Decision Support for Enhanced Water Resource Management Planning of Rain-on-Snow Events in the Mokelumne Watershed

Bureau of Reclamation WaterSMART Applied Science Grant Application Funding Opportunity Number R23AS00446

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List of Acronyms

BCM: Basin Characterization Model

CaDWR: California Department of Water Resources

CNRFC: California-Nevada River Forecast Center

DRI: Desert Research Institute

DSS: Decision Support System

EBMUD: East Bay Municipal Utility District

FIRO: Forecast Informed Reservoir Operations

FAIR: Findable, Accessible, Interoperable, and Reusable

GIS: Geographic Information System NRCS: Natural Resource Conservation Service

OGC: Open Geospatial Consortium

PG&E: Pacific Gas & Electric

ROS: Rain-on-snow

SNOTEL: Snow Telemetry Network

SST: Stochastic Storm Transposition

SR-DSS: Snowpack Runoff Decision Support System

USGS: United States Geological Survey

USBR: United States Bureau of Reclamation

EXECUTIVE SUMMARY

17 October 2023
Applicant: BoR, NSHE obo Desert Research Institute, Reno, Nevada
Project Location: Mokelumne Watershed, Calaveras, Amador, and Alpine Counties, California

Project Summary:

Desert Research Institute (DRI) and the United States Geological Survey (USGS) in collaboration with East Bay Municipal Utility District (EBMUD) and Pacific Gas & Electric (PG&E) will integrate a suite of tools to develop an end-to-end solution for midwinter snowpack runoff decision support ranging from real-time situational awareness to long-term planning of reservoir reliability mid-winter runoff events. This project integrates field measurements, Snowpack Runoff Decision Support System (SR-DSS), the Basin Characterization Model (BCM), and the stochastic storm transposition (SST) technique. We will apply this integrated framework to the Mokelumne watershed where rain-on-snow (ROS) is not only common, but also plays a dominant role in driving "upper tail" flood events. This applied science project aims to improve the understanding of ROS dynamics and their impacts on water resources management from climatological and probabilistic perspectives. Project partners are seeking to upgrade the regional monitoring networks to be used in this research project and assist with modeling efforts. Project funds will cover the time for DRI and USGS to implement their suite of decision support tools and collaborate with EBMUD and PG&E to ensure operational alignment of the decision support tools in the Mokelumne. In addition EBMUD will develop, calibrate, and run a continuous HEC-HMS model to benchmark (i.e., validate) the long-term simulation of the BCM. Our project will take 2 years (starting on May 15, 2024, and ending on May 14, 2026) with a proposed budget of $574,902. The project is not located on a federal facility.

TECHNICAL PROJECT DESCRIPTION

DRI is a Category B applicant located in Nevada working in collaboration with two Category A entities: EBMUD and PG&E, two water authorities with water and power delivery authorities located in California. **DRI was approached by EBMUD, which works collaboratively with PG&E on the Mokelumne, to apply for this specific grant.**

1. Detailed Project Description

The Mokelumne River watershed epitomizes the nexus of contemporary hydrologic challenges: municipal and agricultural water supply, flood control, hydropower generation, and ecological resources. Located in the Central Sierra Nevada of California with elevations spanning rain-dominated low elevations through the rain-snow transition elevations to snow-dominated peaks, runoff responses are highly sensitive to immediate (e.g., precipitation and the rain-snow transition elevation) and antecedent (e.g., soil moisture and snowpack water content) conditions. **Optimizing water management operations during the cool season is necessary to ensure three primary water management goals are met year-round.** Skillfully forecasting runoff during extreme precipitation events, especially those characterized by high rain-snow transition elevations and saturated antecedent soil moisture conditions, is critical to effectively managing water resources. This capability is essential to ensure the safe conveyance and storage of runoff and mitigate flooding while also enabling the availability of water for future beneficial use. Therefore, this applied science project aims to enhance and integrate a suite of tools to gain a comprehensive understanding of ROS dynamics and impacts on water resources management from event to climatological time scales.

This proposed project consists of **five interconnected components**: 1) apply and validate the SR-DSS across seven stations; 2) integrate the SR-DSS with a distributed hydrologic model, the BCM; 3) develop a continuous HEC-HMS model and benchmark the BCM long-term simulation; 4) integrate the SST technique to estimate the probability of reservoir inflow; 5) disseminate results to water managers in a pseudo-operational setting to assess the feasibility and utility of the integration of these tools for real-time operations.

