

# Improving Water Supply Forecasts through Cooperative Collaboration with the Colorado River Climate and Hydrology Workgroup

Colorado River Water Users Association Meeting

Monday, December 13



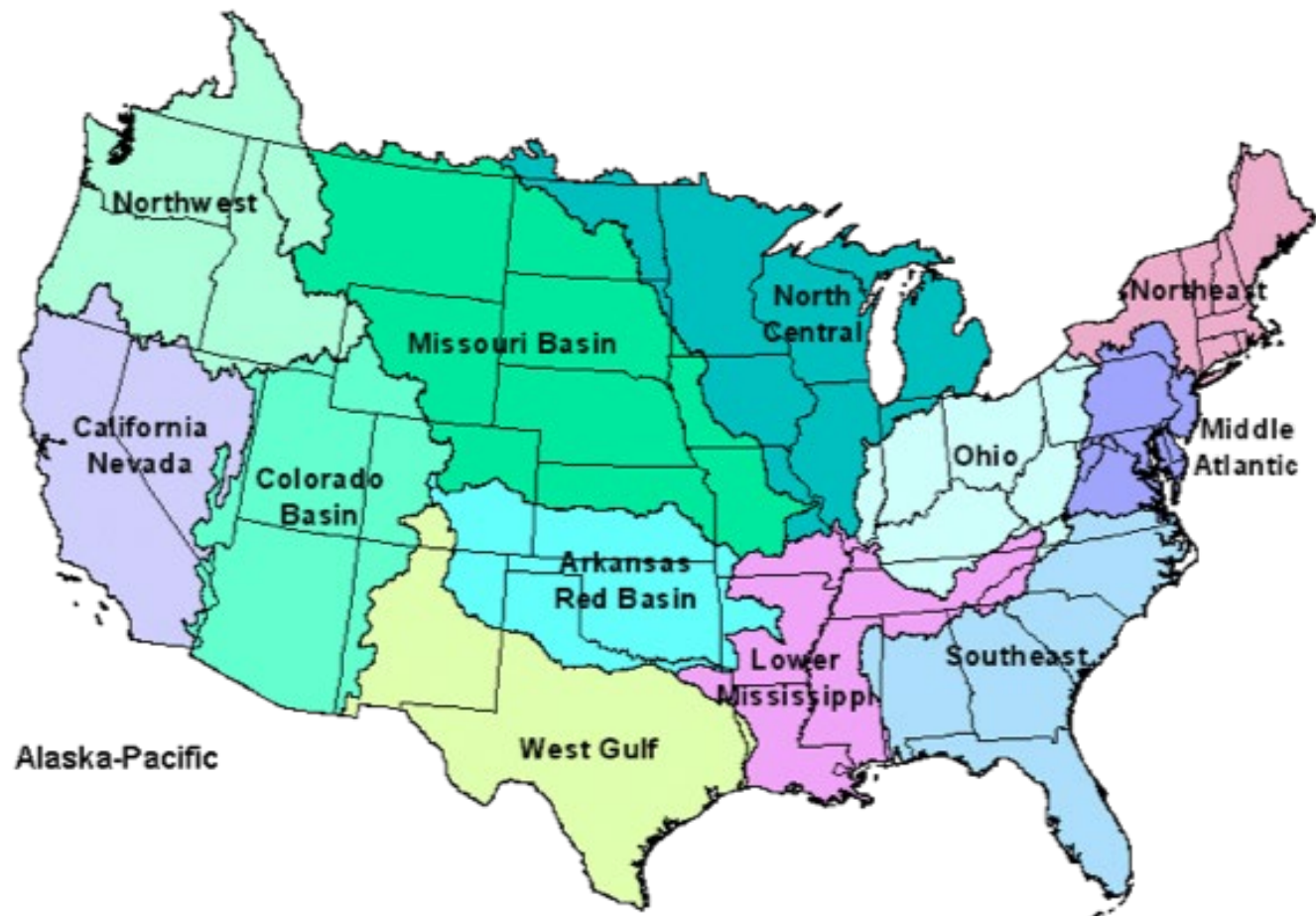


- **Quick overview of the Colorado Basin River Forecast Center**
- **Overview of the Colorado River Climate and Hydrology Work Group**
- **Major Research to Operations Initiatives, Particularly at the CBRFC**
- **Future Work**

