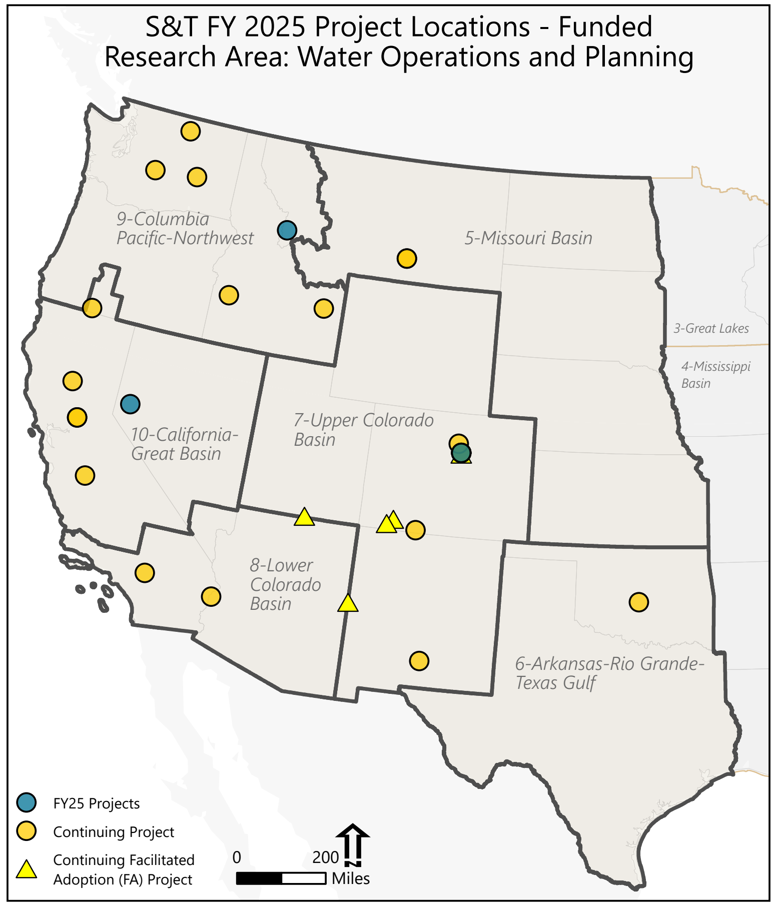
BUREAU OF RECLAMATION

# Research Area Summary
# *Water Operations and Planning*
# Research and Development Office

U.S. Department of the Interior

June 2025

# Executive Summary




The Water Operations and Planning (WP) Research Area of the Science and Technology Program (S&T) examines research in the following categories: Water Supply and Streamflow Forecasting, Water Operations Models and Decision Support Systems, Open Data, and Hydrologic Variability. In FY25, the S&T Research Program funded 10 WP Projects approximately totaling $1.1 M: three new projects received $0.3 M, and seven continuing projects received $0.8 M. Additionally, the S&T Facilitated Adoption Program continued to fund four projects totaling $1 M in FY25. To demonstrate the value of WP research, benefit-cost ratio calculations were estimated for project 19132: Using Ground Measurements and Remote Sensing to Improve Evaporation Estimation and Reservoir Management. The project significantly improved our understanding of evaporation losses at Elephant Butte and Caballo reservoirs, yielding a benefit-cost ratio several times greater than the project's investment. The project found that measurements of evaporation losses at the reservoirs using eddy covariance instrumentation and remote sensing resulted in lower evaporation estimates than those calculated using current methods based on pan evaporation. These improved estimates of evaporation resulted in a better understanding of water available for irrigation. WP research supporting development of tools and techniques to inform efficient water management and use provides great value to Reclamation.

Reclamation's Research and Development Office (R&D) manages the Science and Technology Program (S&T) and is focused on providing innovative solutions for Reclamation water and power facility managers and its western customers and stakeholders, primarily through competitive funding opportunities to Reclamation employees.

