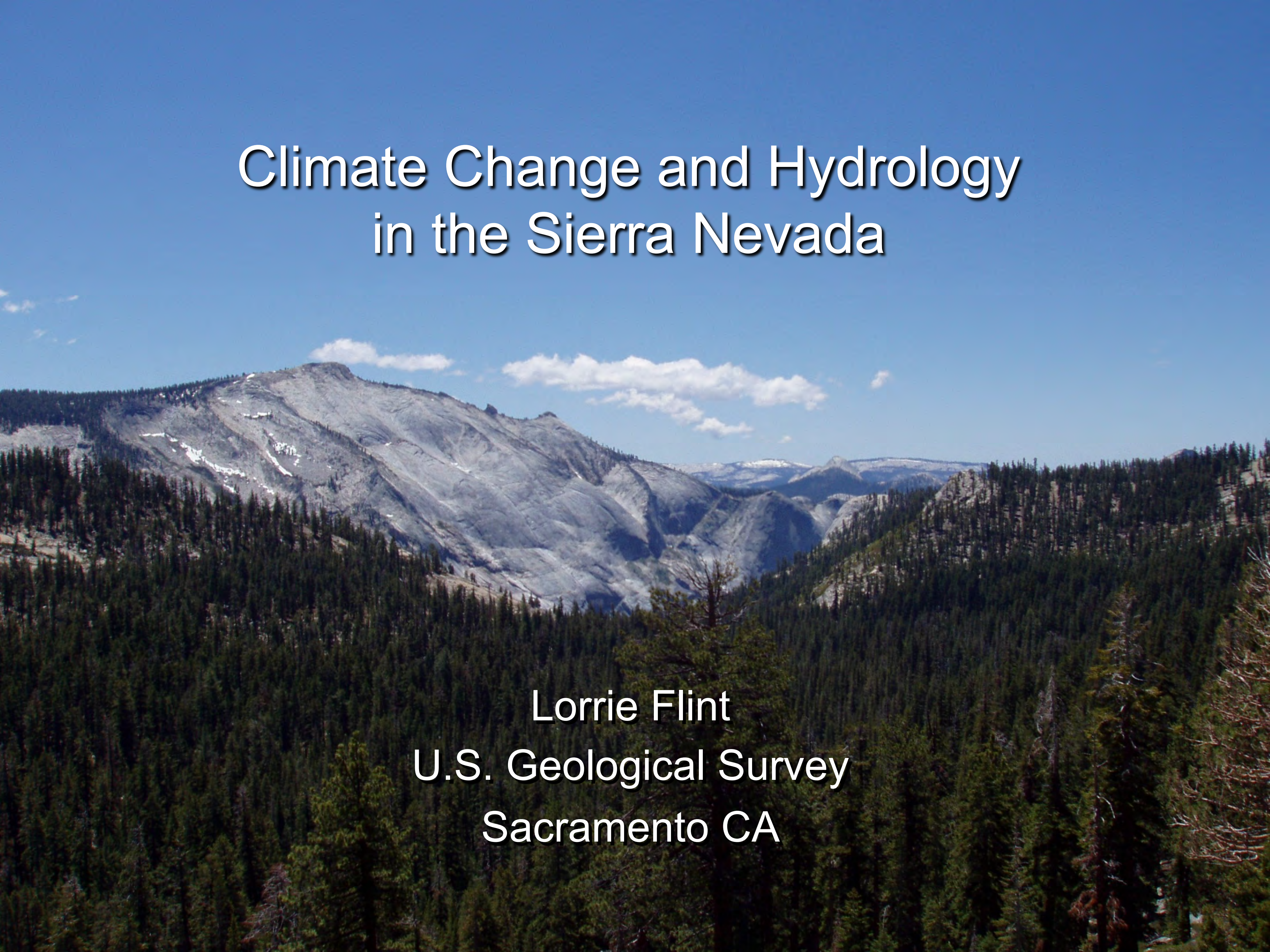


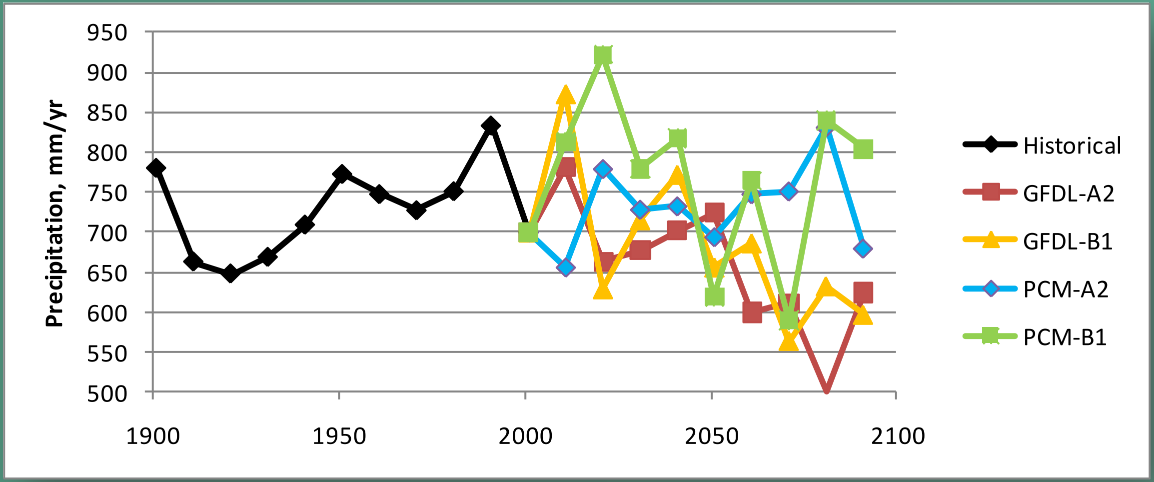
Climate Change and Hydrology in the Sierra Nevada

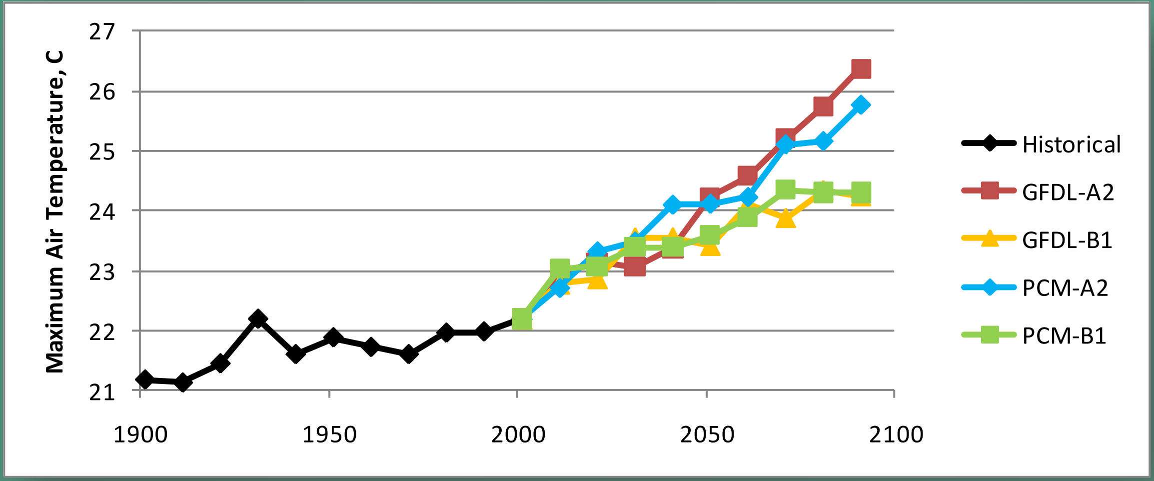
Lorrie Flint
U.S. Geological Survey
Sacramento CA

Discussion Topics

- Climate change for California
- Methods to evaluate hydrologic impacts
  - Water balance modeling
  - Downscaling projections
- Processes contributing to impacts
  - Timing of springtime snowmelt
  - Soil moisture
  - Cold air pooling and refugia
  - Climatic water deficit
  - Changes in delivery mechanisms: recharge vs runoff
- Implications for land and resource management

Climate for California: current and future conditions – 4 scenarios





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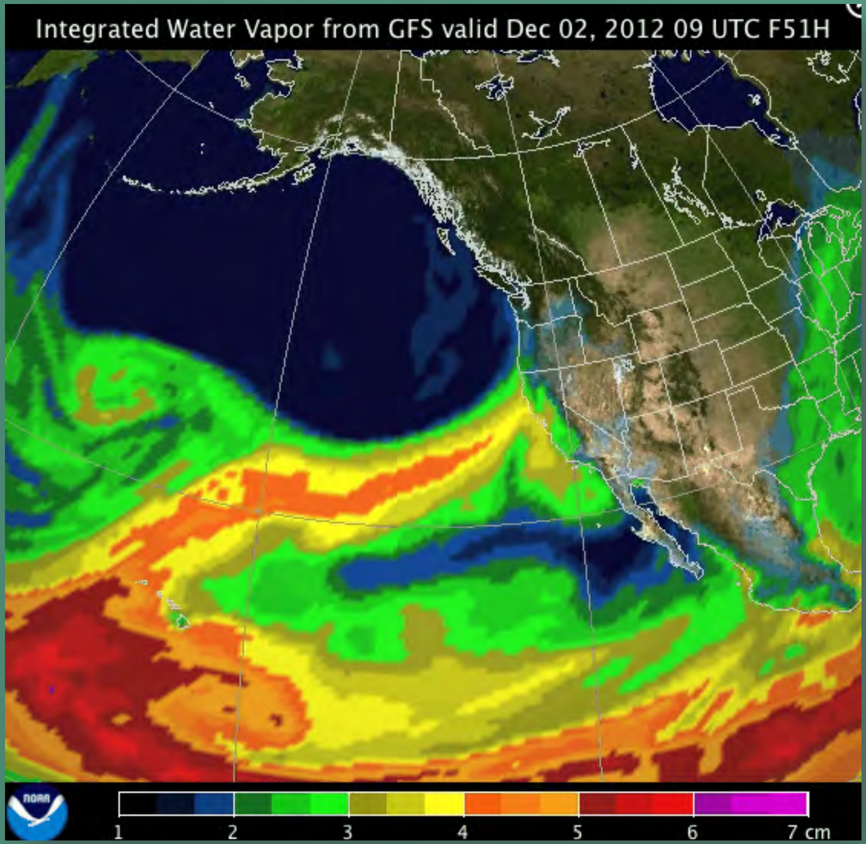
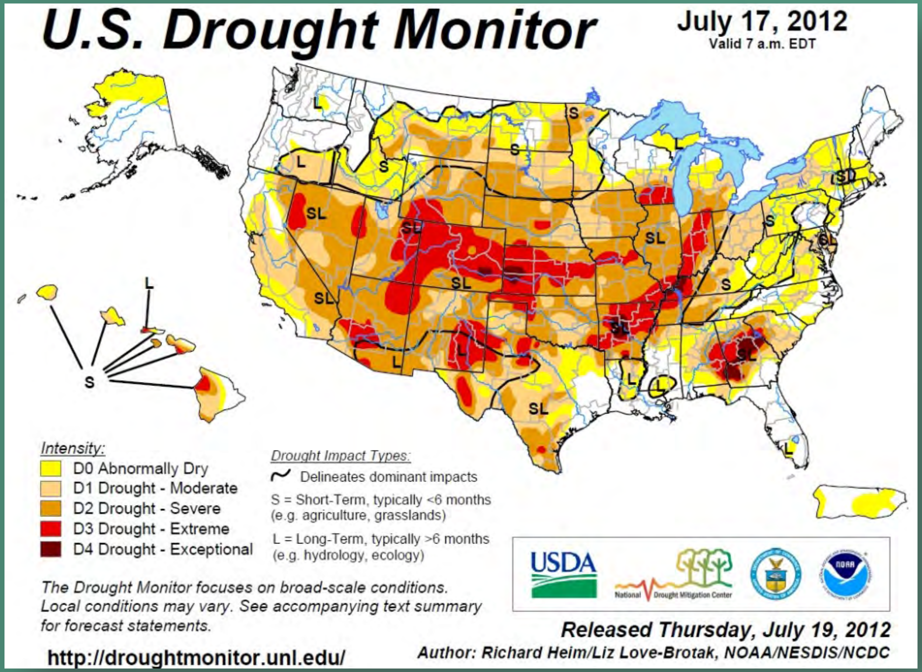
Climate for California: Extremes

Atmospheric Rivers!



Climate Change and Extremes



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Translating climate change to hydrologic response

- Requires an approach to simulate hydrology from available information
  - Basin Characterization Model (BCM)
    - grid-based data
    - uses climate data, soils, and geology to calculate
      - potential evapotranspiration
      - recharge and runoff
      - actual ET
      - climatic water deficit
      - snow accumulation and snow melt

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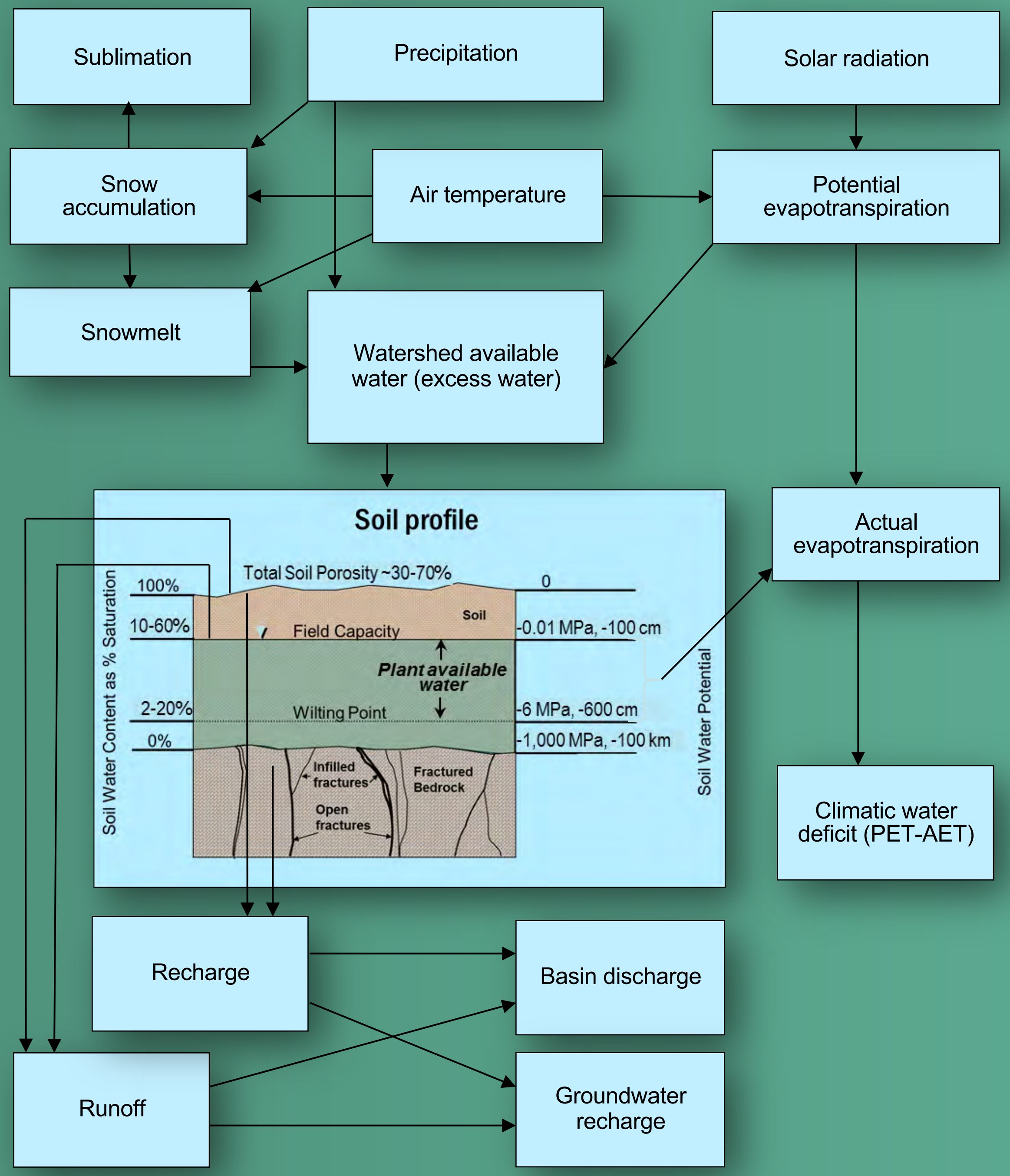

