Simulating Groundwater Change in California

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IGCP 565 3rd Annual Meeting
Reno, Nevada
11 October 2010

Groundwater is part of the Climate System

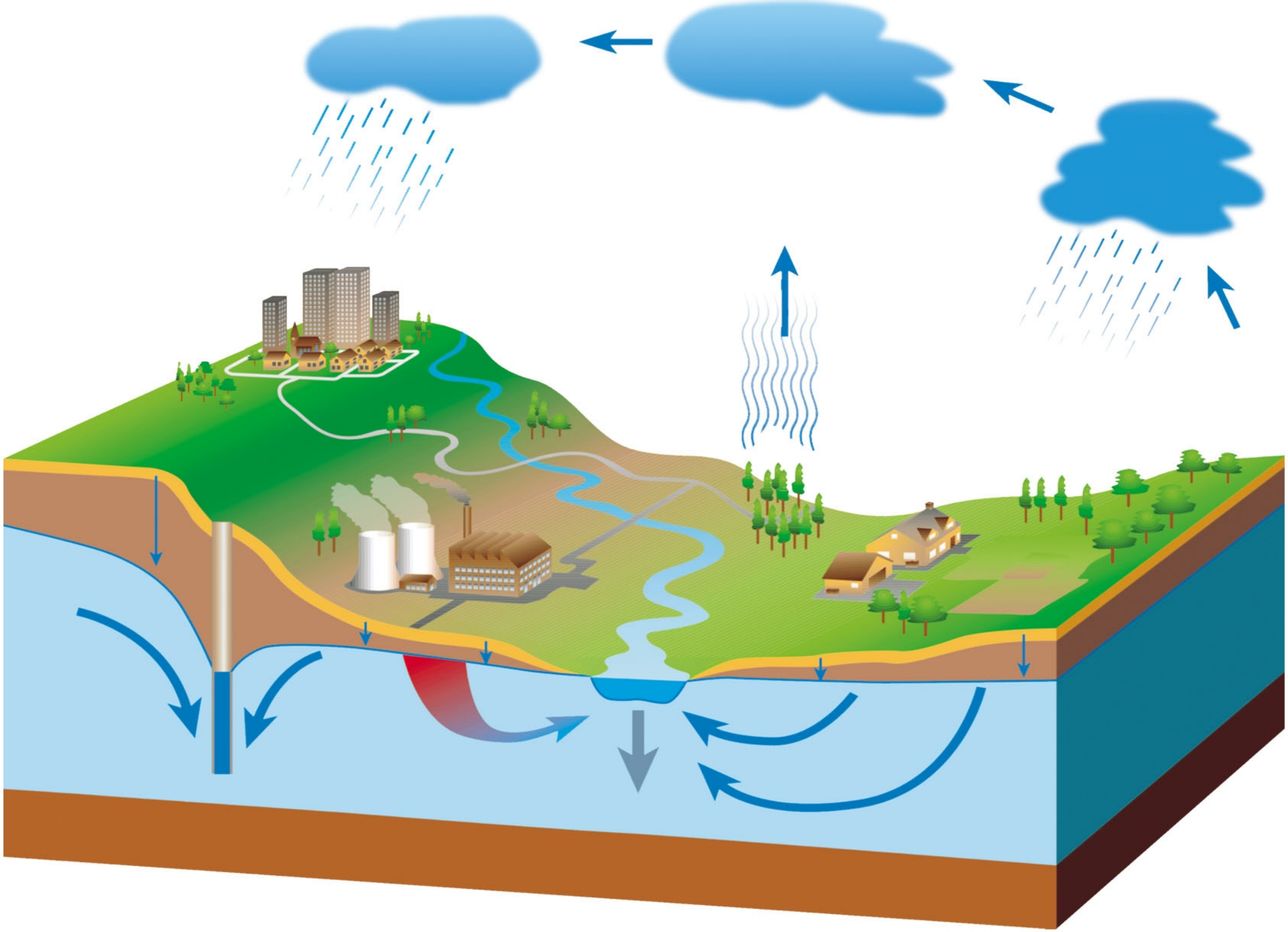
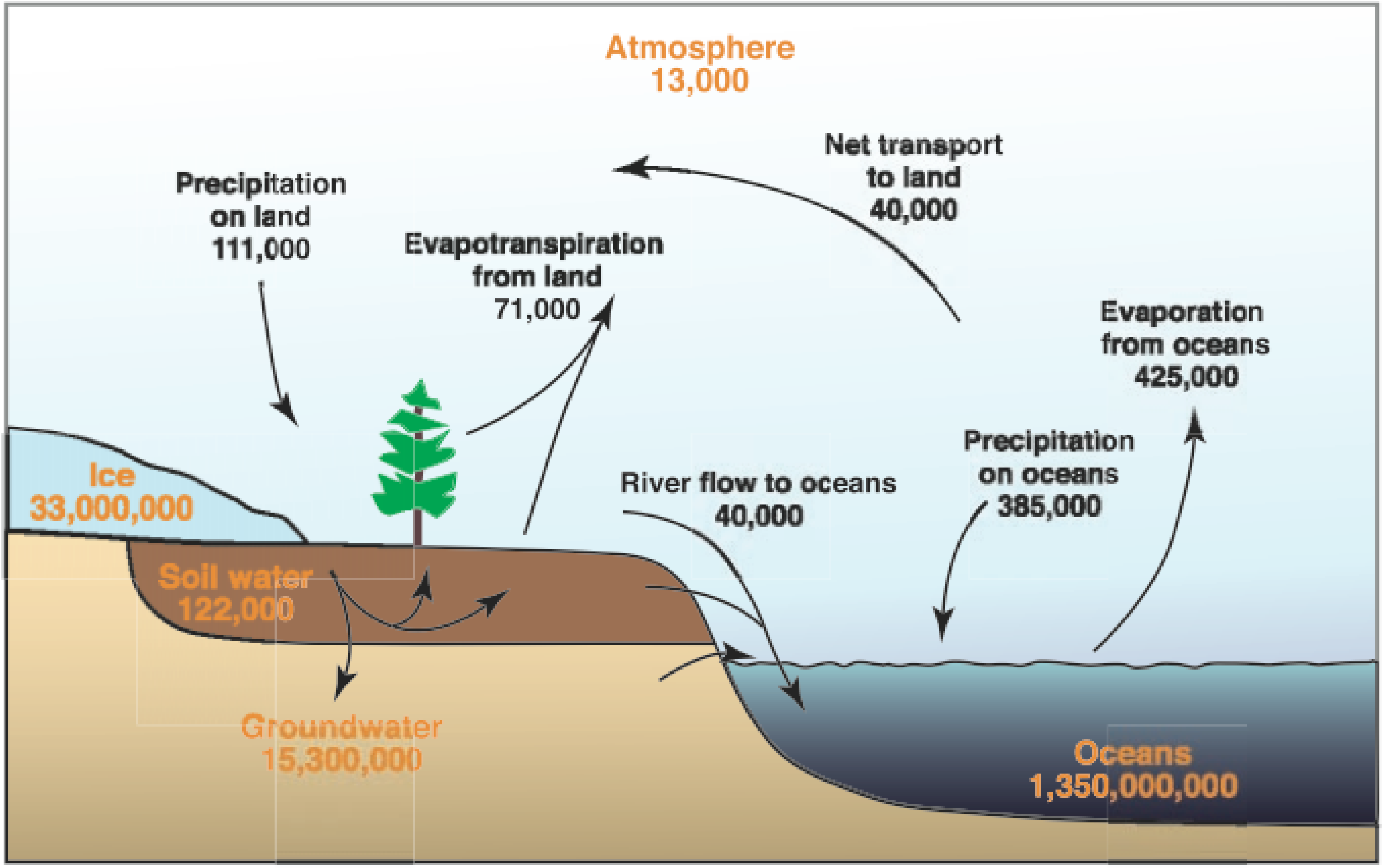


Image from: http://www.eurogeosurveys.org/

Water Storage and Fluxes



Pools are in cubic kilometers

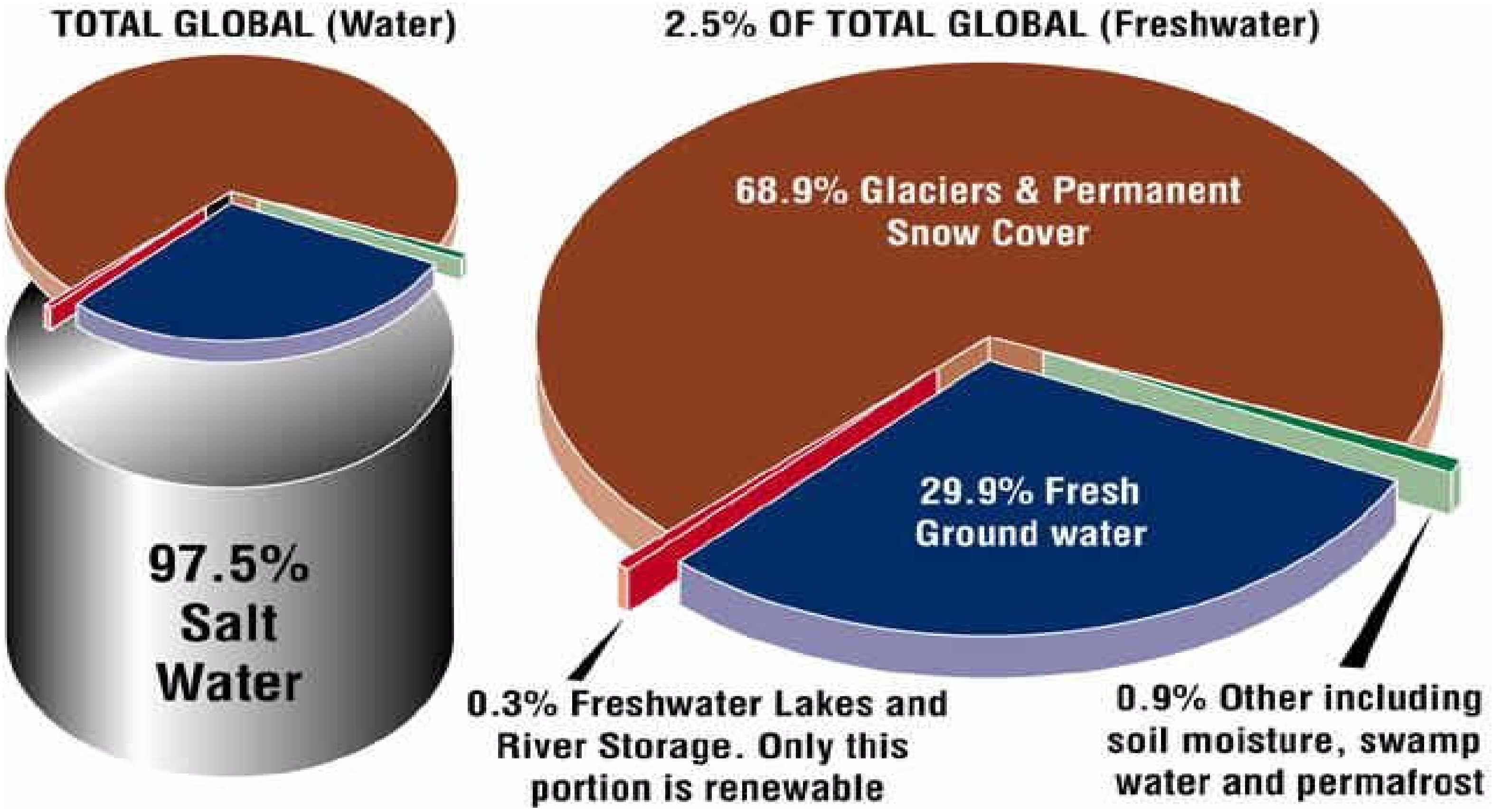
Fluxes are in cubic kilometers per year

Fig. 1. Global pools and fluxes of water on Earth, showing the magnitude of groundwater storage relative to other major water storages and fluxes. [Reproduced from (*82*) with permission from the publisher, Elsevier Science (USA)]

Less than 0.8 % of the Global Water Cycle is Groundwater

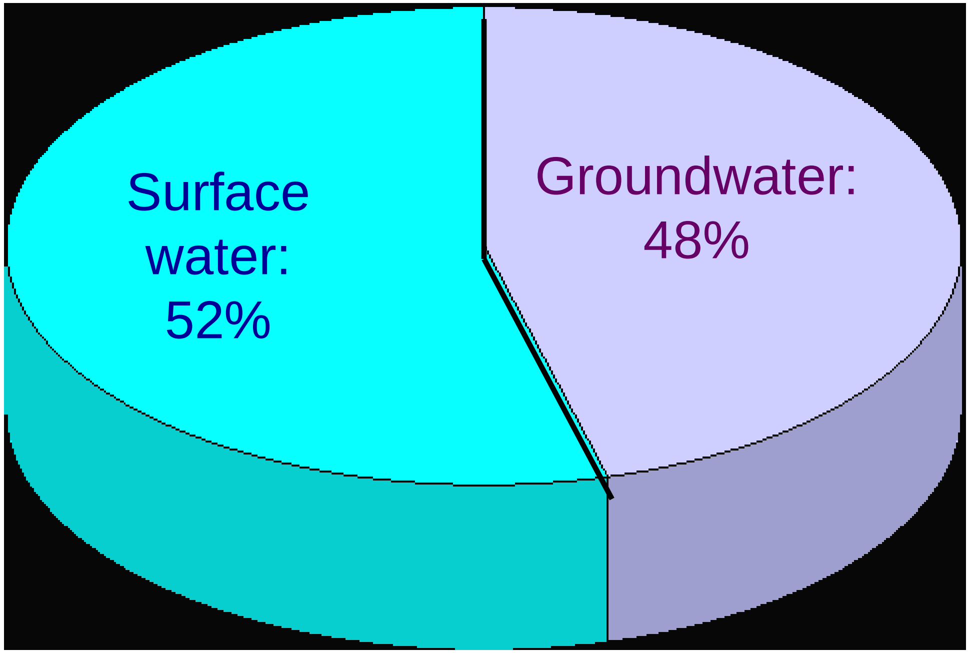
But, this is a very important part of the Hydrologic Cycle !

Groundwater acts as our drought insurance



California Case Study:

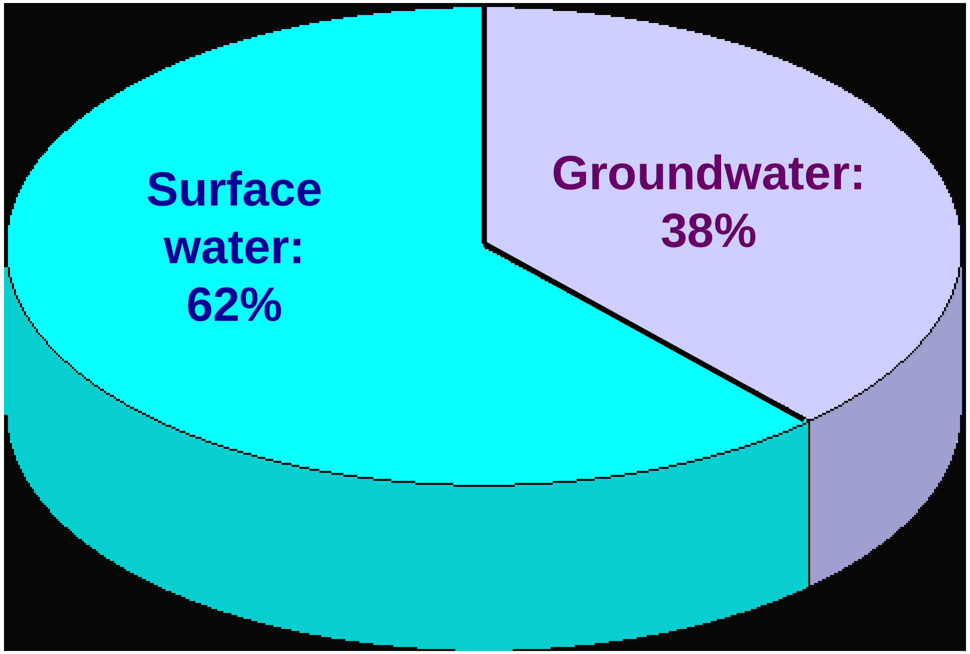
Groundwater an important resource for Public/ municipal water supply in California



(calculated from data in Hutson *et alii*, 2004)

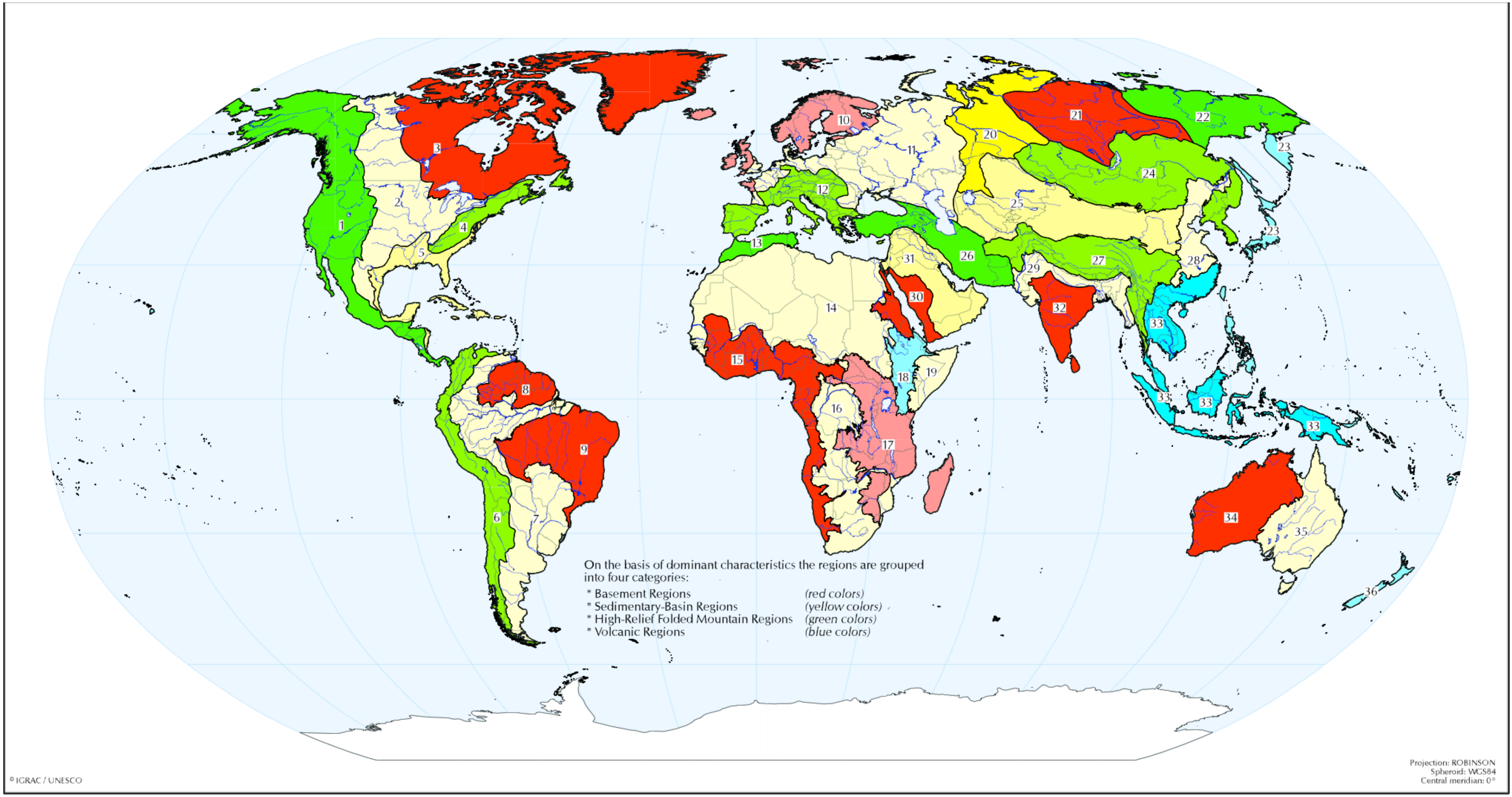
California Irrigation:

This ratio is for Normal years, during DRY or Critically Dry (I.e. Drought) years Groundwater increases and acts as drought insurance for the economy



(calculated from data in Hutson *et alii*, 2004)

IGRAC Monitoring Regions



On the basis of dominant characteristics the regions are grouped into four categories:

- * Basement Regions *(red colors)*
- * Sedimentary-Basin Regions *(yellow colors)*
- * High-Relief Folded Mountain Regions *(green colors)*
- * Volcanic Regions *(blue colors)*

Projection: ROBINSON
Spheroid: WGS84
Central meridian: 0°

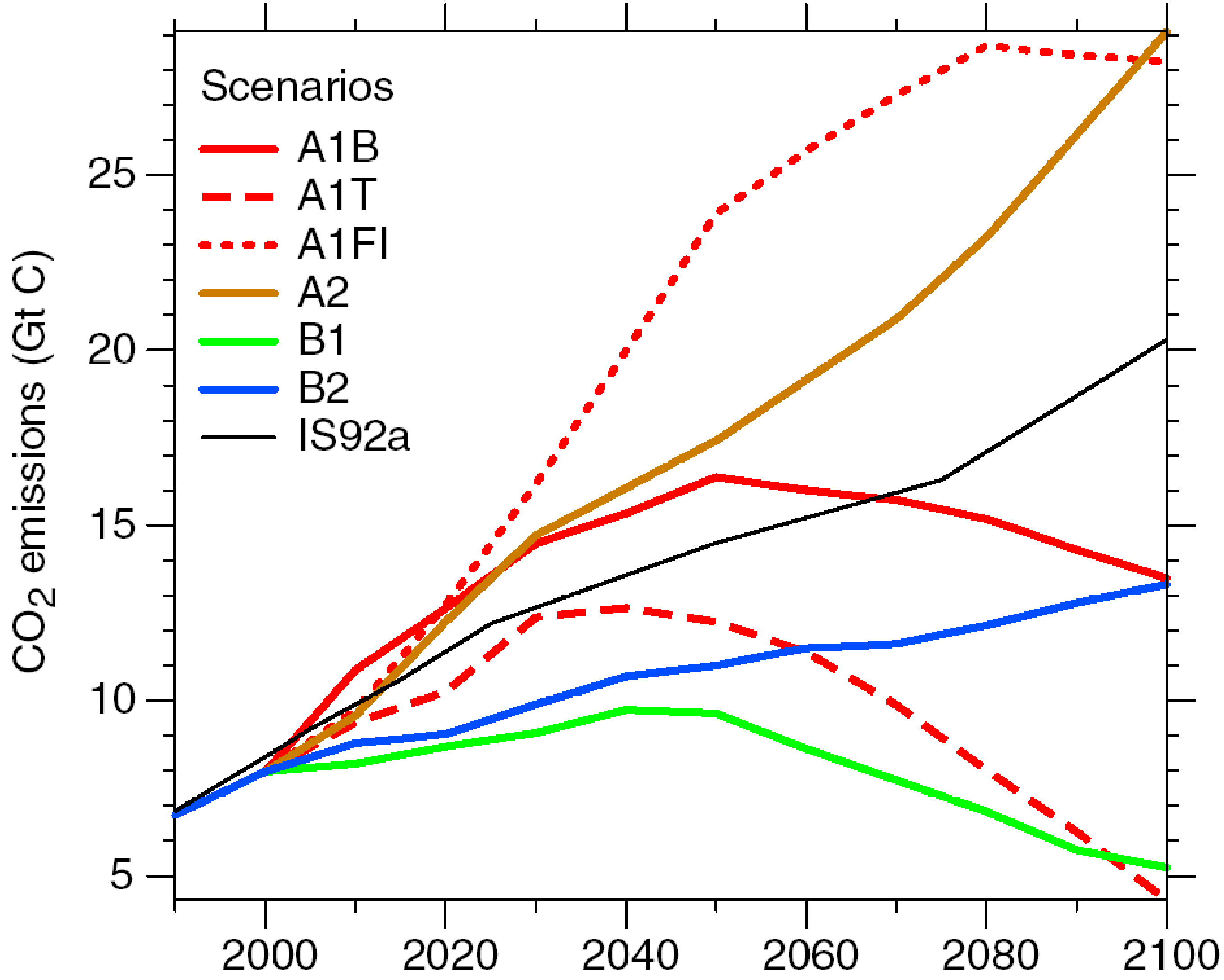
GLOBAL GROUNDWATER REGIONS

1 Western mountain belt of North & Central America
2 Central plains of North & Central America
3 Canadian shield
4 Appalachian highlands
5 Caribbean islands and coastal plains of North and Central America
6 Andean belt
7 Lowlands of South America
8 Guyana shield
9 Brazilian shield and associated basins
10 Baltic and Celtic shields
11 Lowlands of Europe
12 Mountains of Central and Southern Europe
13 Atlas Mountains
14 Saharan basins
15 West African basement
16 Subsaharan basins
17 East African basement and Madagascar
18 Volcanics of East Africa
19 Horn of Africa basins
20 West Siberian platform
21 Central Siberian plateau
22 East Siberian highlands
23 Northwestern Pacific margin
24 Mountain belt of Central and Eastern Asia
25 Basins of West and Central Asia
26 Mountain belt of West Asia
27 Himalayas and associated highlands
28 Plains of Eastern China
29 Indo-Gangetic-Brahmaputra Plain
30 Nubian and Arabian shields
31 Levant and Arabian platform
32 Peninsular India and Sri Lanka
33 Peninsulas and Islands of South-East Asia
34 Western Australia
35 Eastern Australia
36 Islands of Pacific

igrac
International Groundwater Resources Assessment Centre

Version: 17-MAY-2005

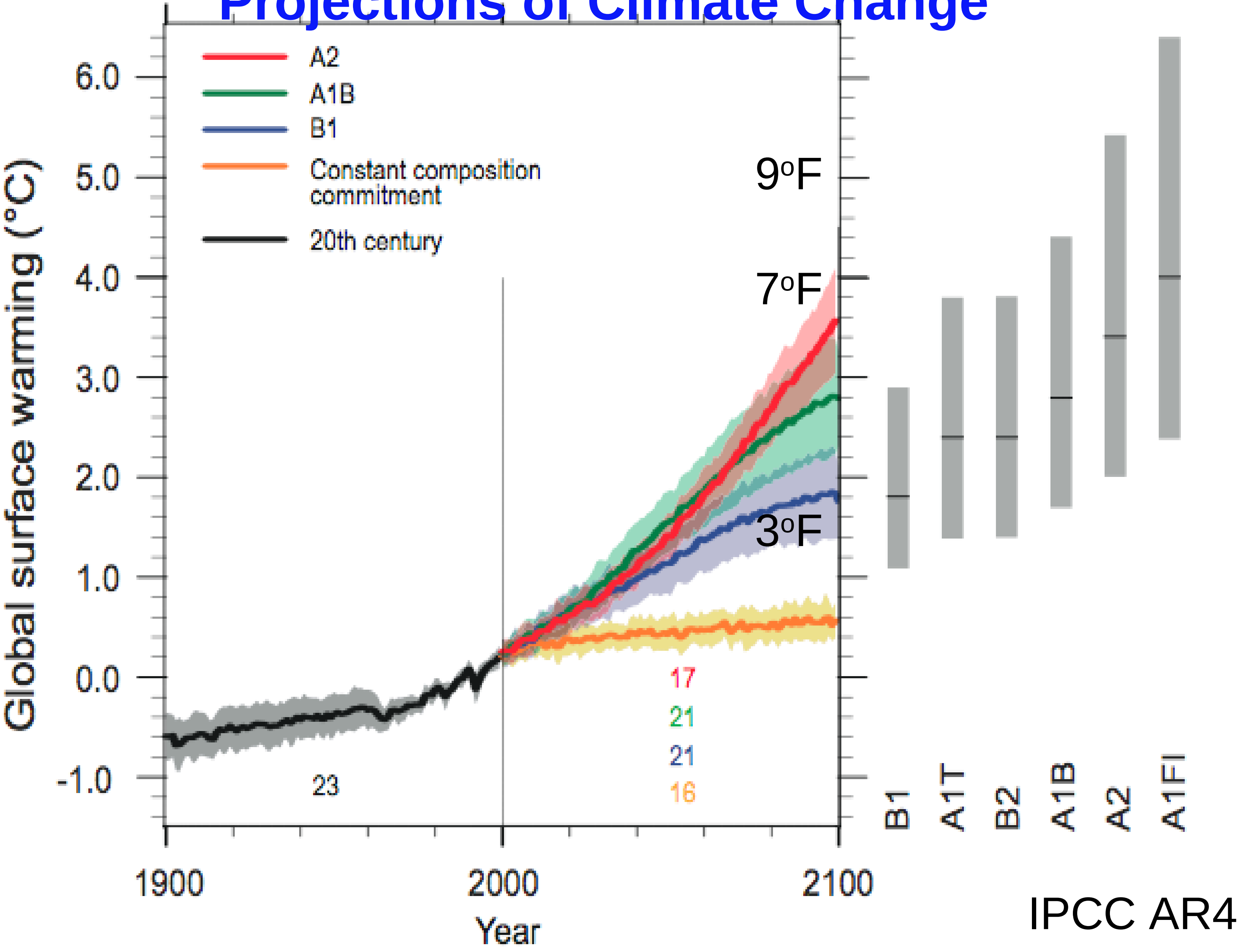
Intergovernmental Panel for Climate Change Special Report on Emissions Scenarios



SRES

IPCC 2001

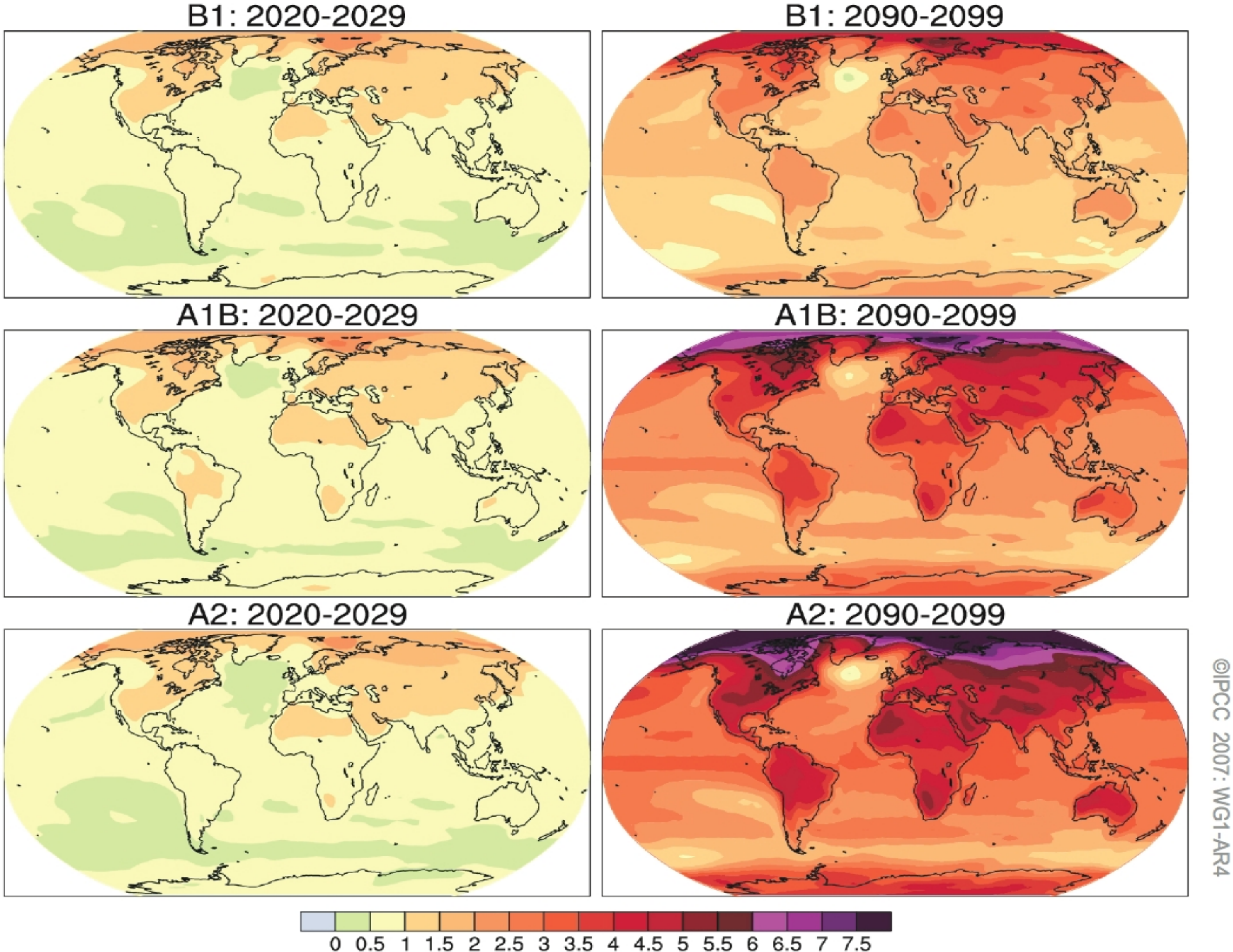
Projections of Climate Change



IPCC AR4

Projections of Climate Change

Greatest warming is over land & at most high Northern latitudes and least over the Southern Ocean & parts of the North Atlantic

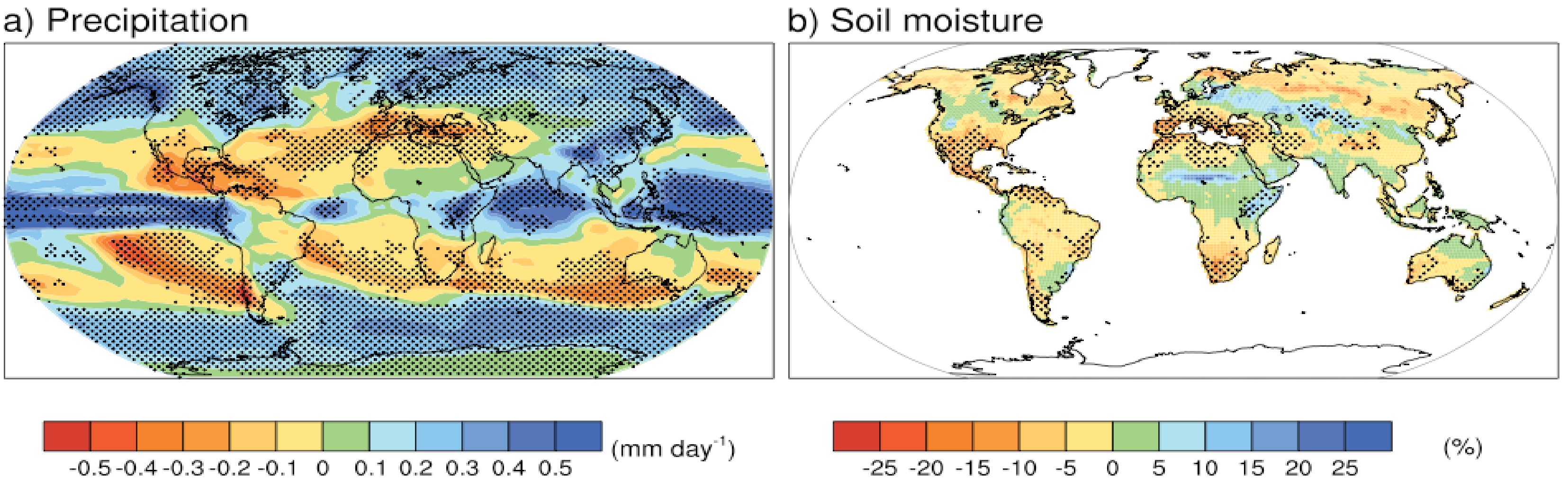


°C

IPCC AR4

As Warming Continues the Sub-Tropics and Mid-Latitudes Dry and Evaporation Increases Everywhere

