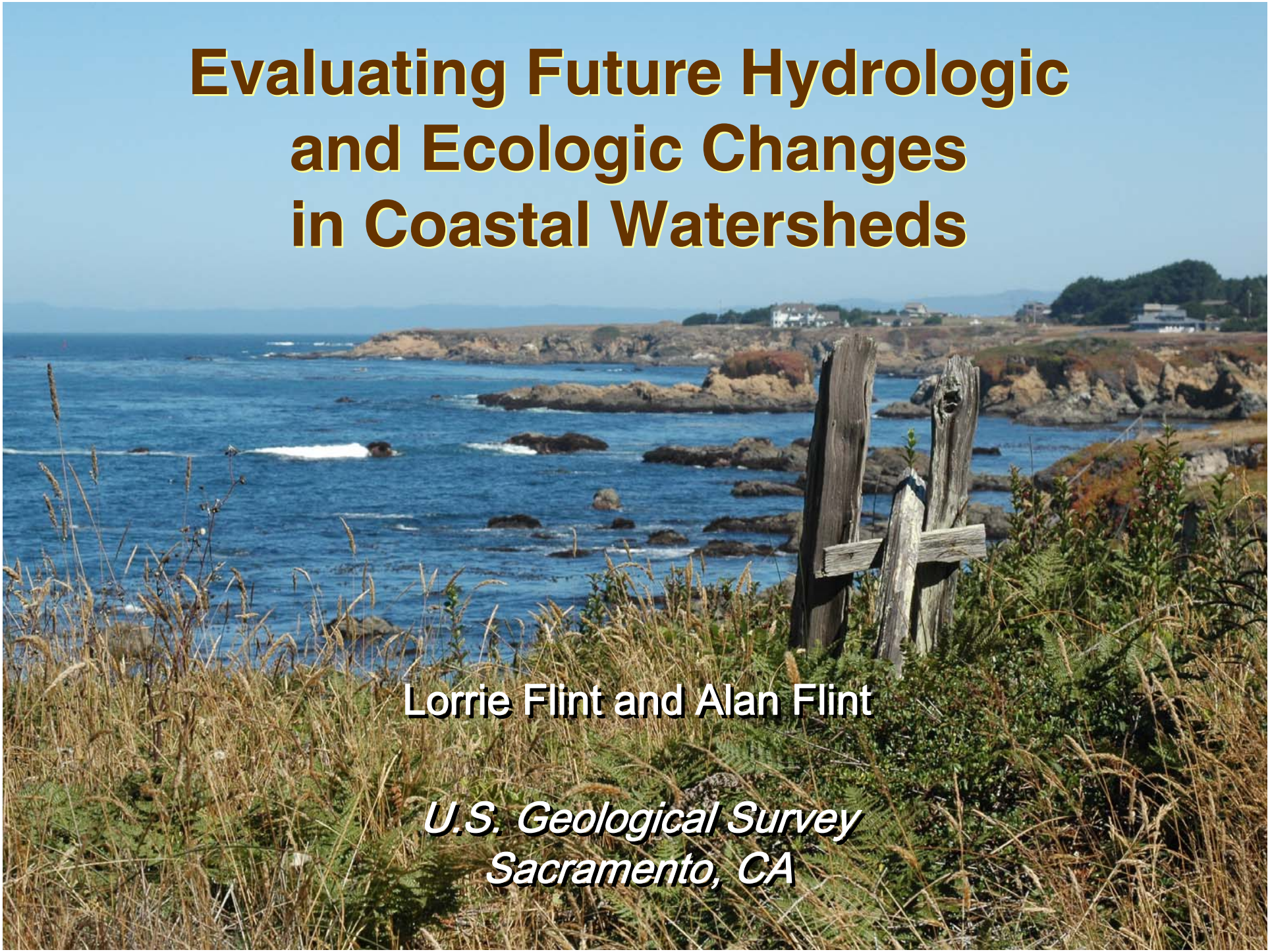
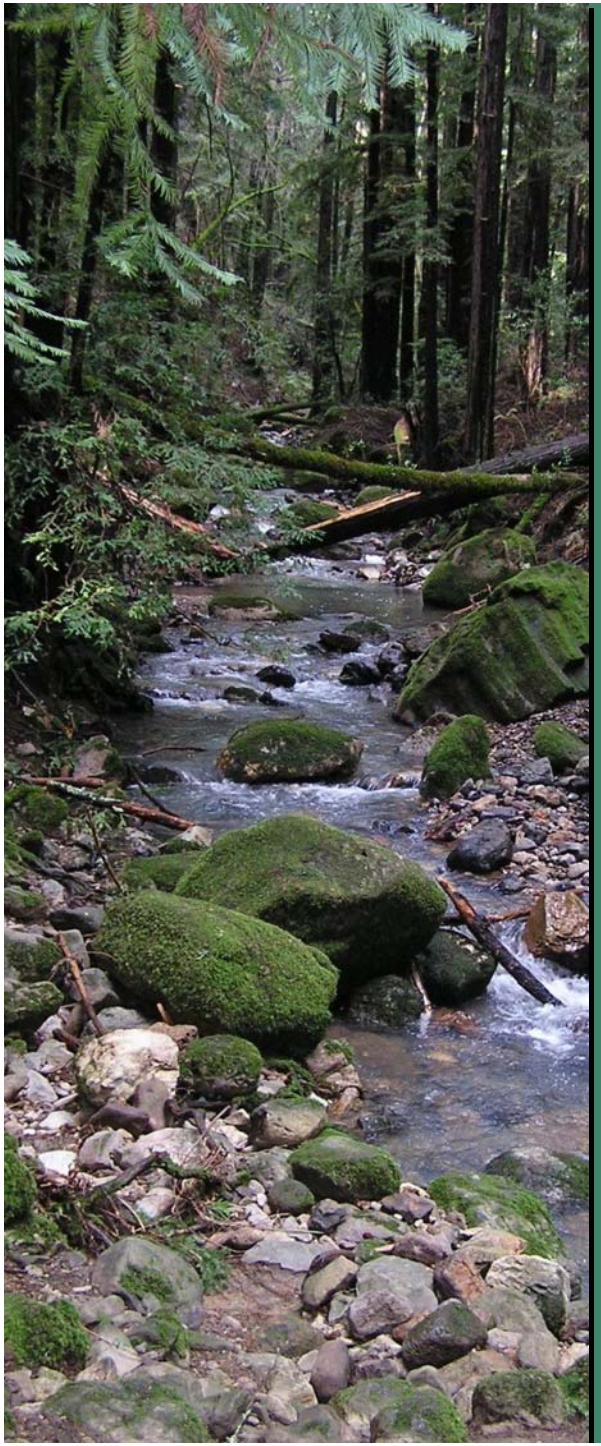
Evaluating Future Hydrologic and Ecologic Changes in Coastal Watersheds



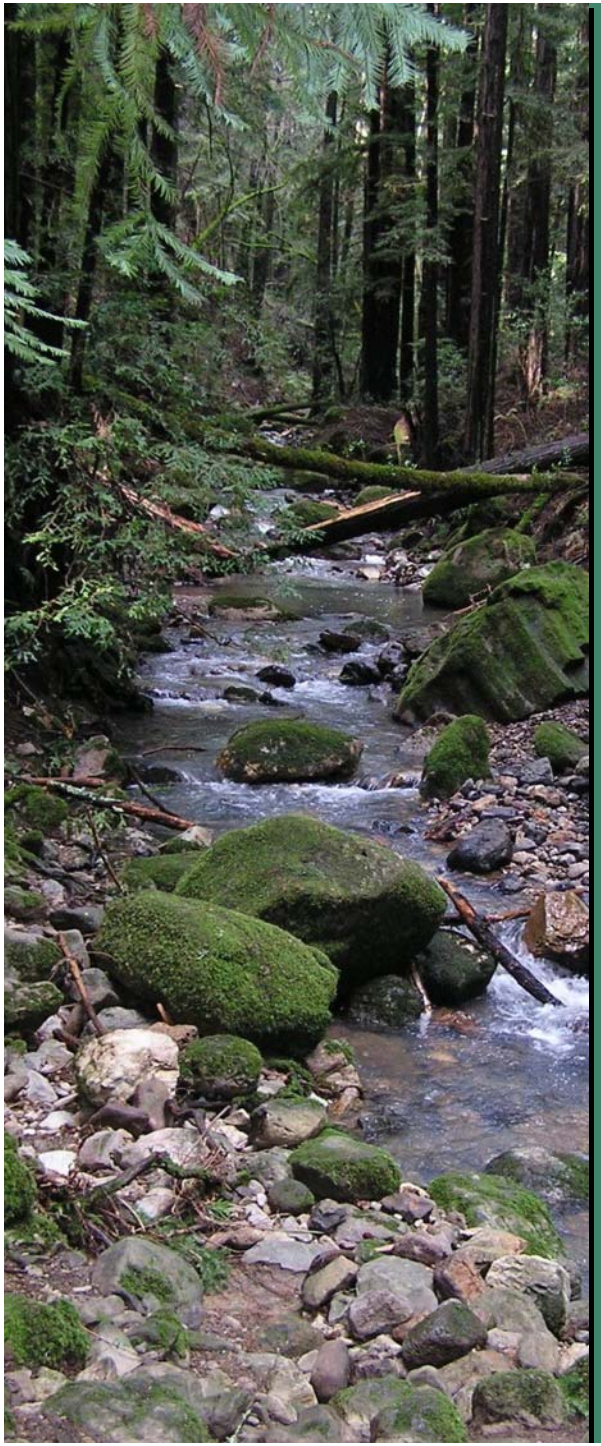
Lorrie Flint and Alan Flint

U.S. Geological Survey
Sacramento, CA



Hydrology and Ecology in a Changing Climate

- What do ecologists need for land management decisions?
  - What processes are important?
  - What environmental variables?
  - What temporal and spatial scales?
- Tools and information available for projections of future ecological conditions
  - Parameters available from global climate models: precipitation, maximum and minimum air temperature
  - Predictive models: mathematical, statistical, numerical, physical

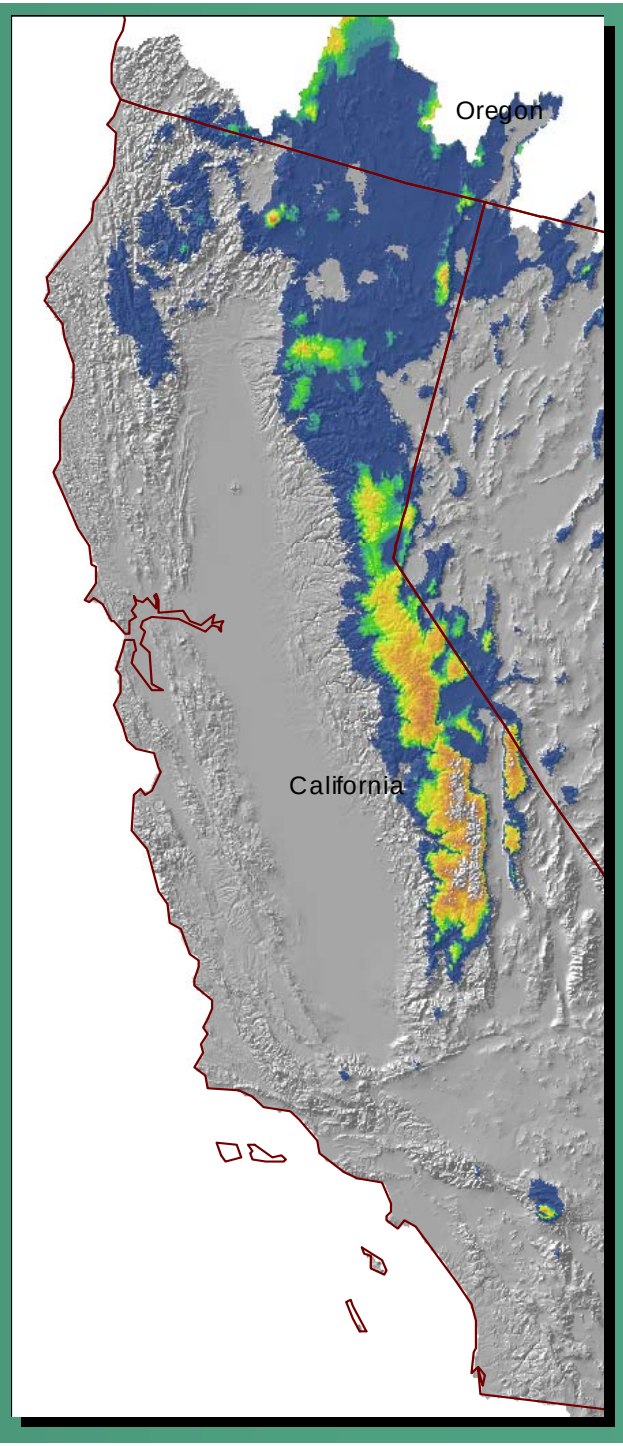


Hydrology and Ecology in a Changing Climate

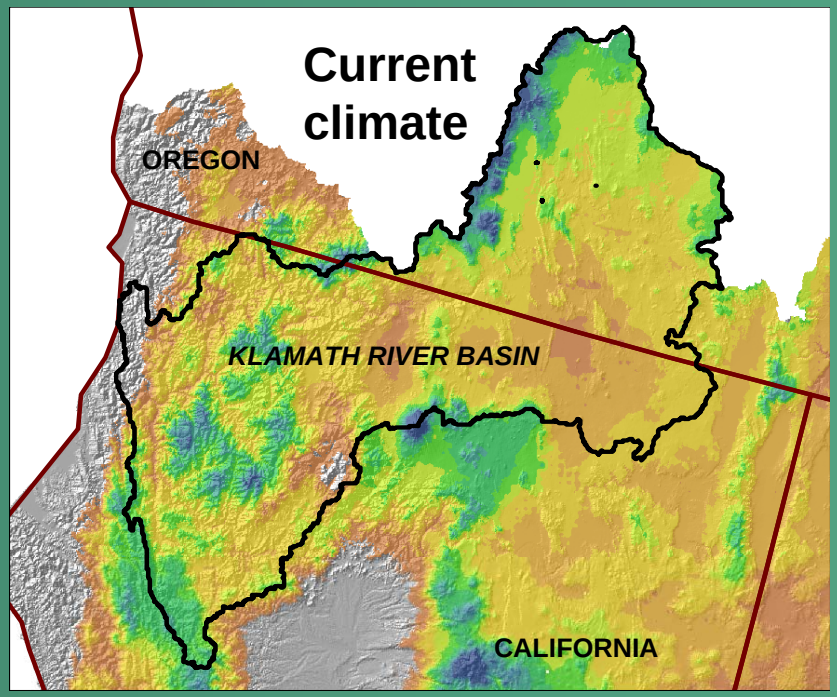
- Distributions of water flow, snow accumulation and melt, soil conditions, and other environmental attributes under climate change scenarios are necessary, at relevant resolution, for resource management and can provide the framework for local detailed process models
  - Streamflow
    - Volume, timing, temperature, peaks
    - Capacity to transport sediment
  - Soil moisture
  - Maximum and minimum air temperature
  - Evapotranspiration
  - Energy loading

