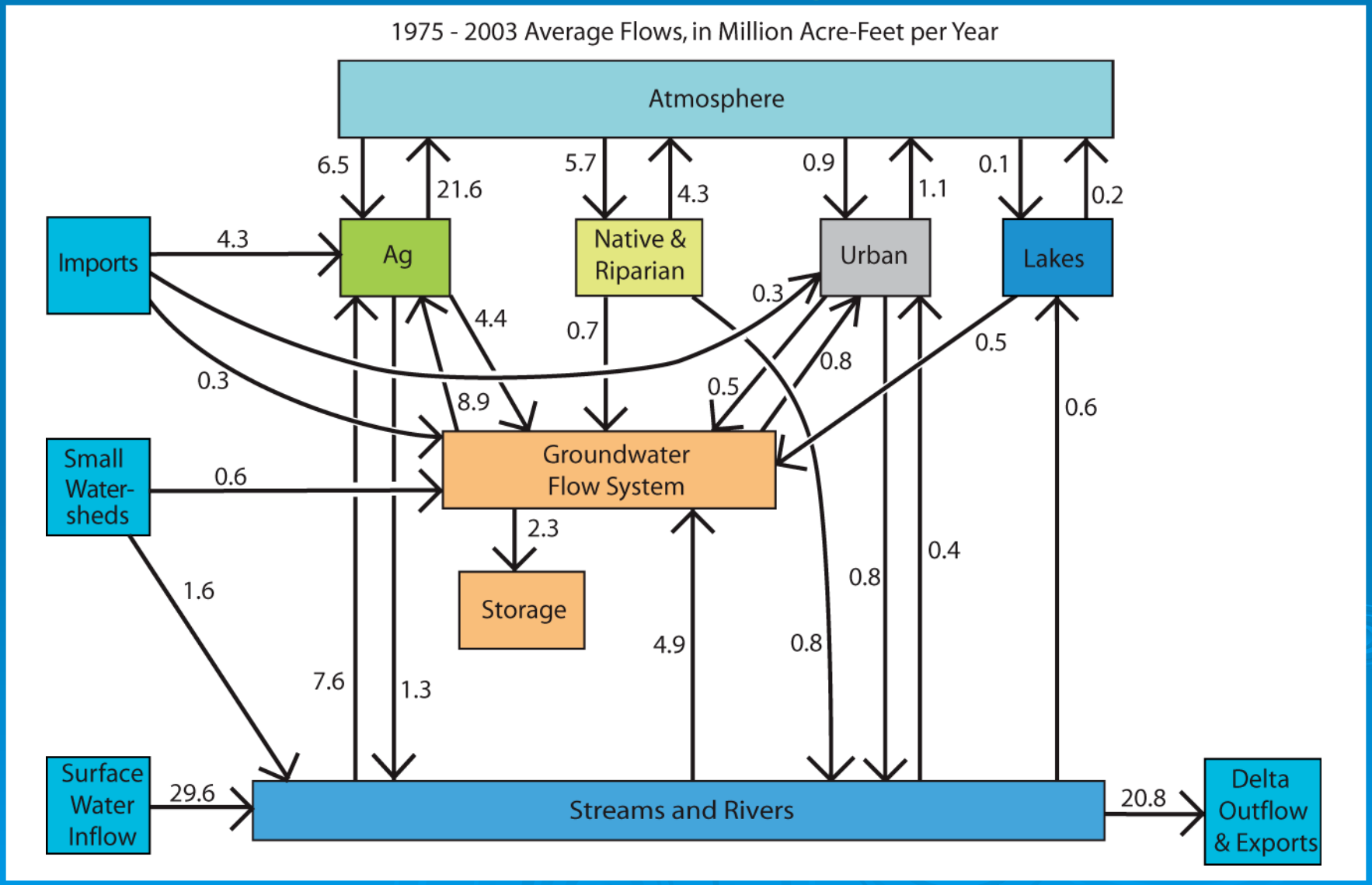
Groundwater Flow System
- Finite Element grid
- 3 layers
- 1393 nodes
- 1392 elements

Surface Water System
- 72 stream reaches
- 97 surface water diversion points
- 2 lakes
- 8 bypass canals

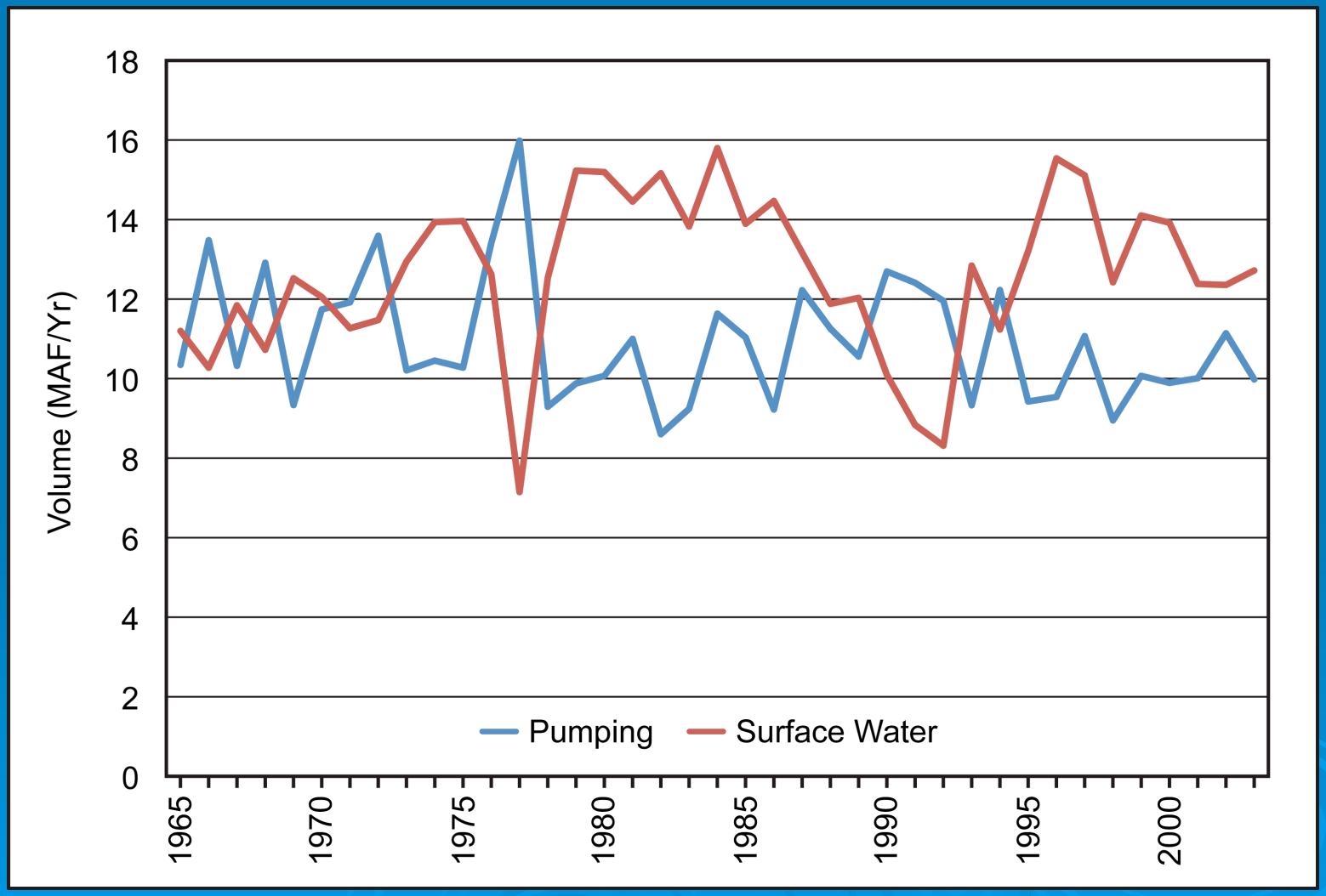
Land Use Process
- 5 Regions
- 21 Subregions
- 4 Land Use Types
  - Agriculture Urban
  - Native Riparian