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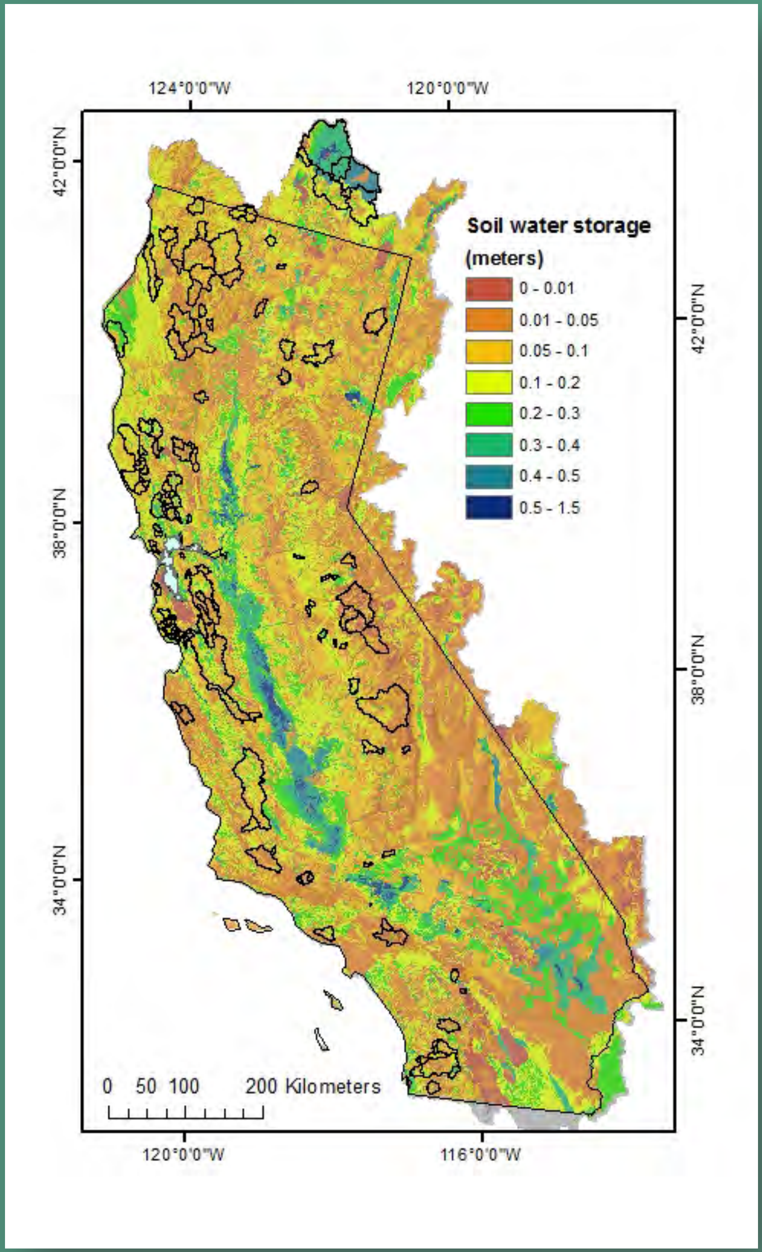
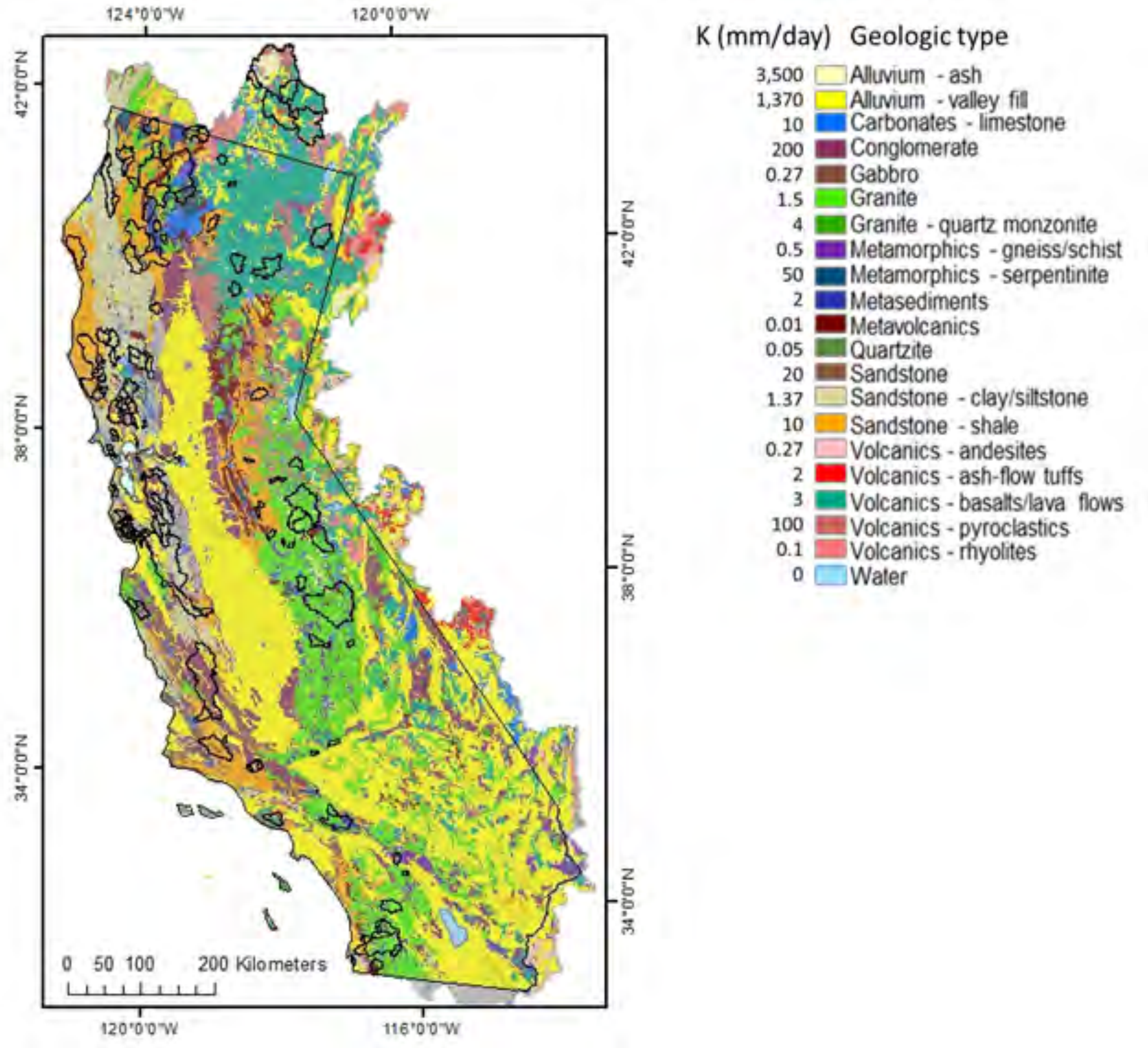
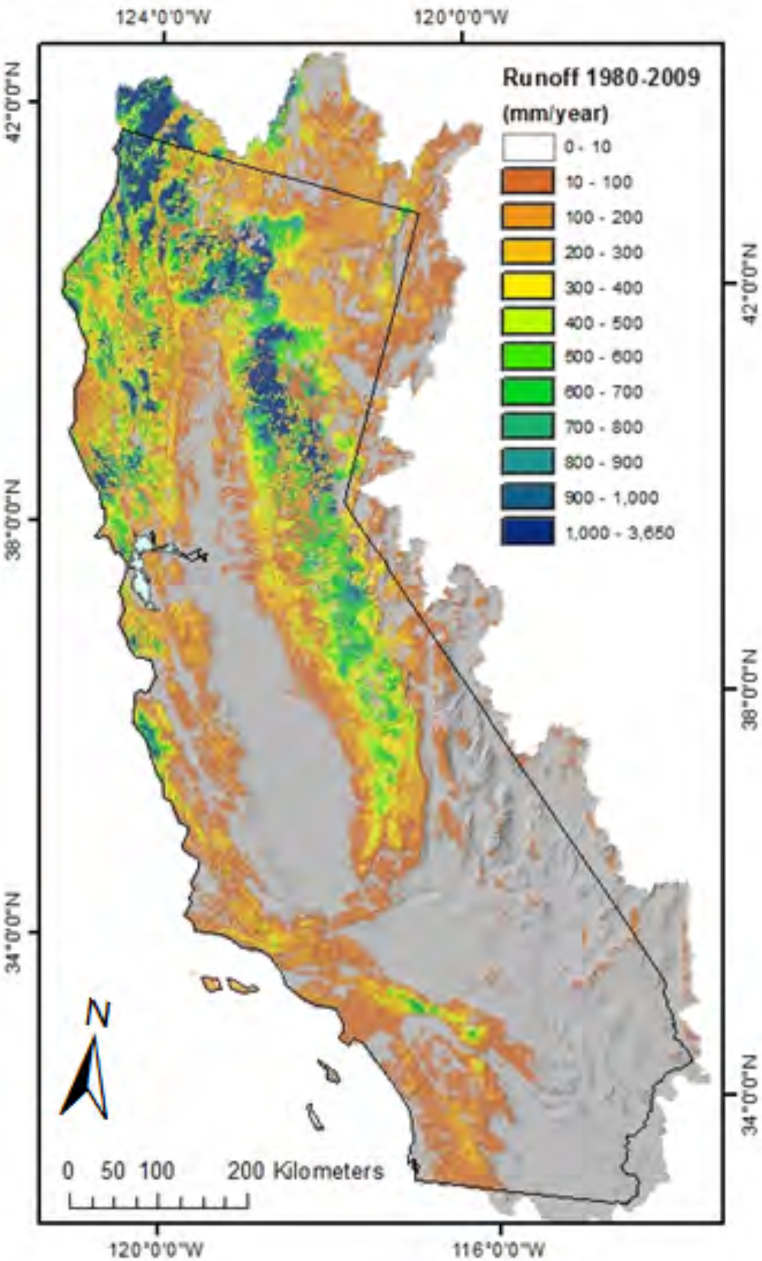
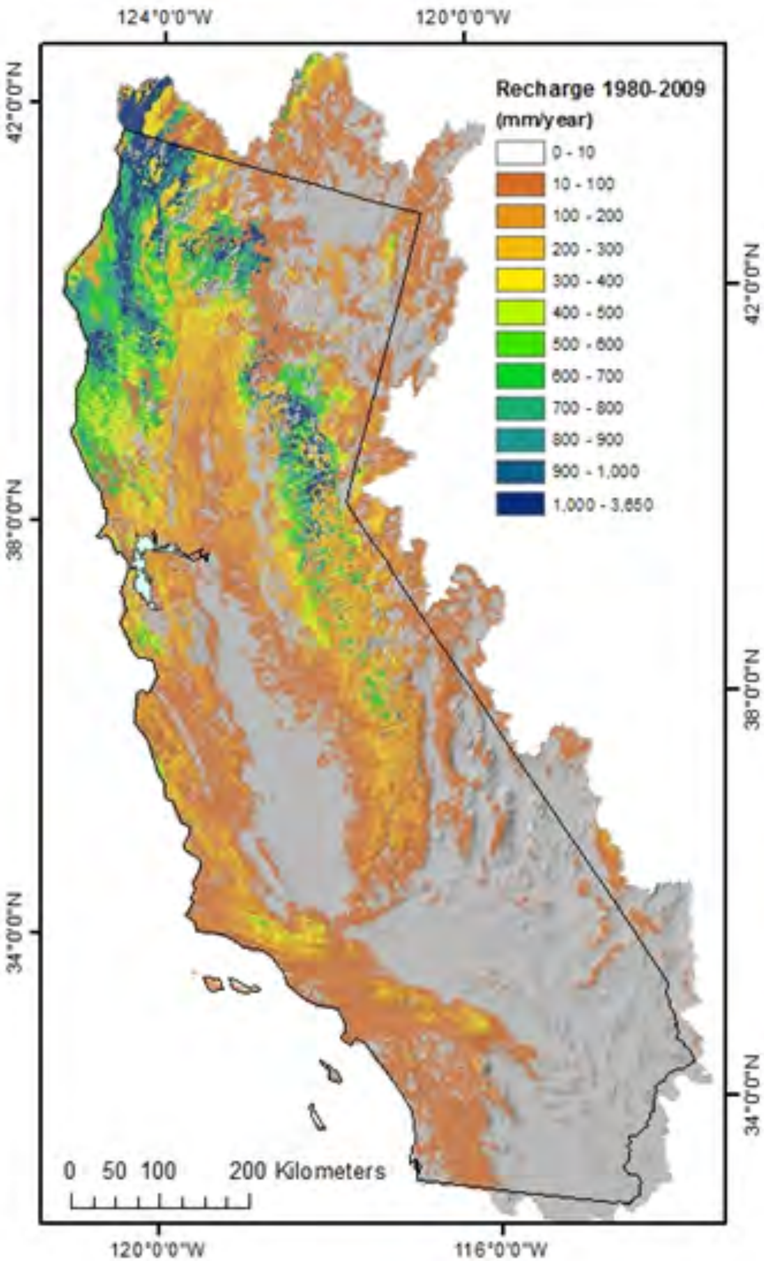
Soil moisture storage from SSURGO soils