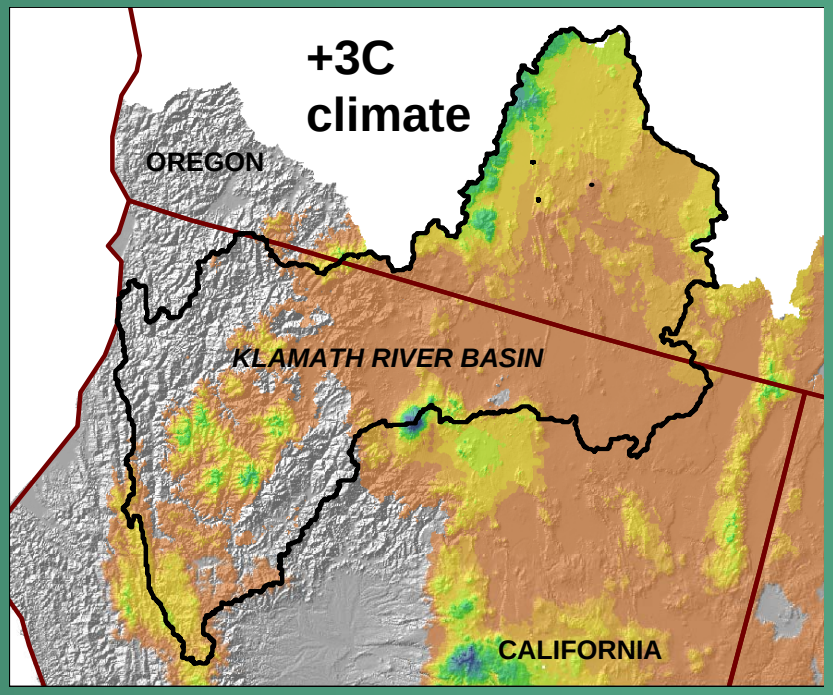
Regional Hydrologic Modeling for Coastal Basins

- Provides a regional perspective for resource management
- Example of change in April 1st snowpack with +3 C air temperature



Change in Snowfall in Klamath River Basin with +3 C Air Temperature

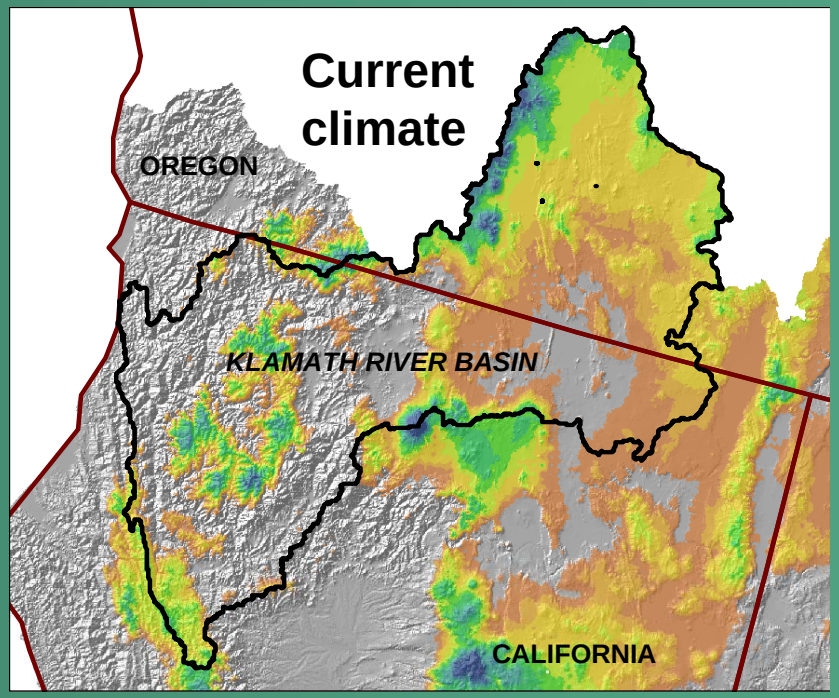


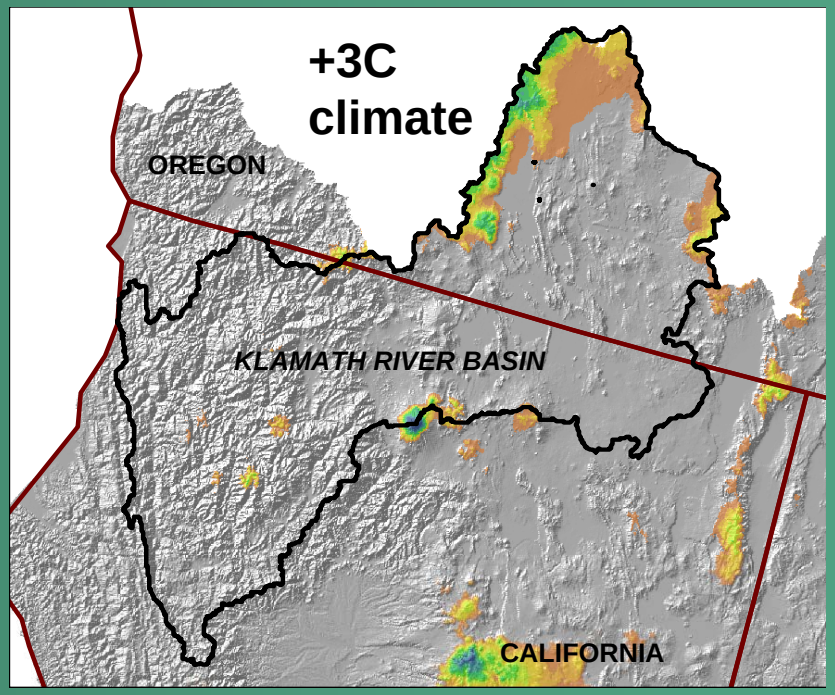


Average Annual Snowfall
(mm)

- 0 - 25
- 25 - 100
- 100 - 150
- 150 - 250
- 250 - 350
- 350 - 450
- 450 - 600
- 600 - 750
- 750 - 900
- 900 - 1,700

Change in April 1 Snowpack in Klamath River Basin

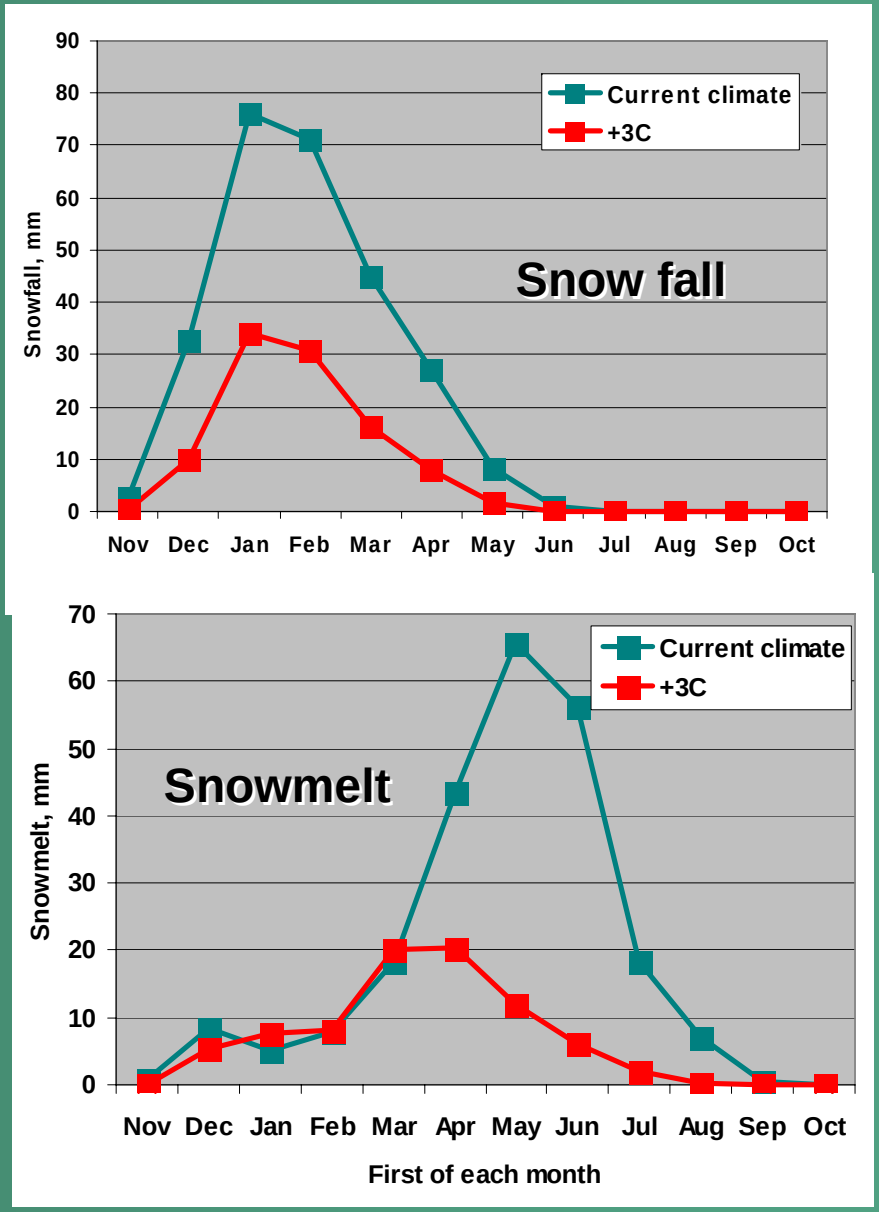


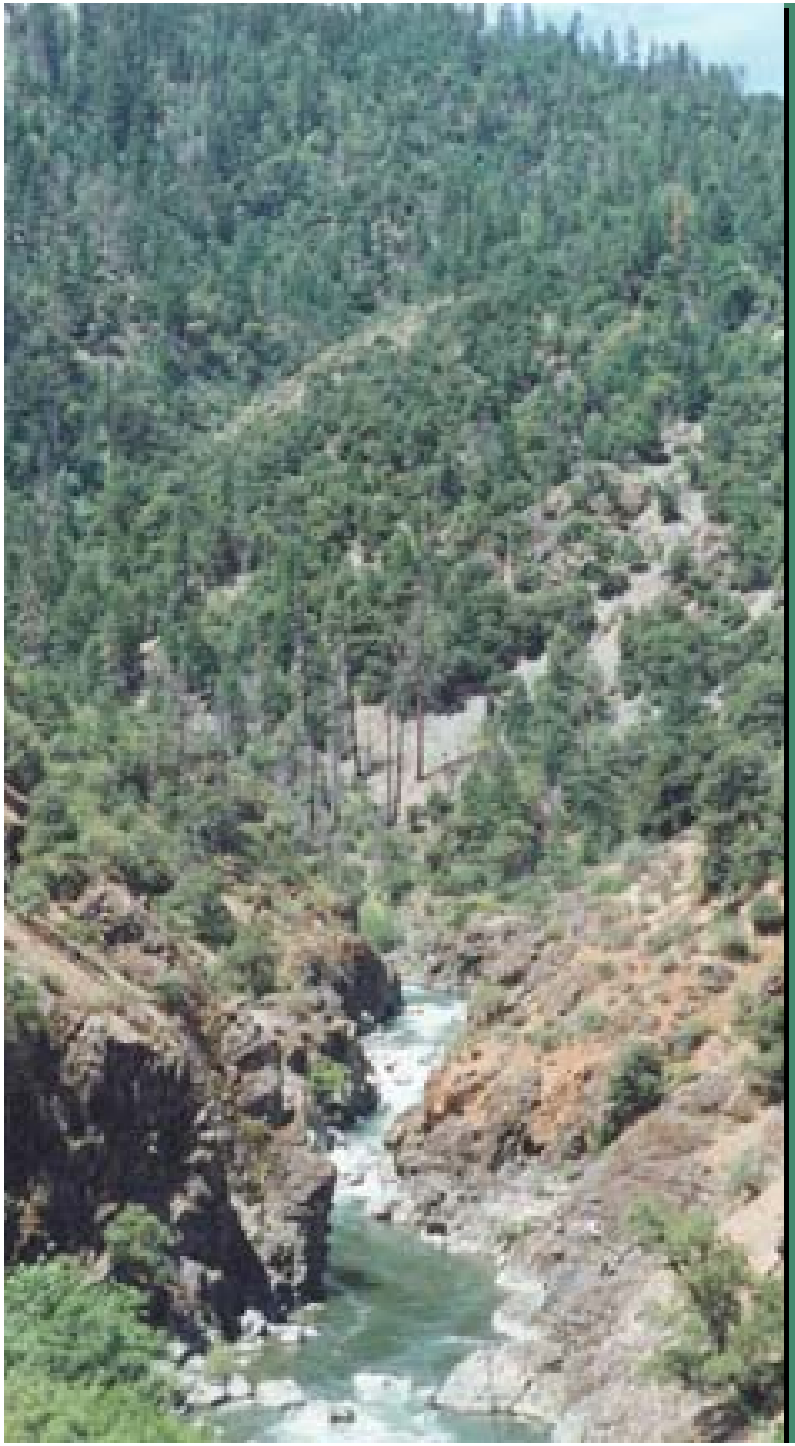


April 1 Snowpack (mm)

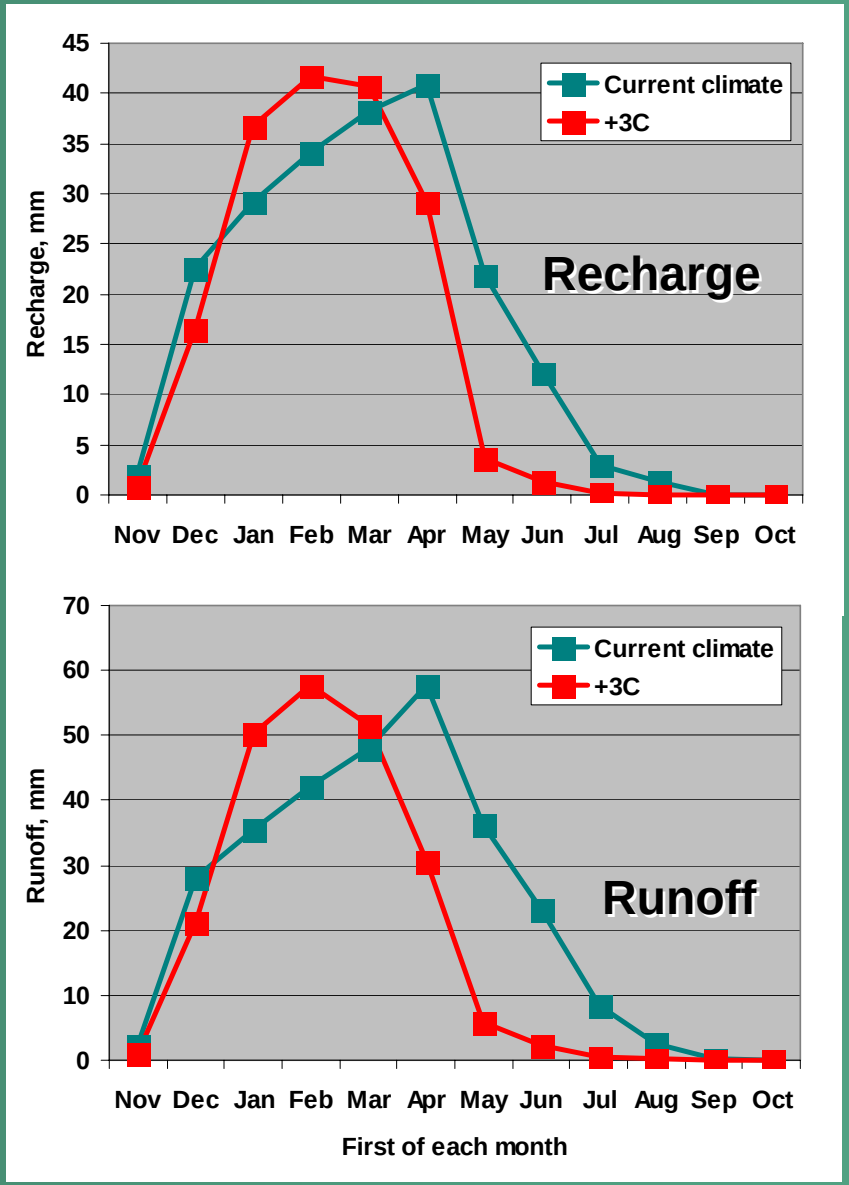
- 0 - 25
- 25 - 100
- 100 - 150
- 150 - 250
- 250 - 350
- 350 - 450
- 450 - 600
- 600 - 750
- 750 - 900
- 900 - 1,700