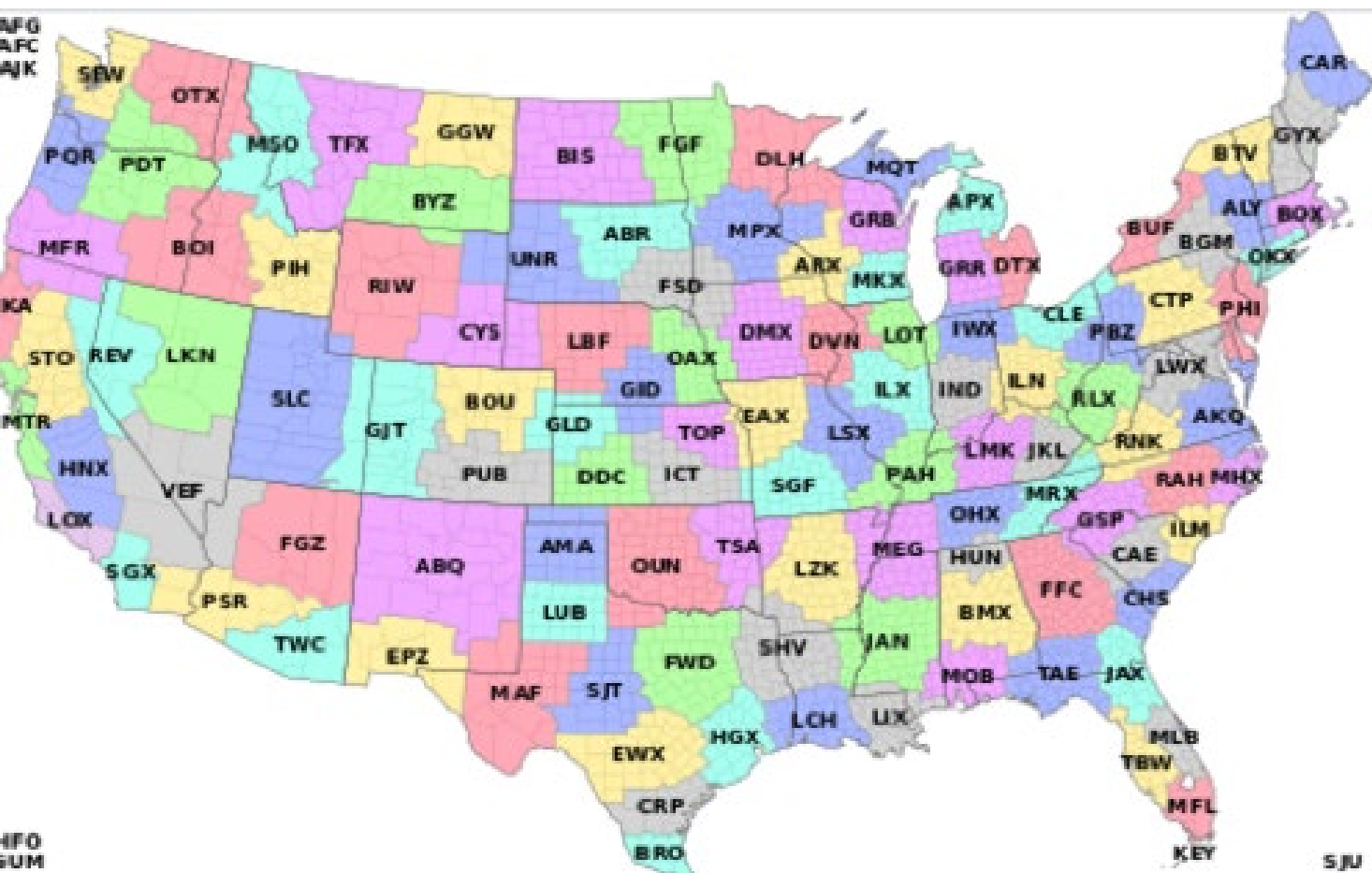


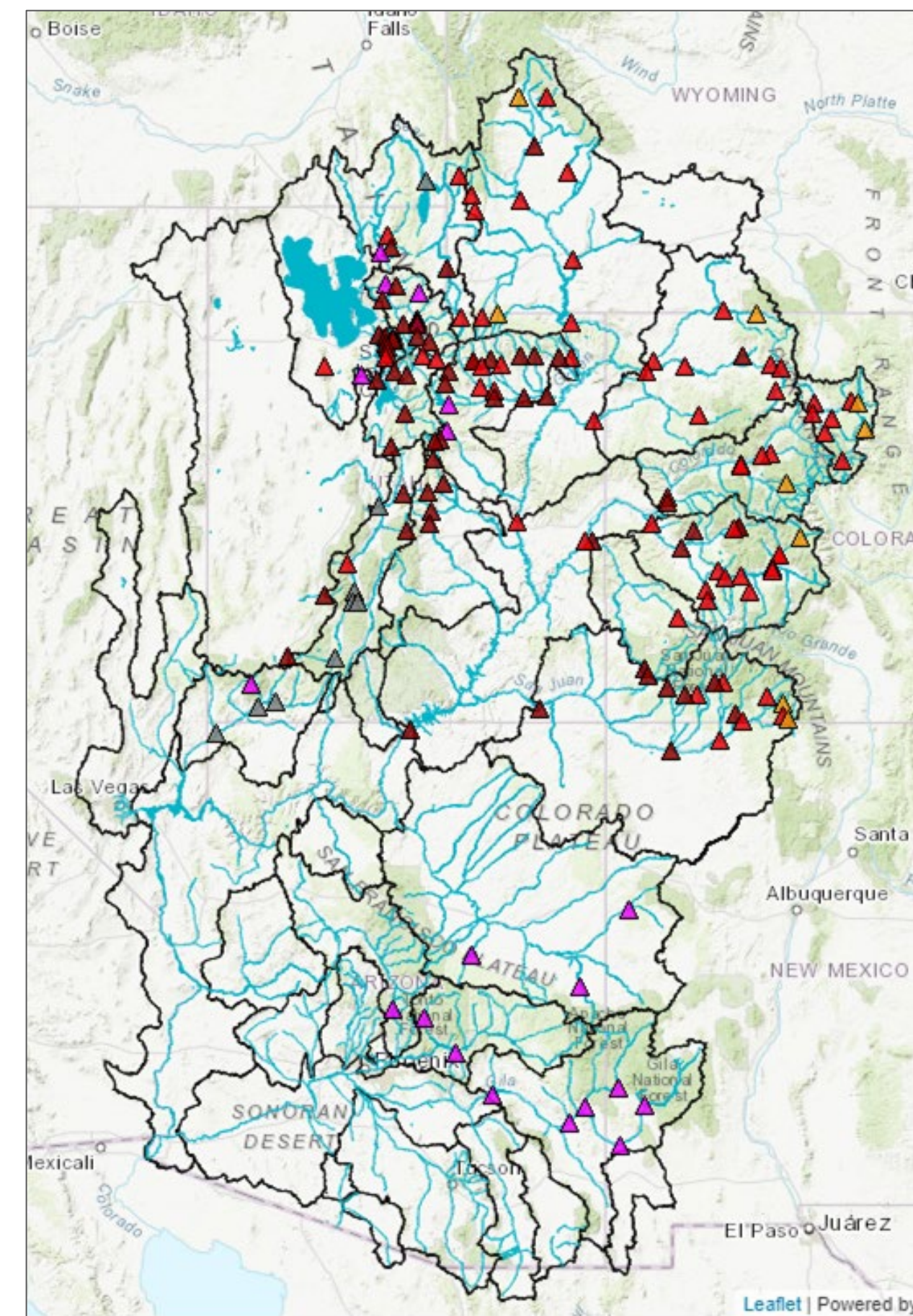
# Colorado Basin River Forecast Center

Monday, December 1



- 13 RFCs nationwide
  - Work with 122 Weather Forecast Offices (WFOs)
  - Support NOAA’s hydrologic services and products
  - Focused on decision support
- Western RFCs have the additional role of providing water supply services





- **RFCs - streamflow and water supply forecasts**

- Monthly water supply forecasts

- 174 locations
- Seasonal (April-July commonly)

- Daily streamflow forecasts

- 460 locations
- 10 day

- **Weather Forecast Offices**

- Flood Watches and Warnings
- Determine flood stages
- Work closely with Emergency Managers



## Goal

**To advance scientific understanding to improve the accuracy of hydrological forecasts and projections,  
to enhance the performance of predictive tools,  
and to better understand the uncertainty related to future supply and demand conditions in the Colorado River Basin**



# Participation

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- **Voluntary, coalition of the willing**
- **Basinwide and user needs focused (!)**
- **Federal participants**
  - Reclamation, NOAA - CBRFC, NASA
- **State and municipal water agency participants**
- **Academic partnerships**



# Blue Table

Monday, December 1

## ● Research projects identified

○ What gaps do they fill?