124°0'0"W
120°0'0"W
42°0'0"N
38°0'0"N
34°0'0"N
120°0'0"W
116°0'0"W
42°0'0"N
38°0'0"N
34°0'0"N
0 50 100 200 Kilometers
K (mm/day) Geologic type
3,500 Alluvium - ash
1,370 Alluvium - valley fill
10 Carbonates - limestone
200 Conglomerate
0.27 Gabbro
1.5 Granite
4 Granite - quartz monzonite
0.5 Metamorphics - gneiss/schist
50 Metamorphics - serpentinite
2 Metasediments
0.01 Metavolcanics
0.05 Quartzite
20 Sandstone
1.37 Sandstone - clay/siltstone
10 Sandstone - shale
0.27 Volcanics - andesites
2 Volcanics - ash-flow tuffs
3 Volcanics - basalts/lava flows
100 Volcanics - pyroclastics
0.1 Volcanics - rhyolites
0 Water


Runoff 1980-2009
(mm/year)
0 - 10
10 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1,000
1,000 - 3,650
N
0 50 100 200 Kilometers
124°0'0"W
120°0'0"W
42°0'0"N
38°0'0"N
34°0'0"N
116°0'0"W


Recharge 1980-2009
(mm/year)
0 - 10
10 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1,000
1,000 - 3,650
0 50 100 200 Kilometers
124°0'0"W
120°0'0"W
42°0'0"N
38°0'0"N
34°0'0"N
116°0'0"W

Impacts of a changing climate on hydrologic processes

- Soil moisture
- Snowpack and springtime runoff
- Changes in mechanisms for water delivery, partitioning recharge and runoff
- Cold-air pooling and refugia
- Climatic water deficit
  - Demand estimates
  - Landscape stress and resiliency

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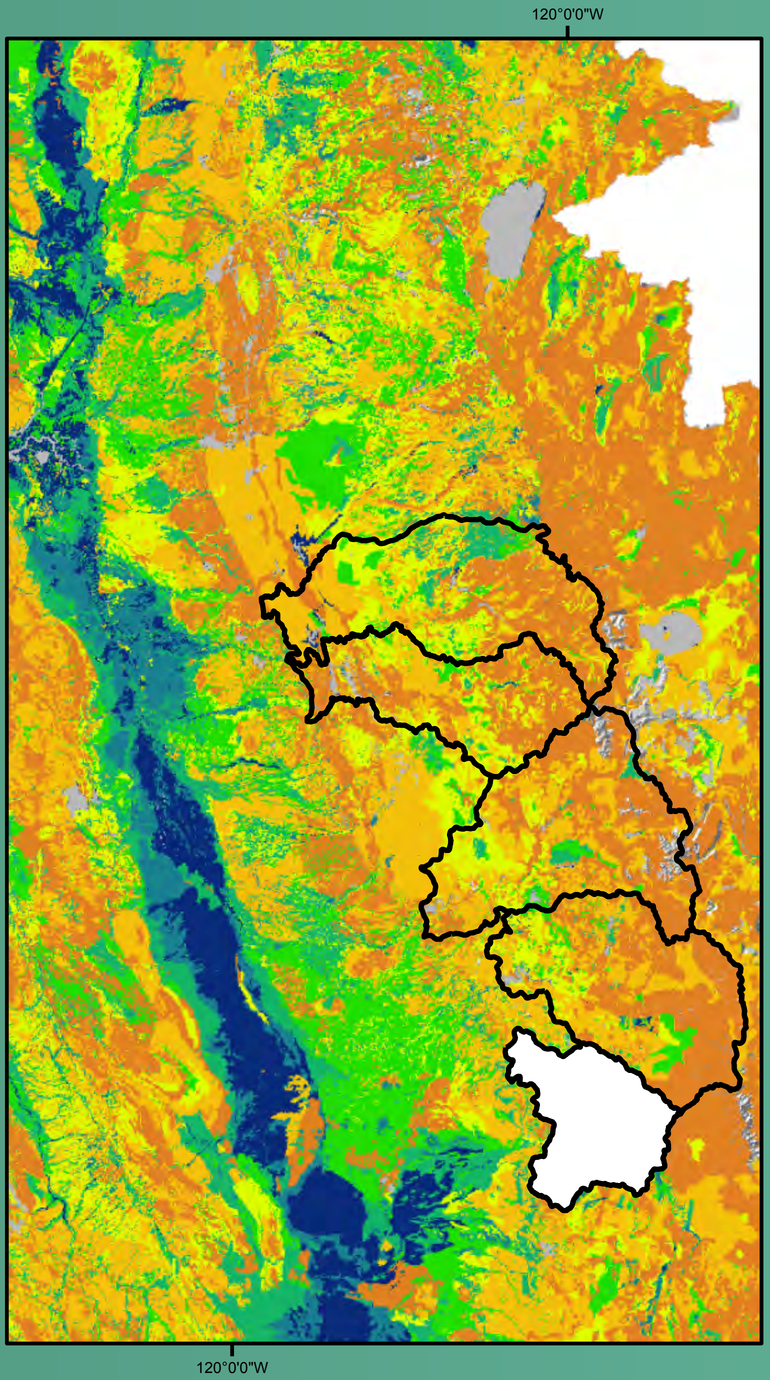
Soil water influences on water availability

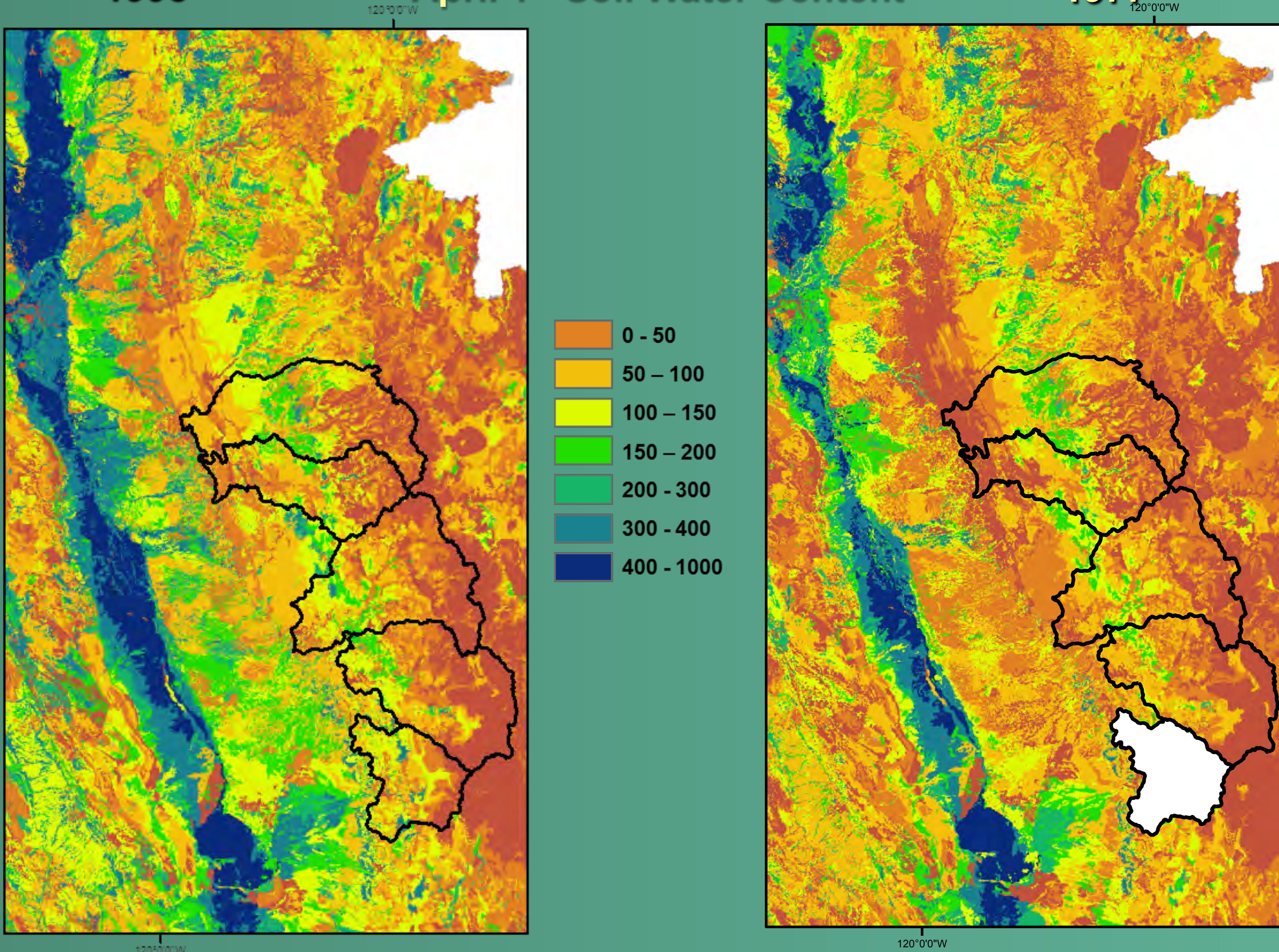
Available Soil Storage (mm)