Change in Snow: Klamath Basin

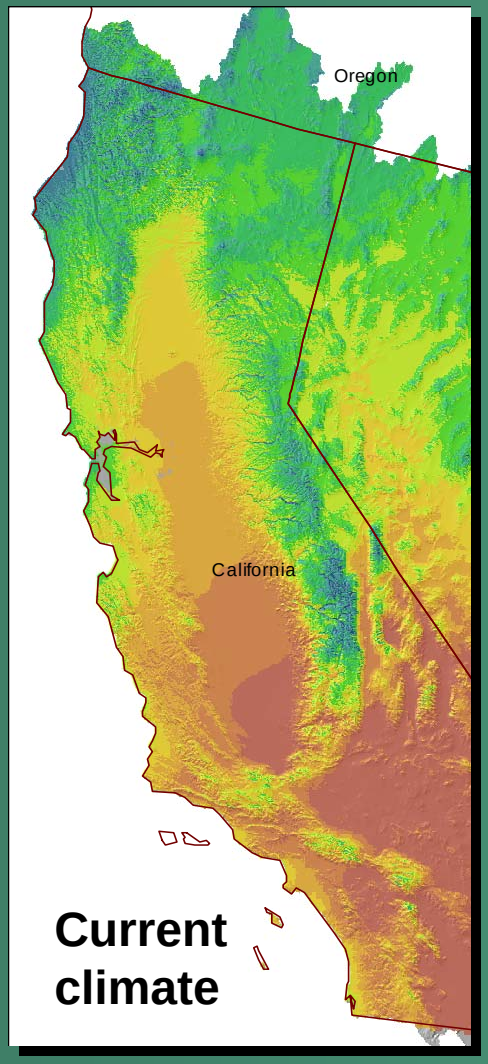


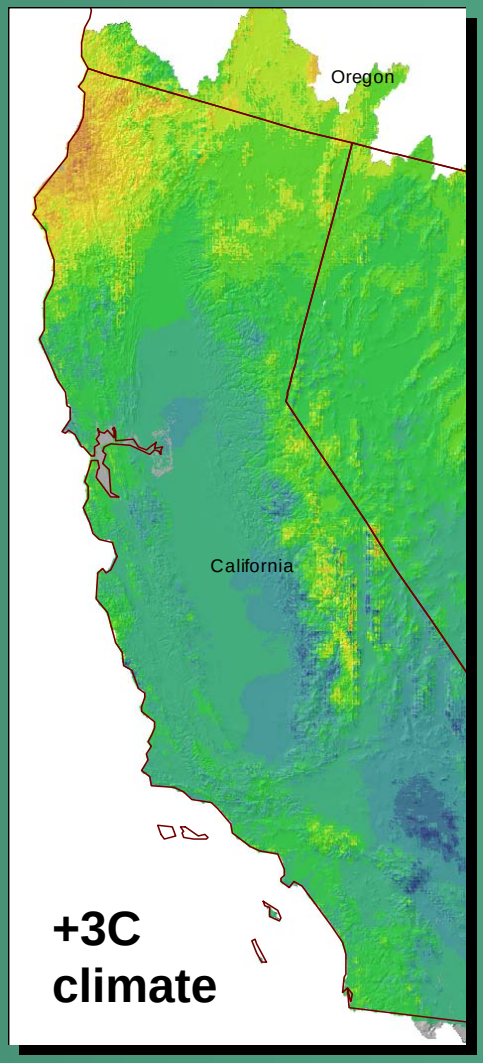


Change in Water Availability: Klamath Basin



Annual Potential Evapotranspiration





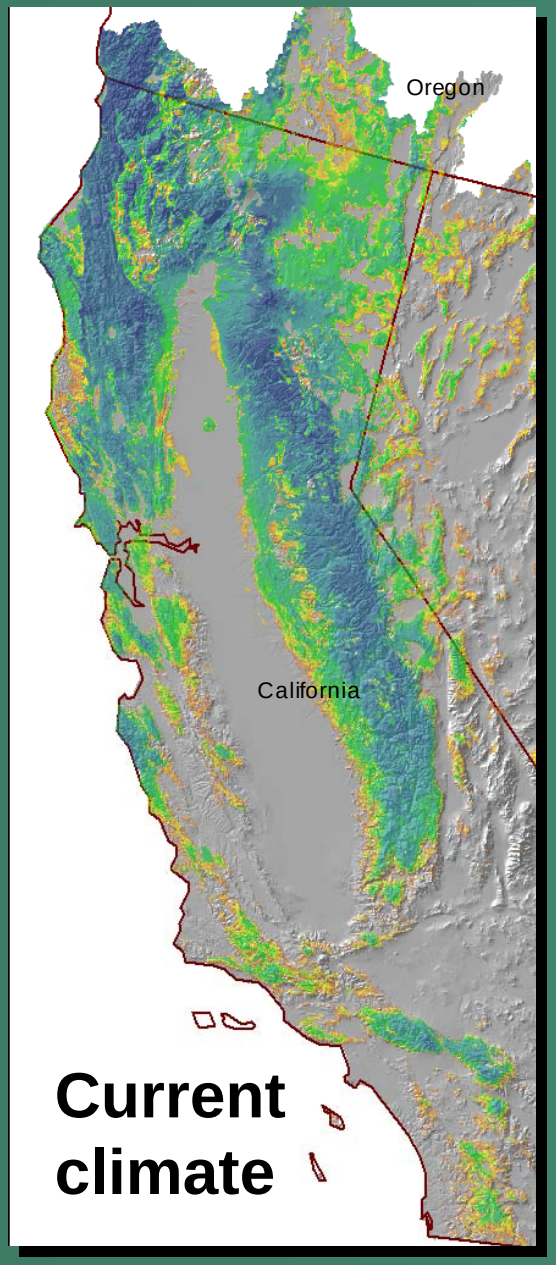
(mm/yr)

250 - 800	1,200 - 1,300
800 - 900	1,300 - 1,400
900 - 1,000	1,400 - 1,500
1,000 - 1,100	1,500 - 1,600
1,100 - 1,200	1,600 - 1,995

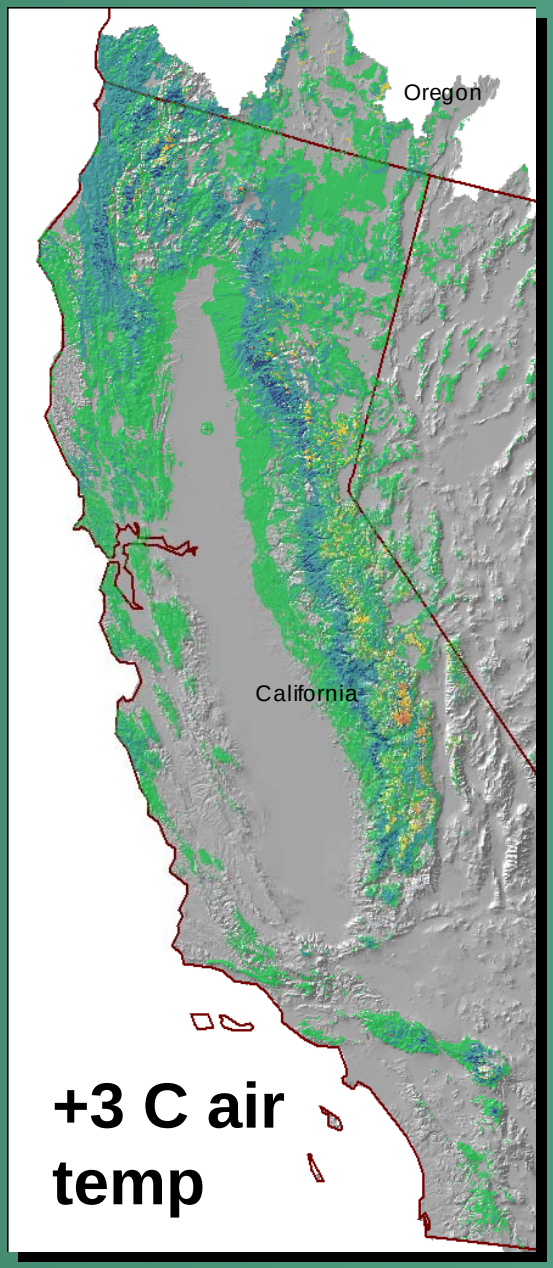
Percent increase

13 - 14	7 - 8
12 - 13	6 - 7
11 - 12	5 - 6
10 - 11	4 - 5
9 - 10	3 - 4
8 - 9	2 - 3

Generation of Annual Runoff



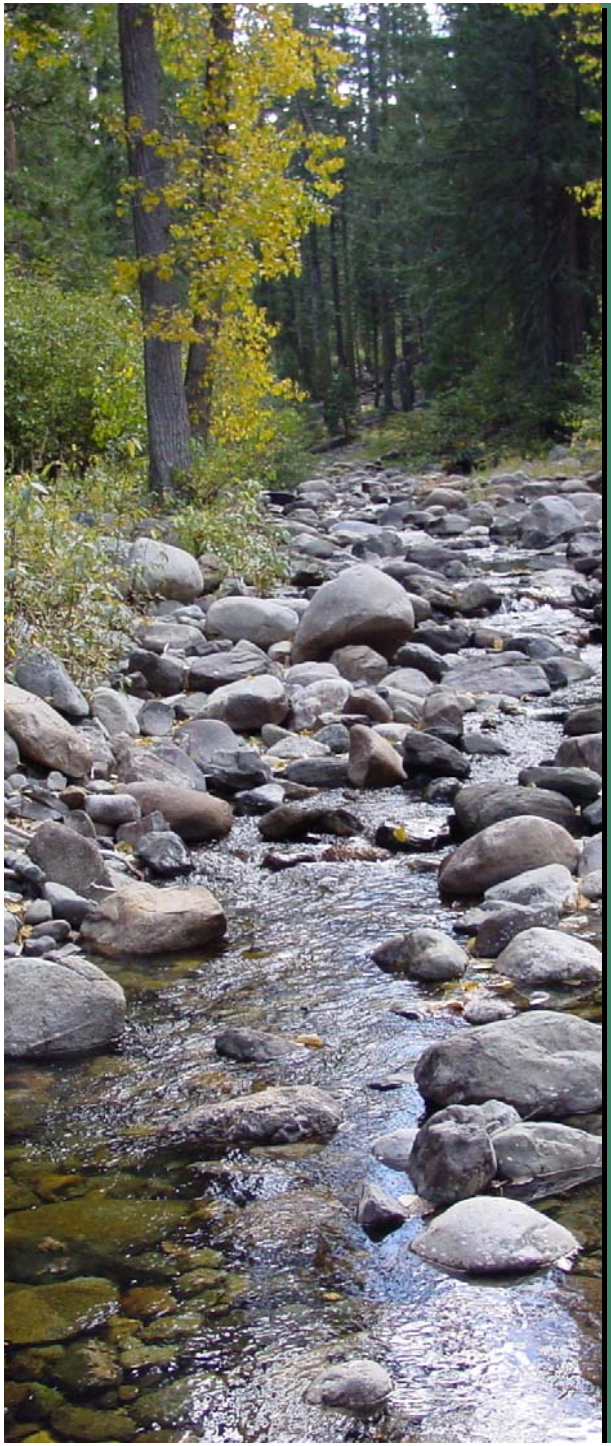
(mm/yr)
- < 0.01
- 0.1 - 1
- 1 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 75
- 75 - 100
- 100 - 200
- 200 - 300
- 300 - 500
- 500 - 750
- 750 - 1,200
- > 1,200



(mm/yr)
- 690 - 250
- 250 - 100
- 100 - 25
- 25 - -25
- -25 - -100
- -100 - -250
- -250 - -505

increase

decrease



Outline

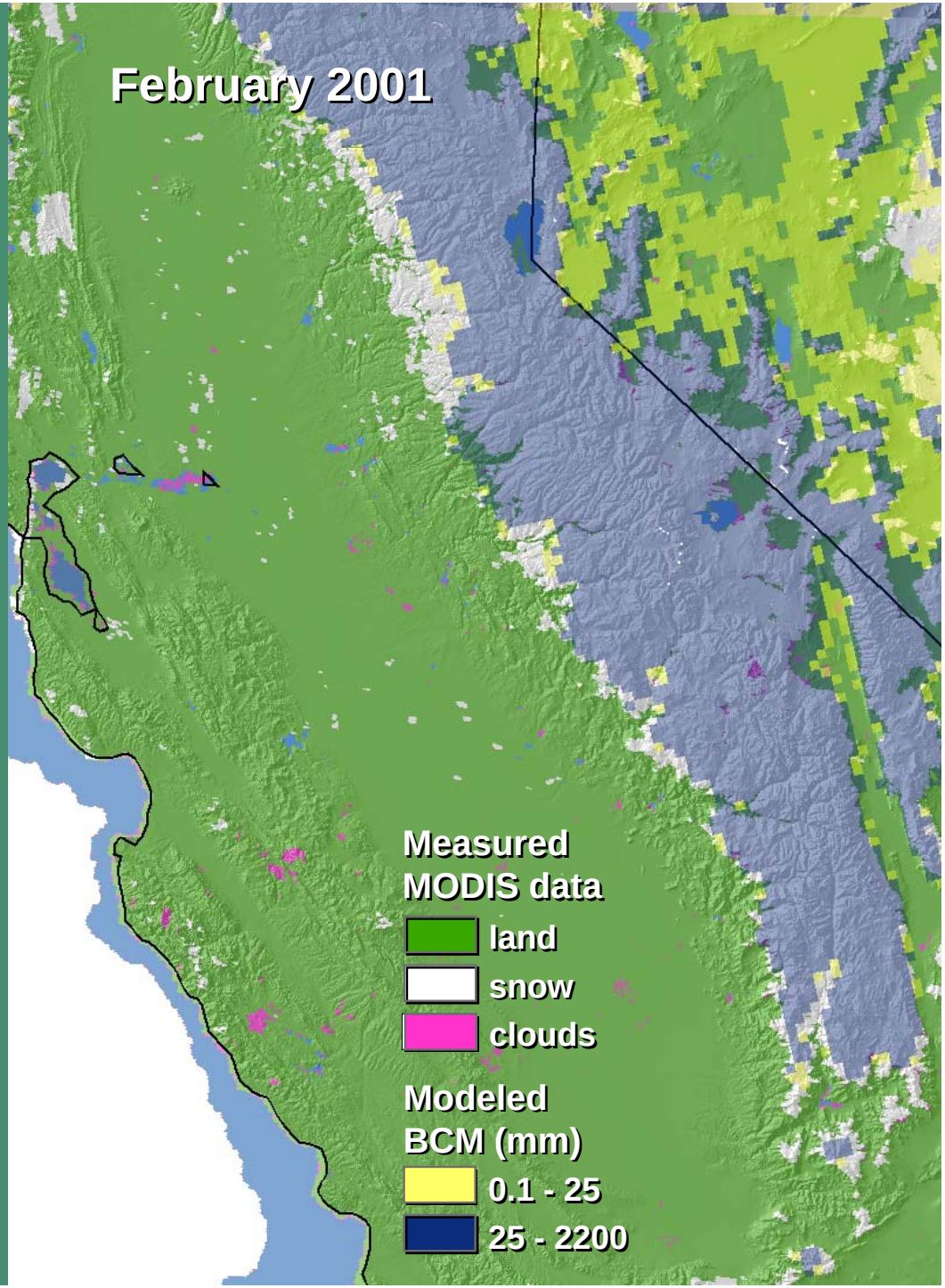
- Regional model description
- Current climate in California coastal basins
- Application of downscaled future climate scenarios to California coastal basins

