Contrasting Climate Impacts in Central Arizona to the Upper Colorado River Basin

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Horse Mesa Dam and Apache Lake on the Salt River

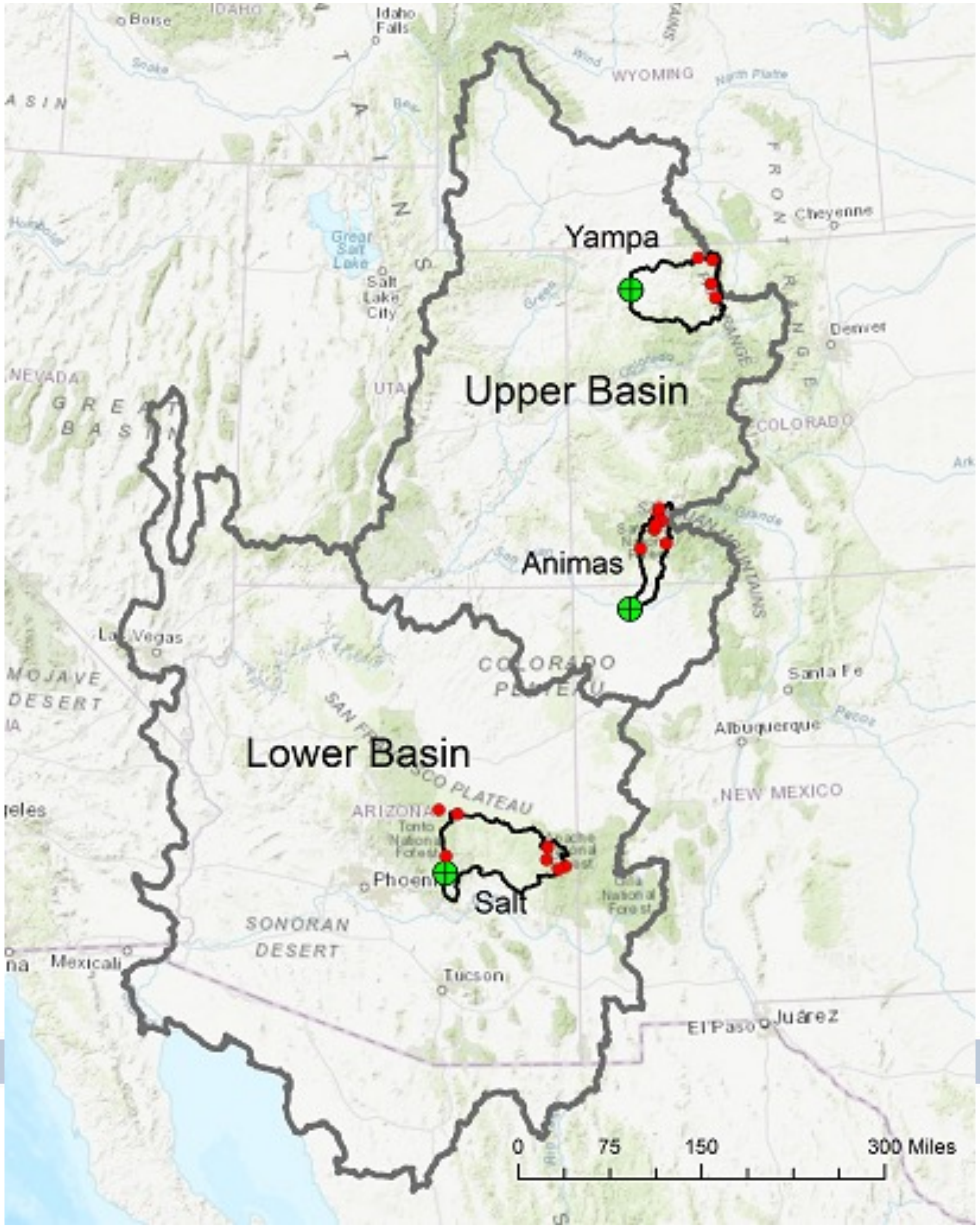
Upper Colorado River Basin vs Central AZ

- What generates the streamflow?
- Long term impacts from drought
- Streamflow sensitivity to warming
- Lake Mead + Lake Powell vs Central AZ Reservoirs

Upper Basin vs Central AZ

Central AZ is:

1. Lower latitude (hotter)
2. Lower elevation (hotter)
3. Closer to the Pacific (higher frequency of warm atmospheric river events)



