CBRFC Water Year in Review

An Overview of Operational Changes, Improvements, and Investigations over the course of Water Year 2024

February, 2025

National Oceanic and Atmospheric Administration (NOAA)

National Weather Service (NWS)

Colorado Basin River Forecast Center (CBRFC)

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1 INTRODUCTION

1.1 Purpose

This document, an annual product from the Colorado Basin River Forecast Center (CBRFC), describes the forecasting activities, research, and improvements undertaken by the CBRFC over the course of water year 2024. An overview of the climate and significant weather events and patterns is presented to provide context regarding CBRFC forecasts, with particular emphasis on volumetric water supply forecasts and efforts to improve those forecasts, especially in response to stakeholder needs.

The activities and results presented here are intended to be comprehensive, and some may be of interest to a narrow range of stakeholders. As such, any omissions are inadvertent, but may be incorporated into a future version of this document if the need arises.

1.2 Water Year 2024 Climate and Significant Weather Events

The 2023 water year was among the wettest on record throughout the Colorado River Basin and Great Basin, so it was not unexpected that modeled antecedent soil moisture conditions in the Fall of 2023 were generally wetter than the previous Fall (2022). Modeled antecedent soil moisture conditions were generally above average throughout much of the Great Basin, and near average to average throughout much of Colorado, with the exception of the San Juan River Basin, where conditions were below average (Figure 1). Modeled Fall antecedent soil moisture conditions can be indicative of potential runoff efficiency of Spring snowmelt conditions.

The 2024 water year began drier than average, with precipitation amounts below average from October through December. Over the Upper Colorado River Basin, precipitation above Lake Powell was 74% of the 1991-2020 average. Portions of the Colorado River Headwaters were closer to normal, with both the Eagle and Roaring Fork River Basins nearing 90% of average; however, portions of Southwest Colorado (i.e., Dolores and San Juan River Basins) and the Duchesne River Basin were near 60% of average. Great Basin conditions showed a similar spread in precipitation conditions, with the Virgin and Sevier River Basins exhibiting 40% and 51% of average, respectively, whereas both the Bear and Six Creeks River Basins in north central Utah were at or near 85% of average. Drier than normal conditions were prevalent throughout the Lower Colorado River Basin, and ranged from 33% of average in the Verde River Basin to 59% of average in the Upper Gila River Basin (Figure 1).

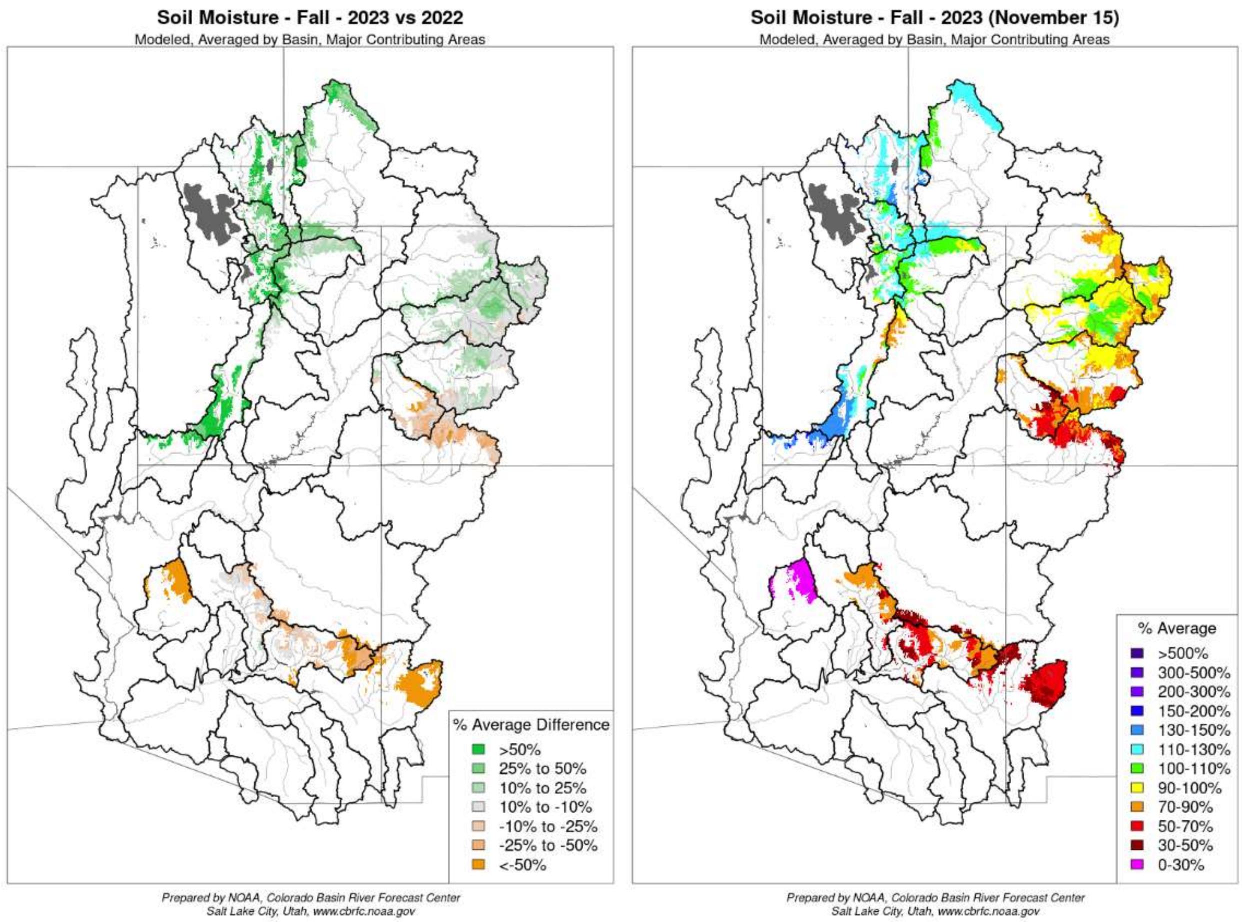

Figure 1: The figure on the left shows the change in modeled Fall soil moisture conditions from 2022 to 2023, and generally indicated a change towards wetter conditions. The figure on the right shows modeled Fall soil moisture conditions as a percent of average historical conditions; generally, the Great Basin showed wetter than average conditions, while most of Colorado indicated near average to average conditions.

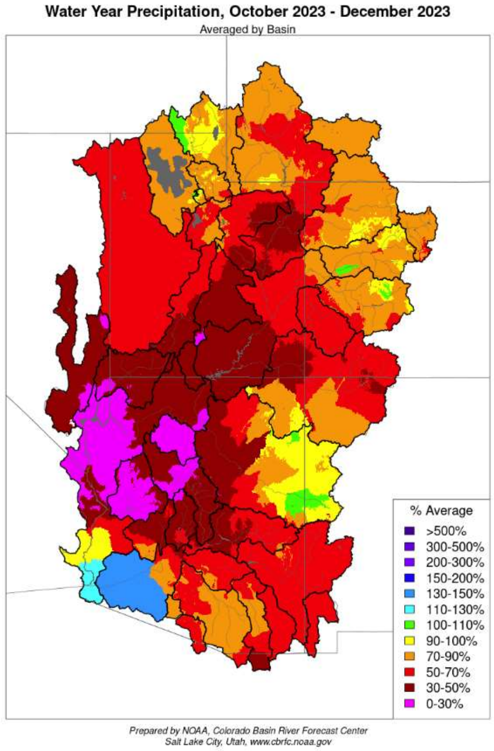

Figure 2: Precipitation through the first three months of the water year was below average.

