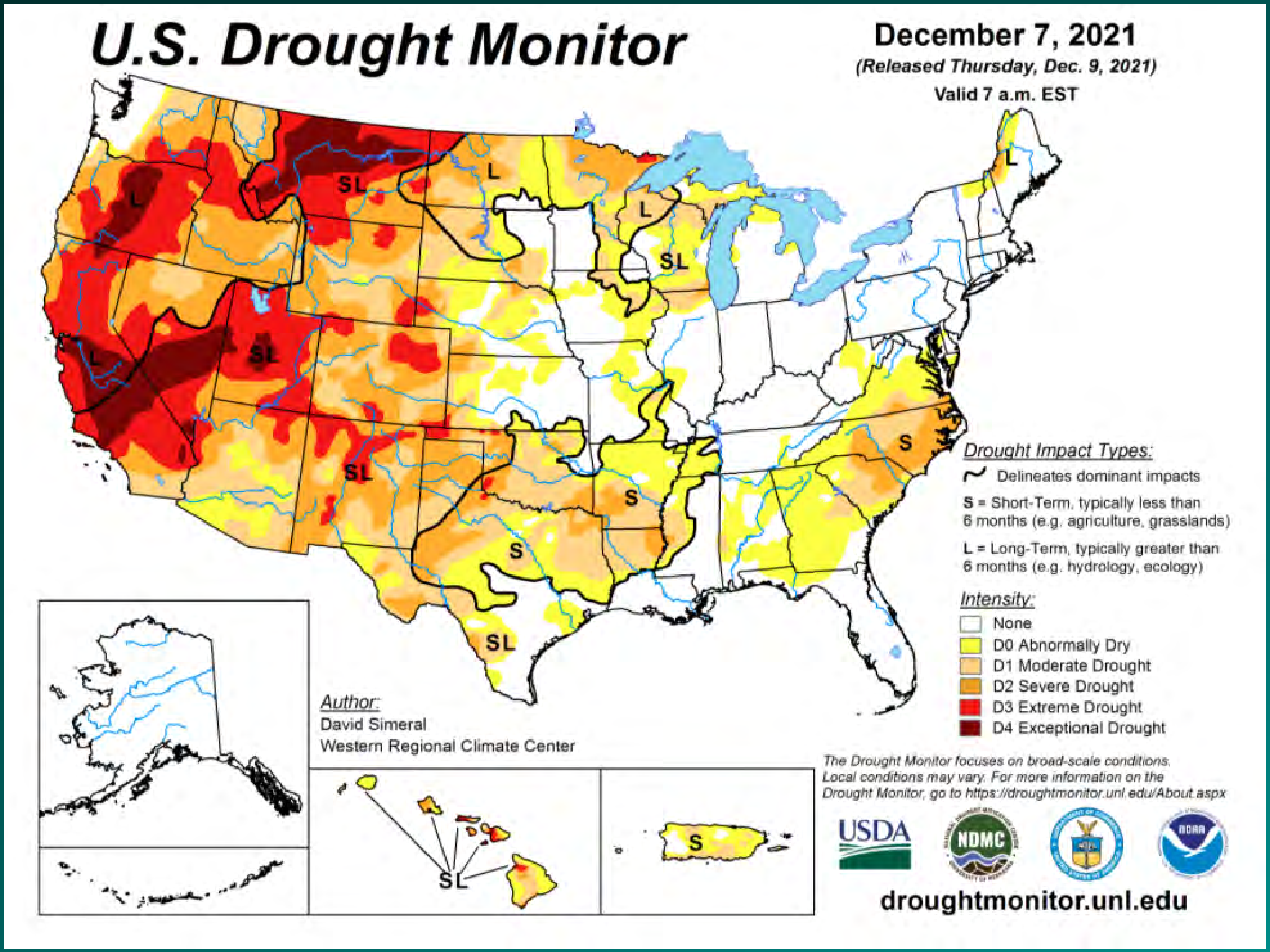
What Will Happen When it Rains?
Runoff Efficiency using the BCM

Lorrie and Alan Flint
Senior Scientists, Earth Knowledge, Inc.
U.S. Geological Survey, retired

Michelle Stern and Joe Hevesi
USGS California Water Science Center

Colorado River Water Users Association
December 14, 2021



U.S. Drought Monitor
December 7, 2021
(Released Thursday, Dec. 9, 2021)
Valid 7 a.m. EST
Drought Impact Types:
Delineates dominant impacts
S = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)
Intensity:
None
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
Author:
David Simeral
Western Regional Climate Center
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to https://droughtmonitor.unl.edu/About.aspx
droughtmonitor.unl.edu

RESEARCH

DROUGHT

Large contribution from anthropogenic warming to an emerging North American megadrought

A. Park Williams[1]*, Edward R. Cook[1], Jason E. Smerdon[1], Benjamin I. Cook[1,2], John T. Abatzoglou[3,4], Kasey Bolles[1], Seung H. Baek[1,5], Andrew M. Badger[6,7,8], Ben Livneh[6,9]

Severe and persistent 21st-century drought in southwestern North America (SWNA) motivates comparisons to medieval megadroughts and questions about the role of anthropogenic climate change. We use hydrological modeling and new 1200-year tree-ring reconstructions of summer soil moisture to demonstrate that the 2000–2018 SWNA drought was the second driest 19-year period since 800 CE, exceeded only by a late-1500s megadrought. The megadrought-like trajectory of 2000–2018 soil moisture was driven by natural variability superimposed on drying due to anthropogenic warming. Anthropogenic trends in temperature, relative humidity, and precipitation estimated from 31 climate models account for 46% (model interquartiles of 34 to 103%) of the 2000–2018 drought severity, pushing an otherwise moderate drought onto a trajectory comparable to the worst SWNA megadroughts since 800 CE.

Western megadrought nearly 20 years long

Drier than any 19-yr period since 1500s

Mostly caused by human-induced climate change

Reservoir water levels falling

Lake Mead 2021

Lowest depth in Lake Mead since it was filled in 1930

Latest Issues

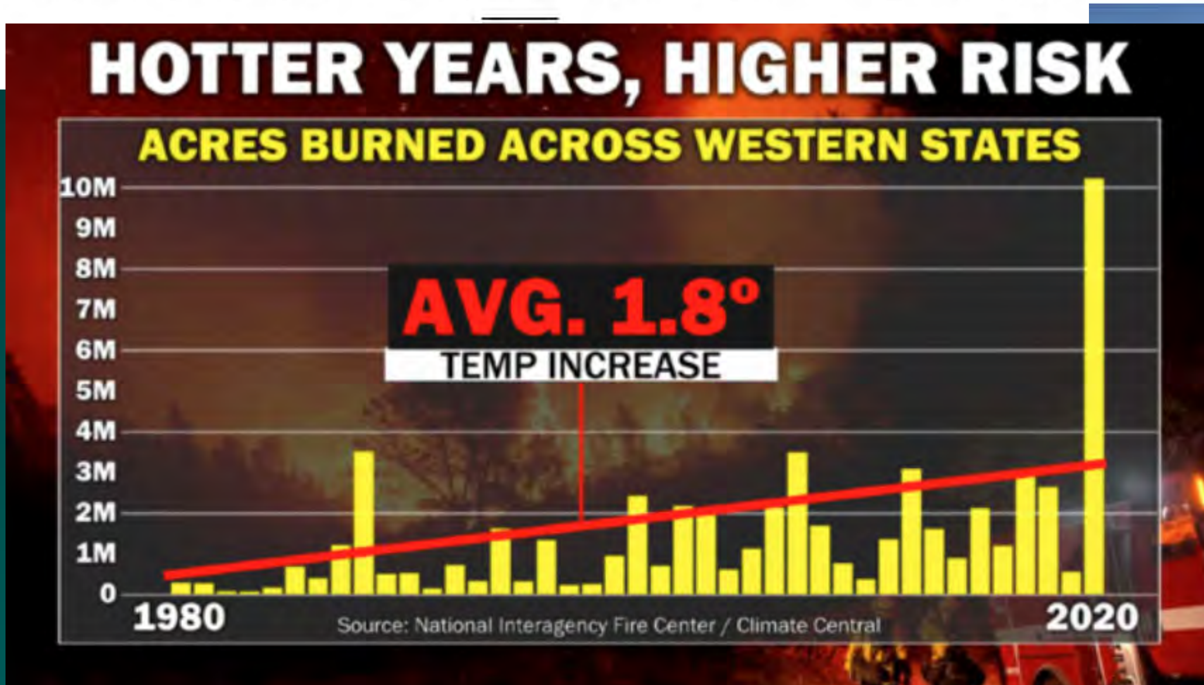
SCIENTIFIC AMERICAN

Cart 0

WEATHER

Western Drought Has Lasted Longer Than the Dust Bowl

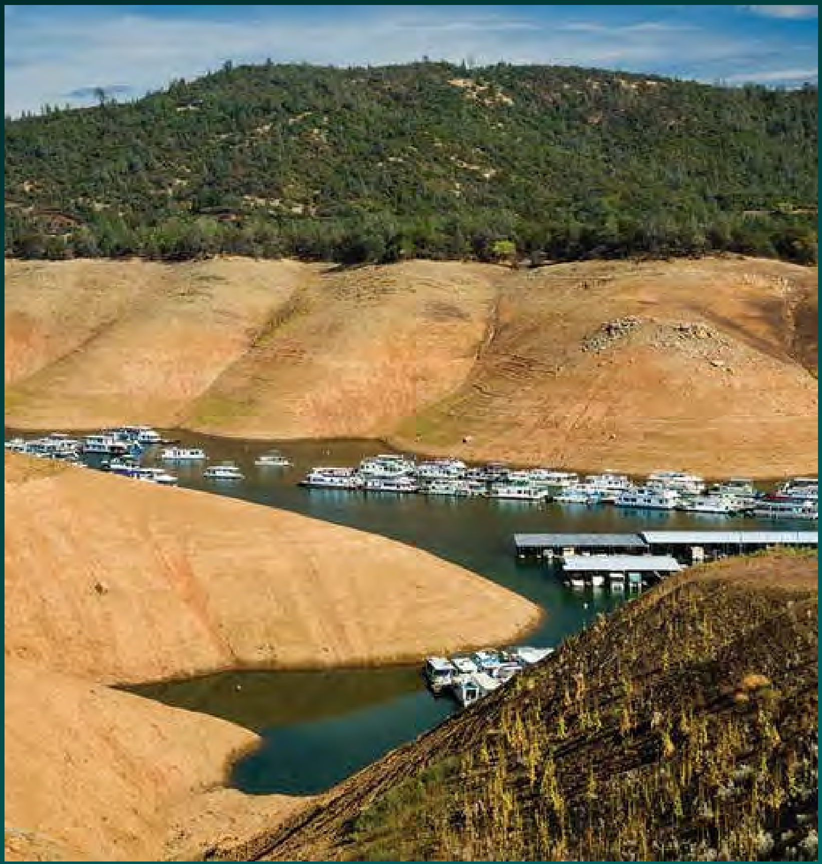
Dry conditions have drawn down reservoirs, fueled massive wildfires and stunted crops



next to a field in May 2021, in Firebaugh, California. Credit: Justin Sullivan Getty Images

It’s not only drier

It’s HOTTER

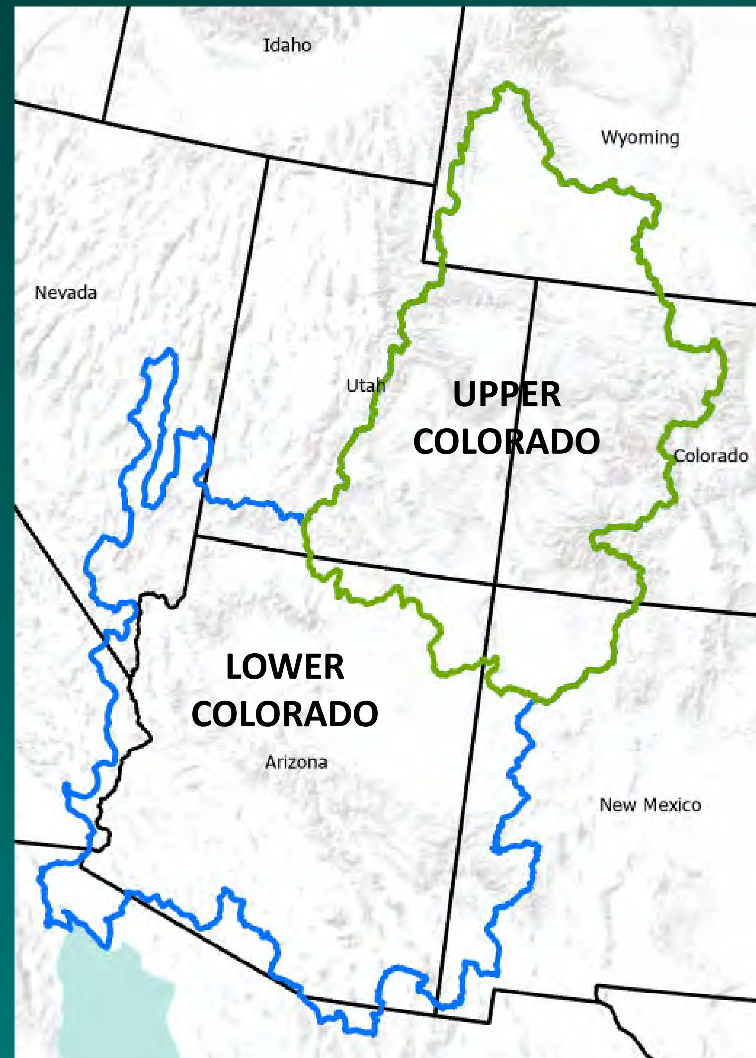


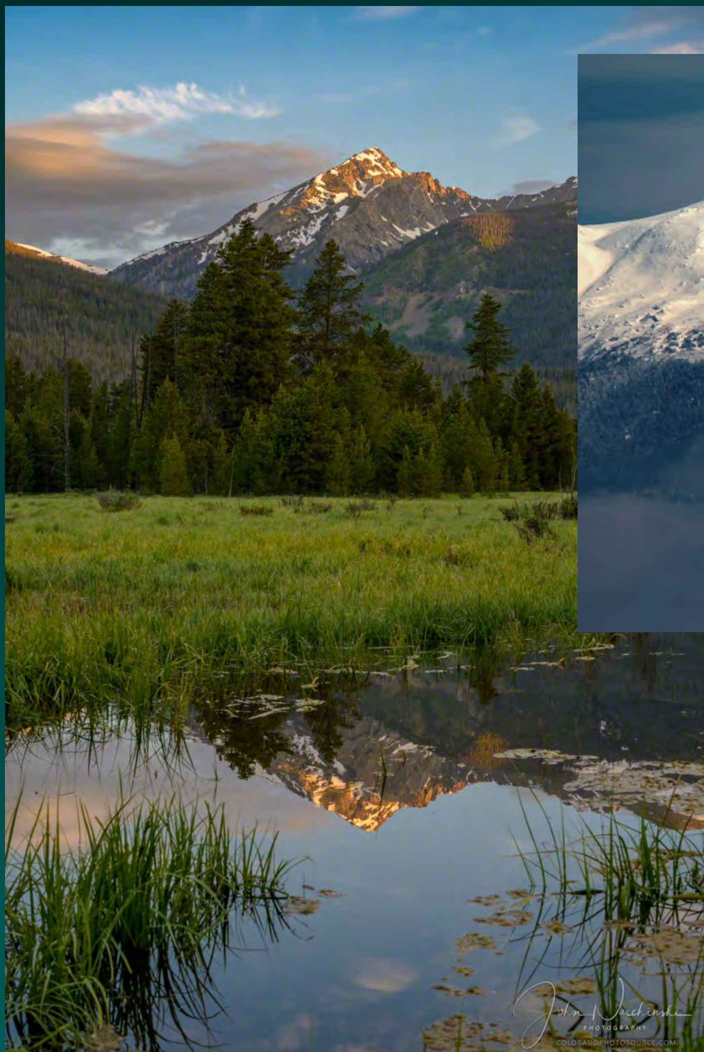
Characterizing Drought and Impacts on Resources