1.1 Snowpack Runoff Decision Support System (SR-DSS)

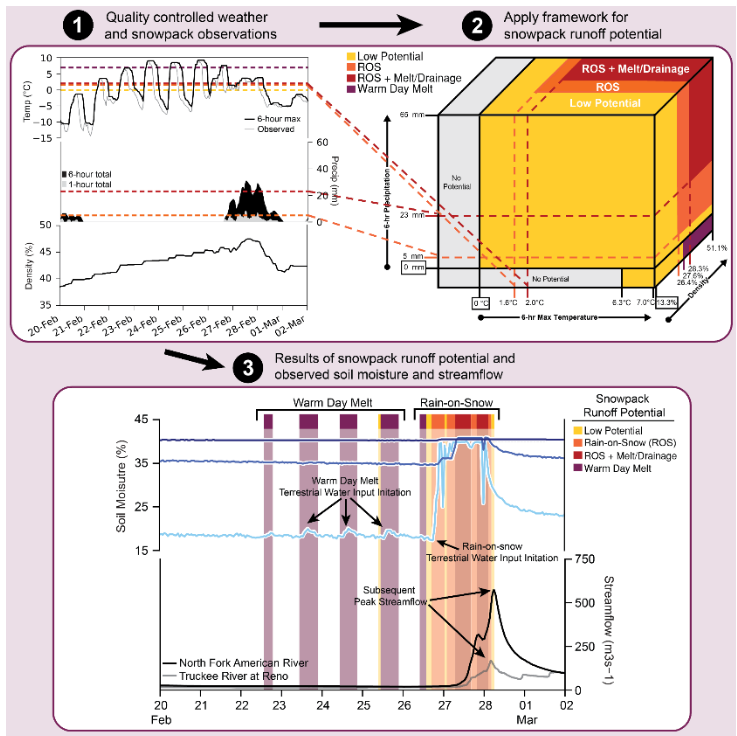

Figure 1. Graphical summary of the snowpack runoff decision support system, which ingests air temperature, precipitation, and snowpack density (step 1) to communicate when the conditions for potential snowpack runoff are met (step 2) and to validate the occurrence with soil moisture and streamflow responses (step 3).

EBMUD will update permits and perform the necessary environmental assessments by working with the US Forest Service, USBR, and California Department of Water Resources (CaDWR) to upgrade two existing USBR snow monitoring stations to include soil moisture sensors. The addition of soil moisture data will provide observational data continuity at the seven stations in the study area spanning the lower-elevation ephemeral snowpack (at 4,695 feet) to the high-elevation persistent deep snowpack (at 8,700 feet), creating the ability to implement the SR-DSS (Heggli, 2023; Heggli et al., 2022). The SR-DSS leverages real-time observations of air temperature, precipitation, snowpack density, and soil moisture to communicate when present weather and antecedent snowpack conditions have the potential to produce runoff (Figure 1). The SR-DSS is currently integrating National Weather Service (NWS) probabilistic forecast information, which will increase the lead time for decision-making. Each of the seven monitoring stations in the Mokelumne will inform the SR-DSS. Soil moisture sensors are a critical component to running the SR-DSS in the Mokelumne because they serve to validate when the snowpack is producing runoff during ROS events. **The SR-DSS is a valuable tool for real-time situational awareness** to aid in the decision-making process during an event, becoming more valuable when coupled with the spatially relevant BCM.

1.2 Basin Characterization Model (BCM)

The BCM is a grid-based model that calculates the water balance for any time step or spatial scale by using climate inputs such as precipitation, minimum and maximum air temperature, and potential evapotranspiration (Figure 2). The BCM has been rigorously calibrated statewide to improve the accuracy of all components of the water balance (Flint et al., 2021). Precipitation inputs are run through the National Weather Service SNOW-17 snowpack model (Anderson, 2006) within the BCM to calculate snow accumulation and melt, as well as excess water that moves to the soil profile. **From there, the BCM will calculate streamflow at key locations identified by EBMUD and PG&E to provide additional situational awareness in ungaged locations.**

The existing monthly California-wide BCM model will be changed to a daily time step and will be locally calibrated to the Mokelumne watershed using existing observed streamflow, evapotranspiration, and snowpack data from the watershed. The BCM will pair with the SR-DSS by using the observed soil moisture and snowpack data at the seven stations in the study area and the calibrated snowpack runoff potential threshold for air temperature, precipitations, and antecedent snowpack conditions to assess and calibrate the model through historical event analysis and using the data to set the initial conditions for forecast operations. The calibrated daily BCM model will be used to run CNRFC forecasts for near-term estimates of water availability, potential runoff, and ROS conditions. The output of the BCM allows our team to communicate key unknown conditions such as streamflow in ungaged areas and the percent of the basin expected to produce runoff under high, low, and best forecast scenarios at multiple time scales.