○ SOS opportunity

○ Path to completion

○ Priority

○ Time scale

○ Considerations

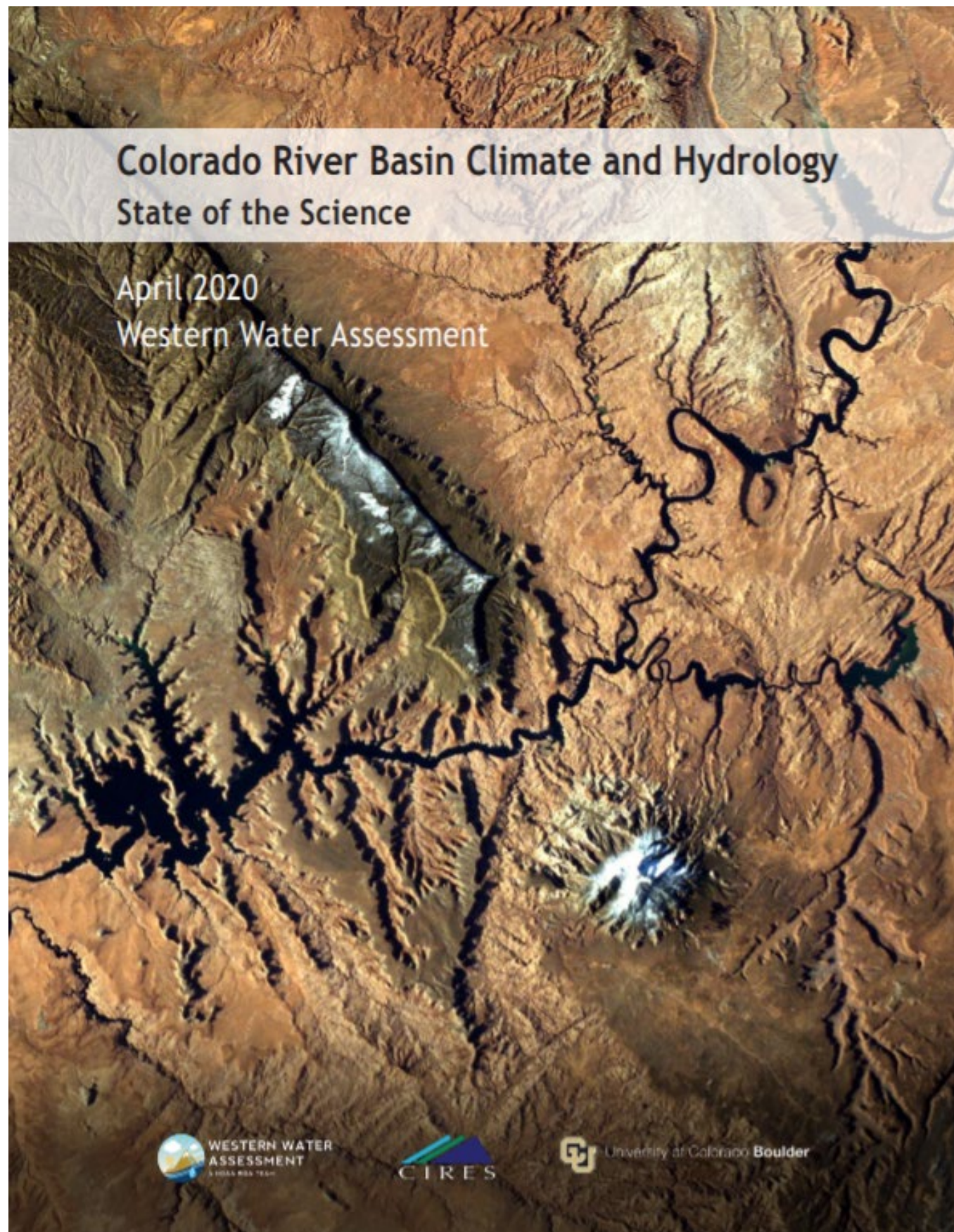
○ Cost

○ Status

## ● 105 projects currently on

# the table!

Date	Time to Complete	Total Cost	Priority	Additional Considerations or Resources Needed	Status	Major Findings
1/19/21	?	?	In-kind	Track/Ongoing	RFC is doing this as an ad-hoc ongoing basis. Part of CBRFC's routine process to calibrate, verify, and improve model performance.	1.19.21: The CBRFC is currently working on a large scale recalibration effort for its entire area of responsibility to incorporate the new 1991-2020 normals. As part of this, all basins are going to be evaluated for possible improvements to performance. We anticipate the new calibration in place sometime in early 2022.
Feasibility of applications	NA	NA	NA	Guiding Principle	This will be a priority for most activities - to transfer advancements to our platform.	
New tools and	5-10	5	500	High	Similar to 2b, this might be more of developing a historical gridded ET dataset. This would be a longer-term investment in either historical dataset or sensor network. Could be part of a monitoring of abn theme. Would be significant effort to integrate into the RFC modeling processes. Need to track progress of OpenET project and use of the NWM or CBRFC's standard model. Both activities have the possibility of significantly reducing the cost of obtaining these data and making them operationally available.	1.19.21: Continue to track OpenET progress and consider results from Project 2a CUModeling to consider opportunities for assimilating new ET data products.
Water study	1.5-2	1.5	150	Completed	Would be in conjunction of #7 to identify data needs and potential model enhancements. See also #1, 11, 14, 15.	1/19/21: Project 1 explore streamflow sensitivity to changes in ET. 2/1/21: Project 1 results show a 2:1 relationship where each 1% increase in ET resulting in a 0.5% decrease in annual streamflow. The study revealed that temperature and ET are uncoupled in the modeling structure and concluded that coupling these components was a potential next step.
Project funded by NASA's the project along with \$123k NASA.	2	2	123	Recommended (3/19/21)	This project has three objectives: 1. Demonstrate an improvement to the CBRFC's April 1 streamflow forecast for the April-July runoff period by incorporating higher resolution snow observing data into forecasting procedures. 2. Facilitate reciprocal communication and data sharing between CBRFC and JPL. 3. Document and evaluate the major obstacles impeding the integration of ASO data into CBRFC's forecasting operations and identify data integration opportunities.	1/19/21: Partner personnel responsible for ASO data collection and processing at NASA are now at a private corporation known as ASO Inc. There are 6 watersheds that have 1-2 ASO flights per year since 2013 (n=33) but only 16 flights have been shared with CBRFC with 14 of 16 shared in Nov. 2020, resulting in very limited project progress. Initial comparison of annual ASO SWE vs. SH0W-17 SWE (*2 flights) show strong correlation and an overestimation of SWE at high elevations by CBRFC. The overestimation may be due to CBRFC's usage of PRISM based precipitation data that may be biased high at high elevations. The influence of density on the ASO SWE calculation was also explored and, while the reduction of the density grid is important, the majority of the SWE uncertainty comes from snow height which ASO observes well. Hindcast analysis have shown that introducing a single ASO flight may improve the streamflow forecast. CBRFC hopes to have additional flights made but will likely be slow. Consideration: ASO Inc. will
Implement; Work	2	2	600-800	Medium	Why not pursuing full range program: How about a sequence in pursuing this; we are pursuing pre-cursor steps. Also, concerns about integration into RFC process as well as data processing	1/25/21: Track progress of 8b for possible use in CBRFC structure.
Air work Quantum collect the	2-5	1	170	Track/Ongoing	Denver Water is working with the Colorado Water Conservation Board on Airborne Snow Observatory flights in the 335 square mile Blue River Watershed above Dillon Reservoir. Two flights are planned, one in mid April and one in mid May. Quantum Spatial will perform the flights and data collection and NASA will perform data analysis.	1/19/21: Denver Water has been spearheading efforts to develop a statewide ASO data collection program in Colorado with willing partners, a program referred to as CoCoASO. Working on linking other SWE products (like the CU-SWE) to fill in the gaps. Working with Reclamation user-wide ASO integration effort (possible Lindray Bearup's work). Last year's omnibus authorization included money for a Snow Water Supply Forecasting Program. (Sec. 1111 - Snow Water Supply Forecasting Program. (Huffman/Hardorf/Sen. Feinstein) - authorize \$15 million for a Snow Water Supply Forecasting program at the Department of the Interior to provide more accurate data about expected runoff that will allow improved water system operations. Passed the House as part of H.R. 2.) Ken Nauask is POC on Snow Water program. 2/10/21: Lindray Bearup presented an intriguing paper on a line or regression to show better times/places to fly ASO flights than others in Hatch Hatchy, then how she updated the SAC-Snow17 model to be consistent with the CBRFC implementation. Her next step is to repeat this effort to see if it can complement CBRFC analysis in the Upper Gunnison. The presentation is
Patrick project	3	2	?	Track/Ongoing	Snow monitoring system for the SMP. They are using process-based hydrological model and artificial neural network (ANN) to generate information about both snow water equivalent (SWE) and snow cover. The snow-cover data is generated with ANN that are applied to Landsat and MODIS satellite reflectance data. The SWE data is generated using a combination of gridded SWE estimator generated by process-based snow model and ANN that account for variations in topography, forest cover, and solar radiation. The model are trained and evaluated with snow data from SNOTEL stations as well as from aerial LIDAR and field data that we collected this past winter in northern AZ, as well as with similar data from	3/21/2019: Patrick Braxton has finished his part-doc at the UofA. The work is ongoing and is still currently being supported by SRP. Patrick presented his work to the CBRFC in February. There needs to be some analysis done to see how viable it is to use operationally, but there's no available timeframe for doing that work yet. 1.19.21: The CBRFC had a summer student, Zach Butler, work on this project over the past summer with Patrick Karmar. Results are still in the process of being written up as part of Zach's M.S. thesis, but initial results may indicate little benefit to improving model snow conditions, but results are still preliminary and the CBRFC is continuing to evaluate. Patrick has a AGU poster describing preliminary results, ( <a href="https://agu2020fallmeeting-aquipartnersession.com/2020-04-25-05-30-08-08-CE-16-47-EB-6A-F2-E5-">https://agu2020fallmeeting-aquipartnersession.com/2020-04-25-05-30-08-08-CE-16-47-EB-6A-F2-E5-</a> )
Water use in Sierra clear if it will	?	?	?	Track/Ongoing	This MODIS based SWE product may be useful for the ASO investigation from project 8 because it could serve as an additional source of comparison to the CBRFC SWE data. We discussed during ASO review call. Need to track potential utility.	1/19/21: The 500-m resolution Spatial Estimator of SWE data product (CU-SWE) is described in the Project 72 survey results found here, <a href="https://drive.google.com/file/d/1jib-KoK7icYKq45642kdYBVj7Y1upH/view?usp=sharing">https://drive.google.com/file/d/1jib-KoK7icYKq45642kdYBVj7Y1upH/view?usp=sharing</a> . CU-SWE does not have a ready funding source so it is unclear how long these data may be produced in the future. However, Nash thinks he can provide a few data reports in 2021 and 2022 while he identifies a secure funding source. Nash is working with Denver Water as part of the CoCoASO effort to evaluate the utility of bias correcting CU-SWE to ASO and then estimating SWE between ASO flights. Note, CDWR is funding Nash to produce about 14 Sierra Nevada reports per year at a cost of \$3K-4K each and Nash is willing to generate ad-hoc reports for us at about that



## State of the Science Report

- Common basis of understanding
- Researcher-user engagement tool
- Acknowledges challenges
- Opportunities to pursue