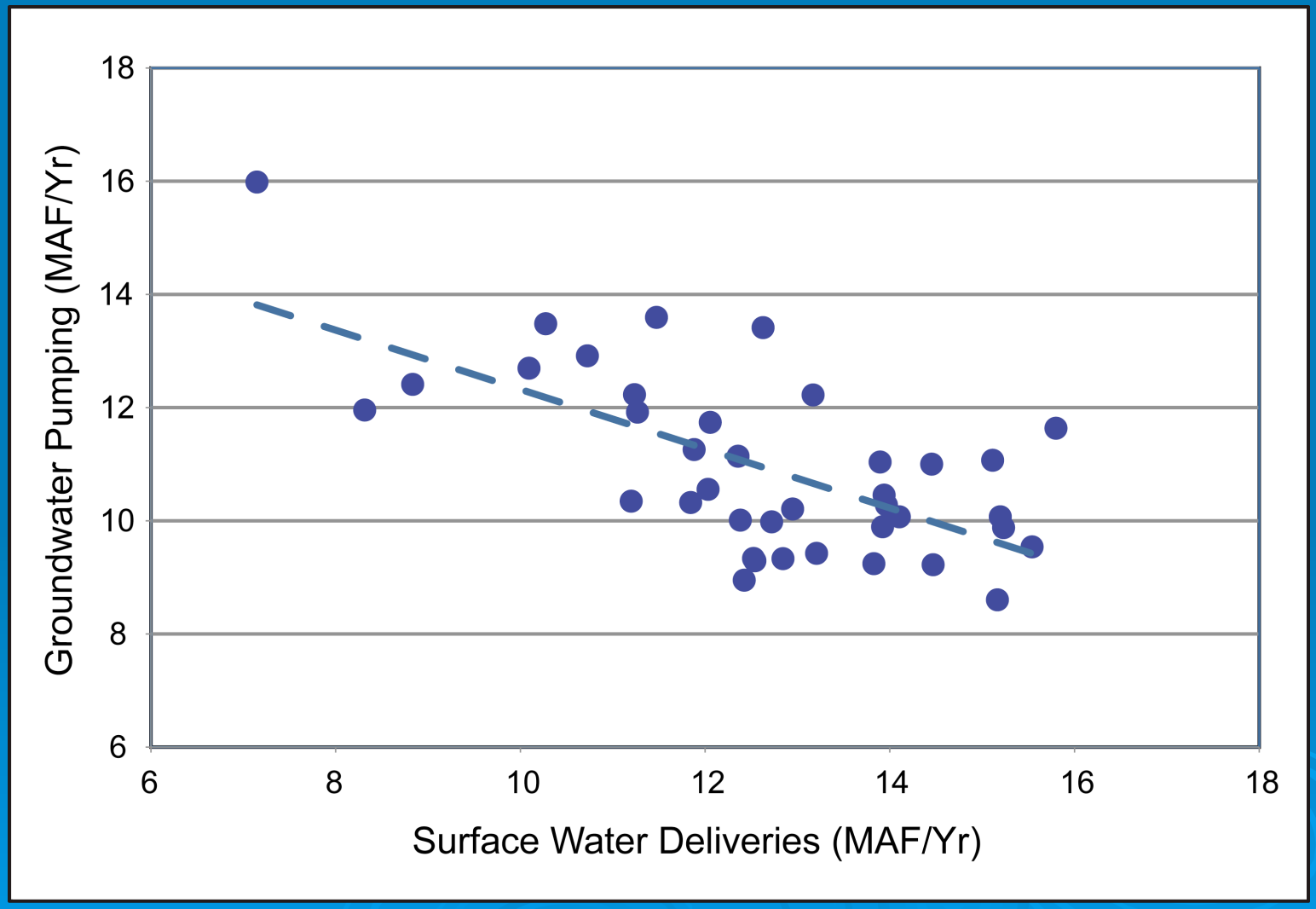
Water Budget



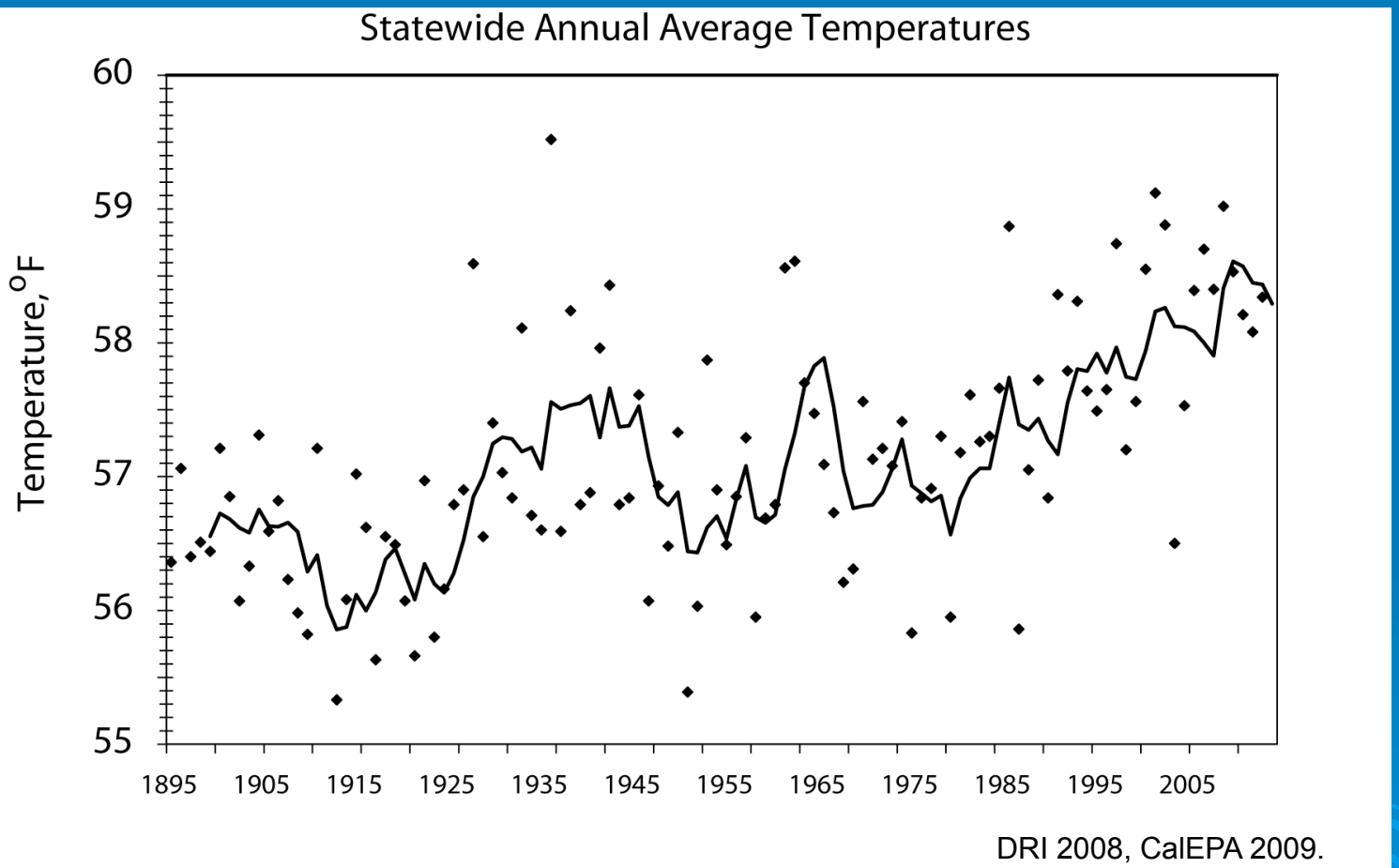
Pumping and Surface Water



de facto Conjunctive Use

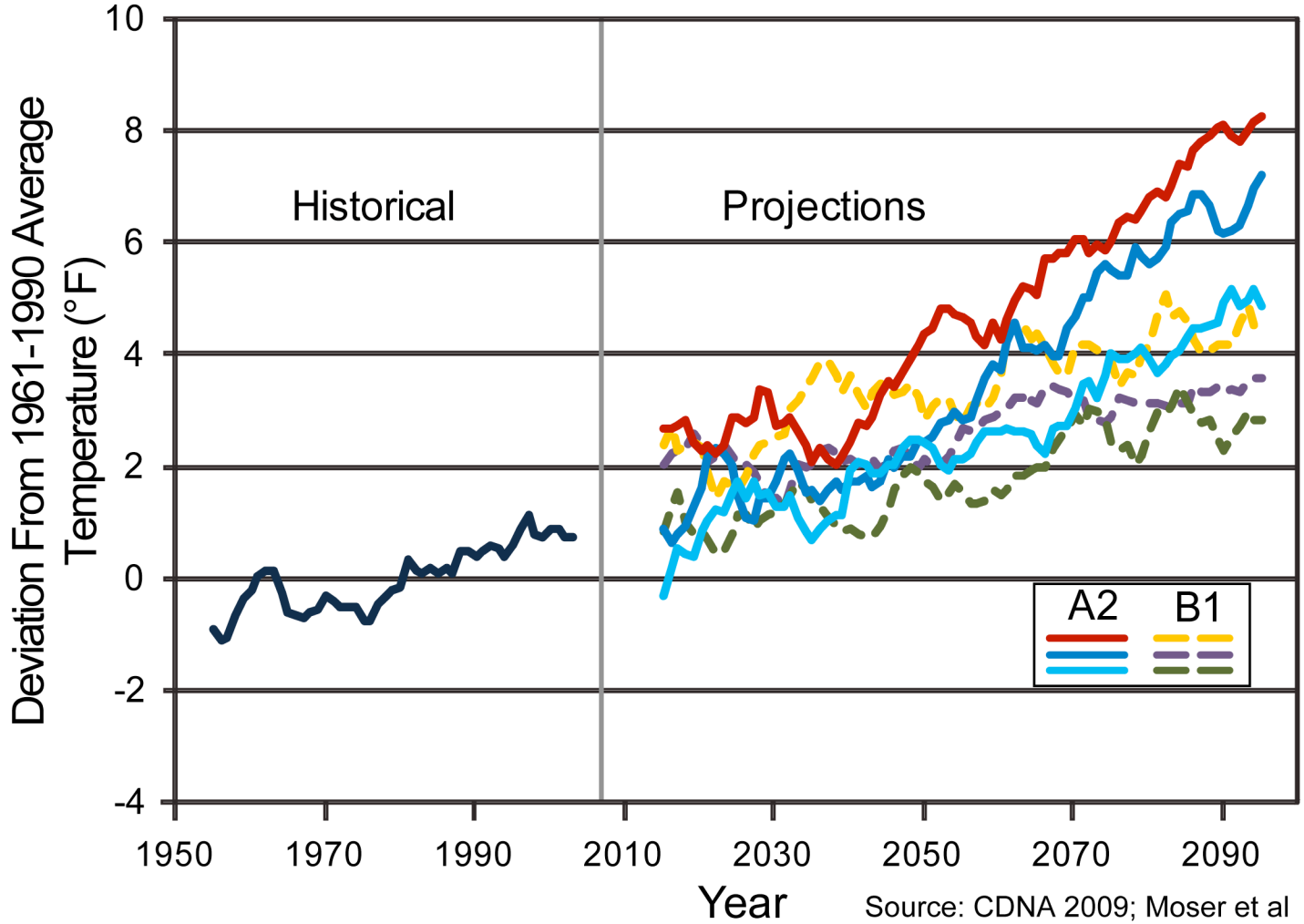


Climate Change