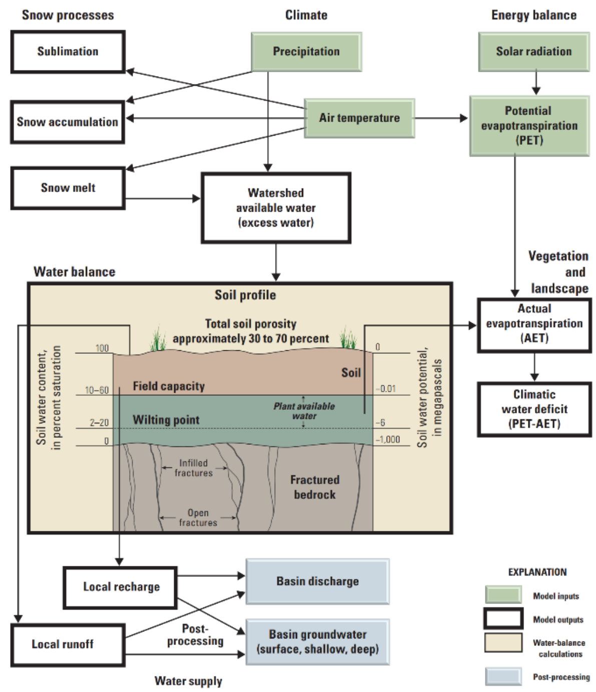

Figure 2. Inputs, outputs, and water-balance components of the Basin Characterization Model (BCM).

1.3 HEC-HMS Model Comparison

EBMUD previously developed an event-based gridded HEC-HMS model of the Mokelumne River watershed for the purpose of performing a Probable Maximum Precipitation (PMP) – Probable Maximum Flood (PMF) study for Pardee and Camanche Reservoirs. In this project, we will re-calibrate the parameters of this existing model and run the updated model for a long-term (>40 years) continuous simulation. The long-term HEC-HMS simulation will be used to benchmark the BCM long-term simulation. Moreover, the continuous HEC-HMS model will be used for long term planning and dam safety assessments (e.g., probabilistic flood hazard analysis) and has the potential to be used for short term operational management with integration of the SR-DSS.

1.4 Stochastic Storm Transposition (SST)

This project will leverage a technique for temporal resampling and spatial transposition known as stochastic storm transposition (SST; Alexander, 1963; Wright et al., 2020) to generate a large number of realistic probabilistic rainfall scenarios. The fundamental rationale of SST is that rainfall could occur anywhere within a meteorologically homogenous region. In other words, a historical rainfall event that never falls in the Mokelumne River watershed has the likelihood to hit this watershed (Figure 3a). One of the main advantages of SST is that the spatiotemporal structures of observed rainfall are well preserved, which facilitates the investigation of the potential hydrologic impacts. By substituting space for time, SST can effectively "lengthen" precipitation records. All the historical rainfall events within the meteorologically homogeneous region will be randomly sampled and spatially transposed by SST to compute the resulting precipitation over the Mokelumne River watershed (Figure 3b). Co-PI Yu has previously applied SST to a small mountainous watershed in Colorado's Front Range to analyze the relationships between flood drivers and flood frequencies (Yu et al., 2021).

Each transposed rainfall event will be paired with a set of watershed antecedent conditions drawn from the continuous BCM simulation outputs based on seasonality to form an event-based hydrologic simulation. Repeating this procedure for 1,000 synthetic years of rainfall scenarios produces 1,000 annual flood events, and therefore the largest flood will have a recurrence interval of 1,000 years (i.e., annual exceedance probability = 0.001). Coupling these simulated results with the developed decision support tool will allow for the risk based DSS.