- 0 - 50
- 50 – 100
- 100 – 150
- 150 – 200
- 200 - 300
- 300 - 400
- 400 - 1000

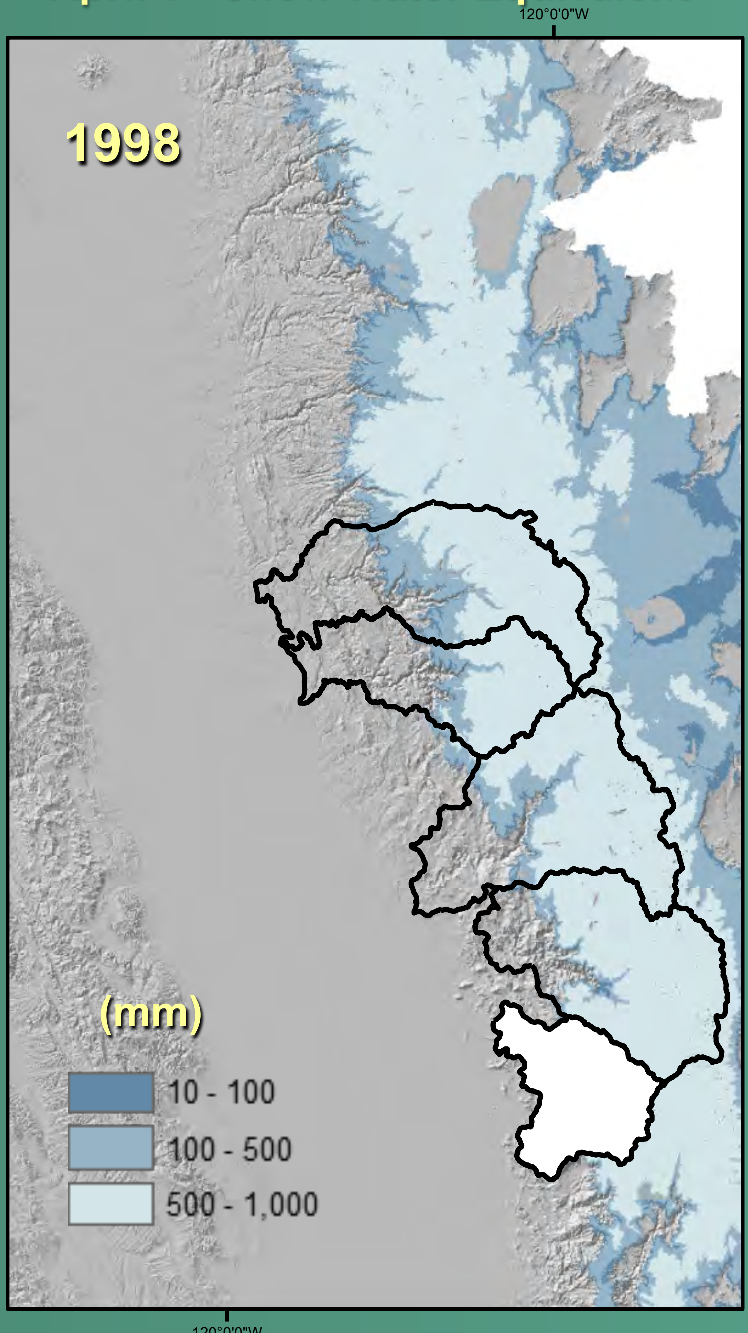


April 1st Soil Water Content

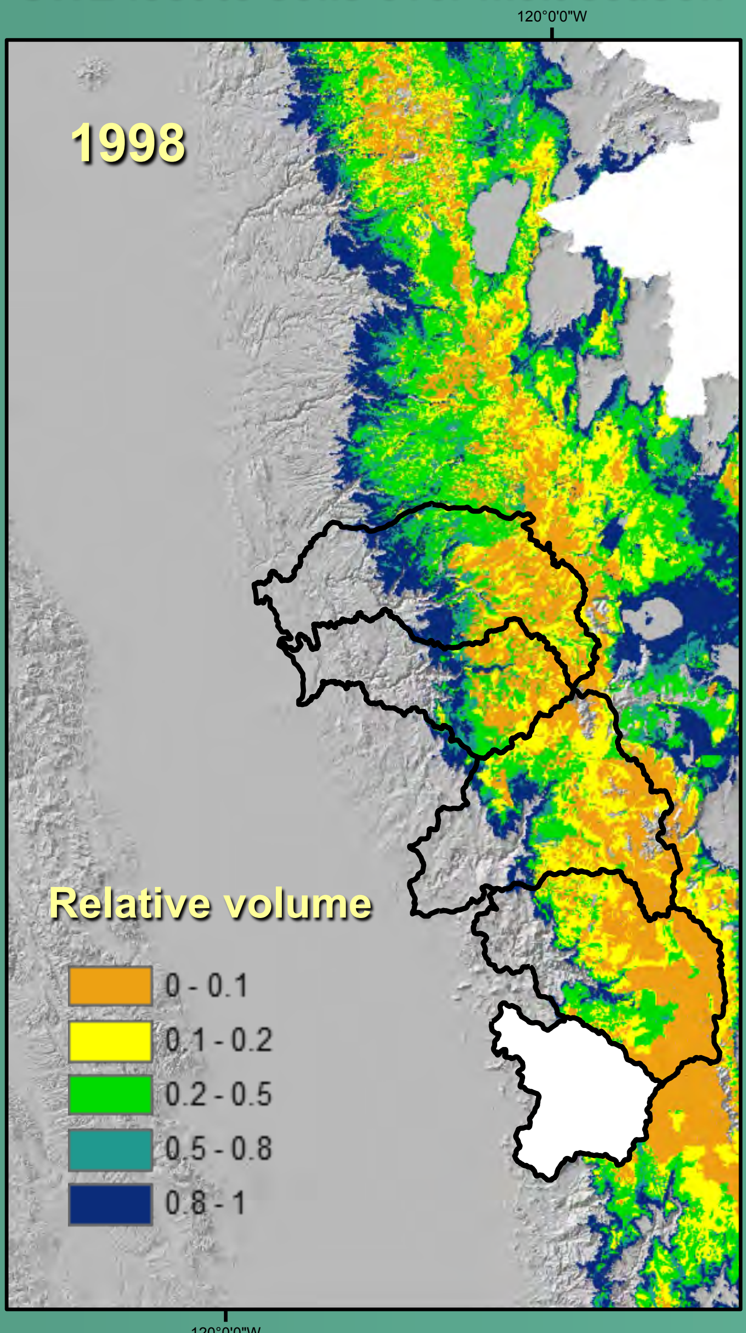
1998 | 1977



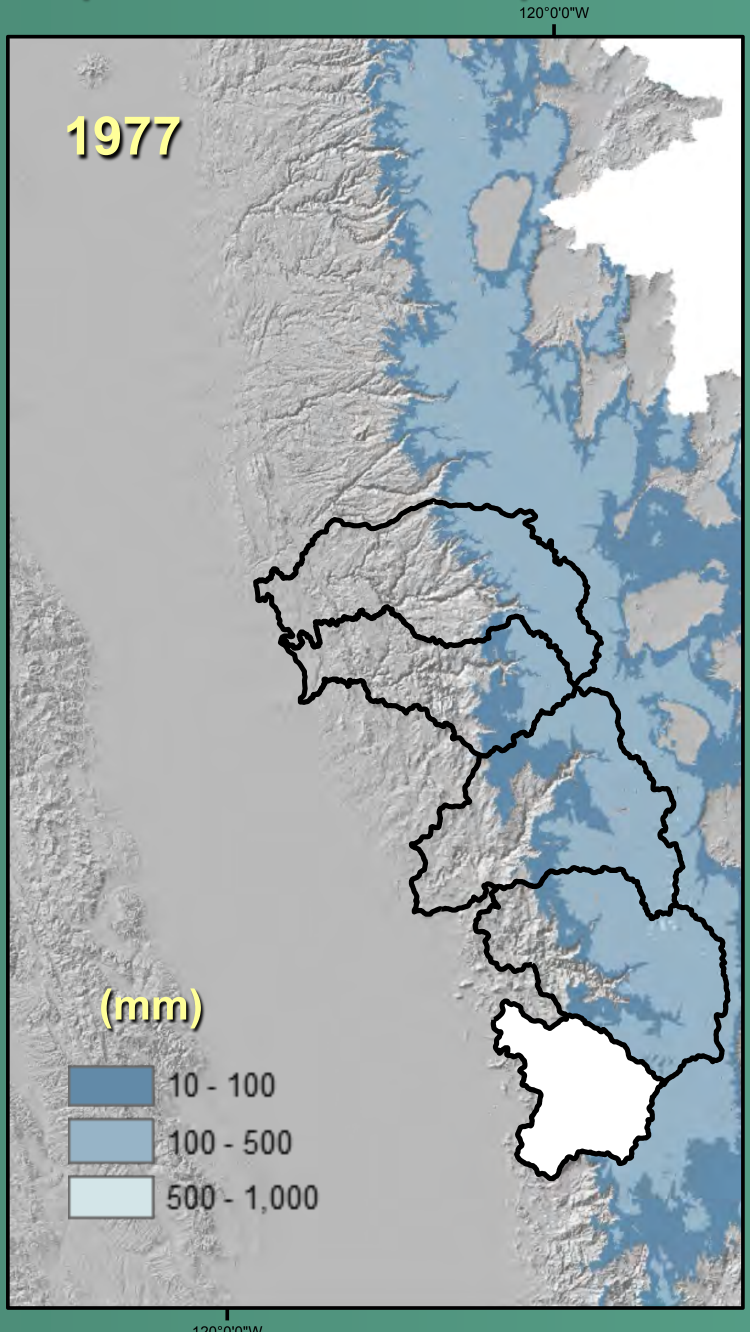
April 1st Snow Water Equivalent



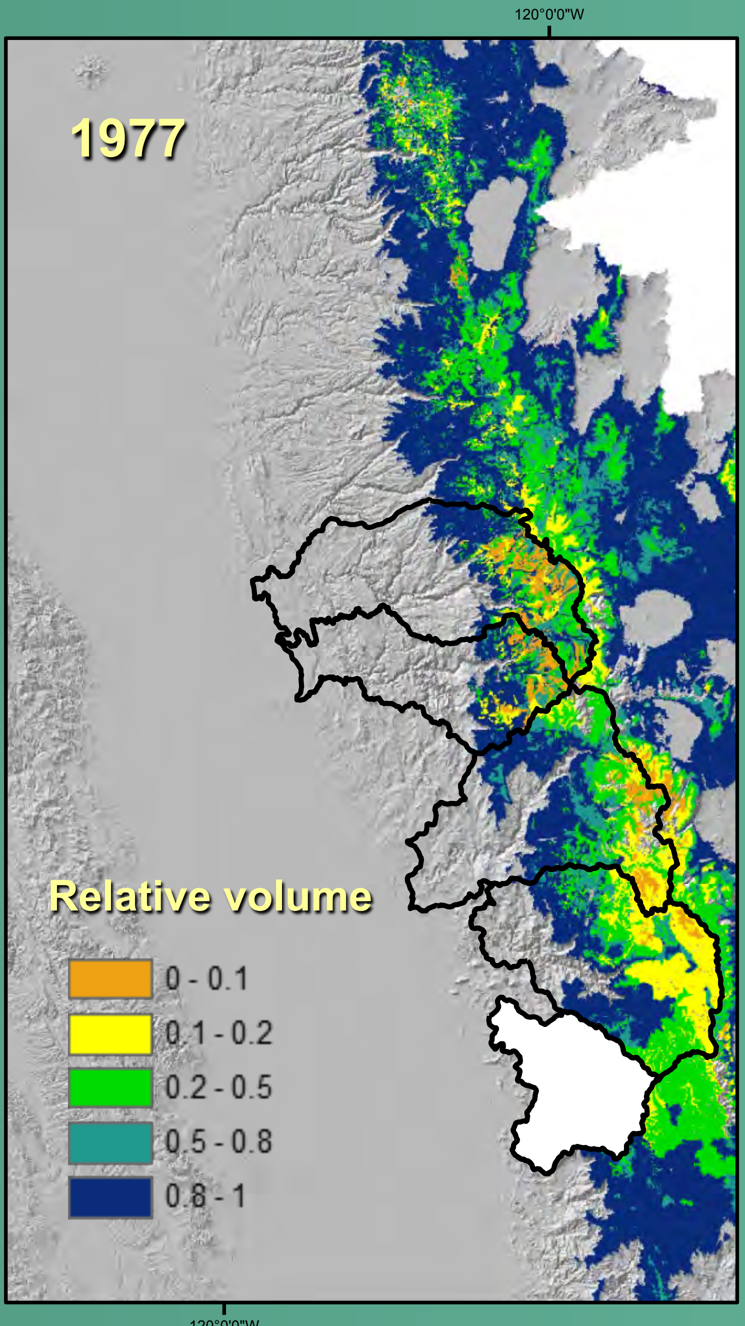
SWE lost to soils over melt season



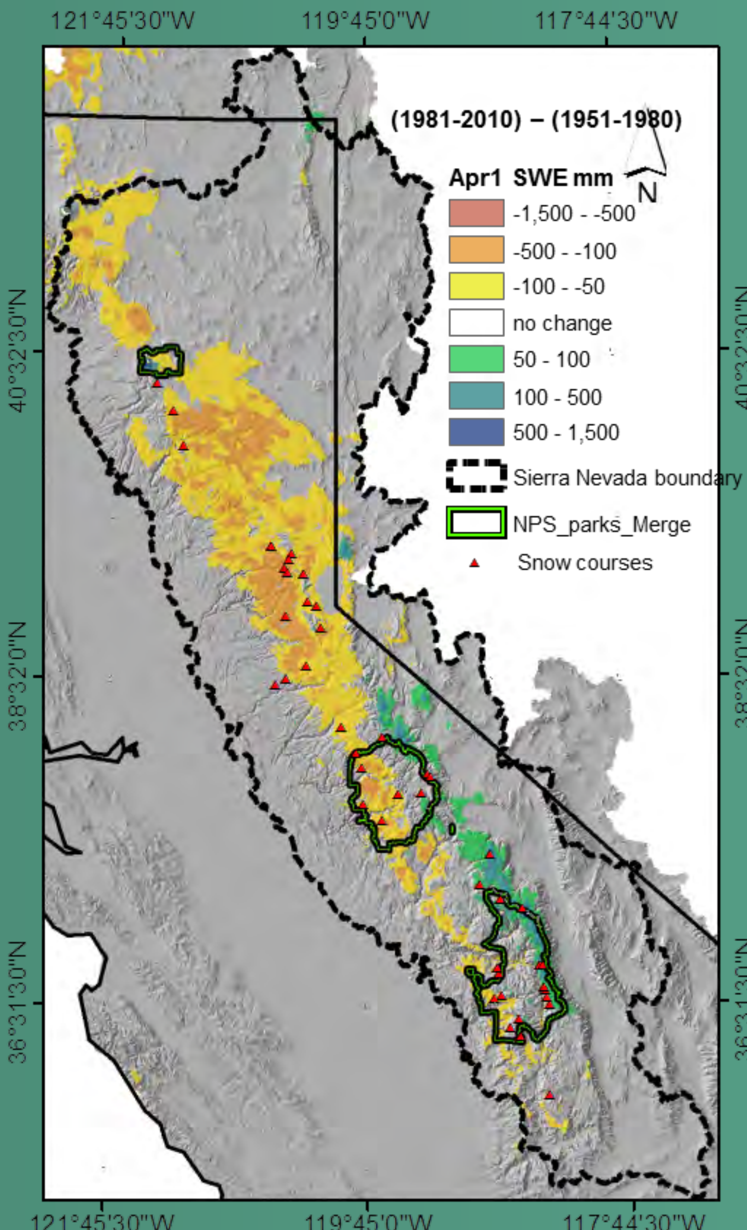
April 1st Snow Water Equivalent



SWE lost to soils over melt season



Changes in April 1st snowpack (SWE)



- Change from baseline (1951-1980) to current (1981-2010)
- Decreases due to warming at all but the highest elevations

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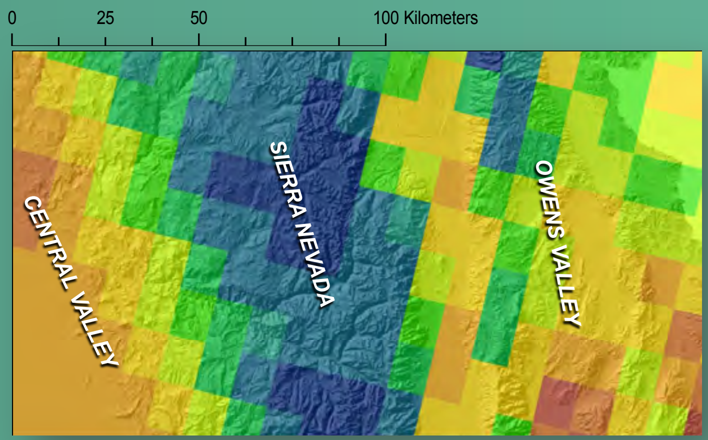
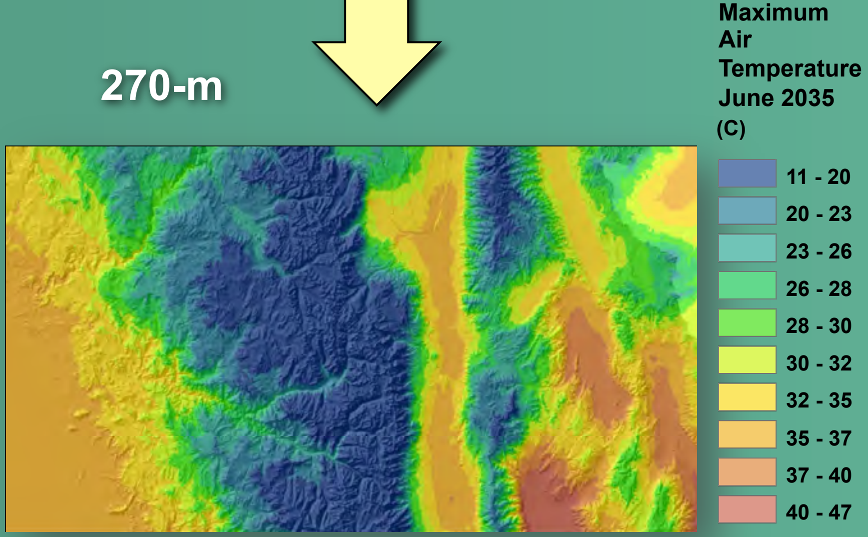
Downscaling Climate Change Scenarios

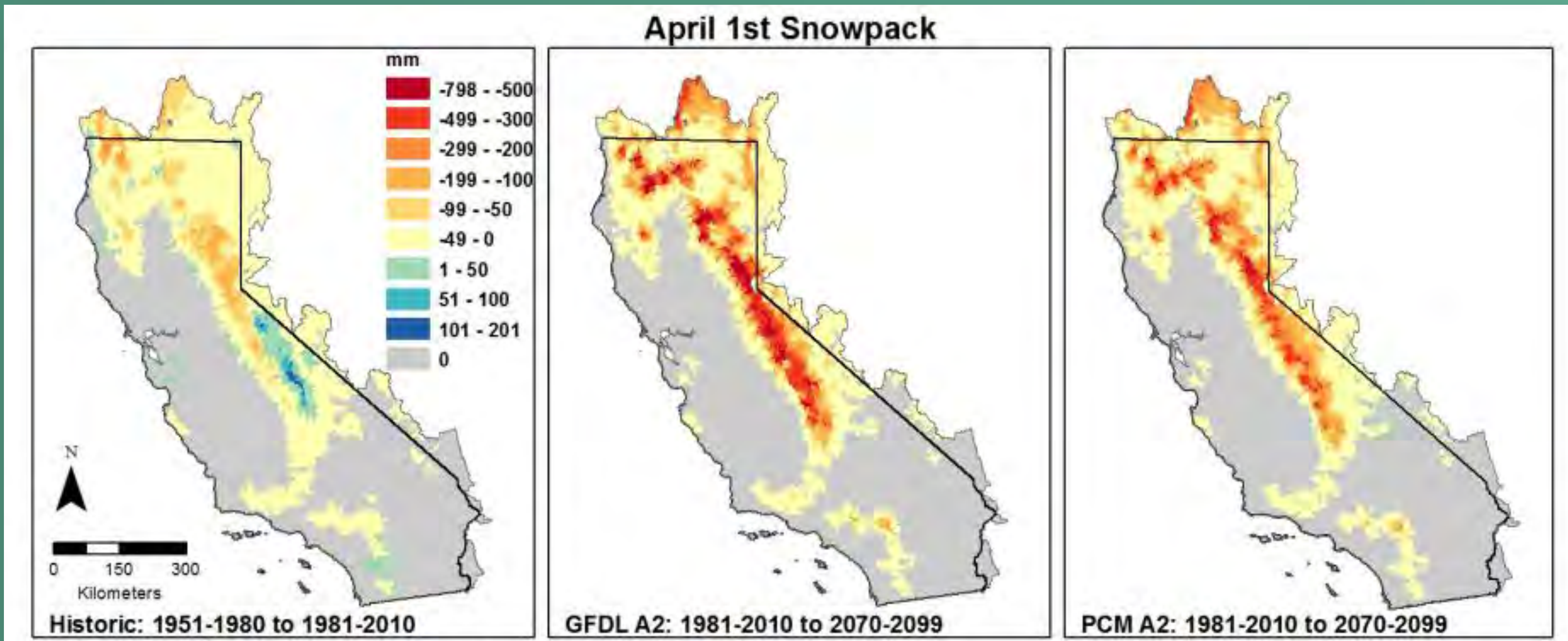
- Data are spatially downscaled to 270-m using Gradient-Inverse-Distance-Squared interpolation for hydrologic model application
- For every month an equation is developed for every grid cell using northing, easting, and elevation to incorporate elevational and regional gradients