Stippled Regions are where 80% of IPCC Models Agree



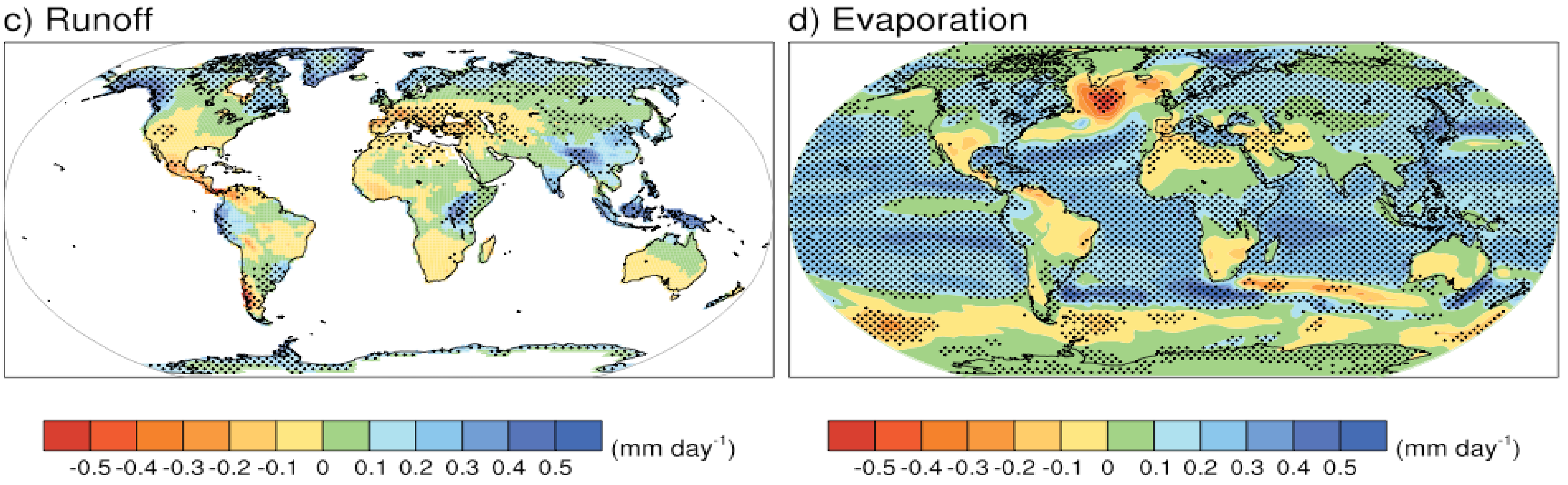
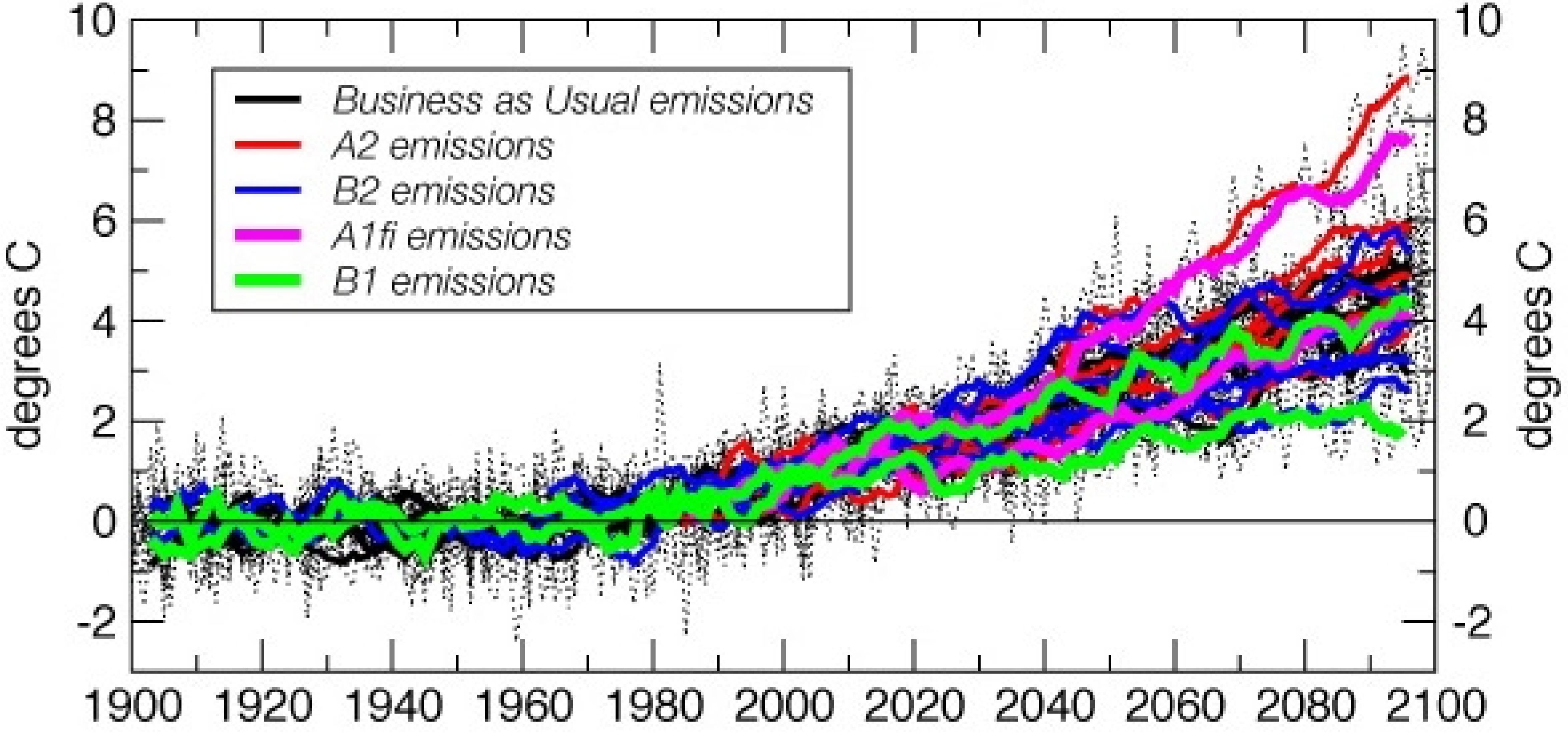


Figure 10.12. *Multi-model mean changes in (a) precipitation (mm day^{-1}), (b) soil moisture content (%), (c) runoff (mm day^{-1}) and (d) evaporation (mm day^{-1}). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models. Details of the method and results for individual models can be found in the Supplementary Material for this chapter.*

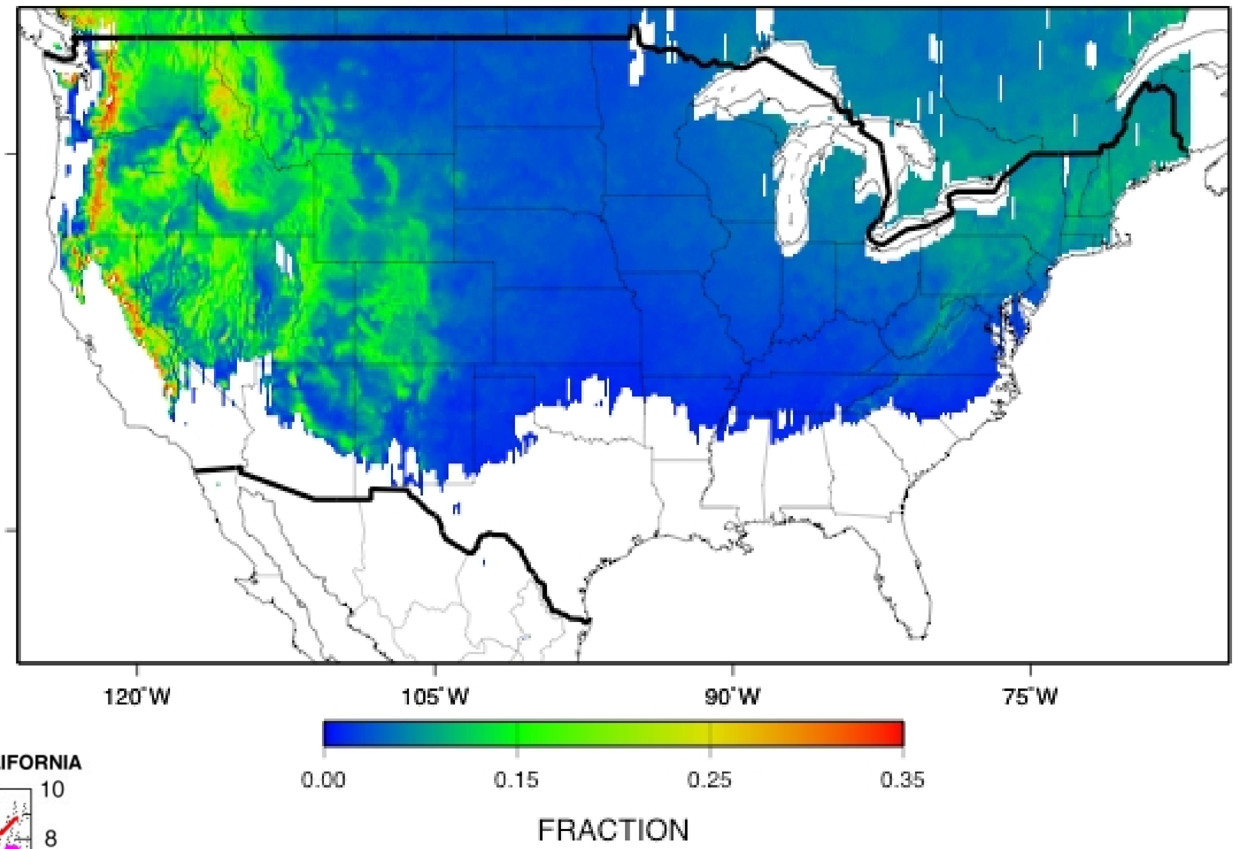


PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

SENSITIVITY OF SNOWFED HYDROCLIMATE TO A +3ºC WARMING … Rain? or Snow?

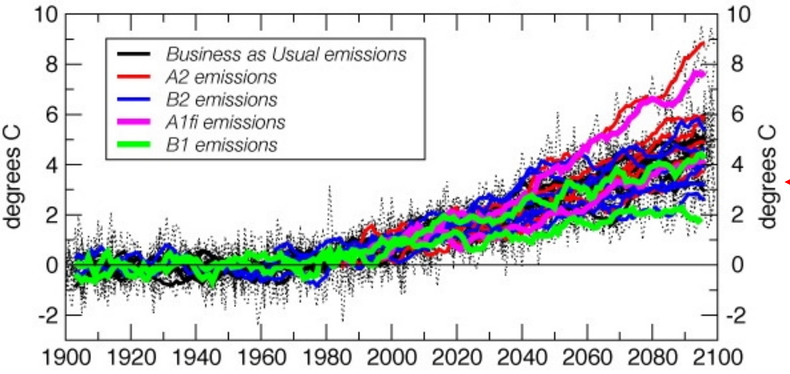
- **What fraction of each year's precipitation historically fell on days with average temperatures just below freezing?**

FRACTION OF ANNUAL PRECIPITATION FALLING IN THE DAILY TEMPERATURE RANGE: -3C < Tavg < 0C
[from 1950-1999 VIC 1/8-degree INPUT DATA]



Less vulnerable **More vulnerable**

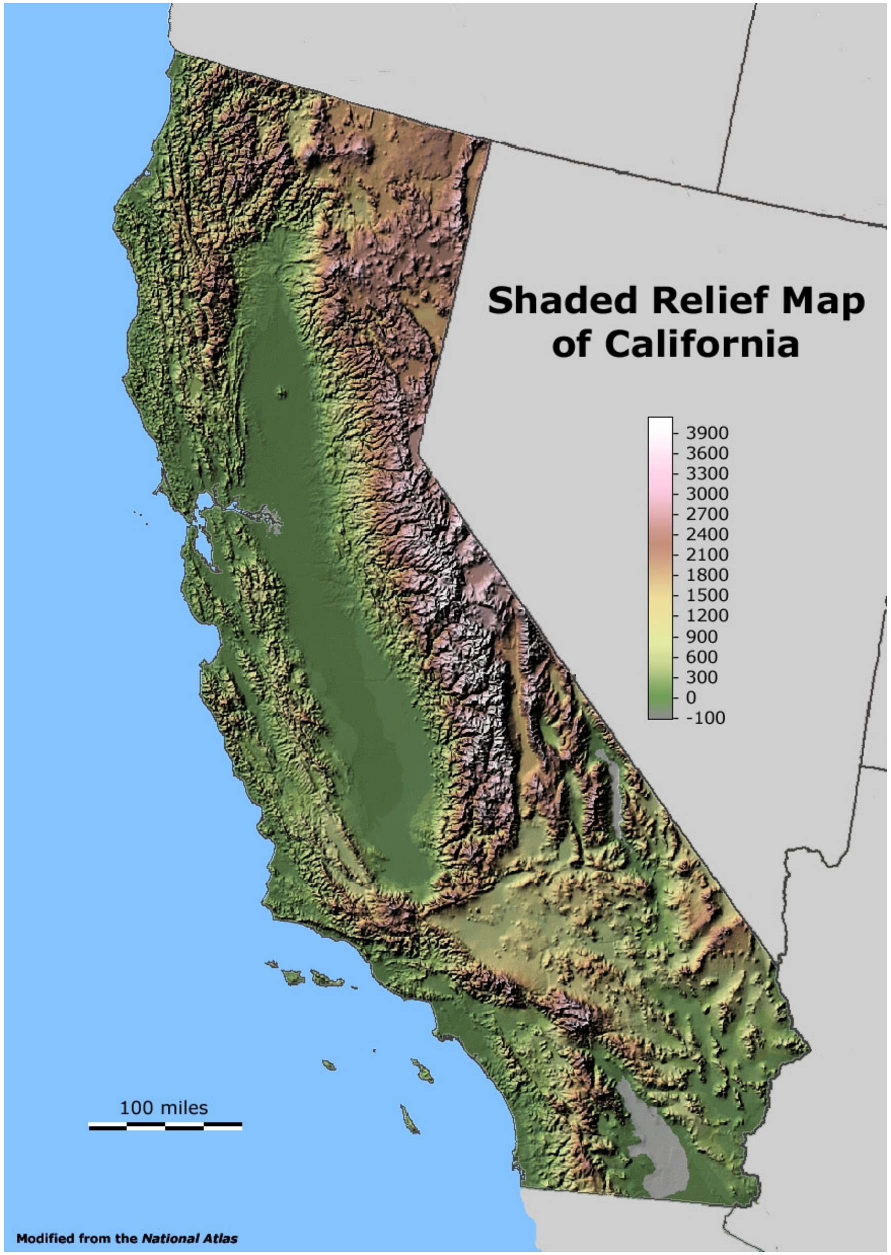
PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

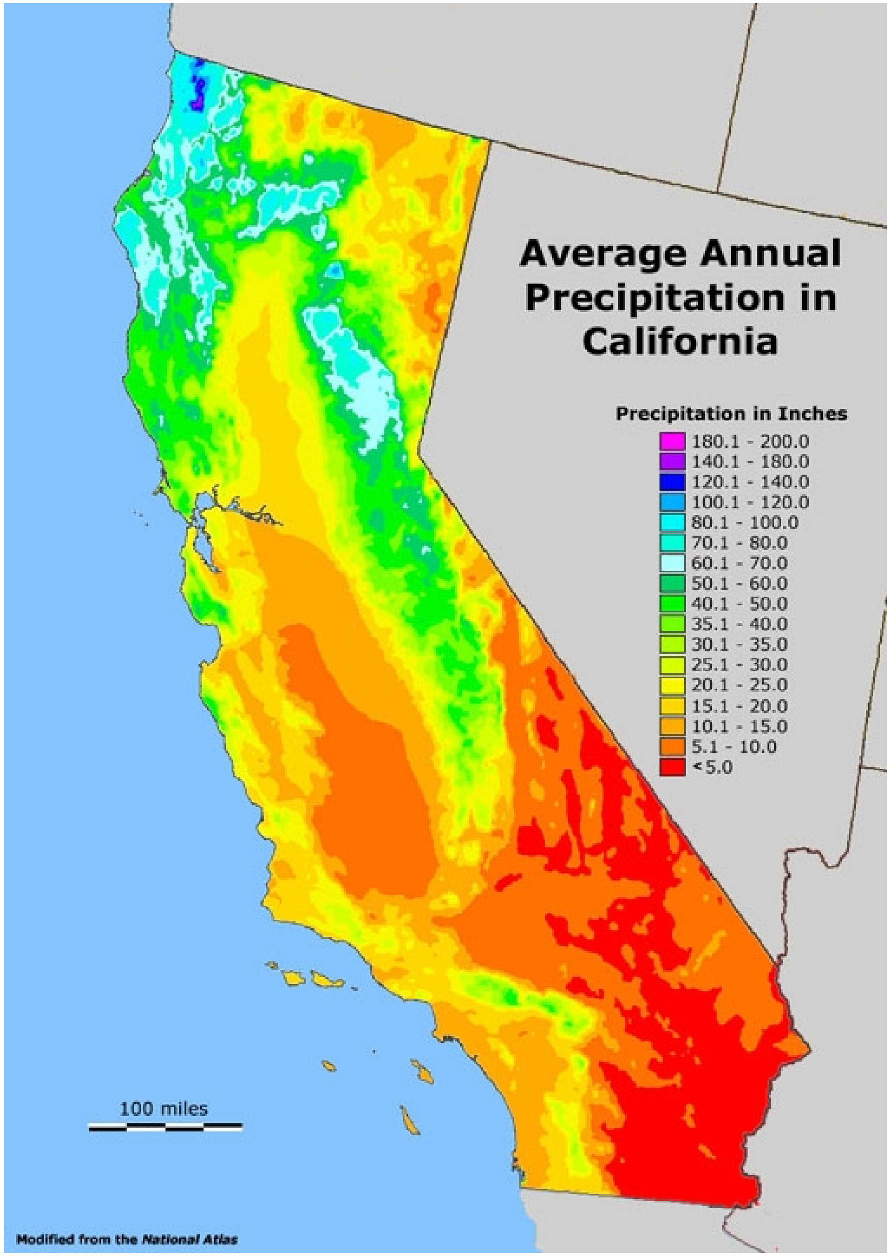


← +3

Computed from UW's VIC model daily INPUTS
Courtesy Mike Dettinger.

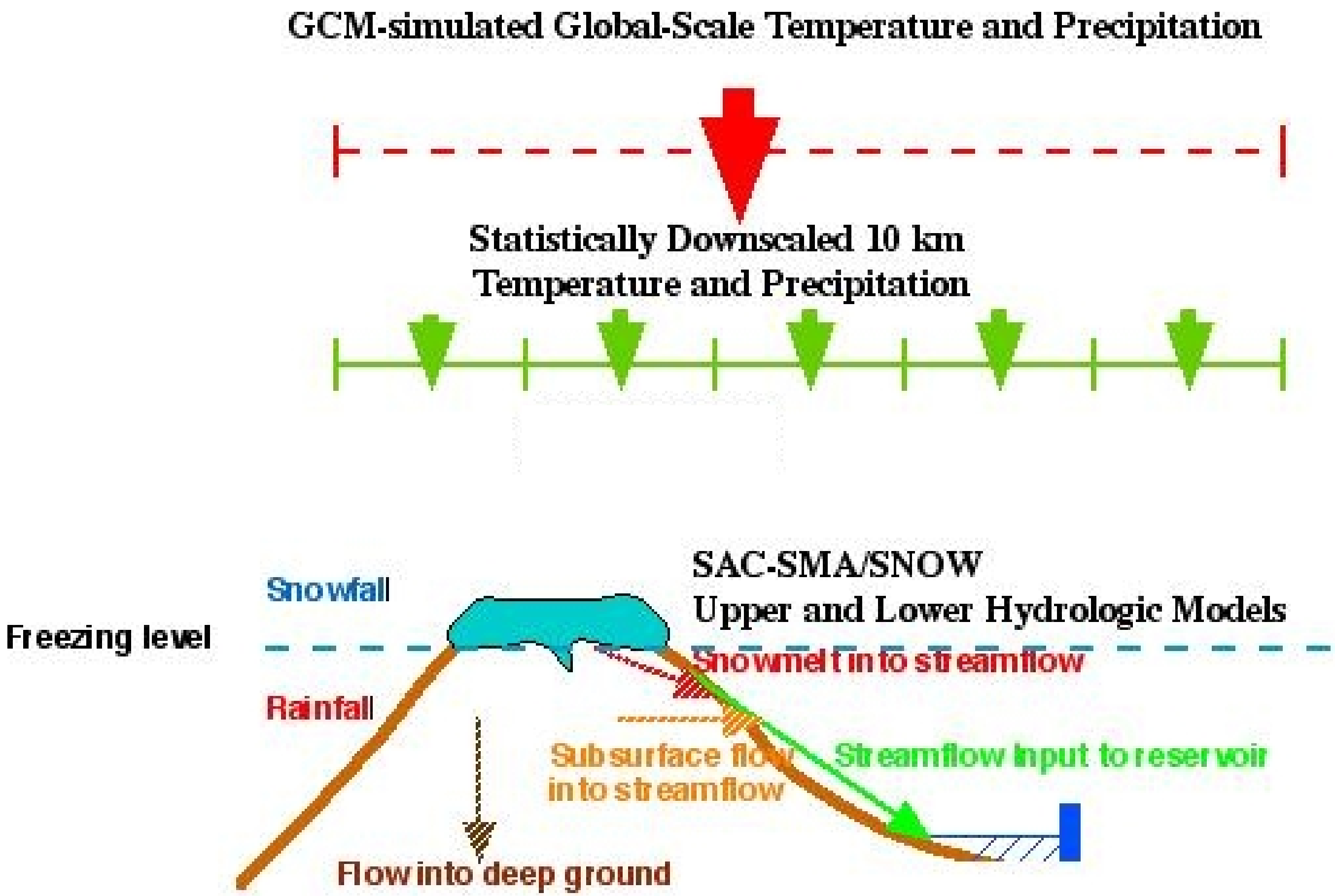
Groundwater recharge—precipitation/elevation relationship