The S&T Program has five research areas (listed below) directly related to Reclamation's mission.
For more information, visit: [https://www.usbr.gov/research/st/index.html](https://www.usbr.gov/research/st/index.html)

## S&T Research Areas and Categories

**Water Infrastructure (WI)**
Dams, Canals, Pipelines, and Miscellaneous Water Infrastructure

**Power and Energy (PE)**
Hydro Powerplants and Pumping Plants

**Developing Water Supplies (WS)**
Advanced Water Treatment, Groundwater Supplies, Agricultural and Municipal Water Supplies, and System Water Losses

**Environmental Issues for Water Delivery and Management (EN)**
Water Delivery Reliability, Invasive Species, Water Quality, Sediment Management, and River Habitat Restoration

**Water Operations (WP)**
Water Supply and Streamflow Forecasting, Water Operations Models and Decision Support Systems, Open Data, and Hydrologic Variability

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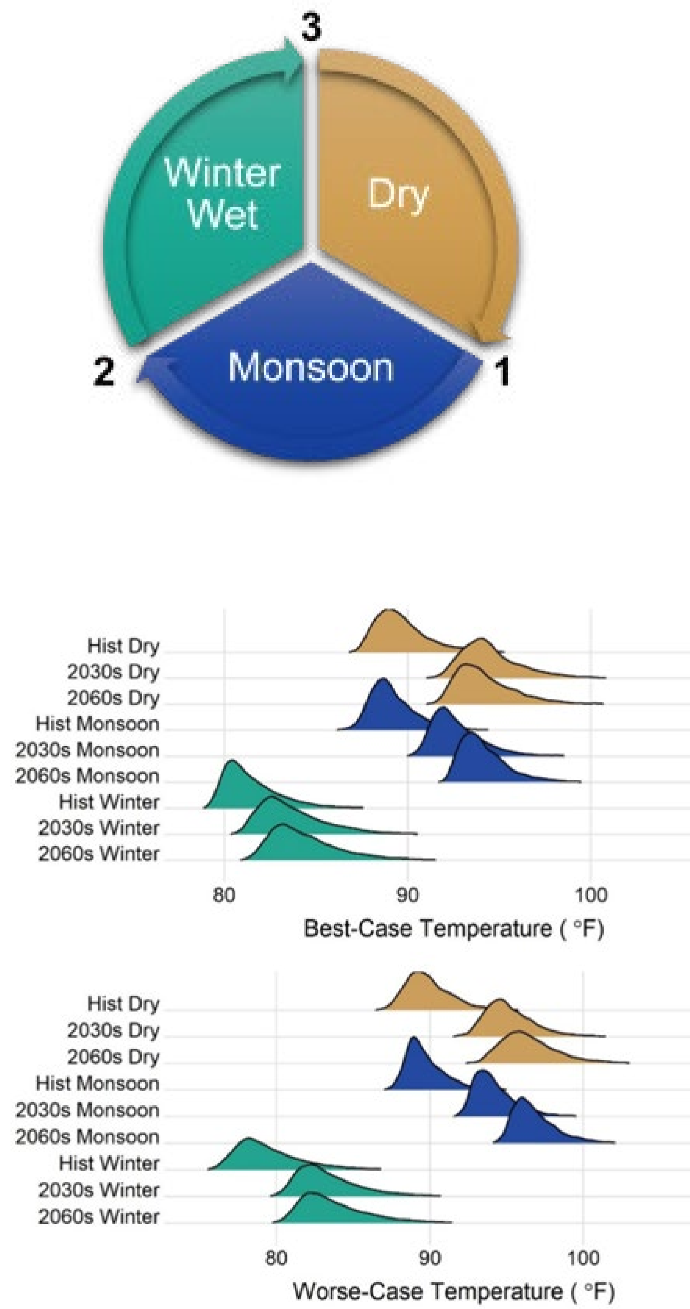
# Water Operations and Planning

## FY24 Completed Projects

### 21039: A Collaborative Stochastic Weather Generator for Climate Impacts Assessment – Subhrendu Gangopadhyay

Stochastic weather generators provide opportunities to simulate weather conditional on a multitude of variables and form a robust approach to climate projections in impacts assessments studies. Though weather generators have been prominent in the literature and have demonstrated varied applications including climate impacts assessments, they don't appear to be a dominant approach that is regularly used in climate impacts assessments. Why? A likely reason is the disconnect between weather generators as a tool and stakeholder understanding as users of the information being developed from the weather generators. A stochastic weather generator was developed through this project with the novel feature of considering seasonality of precipitation and temperature, motivated largely within the context of climate change adaptation and planning. The weather generator is designed to understand changes in seasonal properties including: (1) spell characteristics of the pre-monsoon dry season; (2) length of the monsoon season; (3) precipitation amounts during the monsoon season; (4) precipitation amounts over the winter wet period; and (5) annual temperature variability. These hydroclimate metrics of interest were developed in collaboration with the study stakeholders and the weather generator was developed to address impacts based on these metrics under two future climate scenarios. Mathematically, the developed weather generator uses a non-parametric resampling algorithm based on Markov state transition for precipitation in a three-state system characteristic of southeastern Arizona and consisting of, (1) pre-monsoon dry, (2) monsoon, and (3) winter wet seasons. Temperature distribution was modeled parametrically and includes temperature seasonality modulation coupled with precipitation occurrence. The weather generator, wxgenR, is released as an R language package on the Comprehensive R Archive Network. wxgenR was tested using weather station data from nine locations in the continental United States with varied hydroclimatic regimes. wxgenR development was initiated by a hydroclimate analysis using areal average precipitation and temperature from the Lower Santa Cruz River Basin in Arizona. wxgenR performs well in the cross-validation with both in-sample and out-of-sample data. The weather generator can be found at https://cran.r-project.org/web/packages/wxgenR/index.html.