1.2.1 New Year Brings Welcome Change in Weather

Despite the drier than average conditions which were apparent over the CBRFC's area of responsibility during the first three months of water year 2024, an active weather pattern in January brought above average precipitation over much of the basin and brought water year totals much closer to normal. This pattern continued into February and March (Figure), with February in particular being among the wettest on record at a number of SNOTEL locations; the increase in snow water equivalent (SWE) from January 1 to April 1 (i.e., the difference between SWE measured on April 1 compared to SWE measured on January 1) was the largest, or among the largest on record over most SNOTEL stations in the Colorado River Basin and Great Basin (Figure). As a result of these wetter than average months, precipitation and snowpack conditions throughout the Upper Colorado River Basin and Great Basin were near normal on April 1st.

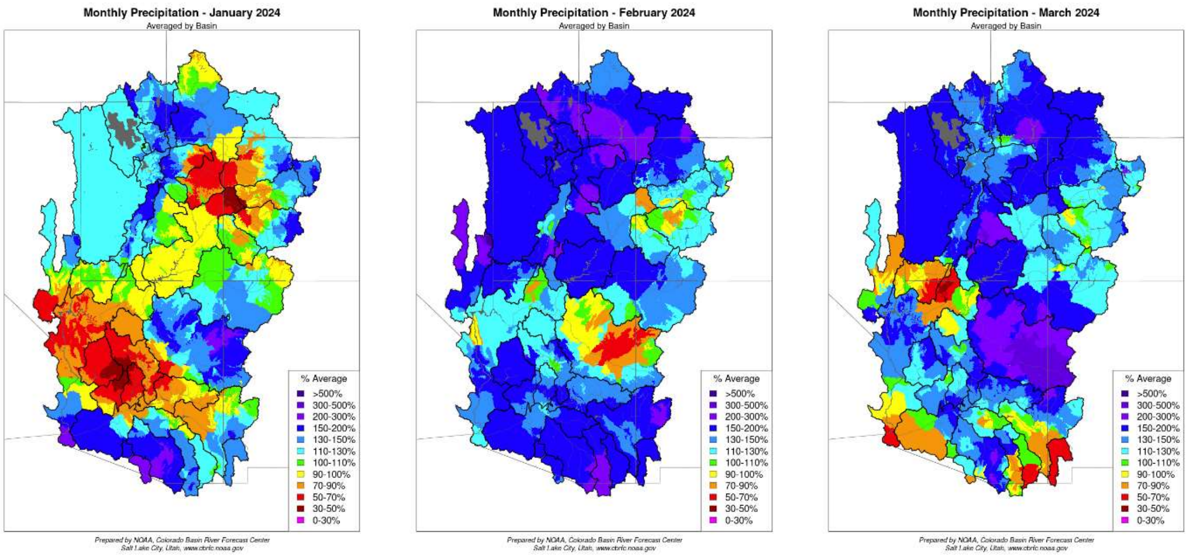

Figure 3: An active weather pattern spanning from January through March significantly improved precipitation conditions after a drier than average start to the water year.

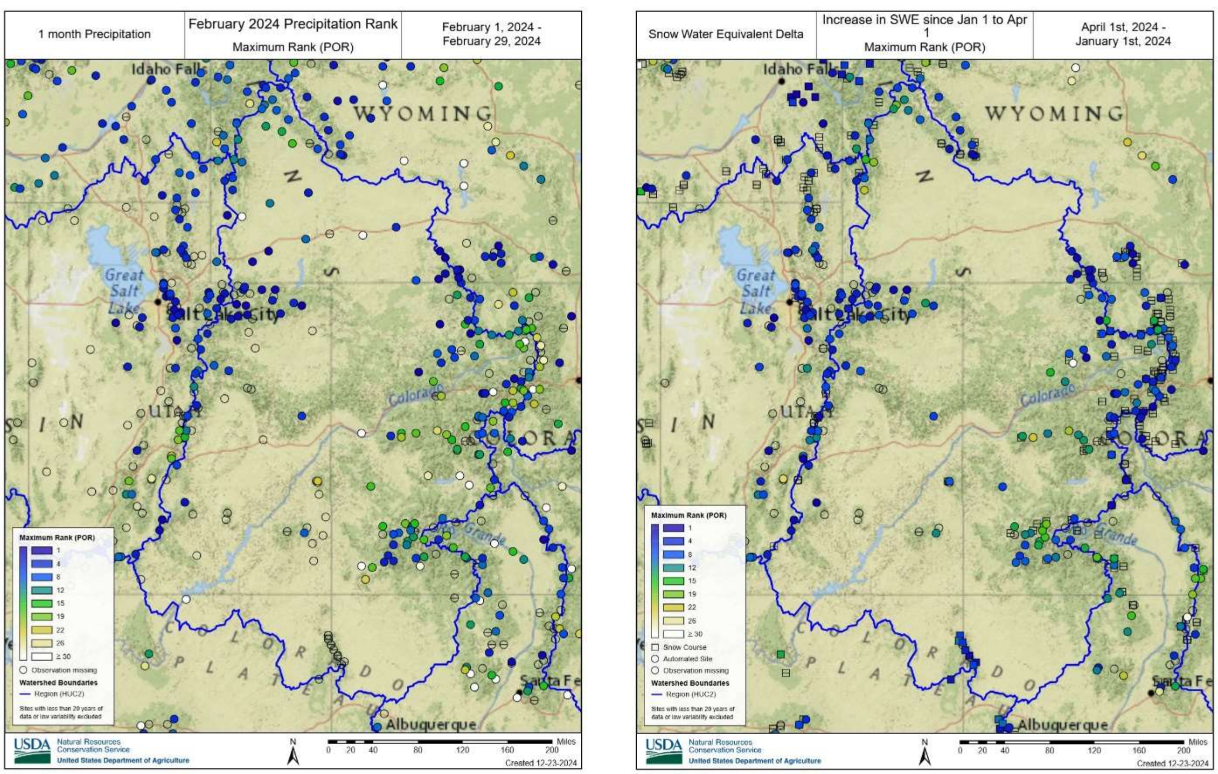

Figure 4: The figure on the left shows the February precipitation maximum rank over the period of record for SNOTEL stations. The figure on the right shows the increase in SWE from January 1 to April 1 as the maximum rank over the period of record for SNOTEL stations.

1.2.2 Dry and Warm Start to the Runoff Season

Near to above average SWE conditions existed throughout much of the Upper Colorado River Basin and Great Basin on April 1st. A drier and warmer than normal April (Figure 3) led to a relatively rapid decline in snowpack initially, before cooler conditions in May resulted in a snowmelt runoff that closely aligned with average conditions (Figure 4).