California annual average temperatures. Bold line is the 5-year running average.

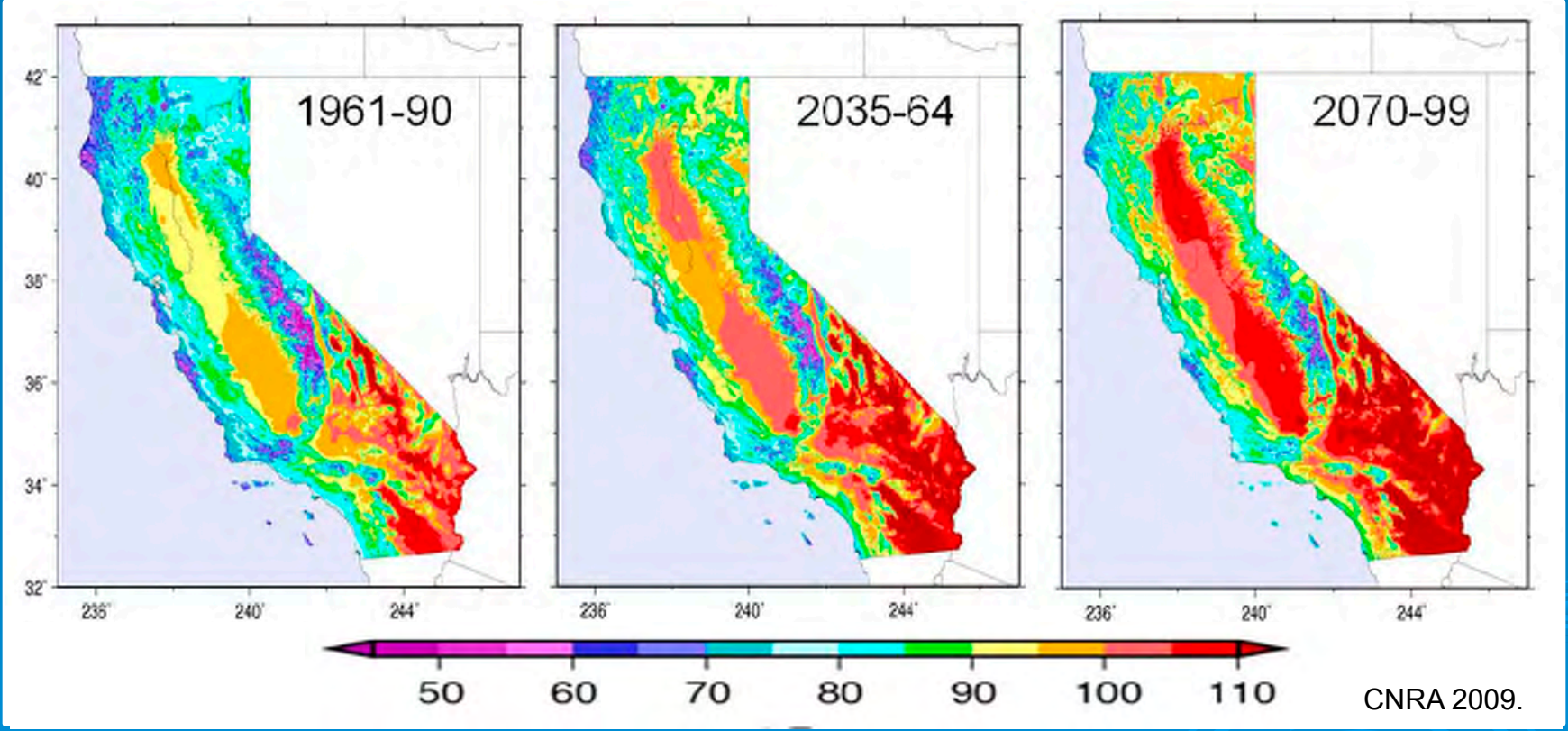
Climate Change



Source: CDNA 2009; Moser et al 2009, The Future is Now.