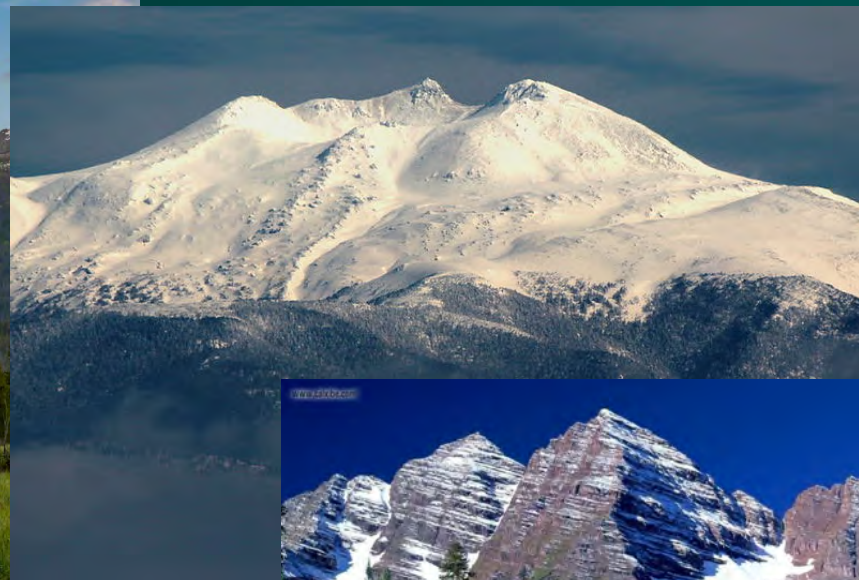
Both Water Supply and Landscape

- Water supply drought, lack of recharge and runoff, is a shorter-term impact that can be ameliorated with shorter wet periods
- Even if reservoirs are full, longer droughts can reduce recharge to the aquifer
- Landscape droughts are exacerbated by dry conditions and HOT temperatures, drying out the vegetation, soils, and unsaturated zone and take much more to reverse

Colorado River Basin



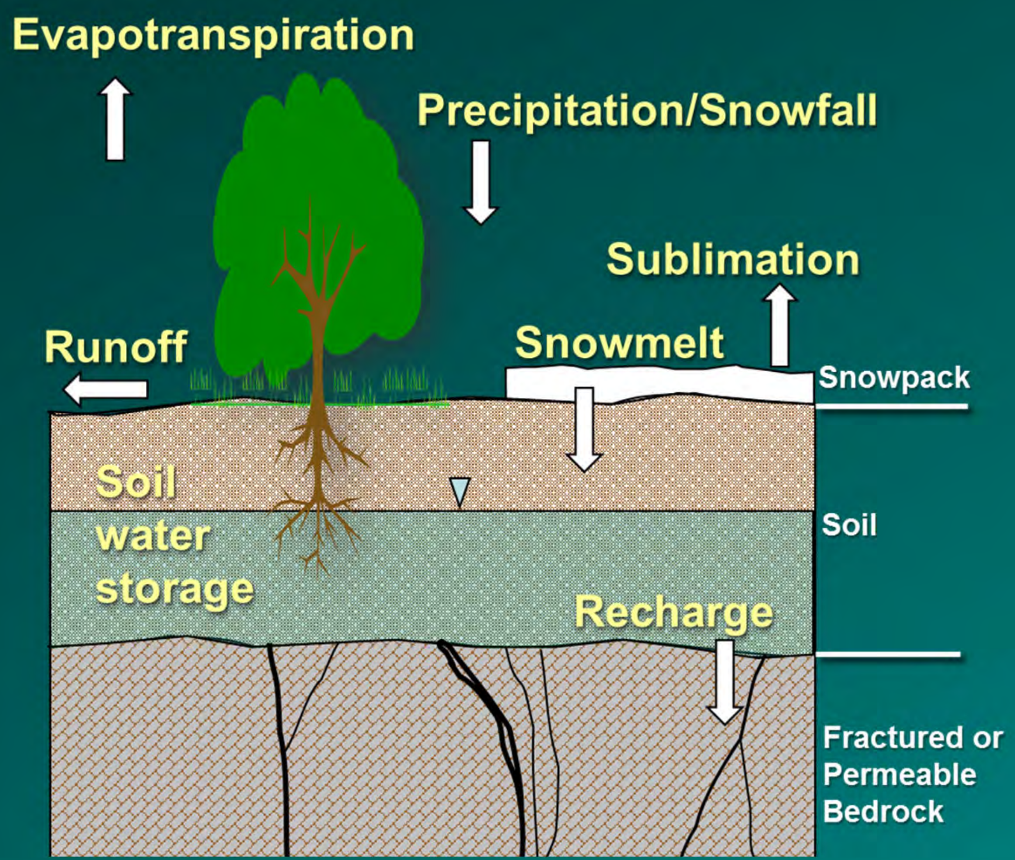




Characterizing Drought and Impacts on Resources

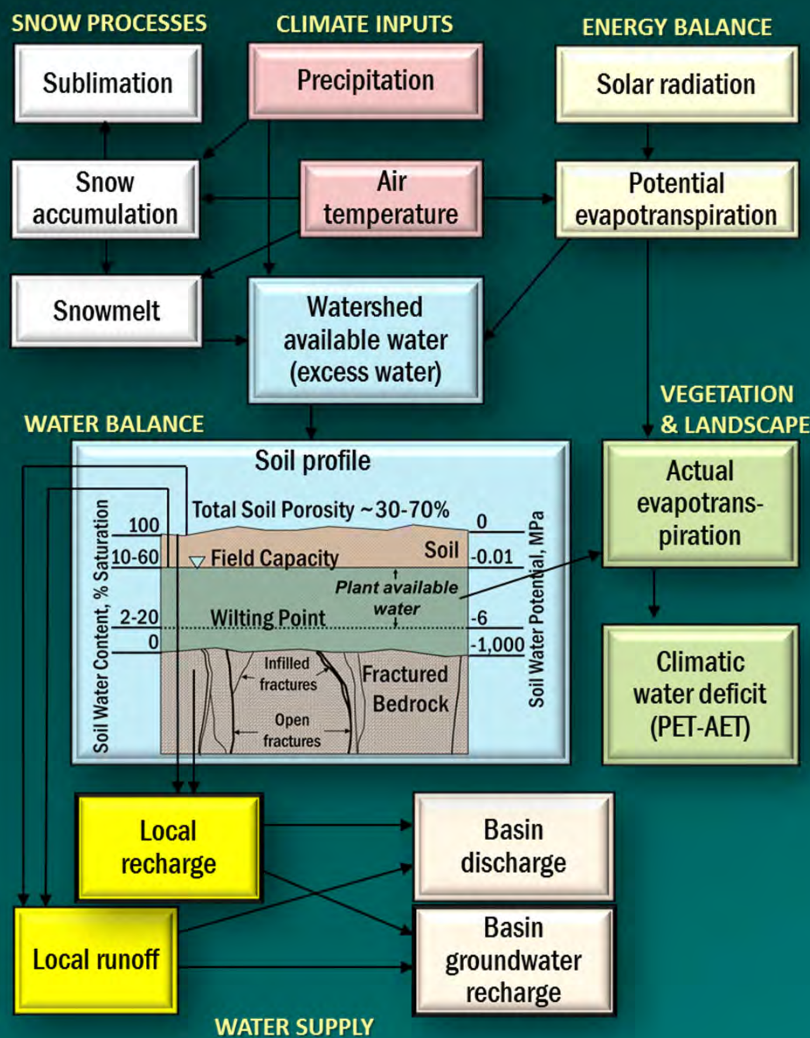
- Tools in the toolbox:
  - Monitoring to understand current and antecedent conditions
  - Remote sensing to spatially distribute data
  - Modeling to forecast water supply and climate extremes
  - Modeling to analyze the range of accumulated drought conditions across the state
- The Basin Characterization Model
  - Under development since 2007, with DWR since 2010
  - Published as a USGS code in 2021
  - CRB model developed with short term funding from the USGS as a proof-of-concept

The Water Balance



Precipitation = Evapotranspiration + Runoff + Sublimation + Recharge + ΔSoil Water Content

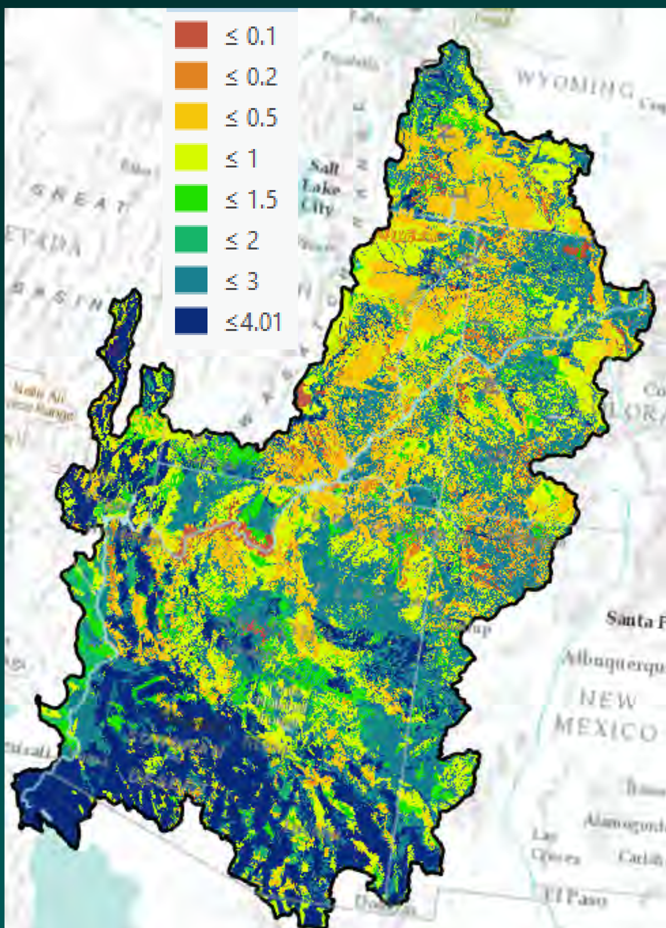
Basin Characterization Model



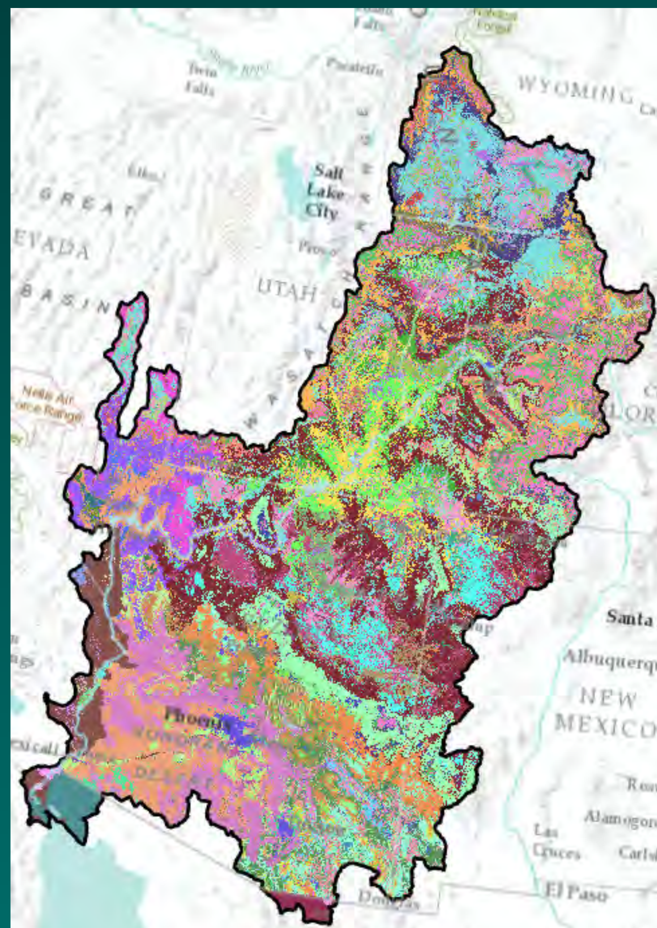
A grid-based water balance model

- Uses gridded climate data downscaled to fine spatial scales 270-m (historical and future)
- Develops a rigorous energy balance
- Incorporates detailed soil properties and estimates of bedrock permeability
- Calculates spatially distributed water supply as recharge and runoff
- Calculates climatic water deficit as an estimate of demand and stress