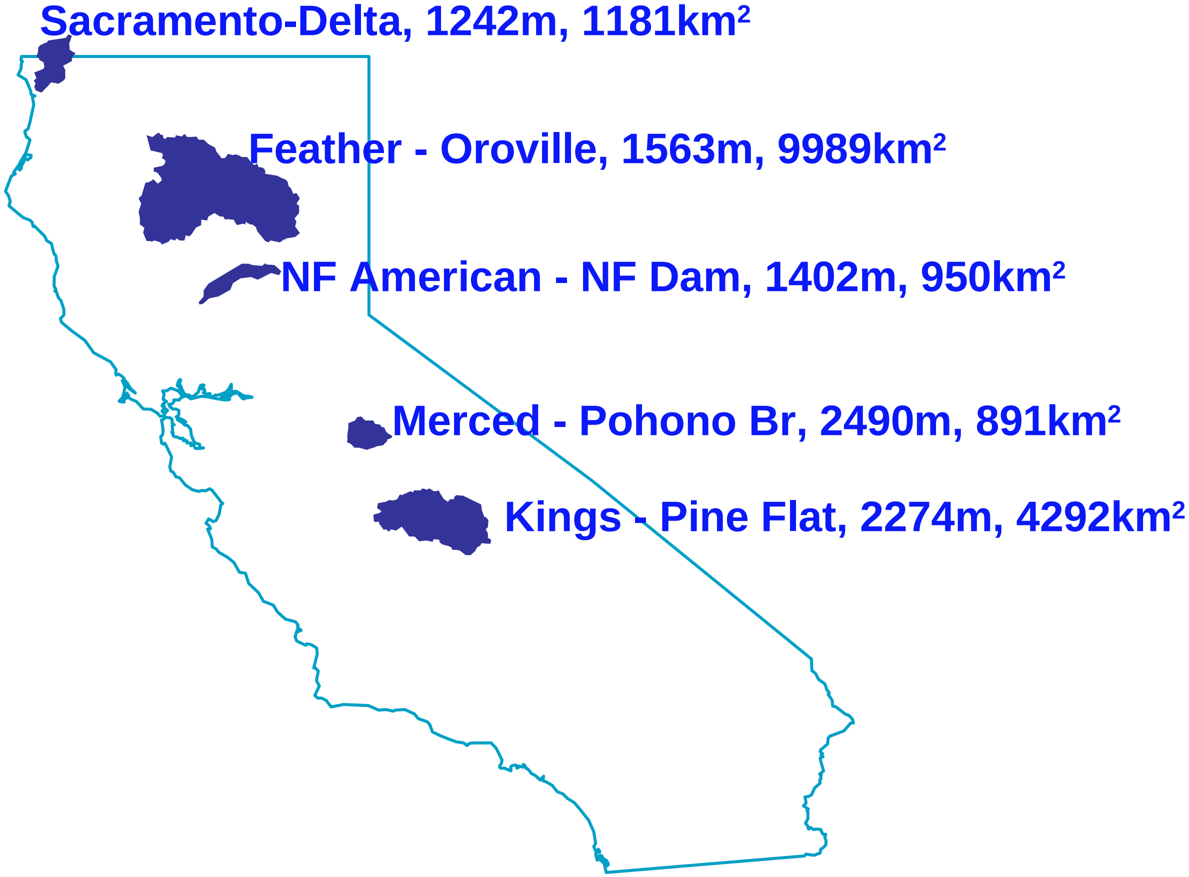
Images from: http://education.usgs.gov/california

Statistically Downscaled Temperature and Precipitation

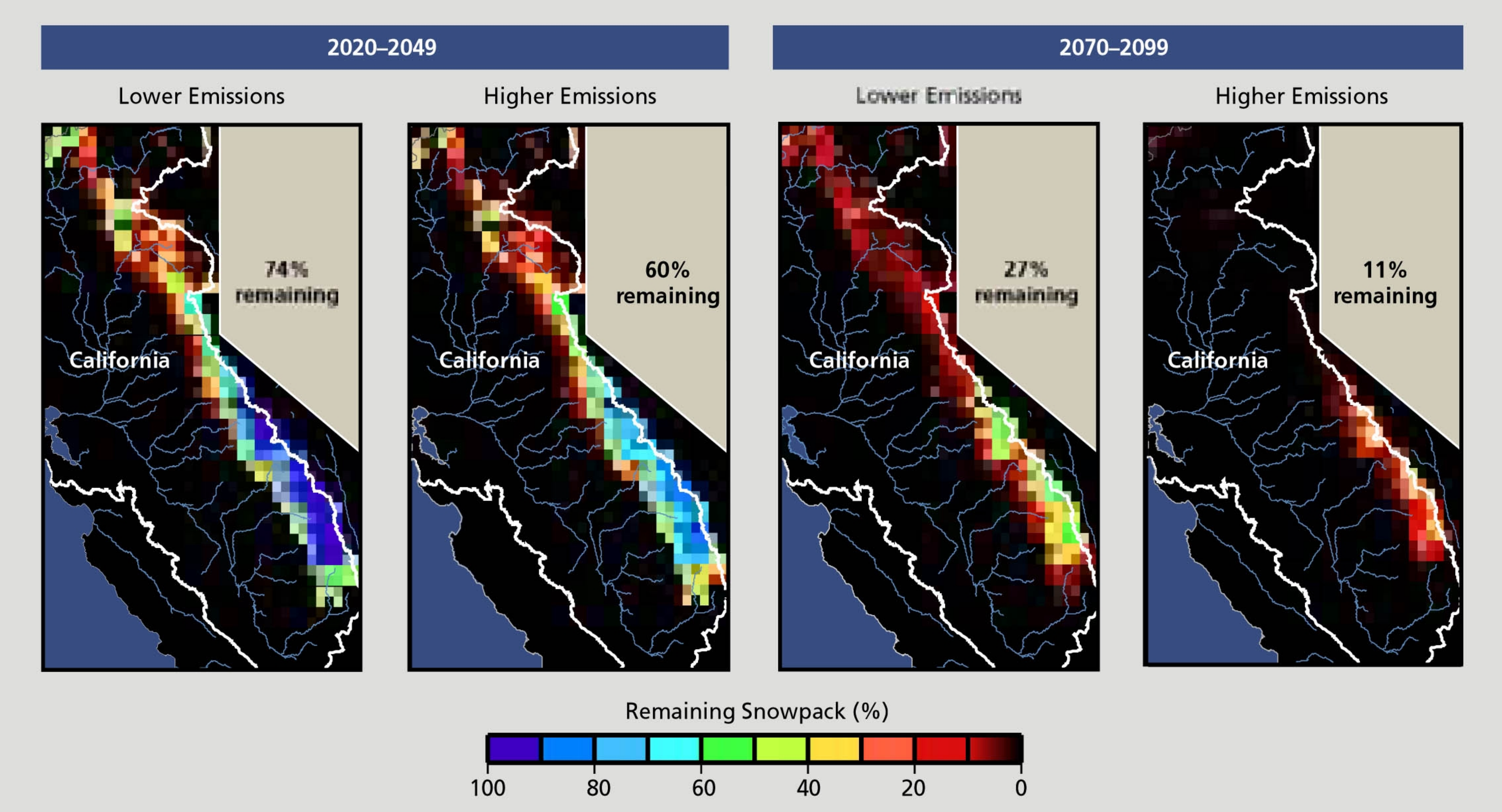


Analysis of the Hydrologic Response

- Miller et al. 2003
- National Weather Service – River Forecast System Sacramento Soil Moisture Accounting Model (Burnash 1973)
- Anderson Snow Model for computing snow accumulation and ablation (Anderson 1973)



Diminishing Sierra Snowpack
% Remaining, Relative to 1961-1990



Miller et al. 2003

Drought Experiments

- Approach:
  - Recreate drought scenarios considering historic data

- Managed Surface Water Drought Scenarios
  - 10 year spin-up;
  - Duration: 10, 20, 30, 60 year managed droughts
  - Intensity: Dry, Very Dry, Critical defined as 30, 50, 70 % effective reduction
  - 30 year rebound period

  - All simulations used fixed 1973-2003 precipitation, urban demands, cropping etc.

Analysis of Snowpack Reduction Impacts on California Groundwater Water Infrastructure Using DWR C2VSIM Model

C2VSIM - California Central Valley Simulation Model

Domain: ~ 20,000 square miles

Framework

Finite Element Grid

- 3 layers
- 1393 nodes
- 1392 elements

Surface Water System

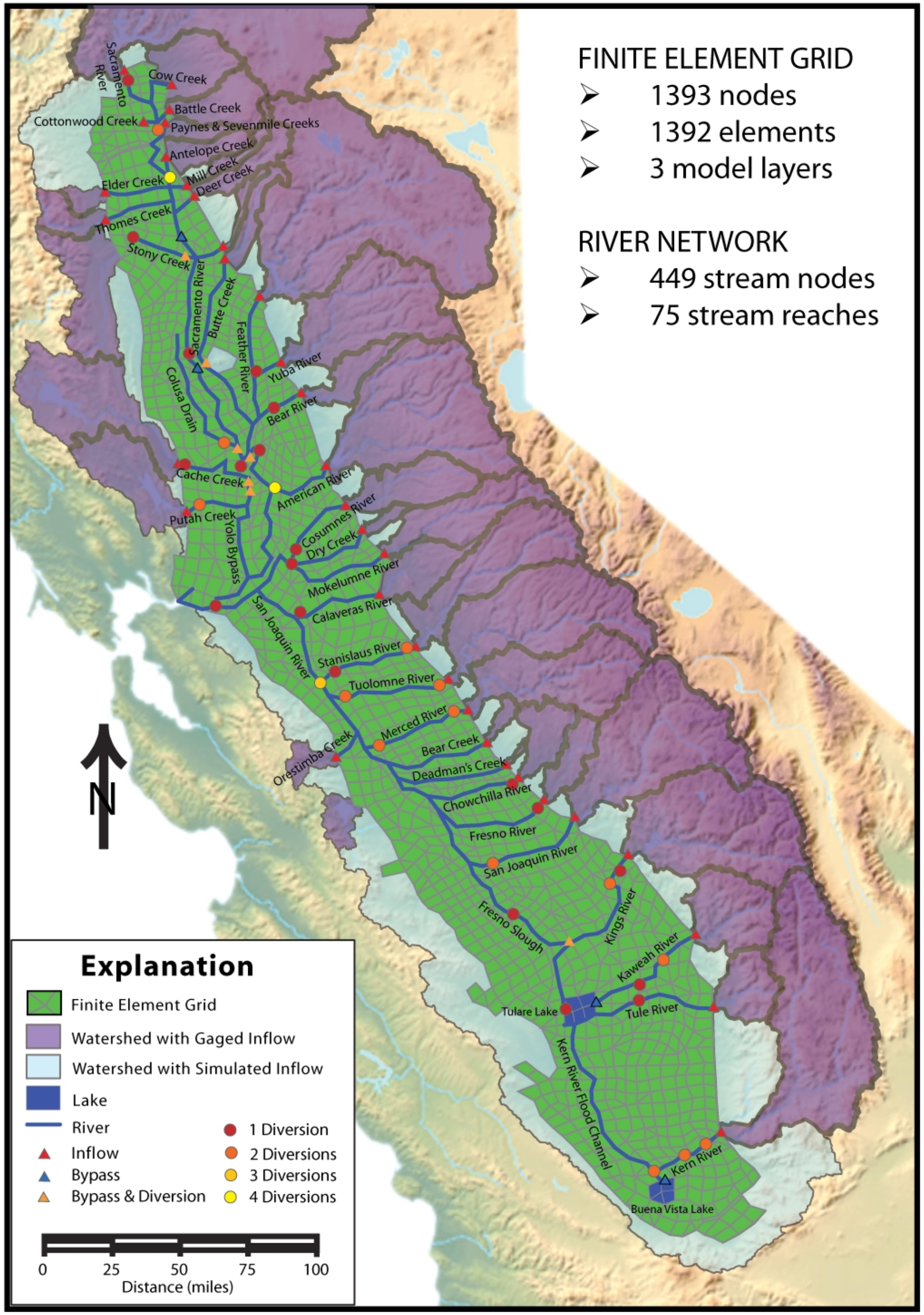
- 75 river reaches
- 2 lakes
- 97 surface water diversion points
- 6 bypasses

Land Use Process

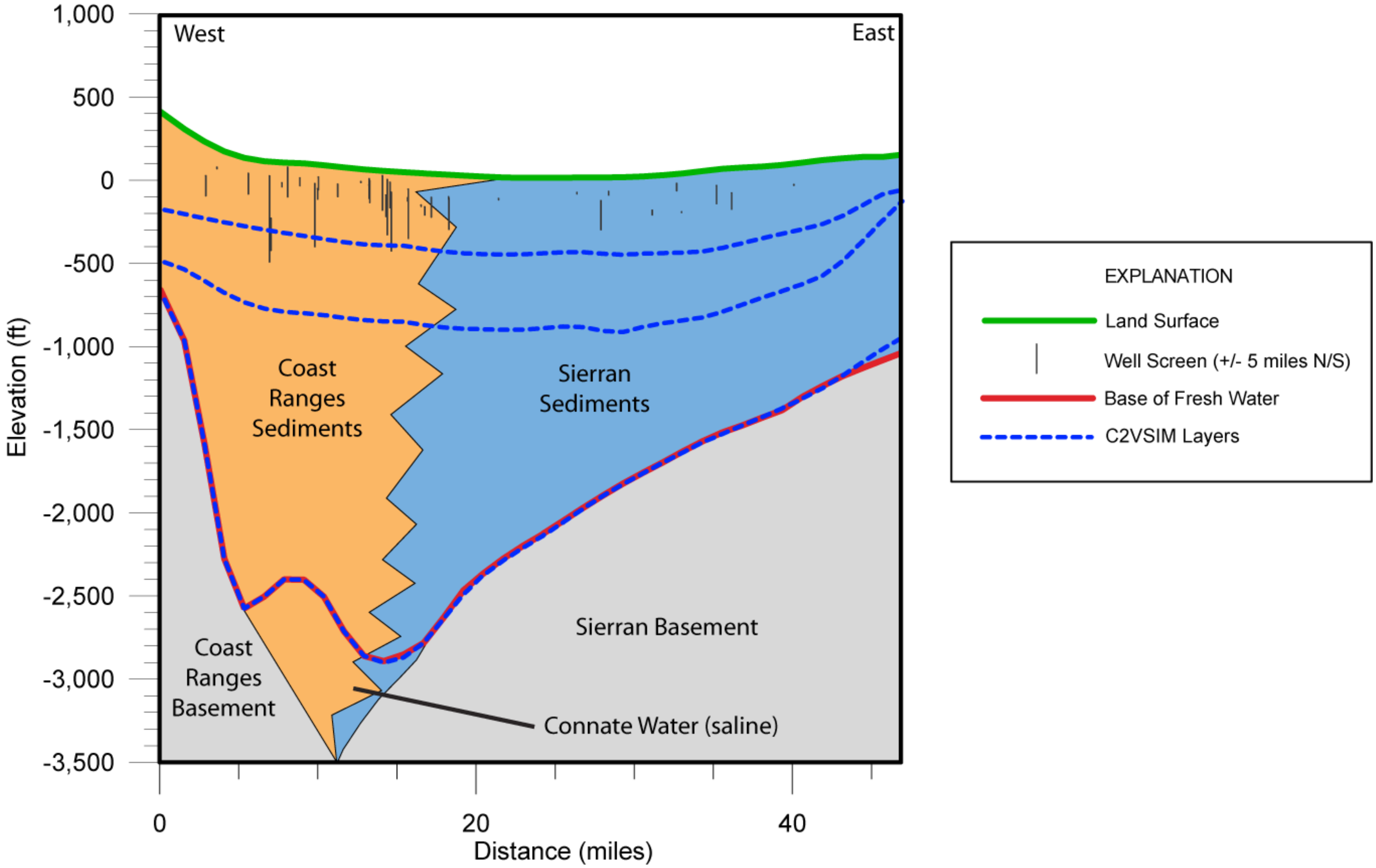
- 21 subregions
- 4 Land Use Types
  - Agriculture
  - Urban
  - Native
  - Riparian

Simulation periods

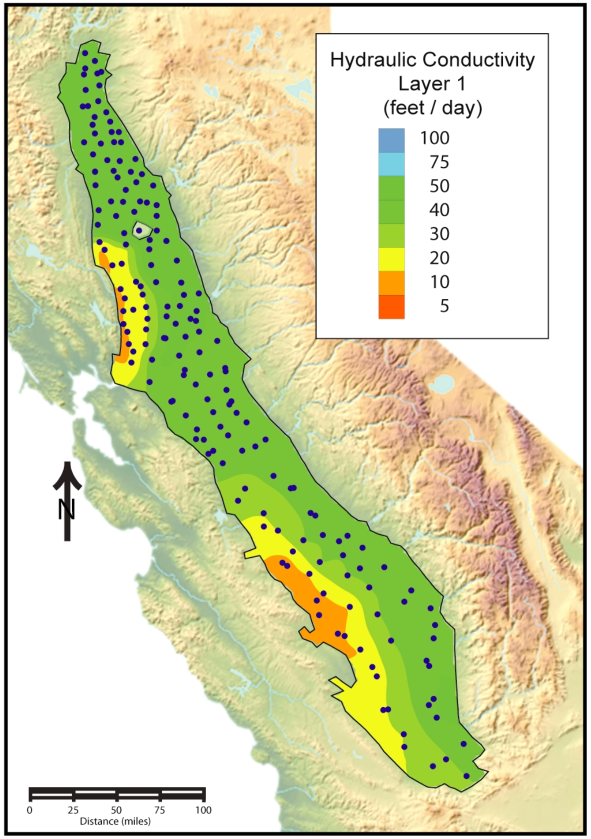
- 10/1921-9/2003 (<8 min)
- 10/1972-9/2003 (<4 min)