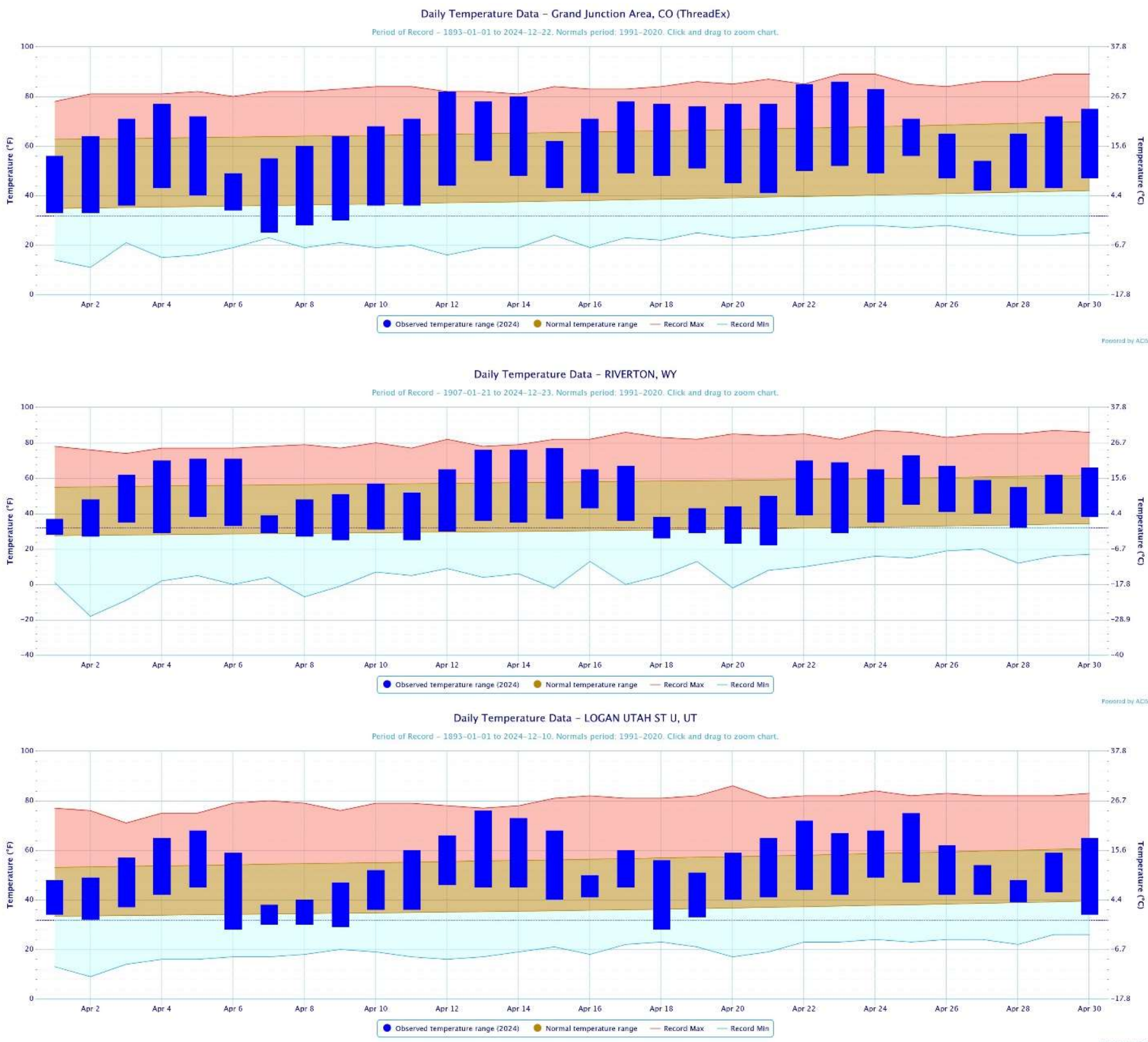

Figure 3: From top to bottom, daily temperature data over April in the Grand Junction, CO, Riverton, WY, and Logan, UT areas. Note the above average temperatures during the first two weeks of the month, which contributed to increased snowmelt.

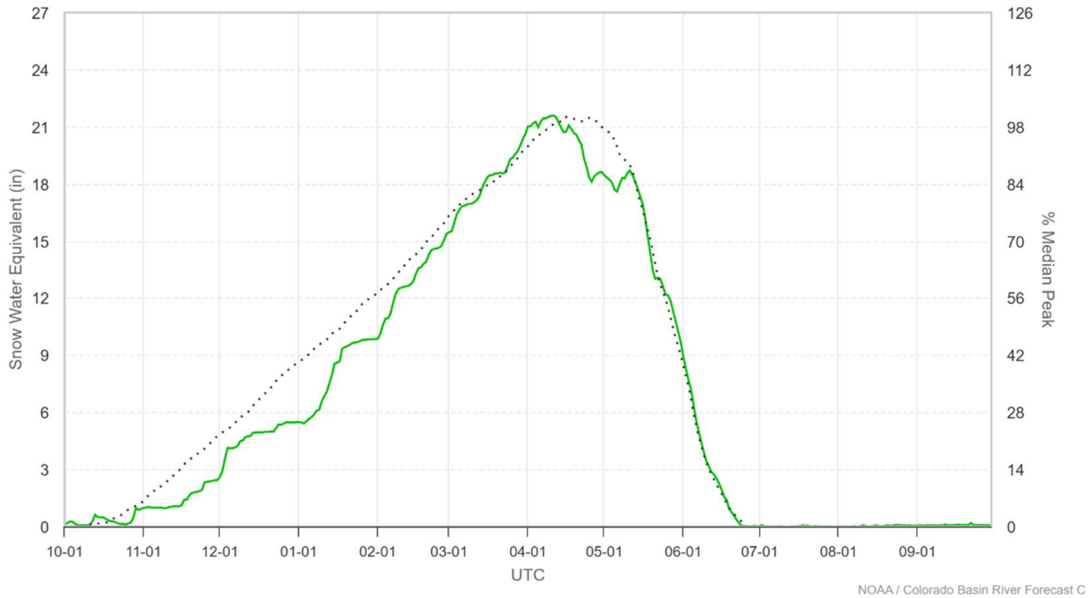

Figure 4: The green line shows snowpack accumulation above Lake Powell compared to normal (median) conditions (dotted line). SWE was near normal on April 1st before declining rapidly due to warmer than normal conditions over the month of April. Cooler than normal temperatures beginning in May slowed melt to near normal conditions for the rest of the runoff season.

1.2.3 Southern Utah Flooding

During the 2024 monsoon, Southern Utah experienced significant heavy precipitation events and flash flooding, impacting parts of Moab and affecting operations at Canyonlands and Arches National Parks, and Zion National Park in the Virgin River Basin. Precipitation amounts in some areas neared 200% of average over the June through August period (Figure 5). Most of the monsoonal precipitation occurred approximately on June 28th, August 13th, and August 24th. While these storms did little from a water supply perspective, the CBRFC extended hours of operations for the event on June 28th to provide the Salt Lake City Weather Forecast Office (WFO) with additional support in light of potential search and rescue operations in Southern Utah, specifically at Zion National Park due to high flows in the Virgin River.