*Conceptual diagram of seasonality (top) and distributions of extreme daily temperatures, averaged over the surface water model boundary area, by period and season (bottom).*

## 22071: Characterizing Historical and Future Snowfall Events across the Western United States – Katie Holman

Seasonal snowpack is a critical resource for water management across many parts of the world, including the Western United States (U.S.). Snow is often characterized by a variable called Snow Water Equivalent (SWE), which represents the depth of water obtained from melting a column of snow. Point and spatial estimates of SWE are used to inform local/regional water resource management, flood forecasting and hazards, climate studies, and wildfire risk assessments. While many recognize the importance of SWE, few studies focus on improving understanding of large snowfall events that drive snowpack growth. In this study, our objective was to improve understanding of heavy snowfall events across the Western U.S. by exploring the following three components of analysis. The first component includes describing historical snowfall events using point observations from the SNOw TELemetry (SNOTEL) dataset. The second component involves characterizing weather types (e.g., atmospheric forcings) associated with the top eight heaviest historical snowfall events in each basin of interest using methods from Prein and Mearnes (2021) and data from the European Center for Mid-range Weather Forecasting's (ECMWF's) ERA-Interim reanalysis dataset (Dee et al. 2011). The final component entails exploring simulation of historical weather types in climate projections from the Community Earth System Model version 2 (CESM2, Rodgers et al. 2021) Large Ensemble 2 dataset (LENS2). We focused on six Bureau of Reclamation (Reclamation) watersheds located in headwater regions, which include the Methow basin, WA, the Sun River basin, MT, the Upper Snake River basin, ID/WY, the Upper Klamath Lake basin, OR/CA, the Truckee-Carson basins, CA/NV, and the Upper San Juan basin, UT/AZ/CO/NM. Each of these basins is differentiated from the others by unique historical snowfall events and relevant weather patterns. We found that Methow and Upper Klamath Lake basins had the greatest number of snowfall days, while some of the largest daily totals occur at stations in the Upper San Juan and Truckee- Carson basins. The dominant forcing mechanisms (up to three) responsible for the eight heaviest historical snowfall events in each basin are summarized in the table below. Finally, we documented how average atmospheric conditions from ten CESM2 LENS2 ensemble members compared with atmospheric conditions from ECMWF's ERA-Interim and focused on atmospheric variables that are important to identifying historical weather types in each basin.

| Basin/Weather Type | 1 | 2 | 3 |
|---|---|---|---|
| **Methow basin** | AR*-like | AR-like | NA |
| **Snake River basin** | AR-like | Upper-level trough | Cold front |
| **Sun River basin** | Cold front | AR-like | Upslope |
| **Truckee-Carson basins** | AR-like | AR-like | NA |
| **Upper Klamath Lake basin** | AR-like | AR-like | Cold front |
| **Upper San Juan basin** | Upper-level trough | Upper-level trough | NA |

* AR: atmospheric river

*Table —Description of weather types responsible for the top eight largest snowfall events in each basin identified using observations from SNOTEL stations.*

*Crane Prairie Dam on the Deschutes River.*

### 23037: Exploring Frameworks for Simulating Historical and Future Hydrology in the Upper Deschutes River Basin – Marketa McGuire