## **CBRFC Water Year In Review**

**An Overview of Operational Changes, Improvements, and Investigations over the course of Water Year 2020**

**March, 2021**

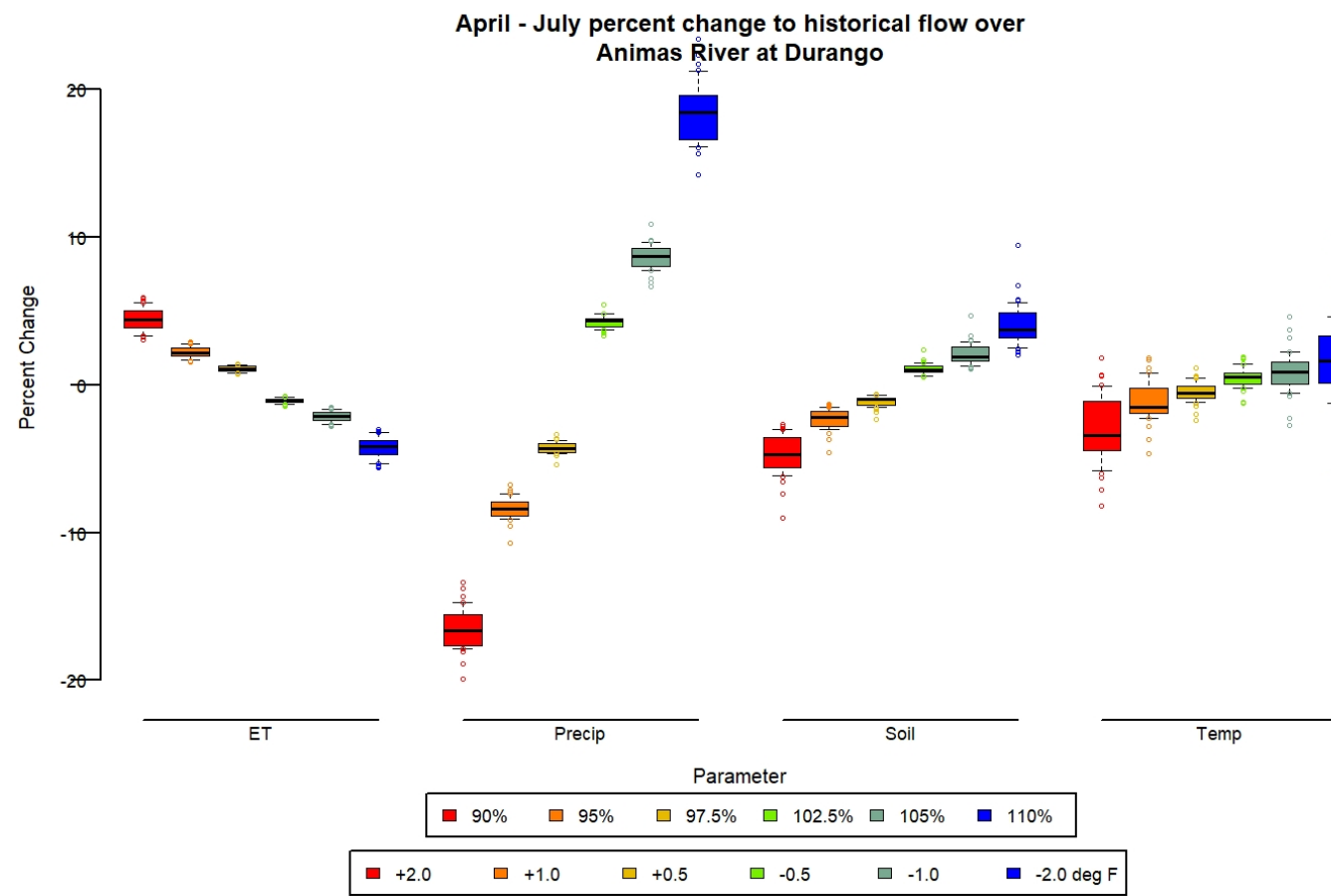
**National Oceanic and Atmospheric Administration (NOAA)**

**National Weather Service (NWS)**

**Colorado Basin River Forecast Center (CBRFC)**

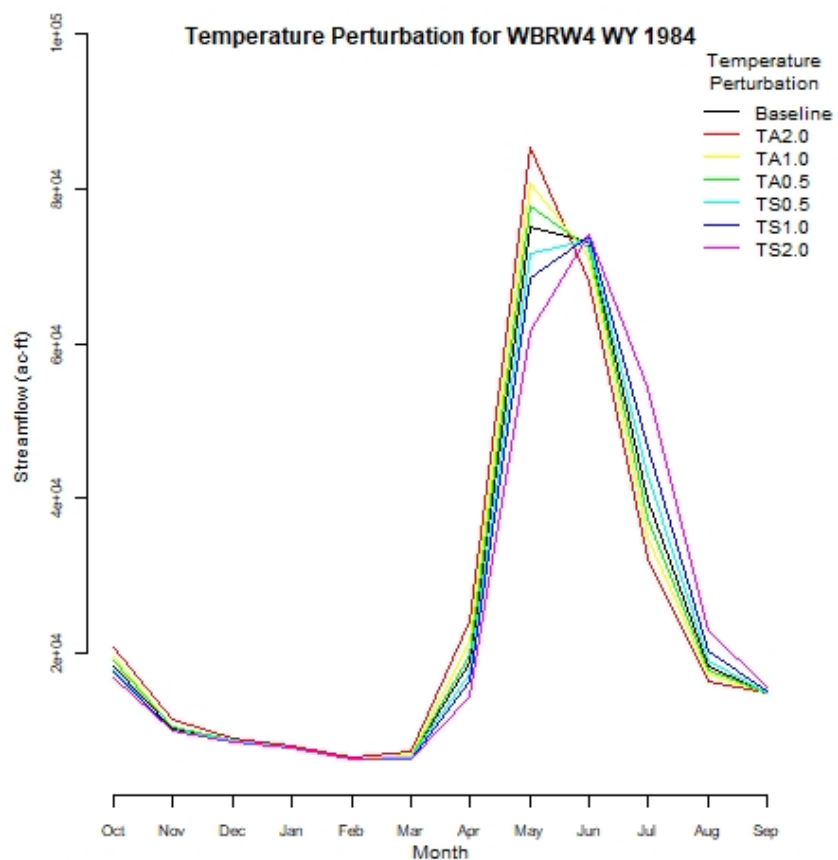
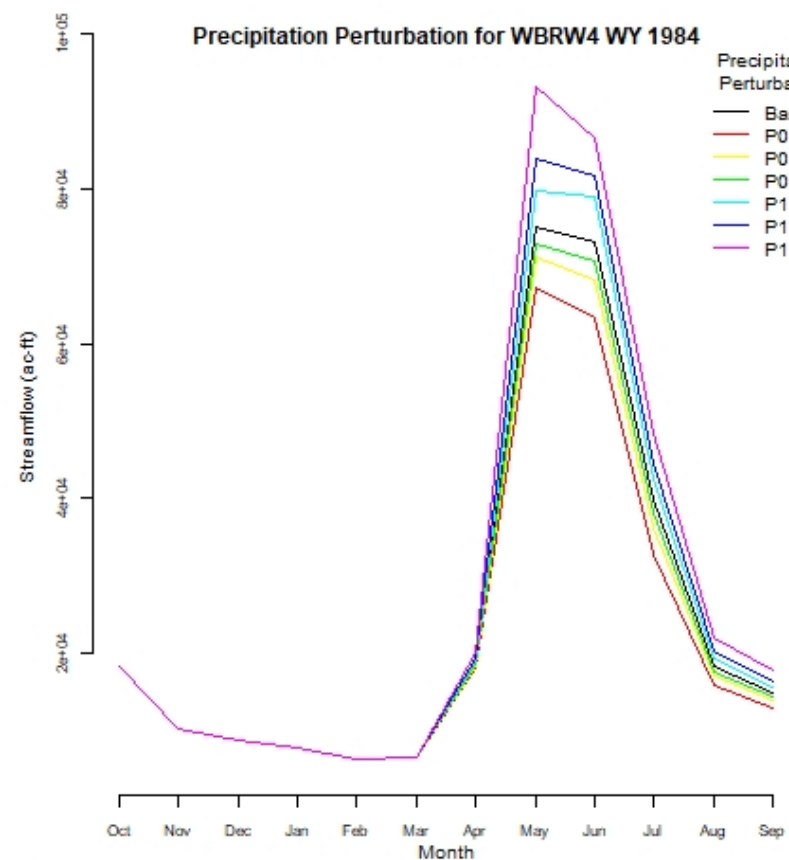