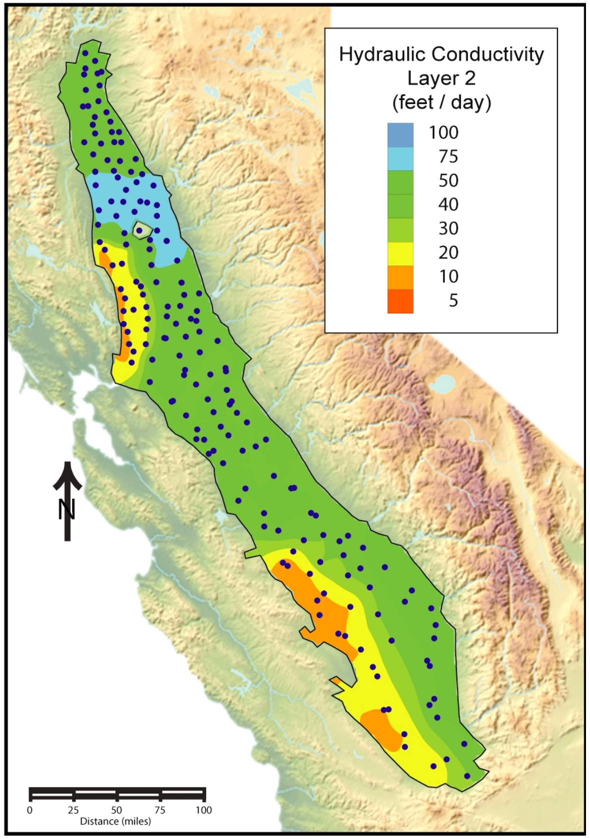


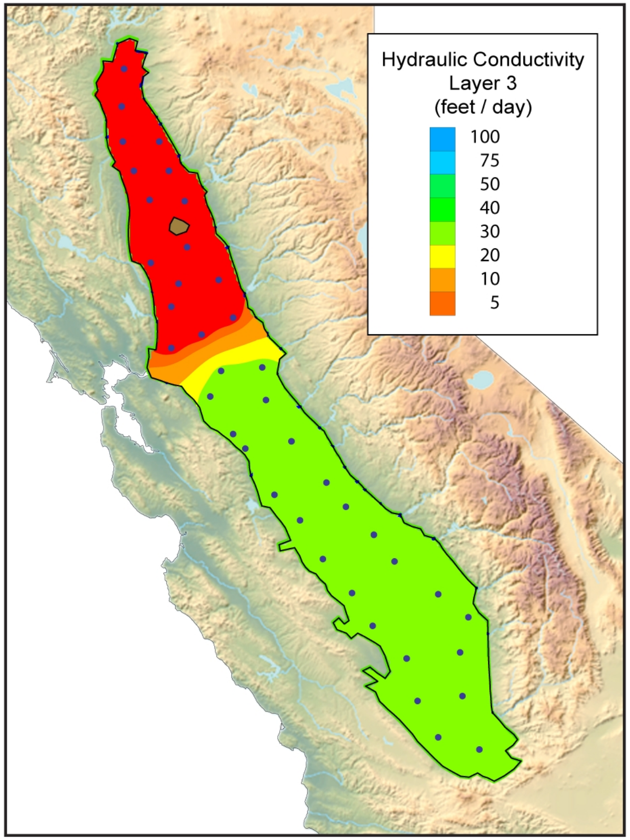
Generalized Cross Section Near Woodland, California



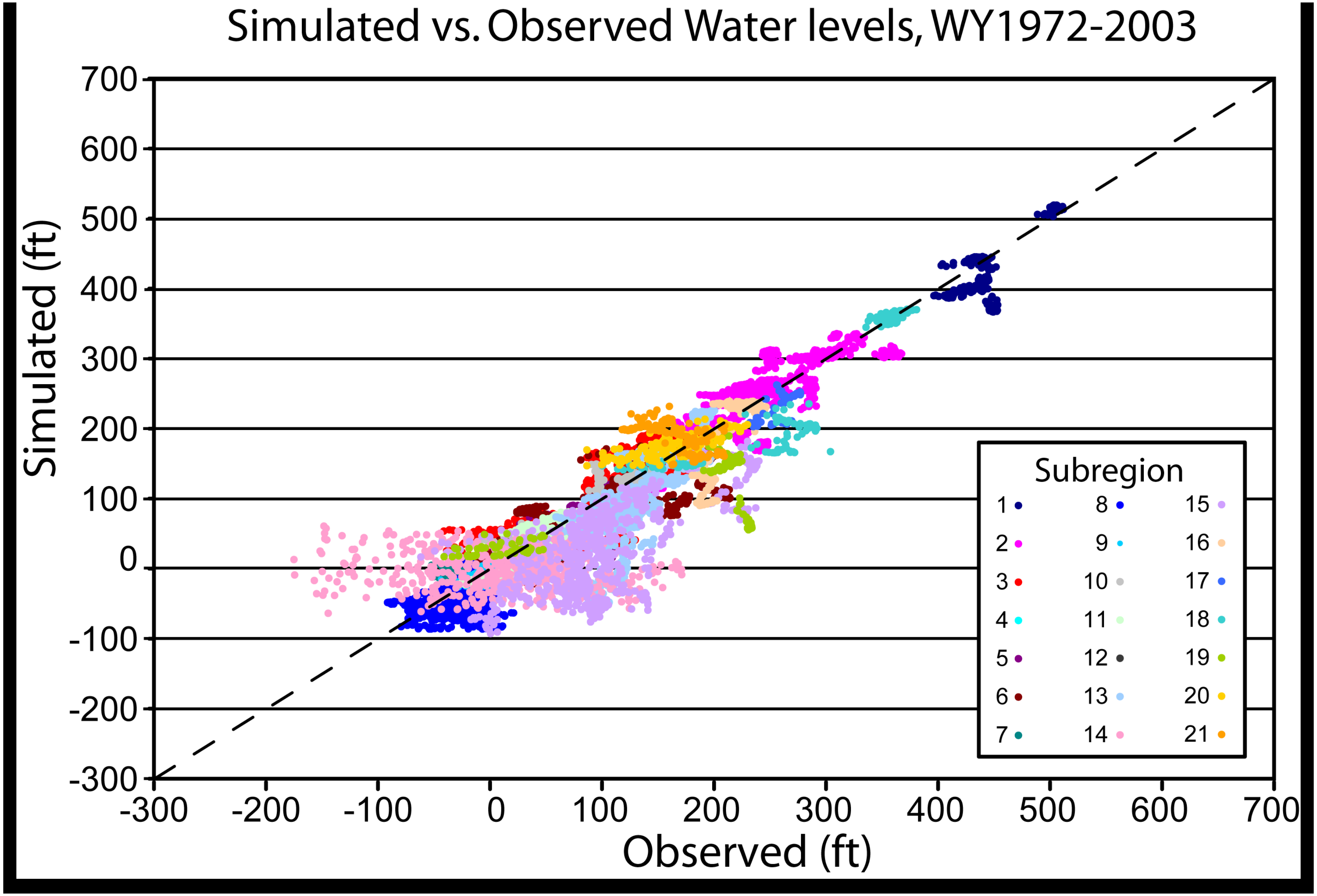
Hydraulic Conductivity



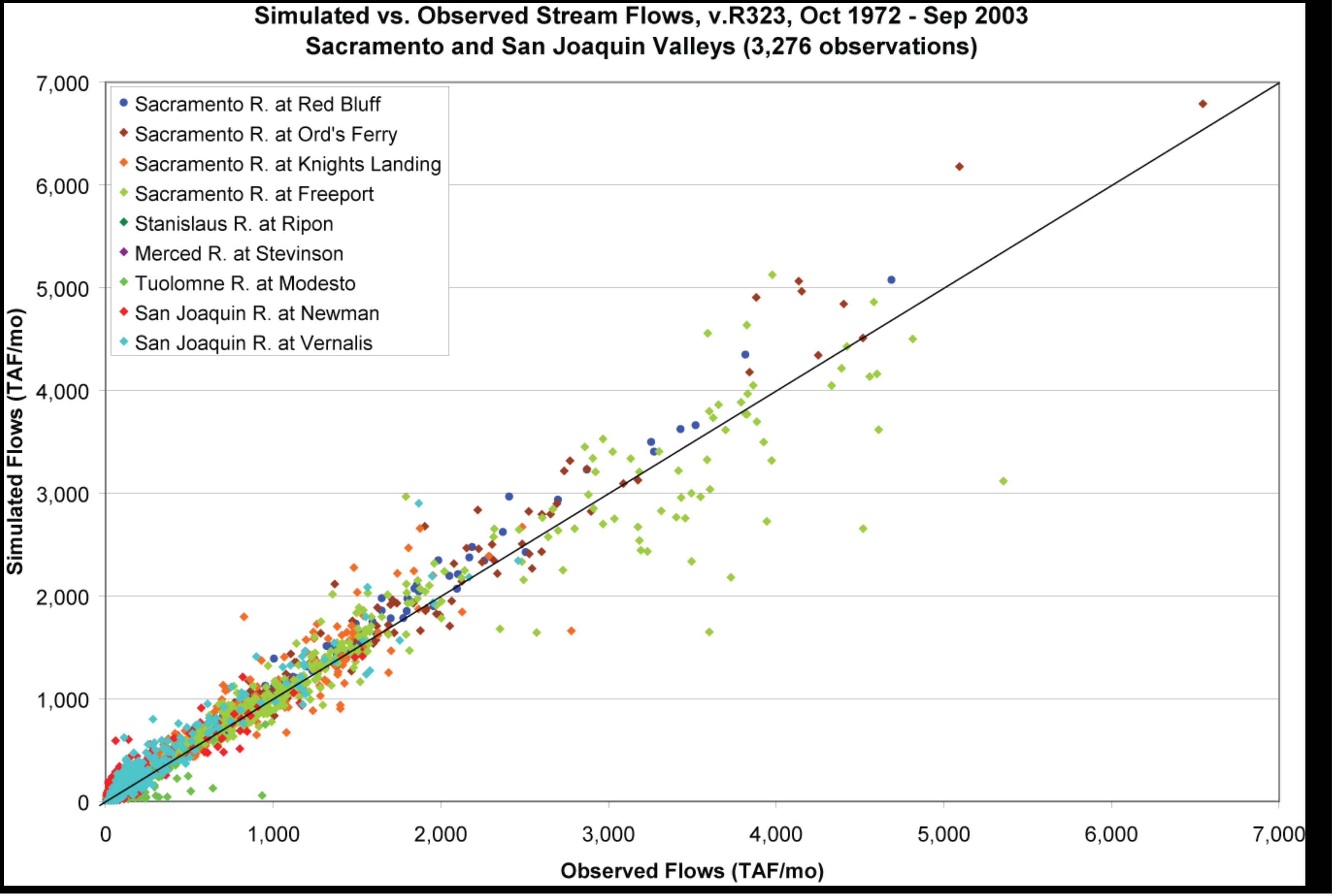




C2VSIM Performance – Heads
R305 – Initial Calibration



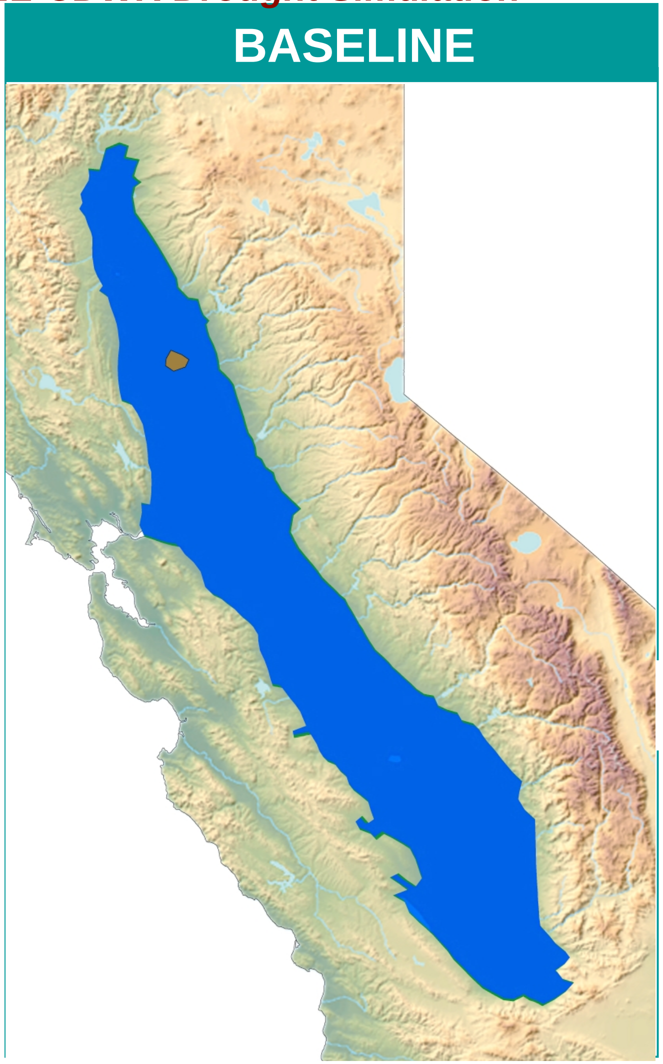
Simulated vs. Observed Water levels, WY1972-2003


Simulated vs. Observed Stream Flows, v.R323, Oct 1972 - Sep 2003
Sacramento and San Joaquin Valleys (3,276 observations)
● Sacramento R. at Red Bluff
◆ Sacramento R. at Ord's Ferry
◆ Sacramento R. at Knights Landing
◆ Sacramento R. at Freeport
◆ Stanislaus R. at Ripon
◆ Merced R. at Stevinson
◆ Tuolomne R. at Modesto
◆ San Joaquin R. at Newman
◆ San Joaquin R. at Vernalis
Simulated Flows (TAF/mo)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Observed Flows (TAF/mo)

Central Valley Water Table ‘Relative’ Response

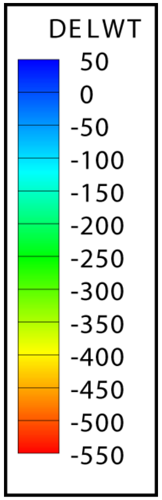
Joint LBNL-CDWR Drought Simulation

- ***Climate simulations using the IPCC SRES output indicates California Snowpack will be reduced by 60-90% by 2100.***
- ***Simulating drought scenarios acts as an analogue to climate warming and provides us with a means to analyze impacts.***



- **Baseline - no surface water reduction**
- **Drought - 30 - 70 percent surface water reduction**
- **All simulations used fixed 1973-2003 precipitation, urban demands, cropping etc.**

Relative WT Change (Feet)

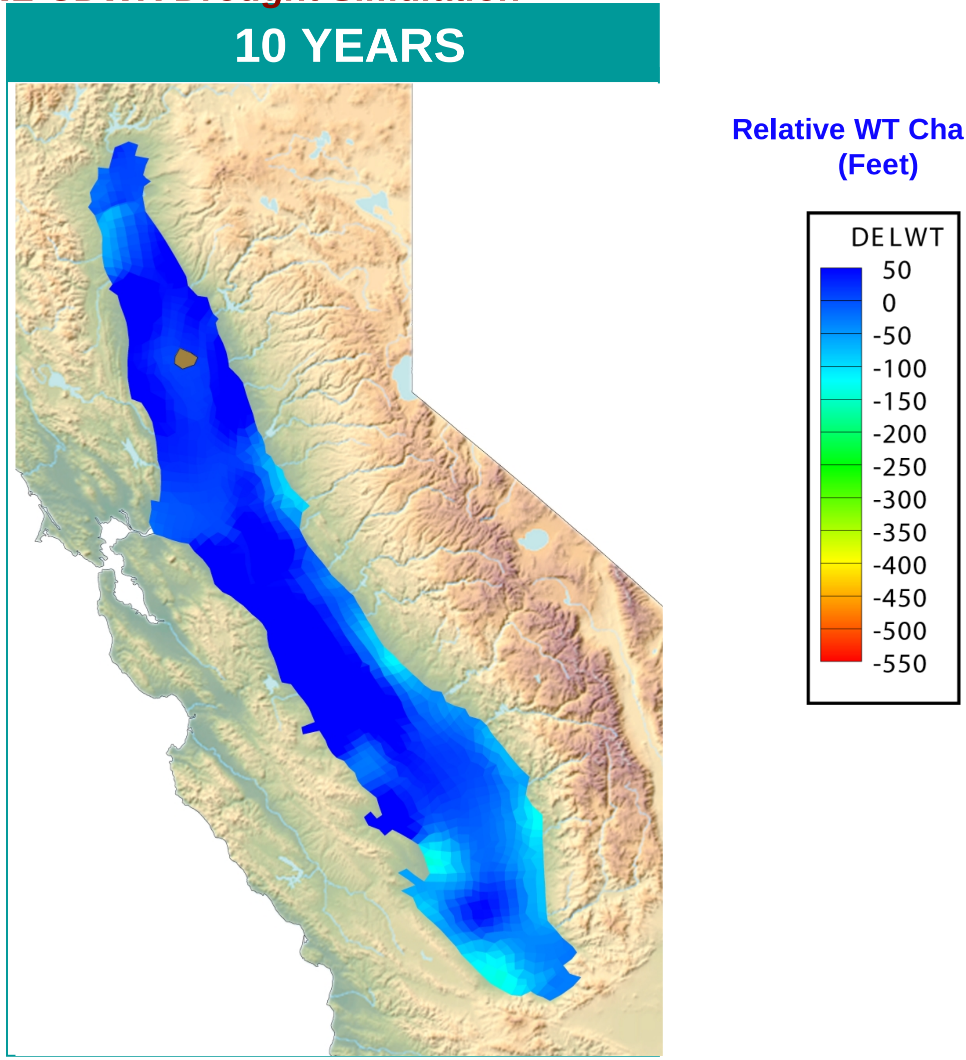


Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



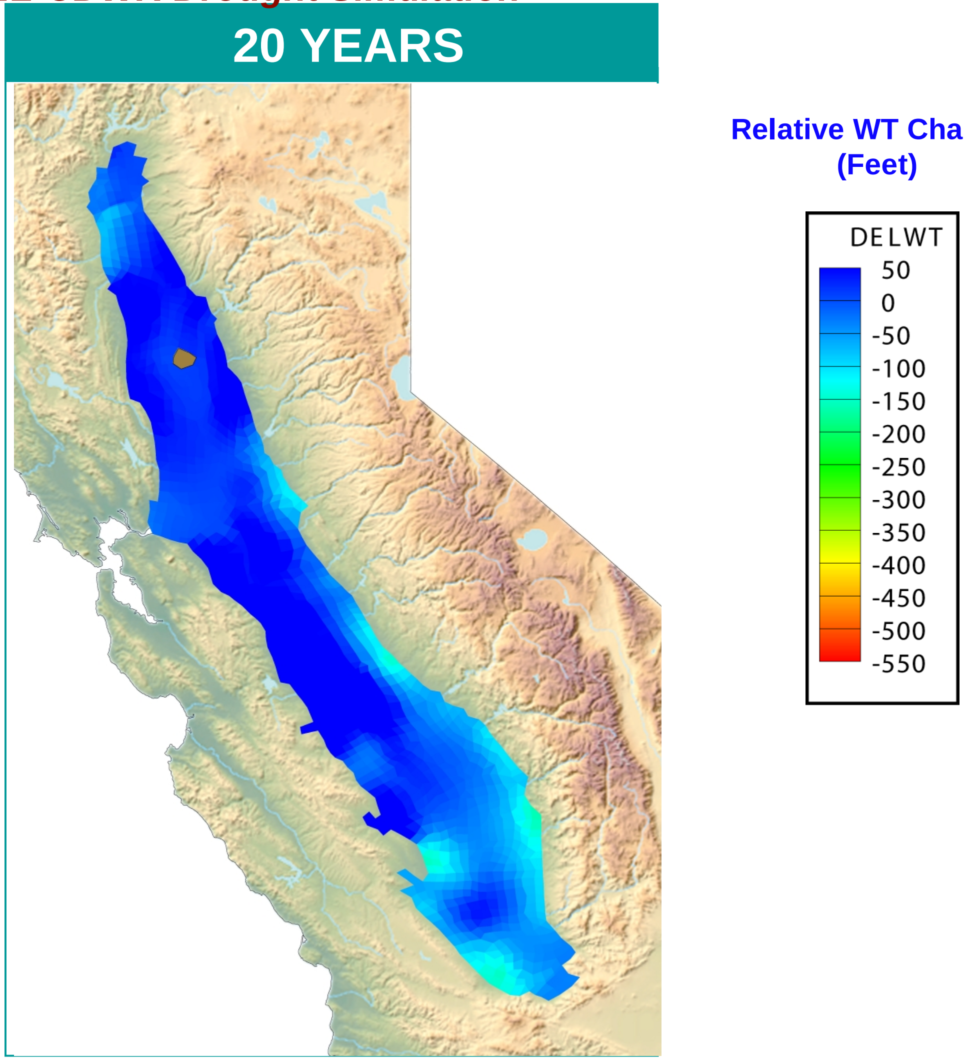
Miller et al. 2006

Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



20 YEARS

Relative WT Change (Feet)