Climate Change

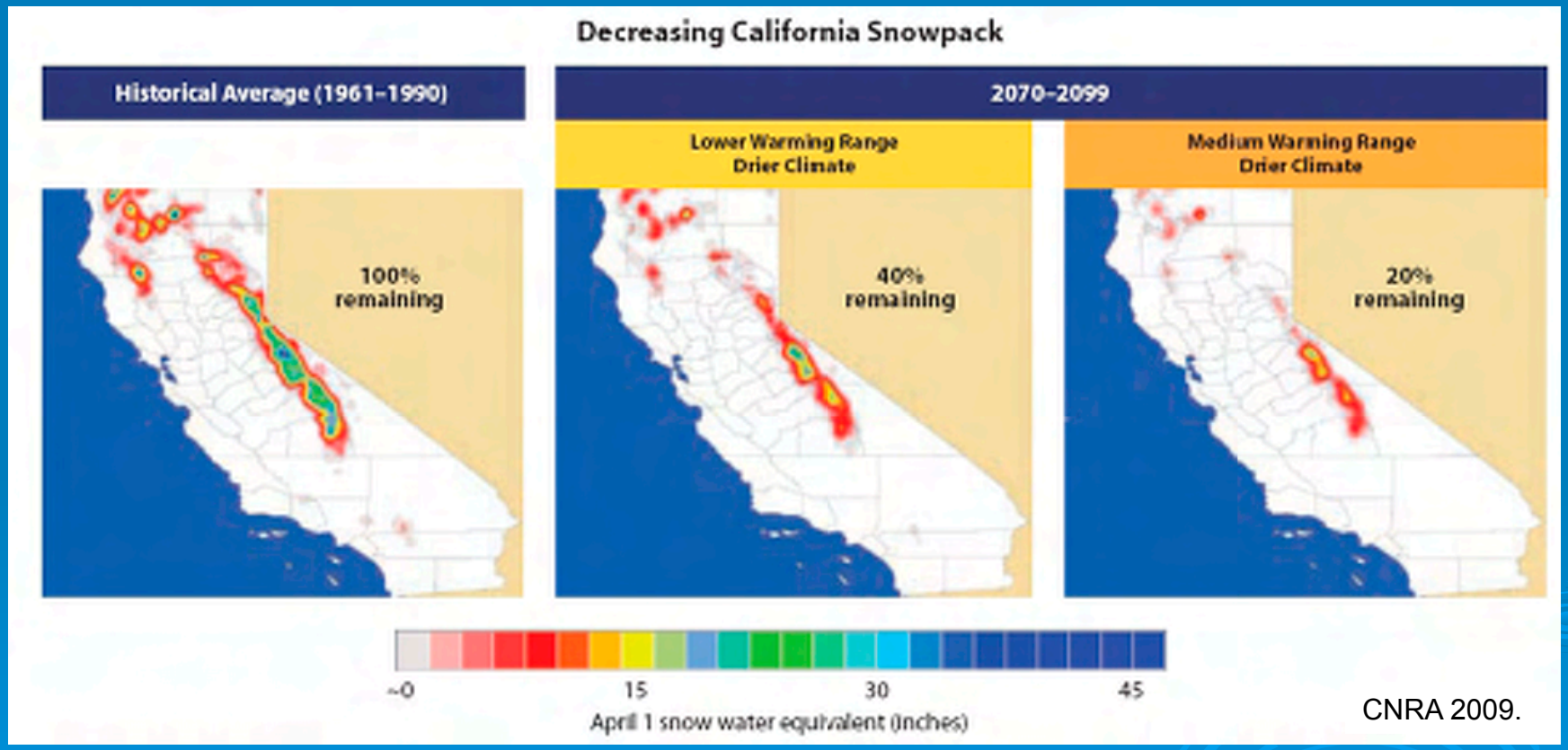
0.6^{o} C temperature rise at higher elevations in the Sierra Nevada



CNRA 2009.

Climate Change

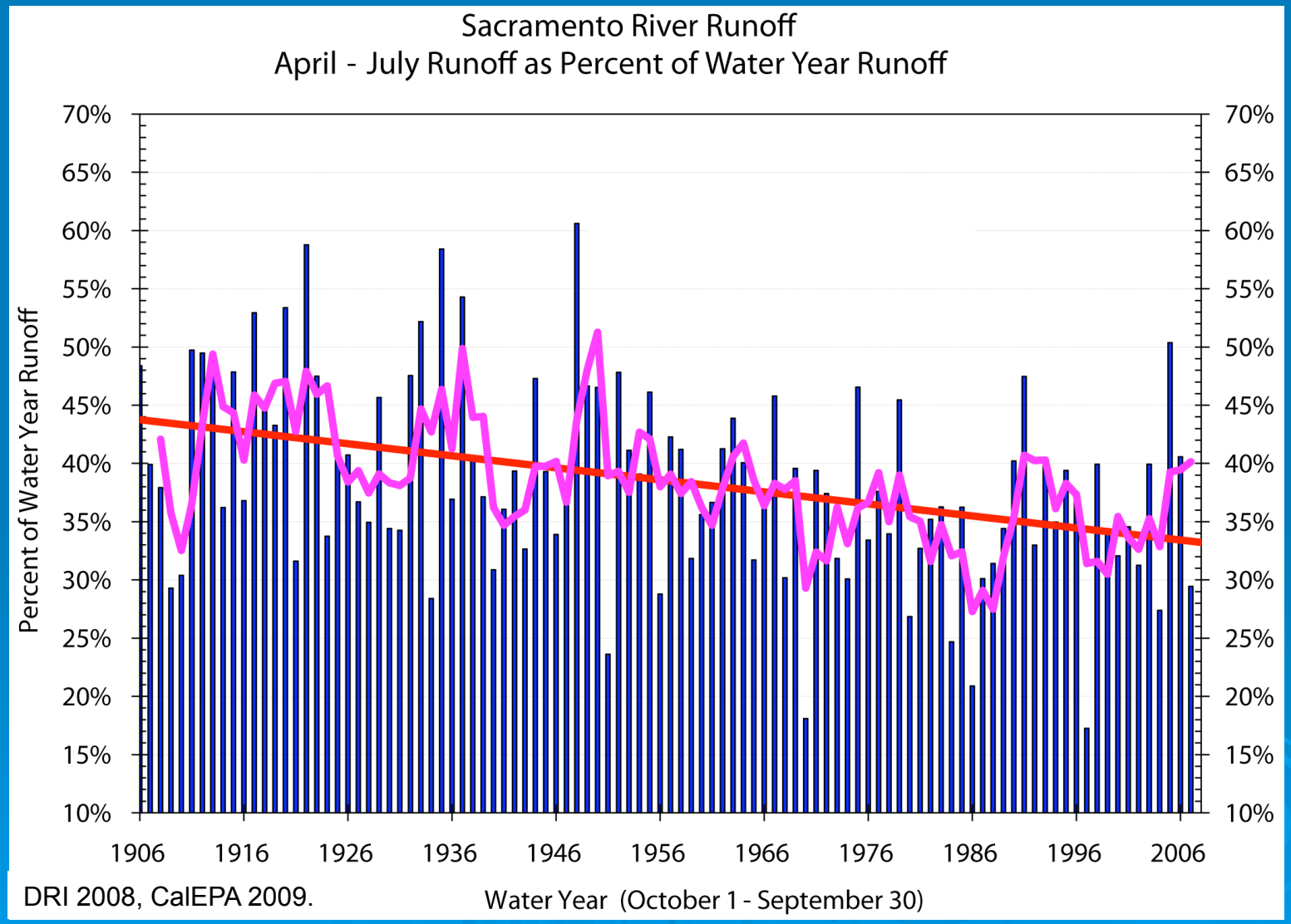
10% snowpack reduction at higher elevations in the Sierra Nevada



CNRA 2009.

Continued warming could reduce snowpack volume by 25% by 2050

Climate Change



DRI 2008, CalEPA 2009.

Planning Issues

- Potential impacts of climate change on Central Valley water resources
- Potential strategies for adapting to these changes
- Problems with ‘stationarity’ – changes in:
  - agricultural and urban demand
  - surface water availability
  - environmental flow requirements
  - physical infrastructure
- Groundwater pumping impacts:
  - Increased pumping costs
  - Subsidence
  - Water quality
  - Affects on river flows