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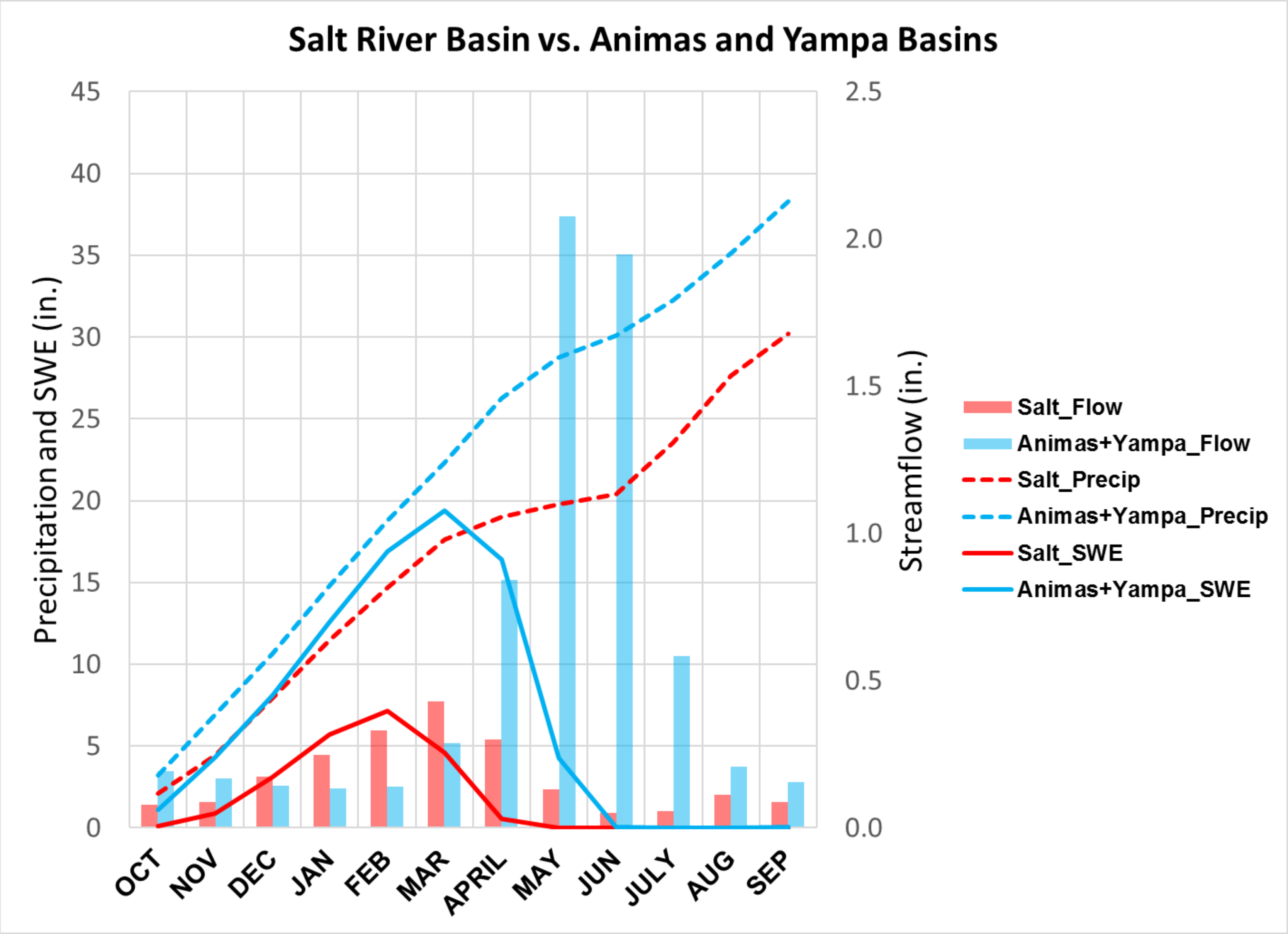
What generates the Streamflow?

Central AZ streamflow:

1. Occurs mostly in winter/early spring
2. Generated by winter rainfall, winter snowmelt, and early spring snowmelt

Upper Colorado streamflow:

1. Occurs late spring/early summer
2. Generated by snowmelt



Central AZ Streamflow Generation Example: Winter Rainfall 2019

Day 1

Day 2

Day 3

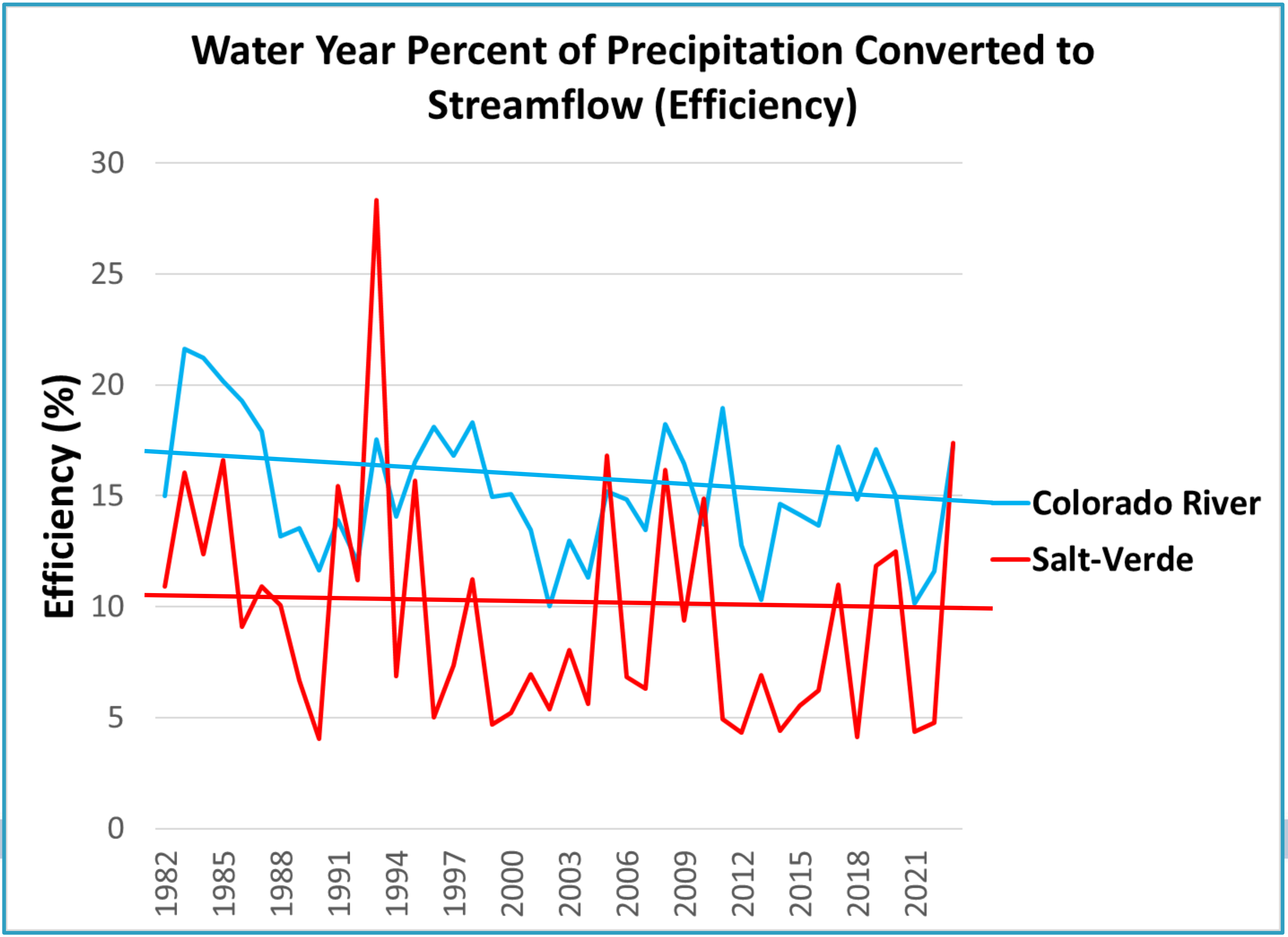
Day 4

Day 5

Day 6

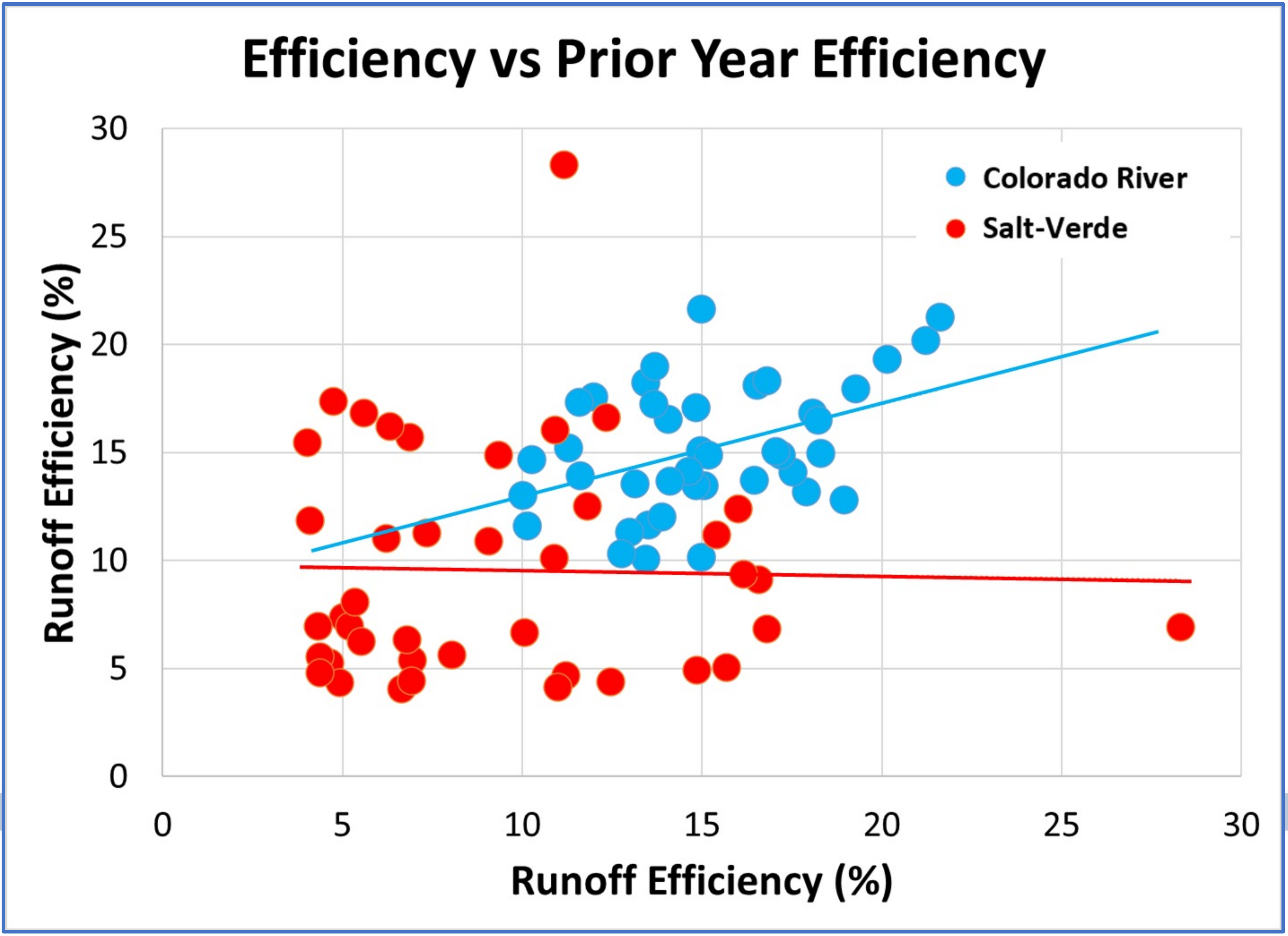
Accumulating Effects of Drought on the Colorado

- **Lower efficiencies since late-1990s suggests that low precipitation reduces efficiency.**
- **Salt-Verde has had years with relatively high efficiency during the drought (e.g., 2005, 2008, 2010, 2023)**



Accumulating Effects of Drought on the Colorado

- On the Colorado, low efficiency years tend to follow low efficiency years, (i.e., lasting effects of drought)
- Colorado River more sensitive to warming