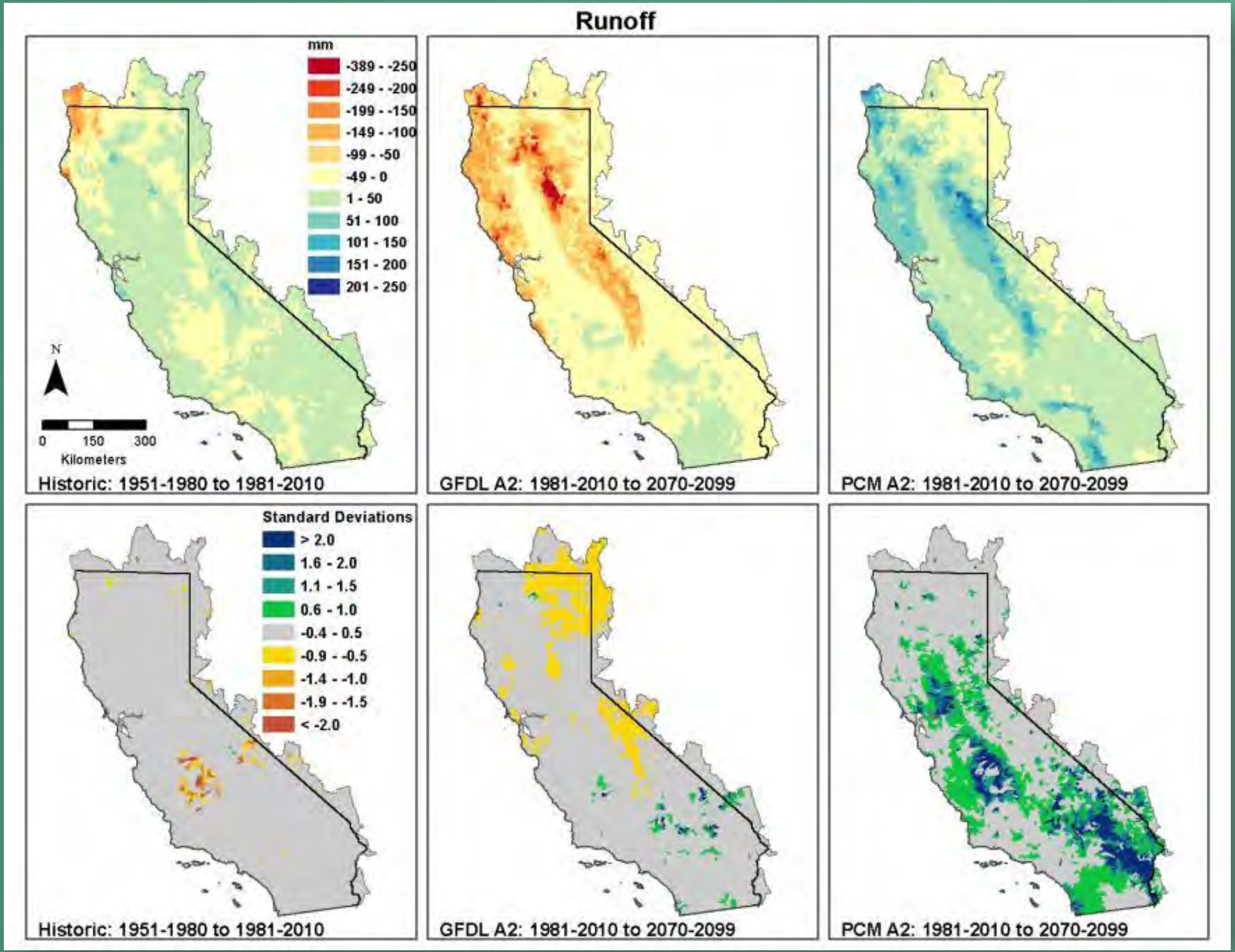
12-km



270-m

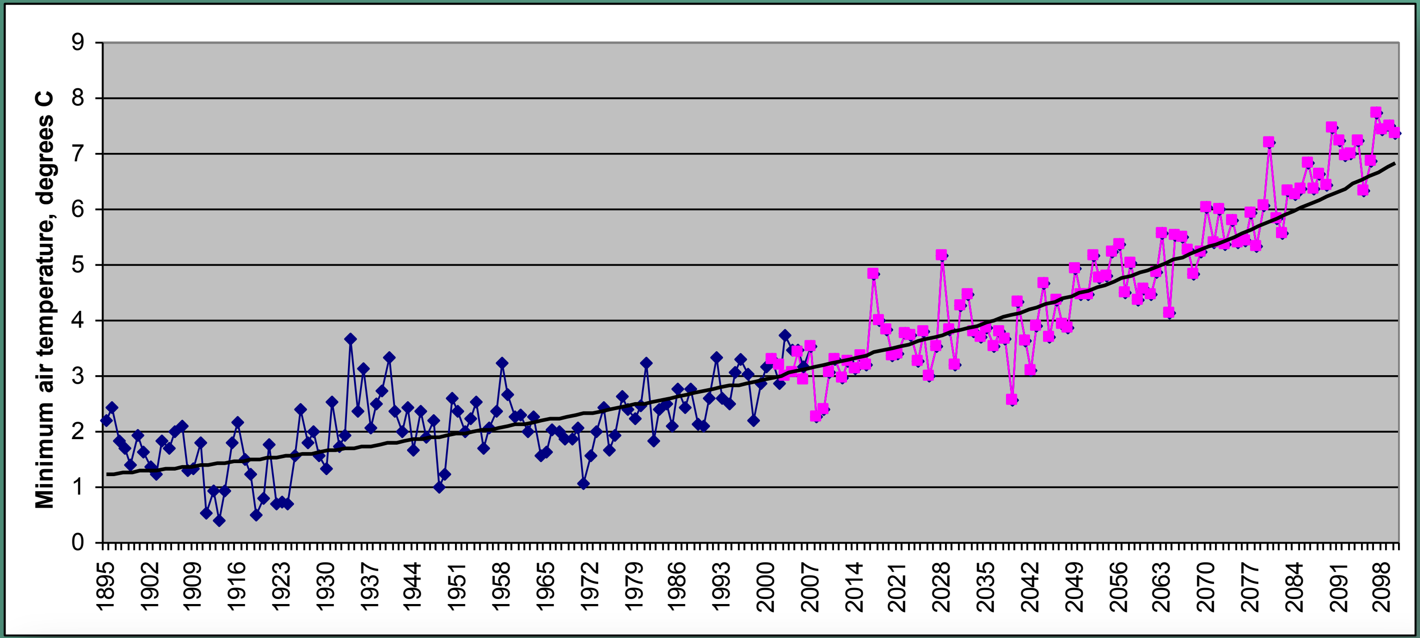


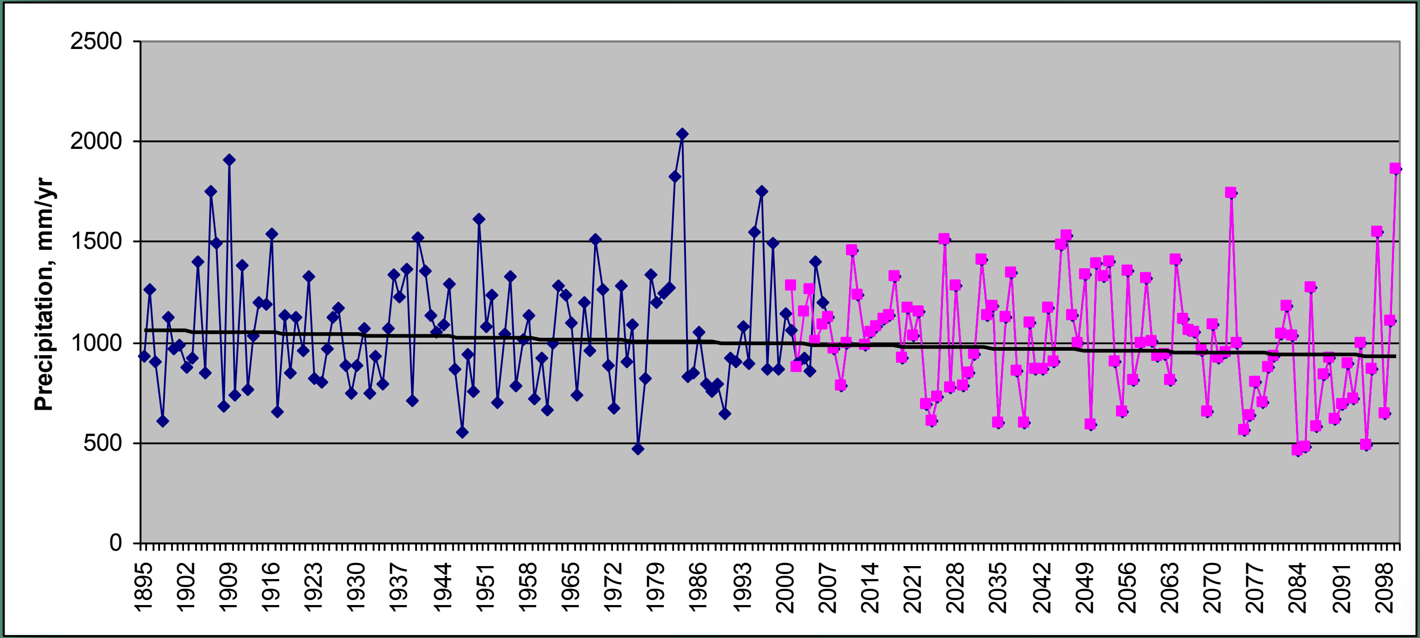

April 1st Snowpack
mm
-798 - -500
-499 - -300
-299 - -200
-199 - -100
-99 - -50
-49 - 0
1 - 50
51 - 100
101 - 201
0
N
0 150 300
Kilometers
Historic: 1951-1980 to 1981-2010
GFDL A2: 1981-2010 to 2070-2099
PCM A2: 1981-2010 to 2070-2099



Runoff
mm
-389 - -250
-249 - -200
-199 - -150
-149 - -100
-99 - -50
-49 - 0
1 - 50
51 - 100
101 - 150
151 - 200
201 - 250
N
0
150
300
Kilometers
Historic: 1951-1980 to 1981-2010
GFDL A2: 1981-2010 to 2070-2099
PCM A2: 1981-2010 to 2070-2099
Standard Deviations
> 2.0
1.6 - 2.0
1.1 - 1.5
0.6 - 1.0
-0.4 - 0.5
-0.9 - -0.5
-1.4 - -1.0
-1.9 - -1.5
< -2.0
Historic: 1951-1980 to 1981-2010
GFDL A2: 1981-2010 to 2070-2099
PCM A2: 1981-2010 to 2070-2099