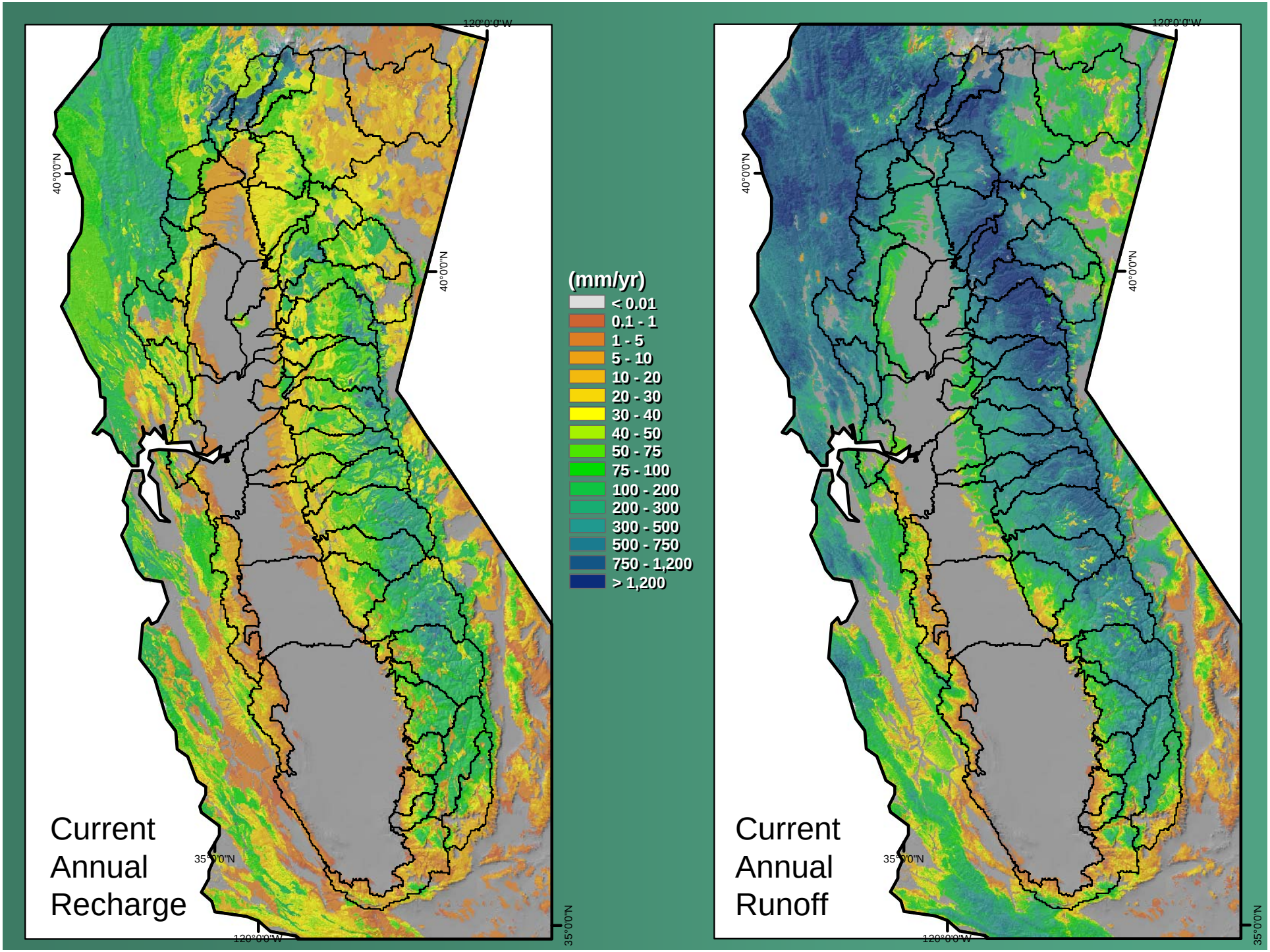
Recharge and Runoff

- Basin Characterization Model (BCM)
  - run in FORTRAN
  - uses grid-based data at any DEM resolution
  - calculates in-place recharge or generated runoff
- Potential evapotranspiration (Priestley-Taylor)
  - solar radiation modeled using topographic shading and cloudiness
  - vegetation density
- Snow accumulation and melt based on NWS Snow-17 Model
- Soils (STATSGO): hydraulic properties and depth determine soil storage
- Geology (state maps) is used to estimate bedrock permeability
- Precipitation and air temperature available using PRISM datasets and downscaled GCMs for future climates

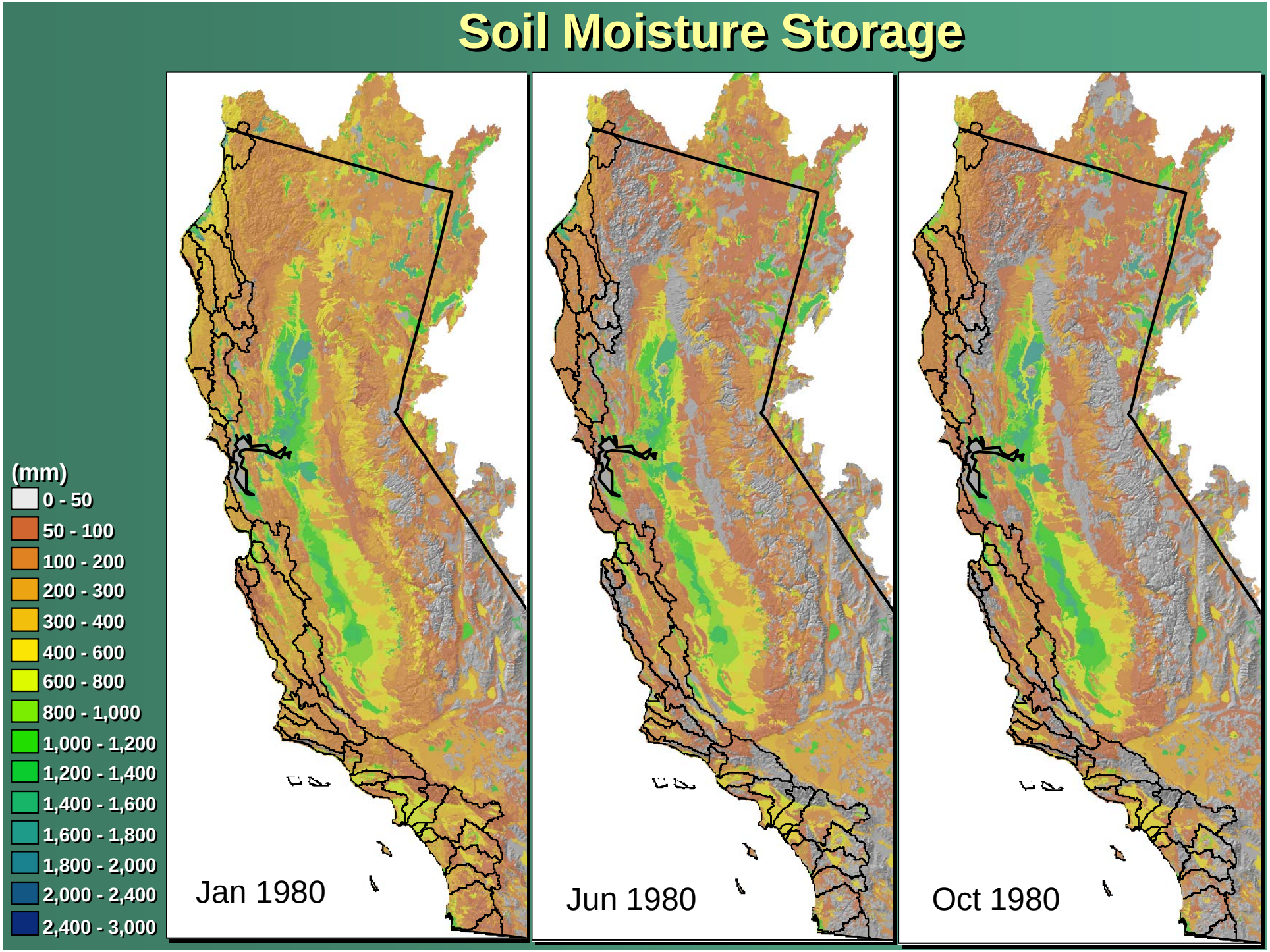
Regional Model Calibration

- MODIS snow cover comparisons, snow pillow data
- Measured ground-received solar radiation
- Measured ETo
- Basin runoff comparisons to streamflow




120°0'0"W
40°0'0"N
35°0'0"N
(mm/yr)
< 0.01
0.1 - 1
1 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 75
75 - 100
100 - 200
200 - 300
300 - 500
500 - 750
750 - 1,200
> 1,200
Current Annual Recharge
Current Annual Runoff

Soil Moisture Storage



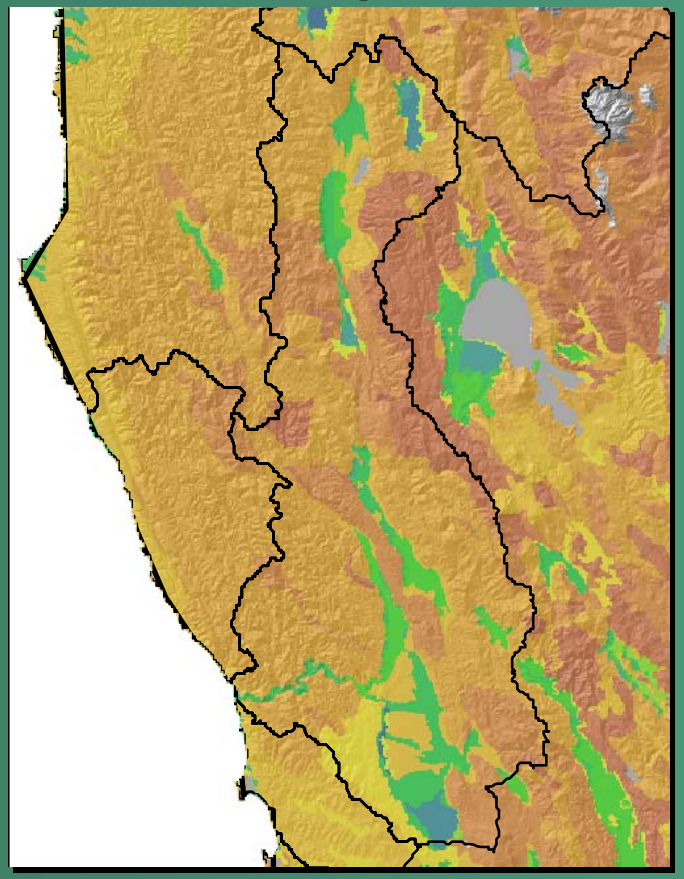
January 1980

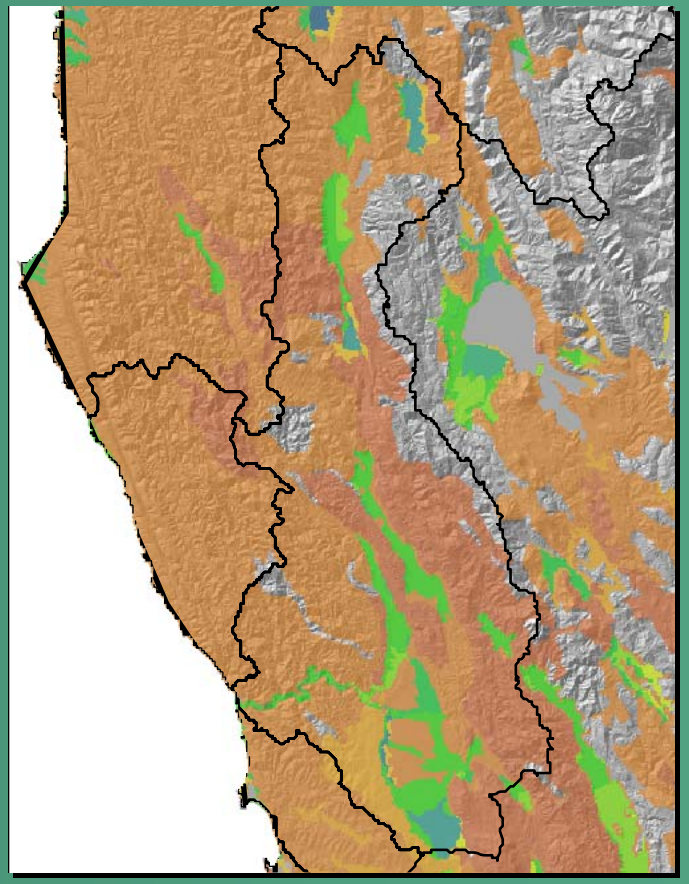
June 1980

Russian River Basin

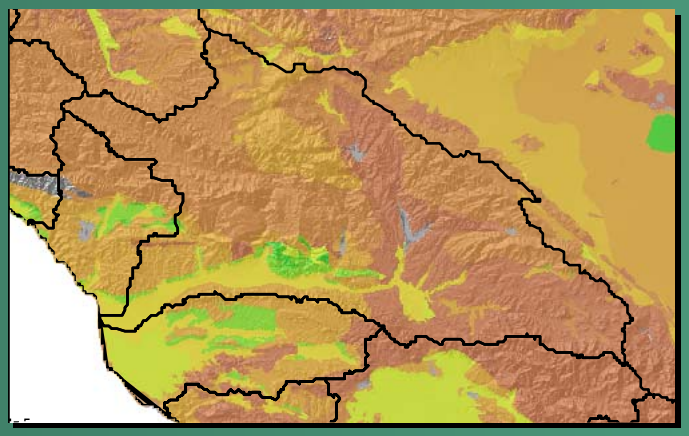
(mm)

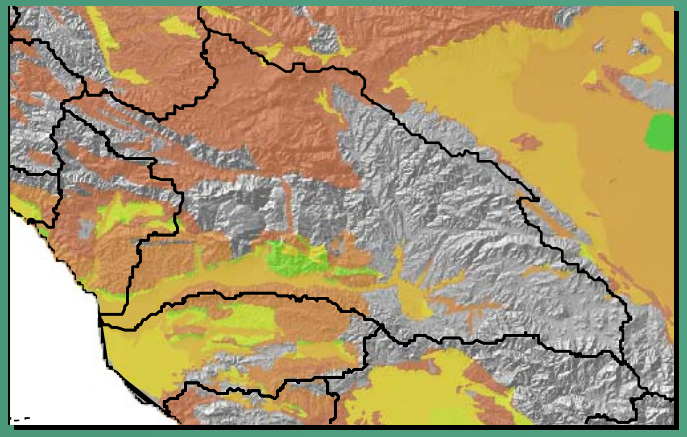
- 0 - 50
- 50 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 600
- 600 - 800
- 800 - 1,000
- 1,000 - 1,200
- 1,200 - 1,400
- 1,400 - 1,600
- 1,600 - 1,800
- 1,800 - 2,000
- 2,000 - 2,400
- 2,400 - 3,000