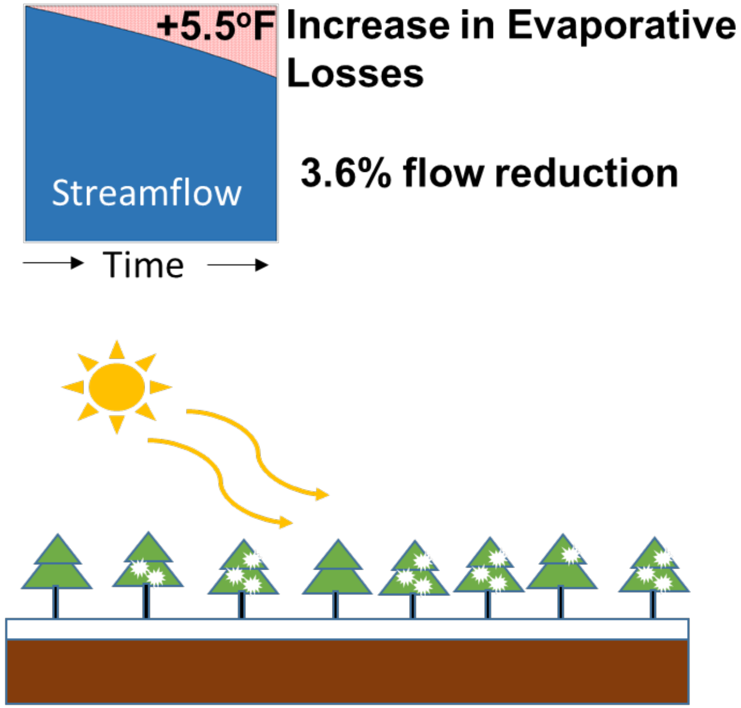
Central AZ Streamflow Less Sensitive to Warming

The peak energy available for evaporative loss occurs 3 months after peak streamflow on the Salt-Verde (Robles et al. 2020).

This is not the case for the Colorado River, partly contributing to a 5 times greater streamflow sensitivity to warming on the Colorado than the Salt-Verde (BOR 2020).