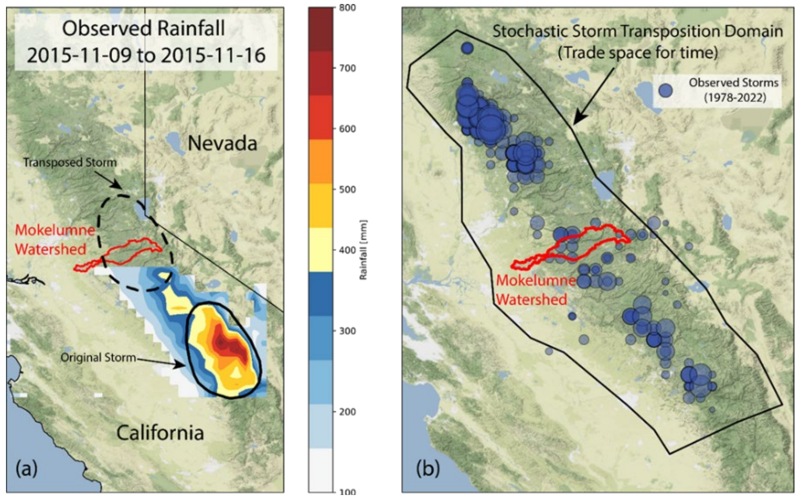

Figure 3. (a) Depiction of one possible transposition of a 7-day storm over the Mokelumne River watershed. Solid and dashed black circles in (a) show the corresponding original and randomly transposed storm contours, respectively. (b) Map of the spatial location

1.5 Disseminate Results in Pseudo-operational Tool

To create a true decision-support tool, this fifth component will fully integrate the SR-DSS and BCM to assess the utility and feasibility of reliably communicating real-time changes across elevation gradients during ROS events. The SR-DSS will integrate observational data from seven stations across and elevation gradient in the Mokelumne and that data will be used to inform the BCM to provide streamflow forecast information and communicate what percent of the watershed has the potential to produce snowpack runoff. Developing useful yet simple visualizations of this information (Heggli et al., 2023) is critical for event operations and this portion of the project will allow our team to refine the visualization of the tool to meet water managers needs to complete the end-to-end application. These visualizations will be a combination of ArcGIS maps and static images that can be output and published on cloud-based repositories for ad-hoc visualizations by water managers when an event is in the forecast.

Goals and Objectives

The goal of this project is to provide guidance in support of optimizing water resource management for the Mokelumne River watershed by developing a decision support framework that communicates the potential of significant, midwinter, ROS runoff events. Figure 4 illustrates how our project spans the decision-making time scales from real-time situational awareness to short-term outlooks, as well as from probabilistic understandings of high and low ROS runoff scenarios to the long-term planning of potential high-impact scenarios. Our project includes a total of five objectives to meet this goal, each with specific tasks outlined in the following sections.

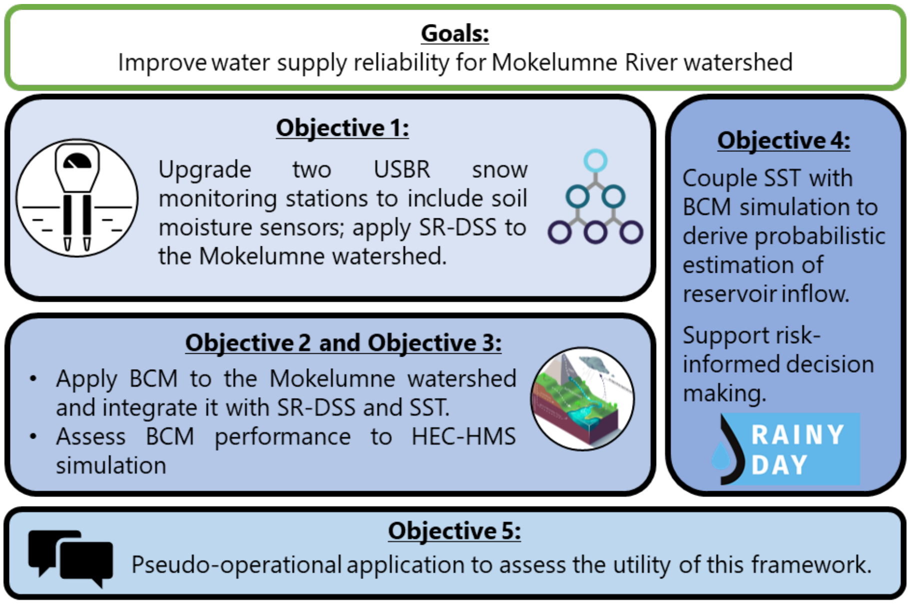

Figure 4. Schematic of proposed goals and objectives.