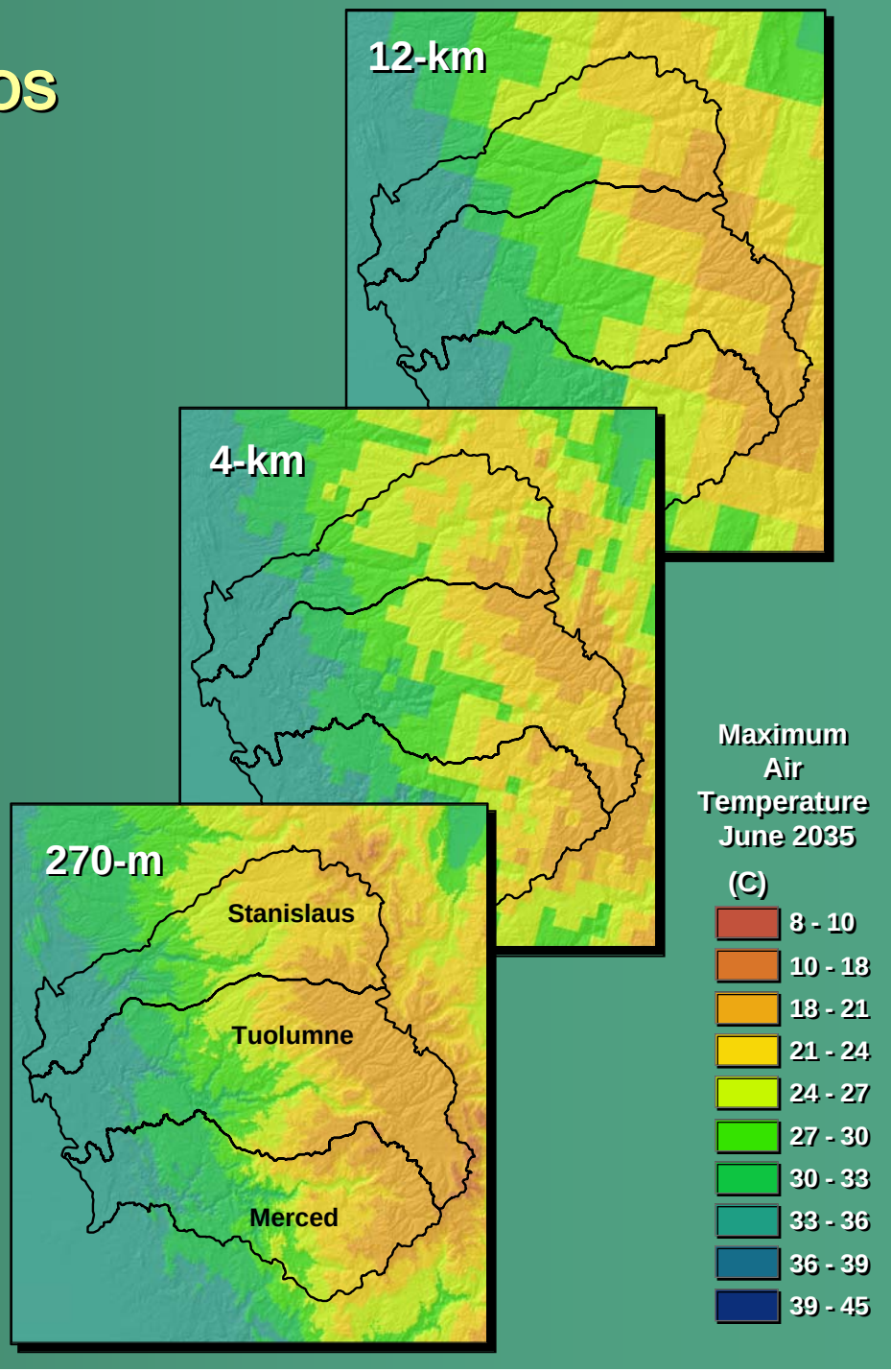
Santa Clara and Santa Monica Basins





Climate Change Scenarios

- Climate model data at 2.5 degree resolution were downscaled to 1/8 degree, 12-km using a constructed analogues method by Hidalgo et al. (2007)
- These data were further downscaled to 4-km using a gradient-inverse-distance-squared (GIDS) method
- Statistical transformation was used to ensure that the climate model and historical data have similar statistical properties: the mean and standard deviation of the 1970-2000 period were used for corrections
- Data was further downscaled to 270-m using GIDS for model application



Climate Change Scenarios

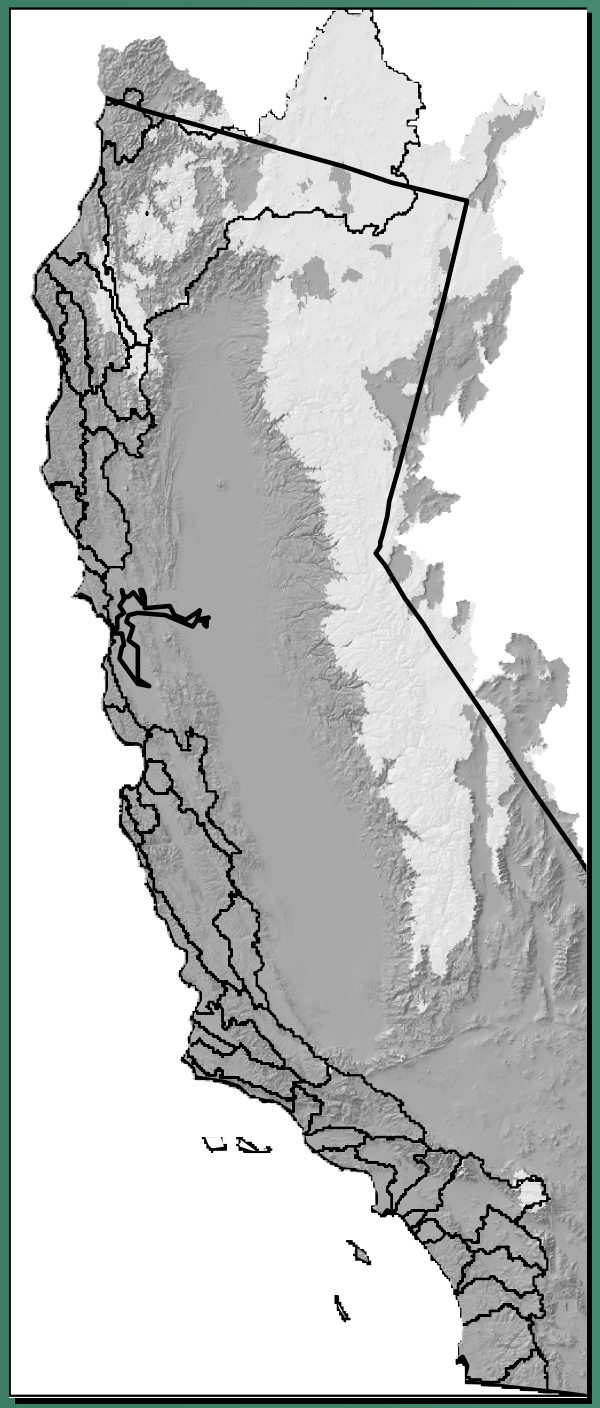
- State of California is using four "families" of emission scenarios to investigate possible future climate changes
- IPCC Fourth climate assessment provides recent model simulations
- Geophysical Fluid Dynamics Lab (GFDL), and NCAR's Parallel Climate Model (PCM)
  - A2: medium-high emissions
  - B1: low emissions

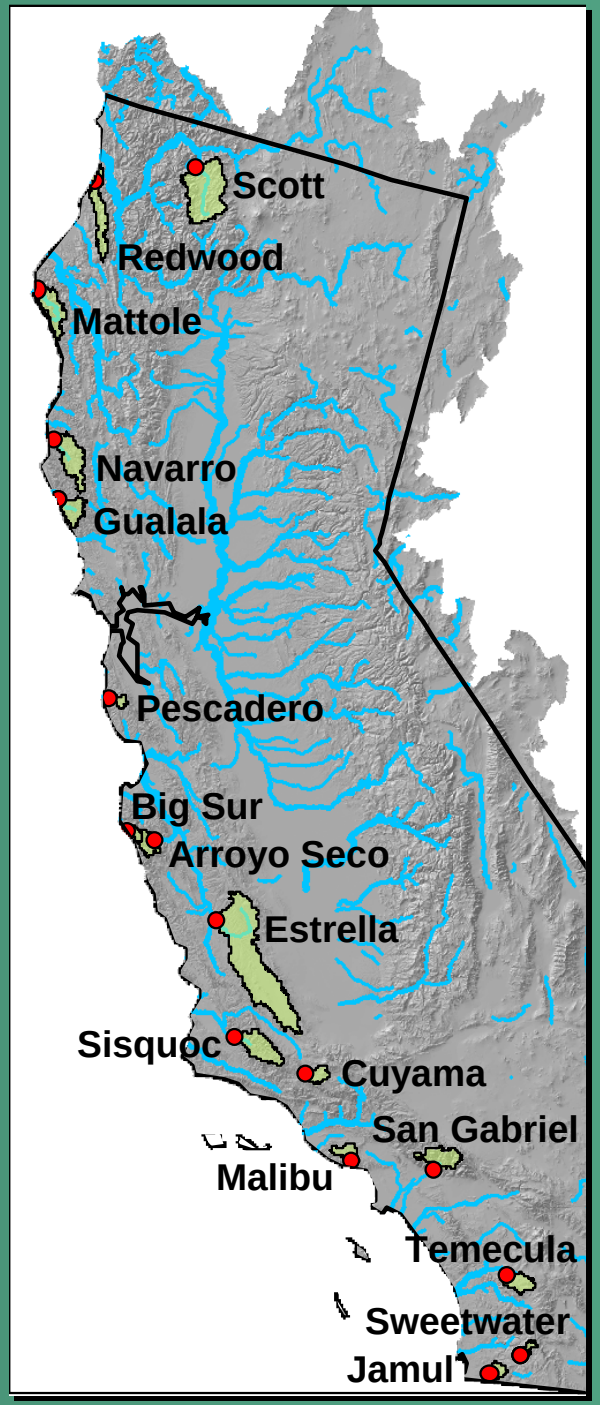
Climate Projections for California for End of Century

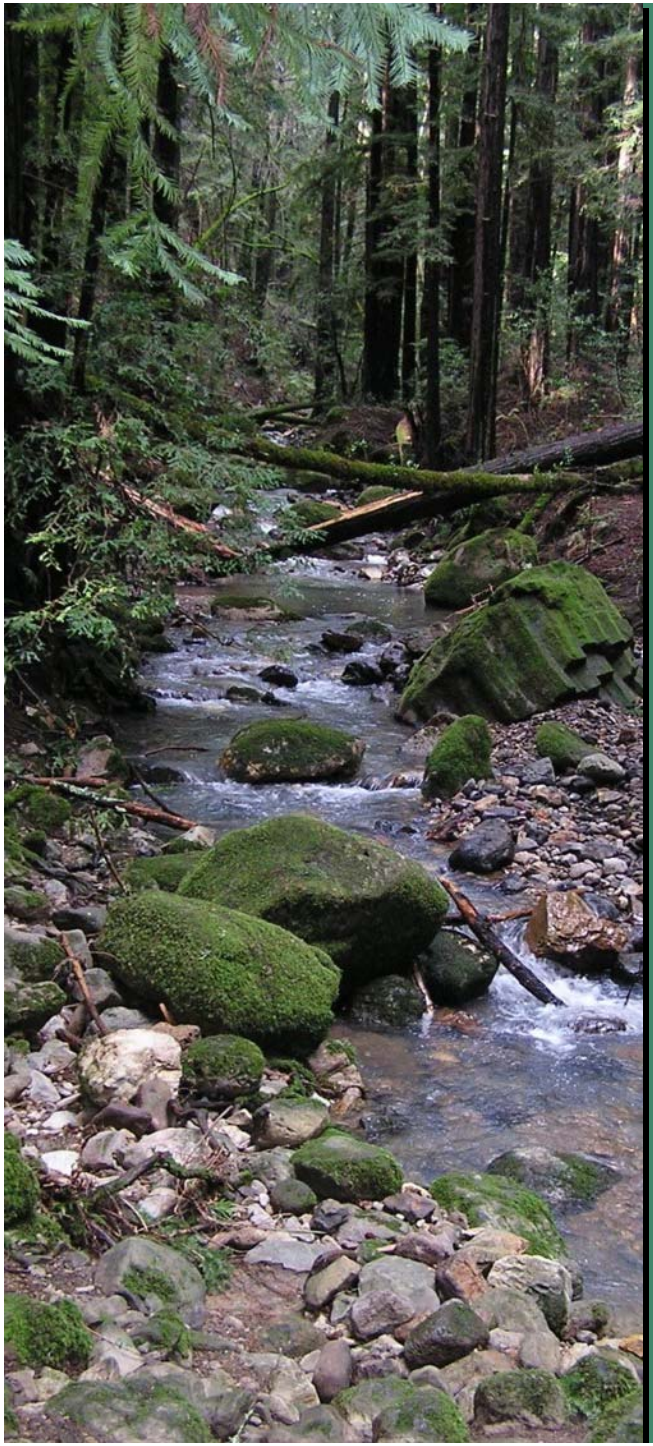
GFDL-A2 scenario

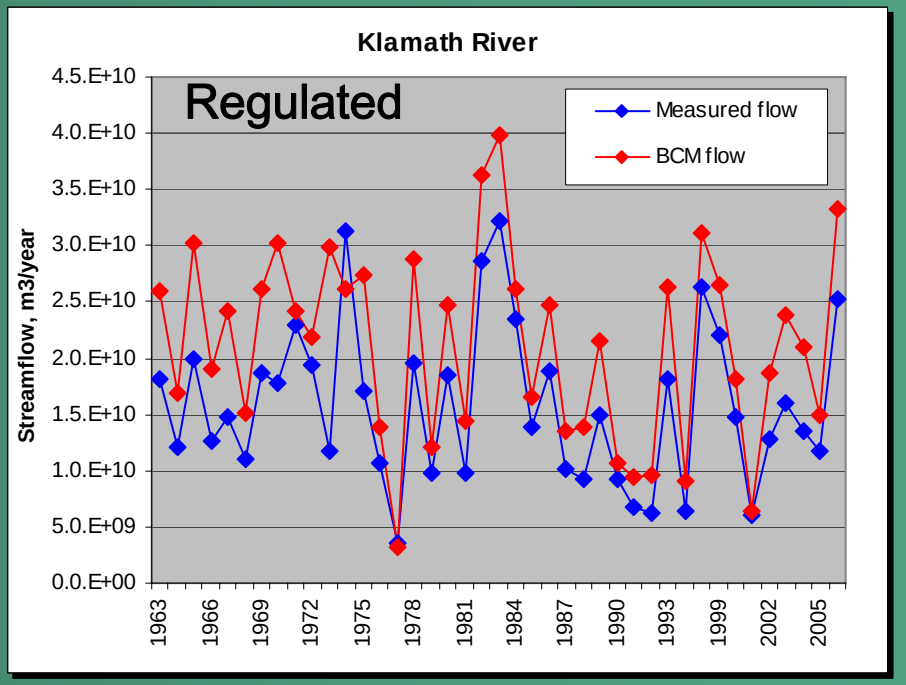
	Change in Air Temperature, C		Change in Precipitation, %	
	Summer	Winter	Summer	Winter
Northern Calif.	6.4	3.4	-68	-9
Southern Calif.	5.3	3.3	-44	-2