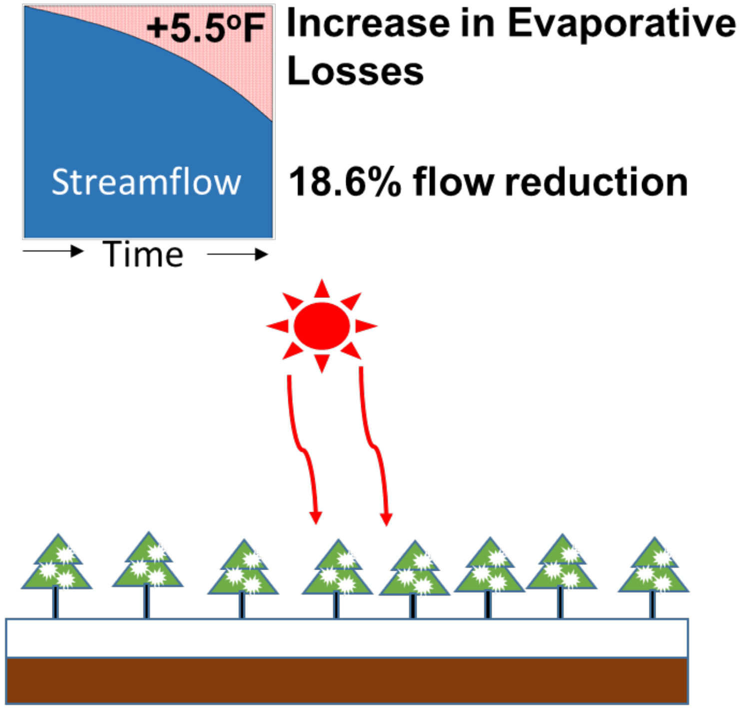
Salt-Verde Runoff Season

January-April



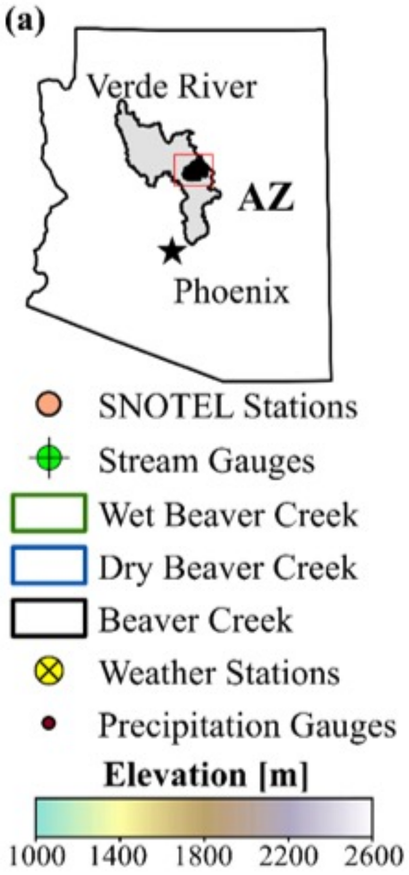
Colorado River Runoff Season

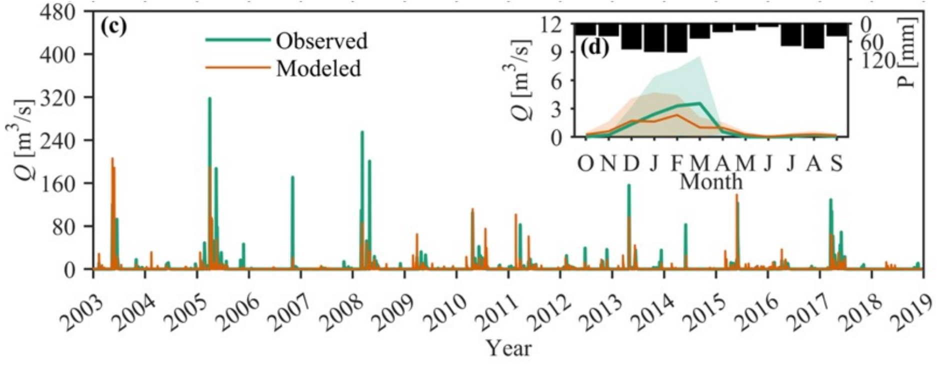
April-July



A Deeper Dive into the Lower Sensitivity to Warming

- **What happens when the temperature increases? No change to precipitation.**



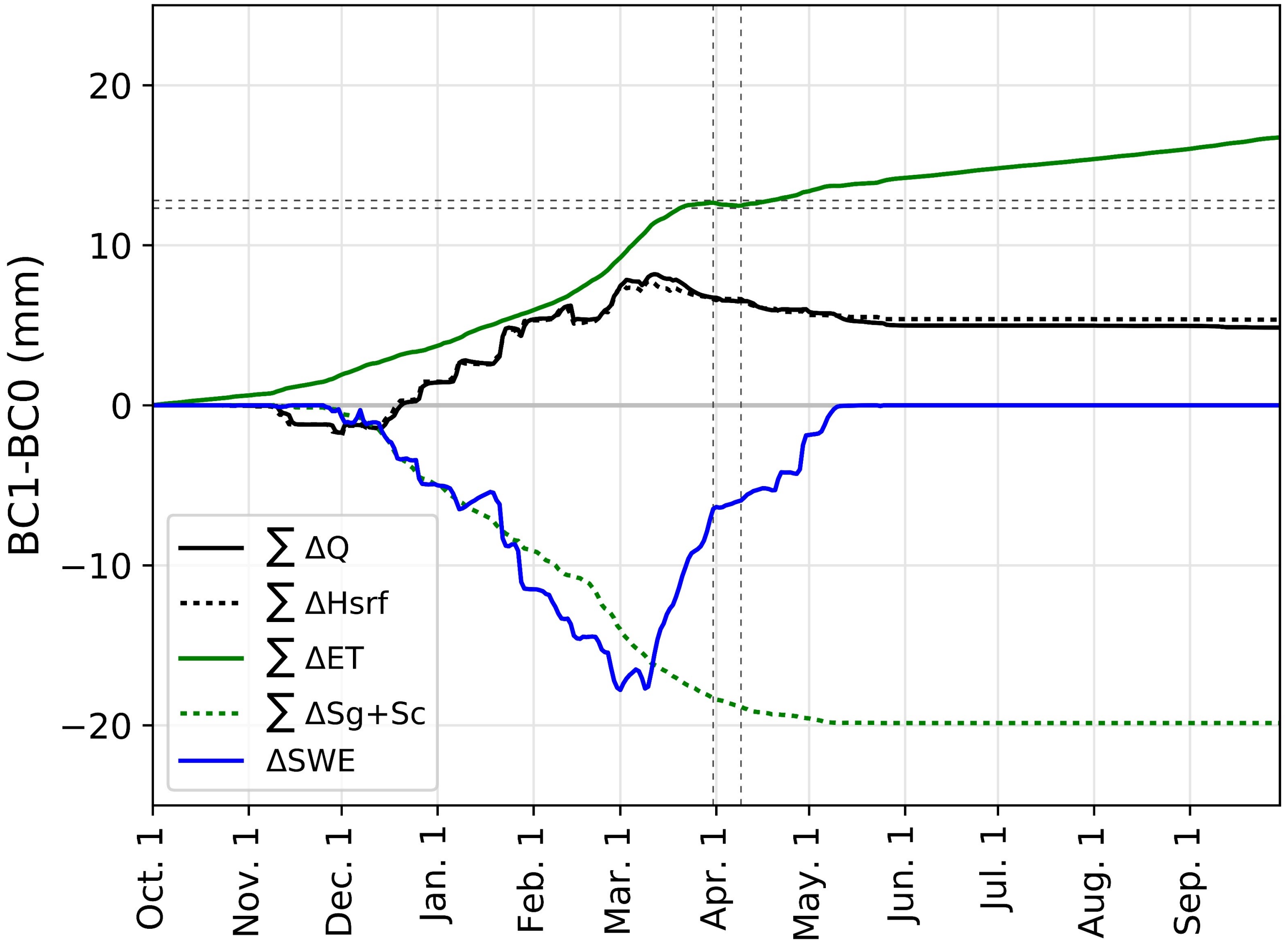


- **Simulate Beaver Creek streamflow with an advanced hydrologic model**

Cederstrom, C., E. Vivoni, G. Mascaro, and B. Svoma (2024), Forest Treatment Effects on Snow Cover, Evapotranspiration, and Streamflow Responses in Arizona under Warming Conditions, ***in review at WRR.***