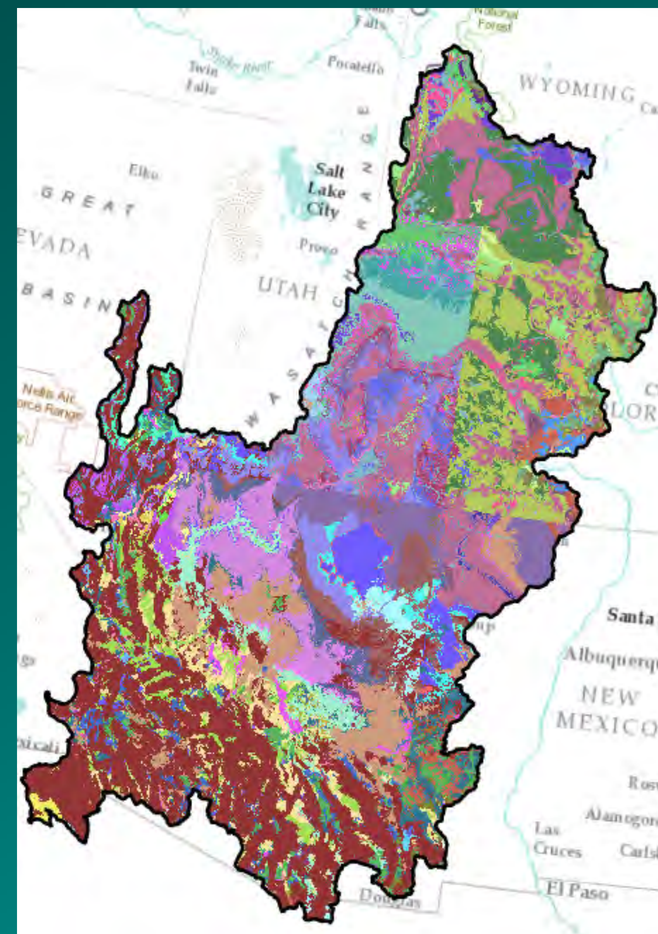
Soil Depth



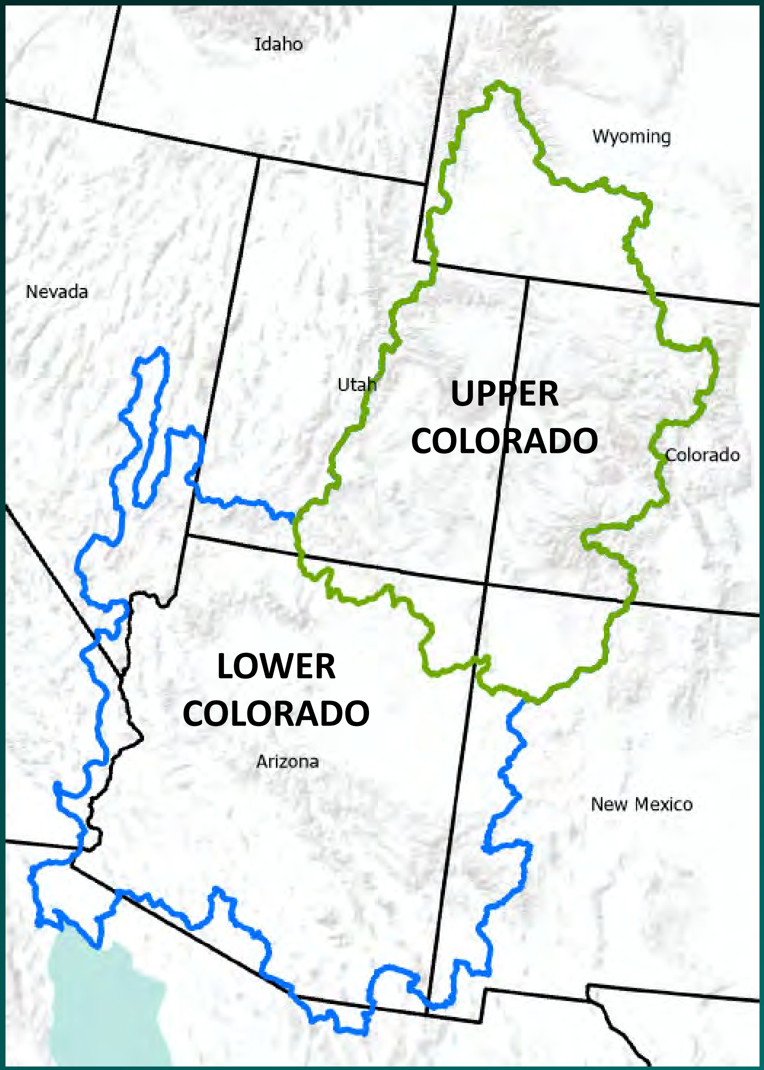
194 Vegetation Types



84 Geology Types

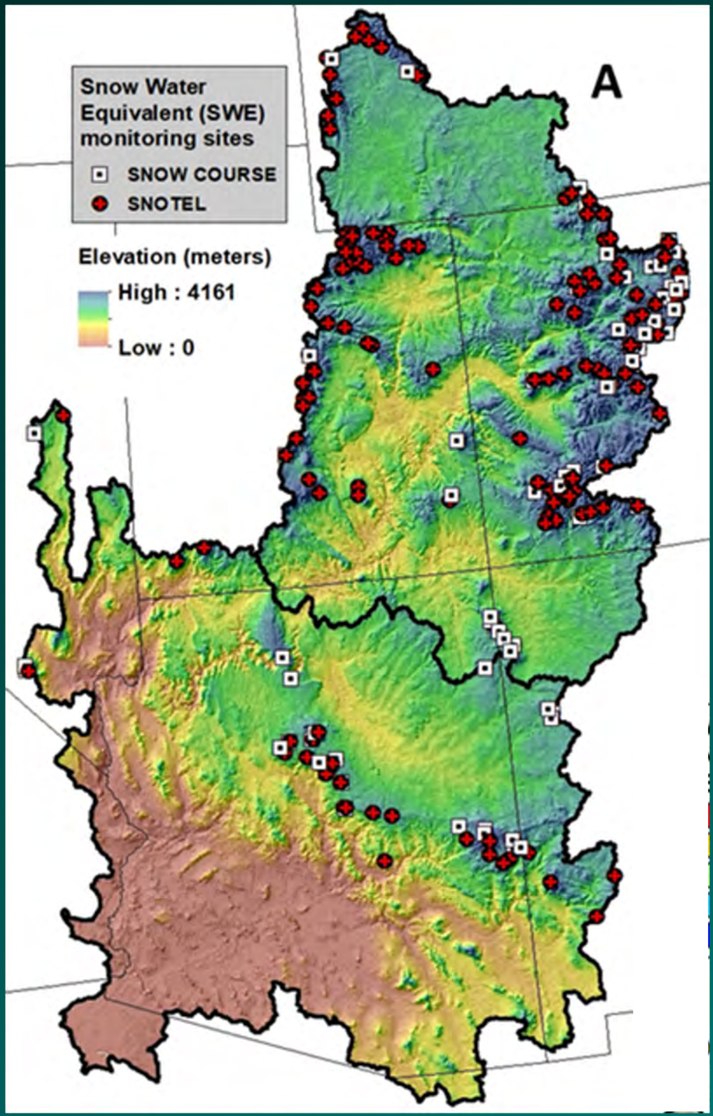


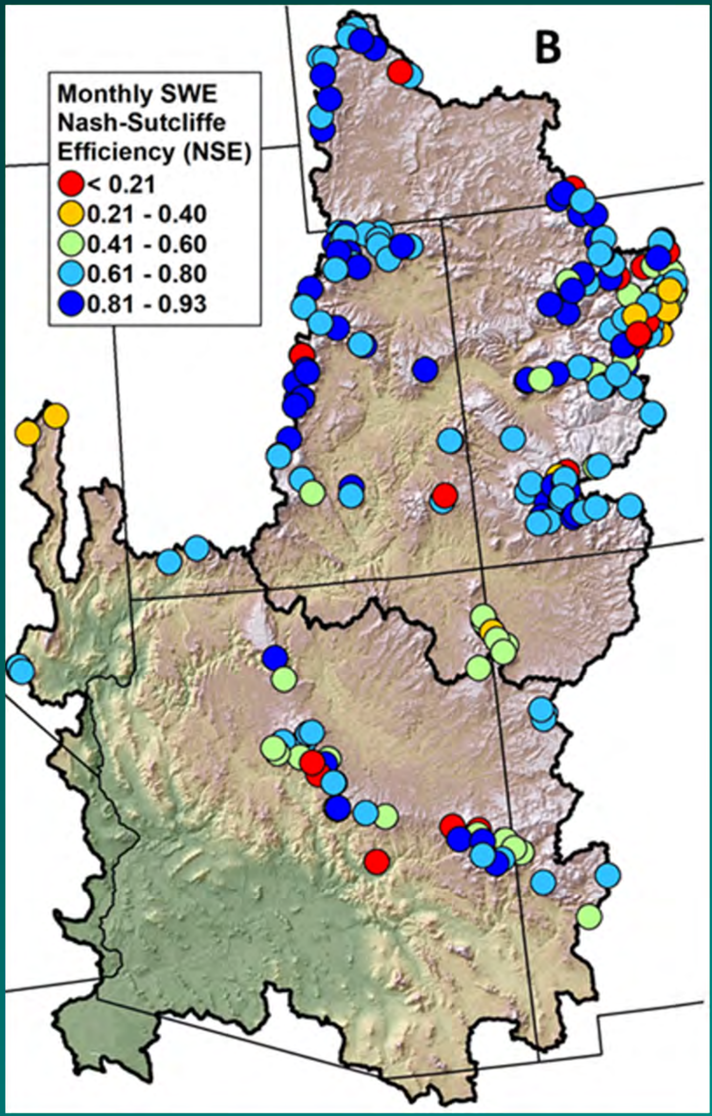
***Non-Publicly releasable information for business use only...



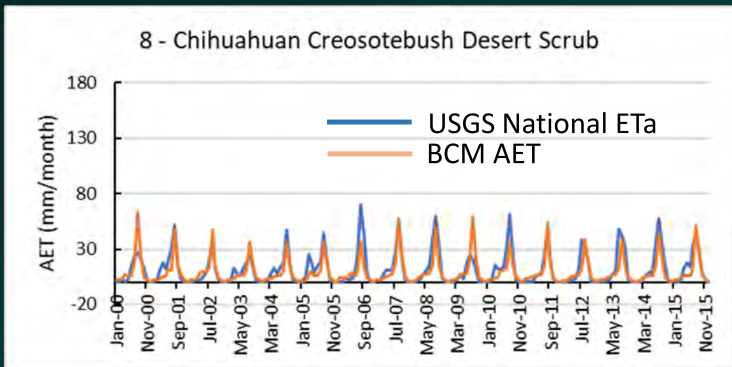
Calibration to measured data

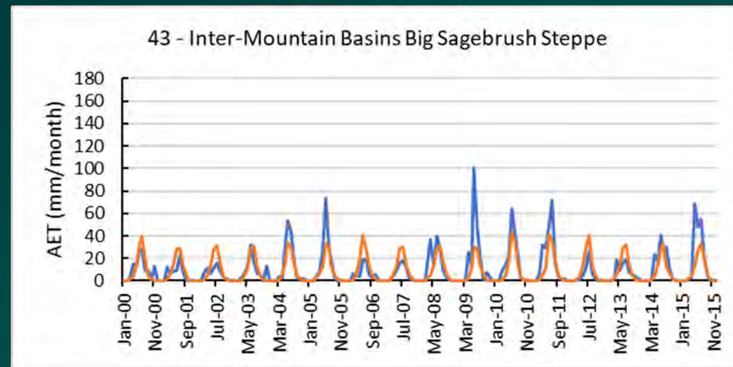
- Spatially distributed snow calibration parameters using SWE at 149 SNOTEL stations and 77 snow-course sites
- Vegetation-specific actual evapotranspiration calibrated to published AET from Reitz et al for 2000-2015
- Preliminary streamflow calibrations to selected gages

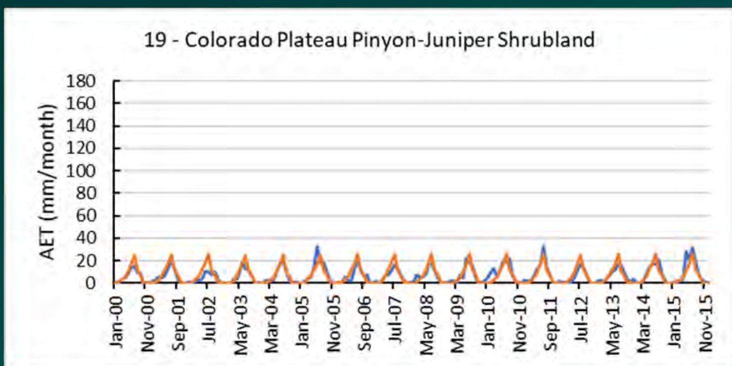

A
Snow Water Equivalent (SWE) monitoring sites
SNOW COURSE
SNOTEL
Elevation (meters)
High : 4161
Low : 0

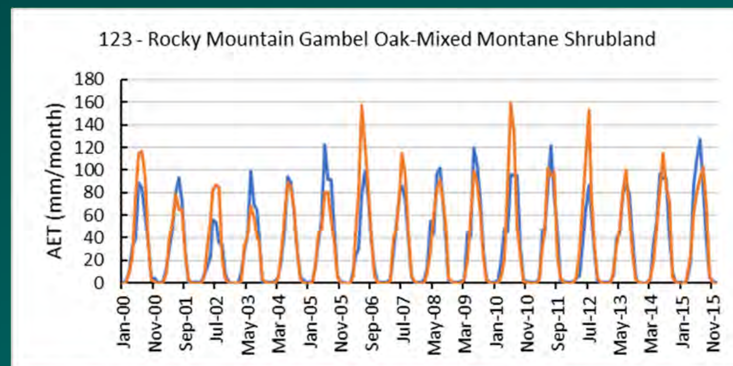

B
Monthly SWE Nash-Sutcliffe Efficiency (NSE)
< 0.21
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 0.93

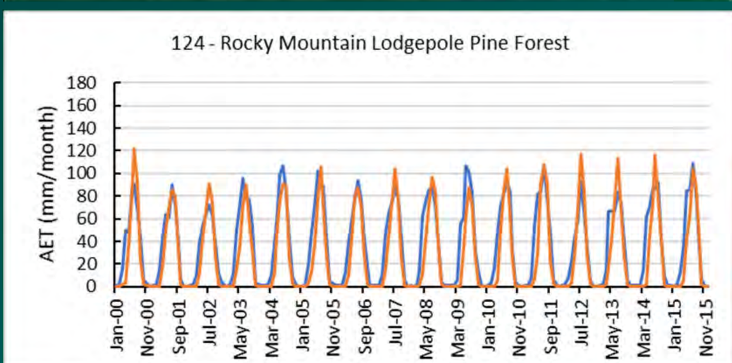
Comparison of Actual Evapotranspiration Estimates