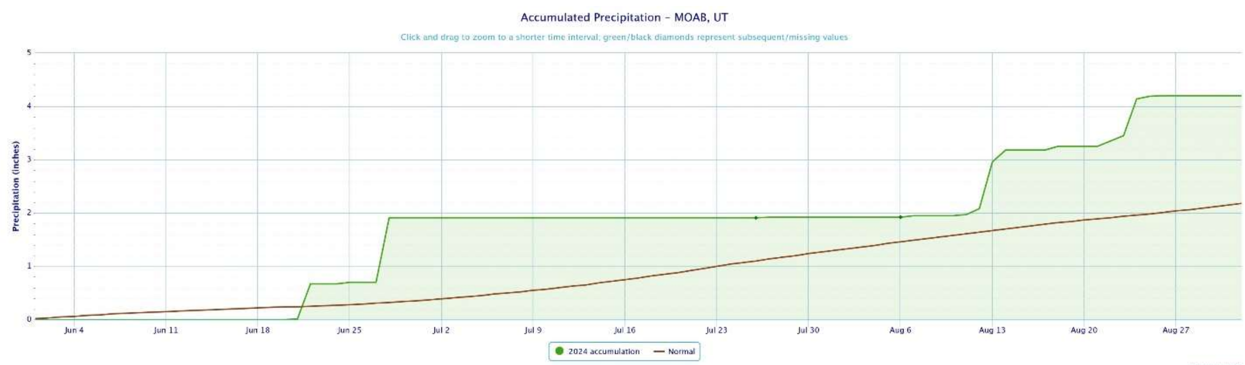

Figure 5: An active monsoon season resulted in much above average precipitation in parts of Southern Utah, impacting operations at National Parks in the area. The above figure shows precipitation accumulation in the Moab, UT area from June 1st through August 31st.

1.2.4 Verification of Lake Powell Forecast

The 2024 observed unregulated seasonal (April through July) runoff volume into Lake Powell was approximately 5.3 MAF, or 83% of average. This reflects an increase from the initial forecast made in January, which was approximately 4.2 MAF, or 65% of average. Overall, the seasonal water supply forecast verified very well, as forecasted values responded to wetter than average conditions in January and February; the March official forecast had improved to 5.0 MAF, or 78% of average and remained relatively consistent through the Spring and Summer (Figure 6).

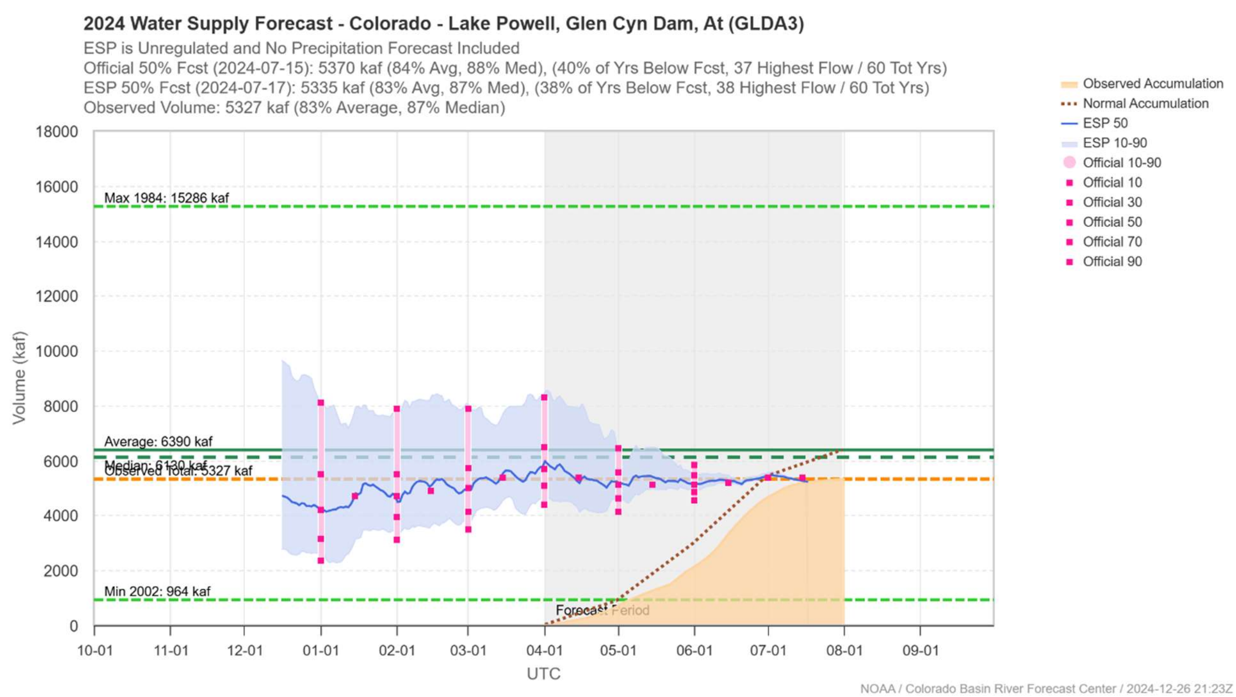

Figure 6: The observed unregulated streamflow volume at Lake Powell was approximately 5.3 MAF, or 83% of average. The above forecast evolution plot shows how the forecasted volume at Powell began relatively low in response to a dry start to the water year, but improved after wetter than average conditions in January through March.

Monthly observed precipitation and unregulated streamflow volumes for Lake Powell are summarized in the table below:

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	WY
% median precip above Lake Powell	92	56	76	120	137	130	69	95	153	65	168	57	100
Unreg Vol (KAF)	324	380	324	283	345	455	733	1421	2527	647	335	208	7982
% Avg	72	91	101	84	95	76	81	69	103	67	89	60	83

2 Summary of Water Year 2024 Improvements

The CBRFC constantly evaluates and works to improve its hydrologic model and methodology, including updating calibrations of specific forecast points when necessary. Additionally, there were several operational improvements at the CBRFC impacting a broad range of stakeholders that will be summarized here, and discussed in more detail in the sections that follow. This year, improvements have been broken down into the following categories:

- Improvements and Further Development of Products and Services for Impact Based Decision Support (Section 3)
- Research, Investigations, and Collaborations (Section 4)

Over the course of water year 2024, the CBRFC worked to provide forecasts to new and traditional stakeholders to meet their decision support goals. In particular, the CBRFC worked closely with the Salt Lake City WFO and partners at the National Park Service to provide increased guidance regarding flooding issues at Zion National Park and investigated trends in forecast accuracy in the Upper Colorado River Basin and Great Basin.

3 Improvements and Further Development of Products and Services for Impact Based Decision Support

3.1 Updates to Snow Plots on CBRFC Website

The CBRFC has been in the process of updating many of the graphics available on its website to be more dynamic, with increased options available for stakeholders to use and interact with the data. Among the most popular products on the CBRFC website are "Snow Group" plots which aggregate information from a subset of available SNOTEL stations to show the progression of SWE over the course of the water year compared to normal (median) conditions throughout the water year (see example Figure 7).