Objective 1: Apply the SR-DSS (Heggli, 2023; Heggli et al., 2022) to the Mokelumne watershed to disseminate the real-time changes in the watershed, which will include five primary tasks. Task 1: Upgrade two USBR snow monitoring stations (Black Springs and Bloods Creek, Figure 5) to include soil moisture sensors. EBMUD is working with the US Forest Service on applicable permits and with the USBR and CaDWR to get permission to upgrade their stations. This upgrade will make it possible for the stations in the Mokelumne to be used in the SR-DSS. Task 2: Establish an operations-aligned workflow for real-time data dissemination. Task 3: Calibrate the SR-DSS for the Mokelumne watershed. Task 4: Integrate probabilistic forecast information into the SR-DSS (leveraging work already funded, see Overlap or Duplication of Effort Statement). Task 5: Integrate the observed point data into the spatially distributed BCM.

Objective 2: Apply a refined BCM (Flint et al., 2021) to the Mokelumne watershed, which will have three primary tasks. Task 1: The existing monthly model has previously been calibrated to streamflow, actual evapotranspiration, and snow stations at a statewide level. This task will refine the calibrations with available data for a daily version of the BCM. Task 2: Run sensitivity tests of the watershed runoff to ROS duration, magnitude, and freezing level height to further calibrate the model and quantify uncertainty in the snow module of the BCM. Task 2 will also include the development of an observation-based estimate and uncertainty analysis of BCM soil moisture and improve the BCM representation of soil moisture processes by comparing new and existing in situ measurements. Task 3: Spatially distribute the SR-DSS using a fine-scale, process-based daily BCM model. This will allow the SR-DSS tool to be spatially distributed across the entire watershed and provide percentages of Snowpack Runoff Potential for the entire watershed or any sub watershed. Additional tasks depend on agency needs for short- and long-term forecasting, specifically by quantifying runoff in subbasins of interest that are either gaged or ungaged, by running CNRFC forecasts through the BCM.

Objective 3. Develop a continuous hydrologic model of the watershed at a daily time step using HEC-HMS. The existing gridded model was calibrated/validated at a sub-daily timestep to three large storm events in the watershed, with the January 1997 and February 2017 storms used for calibration and February 1986 storm event used for validation. Snowmelt parameters were calibrated for each storm against the University of Arizona's spatially distributed SWE dataset; other basin parameters in conjunction with snowmelt parameters were further refined based on streamflow observations at the reservoirs and USGS stream gages. In this project, we will re-calibrate the parameters of existing event-based HEC-HMS model and perform a long-term continuous simulation. Task 1: We will re-calibrate many of the basin and snowmelt parameters (with exception of unit hydrograph parameters) to make it reliable for a long-term (e.g., 1978-2022) continuous simulation. The observed daily forcing data that force the BCM long-term simulation will also be used for the HEC-HMS model. Unit hydrograph parameters from the existing model that were calibrated at a sub-daily time step would be used to avoid numerical diffusion in the results. Task 2: Model performance will be evaluated at several locations in the basin model (similar to the existing model) in conjunction with the BCM (i.e., model benchmarking).

Objective 4: Probabilistic estimation of reservoir inflow via a Monte Carlo simulation framework that combines results from objectives 1 and 2 with SST, which will include five primary tasks. Task 1: Identify and verify a meteorologically homogeneous region that encompasses the Mokelumne River watershed for SST analysis. Task 2: Develop a storm catalog that includes the largest *m* observed rainfall events within the identified homogenous region, where *m* in practice is the product of 10 and the number of years. Task 3: Randomly select a few storms from the catalog, transpose them within the homogenous domain, and compute the precipitation field over the Mokelumne River watershed. Task 4: Pair each transposed precipitation field with a seasonally realistic antecedent watershed condition (results from objective 2) to simulate the runoff generation across the watershed. Repeat tasks 3 and 4 *n* times to create an ensemble of *n* synthetic years of BCM simulation. Task 5: The simulated results from Task 4 will be integrated to support risk-based decision-making (i.e., a probabilistic assessment of reservoir reliability).