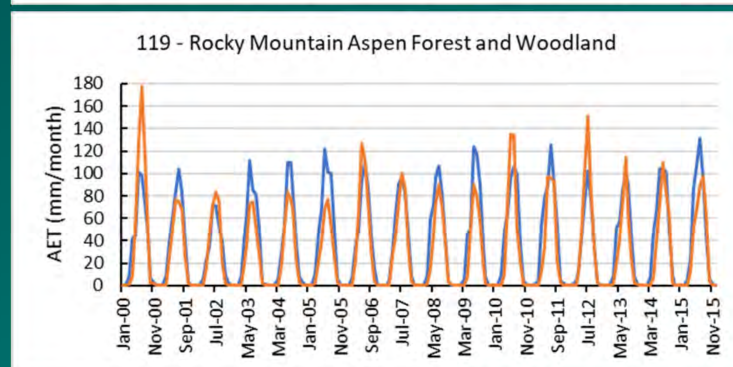




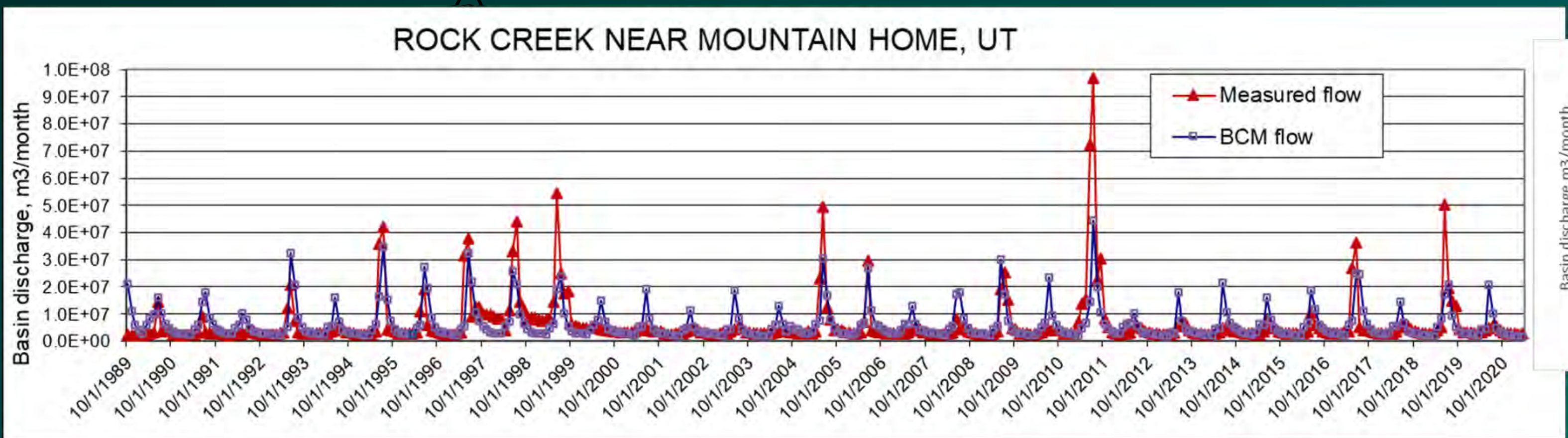


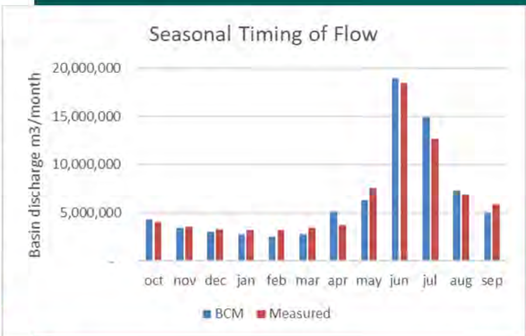


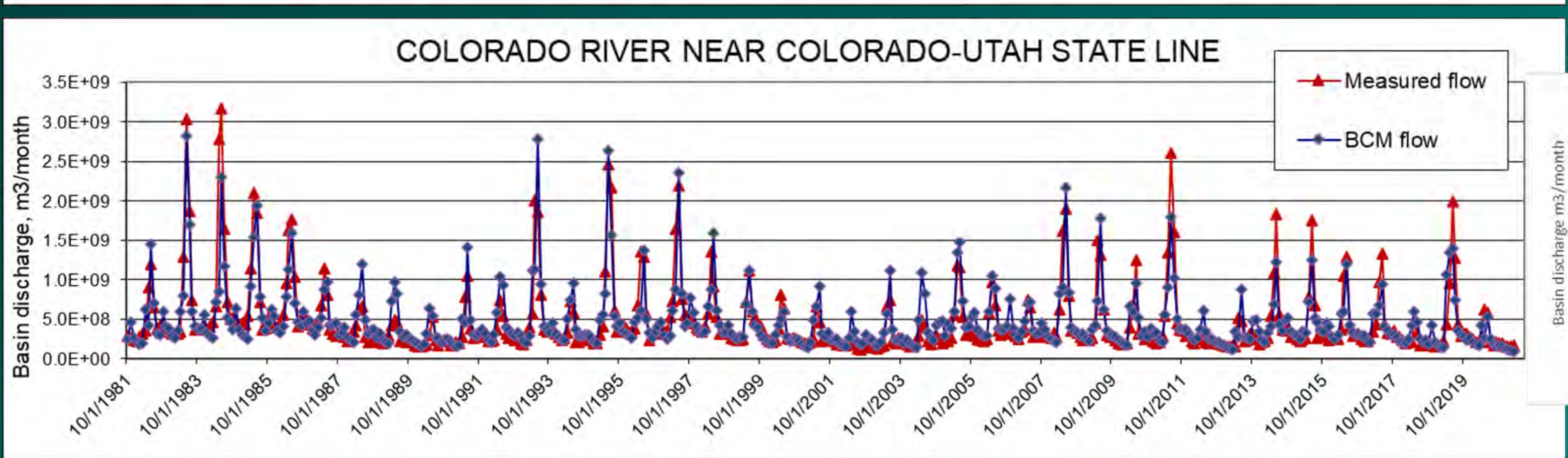


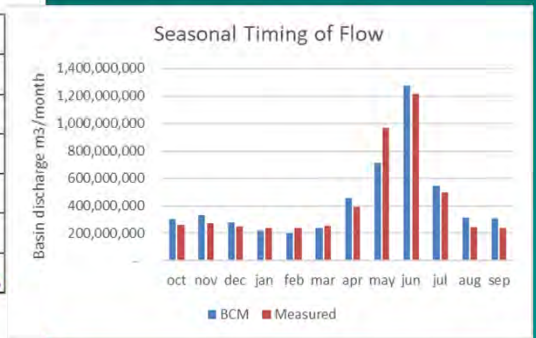


Calculating Basin Discharge from Recharge and Runoff to Match Streamflow Measurements

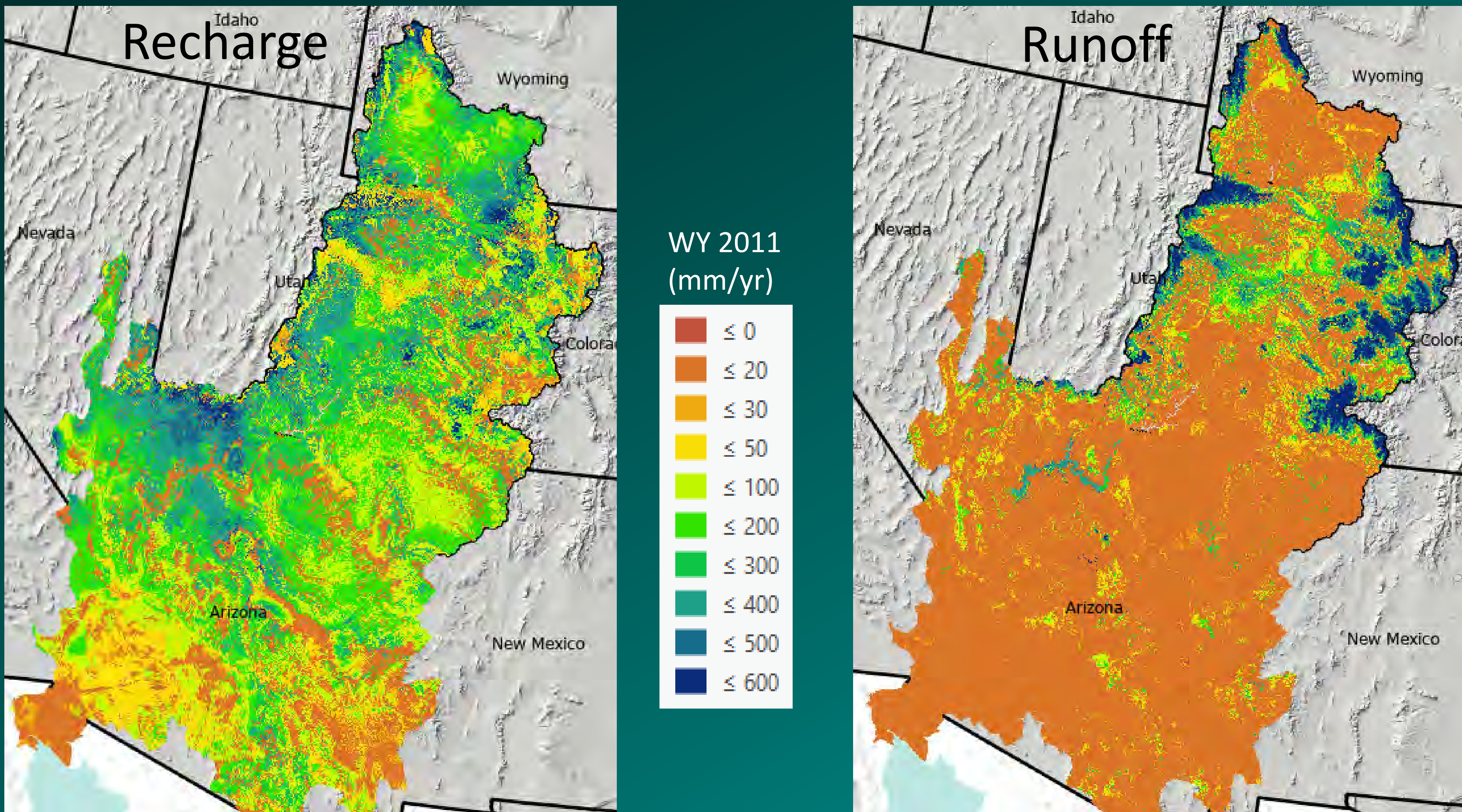








Colorado River Basin Annual Water Supply

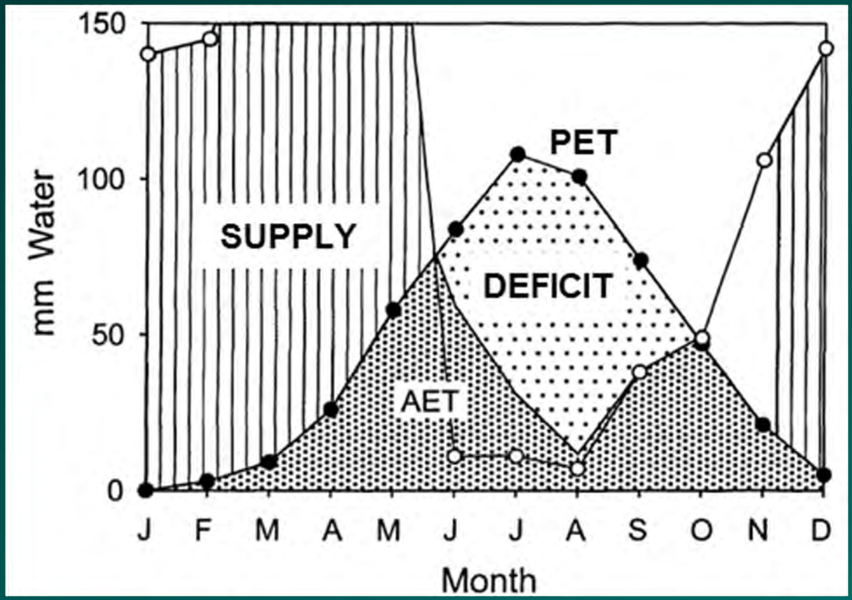


Climatic Water Deficit: a Calculation of Landscape Condition

Climatic Water Deficit

Annual evaporative demand
that exceeds available water

Potential – Actual Evapotranspiration

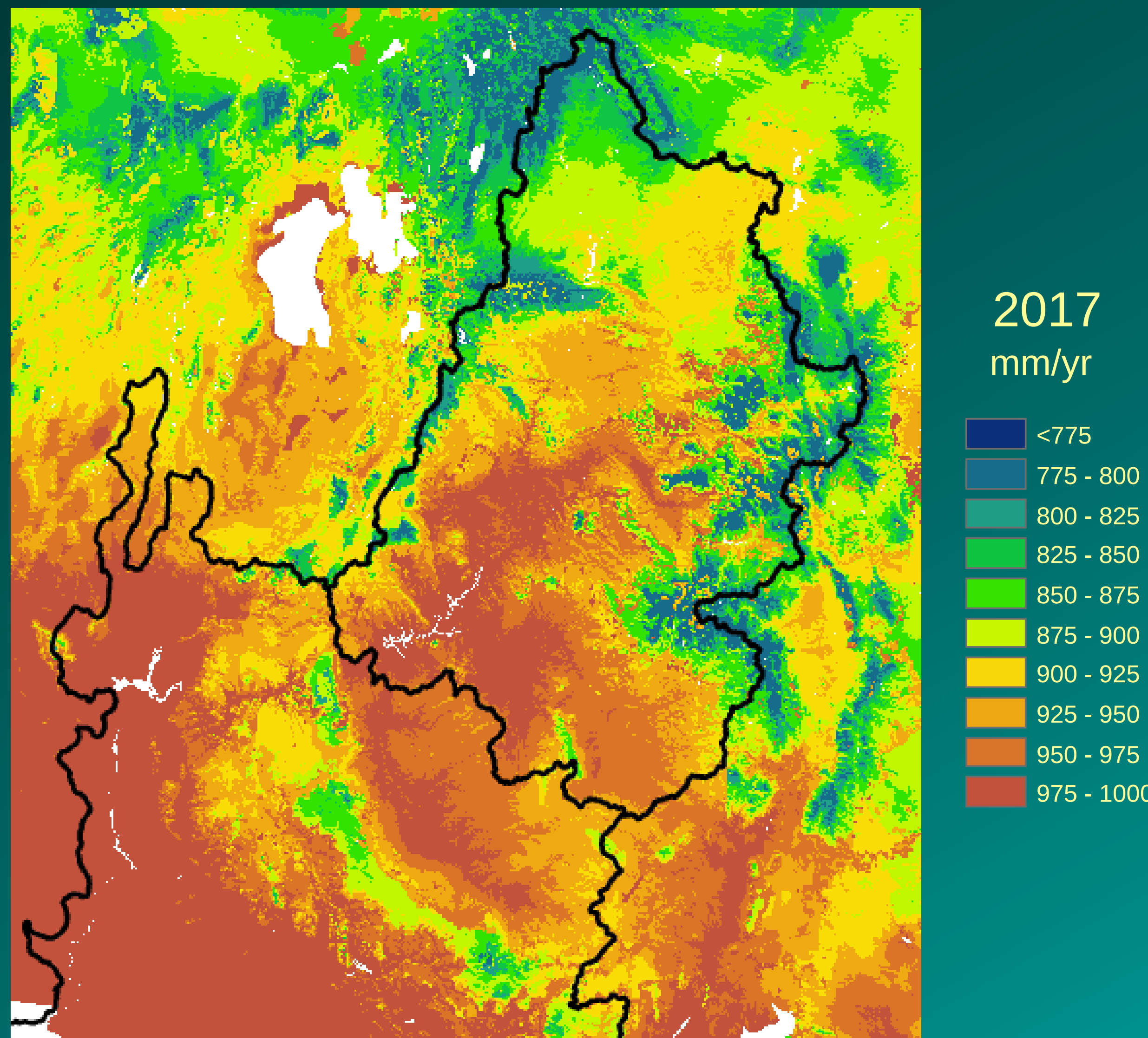


- Integrates climate, energy loading, drainage, and available soil moisture storage
- Addresses irrigation demand
- Defines level of stress on landscape
- The earlier the snowmelt the higher the annual CWD
- The hotter it is the higher the potential evapotranspiration, and the higher the accumulated CWD over the season
- When accumulated over multiple seasons it can describe the loss of water from a deep unsaturated zone