- **Part 1 describes the need for the CBRFC to provide an annual report summarizing CBRFC activities**
- **Second annual report was published in March and is now available on the CBRFC website**
- **Third report upcoming early next year**



## ● Sensitivity Analysis

- Completed in October, 2020
- Report and all data files are available on our website
- Precipitation is the primary driver, but other parameters play important roles over the course of the year
- Temperature impacts little of the annual streamflow volume, but does impact timing
- Key next steps were identified
- Several funded projects are currently in the works to address next steps

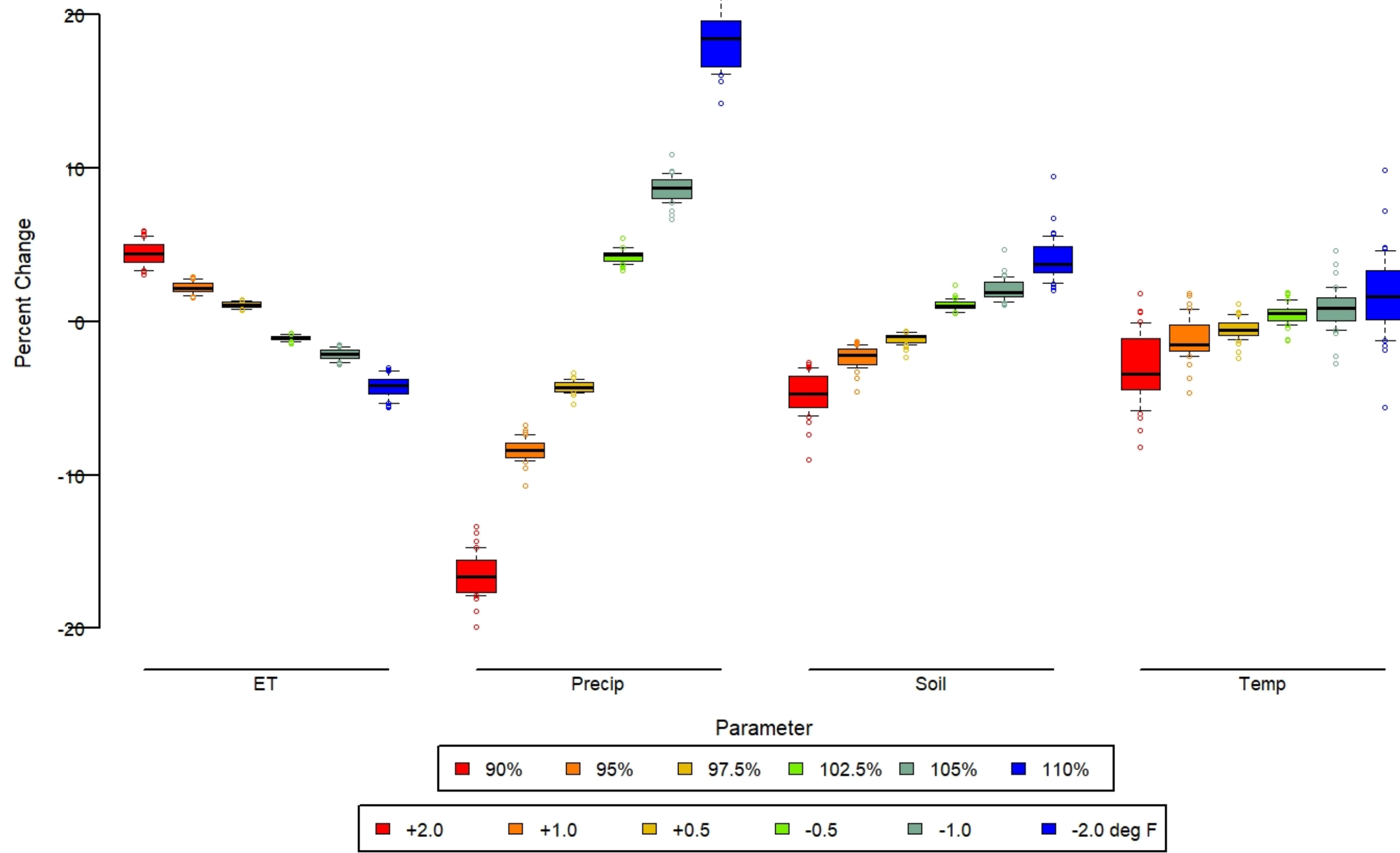




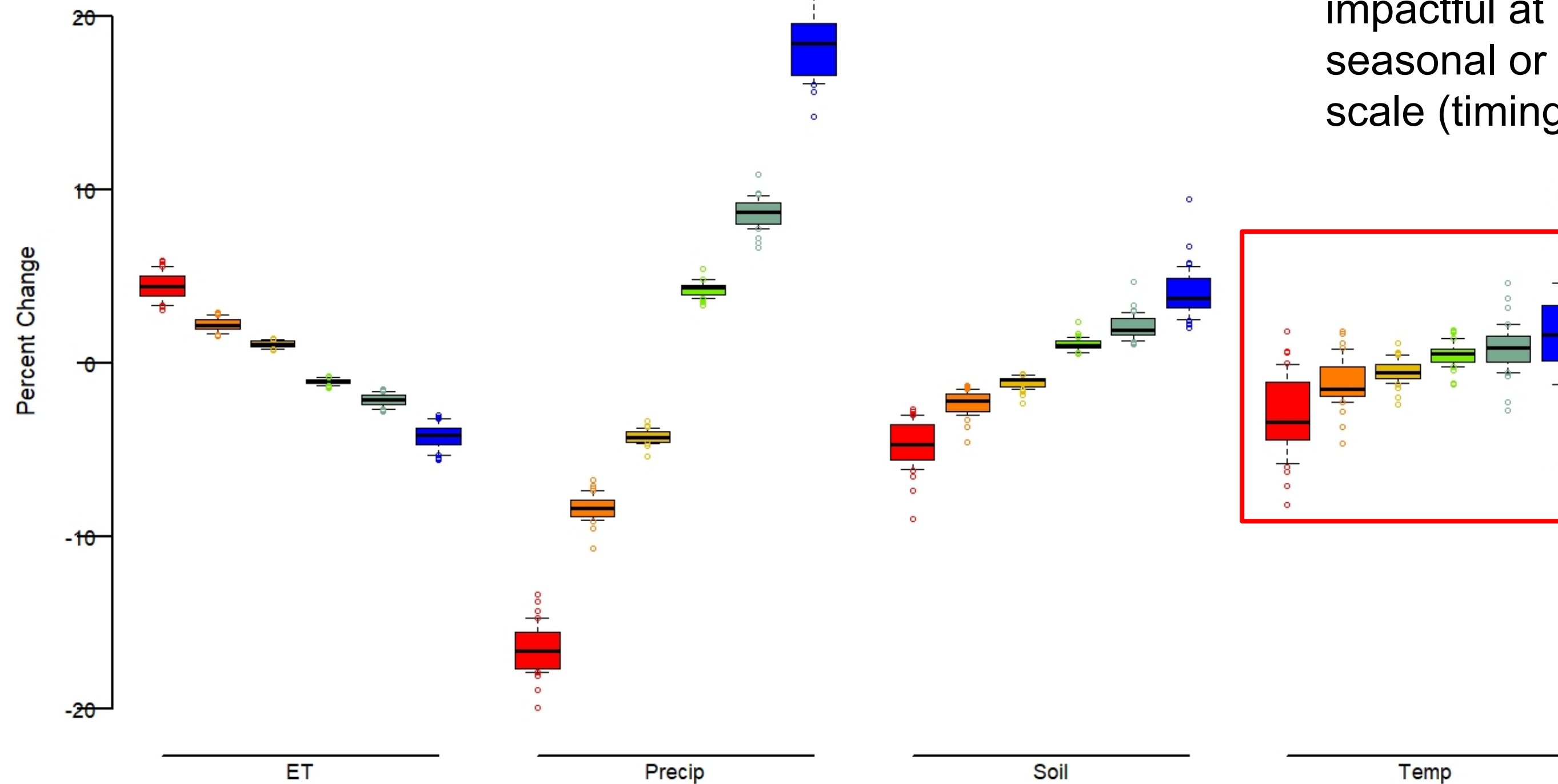
# April - July Results

- **Very similar to annual results**
- **Precipitation most impactful**
  - 1.7% increase per 1% increase in precipitation
- **Temperature more impactful over runoff season**
  - 1% decrease per 0F increase in temperature
  - Temperature significantly impacts timing
- **Evapotranspiration and Soil Moisture next most impactful parameters**
  - 0.4% increase per 1% increase in soil moisture
  - 0.4% decrease per 1% increase in ET