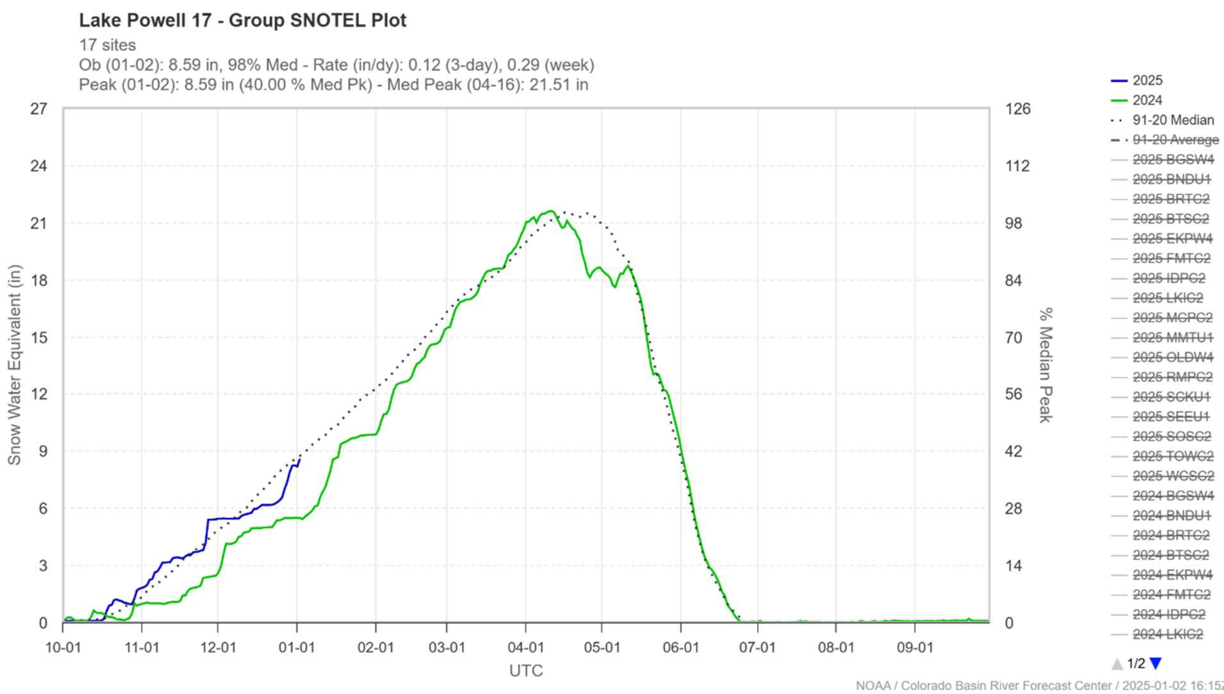

Figure 7: The figure above shows an example of a popular CBRFC "Snow Group" plot. The default options on the plot show the current water year's SWE progression (blue line) compared to normal conditions (dashed line) and last water year's conditions (green line)

The page to access these plots was divided into drop down menus to aid stakeholders in identifying plots most pertinent to their needs, and the plots themselves were updated to be more dynamic with additional options for stakeholders to customize the plots (Figure 8). The option for users to create and save their own snow group plot directly on the website was removed due to cybersecurity concerns; users can e-mail the CBRFC at cbrfc.webmasters@noaa.gov with a plot title and which SNOTEL stations they would like included for inclusion on the website.

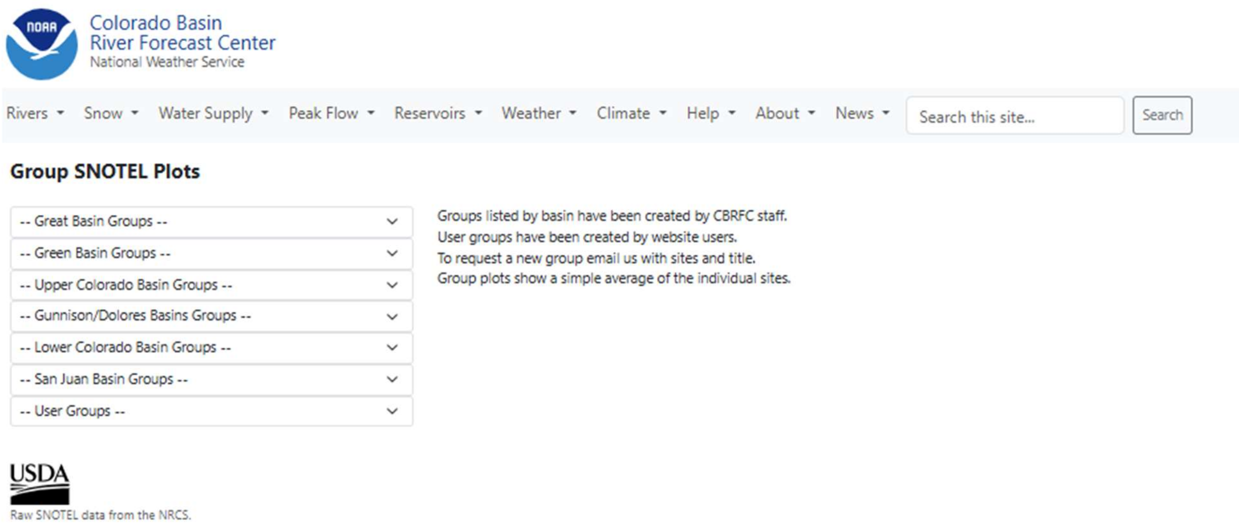

Figure 8: The CBRFC redesigned Snow Group page can be accessed most easily by selecting "Snow Groups" from the "Snow" drop down menu from the CBRFC's home page: www.cbrfc.noaa.gov Users can then select their snow group of interest from a series of drop down menus covering areas, or user-defined snow groups.

3.2 Revamped Flash Flood Guidance

In a cooperative effort with the Northwest River Forecast Center (NWRFC) and California Nevada River Forecast Center (CNRFC), the CBRFC worked to develop and implement a new Flash Flood Guidance (FFG) product for use at WFOs. The FFG product developed by RFCs is a gridded product showing the estimated rainfall over an area that would cause flooding over 1, 3, and 6 hour intervals. The legacy product was relatively static over the Western Region, had not been updated in approximately 20 years, lacked skill, and was generally disregarded by WFOs and seldom referenced.

The effort was initiated in late 2022 with the goal to update the legacy FFG product with contemporary geospatial datasets with the potential to allow for changes in response to fires or other land surface changes. The initial scope of work was for a year and did not include much feedback from WFOs; however, FFG focal points from each of the RFCs identified an opportunity to engage more thoroughly with WFO customers, improve skill associated with FFG through the use of machine learning models, and update the FFG product using parameters more closely related to flooding that were not included in the original base datasets used to develop the FFG product. Based on available research and methods, historical precipitation and flooding events were provided by WFOs to train a random forest regression model to develop a FFG product which targeted a low Root Mean Squared Error (RMSE) (Figure).