Upper Tuolumne Basin GFDL A2





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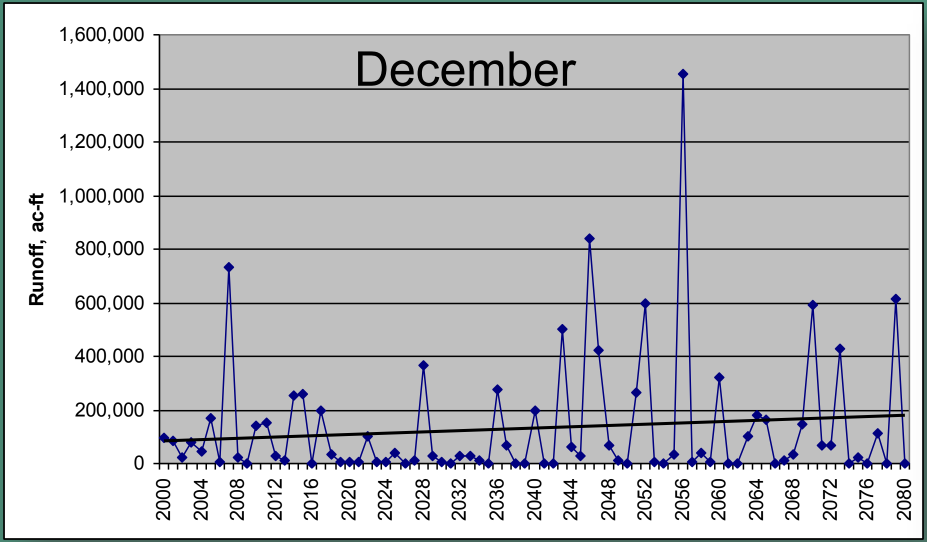
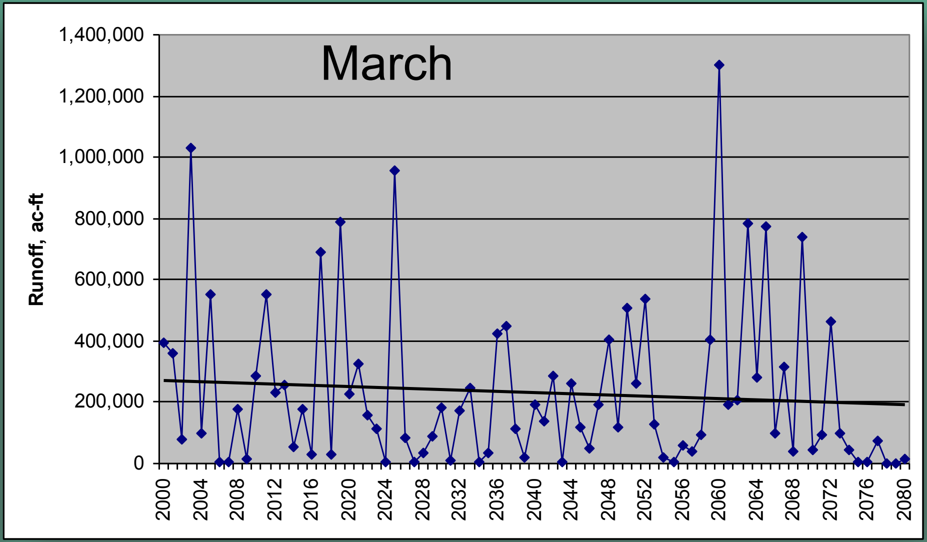
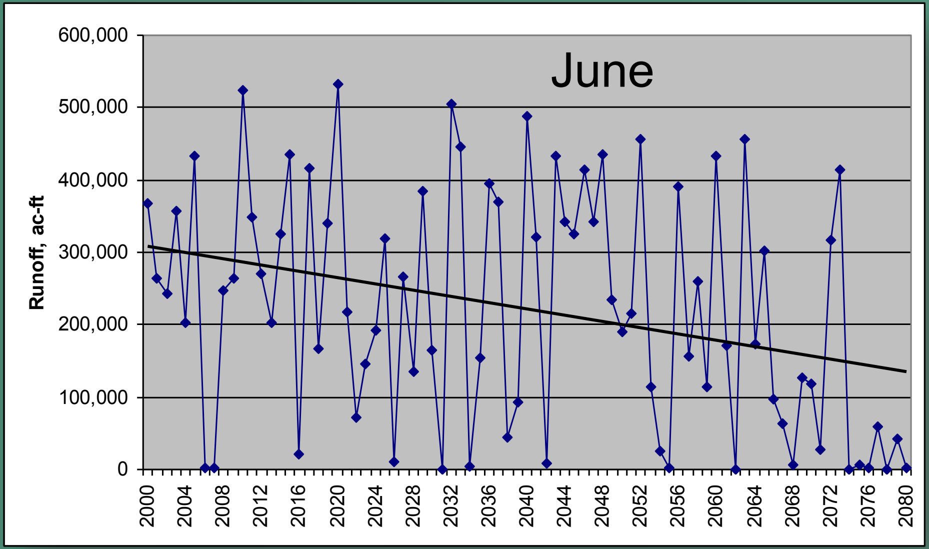
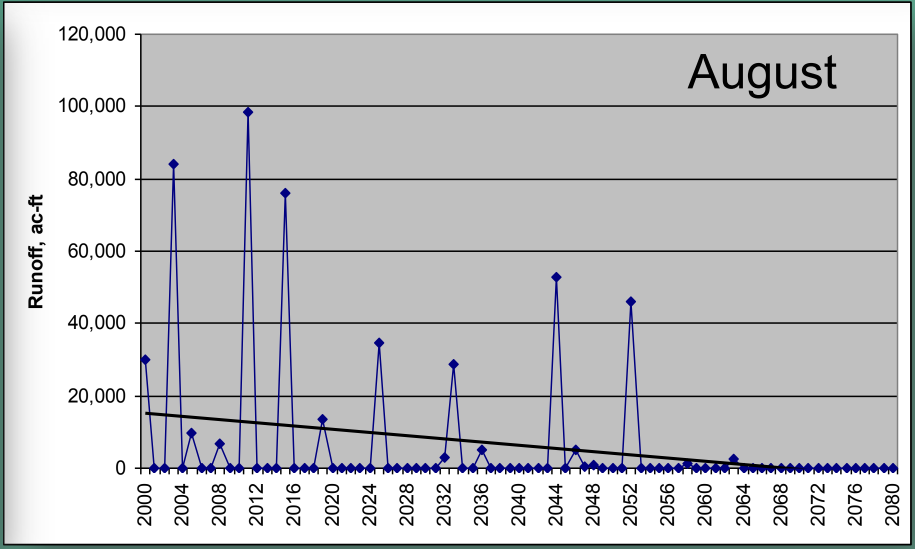
Upper Tuolumne Basin
Surface runoff contribution, no baseflow









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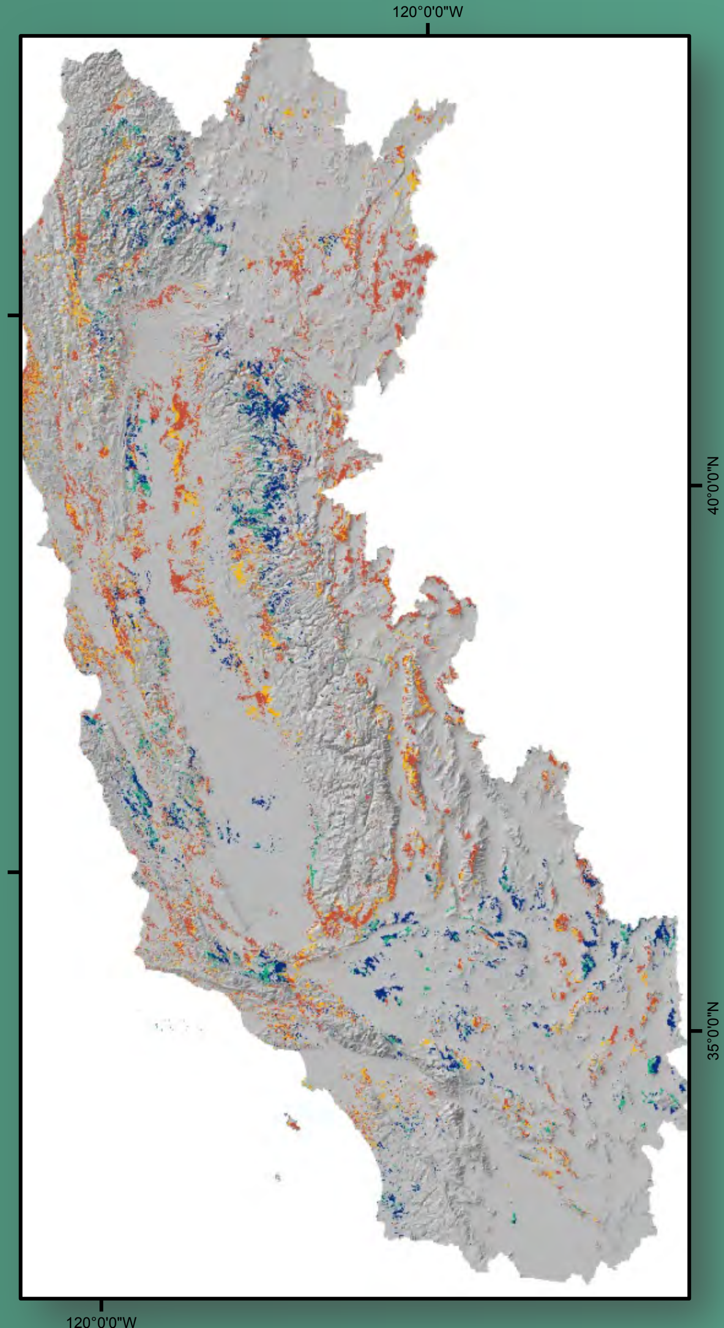
Changes in Recharge/Runoff Mechanisms

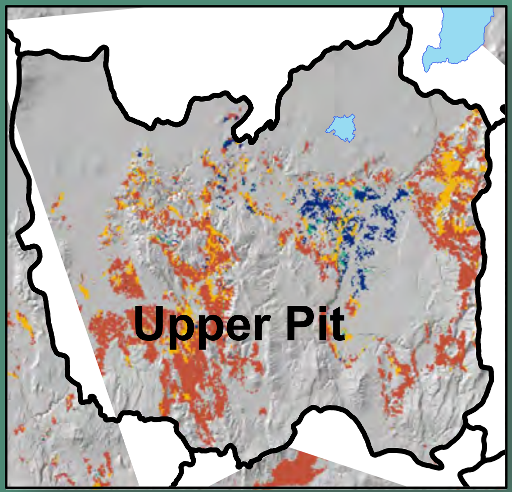
How water is delivered to the system will change



< -2	Rch/run increases
-2 - -1	
-1 - 1	
1 - 2	
> 2	Rch/run decreases

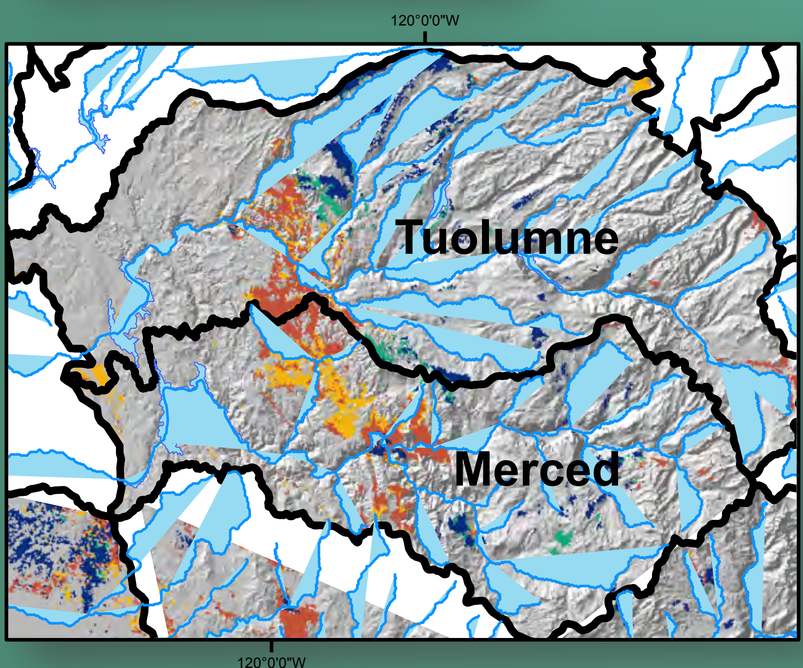
- Loss of snow cover increases recharge
- Higher peak flows and compressed wet season increase runoff where there is shallow soils or no snow cover
- Deep soils can maintain recharge processes with compressed season, higher peaks, and increasing aridity

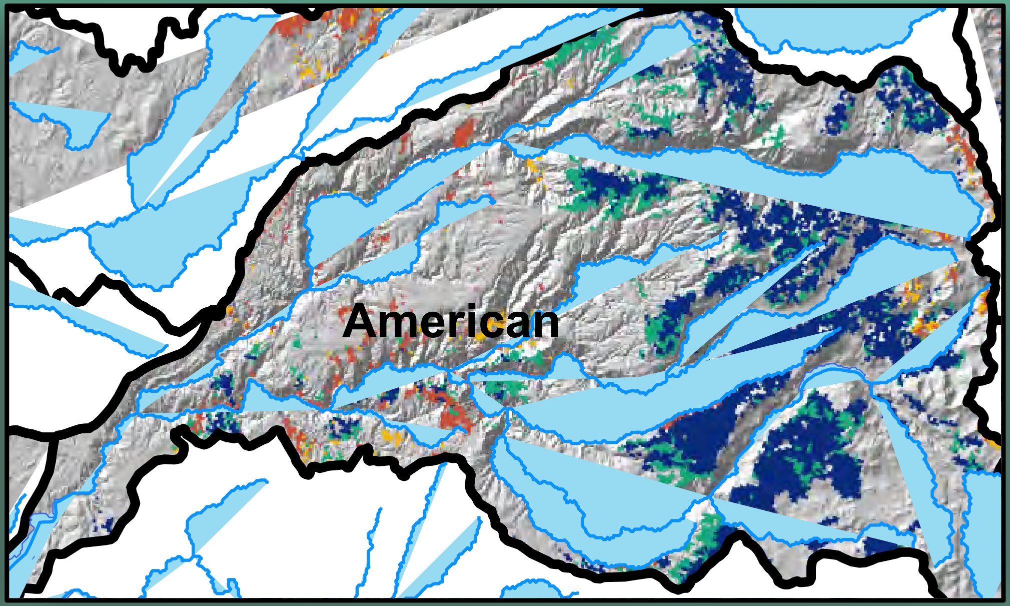
Change in ratio of recharge to runoff (1981-2010) - (2071-2100)



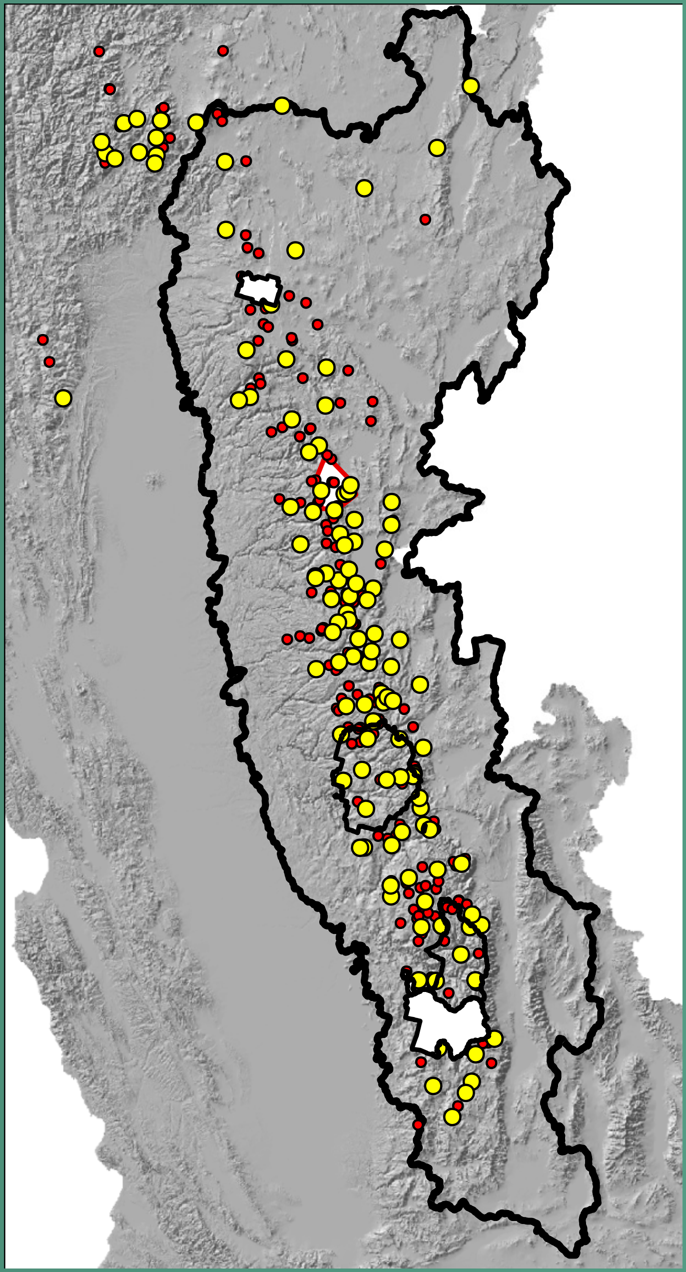
Change in ratio of recharge to runoff (1981-2010) – (2071-2100)