This scoping study identified a potential approach for estimating unregulated streamflow in the Deschutes River basin for both historical and projected future conditions. The Deschutes River streamflow can be characterized as dominated by groundwater discharge (Gannett et al. 2017). Prior hydrologic modeling methodologies have not produced simulated streamflow of adequate quality. The study team explored multiple modeling approaches and evaluated two approaches over three selected case study basins. The first approach evaluated is similar to that taken in the St. Mary and Milk River Basin Study Update (Reclamation and Montana Department of Natural Resources and Conservation 2024), which includes a precipitation-runoff model with a routing module to simulate both the quick and slow components of runoff. The second evaluated approach uses a simplified lagged precipitation model that calculates an effective lagged precipitation from the current water year precipitation and water year annual precipitation in the previous one or two years. This report provides an overview of historical climate and hydrology in the Deschutes River basin, describes modeling and calibration methods employed to improve simulated streamflow estimates at key case study locations, and summarizes preliminary modeling results. Where possible, other existing sources of information were brought into the analysis for comparison, such as simulated streamflow from the United States Geological Survey Monthly Water Balance Model and simulated streamflow from the Second Edition of Climate and Hydrology Datasets for River Management Joint Operating Committee Long-Term Planning Studies. Sources for these comparisons are described in the main body of this report. Recommended next steps for follow-on study based on these study results are also discussed.

## FY25 New S&T Research Projects

### 25012: Combining Physically Based Spatially Distributed Snow Modeling with High Spatial Resolution Remote Sensing to Improve Snowmelt Runoff Forecasts in the Truckee-Carson Basin – Austin Balser

This project seeks to develop a model to track snowpack evolution spatially across the Truckee and Carson River watersheds. The upper reaches of the Truckee and Carson basins are characterized by large elevation changes, from 5,000 feet above sea level to over 10,000 feet above sea level. The prominence of the highest elevations in the basin lead to significant impacts from wind redistribution of snow and changes in the snowpack that are not accurately represented in data from lower elevation observation sites such as those typically used from the Snow Telemetry (SNOTEL) network. Better understanding the extent of snow in the basin will improve forecasting and inform operational decisions for the management of water resources while protecting life and property in the basin.

### 25032: Developing a Low-Maintenance Precipitation Sensor – Joseph Wright

This project continues the effort made by Reclamation's "Counting Every Drop" prize competition by developing a low-maintenance, non-contact precipitation sensor that can be deployed in remote Reclamation watersheds. A low-maintenance, non-contact sensor would eliminate many of the challenges and constraints of current precipitation gauges, including the use of antifreeze fluid to melt solid precipitation in all-season storage gauges (e.g., the "rocket gauge" design used at Natural Resources Conservation Service SNOTEL) sites as well as the high-power requirement needed by heated tipping bucket gauges. Reclamation water managers rely on precipitation measurements for both planning and operations. Such measurements are used to characterize watershed hydrology and monitor basin conditions. These measurements are also critical inputs for hydrologic models, streamflow forecast models, and other decision support tools.

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### 25043: Current and Future Potential for Heavy Springtime Liquid Precipitation in the Bitterroot Mountains – Amanda Stone

The potential for floods caused by large rain events on snow during spring in mountainous watersheds is generally not well understood due to few observations in the streamflow records. This phenomenon is even more elusive in orographically protected regions where large rain events are generally less probable and therefore less likely to have direct observations. Furthermore, future climate scenarios may result in shifts from snow to rain during spring. Through collaboration with climate scientists at the National Center for Atmospheric Research, this project intends to examine current and future potential for springtime liquid precipitation events in orographically headwater basins at a pilot study site at Como Dam in the Bitterroot

Mountains of Montana. Findings of this study may inform future understanding at other facilities in other regions regarding current and future potential for liquid precipitation at times that are crucial for refilling reservoirs and managing dam safety risk.

## FY25 Continuing Facilitated Adoption Project

### FA25052: Evaporation Monitoring at Lemon Reservoir and Lake Nighthorse – Kathleen Holman

This study will deploy instrumented buoys to measure meteorological parameters at Lemon Reservoir and Lake Nighthorse, two high desert reservoirs in the San Juan Mountains. These reservoirs represent a significant source of water for the region: Lake Nighthorse supplies tribal water, while Lemon Reservoir supplies water for irrigation and municipal needs. The measured meteorological parameters will be used to calculate evaporation rates at each reservoir. Improved understanding of evaporative losses from these reservoirs will benefit water managers and reservoir operators, who rely on precise water accounting to meet downstream needs. Additionally, this study will serve as a proof-of-concept investigation into the scalability of instrumented buoys within the high desert region.

### FA25054: Evaporation Monitoring on Lake Powell for Water Management – Kathleen Holman

Lake Powell is the largest storage reservoir in the Upper Colorado River Basin by surface area and capacity. Historical evaporation estimates suggest that evaporative losses from Lake Powell account for 60% of the Upper Basin's total evaporative losses. However, those estimates are based on overly simplistic and outdated methods. This study will continue evaporation monitoring on Lake Powell using two modern methods to support informed water management in the Upper Basin. Data and results from this study will be used to support activities in three different groups in the Upper Colorado Basin Regional Office.