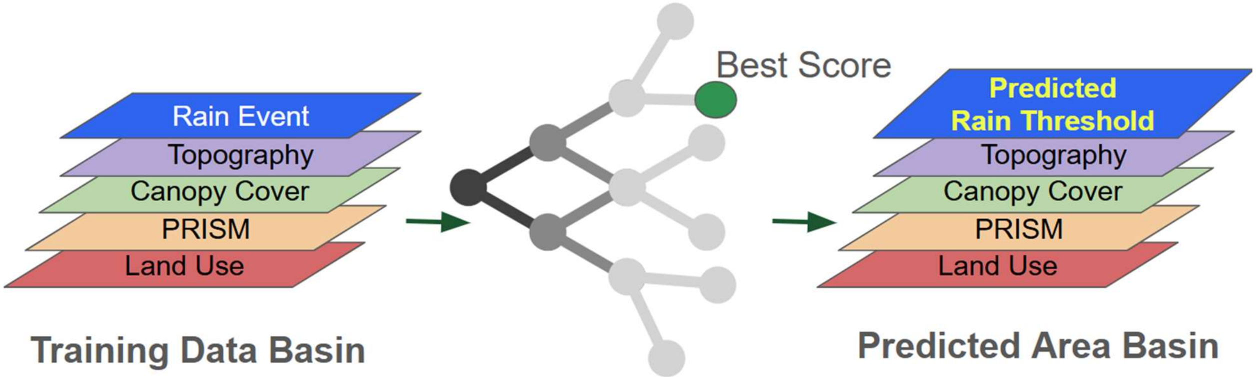

Figure 11: The schematic above illustrates the use of a random forest regression model to incorporate historical rain events associated with flooding with the latest land use and cover data available to produce a more robust and skillful FFG product.

The updated FFG product became operational in October, with all three RFCs distributing the updated FFG over the Advanced Weather Interactive Processing System (AWIPS) for use by WFOs. An example of the 1-hour FFG product is shown in Figure . This new FFG methodology allows for continual feedback from WFOs and the ability to quickly change FFG values in response to changing land surface conditions (e.g., due to fire) or understanding as events occur. Institutional knowledge from WFOs is and can also be used to update FFG values in the product to better support WFO operations. This continued collaboration between RFC and WFO offices will allow for a more skillful and useful product as this iteration of the FFG product is further updated and developed.

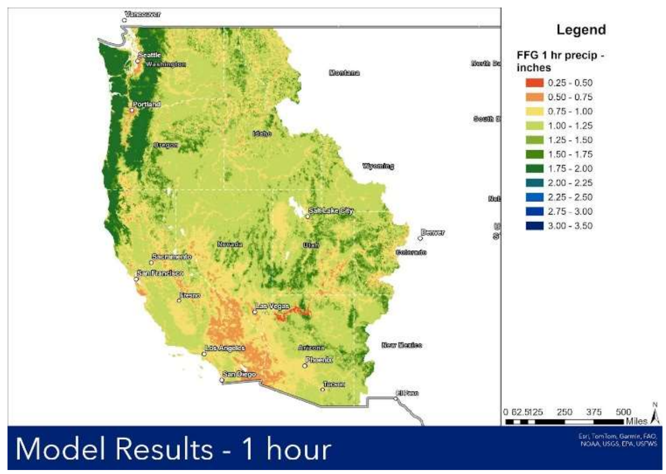

Figure 12: An example of 1-hour FFG produced through a newly developed methodology utilizing machine learning methods.

3.3 New Tools for Quality Assurance and Quality Control of Forcing Data Used in Operations

The CBRFC is an intensive user of hydrometeorological data, both observed and forecasted, for forcing its hydrologic model and developing streamflow forecasts. Two new tools were developed over the water year, primarily to aid CBRFC forecasters with the quality assurance and quality control of data being incorporated into the CBRFC's forecasting paradigm. The first tool identifies tipping bucket precipitation gages above the freezing level, and prevents precipitation observations from these frozen tipping bucket precipitation gages from being used in the CBRFC's hydrologic model. Prior to the development of this tool, CBRFC forecasters had to identify and manually set information from frozen tipping bucket precipitation to be ignored; depending on weather activity, this was a time-consuming process. While CBRFC forecasters still retain the ability to set observations from tipping bucket precipitation gages as usable or not, this tool's ability to identify and set precipitation information from tipping bucket gages above the freezing level as unusable automatically has been extremely beneficial and time saving to CBRFC forecasters.

The second tool developed, termed the "Daily QC Helper Map," uses Meteorological Terminal Air Reports (METARs) to develop a map showing weather conditions over the CBRFC's area of responsibility (Figure 9). The observations can help CBRFC forecasters confirm gage observations, particularly in areas that typically lack reliable radar coverage. The map also includes precipitation observations from the NWS Cooperative Observer Program (Coop), where volunteers report precipitation information (among other variables) for use by the NWS. These manual observations from the NWS Coop can aid in the confirmation of observations reported from stations that automatically report (e.g., ALERT, SNOTEL, etc…). While not used quantitatively, the Daily QC Helper Map allows CBRFC forecasters to leverage information from METAR and Coop sources to aid in the assessment of model forcing data.