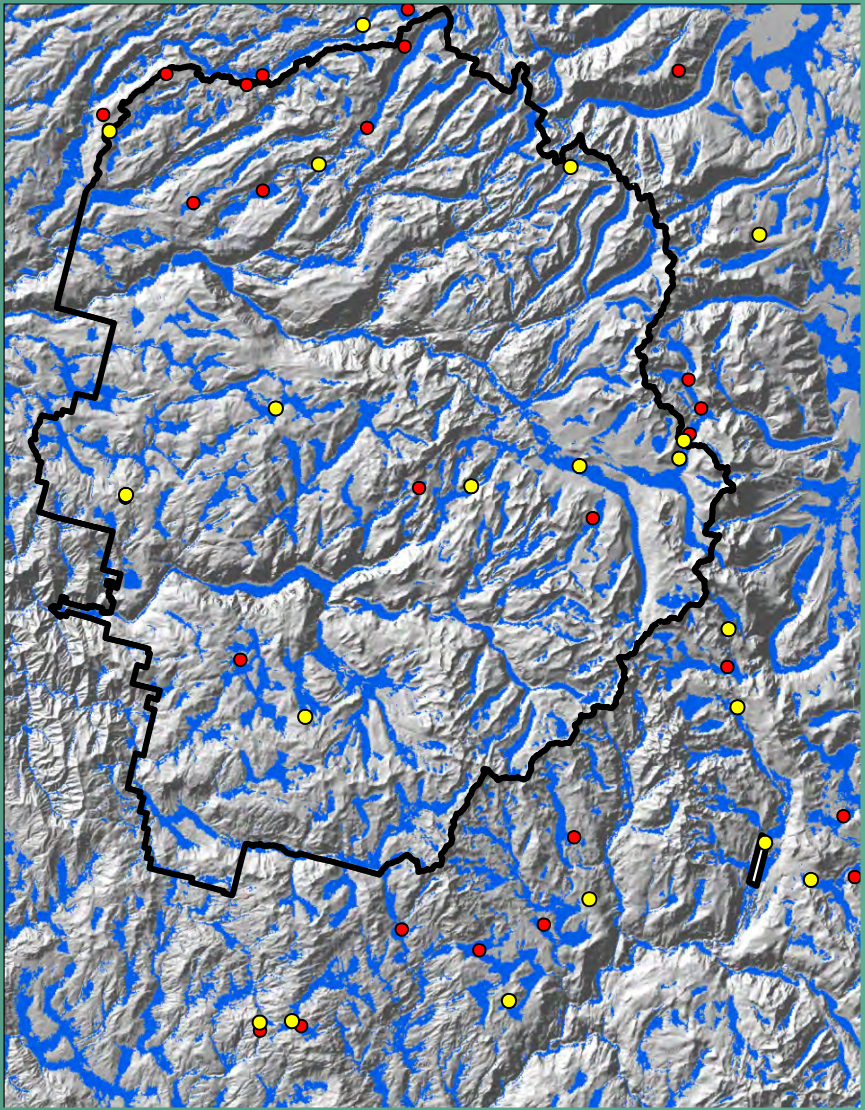
< -2		Rch/run increases
-2 - -1		
-1 - 1		
1 - 2		
> 2		Rch/run decreases





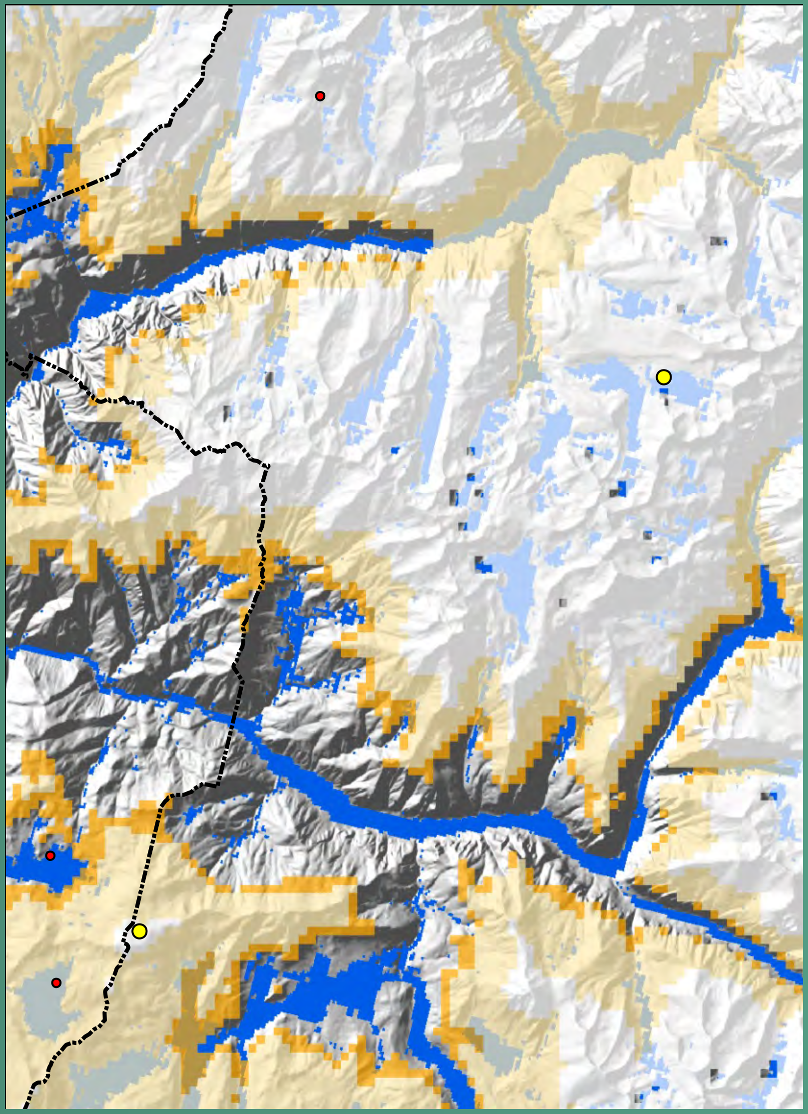
Snow data to assess cold-air pooling



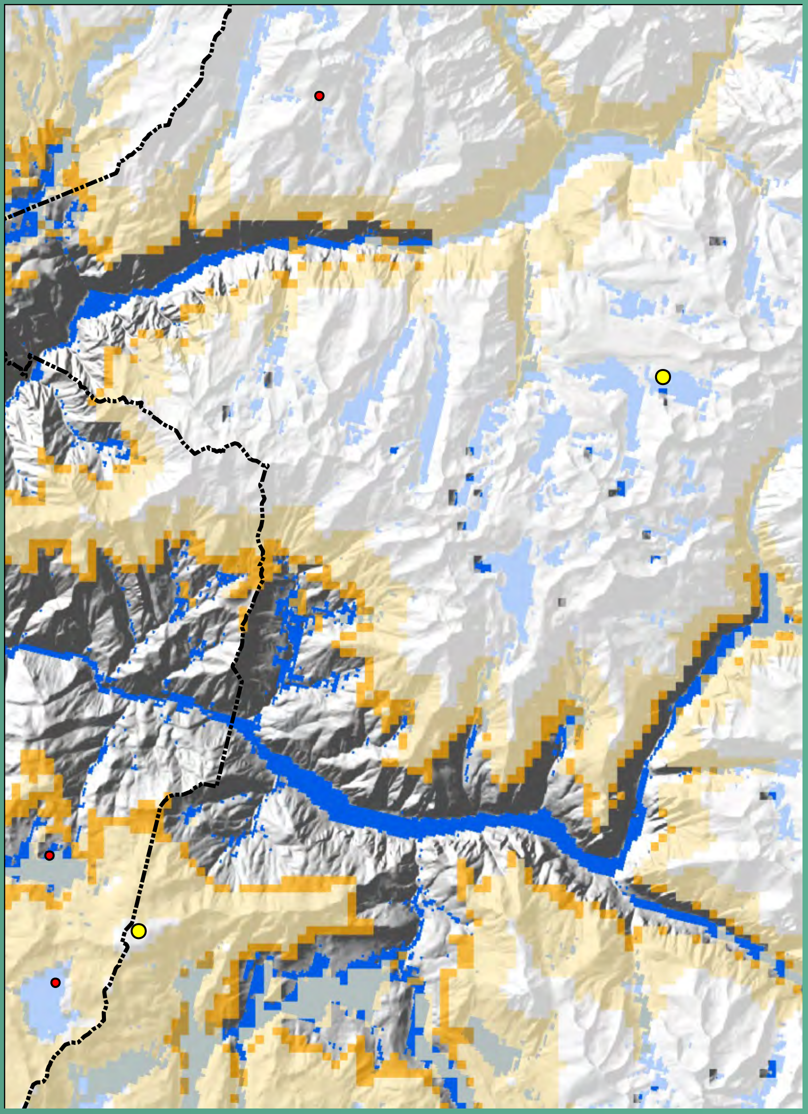


following Lundquist et al. 2008

No Cold Air Pooling



With Cold Air Pooling -1.6 C



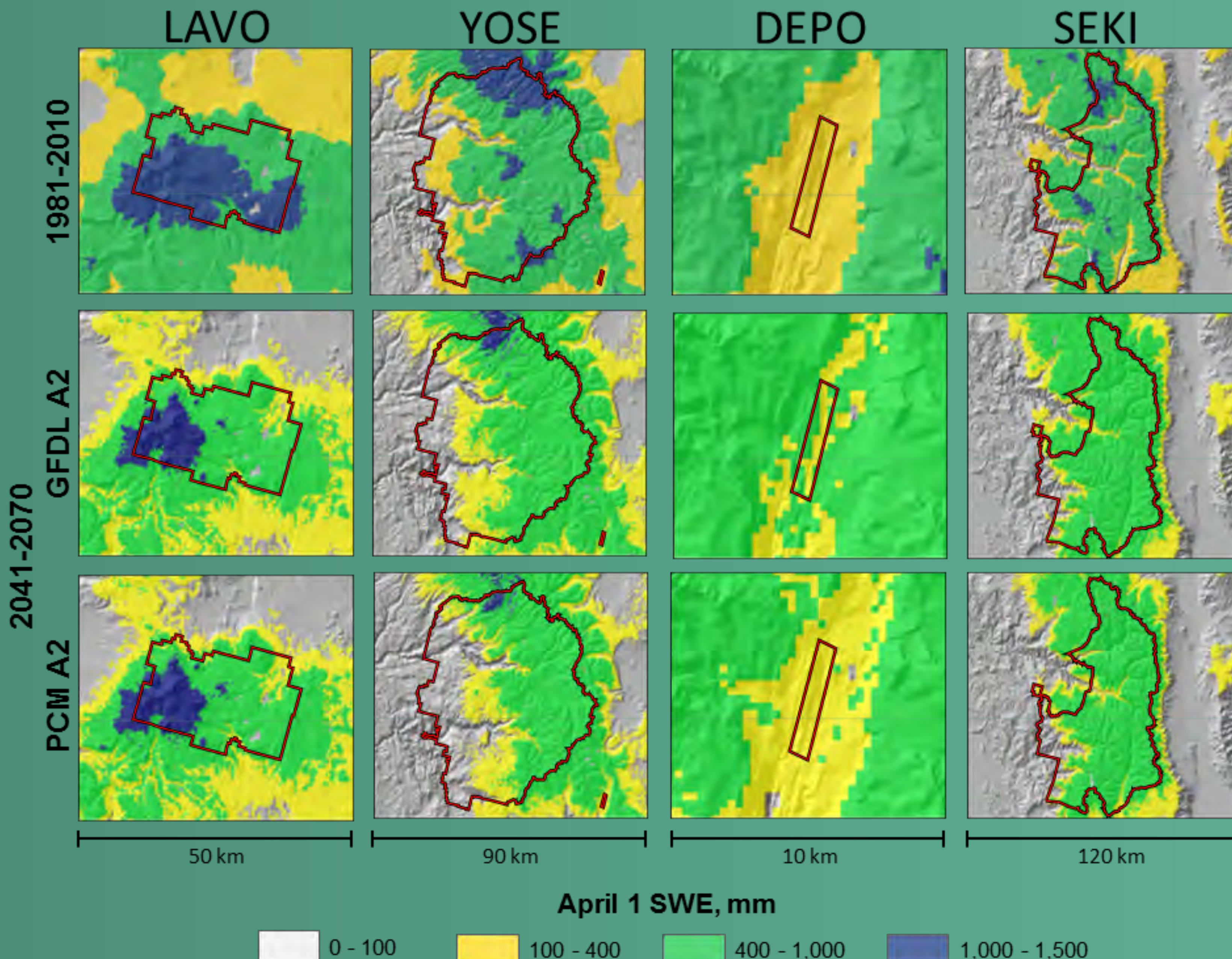
2001GA2jun

<mm>

10 - 100

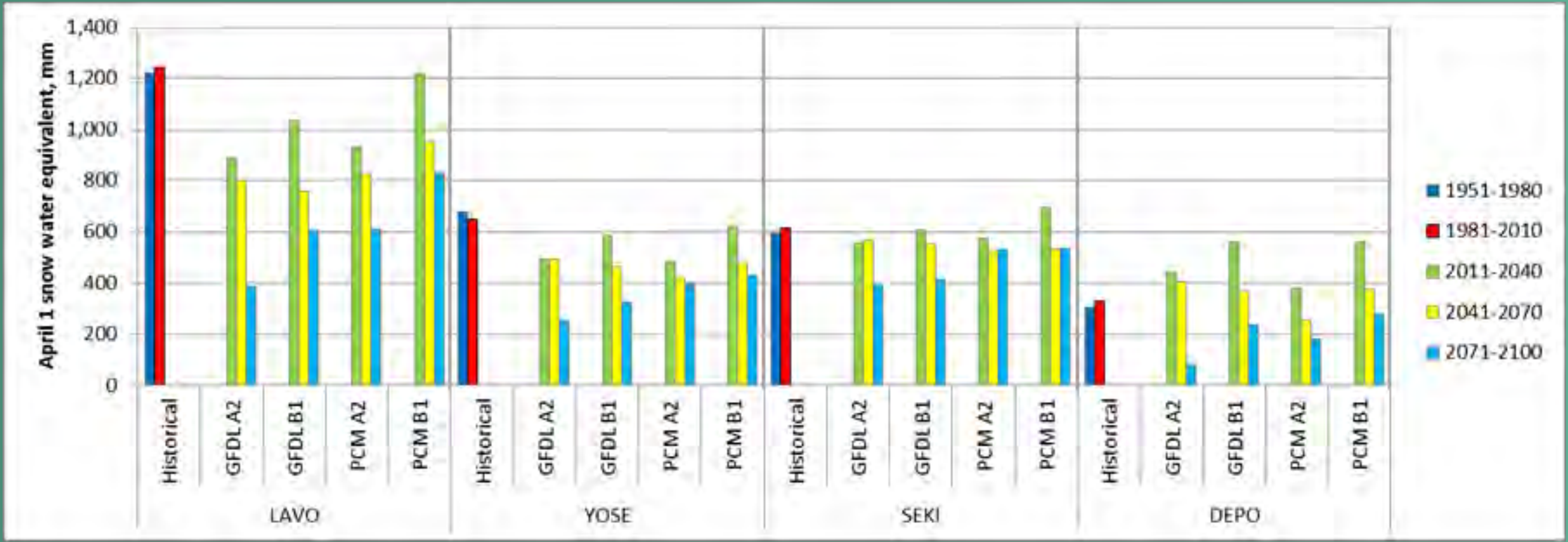
100 - 500

500 - 1,000



LAVO
YOSE
DEPO
SEKI
1981-2010
2041-2070
GFDL A2
PCM A2
50 km
90 km
10 km
120 km
April 1 SWE, mm
0 - 100
100 - 400
400 - 1,000
1,000 - 1,500