Change in Beaver Creek Water Budget +1°C

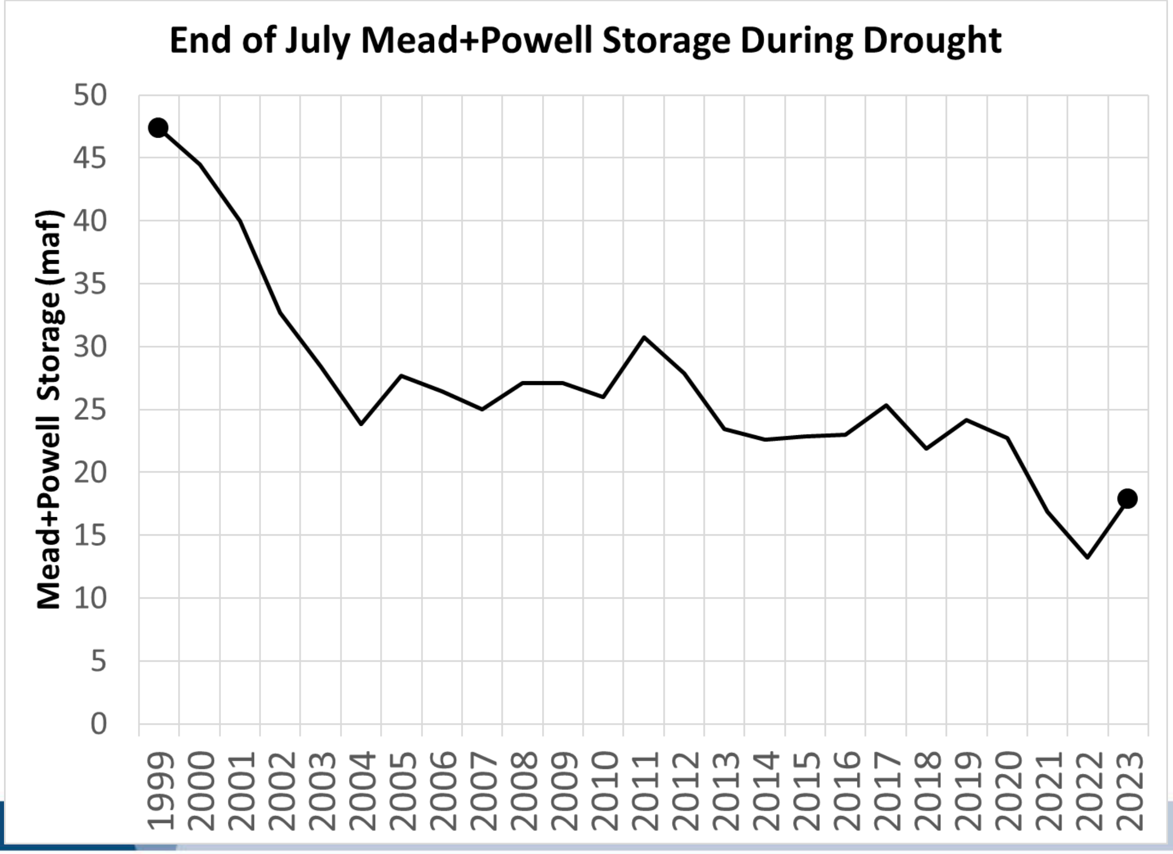
- **Streamflow increases with 1°C warming.**
  - **Snow sublimation (S_g+S_c) change overcomes Evapotranspiration (ET) change up to ~2°C warming**
  - **Exceptions are dry years when ET change overcomes S_g+S_c change**
- **Increased variability due to warming alone**



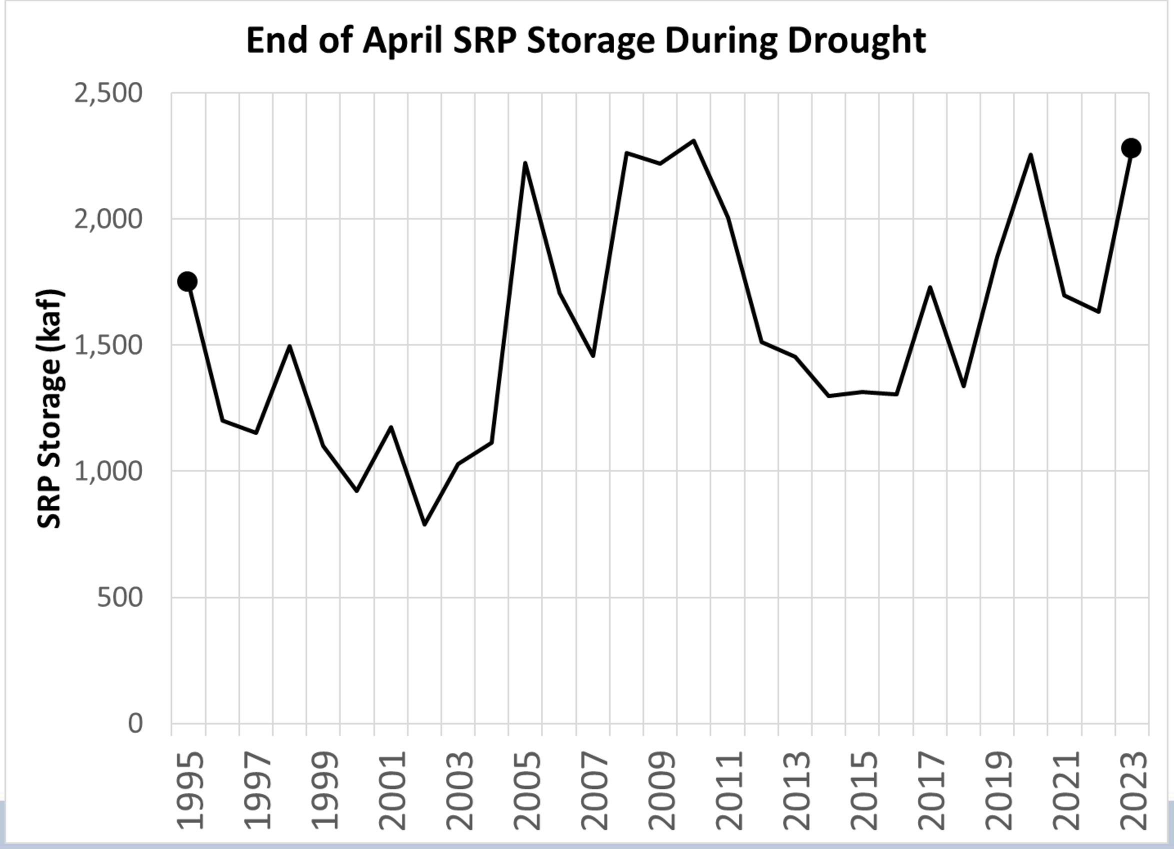
Cederstrom, C., E. Vivoni, G. Mascaro, and B. Svoma (2024), Forest Treatment Effects on Snow Cover, Evapotranspiration, and Streamflow Responses in Arizona under Warming Conditions, ***in review at WRR*.**