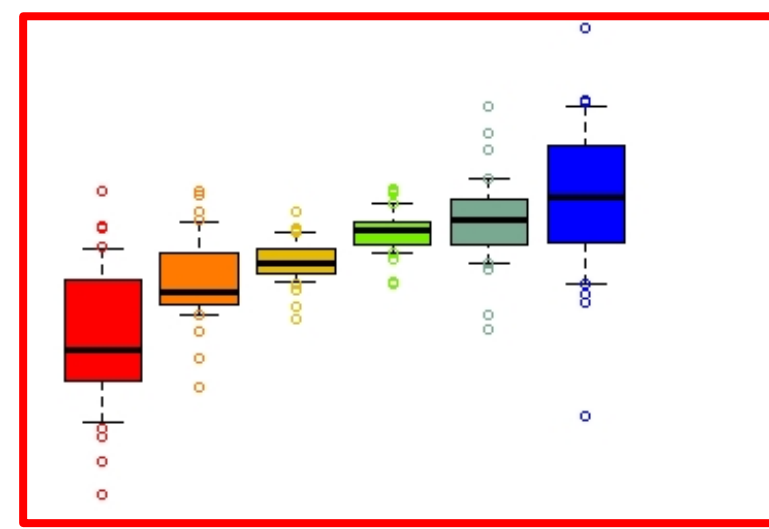
### April - July percent change to historical flow over Animas River at Durango



April - July percent change to historical flow over Animas River at Durango



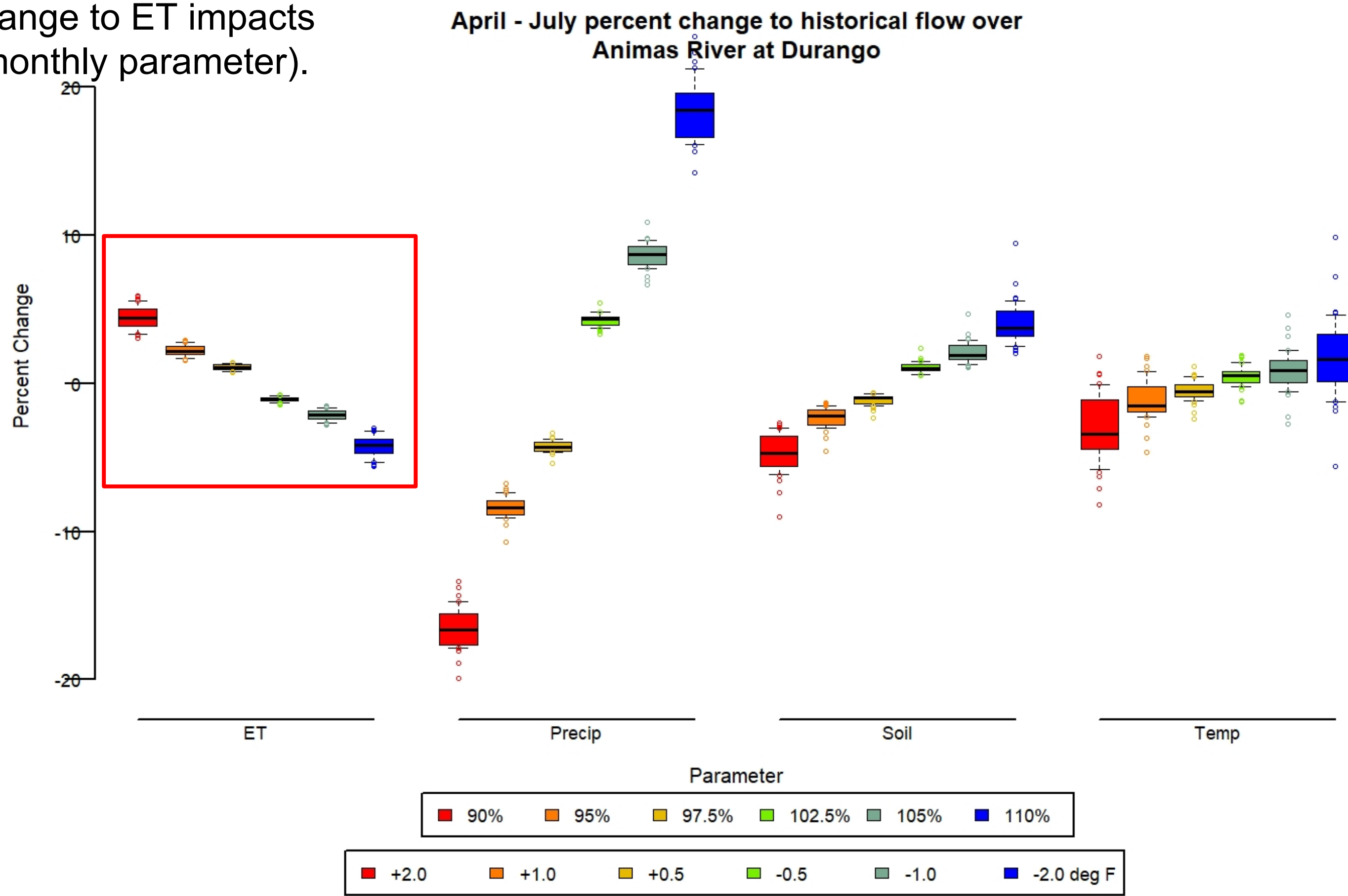
Temperature more impactful at seasonal or monthly scale (timing).



90% 95% 97.5% 102.5% 105% 110%

+2.0 +1.0 +0.5 -0.5 -1.0 -2.0 deg F

Little change to ET impacts  
(static monthly parameter).