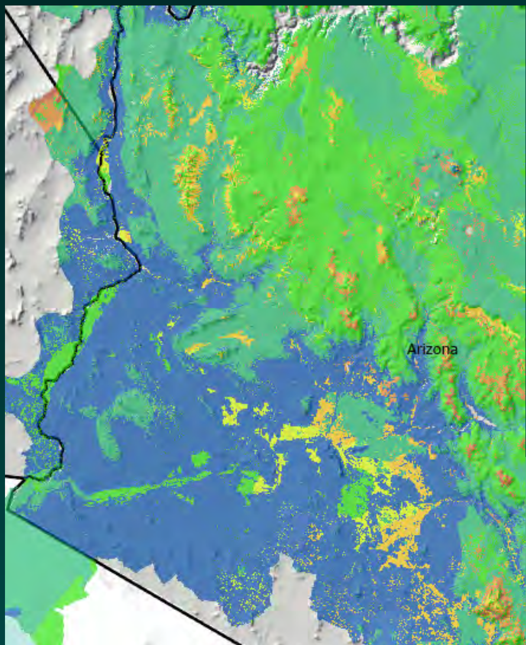
Climatic Water Deficit

Annual evaporative demand that exceeds available water

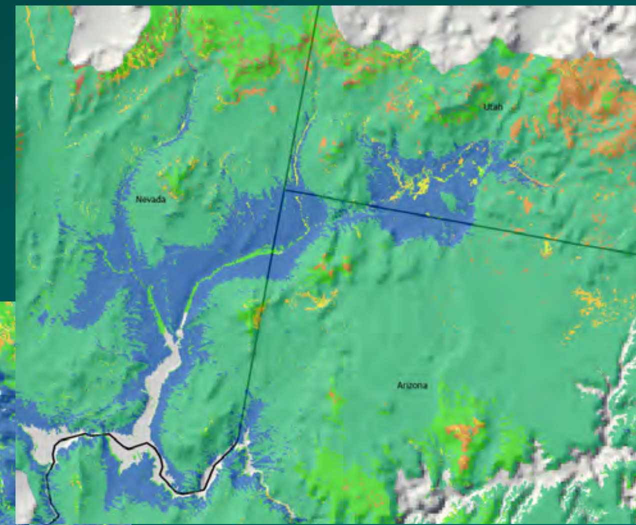
Potential – Actual Evapotranspiration

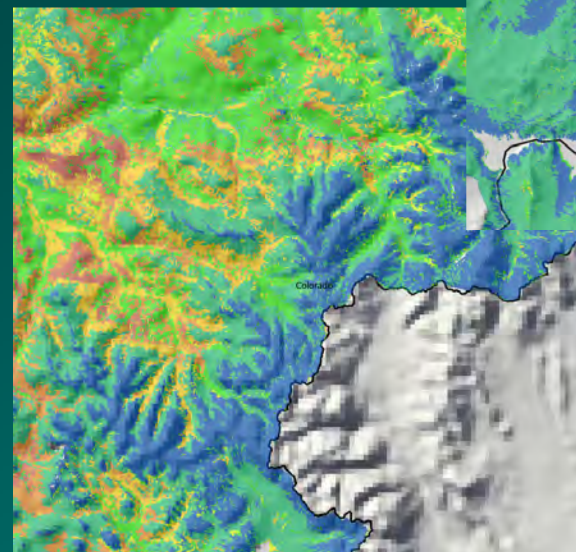


CWD as an indicator for refugia and resilience to climate change



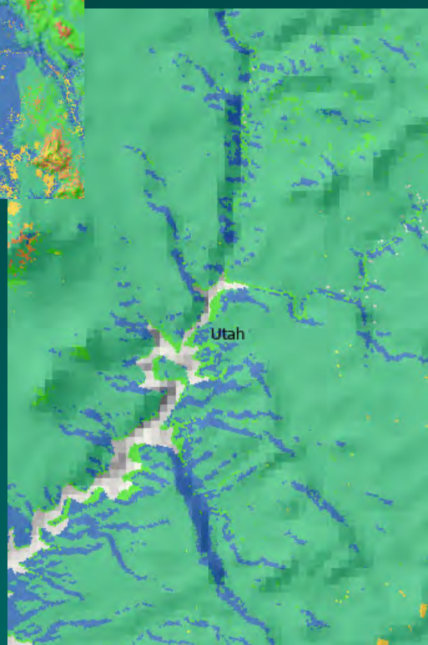
Places with low rainfall so long term variability is low





Lower lying areas with fine sediment deposits or floodplains that have high soil water holding capacity

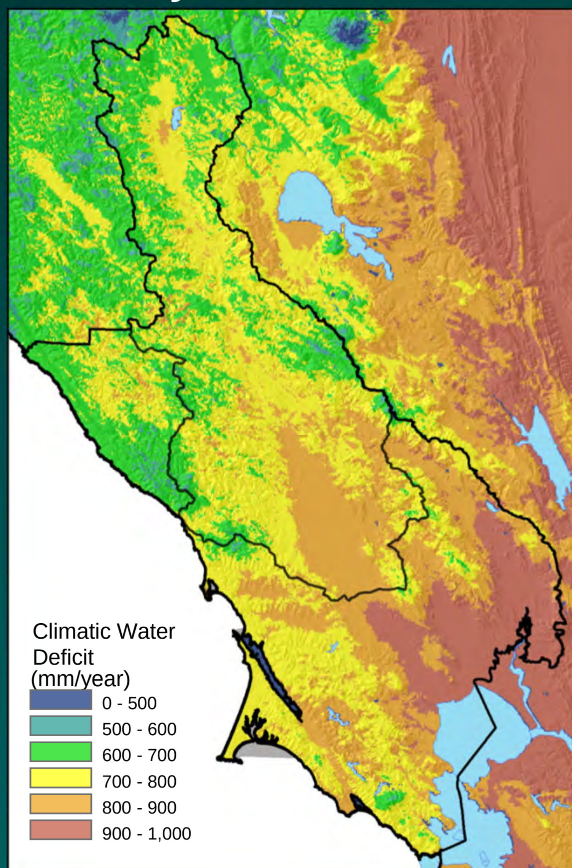
North facing aspects with lower radiation loading and later snowmelt



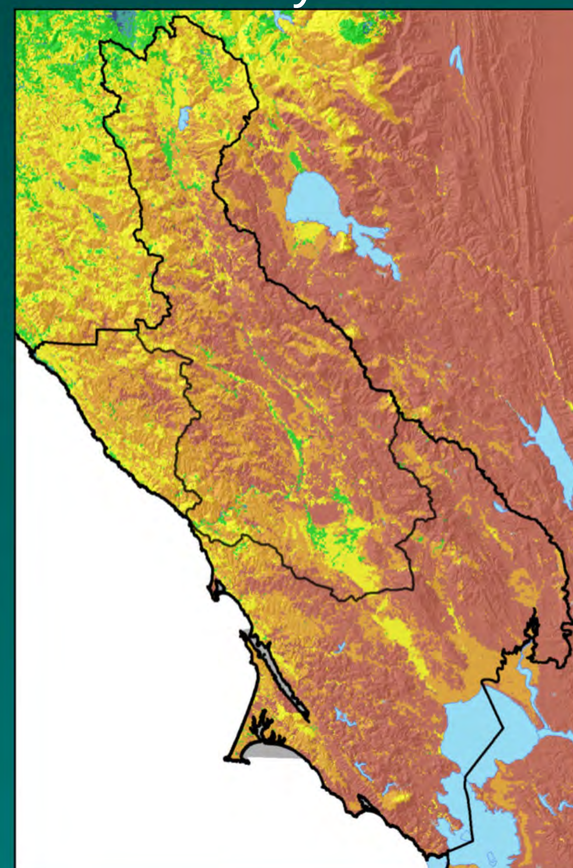
Highest elevations where there is always some seasonal snow