Objective 5: Run the SR-DSS and BCM to assess the utility and feasibility of reliably communicating real-time changes across elevation gradients during ROS events. This objective will consist of three primary tasks. Task 1: Enhance existing map visualization to include new point location validation, the percent of the basin expected to experience ROS runoff, and high- and low-end scenarios of the percent of the basin that could experience ROS runoff based on probabilistic forecast information integrated from the NWS. Task 2: Test the pseudo-operational workflow to address any issues encountered by the intended users before winter begins. Task 3: Run the pseudo-operational tool and update as needed throughout the winter.

PROJECT LOCATION

The Mokelumne River watershed lies on the western slope of the Central Sierra Nevada range in Alpine, Amador, Calaveras, and San Joaquin Counties in California and covers an area of approximately 621 square miles from Camanche Dam to the headwaters of the basin near Highland Peak (Figure 5). Elevations range from 265 feet at Camanche Dam to 10,367 feet, encompassing both rain-dominate, transitional, and snow-dominate elevation bands. Most of the watershed consists of forested land within the El Dorado and Stanislaus National Forests. The north, middle, and south forks of the Mokelumne River are the three main tributaries to the Mokelumne River, with the north fork draining more than 60 percent of the basin. The three tributaries join and become the Mokelumne River approximately 10 miles upstream of Pardee Reservoir, which releases to the basin outlet at Camanche Dam. There are a total of seven snow monitoring stations that are representative of the Mokelumne though five do not fall technically within the watershed borders. Each snow monitoring station is equipped to measure precipitation, air temperature, snow water equivalent, and snow depth. All of the stations except Black Springs and Bloods Creek also monitor soil moisture and soil temperature. There are also a total of seven USGS stream gages with the lowest elevation station at Mokelumne River Near Mokelumne Hill serving as a CNRFC forecast point.