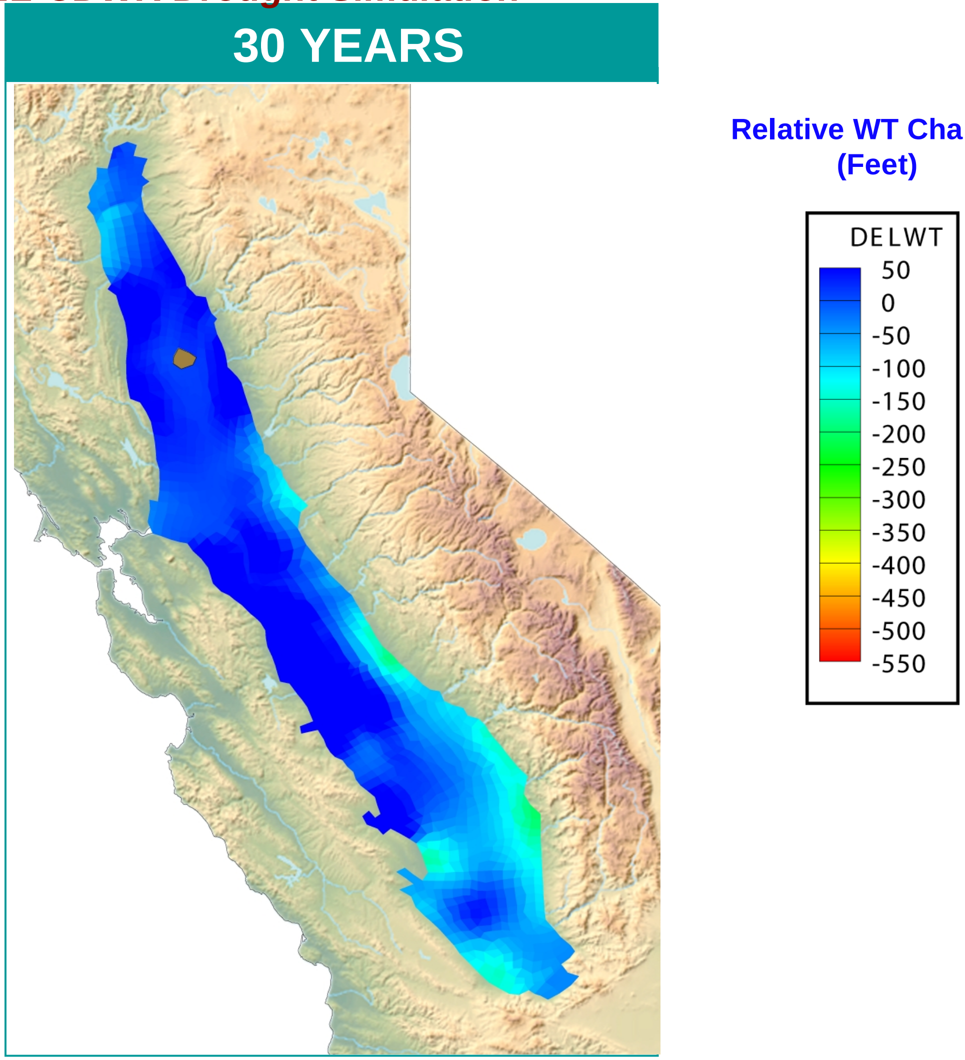
Miller et al. 2006

Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Relative WT Change (Feet)

Miller et al. 2006

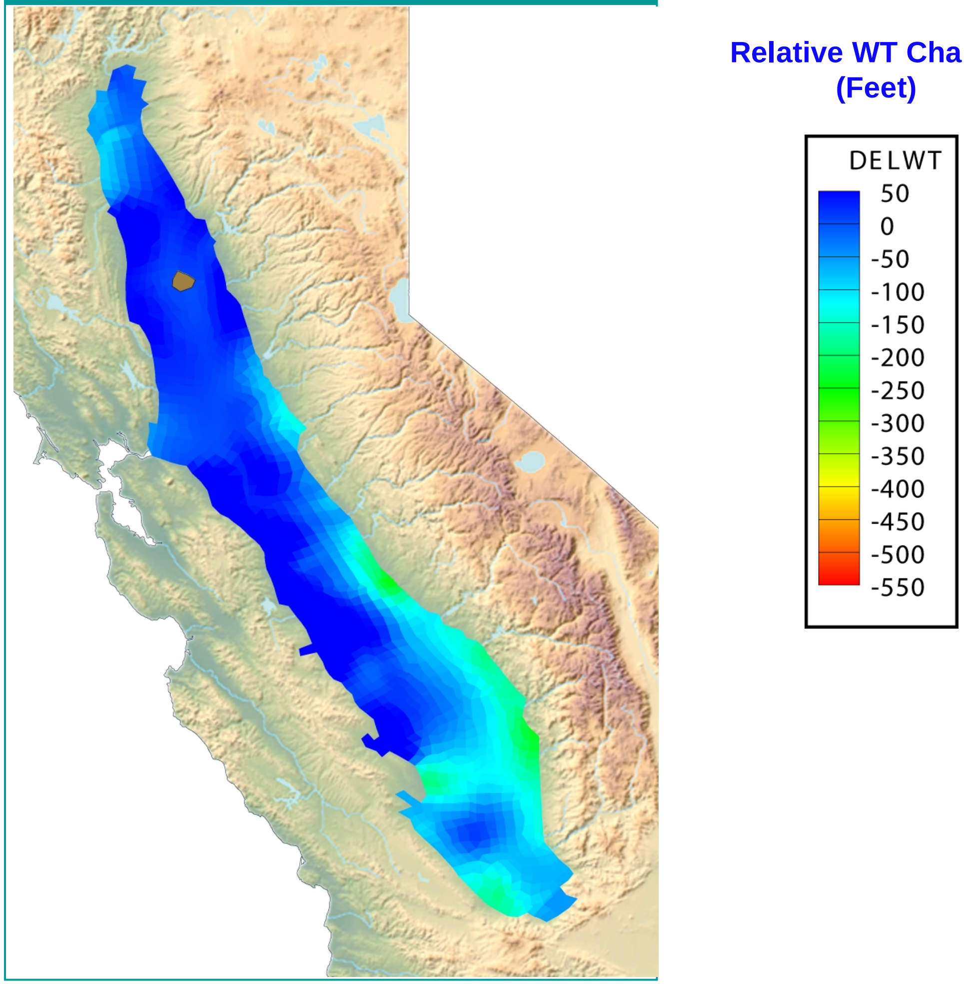
Case II: Initial Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

DRY

30 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

60 YEARS



Relative WT Change (Feet)

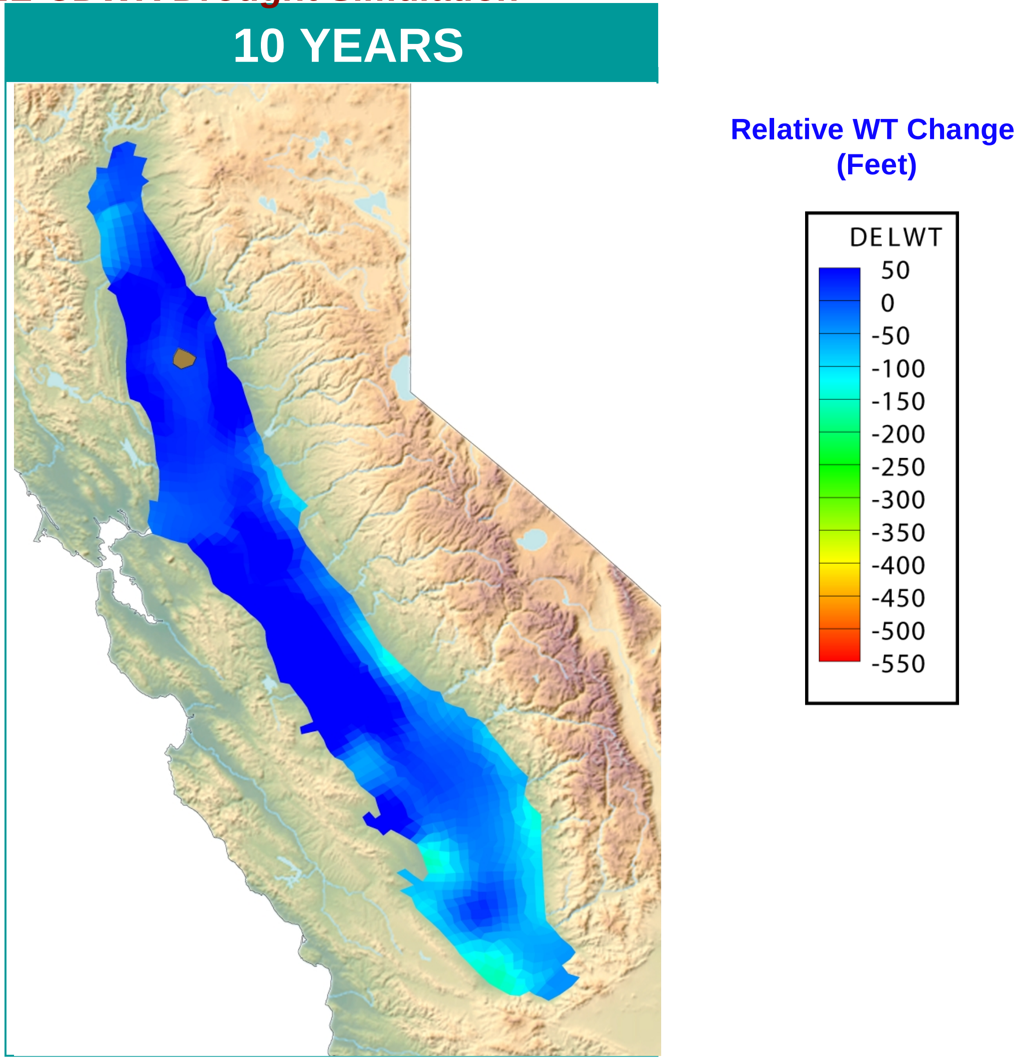
Miller et al. 2006

Central Valley Water Table 'Relative' Response

Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Miller et al. 2006

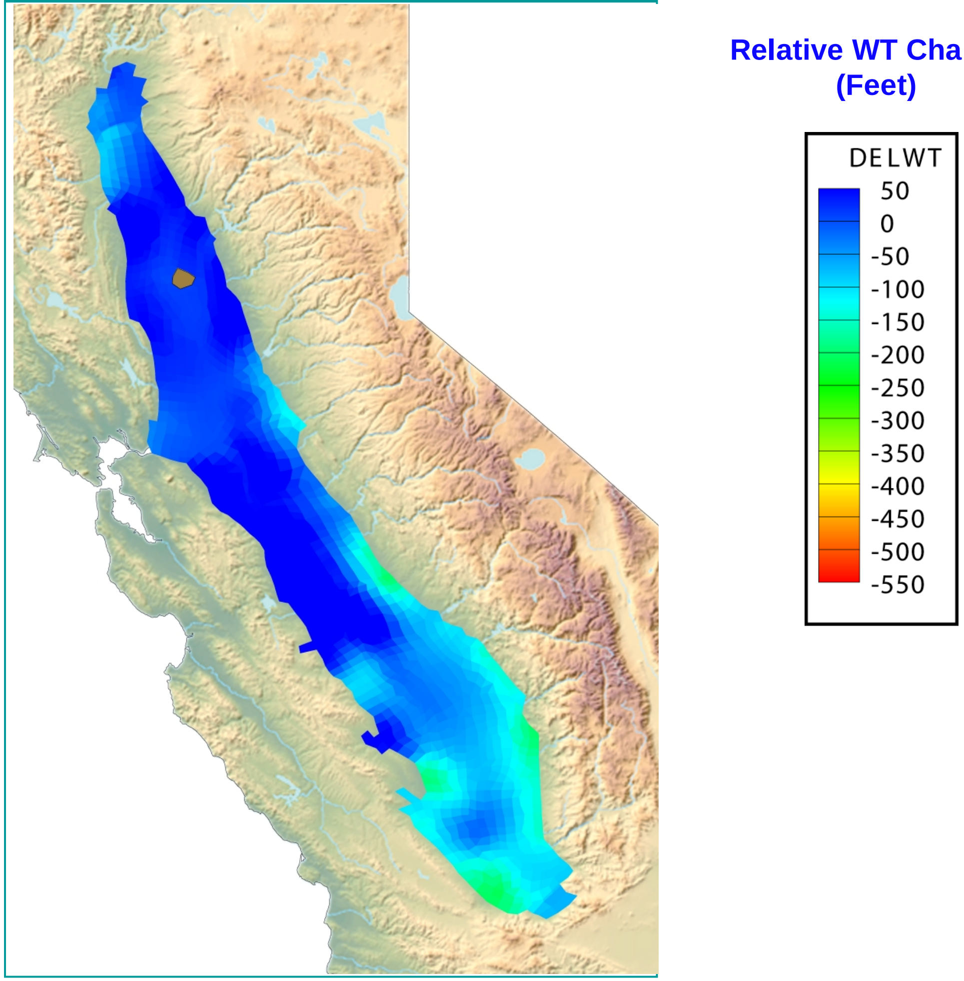
Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

20 YEARS



Miller et al. 2006

Central Valley Water Table ‘Relative’ Response

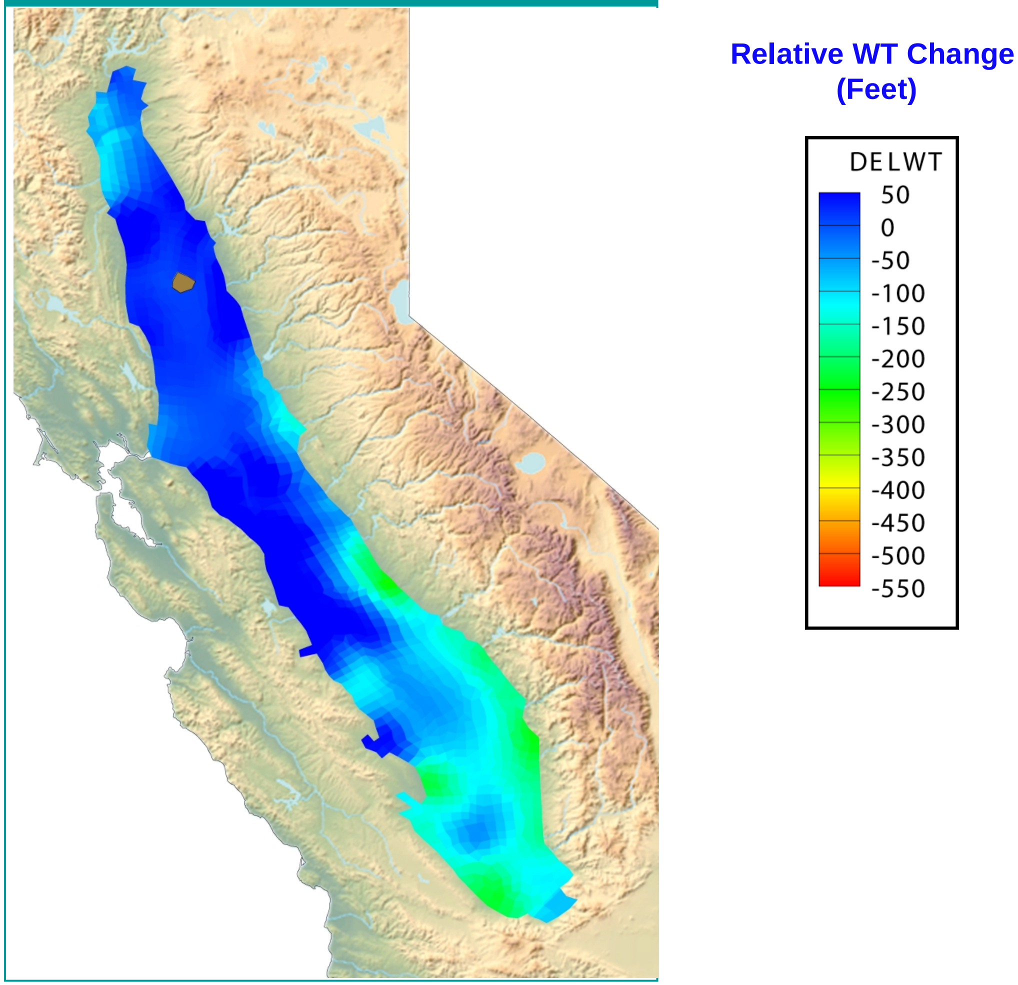
Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

30 YEARS

Relative WT Change (Feet)