Landscape drought: The influence of temperature

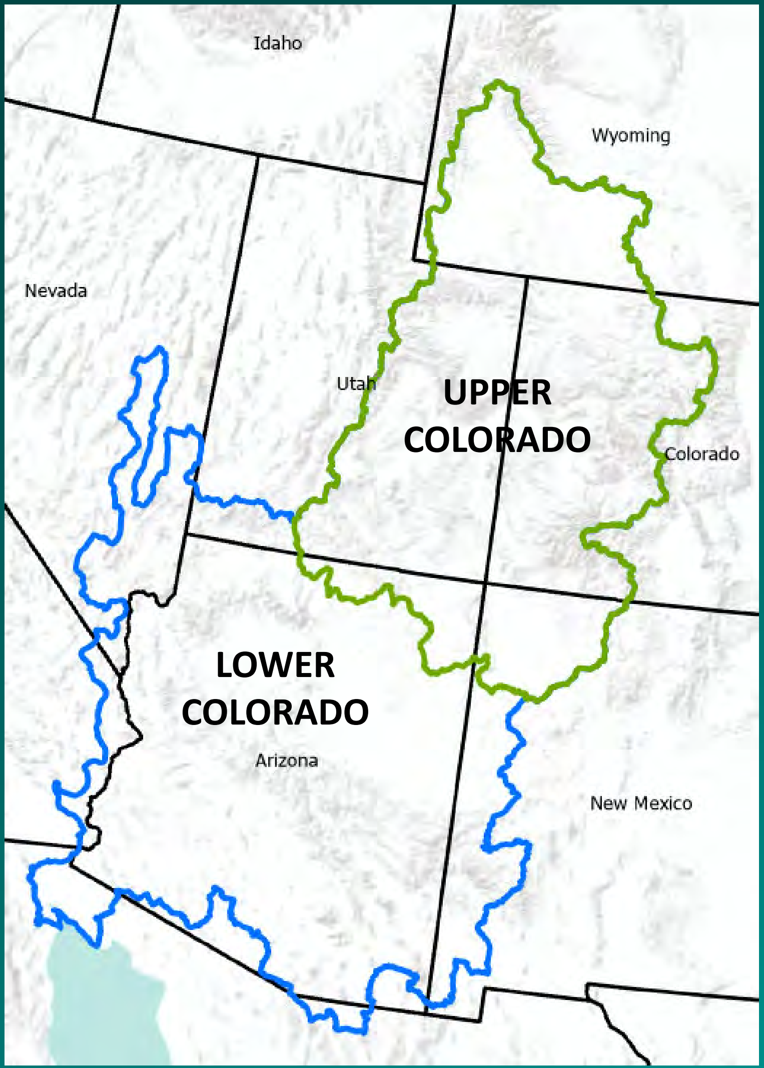
1977: A year with no water

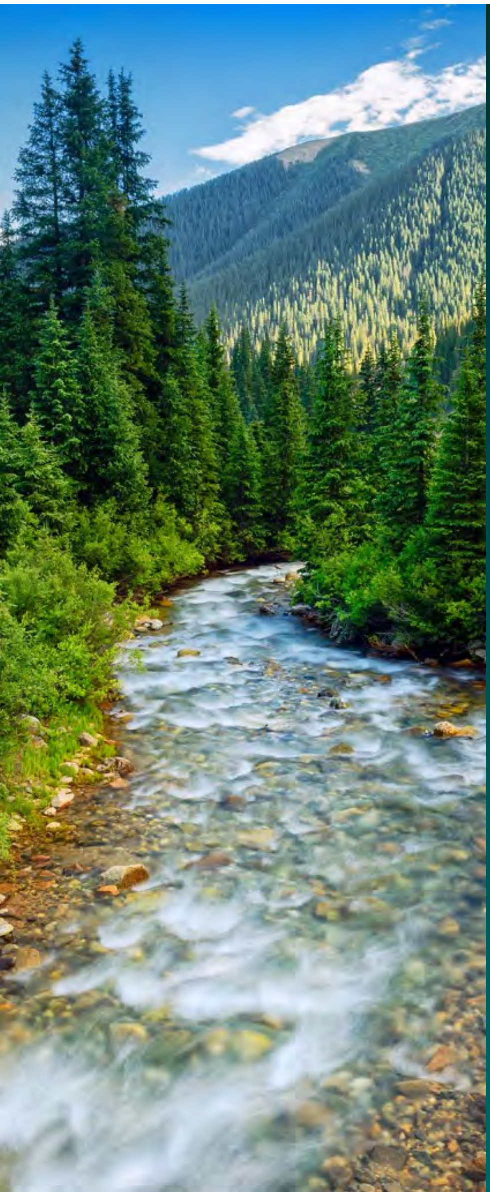


Jan 2014: A HOT year with no water



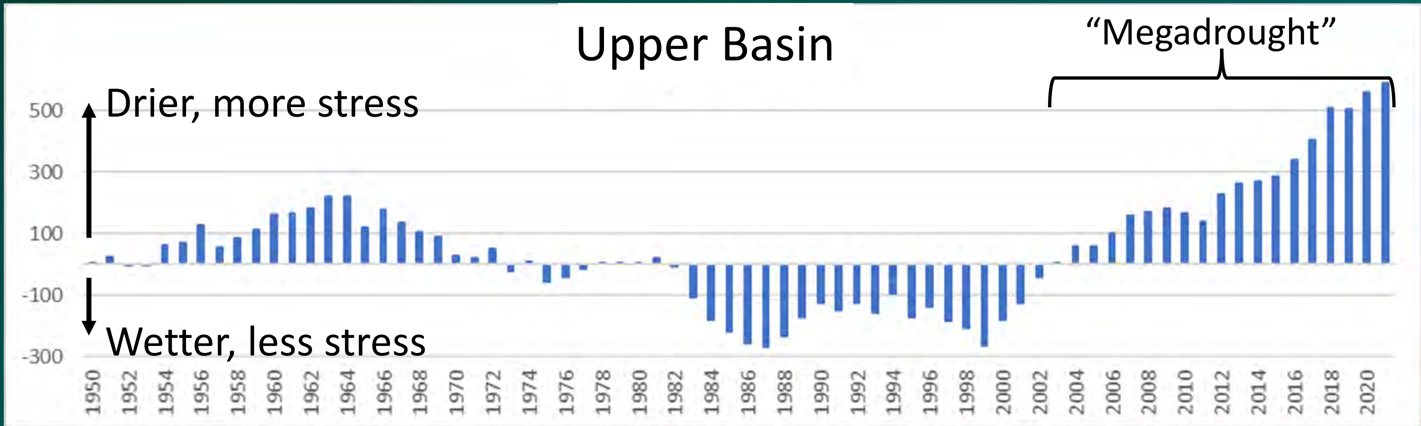
Colorado River Basin

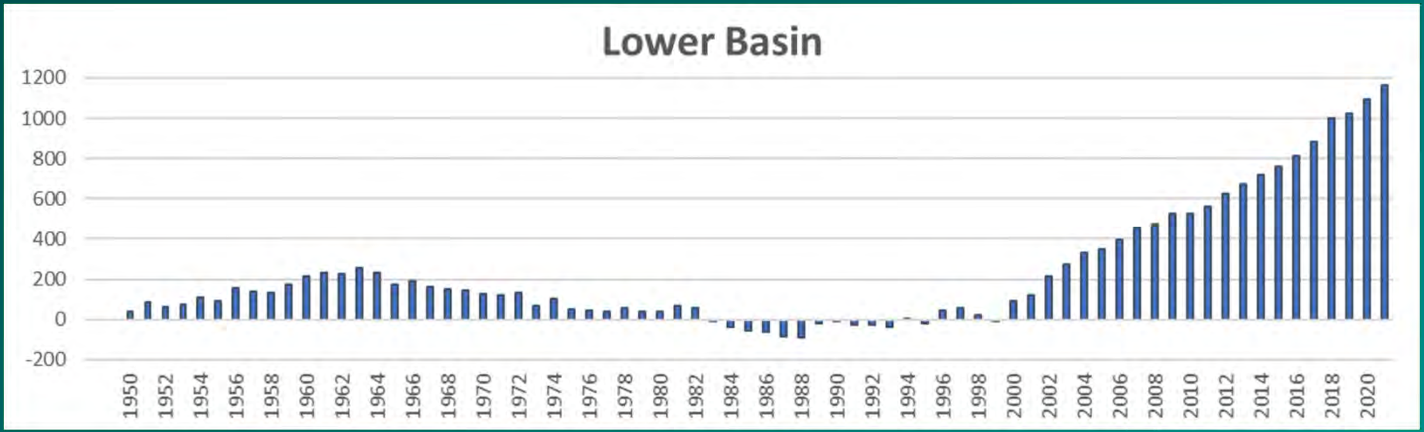


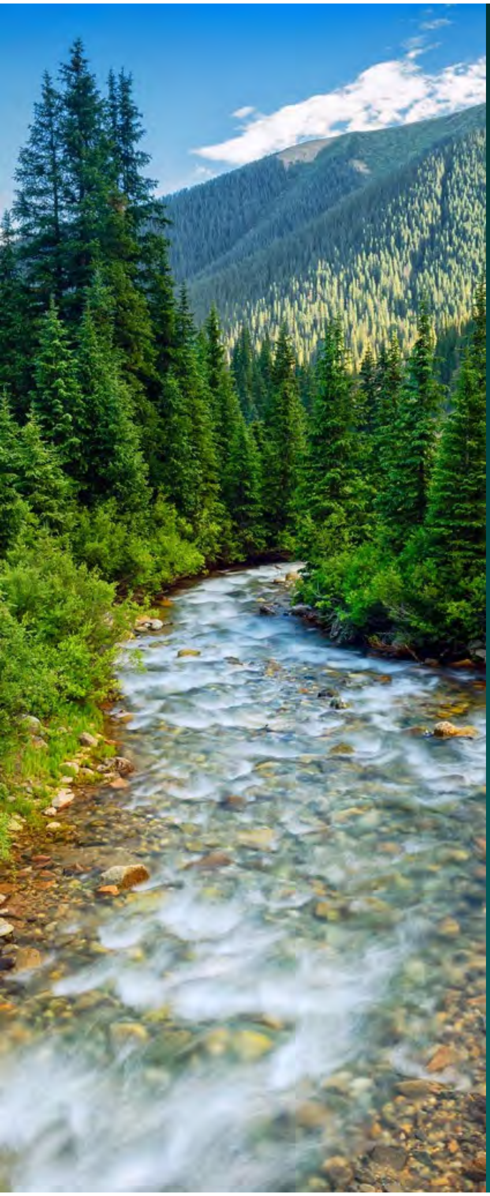


Drought Evolution in the Colorado River Basin

Accumulated CWD Difference from 1951-1980 mean

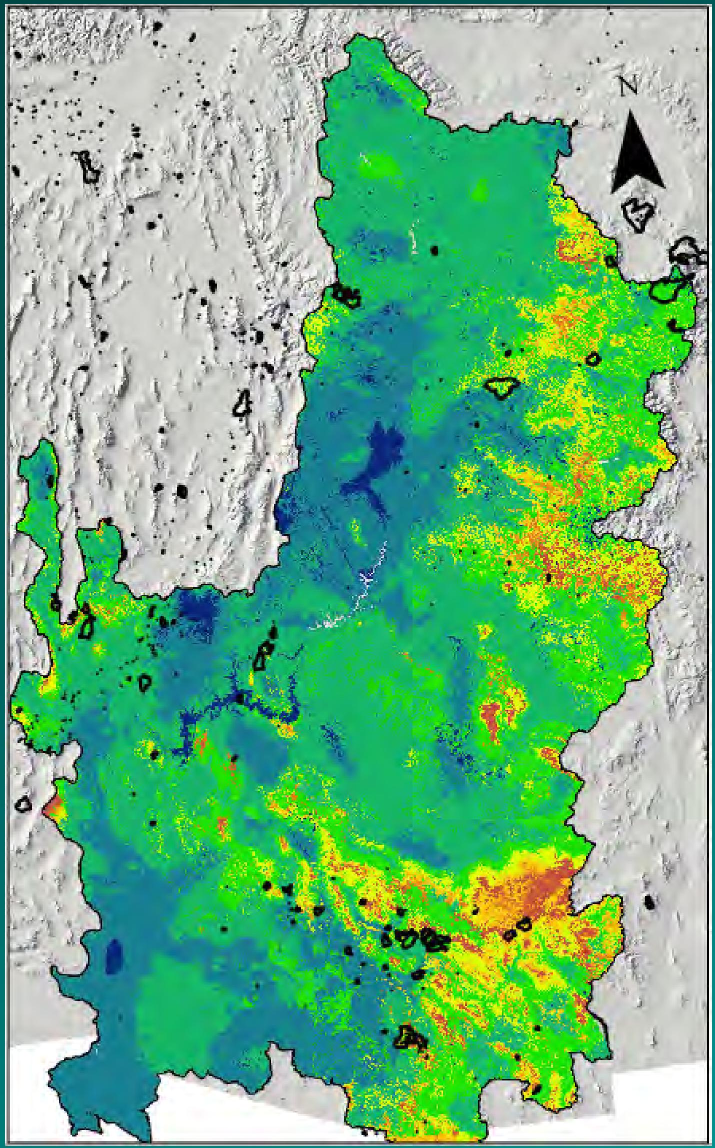






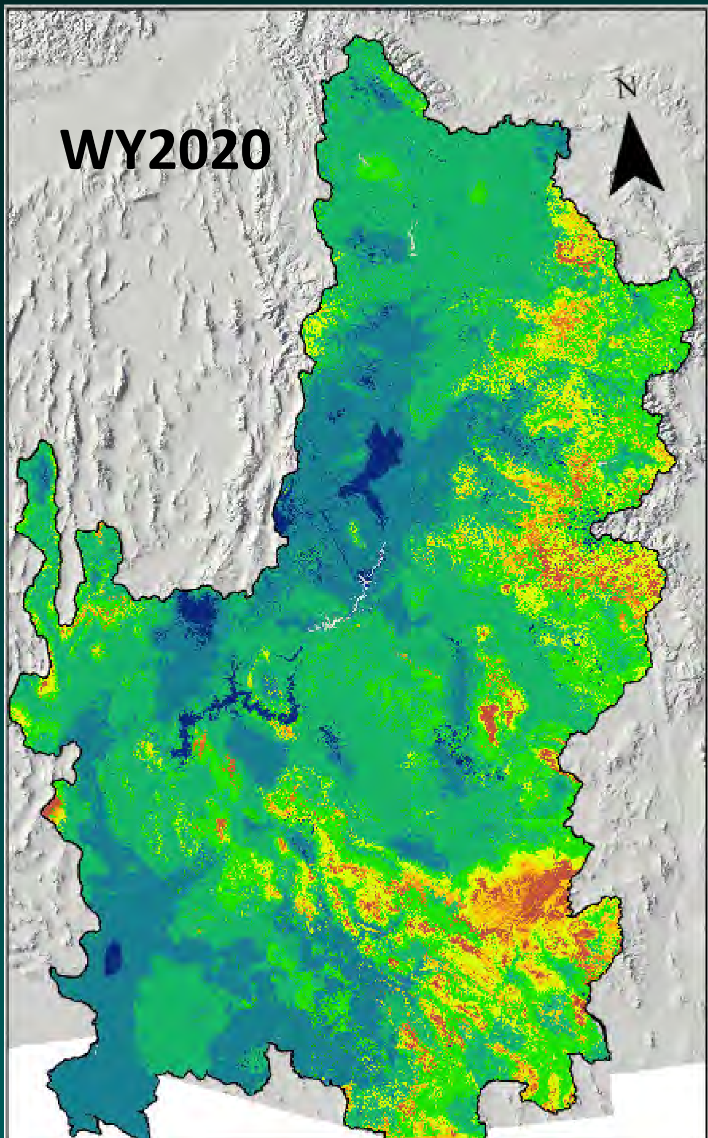
Using CWD to Characterize Drought Evolution in a Basin 2020

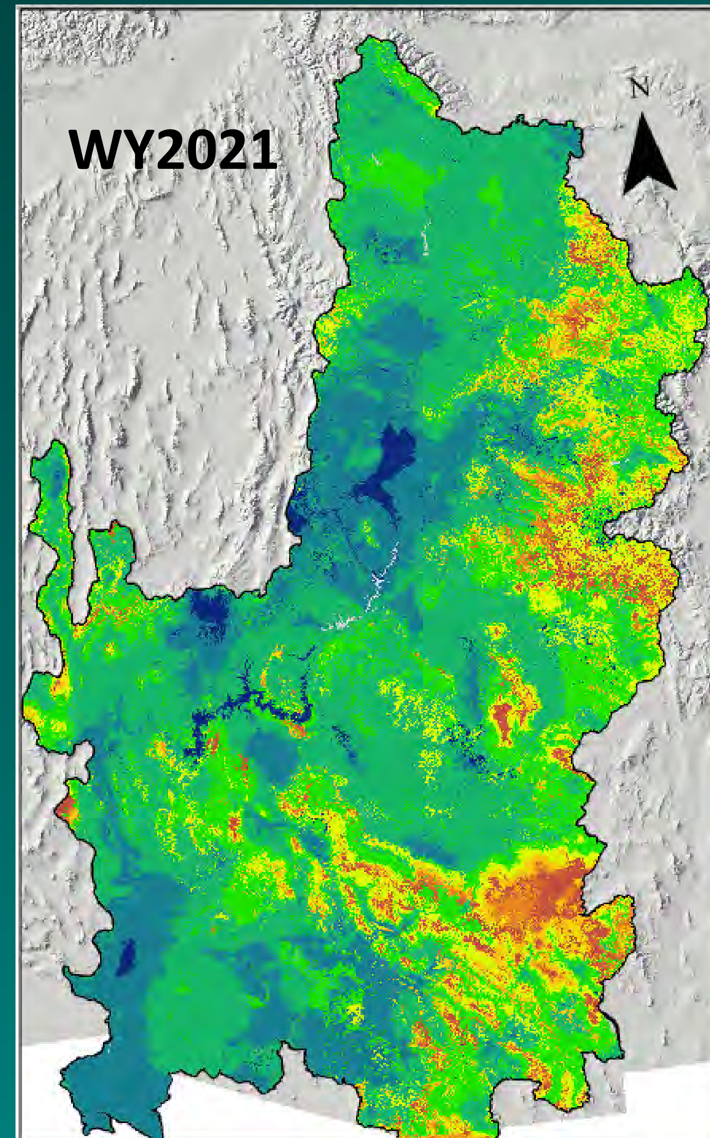
Accumulated CWD Difference from 1951-1980 mean