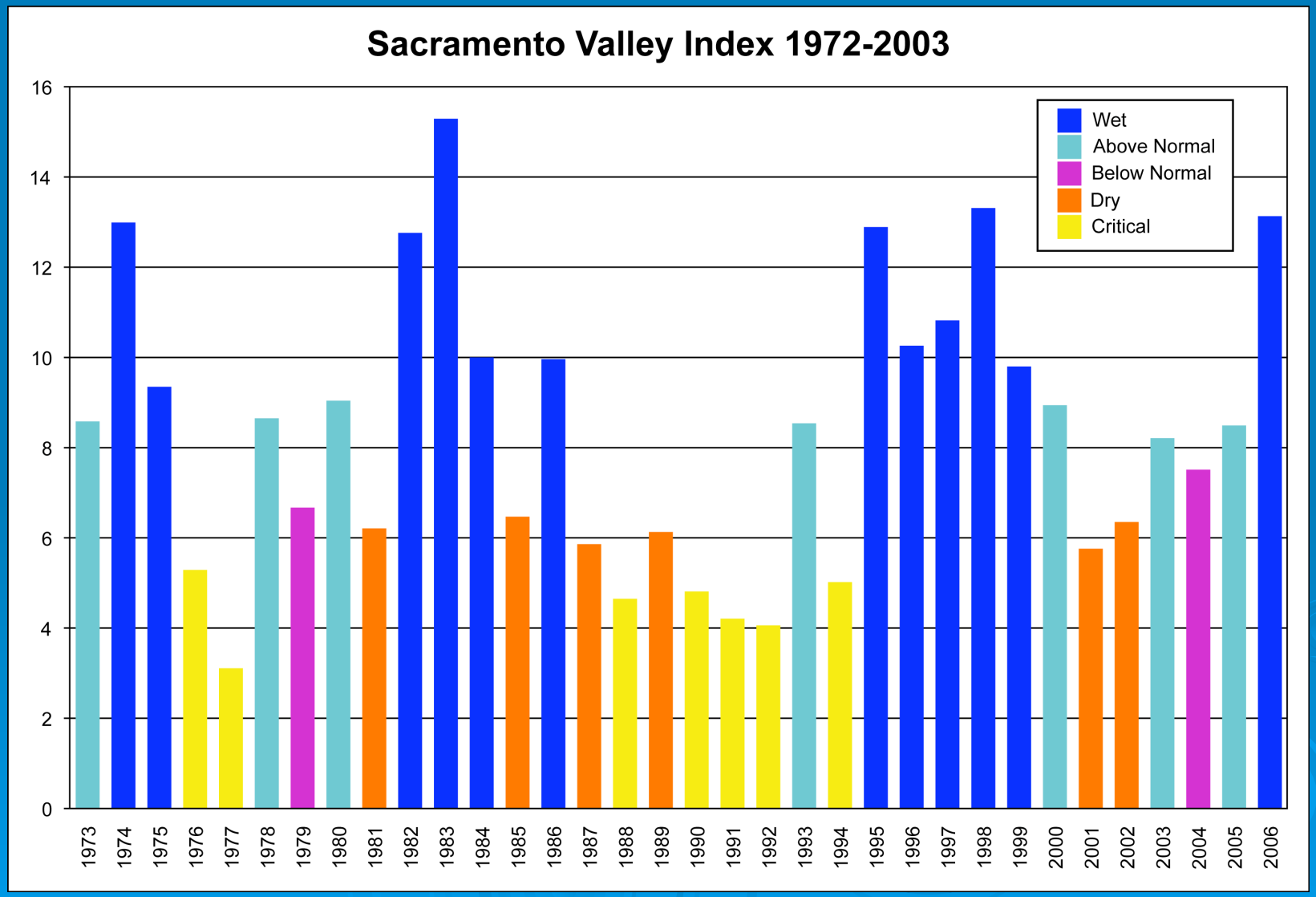
Research Questions

- Sensitivity of groundwater levels to climate-dependent inputs and groundwater pumping
- Will the surface water-groundwater system reach a new equilibrium after extended surface water reductions
- To what extent will changes in cropping patterns reduce impacts on groundwater levels

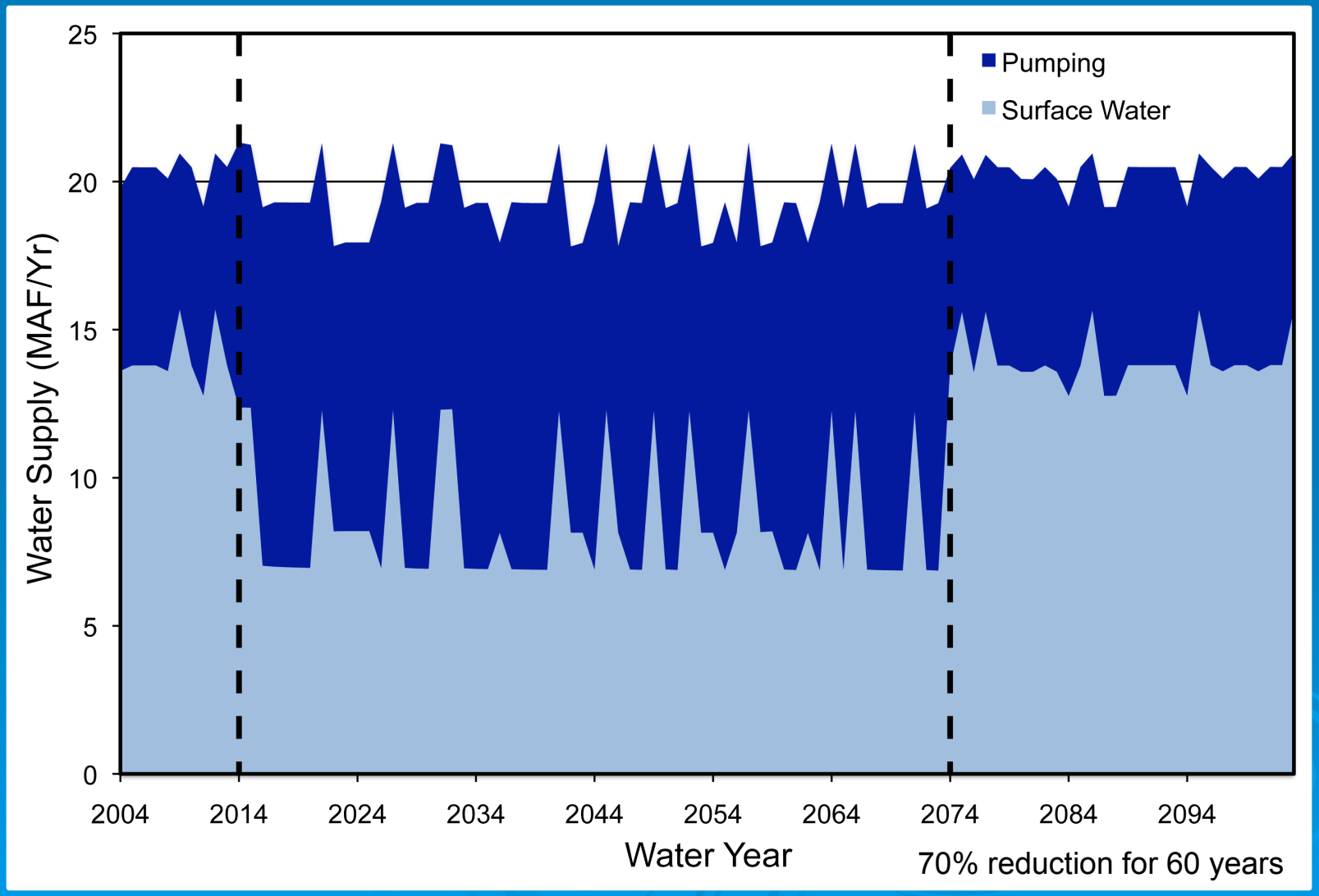
Methodology

- Construct valley-rim inflows for drought scenarios
  - 30%, 50% and 70% less precipitation
  - Develop diversion scenarios using CALSIM-II
- C2VSIM simulations
  - 10-year spin-up at ‘average’ conditions
  - 10-, 20-, 30- or 60-year drought
  - 30-year recovery period
  - Calculate groundwater pumping to meet demands
- Scenarios
  1) Fixed agricultural water demand
  2) Variable agricultural water demand