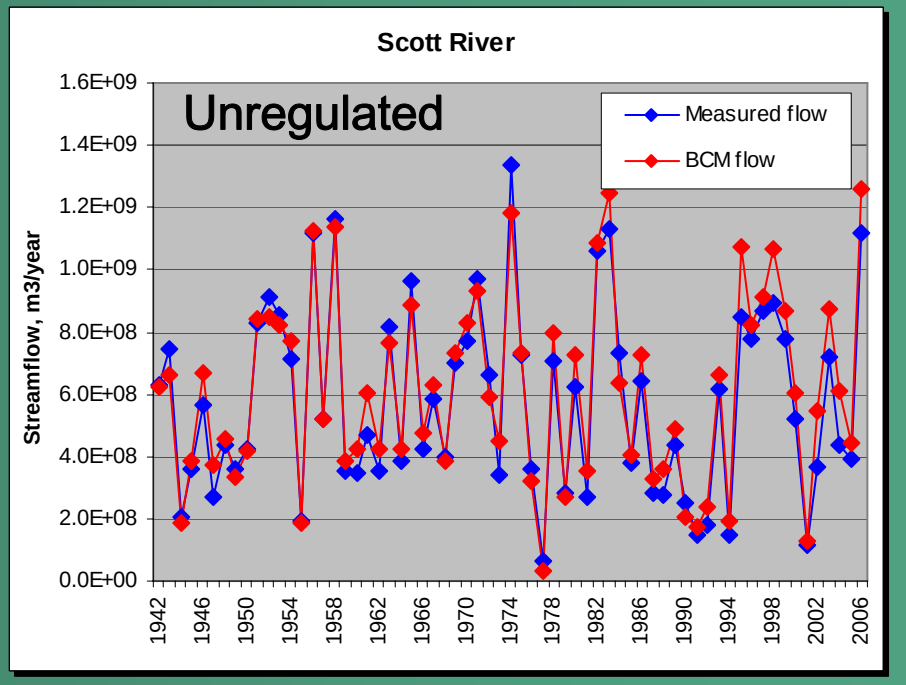
From Cayan et al., 2007: "Climate change scenarios for the California region"

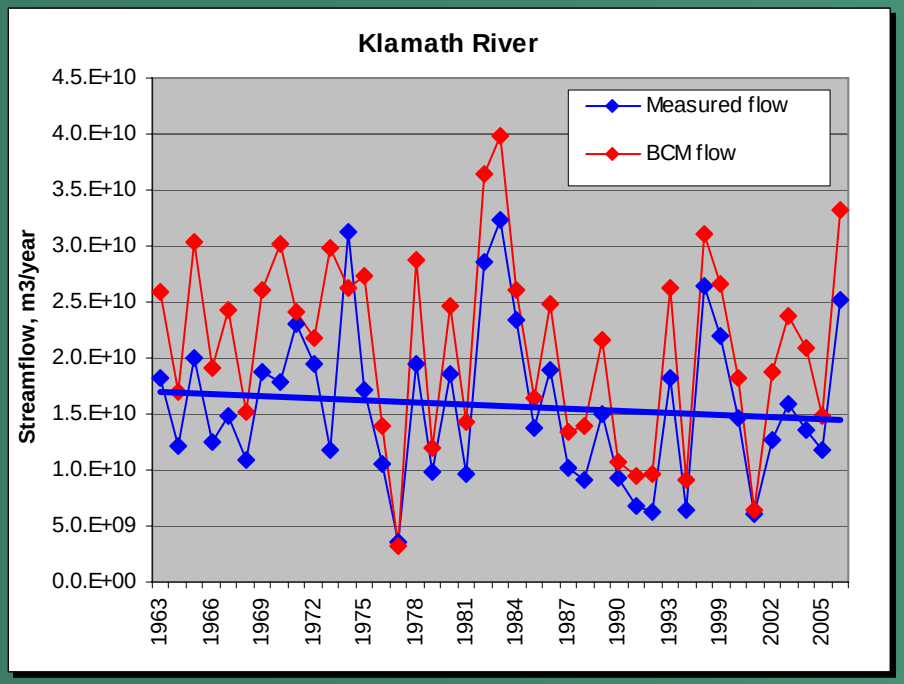


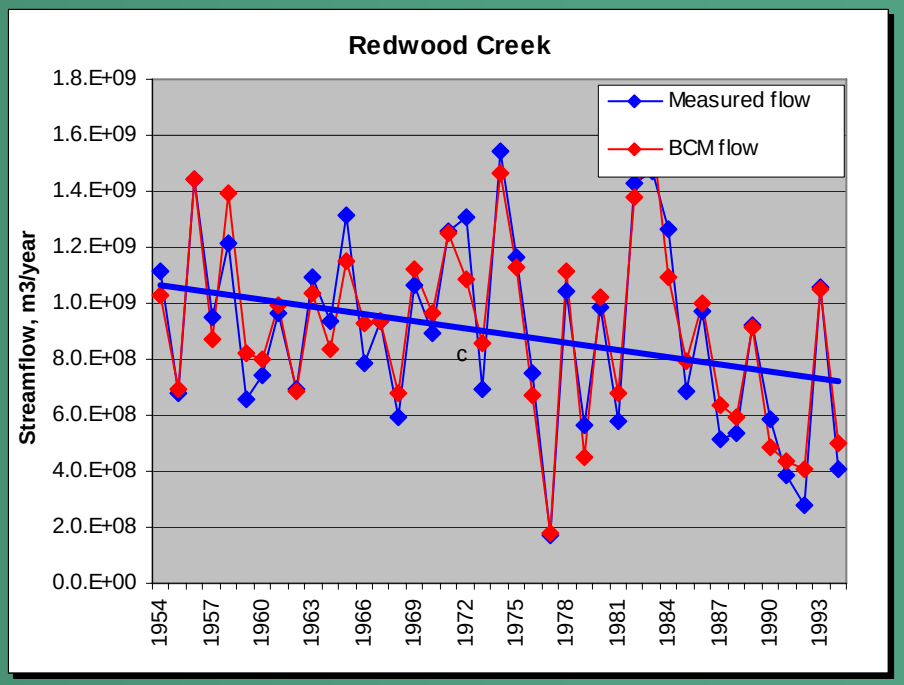

Scott
Redwood
Mattole
Navarro
Gualala
Pescadero
Big Sur
Arroyo Seco
Estrella
Sisquoc
Cuyama
San Gabriel
Malibu
Temecula
Sweetwater
Jamul

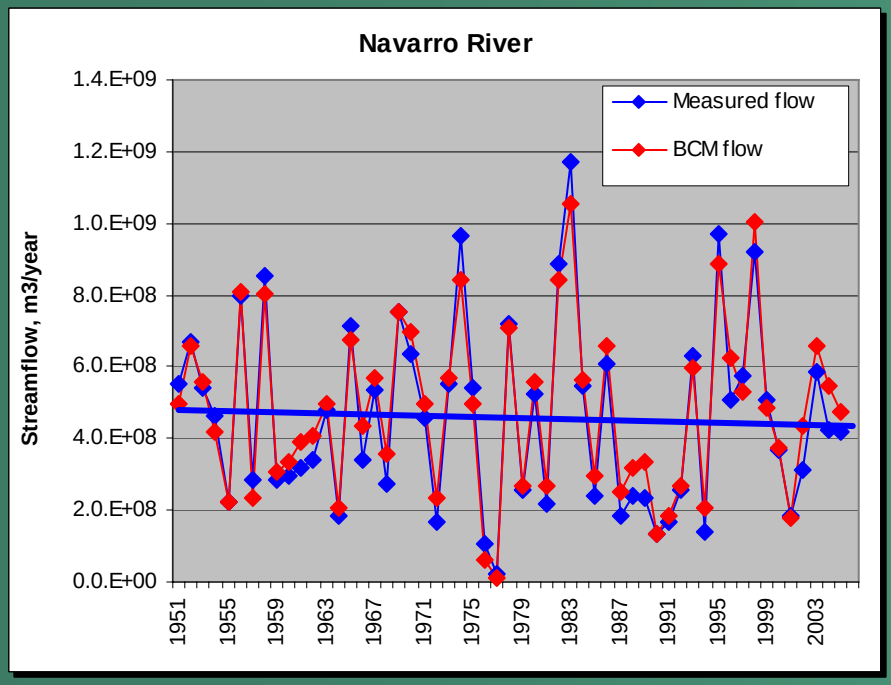


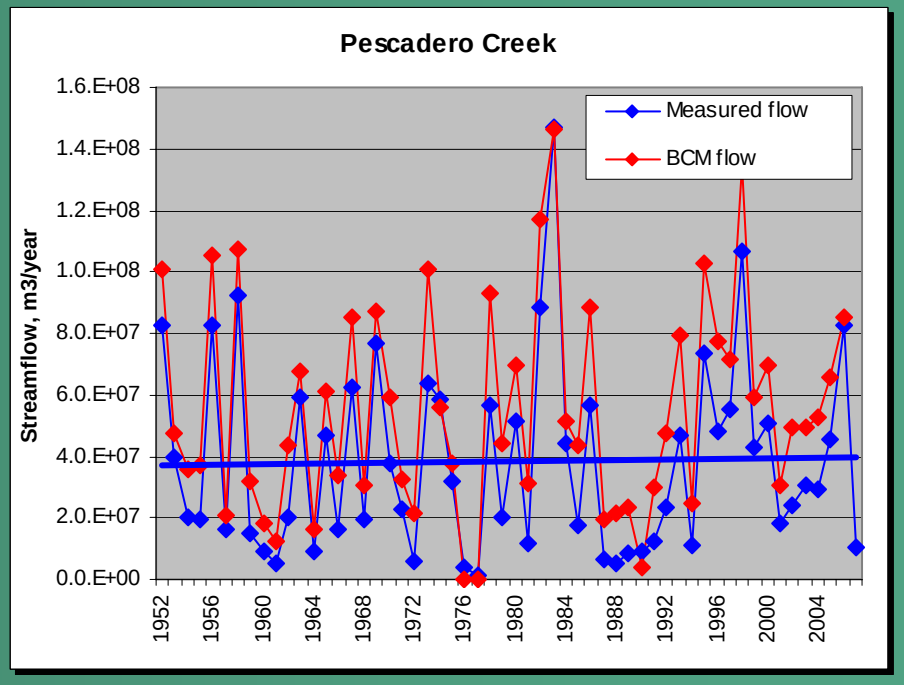

Klamath River
Regulated
Measured flow
BCM flow
Streamflow, m3/year
4.5.E+10
4.0.E+10
3.5.E+10
3.0.E+10
2.5.E+10
2.0.E+10
1.5.E+10
1.0.E+10
5.0.E+09
0.0.E+00
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1999
2002
2005

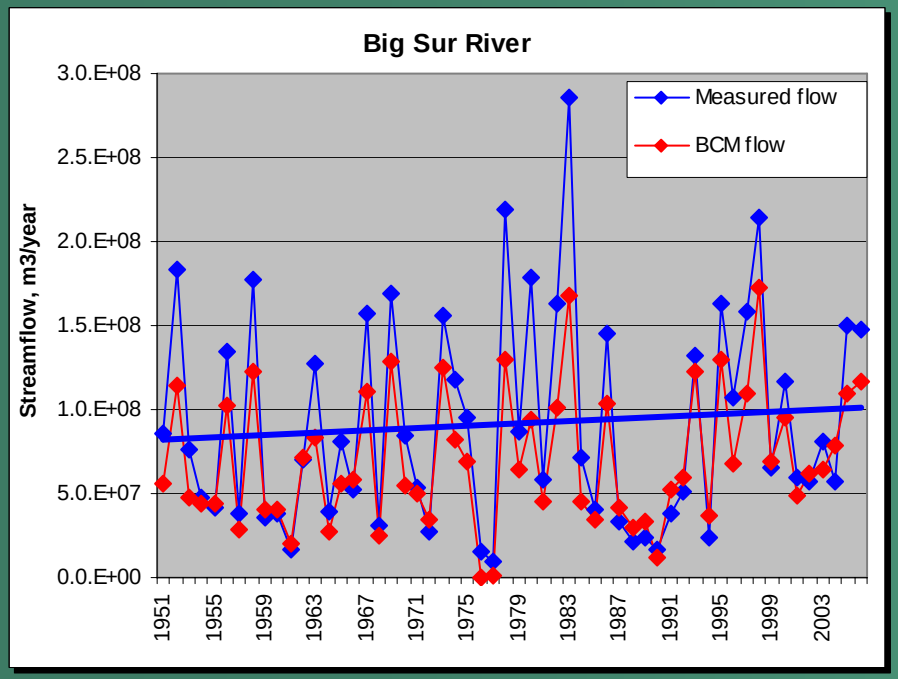

Scott River
Unregulated
Measured flow
BCM flow
Streamflow, m3/year
1.6E+09
1.4E+09
1.2E+09
1.0E+09
8.0E+08
6.0E+08
4.0E+08
2.0E+08
0.0E+00
1942
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006

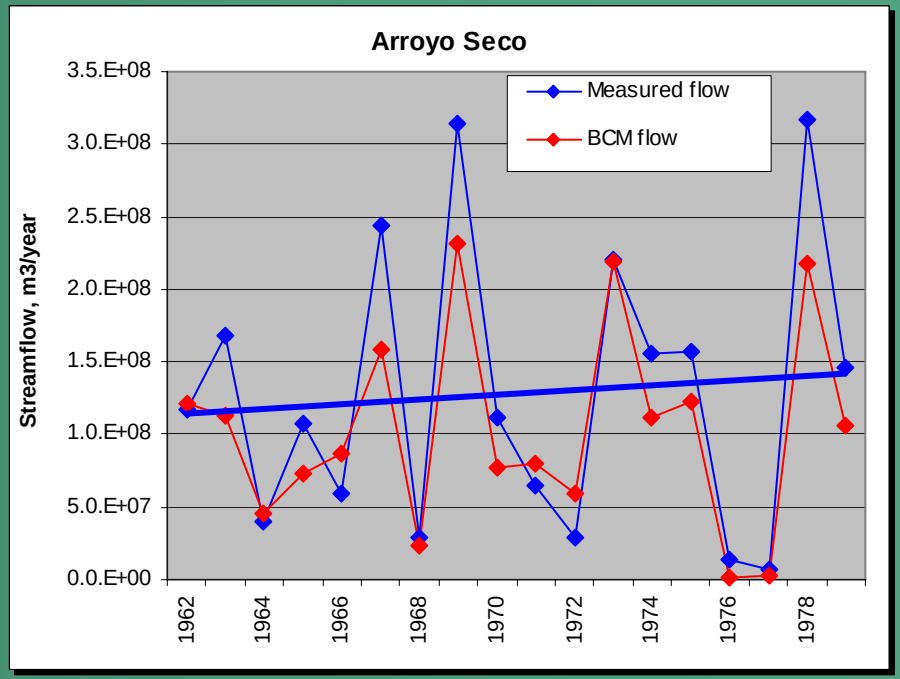

Klamath River
Streamflow, m3/year
4.5.E+10
4.0.E+10
3.5.E+10
3.0.E+10
2.5.E+10
2.0.E+10
1.5.E+10
1.0.E+10
5.0.E+09
0.0.E+00
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1999
2002
2005
Measured flow
BCM flow