Projected changes in wolverine habitat for consideration of reintroduction to Sierra Nevada



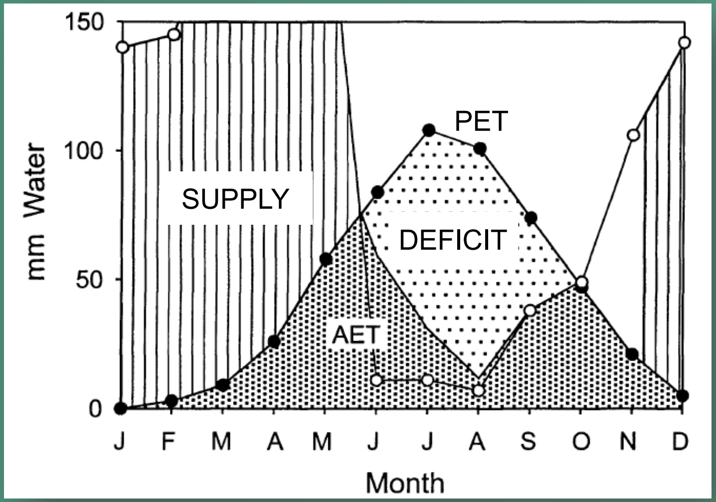
- Used 8 scenarios of climate change, size of home ranges, and relationship between snowpack and fecundity
- Currently enough habitat to support 170 adult female home ranges declining to 70 by 2100
- Depending on scenario
  - Projections of increased habitat to 60% loss by mid-century
  - 11% to 90% loss by end of century

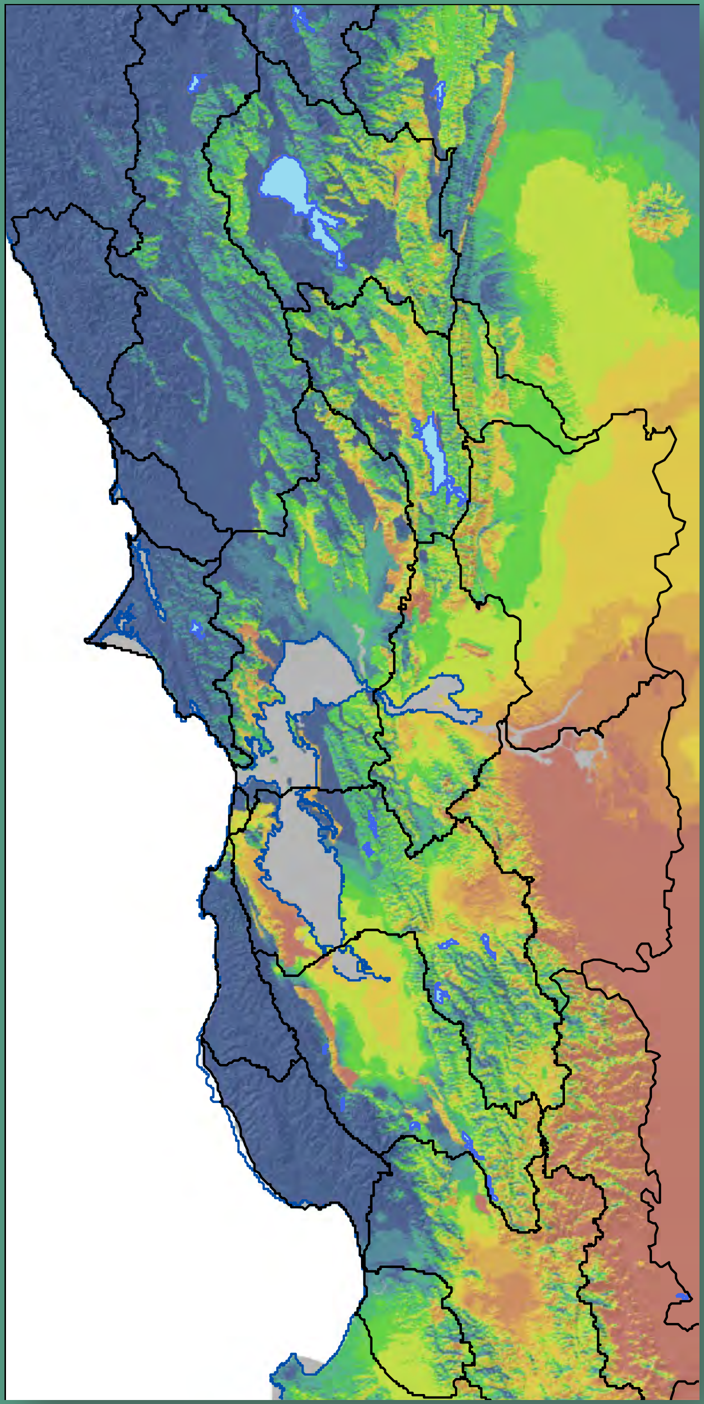
Climatic Water Deficit

Annual evaporative demand
that exceeds available water

Potential – Actual Evapotranspiration

- **Integrates climate, energy loading, drainage, and available soil moisture storage**
- **Vegetation independent (indicator)**
- **Address irrigation demand**
- **Generally increases with all future climate scenarios**





2001

mm/yr

- <775
- 775 - 800
- 800 - 825
- 825 - 850
- 850 - 875
- 875 - 900
- 900 - 925
- 925 - 950
- 950 - 975
- 975 - 1000

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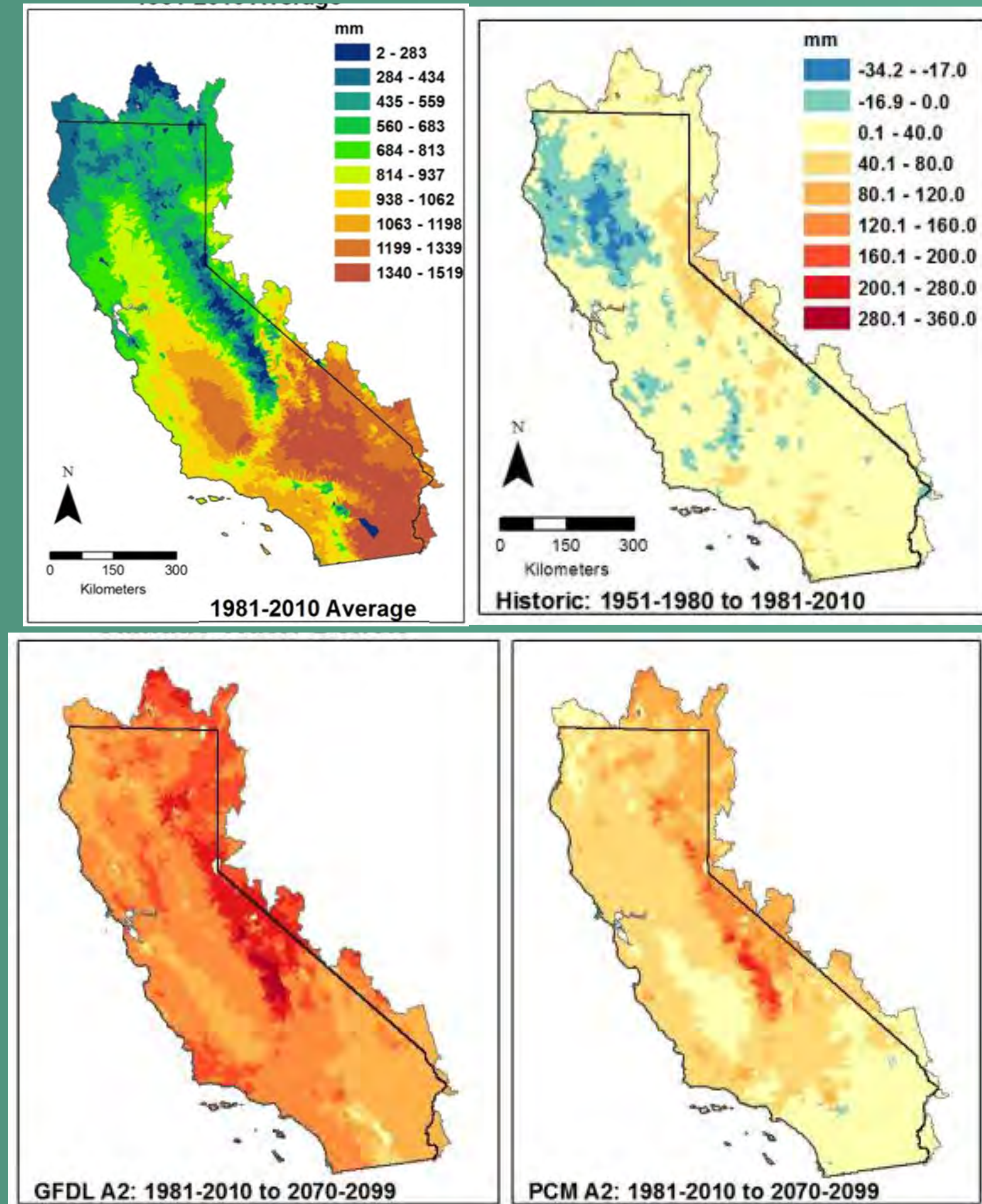
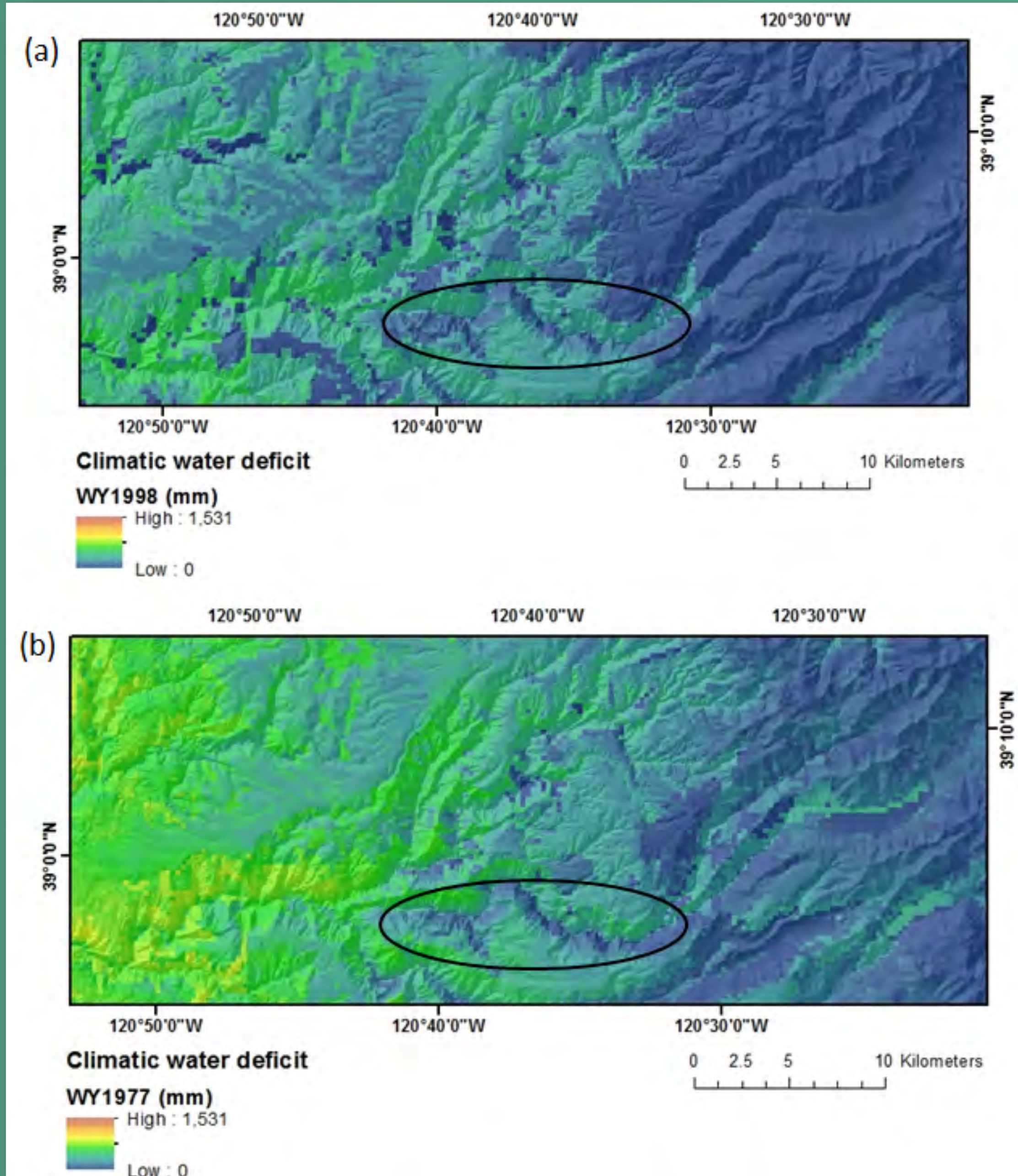
Climatic Water Deficit




(a)
120°50'0"W
120°40'0"W
120°30'0"W
39°10'0"N
39°0'0"N
120°50'0"W
120°40'0"W
120°30'0"W
Climatic water deficit
WY1998 (mm)
High : 1,531
Low : 0
0 2.5 5 10 Kilometers
(b)
120°50'0"W
120°40'0"W
120°30'0"W
39°10'0"N
39°0'0"N
120°50'0"W
120°40'0"W
120°30'0"W
Climatic water deficit
WY1977 (mm)
High : 1,531
Low : 0
0 2.5 5 10 Kilometers

Summary

- GCM output provides projections of climate change for the next century
- Needs downscaling for effective application and translated to hydrologic response to provide impacts of the interrelated processes at landscape level
- Climate change impacts hydrology with local variations
- Impacts in the Sierra Nevada and implications for management
  - Rising air temperatures and earlier and more variable springtime snowmelt
  - More frequent summer droughts
  - Uncertainties in runoff due to soil moisture
  - Landscape stresses due to increasing CWD
    - Species distributions, forest health, wildfire
  - Fine scale representation offers potential refugia and connectivity