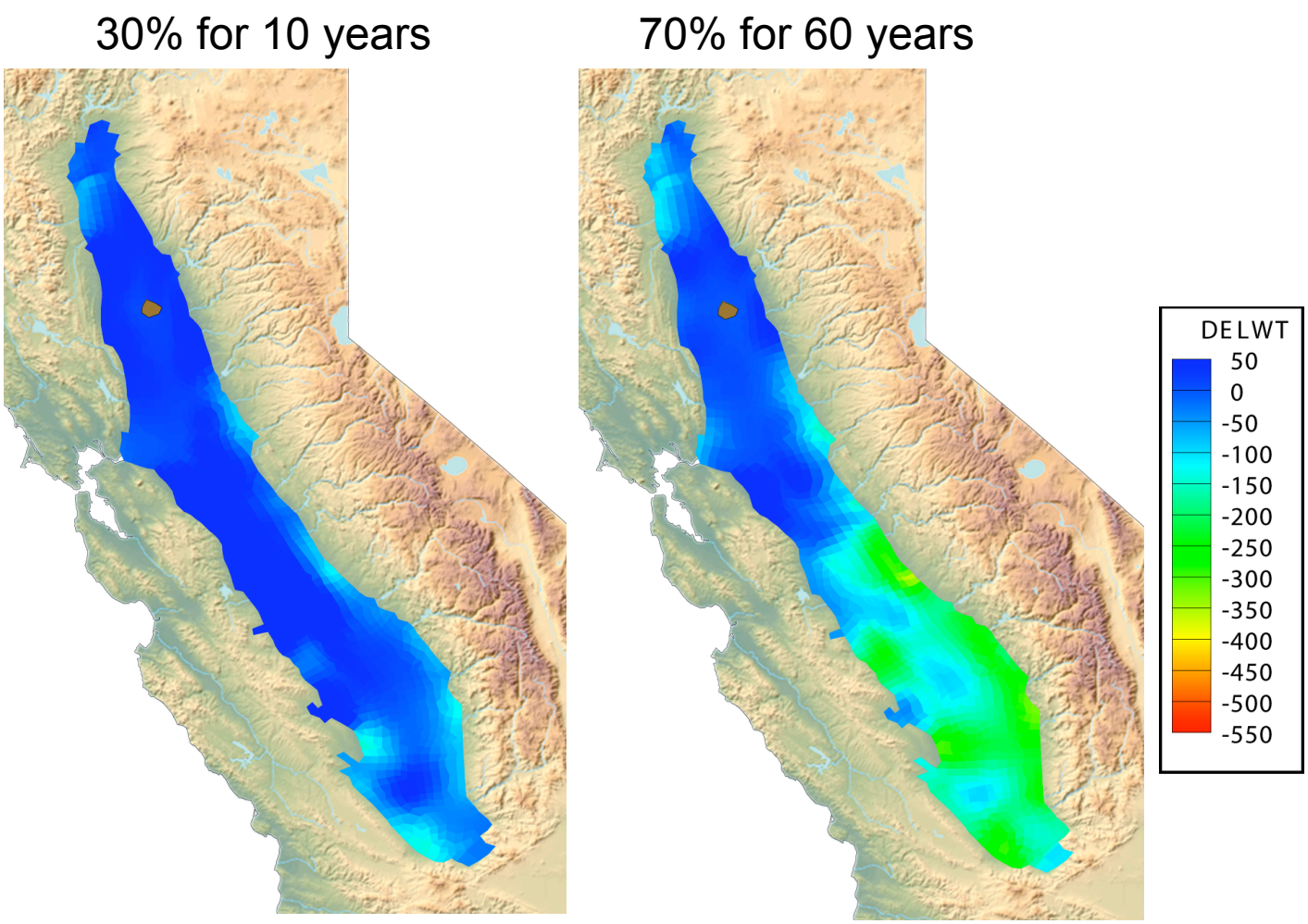
Sacramento Valley Index



Water Sources

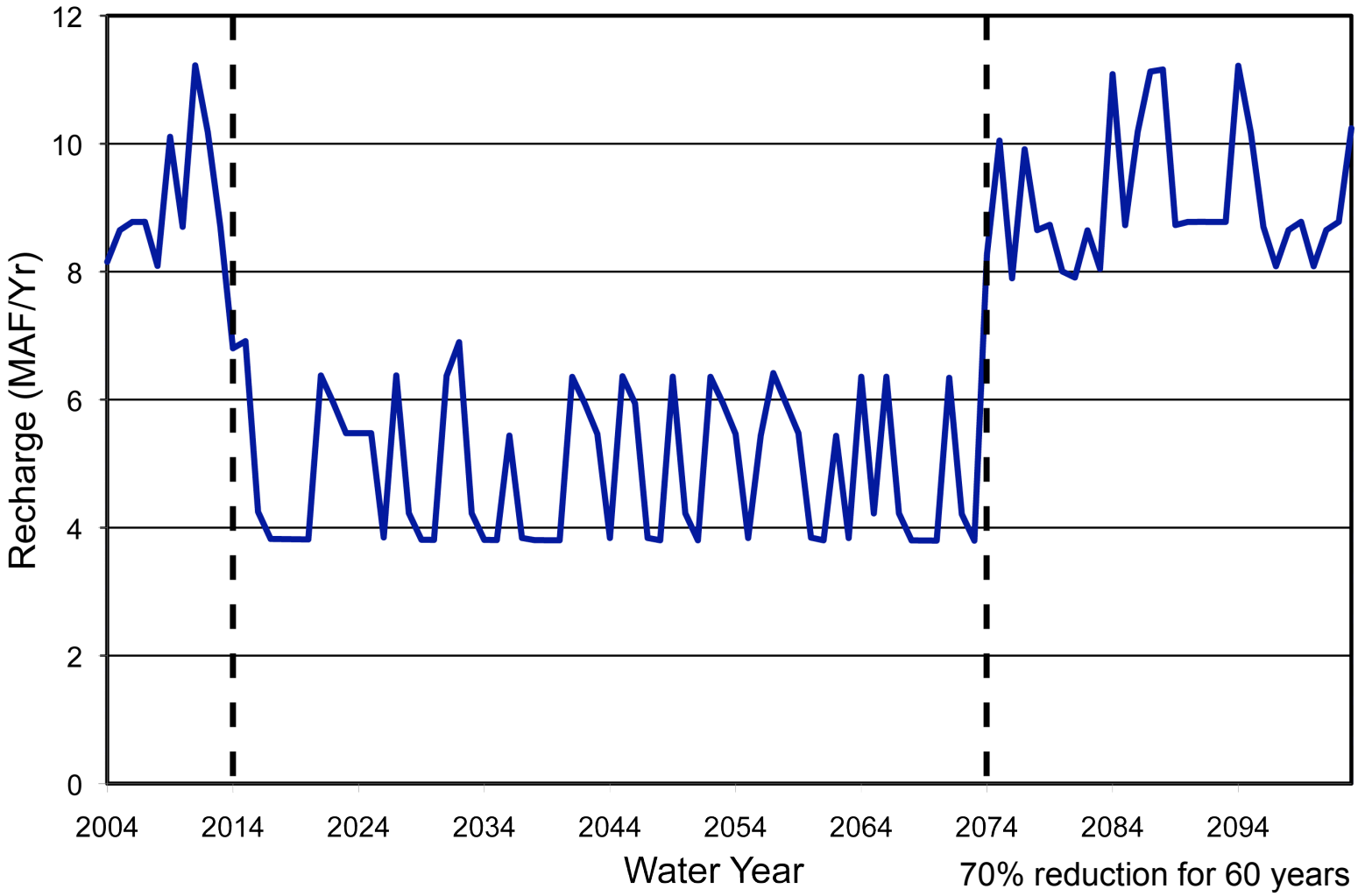


Relative Water Level Change

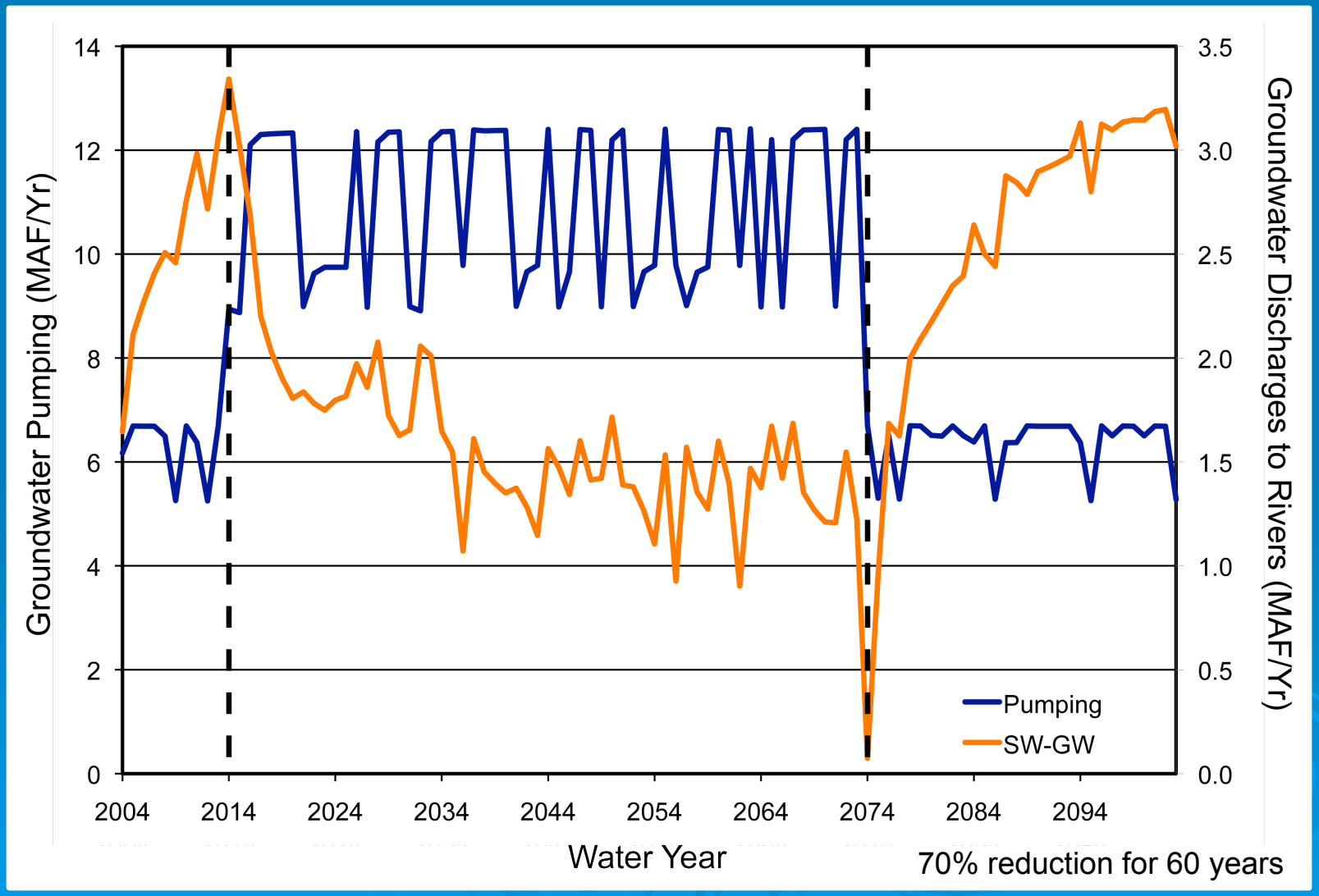


Relative WT Change (Feet)

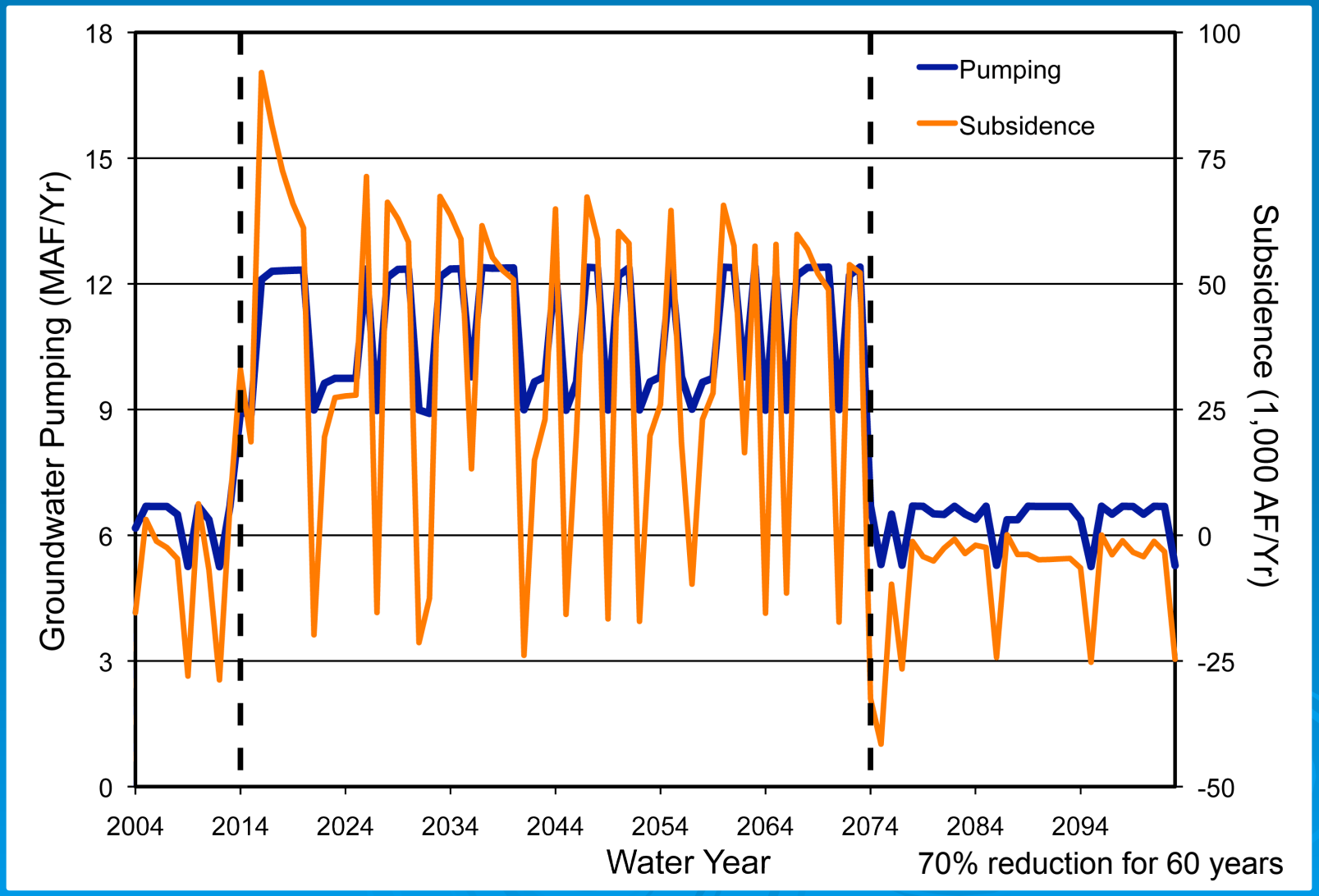
Recharge


12
10
8
6
4
2
0
Recharge (MAF/Yr)
2004
2014
2024
2034
2044
2054
2064
2074
2084
2094
Water Year
70% reduction for 60 years

Stream-Groundwater Interaction



Land Subsidence



Results

- Regional impacts of extreme drought
  - Moderate in north (Sacramento River Basin)
  - Locally severe in center (San Joaquin River Basin)
  - Severe in south (Tulare Basin)
- River flows impacted by reduced groundwater discharges to rivers
- Permanent land subsidence is suggested with sustained pumping rates greater than 9 MAF/yr

Incorporating Variable Demand

- Crop mix is a function of water cost
  - Surface water availability
  - Depth to groundwater
  - Crop Water Demand
  - Crop Production Costs and Returns
- Incorporate Logit equation in IWFM application
- Determine Logit equation parameters from a series of simulations conducted with the Central Valley Production Model

Central Valley Production Model

Economic Model

- Positive Mathematical Programming Model