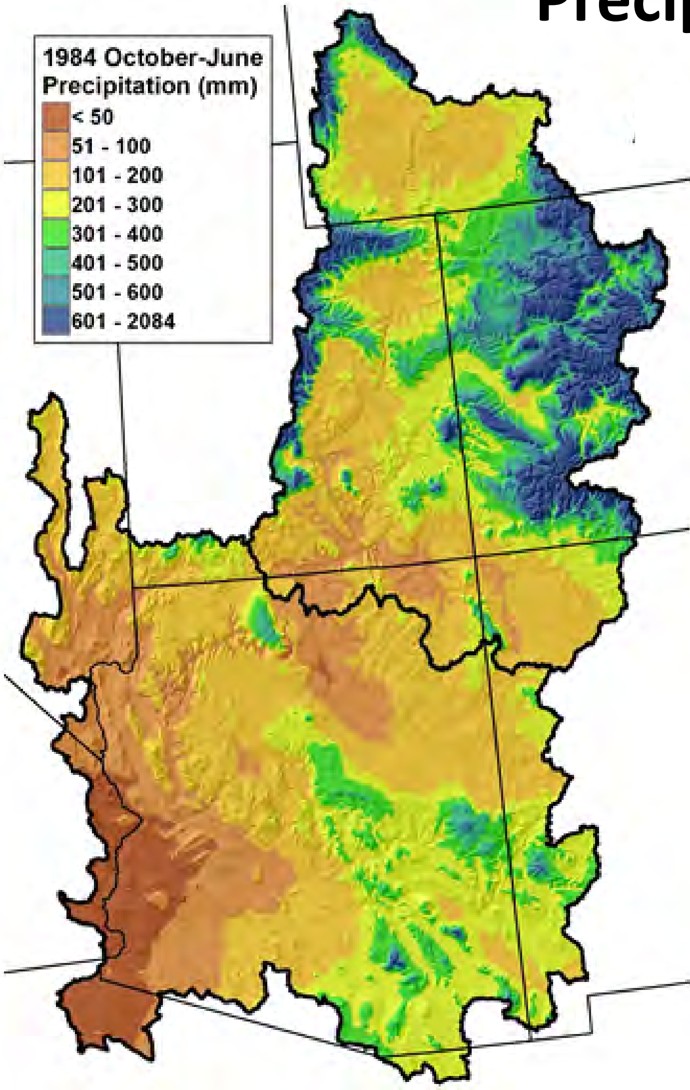
Using CWD to Characterize Drought Evolution

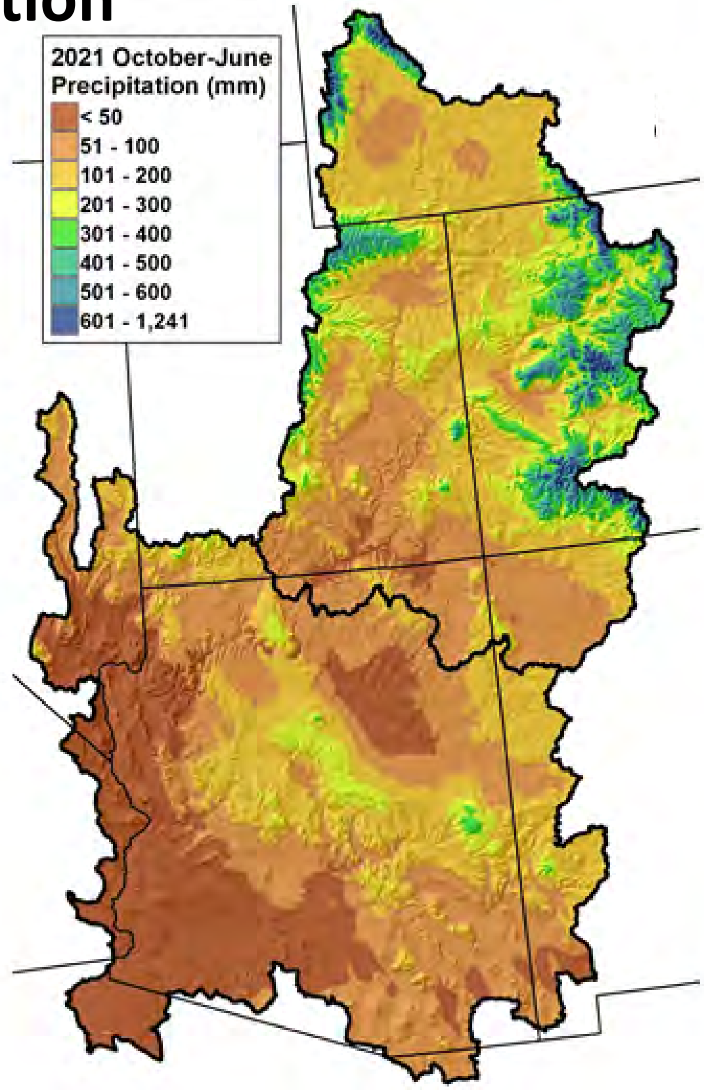
Accumulated CWD Difference from 1951-1980 mean



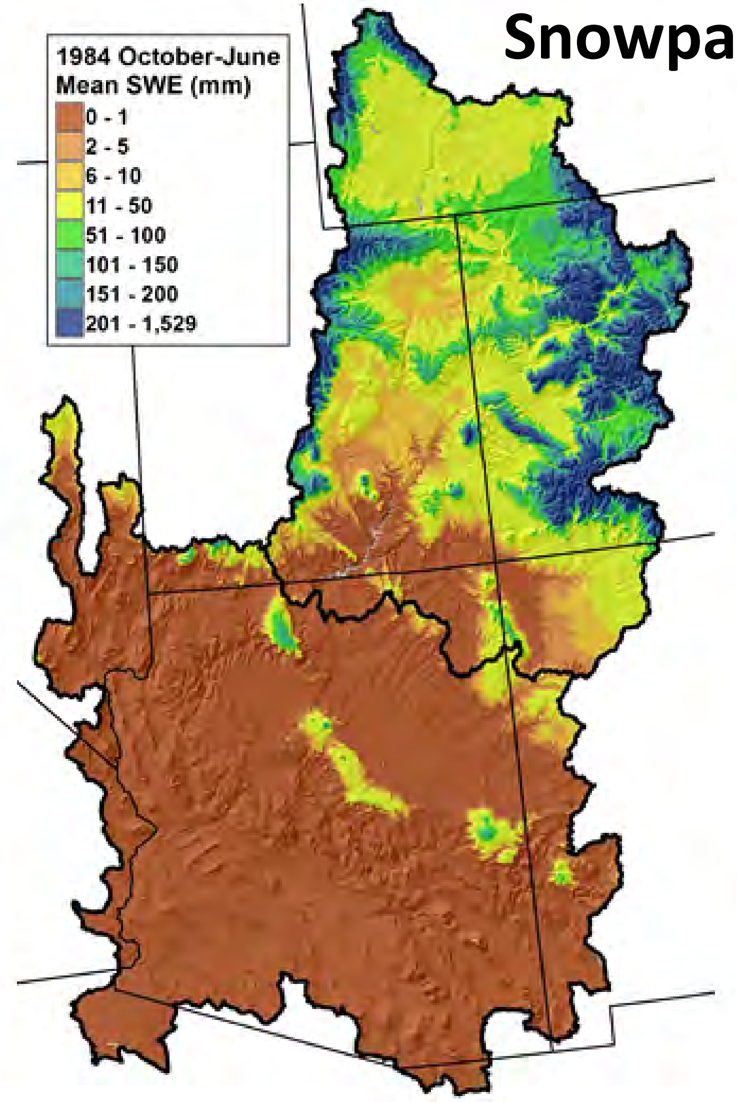


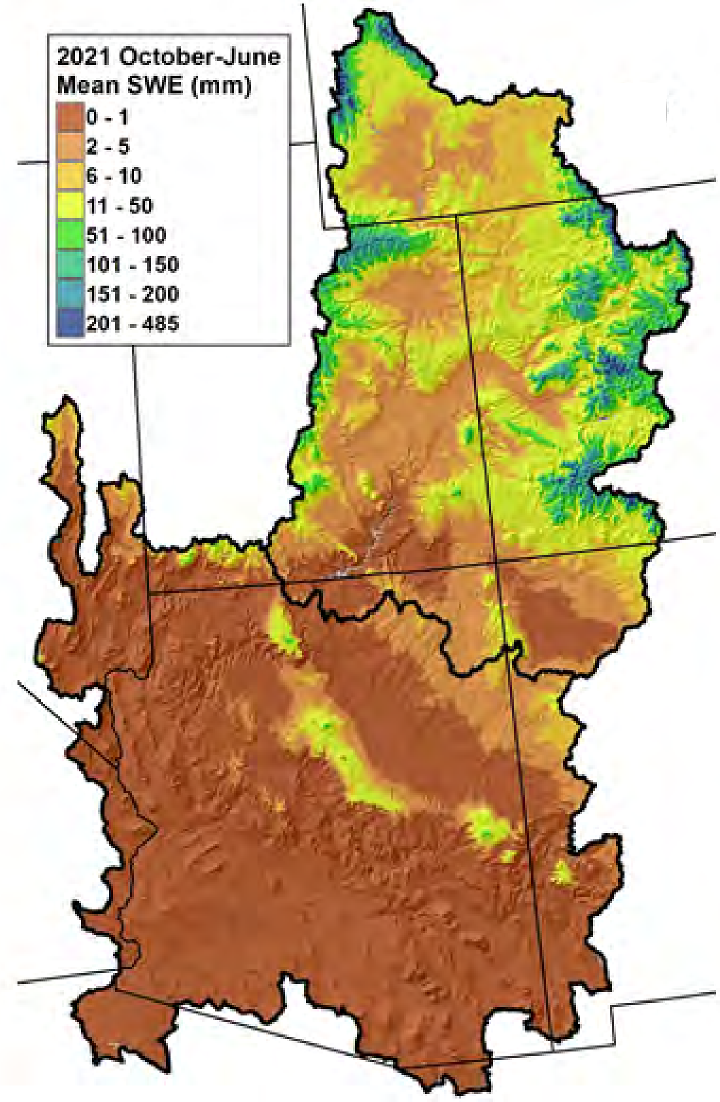
Precipitation





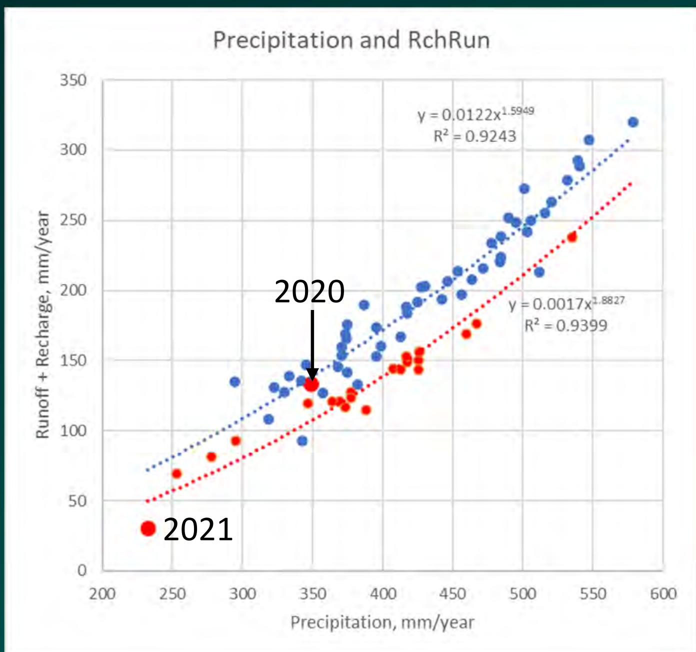
Snowpack

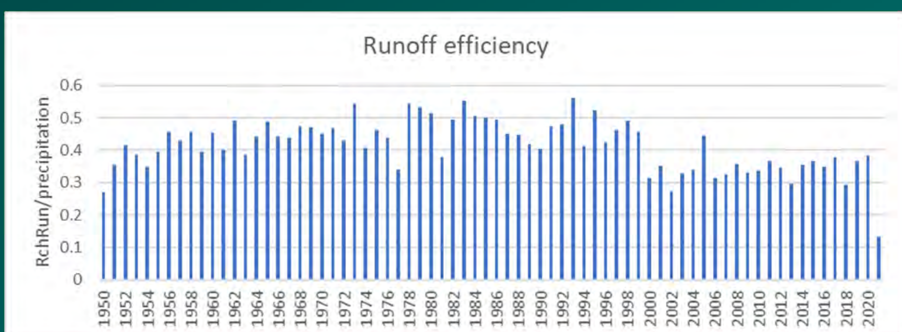

1984 October-June
Mean SWE (mm)
0 - 1
2 - 5
6 - 10
11 - 50
51 - 100
101 - 150
151 - 200
201 - 1,529


2021 October-June
Mean SWE (mm)
0 - 1
2 - 5
6 - 10
11 - 50
51 - 100
101 - 150
151 - 200
201 - 485

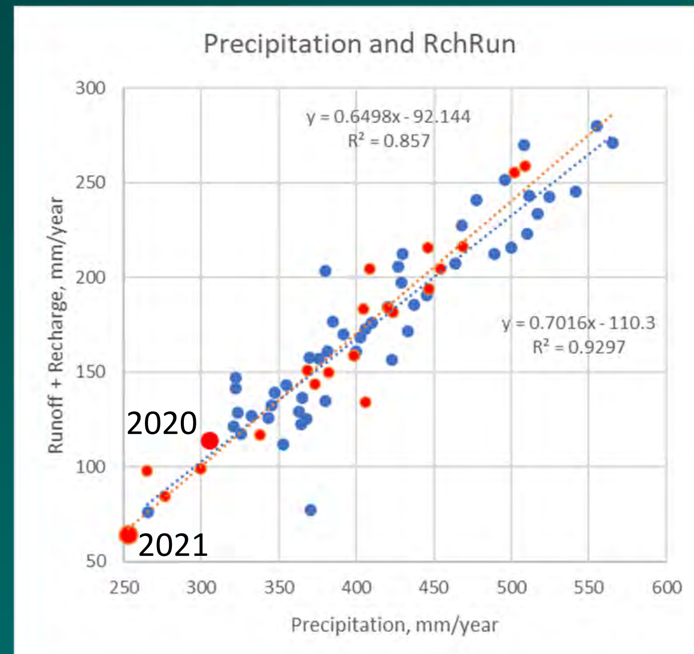
Runoff Efficiency 1950-1999 vs 2000-2021