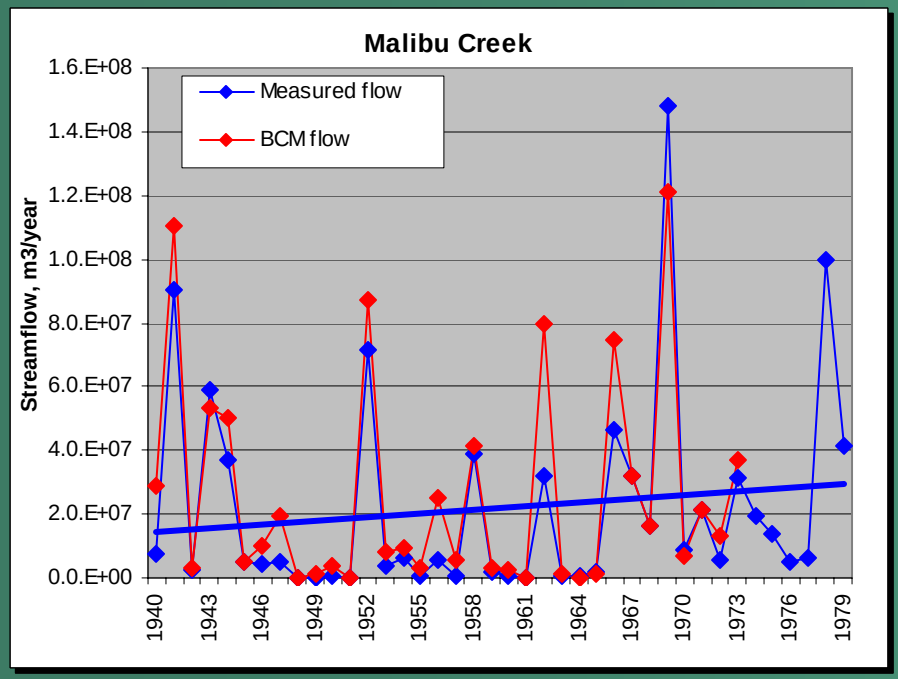

Redwood Creek
Streamflow, m3/year
1.8.E+09
1.6.E+09
1.4.E+09
1.2.E+09
1.0.E+09
8.0.E+08
6.0.E+08
4.0.E+08
2.0.E+08
0.0.E+00
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
Measured flow
BCM flow

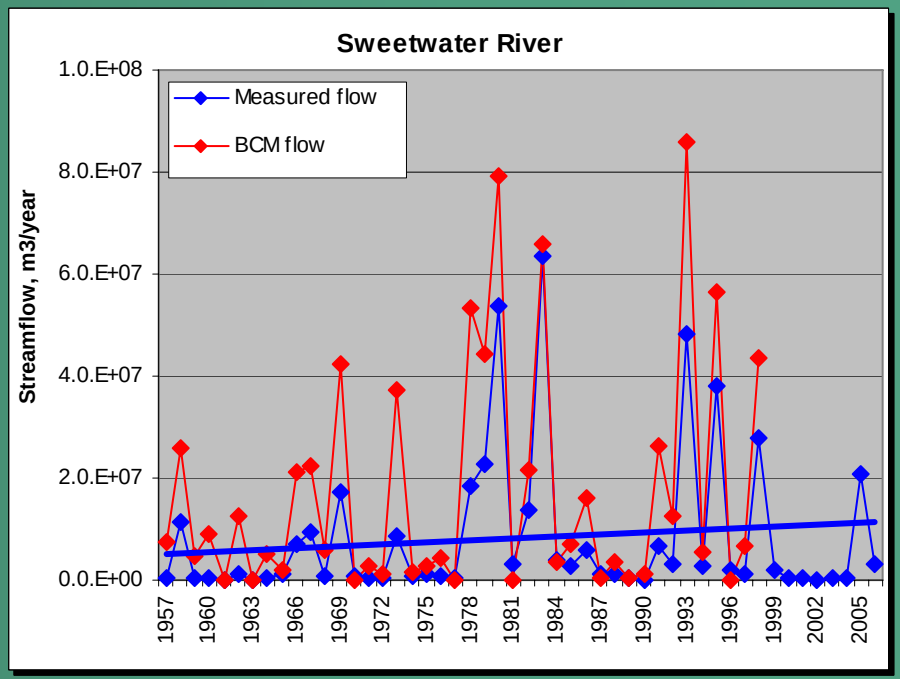

Navarro River
Streamflow, m3/year
1.4.E+09
1.2.E+09
1.0.E+09
8.0.E+08
6.0.E+08
4.0.E+08
2.0.E+08
0.0.E+00
1951
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
Measured flow
BCM flow


Pescadero Creek
Streamflow, m3/year
1.6.E+08
1.4.E+08
1.2.E+08
1.0.E+08
8.0.E+07
6.0.E+07
4.0.E+07
2.0.E+07
0.0.E+00
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
Measured flow
BCM flow

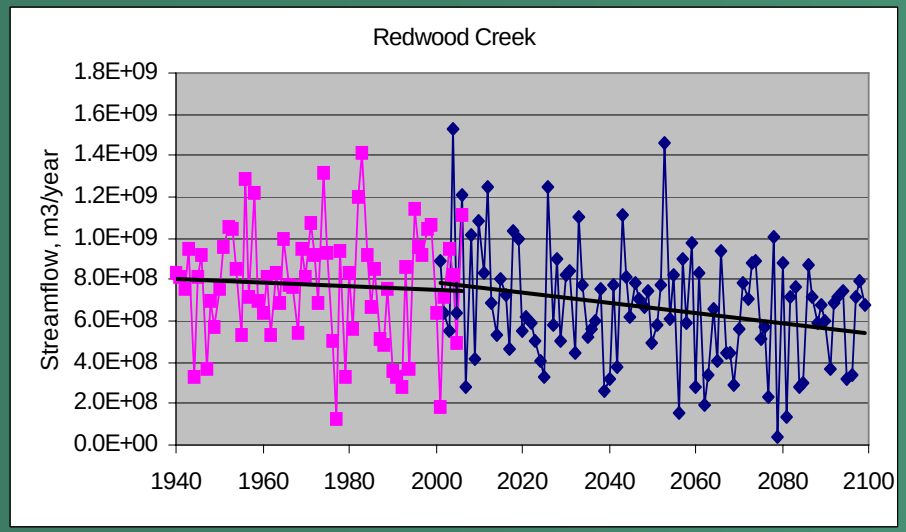

Big Sur River
Streamflow, m3/year
Measured flow
BCM flow
3.0.E+08
2.5.E+08
2.0.E+08
1.5.E+08
1.0.E+08
5.0.E+07
0.0.E+00
1951
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003

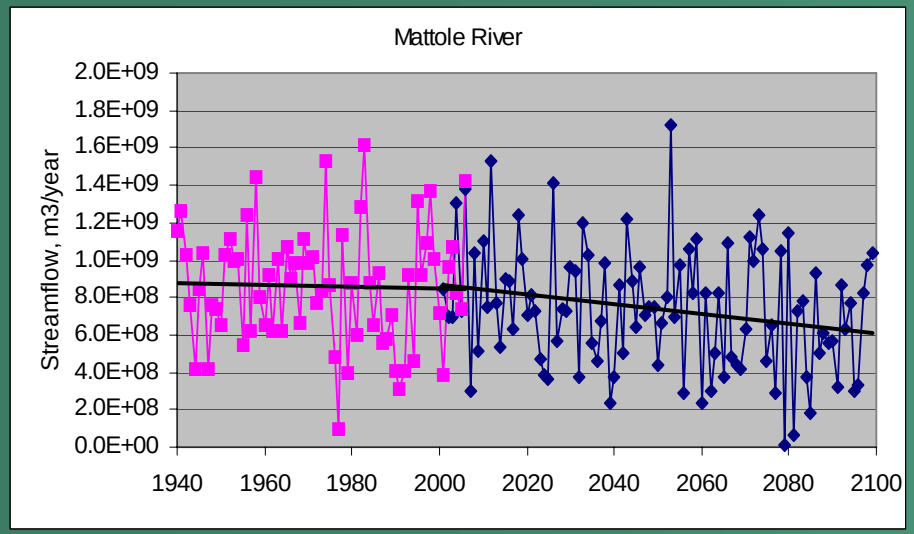

Arroyo Seco
Streamflow, m3/year
Measured flow
BCM flow
3.5.E+08
3.0.E+08
2.5.E+08
2.0.E+08
1.5.E+08
1.0.E+08
5.0.E+07
0.0.E+00
1962
1964
1966
1968
1970
1972
1974
1976
1978


Malibu Creek
Streamflow, m3/year
Measured flow
BCM flow
1.6.E+08
1.4.E+08
1.2.E+08
1.0.E+08
8.0.E+07
6.0.E+07
4.0.E+07
2.0.E+07
0.0.E+00
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979

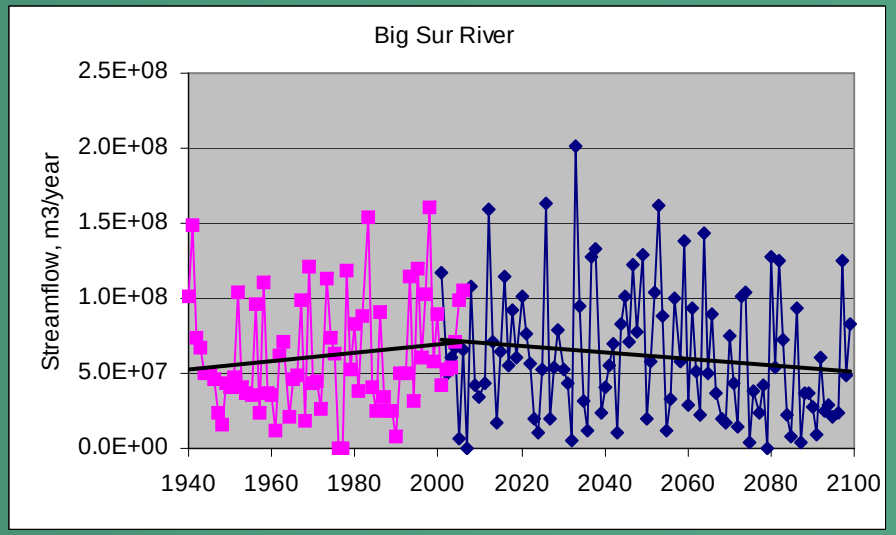

Sweetwater River
Streamflow, m3/year
Measured flow
BCM flow
1.0.E+08
8.0.E+07
6.0.E+07
4.0.E+07
2.0.E+07
0.0.E+00
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005