- Crop Production Costs
- Impact of Yields on Prices
- Crop Distribution in Central Valley

Emulate CVPM in IWFM

- Use Logit Equation to Determine Crop Mix
- Determine Parameters with Multiple CVPM Runs

C2VSIM and CVPM

- 21 Subregions
- Crops
- Time Step

Logit Equation

Predicts the share of each crop in each region

$$\alpha_{ir} = \frac{e^{x_r \beta_{ir}}}{1 + \sum_j e^{x_r \beta_{jr}}}$$

where *i* and *j* are crops
r and *s* are regions
x is a vector of regional explanatory variables
β is a vector of estimated coefficients

Crop water use is calculated from the acreage as

$$a_{ir} = x_r \gamma_{ir}$$

where γ is a vector of estimated coefficients that can vary by region and by crop

Logit Equations

Fallow	P_0	$\Pr(y=0)=\dfrac{1}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Cereal	P_1	$\Pr(y=1)=\dfrac{e^{XB_1}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Orchard	P_2	$\Pr(y=2)=\dfrac{e^{XB_2}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Pasture	P_3	$\Pr(y=3)=\dfrac{e^{XB_3}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Rice	P_4	$\Pr(y=4)=\dfrac{e^{XB_4}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$
Row	P_5	$\Pr(y=5)=\dfrac{e^{XB_5}}{1+e^{XB_1}+e^{XB_2}+e^{XB_3}+e^{XB_4}+e^{XB_5}}$