# FY25 New and Continuing Projects*

| ID | Final Year | Title | Lead |
|---|---|---|---|
| 20025 | 2025 | Developing a Holistic Framework for Evaluating System-Wide Groundwater Surface Water Interaction and Interconnected Projects using System Dynamics Modeling Methods | Jennifer Johnson |
| 20056 | 2025 | Exploring the Possibilities of Improving Flood Frequency Analysis in the West by Incorporating Paleohydrologic Reconstructions | Subhrendu Gangopadhyay |
| 20075 | 2025 | Simulating California's Water Supply System Under Future Climate Stresses | Drew Loney |
| 21023 | 2025 | Measurement and Modeling of Effects of Differential Wind Stress Due to Topography and Wind Sheltering Elements on Hydrodynamics of Augmented Lakes and Reservoirs | Melissa Shinbein |
| 21041 | 2025 | Combining Physically Based Snow Modeling and Remote Sensing at High Spatial Resolution to Improve Snowmelt Runoff Forecasts in the Big Thompson and Willow Creek Basins | Claudia Leon Salazar |
| 21048 | 2026 | Assessing the Impact of Land Use and Land Cover Changes on River Diversions in Semi-Arid River Basins | Michael Poulos |
| 21082 | 2025 | Evaluating Big Thompson Water Supply Modeling Capability Improvements from New Model Forcing and Recalibration | Lindsay Bearup |
| 22045 | 2025 | The Development of a Temperature and Dissolved Oxygen Water Quality Model to Inform Water Management Options to Benefit Yakima River Salmon Migration | Kristin Mikkelson |
| 22050 | 2025 | Evaluating Water Temperature Modeling and Prediction in the Sacramento River Basin | Randi Field |
| 22072 | 2025 | Pyforecast Continued Development – Expanding Pyforecast's Reach and Capabilities | Peter Cooper |
| 22108 | 2025 | Optimization of Water Management within the Colorado River Indian Reservation in Arizona | Meghan Thiemann |
| 23027 | 2025 | Developing a Robust Planning Framework for Climate Change in California | Kevin Thielen |
| 23035 | 2025 | Stochastic Streamflow Generation: A Complementary Approach for Hydroclimate Projections in Hydrologically Complex Basins | Subhrendu Gangopadhyay |
| 23038 | 2025 | Understanding Historical and Projected Flood Mechanisms for Headwater Basins in the Western US | Amanda Stone |
| 23041 | 2025 | Climate Change Impact Analysis on Groundwater Availability and Managed Aquifer Recharge in California | Kirk Nelson |
| 23061 | 2025 | Assessing Satellite Remote Sensing Products to Improve Spatial and Temporal Resolution of Snow Water Equivalence (SWE) Measurements in the San Juan – Chama Project's Source Watersheds | Emma Metcalf |
| 24037 | 2026 | Changes to GHG Emissions as a Result of Dam Removal in the Klamath | Kevin Thielen |
| 24050 | 2025 | Constructing a Generalized Framework for Implementing Risk-Informed Reservoir Operations | Ian Ferguson |
| 24056 | 2027 | Snow Depth Estimation using InSAR (Interferometric Synthetic-Aperture Radar) Technique | Jong Kang |
| 25012 | 2027 | Combining Physically Based Spatially Distributed Snow Modeling with High Spatial Resolution Remote Sensing to Improve Snowmelt Runoff Forecasts in the Truckee-Carson Basin | Austin Balser |
| 25032 | 2026 | Developing a Low-Maintenance Precipitation Sensor | Joseph Wright |
| 25043 | 2027 | Current and Future Potential for Heavy Springtime Liquid Precipitation in the Bitterroot Mountains | Amanda Stone |
| FA24071 | 2026 | Demonstrating Merged Airborne Snow Observatory and Station Data Tools | Lindsay Bearup |
| FA24073 | 2026 | Operationalizing Monsoon Forecasts in New Mexico and Arizona | Noe Santos and Lucas Barrett |
| FA24074 | 2026 | Piloting Machine Learning Inflow Forecasts Across Reclamation | Lindsay Bearup |
| FA25052 | 2027 | Evaporation Monitoring at Lemon Reservoir and Lake Nighthorse | Kathleen Holman |
| FA25054 | 2027 | Evaporation Monitoring on Lake Powell for Water Management | Kathleen Holman |

*Continuing projects include those that received no-cost extensions.

**Front cover photo:** Glen Canyon Dam, Arizona.
**Back cover photo:** Owyhee Dam, Oregon.