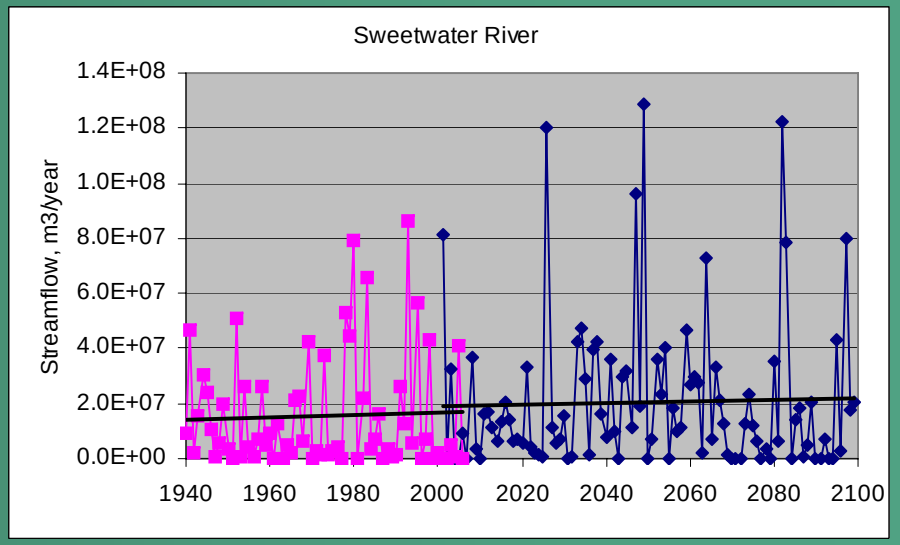
Northern California

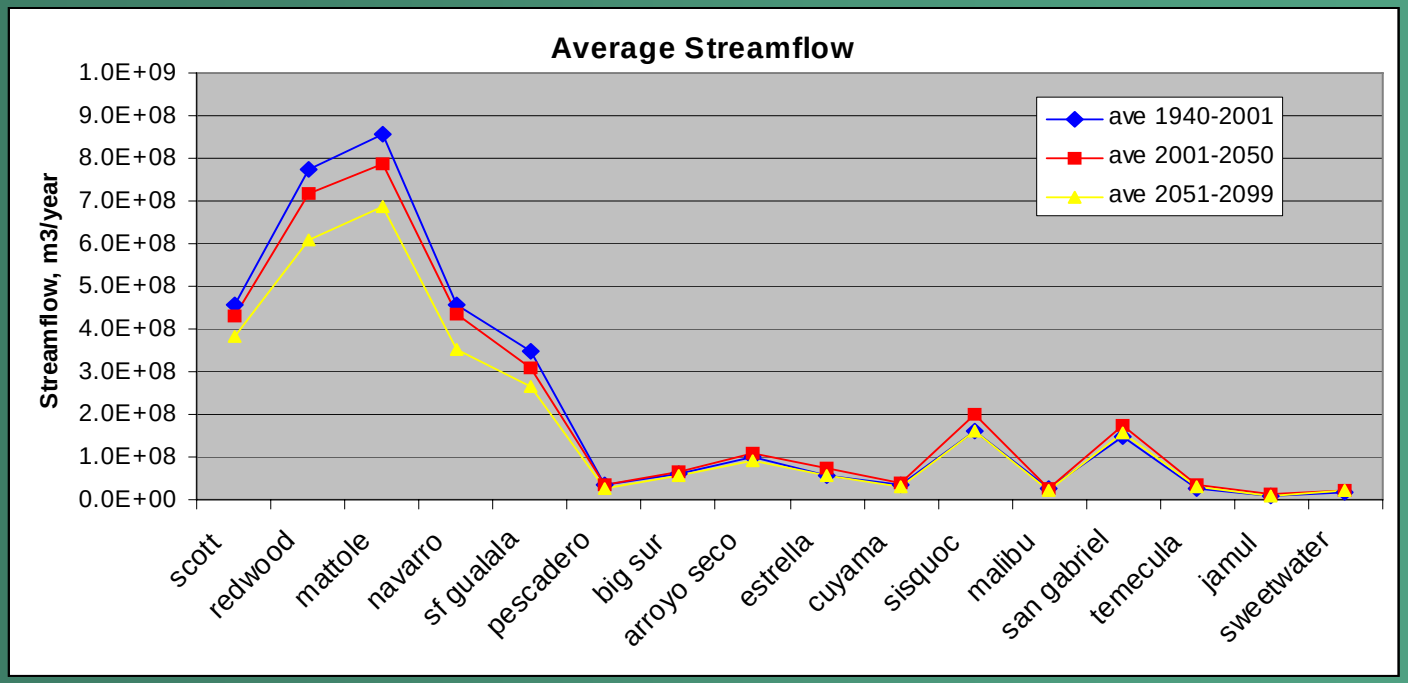


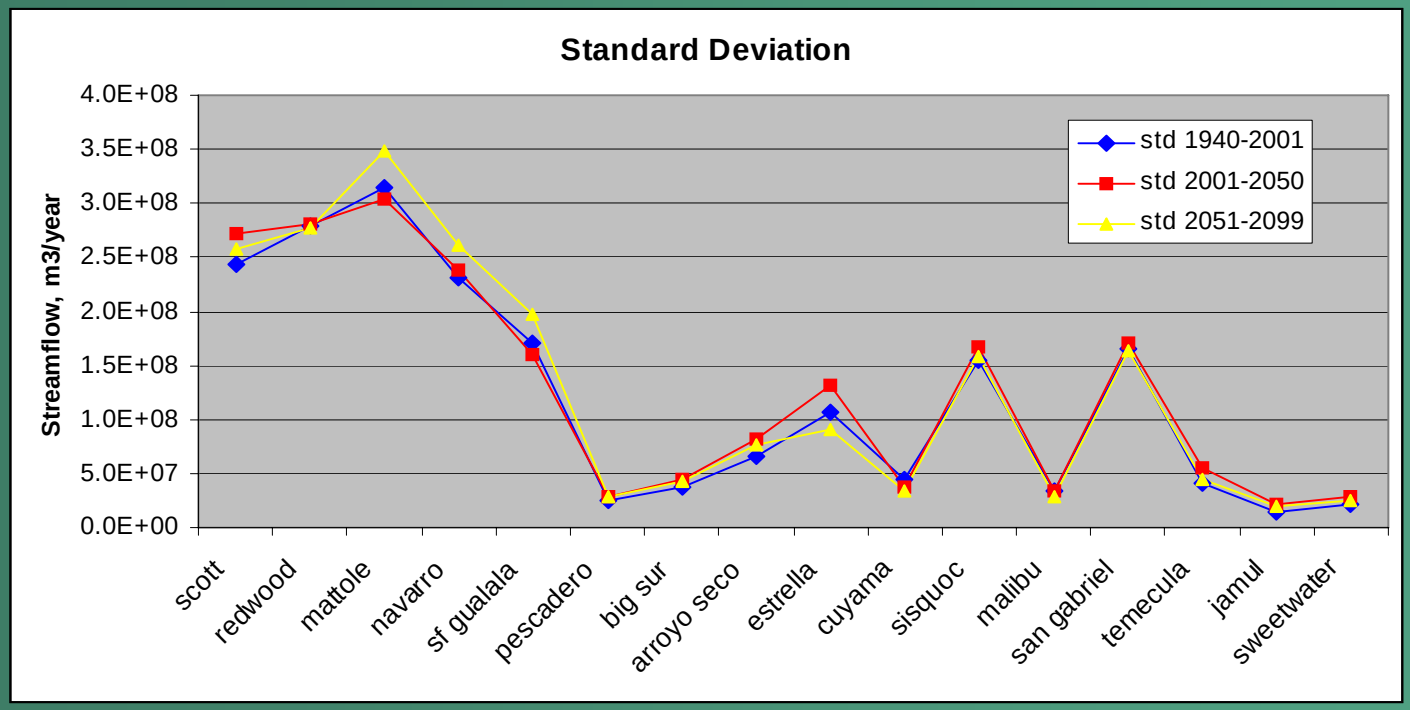


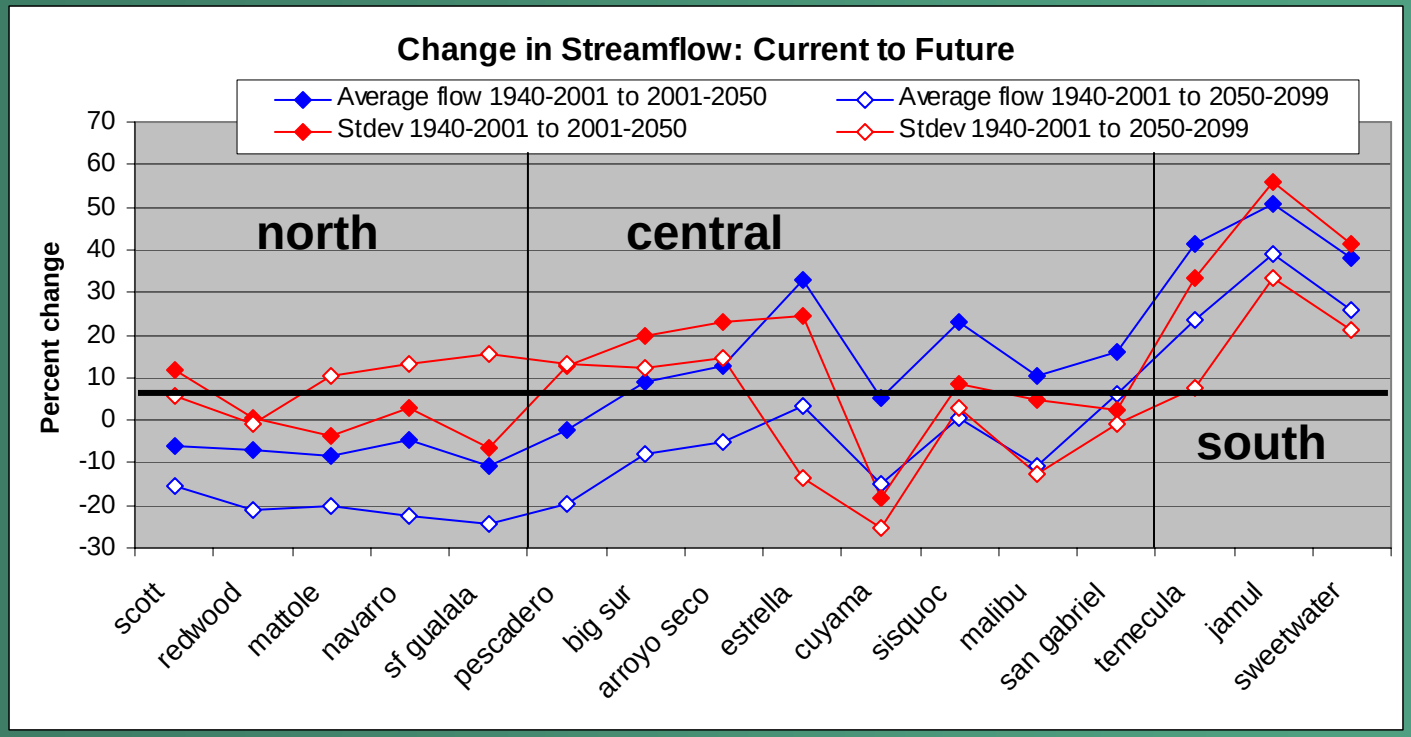
Southern California

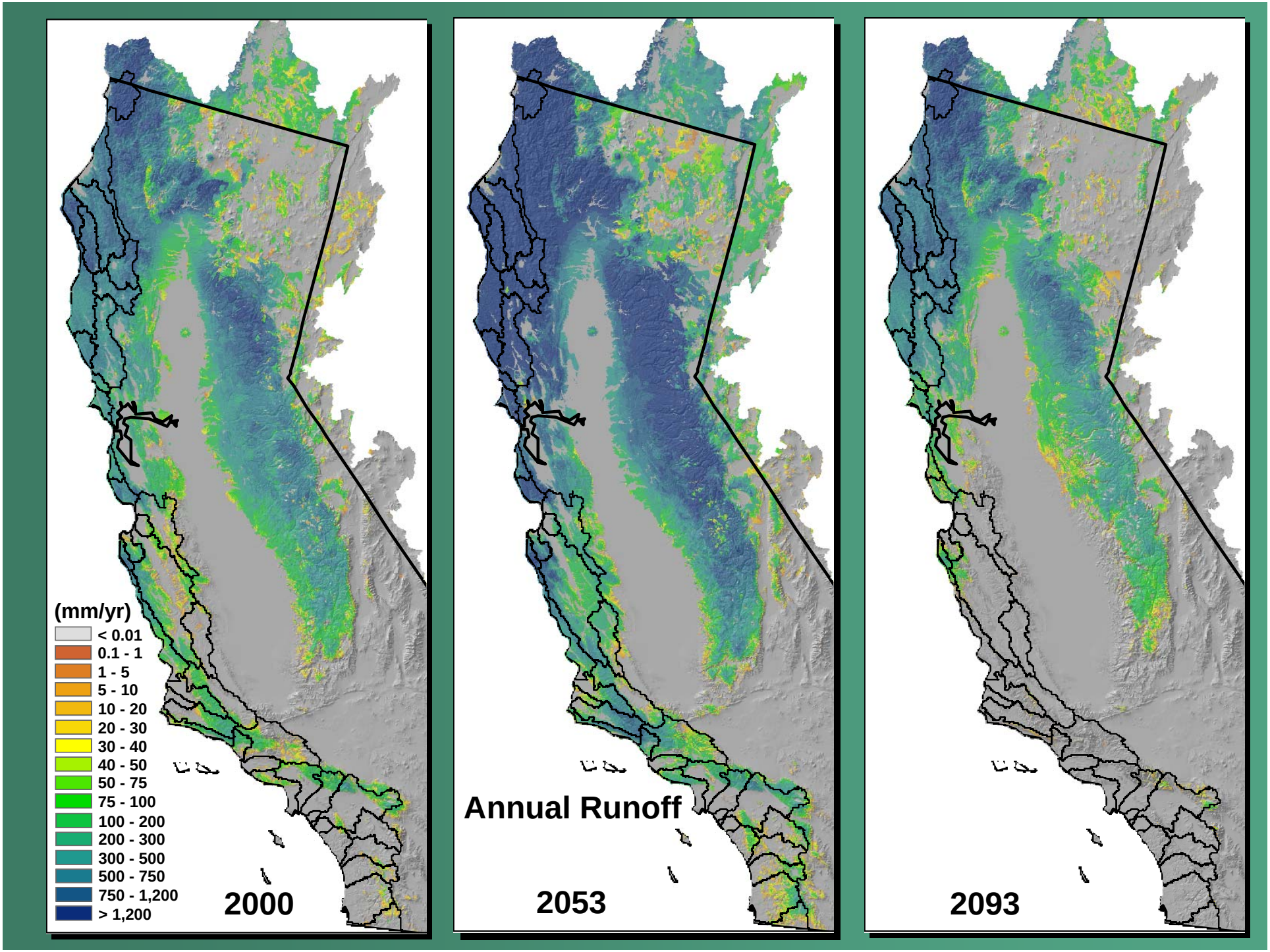


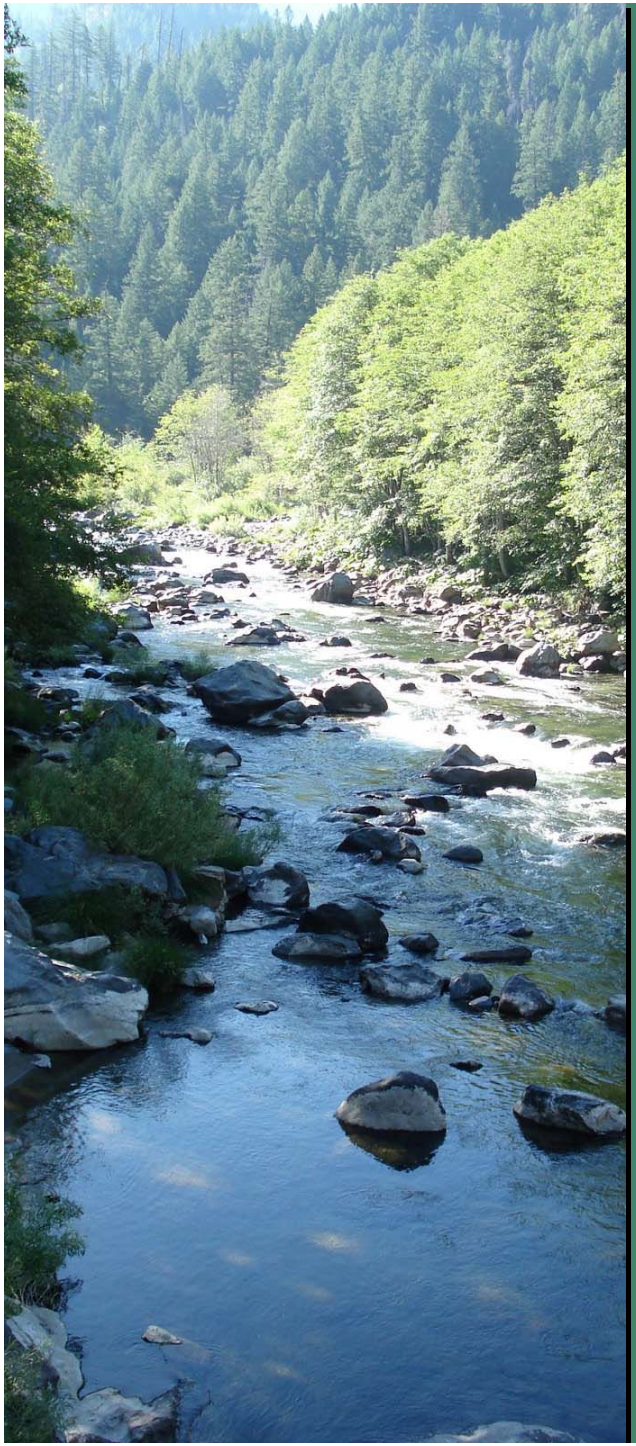



Average Streamflow
Streamflow, m3/year
1.0E+09
9.0E+08
8.0E+08
7.0E+08
6.0E+08
5.0E+08
4.0E+08
3.0E+08
2.0E+08
1.0E+08
0.0E+00
ave 1940-2001
ave 2001-2050
ave 2051-2099
scott
redwood
mattole
navarro
sf gualala
pescadero
big sur
arroyo seco
estrella
cuyama
sisquoc
malibu
san gabriel
temecula
jamul
sweetwater


Standard Deviation
Streamflow, m3/year
4.0E+08
3.5E+08
3.0E+08
2.5E+08
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
std 1940-2001
std 2001-2050
std 2051-2099
scott
redwood
mattole
navarro
sf gualala
pescadero
big sur
arroyo seco
estrella
cuyama
sisquoc
malibu
san gabriel
temecula
jamul
sweetwater


Change in Streamflow: Current to Future
Average flow 1940-2001 to 2001-2050
Average flow 1940-2001 to 2050-2099
Stdev 1940-2001 to 2001-2050
Stdev 1940-2001 to 2050-2099
Percent change
70
60
50
40
30
20
10
0
-10
-20
-30
north
central
south
scott
redwood
mattole
navarro
sf gualala
pescadero
big sur
arroyo seco
estrella
cuyama
sisquoc
malibu
san gabriel
temecula
jamul
sweetwater


(mm/yr)
< 0.01
0.1 - 1
1 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 75
75 - 100
100 - 200
200 - 300
300 - 500
500 - 750
750 - 1,200
> 1,200
2000
Annual Runoff
2053
2093



Summary

- Climate change projections were downscaled to ecologically relevant scales and scenario GFDL-A2 was translated to hydrologic variables for gaged and ungaged basins for all California coastal basins
- Projected streamflow differed among northern and southern basins
  - Northern basins generally had less average flow with increased variability later in the century
  - Central basins generally had more average flow and variability early in the century and less average flow and variability late
  - Southern basins had more average flow and more variability

Potential Application of Regional Modeling to Ecologic Resources

- Region-wide monthly distributions of
  - natural streamflow and timing
  - snowmelt and timing
  - air temperature
  - potential evapotranspiration
  - soil moisture
- Changes in monthly flows along with soil type, conditions, and slope, could provide indications of vulnerability to sediment transport
- Timing of temperature and moisture conditions can be applied to potential changes in plant distributions, forest health, and vulnerability to wildfire
- Regional hydrologic conditions can be applied to ecological assessments such as ELOHA, describing the baseline conditions for the “hydrologic foundation” for environmental flows

Ongoing Work

- Downscaling of additional climate projections
- Calibration of water-balance model to 190 ungaged basins in California
- Application to various ground-water models throughout California and integration with Modflow
- Refinement of water-balance model
  - daily time scale
    - applicable to environmental flows
    - applicable to sediment transport
  - seasonality in vegetation density
    - could also include temporal variation associated with regional distributions or wildfire
  - variation in future potential evaporation
  - solar radiation component to snow melt
    - DWR model (Snow-17) is based on air temperature only and don't reflect variation due to topographic shading from low sun angle when snow melt occurs earlier in the season due to warming
  - refinement of input data such as SSURGO soil data and fine-scale geologic mapping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