Multiple CVPM Runs

Regress results to obtain Logit parameters

groundwater depth	percent surface supply	reg3	reg3b	reg4	reg5	Cereal percent	Orchard percent	Pasture percent	Rice percent	Row percent	Fallow percent
110	1	0	1	0	0	25%	32%	18%	11%	14%	0%
160	0.8	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.85	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.9	0	1	0	0	25%	32%	17%	11%	14%	2%
160	0.95	0	1	0	0	25%	32%	17%	11%	14%	2%
210	0.8	0	1	0	0	24%	32%	17%	10%	14%	4%
210	0.85	0	1	0	0	24%	32%	16%	10%	14%	4%
210	0.9	0	1	0	0	24%	32%	16%	10%	14%	4%
210	0.95	0	1	0	0	24%	32%	16%	10%	14%	4%
260	0.8	0	1	0	0	24%	32%	16%	10%	14%	6%
260	0.85	0	1	0	0	24%	32%	15%	10%	14%	6%
260	0.9	0	1	0	0	24%	32%	15%	10%	14%	6%
260	0.95	0	1	0	0	24%	32%	15%	10%	14%	5%
310	0.8	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.85	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.9	0	1	0	0	23%	32%	15%	10%	14%	7%
310	0.95	0	1	0	0	23%	32%	15%	10%	14%	7%
60	1	0	0	1	0	32%	11%	3%	32%	22%	0%
75	1	0	0	0	1	10%	34%	7%	46%	3%	0%
85	1	1	0	0	0	16%	6%	9%	48%	21%	0%

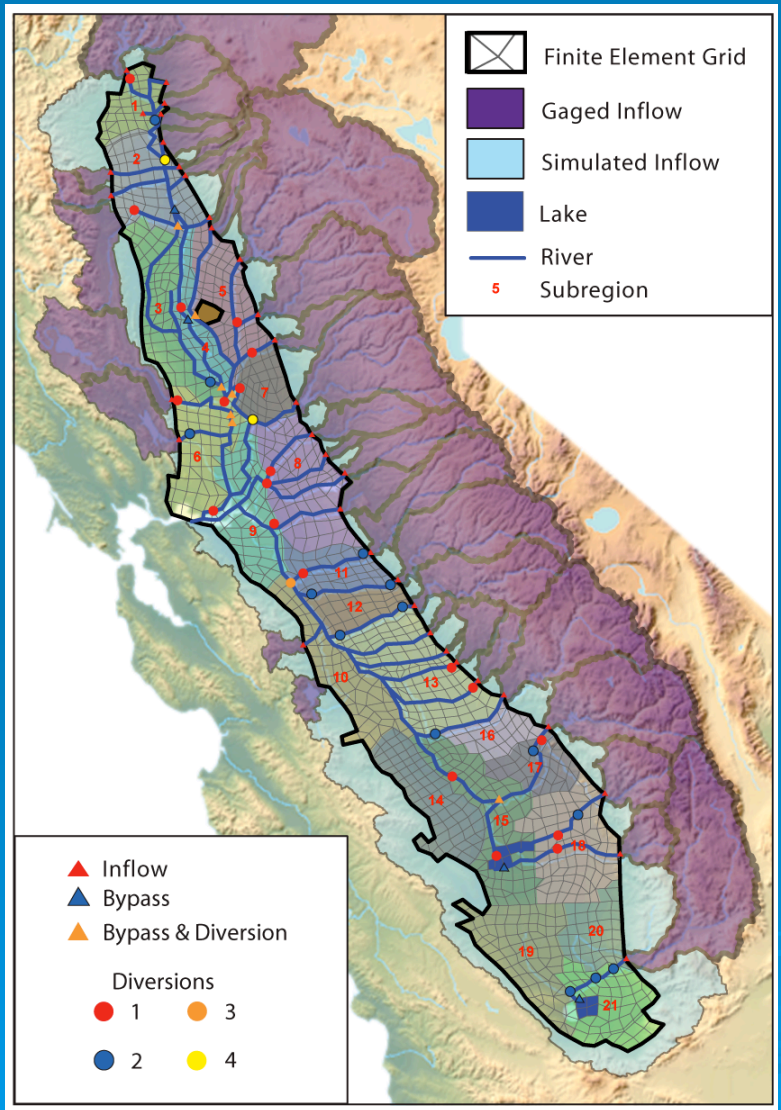
Findings

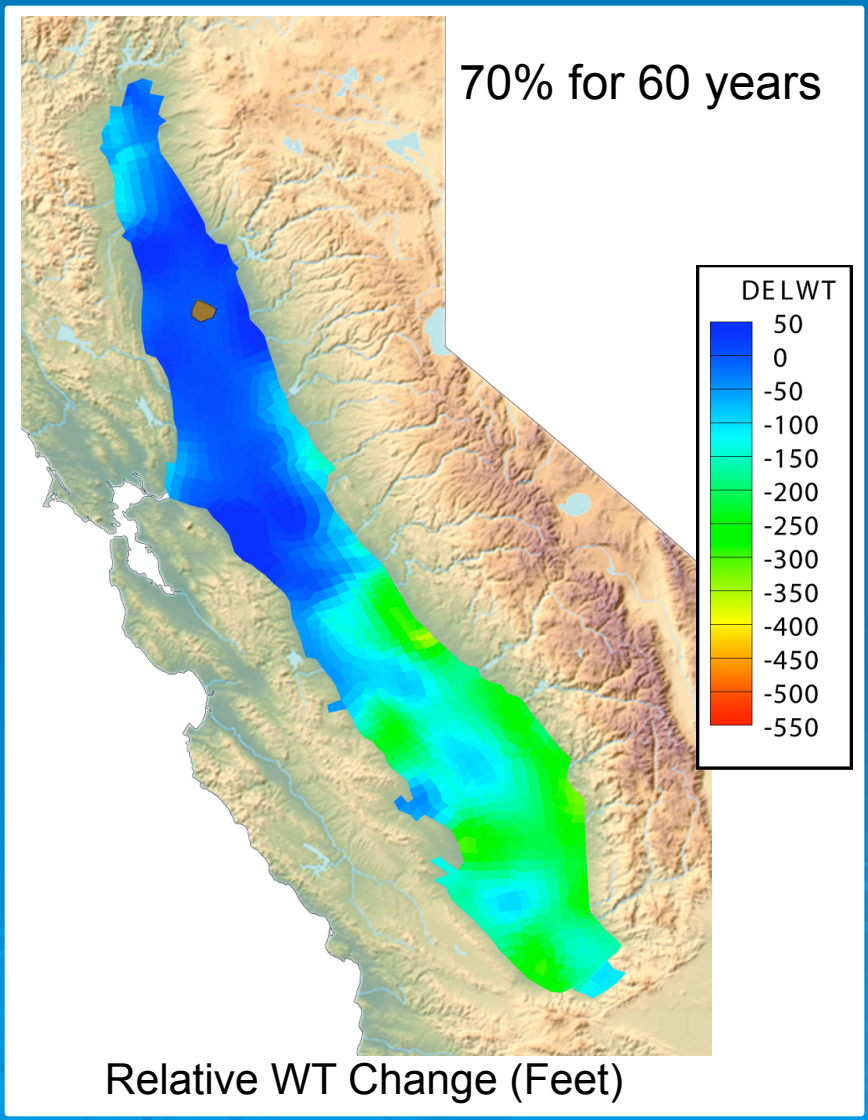
- Regional impacts of extreme drought
  - Moderate in north (Sacramento River Basin)
  - Locally severe in middle (San Joaquin River Basin)
  - Severe in south (Tulare Basin)
  - Extensive pumping can cause permanent subsidence and may lead to new equilibrium groundwater levels
- Modeling tools
  - C2VSIM can provide valuable insights into the impacts of climate change on Central Valley aquifers
  - C2VSIM can be tailored to investigate the impacts of specific stressors

Future Work

- Complete variable-crop drought simulations
  - Logit parameters have been calculated
  - C2VSIM simulations have been conducted
  - Currently analyzing results
- Develop more realistic drought scenarios
  - Downscale GCM precipitation and runoff predictions
  - Monte Carlo simulations
  - Changes in amount and timing of crop water demands
  - Changes in amount and timing of reservoir releases
  - More elaborate economic model

Questions?


Finite Element Grid
Gaged Inflow
Simulated Inflow
Lake
River
5 Subregion
Inflow
Bypass
Bypass & Diversion
Diversions
1
2
3
4


70% for 60 years
DELWT
50
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
-550
Relative WT Change (Feet)