Storage During Extreme Long-term Drought

Colorado River



Central AZ (Salt-Verde Rivers)



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Summary

- **Colorado River is snow dominated and therefore more sensitive to warming than Central AZ rivers**

- **Large storage decrease on Lake Mead and Lake Powell during long-term severe drought**
  Storage increase in Central AZ reservoirs

- **More variable streamflow with warming highlights the importance of storage in reservoirs in the future.**

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References

BOR 2020; https://www.usbr.gov/watersmart/pilots/docs/reports/Final_Reservoir_Operations_Pilot_Report-Salt_and_Verde_Az.pdf

Barnes, EA, and L Polvani, 2013, Response of the midlatitude jets, and of their variability, to increased greenhouse gases in the CMIP5 models. J. Climate, 26, 7117–7135, https://doi.org/ 10.1175/JCLI-D-12-00536.1.

Gangopadhyay, S., McCabe, G., Pederson, G. *et al.* Risks of hydroclimatic regime shifts across the western United States. *Sci Rep* **9,** 6303 (2019). https://doi.org/10.1038/s41598-019-42692-y

Robles, M.D., J.C. Hammond, S.K. Kampf, J.A. Biederman, E.M.C Demaria. 2020. Winter Inputs Buffer Streamflow Sensitivity to Snowpack Losses in the Salt River Watershed in the Lower Colorado River Basin. *Water, 13*, 3.

Ellis AW and K. Sauter, 2017, The significance of snow to surface water supply: an empirical case study from the southwestern United States, Physical Geography, DOI: 10.1080/02723646.2017.1281014

Hammond and Kampf (2020). WRR. https://doi.org/10.1029/2019WR026132

Harpold AA and PD Brooks, 2018, Humidity determines snowpack ablation under a warming climate. PNAS. doi/10.1073/pnas.1716789115

Hawkins GA, Vivoni ER, Robles-Morua A, MascaroG, Rivera E, and Dominguez F, 2015, A climate change projection for summer hydrologic conditions in a semiarid watershed of central Arizona. Journal of Arid Environments, 118, 9–20. h ttps:// doi.org/ 10.101 6/j. jaride nv.2 015.0 2.02 2

Pierce, DW, DR Cayan, and BL Thrasher, 2014, Statistical Downscaling Using Localized Constructed Analogs (LOCA), Journal of Hydrometeorology, 15(6), 2558-2585.

Lehner, F. C. Deser, IR Simpson, and L. Terray. (2018). Attributing the US Southwest's recent shift into drier conditions. Geophysical Research Letters, 45,6251-6261, https://doi.org/10.1029/2018GL078312

Luong, TM *et al.*, 2017, The more extreme nature of North American monsoon precipitation in the southwestern US as revealed by a historical climatology of simulated severe weather events. *J. Appl. Meteor. Climatol.* 56, 2509–2529.

Lu J, X Daokai, G Yang, G Chen, LR Lueng, and P Staten, 2018, Enhanced hydrological extremes in the western United States under global warming through the lens of water vapor wave activity. NPJ -Climate and Atmospheric Sciences.

Mahmood TH and ER Vivoni, 2014, Forest ecohydrological response to bimodal precipitation during contrasting winter to summer transitions. *Ecohydrology.* 7, 998–1013.

McCabe et al. (2018) https://doi.org/10.1175/JHM-D-17-0227.1

Mo KC, JE Schemm, and S Yoo, 2009, Influence of ENSO and the Atlantic Multidecadal Oscillation on Drought over the United States. Journal of Climate. doi:10.1175/2009JCLI2966.1

Murphy K and AW Ellis, 2019, Ana analysis of past and present megadrought impacts on a modern water resource system. Hydrological Sciences Journal. doi: 10.1080/02626667.2019.1571274.

Painter TH, SM Skiles, JS Deems, WT Brandt, and J Dozier, 2018, Variation in rising limb of Colorado River snowmelt runoff hydrograph controlled by dust radiative forcing in snow. Geophysical Research Letters, 45, 797–808. https://doi.org/10.1002/2017GL075826

Robles MD, DS Turner, JA Haney, 2017, A century of changing flows: Forest management changed flow magnitudes and warming advanced the timing of flow in a southwestern US river. PLoS ONE 12 (11): e0187875.