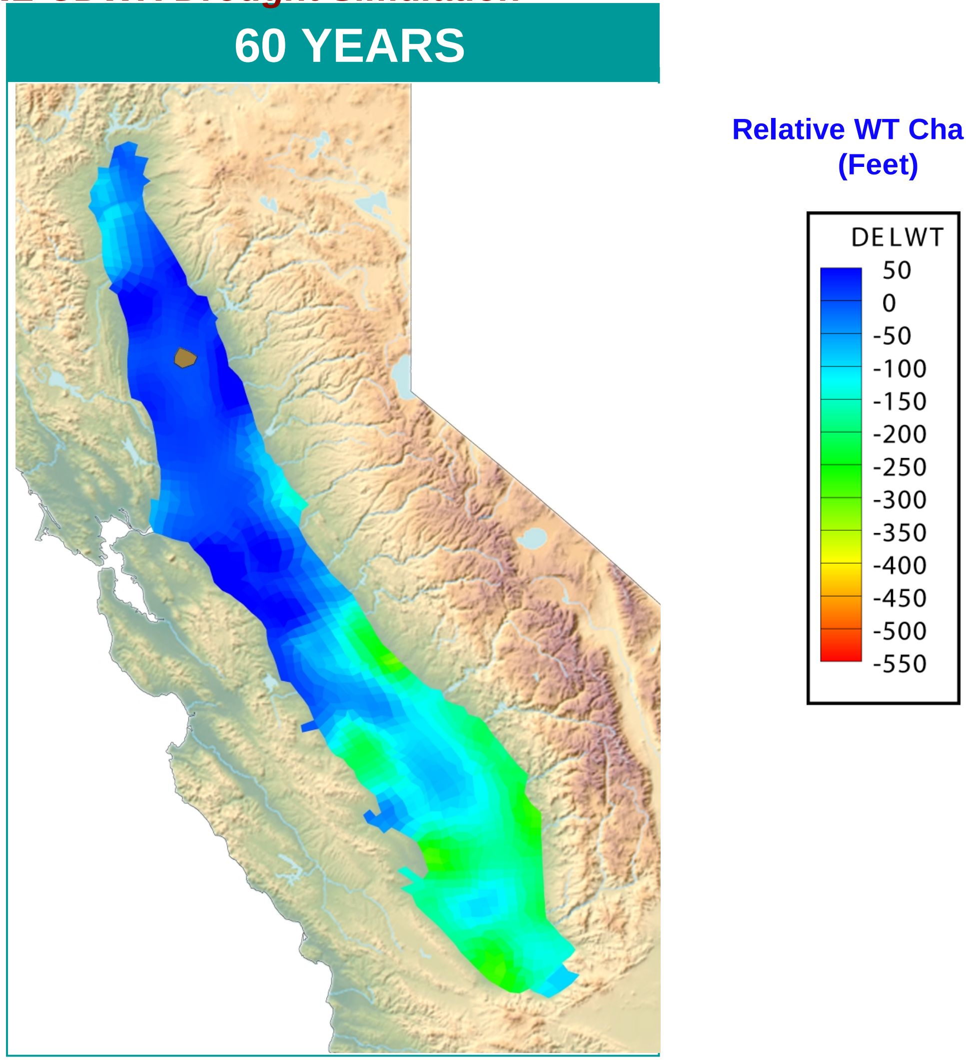
Miller et al. 2006

Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

VERY DRY

50 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



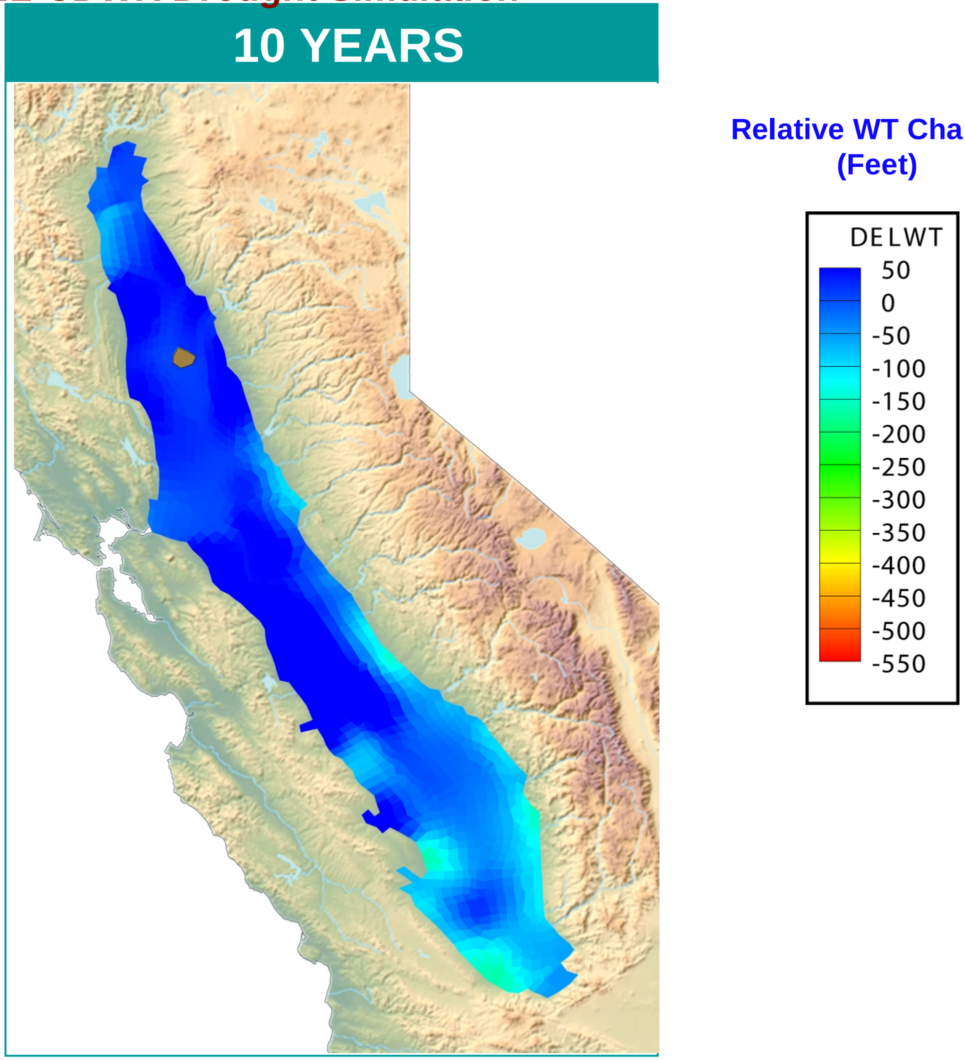
Miller et al. 2006

Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Miller et al. 2006

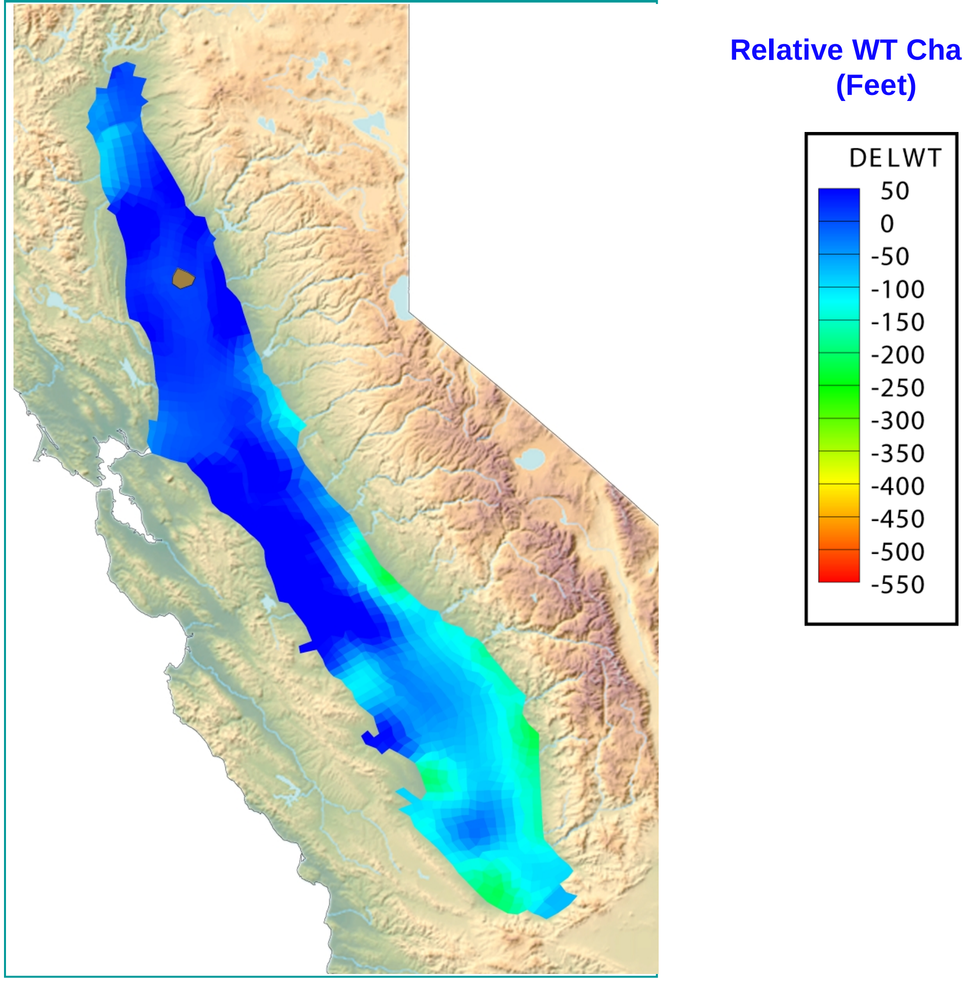
Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

20 YEARS

CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



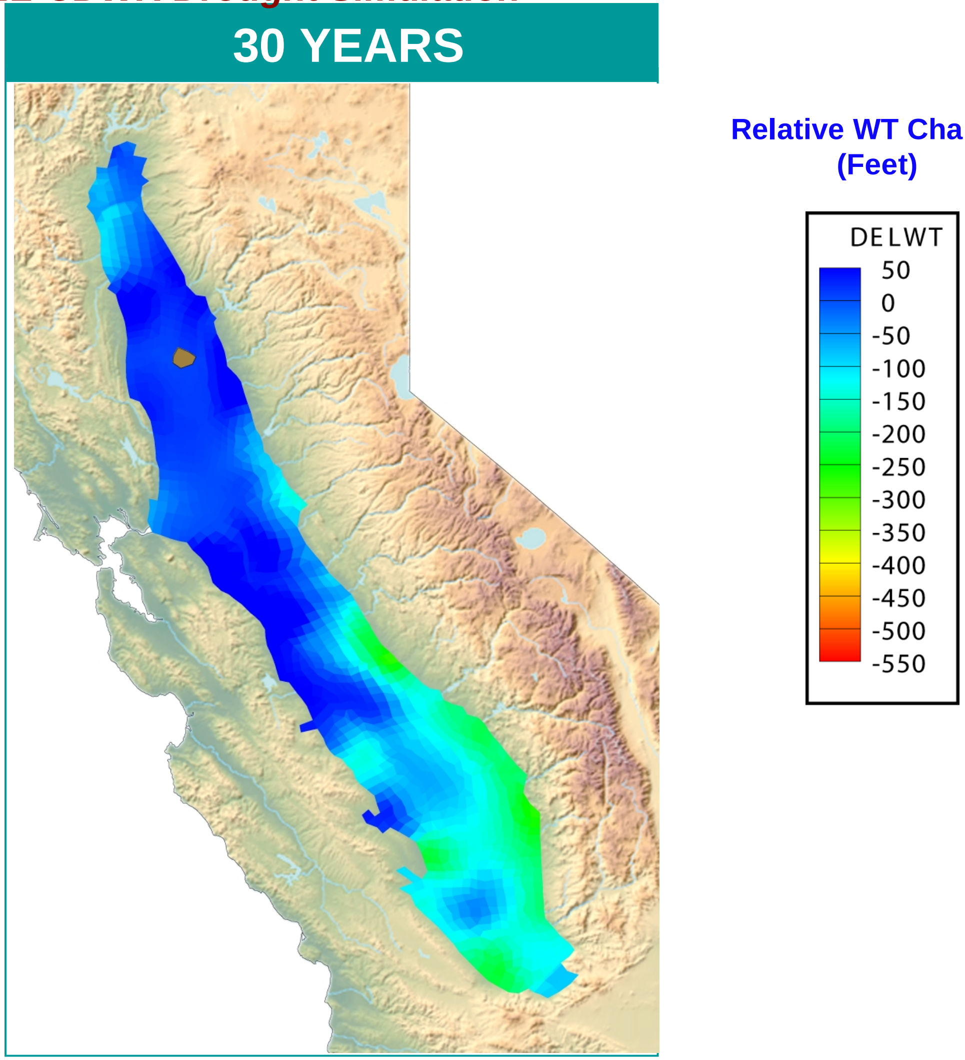
Miller et al. 2006

Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.



Miller et al. 2006

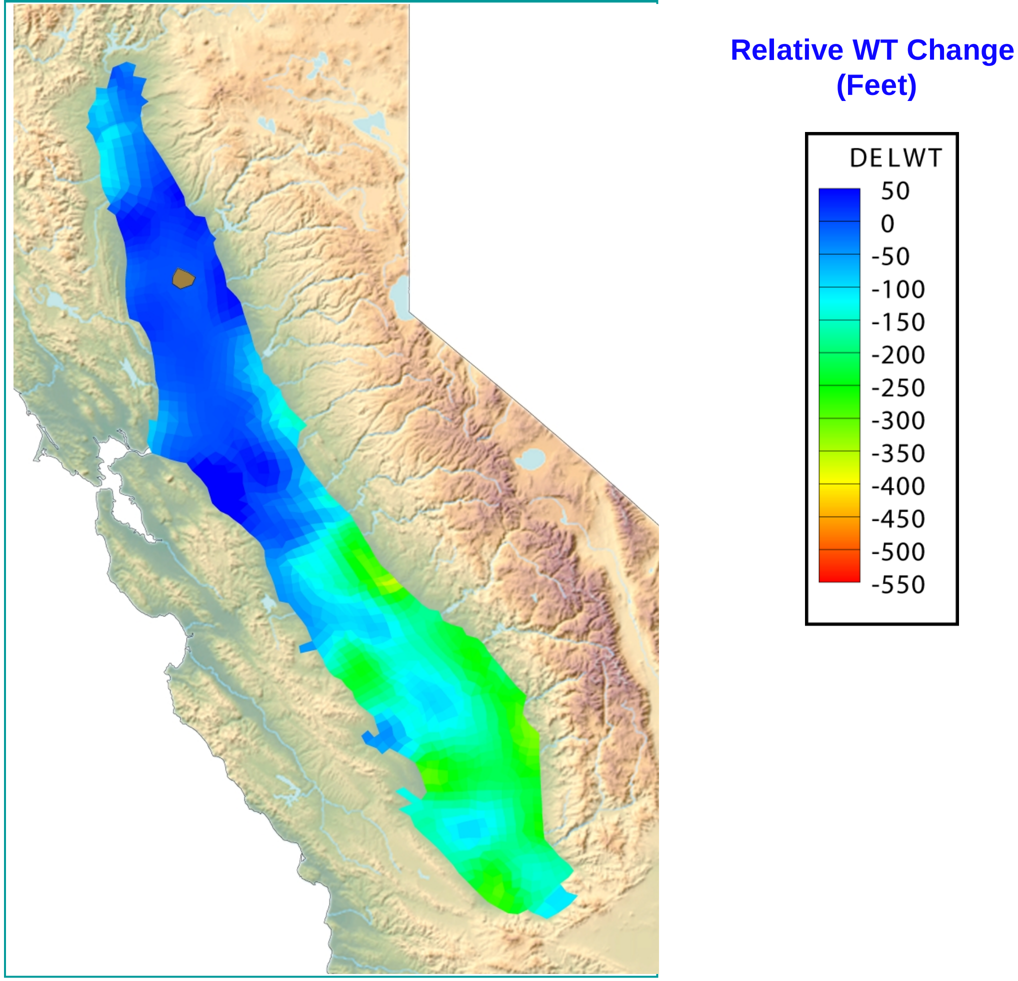
Central Valley Water Table ‘Relative’ Response