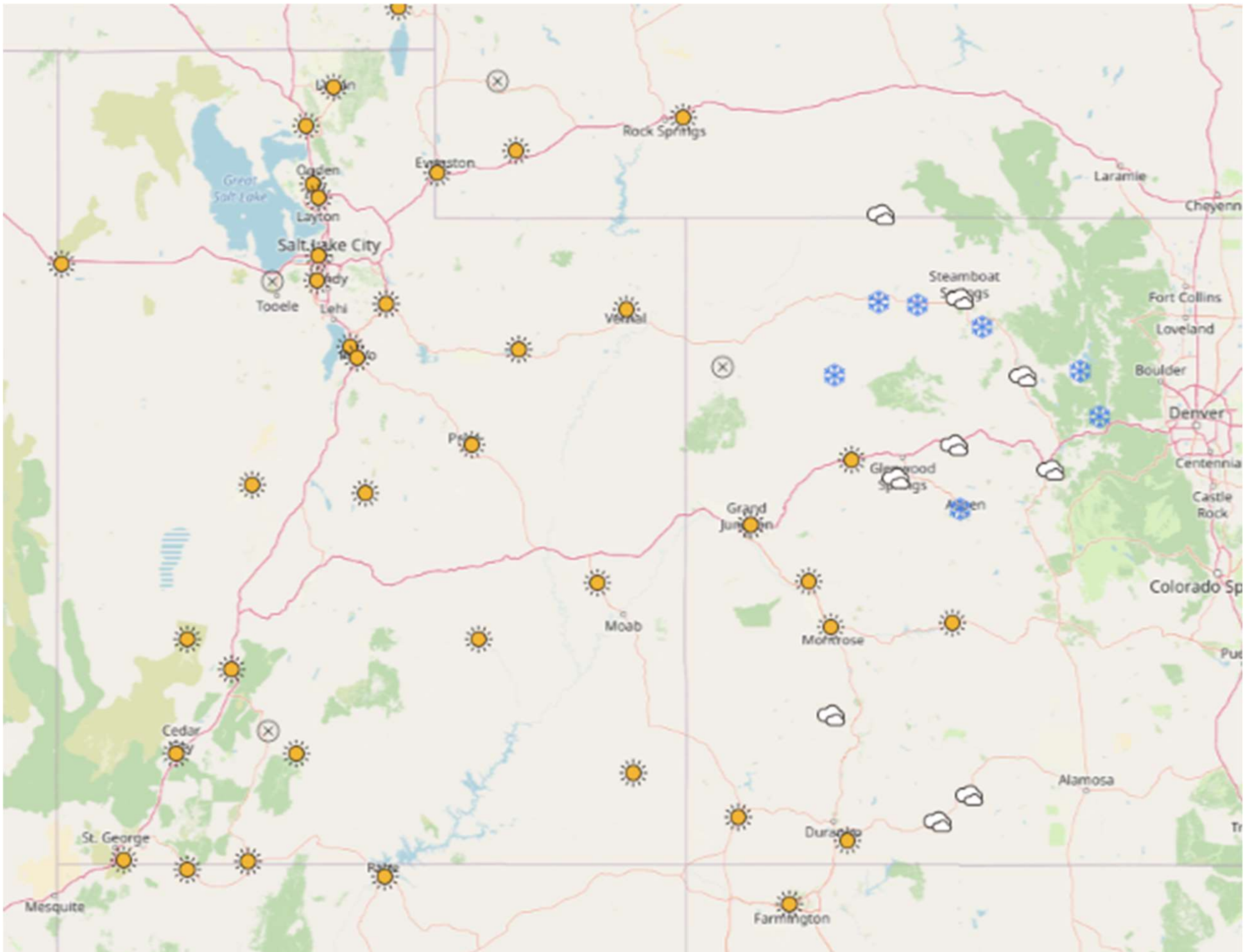

Figure 9: A screenshot of the Daily QC Helper Map, which converts text-based METAR information into visual information that can be used qualitatively by CBRFC forecasters to confirm observations at gages.

4 Research, Investigations, and Collaborations

4.1 Reclamation Snow Water Supply Forecast Program Funding Recipients

Over the course of the 2024 fiscal year, Reclamation's Research and Development Office solicited proposals for projects utilizing airborne lidar snow surveys that could be used to improve or develop improved water supply forecasts in the West. The CBRFC provided letters of support for three of the projects funded by the Snow Water Supply Forecast Program (SNOFO) for this year.

4.1.1 Wings Over Weber

The Utah Department of Natural Resources, Division of Water Resources proposal, "Wings Over Weber: Advancing Snow Water Supply Forecasts in the Great Salt Lake Basin" intends to use aerial snow survey methods provided by Airborne Snow Observatories (ASO) Inc., including WRF-hydro modeled streamflow predictions dynamically linked to snow water equivalent estimates. By using flights and LiDAR in portions of the upper Weber River watershed, ASO Inc. will detect snow depth over a large area, thereby complementing existing snow measurements and providing runoff estimates within the basin. The CBRFC used SWE estimates derived by ASO Inc. to develop experimental water supply forecasts similarly to how experimental forecasts are currently being derived (i.e., direct insertion) using ASO Inc. SWE data in the Upper Colorado River Basin. These experimental forecasts can then be used as complimentary information with official CBRFC water supply forecasts.

4.1.2 Fusing LiDAR and In-Situ Community Measurements to Improve Estimates of Snowpack

The CBRFC supported a proposal led by Oregon State University entitled, "Fusing LiDAR and In-Situ Community Measurement to Improve Estimates of Snowpack Distribution and Evolution." This research intends to develop snow data for use in operational forecasts which blends high spatial resolution, low temporal resolution LIDAR information with point measurements from SNOTEL and community science programs (low spatial resolution, high temporal resolution). This effort further aims to examine model accuracy with respect to the spatial and temporal availability of LIDAR information, which may inform how LIDAR information is collected in the future. The CBRFC has spun up a testbed framework to evaluate new snow datasets for use in operations; this testbed, led by a post-doctoral researcher from Boise State, would be able to evaluate the products from this project for use in an operational setting.

4.1.3 The Utility of Aerial LiDAR Snow Surveys to Improve Water Supply Forecasts Across the Western United States

The CBRFC supported a second proposal submitted by Oregon State University entitled, "The Utility of Aerial LiDAR Snow Surveys to Improve Water Supply Forecasts Across the Western United States: Comparing the Relative Importance of Current Snow Conditions and Future

Weather." The proposed research will investigate how point-in-time lidar surveys can be combined with point snowpack data to produce gridded SWE products, and then to evaluate how the gridded data affects water supply forecasts. Substantial investment and interest from stakeholders throughout the basin exist with regards to SWE products developed using airborne lidar technology. The work proposed here will better help the CBRFC understand the impact of information from airborne LiDAR technology to SWE information that is an important driver in the development of CBRFC products and services.

4.2 Improving Streamflow Forecasts and Reservoir Projections Through Temperature Detrending and Dynamic Evapotranspiration Modeling

In 2021, Reclamation funded RTI International (RTI) to examine both the impact of increasing temperature trends over the Colorado River Basin and the limitations of using a static representation of evapotranspiration in the development of CBRFC water supply forecasts. This research was funded and supported by the Colorado River Climate and Hydrology Work Group (Work Group). With the realization of climate change and increasing temperatures over the CBRFC's area of responsibility, stakeholders within the basin questioned if using temperatures from historical traces was appropriate, given that contemporary temperatures were generally warmer than past temperature. RTI proposed detrending historical mean areal temperatures used by the CBRFC to develop water supply forecasts to create a forcing dataset more representative of contemporary temperatures. RTI, through an incredibly robust study, developed a detrended dataset for use by the CBRFC, and additionally developed an interactive supplementary data dashboard for others to review and interpret the temperature datasets (Figure 10).

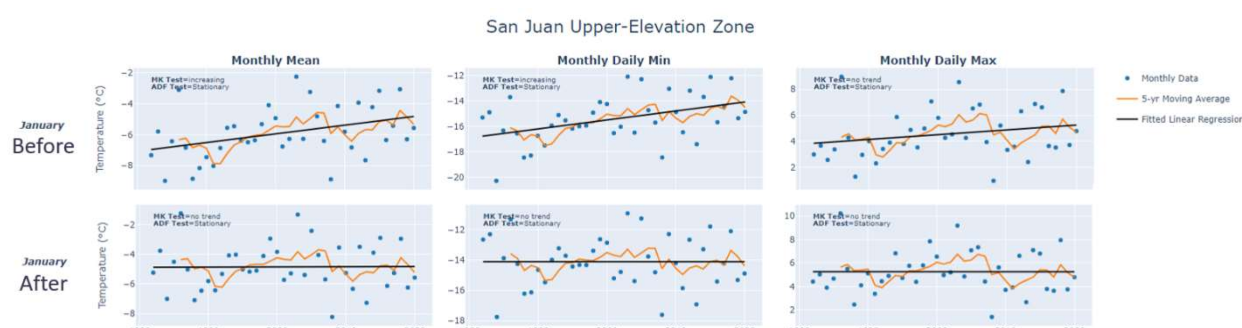

Figure 10: An example of the data dashboard developed by RTI showing the impacts of detrending temperature data over the San Juan River Basin. This is Figure 5 from RTI's report: Improving Streamflow Forecasts and Reservoir Projections Through Temperature Detrending and Dynamic Evapotranspiration Modeling.