Robles MD, RM Marshall, F O'Donnell, EB Smith, JA Haney, 2014, Effects of Climate Variability and Accelerated Forest Thinning on Watershed-Scale Runoff in Southwestern USA Ponderosa Pine Forests. PLoS ONE 9(10): e111092. doi:10.1371/journal.pone.0111092

Ropelewski C, and M Halpert, 1986, North American precipitation and temperature patterns associated with the El Niño-Southern Oscillation (ENSO). Monthly Weather Review, 114,2352-2362, doi:10.1175/1520-0493

Yu JY, P Kao, H Paek, HH Hsu, C Hung, M Lu, S AN, 2015, Linking Emergence of the Central Pacific El Niño to the Atlantic Multidecadal Oscillation. Journal of Climate. doi:10.1175/JCLI-D-14-00347.1

Seager R and GA Vecch, 2010, Greenhouse warming and the 21st century hydroclimate of southwestern North America. PNAS. doi/10.1073/pnas.0910856107

Singh I, F Dominguez, E Demaria, and J Walter, 2018, Extreme landfalling atmospheric river events in Arizona: Possible future changes. *Journal of Geophysical Research: Atmospheres*, *123*. https://doi.org/10.1029/2017JD027866

Svoma BM, 2017, Canopy Effects on Snow Sublimation from a Central Arizona Basin. *Journal of Geophysical Research-Atmospheres*. DOI: 10.1002/2016JD025184

Vano JA, T Das, and DP Lettenmaier, 2012, Hydrologic sensitivities of Colorado River runoff to changes in precipitation and temperature. J. Hydrometeor., 13, 932–949, doi:10.1175/JHM-D-11-069.1.

Vano, JA et al. 2014. BAMS. *https://doi.org/10.1175/BAMS-D-12-00228.1*

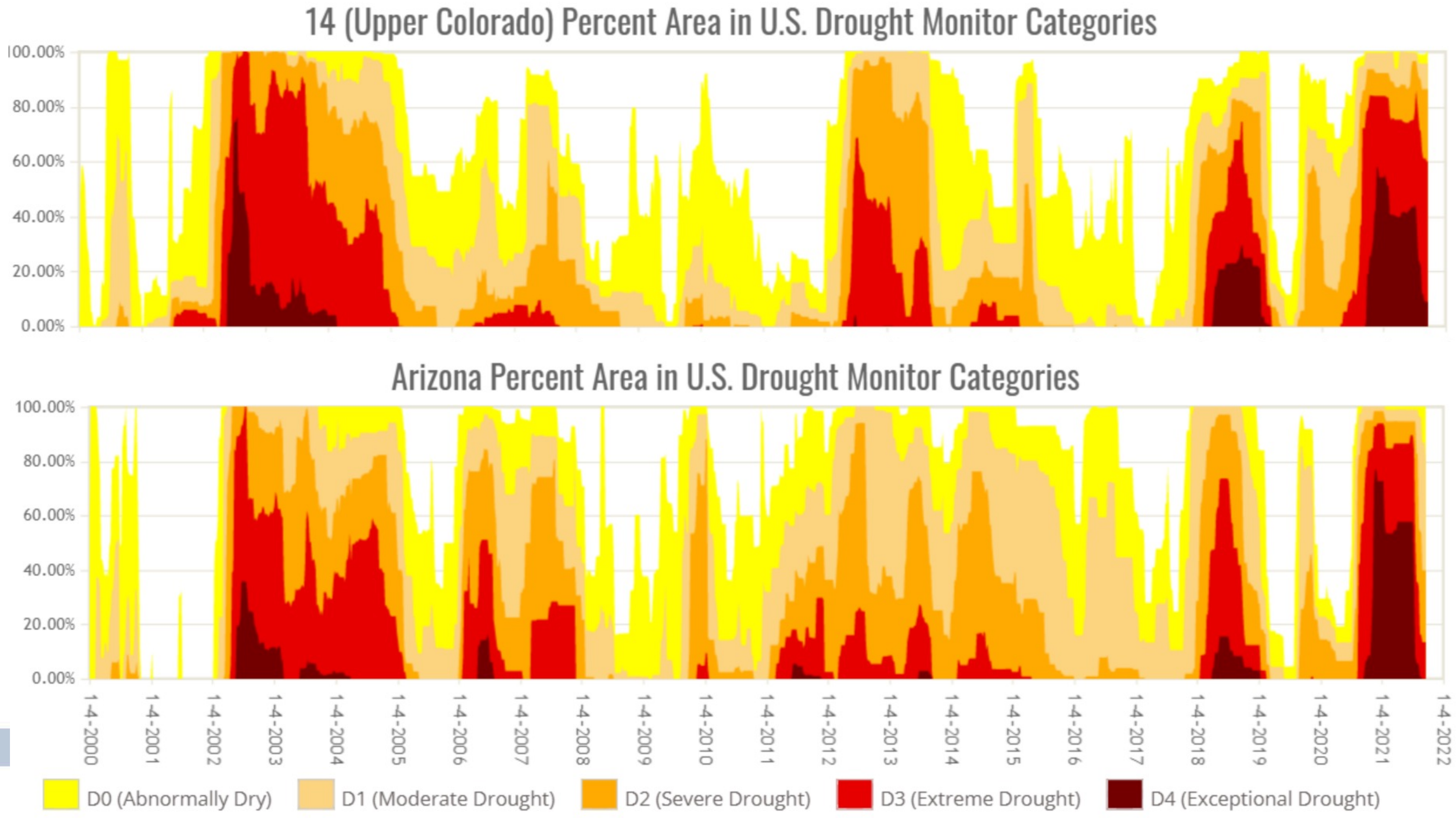
Woodhouse CA, and GT Pederson, 2018, Investigating runoff efficiency in upper Colorado river streamflow over past centuries. Water Resources Research, 54, 286–300. https://doi.org/ 10.1002/2017WR021663

Woodhouse CA, GT Pederson, K Morino, SA McAfee, and GJ McCabe, 2016, Increasing influence of air temperature on upper Colorado River streamflow, Geophys. Res. Lett., 43, 2174–2181, doi:10.1002/2015GL067613.

Both Regions in Severe Long-Term Drought

Upper Colorado

Arizona



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https://droughtmonitor.unl.edu/DmData/TimeSeries.aspx