Joint LBNL-CDWR Drought Simulation

CRITICAL

70 PERCENT EFFECTIVE REDUCTION IN MANAGED SURFACE FLOW.

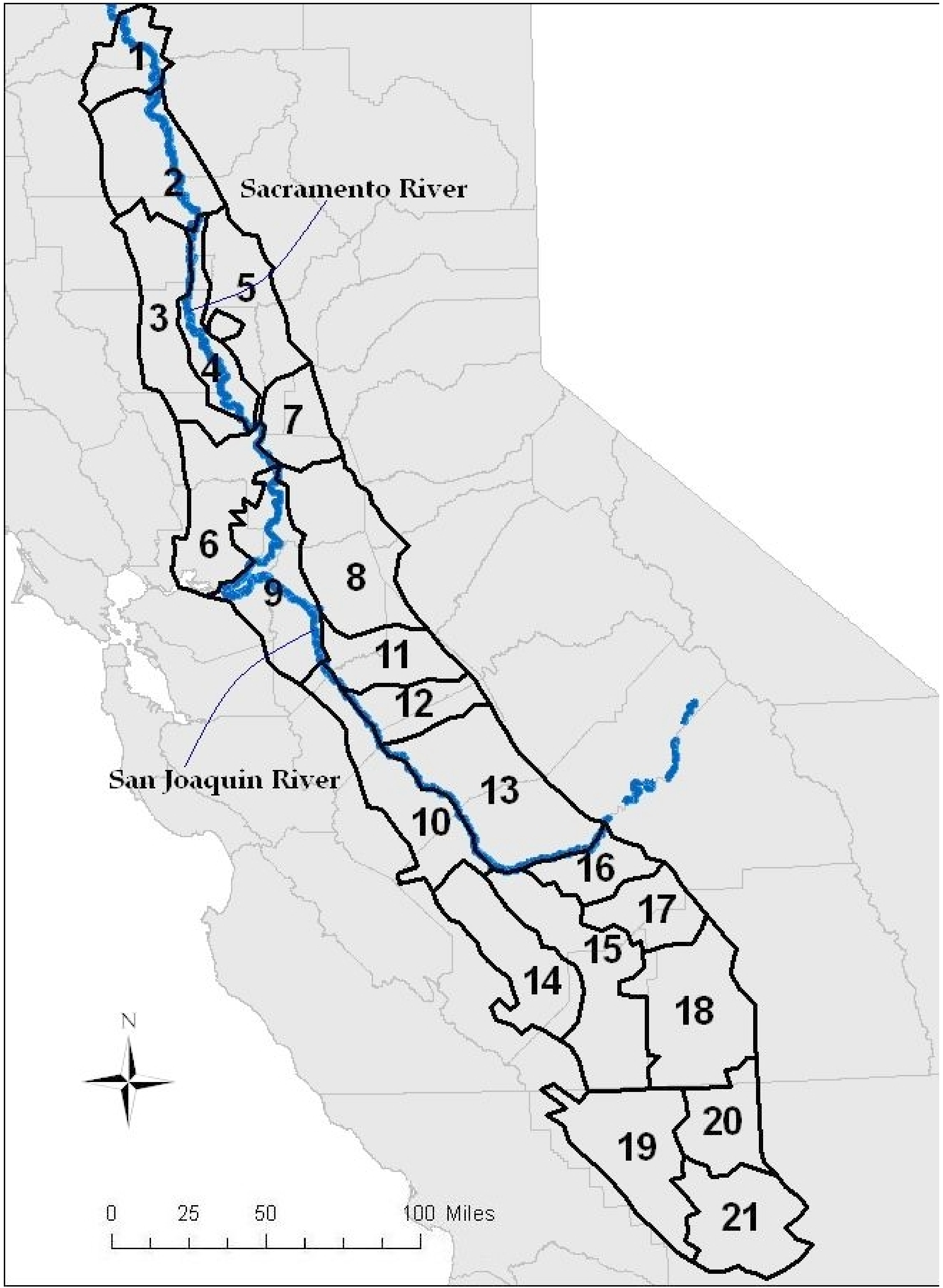
60 YEARS

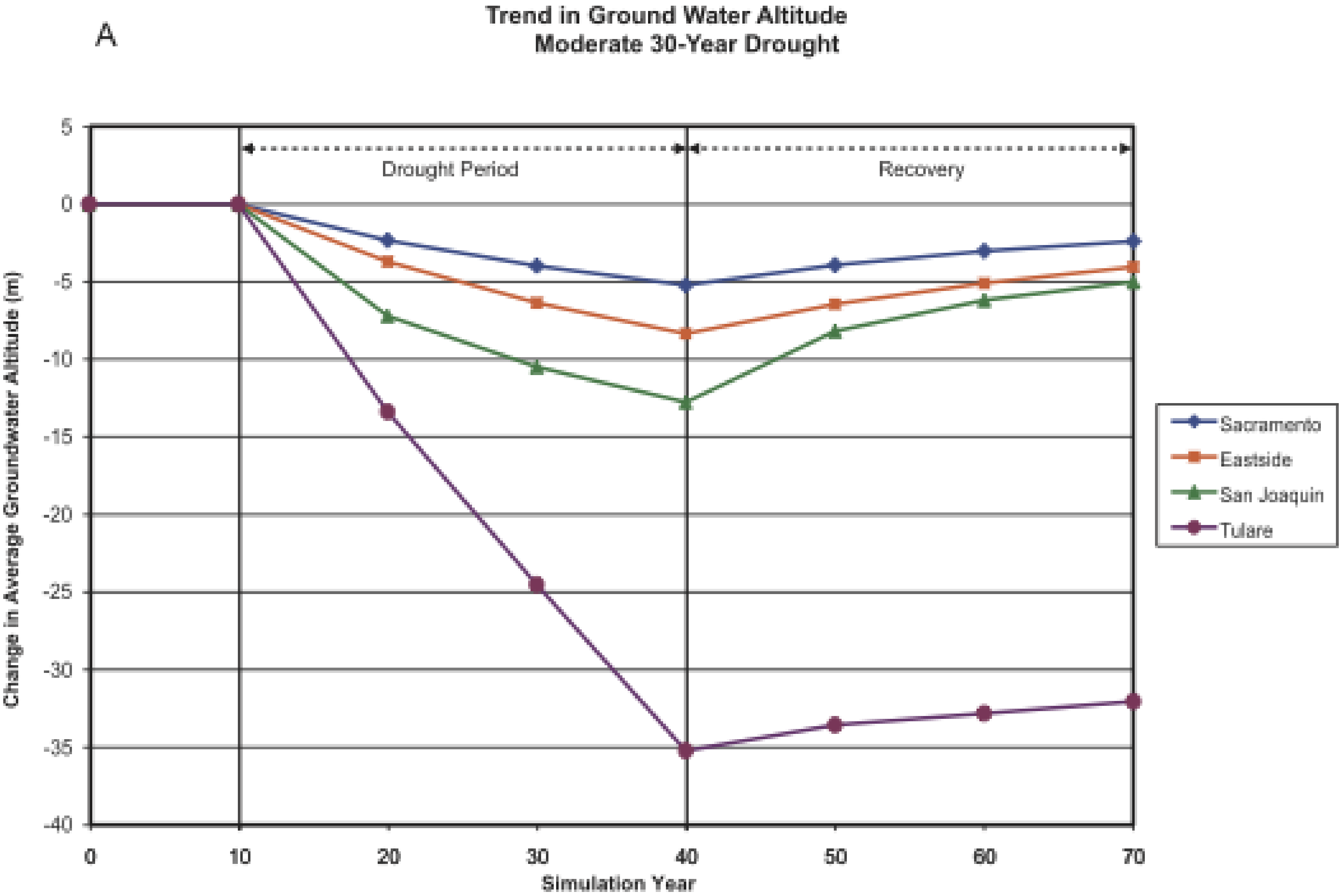


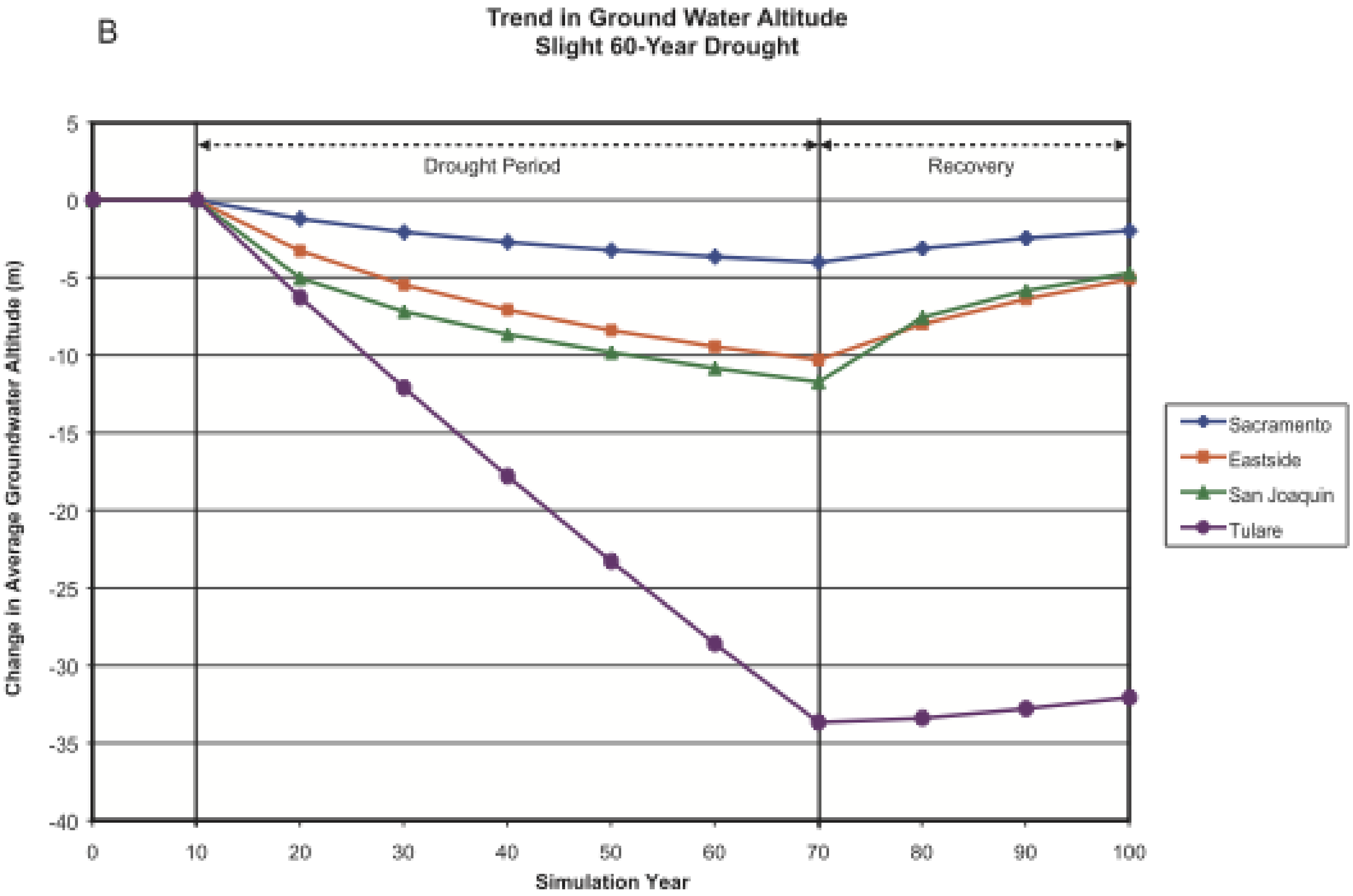
Relative WT Change (Feet)

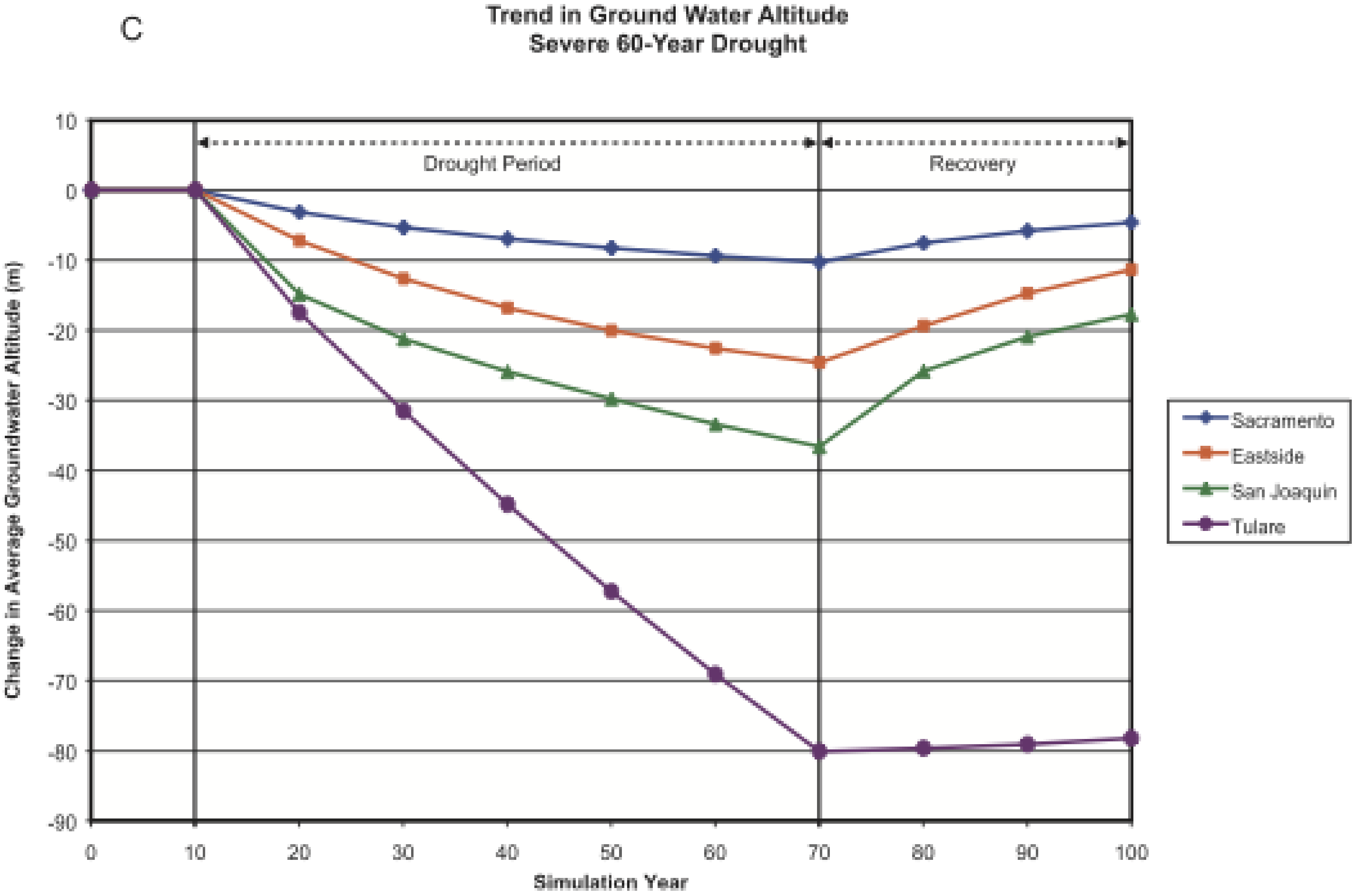
Miller et al. 2006

C2VSIM Sub-Regions



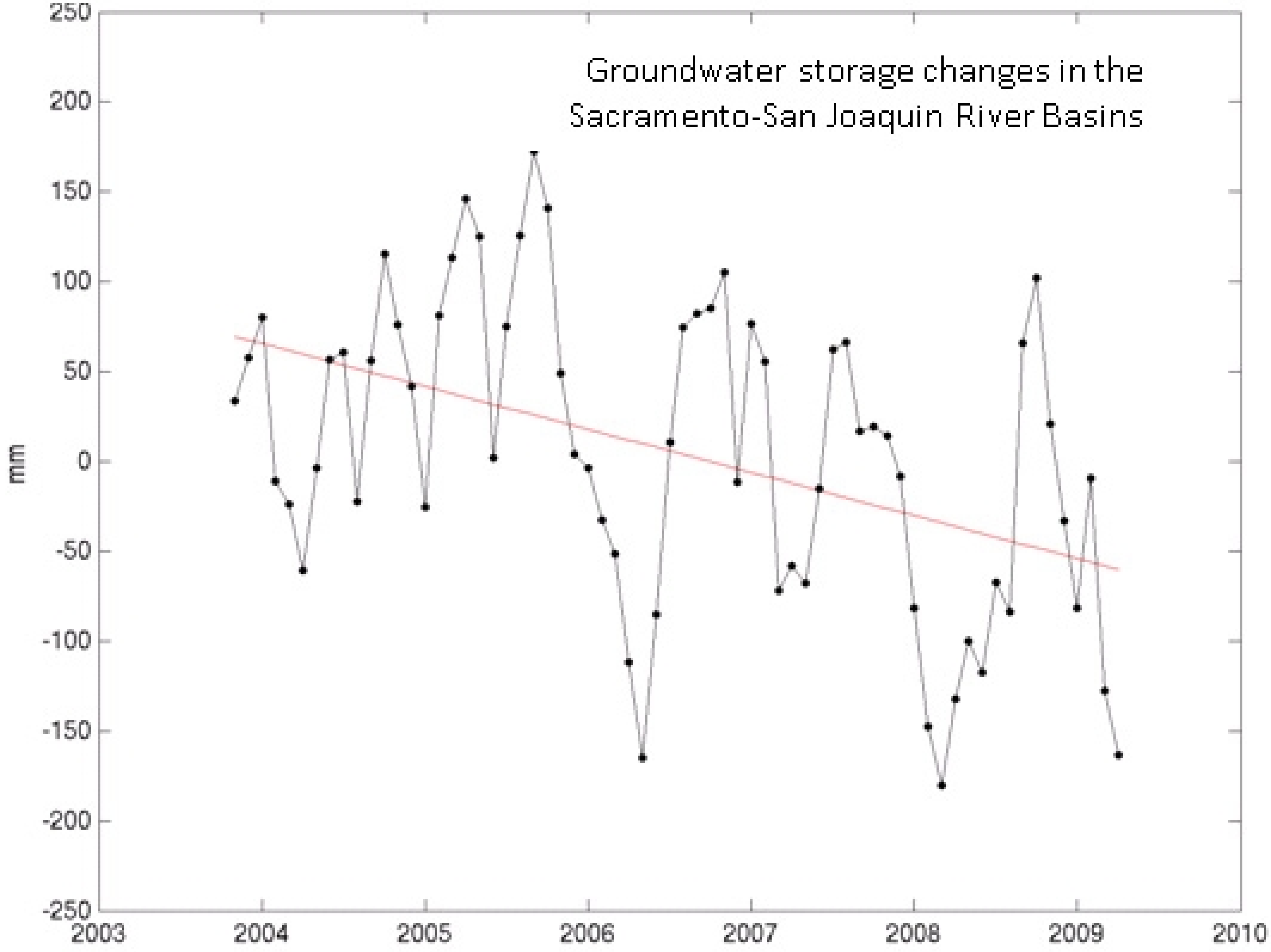

A
Trend in Ground Water Altitude
Moderate 30-Year Drought
Drought Period
Recovery
Change in Average Groundwater Altitude (m)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
Simulation Year
Sacramento
Eastside
San Joaquin
Tulare


B
Trend in Ground Water Altitude
Slight 60-Year Drought
Drought Period
Recovery
Change in Average Groundwater Altitude (m)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80
90
100
Simulation Year
Sacramento
Eastside
San Joaquin
Tulare

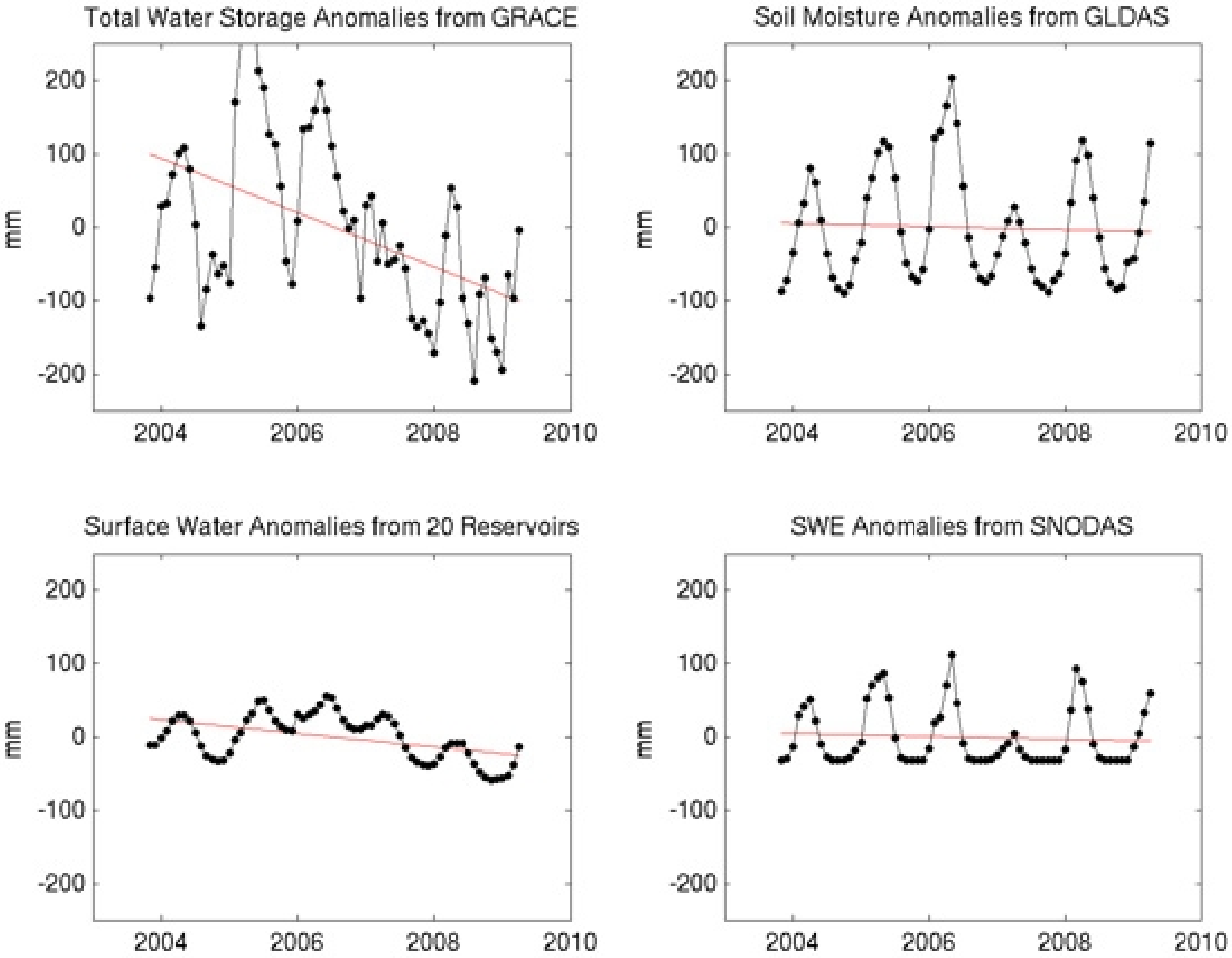

C
Trend in Ground Water Altitude
Severe 60-Year Drought
Drought Period
Recovery
Change in Average Groundwater Altitude (m)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
70
80
90
100
Simulation Year
Sacramento
Eastside
San Joaquin
Tulare

Qualifiers

- C2VSIM and ALL water allocation models are only partially verified. Many empirical parameters are tuned.
- The groundwater processes lack sufficient physical descriptions.
- Groundwater total mass and variation is not known.
- Pumping is based on a limited available demand record.
- Demand is fixed and agriculture does not shift with change in supply.



Groundwater storage changes in the Sacramento-San Joaquin River Basins


Total Water Storage Anomalies from GRACE

Soil Moisture Anomalies from GLDAS

Surface Water Anomalies from 20 Reservoirs

SWE Anomalies from SNODAS

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THANK YOU !