CBRFC has historically used monthly static evapotranspiration coefficients within its hydrologic modeling paradigm. RTI compared multiple methods (Figure 11) for dynamically developing an evapotranspiration dataset, and ultimately developed a model utilizing the Priestly-Taylor methodology; when water was available, this resulted in increased evapotranspiration and changes to the timing of runoff in preliminary results over test basins within the CBRFC's area of responsibility.

The CBRFC intends to test the operational capability of both the detrended temperature dataset and dynamic evapotranspiration methodology in collaboration with Reclamation and the implementation of a testbed framework integrated into the CBRFC in 2025. A copy of RTI's report is available upon request from the CBRFC[1].

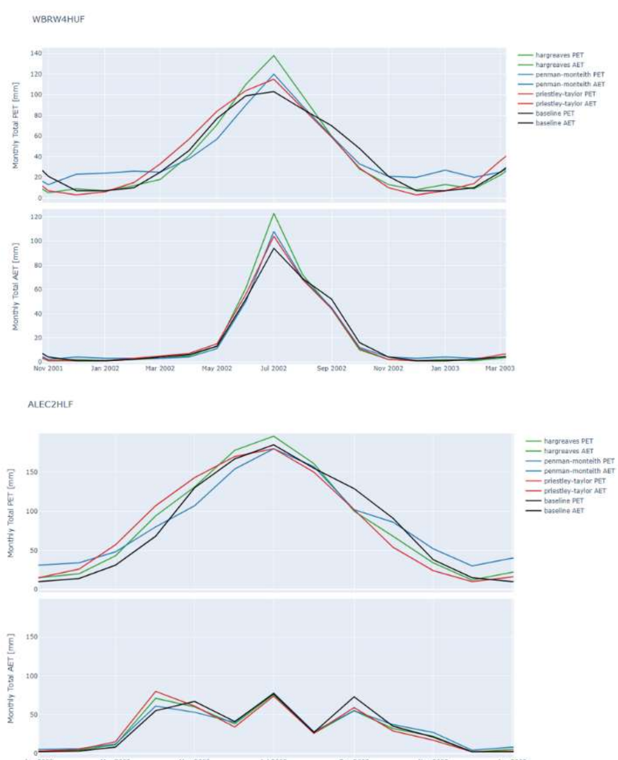

Figure 11: Monthly total PET and AET from each simulation for select subbasin elevation zones (WBRW4UF and ALEC2LF). This is figure 4 from RTI's report: Improving Streamflow Forecasts and Reservoir Projections Through Temperature Detrending and Dynamic Evapotranspiration

4.3 Progress by Snow Water Equivalent "Landing Strip" for Use Towards Improved CBRFC Water Supply Forecasts

Reclamation is funding a post-doctoral researcher from Boise State University to lead a SWE "Landing Strip," or testbed, at the CBRFC. The purpose of this landing strip is to evaluate new SWE datasets in an objective way for possible use operationally. Over the 2024 water year, the landing strip has developed the capacity to compare four different SWE products against the CBRFC's SNOW-17 model currently used operationally. The four SWE products initially investigated are:

[1] Contact cbrfc.operations@noaa.gov to request a copy of Improving Streamflow Forecasts and Reservoir Projections Through Temperature Detrending and Dynamic Evapotranspiration Modeling. Final Report No. ROP-YEAR (2024)-Report Number (R22AC00175) by Paul Micheletty and Abby Watson

- University of Arizona SWE (UA-SWE)
- University of Colorado Boulder SWE (CU Boulder)
- Snow Data Assimilation System (SNODAS)
- Airborne Snow Observatory (ASO)

Initial analysis suggests that the CBRFC's SNOW-17 model tends to simulate higher amounts of SWE at higher elevations when compared to other SWE models, and lower amounts of SWE at lower and middle elevations when compared to other SWE models (Figure 12).

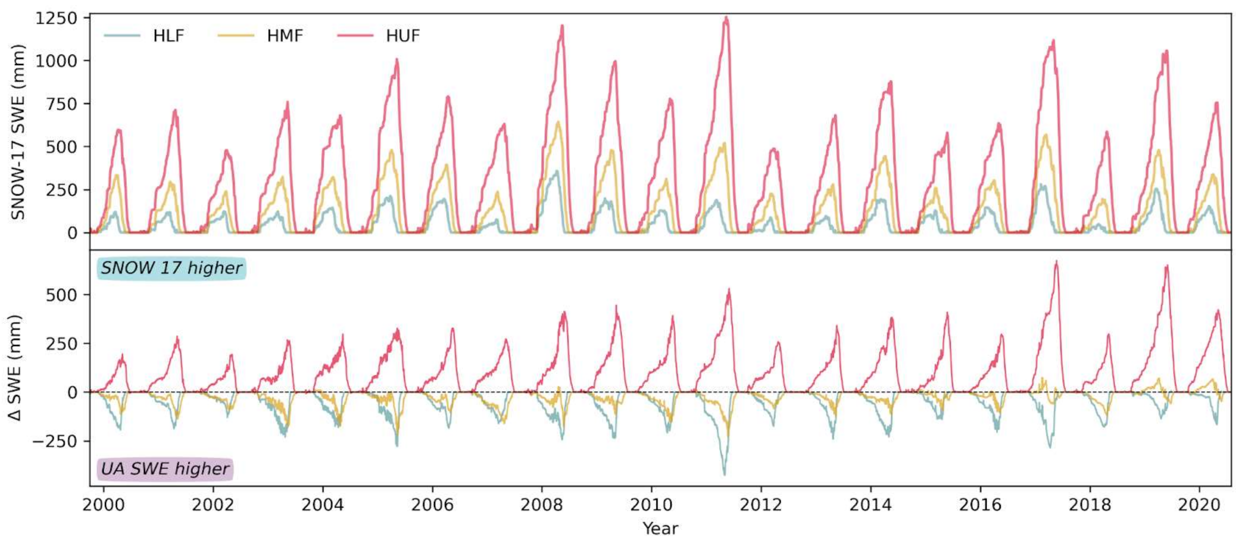

Figure 12: Comparison of SNOW-17 SWE amounts to UA-SWE amounts over the East River Basin.

The SWE landing strip is expected to be further developed over water year 2025, including development of a distributed energy balance snow model for evaluation (iSNOBAL).

5 Staffing Challenges at the CBRFC

Over the 2024 water year, the CBRFC navigated a significant number of vacancies, particularly with regards to lead hydrologist positions. While the vacancies stressed capacity at the office for much of the water year, newly hired staff have filled some vacancies since. The loss of experience and knowledge is difficult to replace in the short term; however, new personnel often provide the opportunity to revisit operational methodologies and research with fresh perspective and ideas.