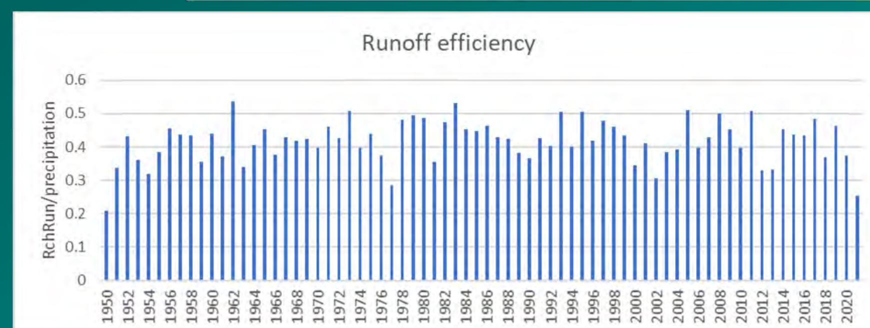
Lower Basin





Upper Basin



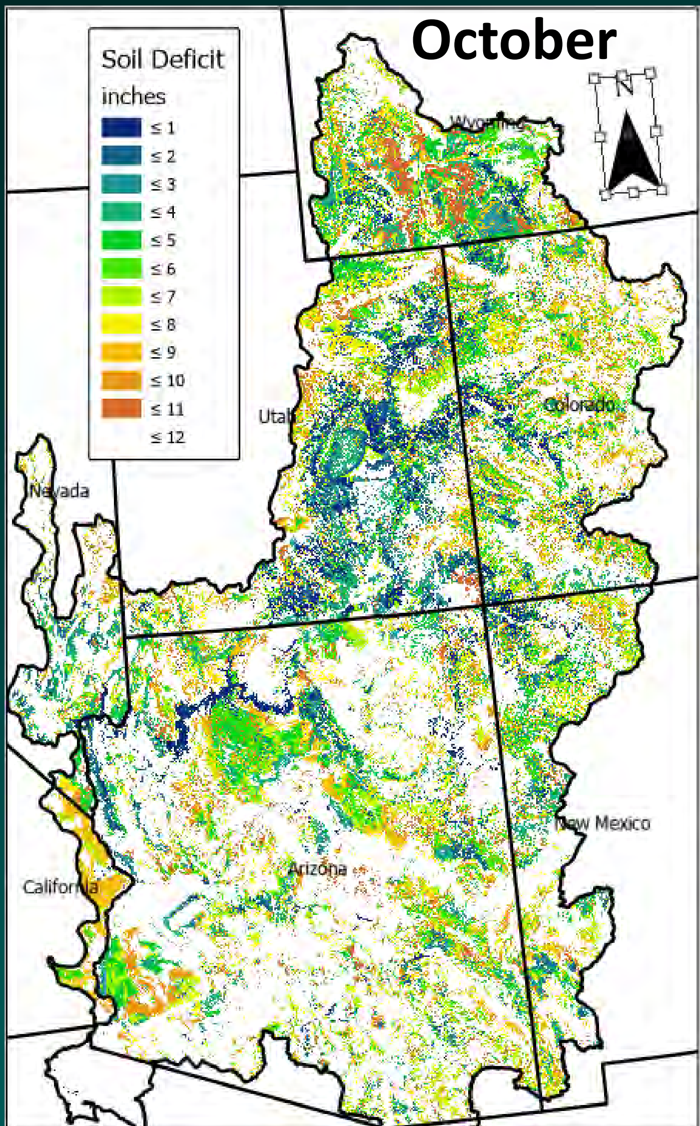


	Upper Basin	Lower Basin
	Recharge + Runoff	Recharge + Runoff
	Acre-feet/year	
% difference (1981-2010)	-70%	-75%

	Upper Basin	Lower Basin
	Recharge + Runoff	Recharge + Runoff
	Acre-feet/year	
WY1981-2010	25,695,209	40,793,662
avg * 10% precip	11,646,737	25,674,071
avg * 20% precip	13,880,870	30,364,497
avg * 30% precip	16,376,078	35,915,185
avg * 40% precip	18,960,553	41,904,041
avg * 50% precip	21,634,296	48,331,065
avg * 60% precip	24,397,307	55,196,256
avg * 70% precip	27,249,585	62,499,616
	Percent Difference from 1981-2010	
	Recharge + Runoff	Recharge + Runoff
avg * 10% precip	-55%	-37%
avg * 20% precip	-46%	-26%
avg * 30% precip	-36%	-12%
avg * 40% precip	-26%	3%
avg * 50% precip	-16%	18%
avg * 60% precip	-5%	35%
avg * 70% precip	6%	53%

WY2021 is about 70-75% of average water supply conditions, calculated as recharge plus runoff.

To return the basin to average water supply conditions it takes about 140% of average precipitation for the lower basin, and about 165% for the upper basin.

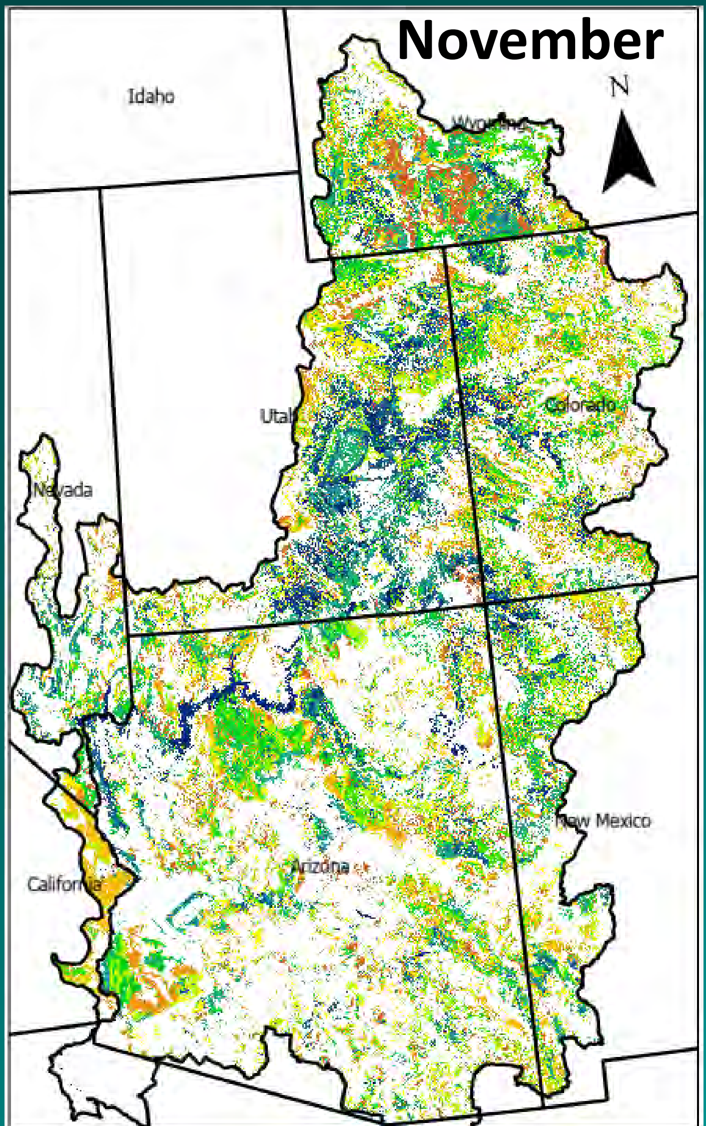


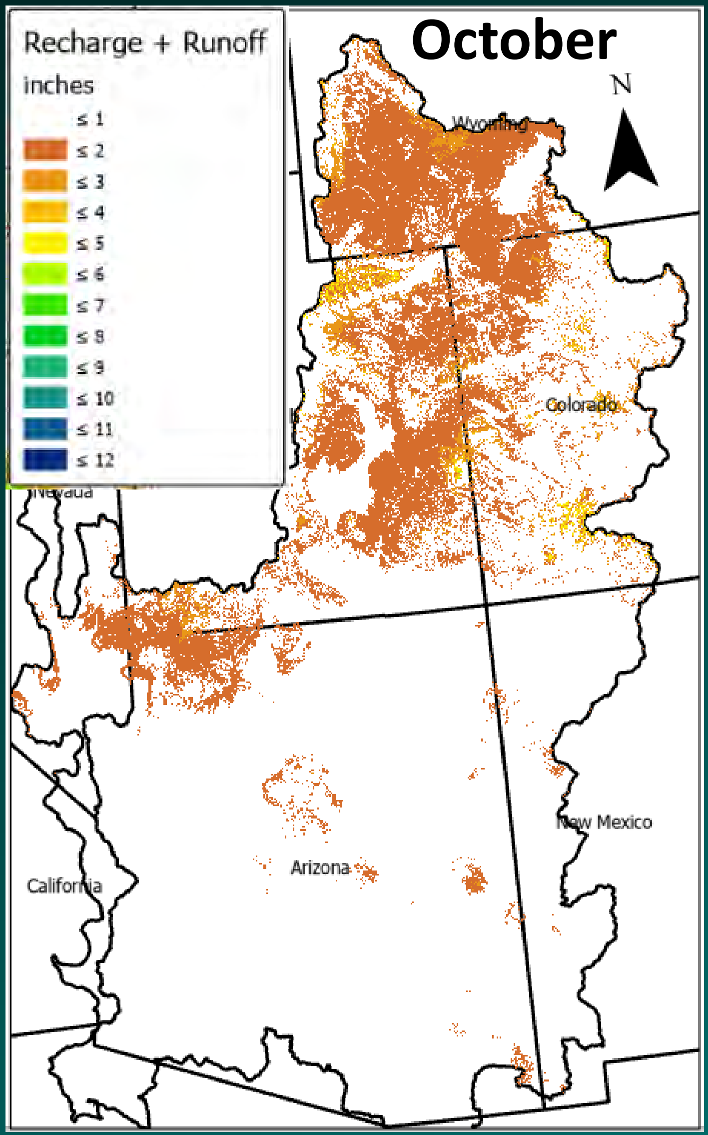
Colorado River Basin

October and November 2021

Soil Deficit

Soil deficit will need to be filled before significant runoff and recharge occur this winter





Colorado River Basin

October 2021
0-4” of water supply

November 2021
0-2” of water supply

***Non-Publicly releasable information for business use only...

Summary and Conclusions

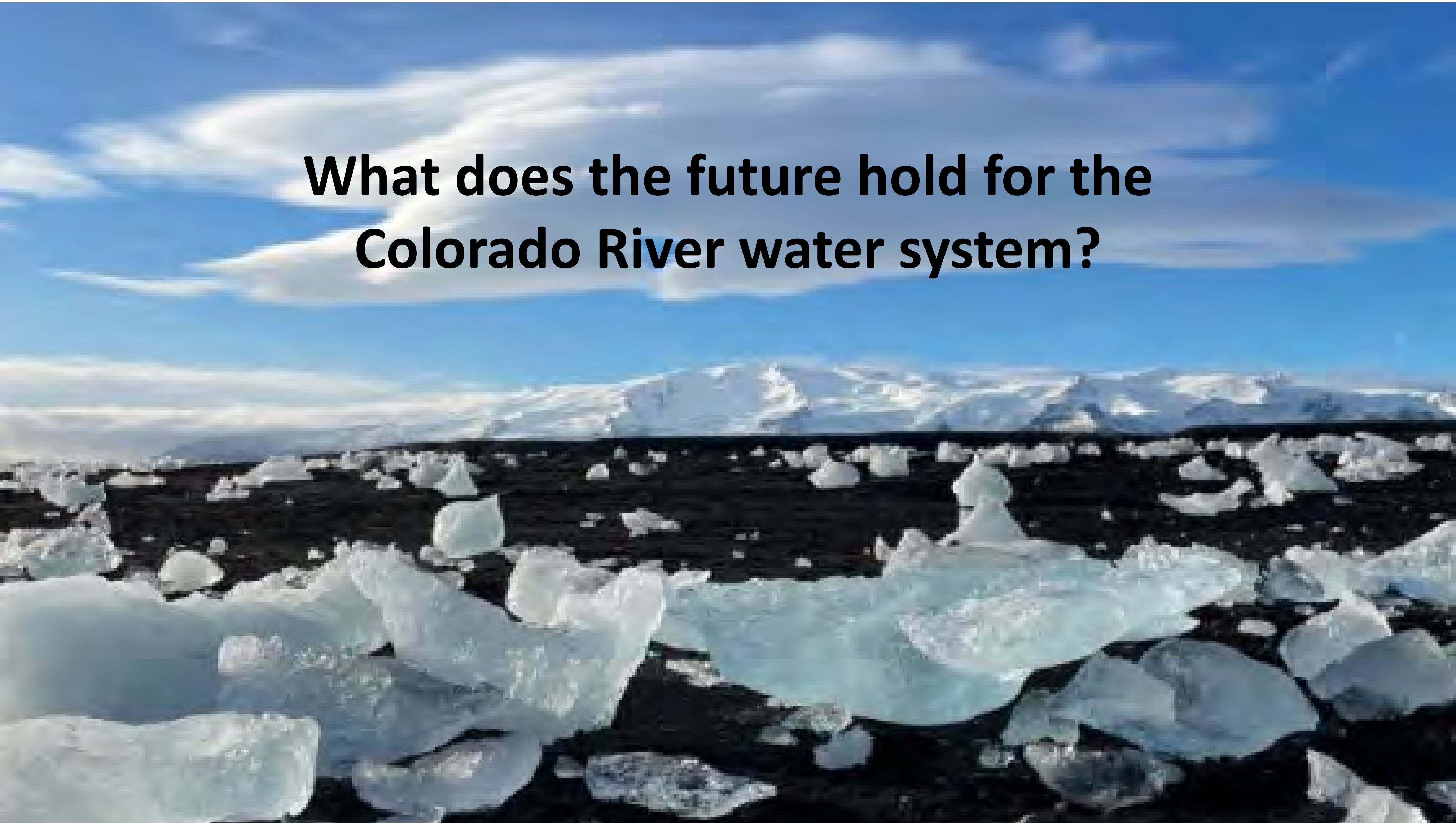
- The Colorado River Basin is experiencing a “megadrought” that exceeds any since the 1500s.
- Impacts include diminishing snowpack, water supply shortage, increasing landscape stress and wildfire.
- Fine spatial scales allow for the identification of climate refugia and landscapes that are more or less resilient to changes in climate.

Summary and Conclusions

- 2020 & 2021 were the hottest and driest years on record in the CRB.
- Increased landscape stress persists, in comparison to long term means and will likely take much longer than the water supply to recover.
- Runoff efficiency has declined in recent years for the lower CRB, indicating that it will take more rain to fill soils and become runoff than in the past.

Summary and Conclusions

- Water balance modeling can be used to characterize the spatially variable hydrologic processes that lead to drought effects and highlight where on the landscape management actions could be prioritized.
- It can be used to update antecedent conditions and provide information to inform forecasts.
- Monitoring and modeling should combine to inform resource management.


What does the future hold for the
Colorado River water system?