# Opportunities

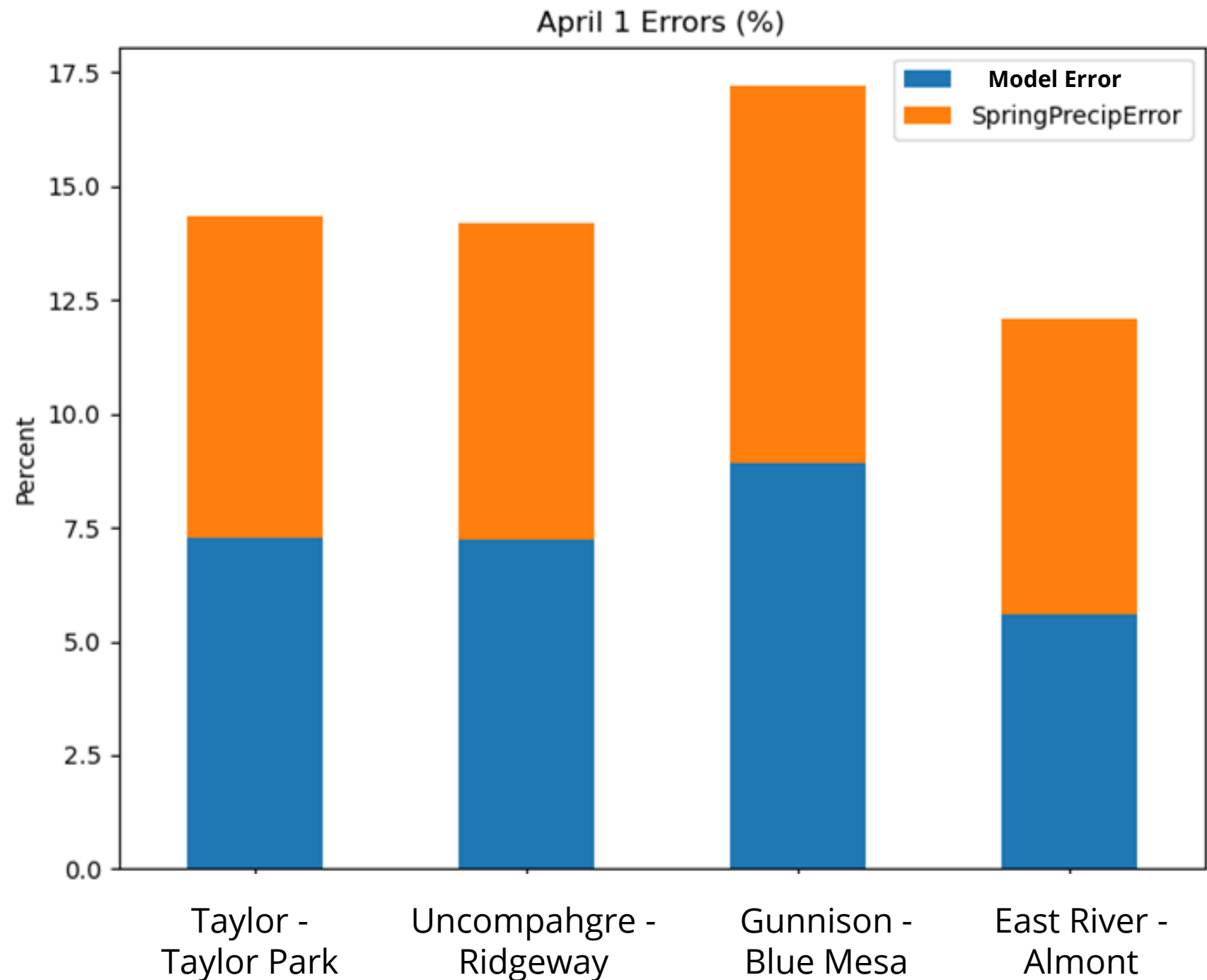
Monday, December 1

- Improvements to precipitation forecasts, especially at the seasonal to sub-seasonal scale
- Aligning model impacts with timing of policy? Or vice versa?
- Temperature dynamics
  - Relationship with other variables
  - Contemporary trends
- Evapotranspiration incorporation
- Soil Moisture analysis

# Error and Uncertainty Exists



- Roughly half of the volume error in an April 1 Water Supply Forecast is from **unknown spring weather** (spring precip. amount).
- The other half is due to **model error**.
  - Errors in model soil moisture
  - Errors in model **snow pack**
  - Errors in model parameters
  - Errors in model structure

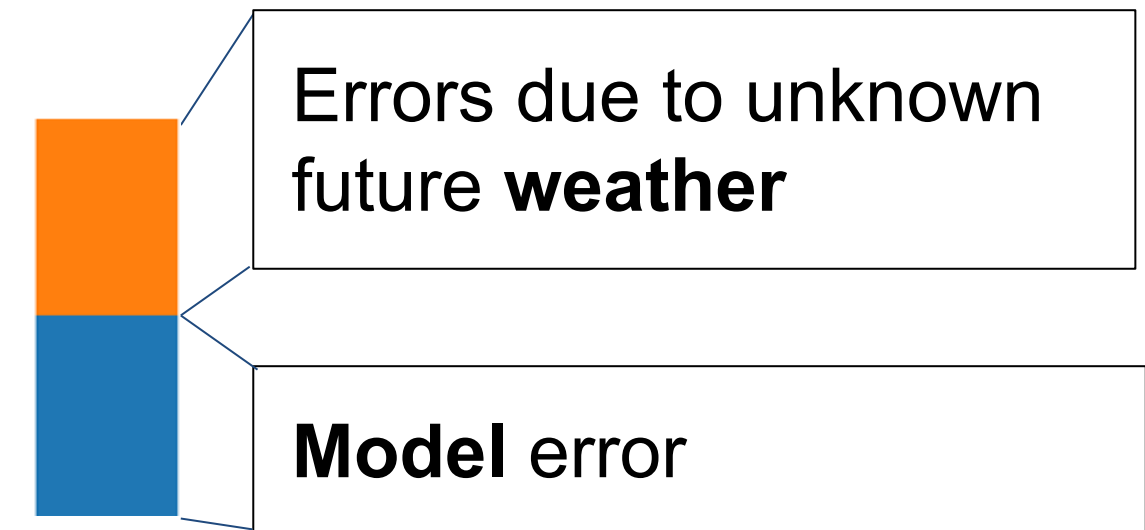




# Forecast Improvement



- CBRFC is always trying to improve forecasts
- Future Weather Uncertainty
  - Seasonal to subseasonal weather prediction
  - Global Climate Indices (El Niño vs. La Niña)
- Model Errors
  - Improved calibrations - every 5 years
  - New datasets/products to incorporate into our model
    - External ET data sets
    - External Snow Products
      - MODIS - snow covered area, dust radiative forcing
      - SWANN - Neural Network SWE product
      - ASO - Airborne snow depth mapping and SWE estimation
      - NOHRSC-SNODAS
      - CU-JPL Real-Time Snowpack Estimations from Satellites
  - Alternate models and methods
    - Physically based snow models (UEB, iSnoBAL)
    - Distributed Modeling - RDHM
    - Data Assimilation
    - Impacts of fires



# Physically Based Snow Modeling

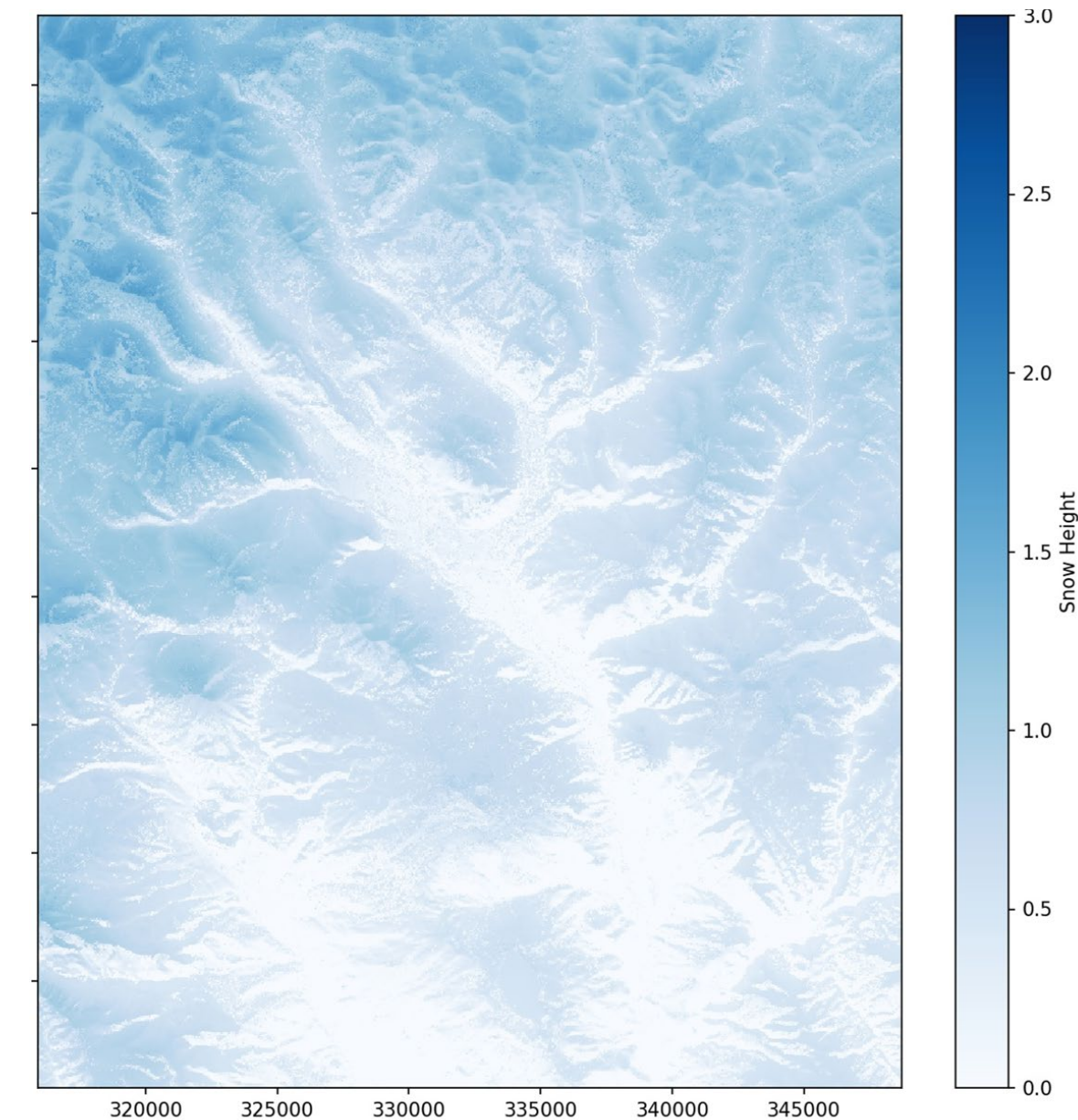


- NASA Applied Sciences
- Earth Science Applications: Water Resources
  - 80NSSC19K1243
  - [Developing an operational framework for incorporating remote sensing and snow energy balance modeling into runoff forecasting in snow dominated watersheds in the Colorado River Basin](#)

- Research to Operations
- UofU, NWRC - ARS - Boise, CBRFC
- Physically Based Snow Modeling with iSnobal
- 0-hour HRRR forcings (NWS Weather Model)
- Albedo Remote Sensing Component

ASO integration has been demonstrated and published (Hedrick et al., 2018 WRR)

<https://doi.org/10.1029/2018WR023190>





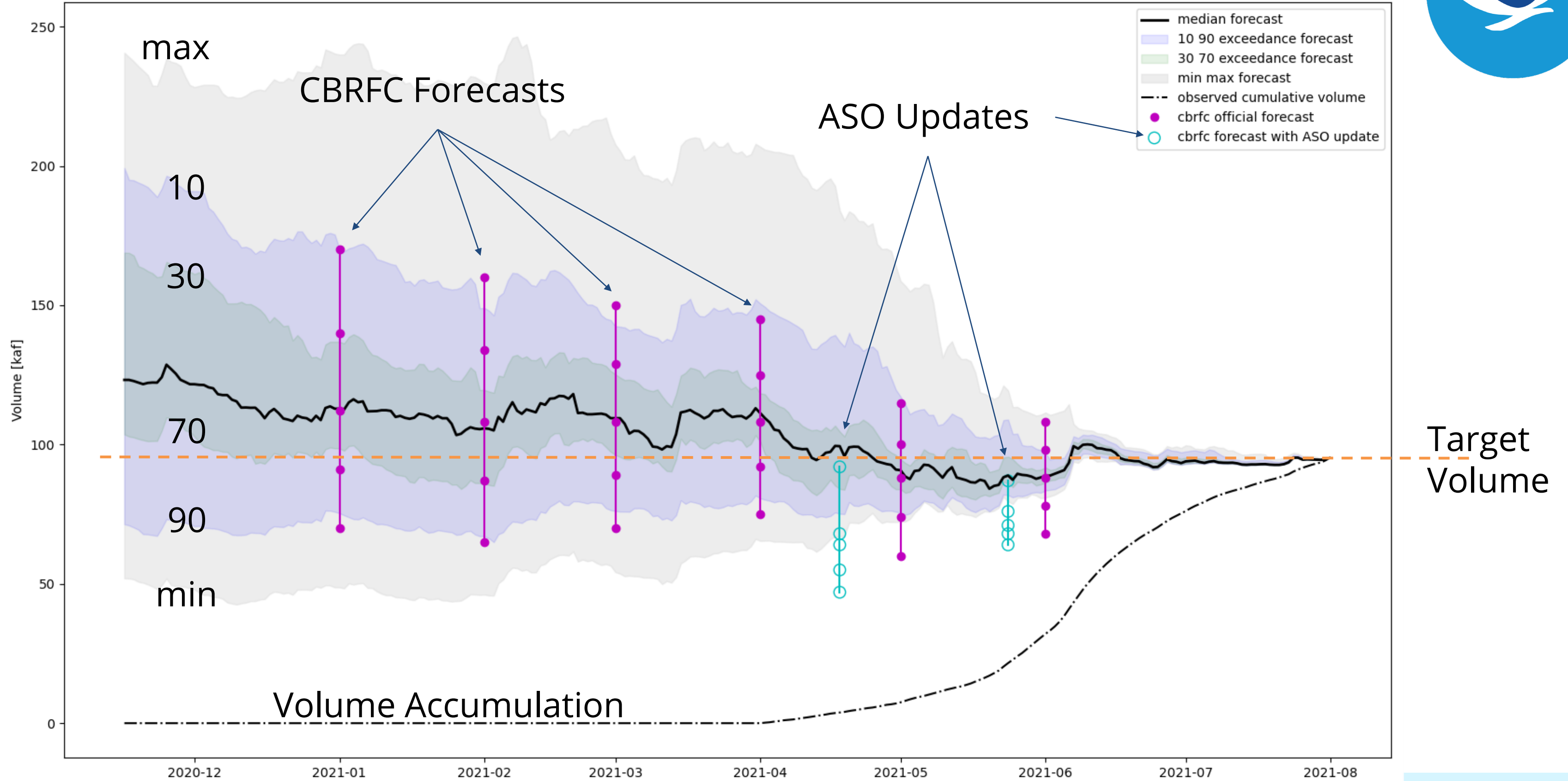
# ASO Integration and Comparison

- Current Forecasting System - Calibrated Model
- Methods
  - a. Substitute ASO estimated SWE into our Model
  - b. Run ESP (35 years of historic data)
  - c. Graphically Compare Forecasts
  - d. Also Compare to NCAR Forecasts

# Dillon Reservoir: 95.5 KAF



Forecast Evolution for DIRC2



## PROJECT OVERVIEW

The Colorado Basin River Forecast Center (CBRFC) is constantly investigating ways to improve its hydrologic model and forecasting. Traditionally, the CBRFC has utilized a simple model to estimate unmeasured depletions typically associated with smaller scale agricultural use in the Colorado River Basin.

Over the past 2 years, the CBRFC and Bureau of Reclamation partnered with RTi to leverage water use information in the state of Colorado to develop a more dynamic, physically based model to estimate unmeasured depletions in the Colorado River Basin. The CBRFC plans to implement this methodology within its operational model to improve forecasts in the region.

## COLLABORATORS

**RTI** - Shaun Carney, Paul Micheletty

**Bureau of Reclamation** - Rebecca Smith, Jim Prairie

**Southern Nevada Water Authority** - Seth Shanahan, Casey Collins

**Colorado Water Conservation Board** - Michelle Garrison, Brian Macpherson

## PROJECT SCHEDULE





## PROJECT OVERVIEW

- Evaluate existing StateCU/StateMod models
- Consider implementation alternatives in CBRFC system (CHPS)
- System implementation and calibration (pilot basin)



## PILOT IMPLEMENTATION

- Implemented for San Juan basin in CHPS
- Effectively modeled diversions, losses, and returns

# TRANSITION TO OPERATIONS PLAN

- Evaluate the performance of the methodology developed by RTi in a CHPS stand alone, compare against traditional modeling of unmeasured depletions
- Begin to incorporate this methodology operationally over basins in Colorado
- Extend the analysis and results to basins outside of Colorado



# NEXT STEPS

- Full implementation over basins in Colorado
- Data collection and implementation for areas and basins outside of Colorado
- Work with stakeholders to evaluate future goals and next steps
  - CBRFC needs to quantify and present our findings to stakeholders
  - Are there opportunities to address additional phases more efficiently or concurrently?



# Tracking other efforts

Monday, December 1

- **There are more efforts! I really just scratched the surface with what we're most directly involved in...**
- **Work Group actively tracks other projects and engages with researchers to help advance goals**
- **Biennial symposiums**
- **Annual and ad hoc calls/webinars**



# Contact Info

Monday, December 1

Don't hesitate to reach out with any questions or comments

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