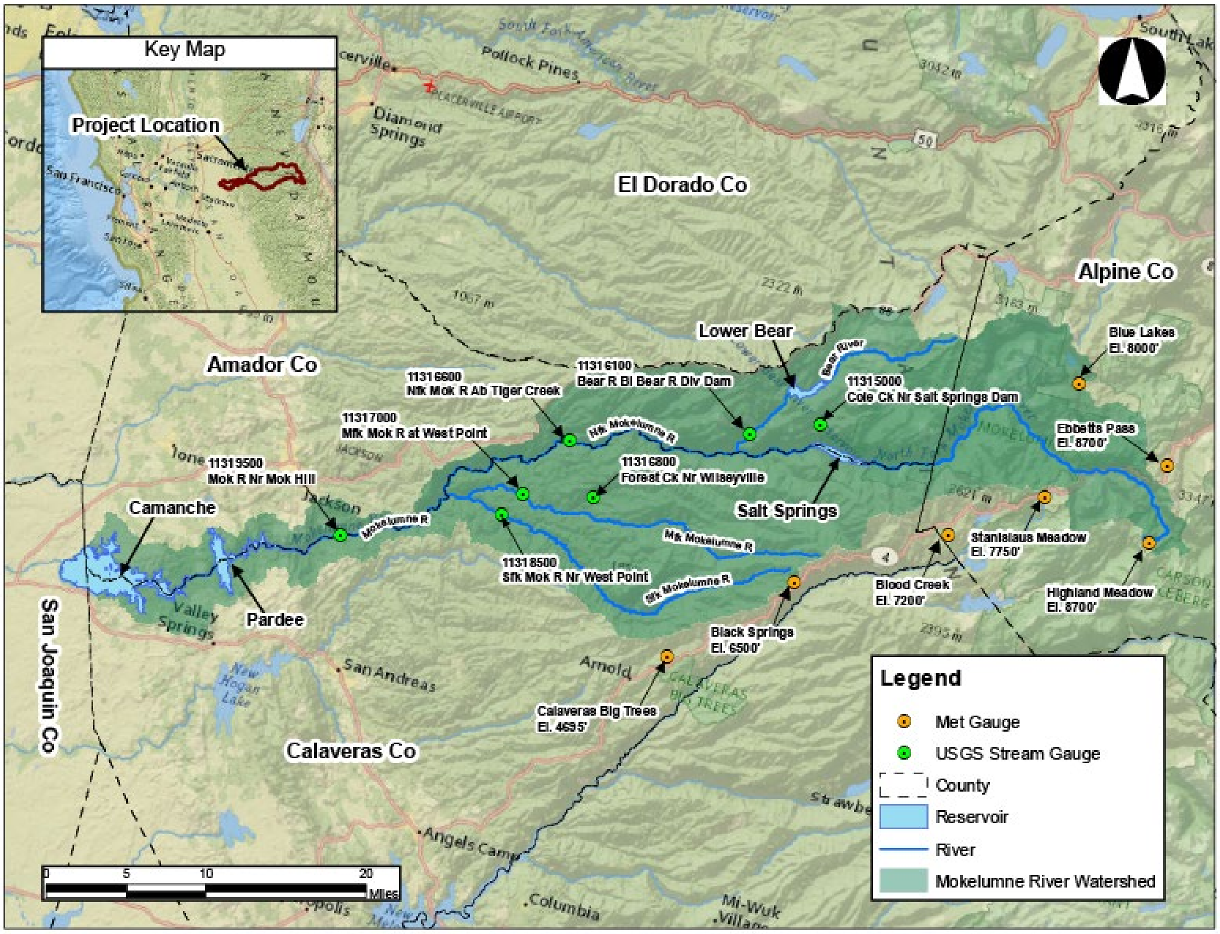

Figure 5. Study area map of the Mokelumne River Watershed in the Sierra Nevada mountains in California.

The North Fork of the Mokelumne River watershed contains several PG&E reservoirs and four powerhouses with a normal operating capacity of approximately 210 megawatts, the fourth largest producing river system in PG&E's hydro fleet. Feeding these powerhouses are two relatively large storage reservoirs – Salt Springs with a storage capacity of approximately 142,000 acre-feet and Lower Bear with a storage capacity of approximately 52,000 acre-feet – as well as five smaller storage reservoirs upstream, and several smaller regulating reservoirs and diversions downstream. The project is operated to provide ecological habitat and recreational opportunities, as well as water supply to EBMUD and Amador Water Agency, in addition to year-round clean energy optimized for dispatch when most needed to meet electricity demand.

Historically, approximately 90 percent of EBMUD's water supply originates from the Mokelumne River watershed. EBMUD owns and operates two reservoirs, Pardee and Camanche, in the lower Mokelumne River to meet its customers' water supply needs in the East Bay of the San Francisco

Bay Area, as well as the needs of fisheries, riparian habitat, flood control requirements, and downstream senior and riparian water rights holders on the river. The Mokelumne Aqueducts convey the Mokelumne River supply from Pardee Reservoir to local storage and treatment facilities in the district's service area. EBMUD is a public utility that provides water and wastewater treatment for significant portions of Alameda and Contra Costa Counties, which are located in the East Bay. Based on 2020 census data, approximately 1.4 million people are served by EBMUD's water system in a 332-square-mile area. EBMUD customers include residential, industrial, commercial, institutional, and irrigation water users.

DATA MANAGEMENT PRACTICES

This proposed project will generate environmental data, including field-measured soil moisture data (**Objective 1**), BCM and HEC-HMS simulated historical hydrologic variables (e.g., snow water equivalent, soil moisture, and runoff) for the Mokelumne River watershed (**Objective 2 and Objective 3**), and a storm catalog and simulated synthetic hydrologic variables by coupling SST with BCM (**Objective 4**). These data will mainly be stored as ascii text files and NetCDF, which are compliant with Open Geospatial Consortium (OGC) common data form and Geographic Information System (GIS) platforms. BCM model inputs and outputs will be reviewed and publicly accessible on ScienceBase following USGS guidelines.

The data management practices will follow the FAIR guidelines, making the outputs from this proposed project **findable**, **interoperable**, **accessible**, and **reusable**. All codes will be properly commented (e.g., several Python Jupyter Notebooks) to facilitate usability and reproducibility. All datasets and codes will be publicly accessible via data archival (e.g., Figshare or Hydroshare) and the relevant publications will be submitted to open-access journals. Codes, finalized results, figures, and manuscripts will be saved on the researchers' desktop computers and will be backed up in an existing 10 TB Seagate external hard drive (offline) and DRI's OneDrive (online). The PI (Dr. Heggli) will take the lead role for data management with support from Co-PI (Dr. Yu).

EVALUATION CRITERIA

Evaluation Criterion A—Water Management Challenge(s)

A1-Describe the water management challenge(s).

EBMUD and PG&E's water supply system operating goals and objectives must conform to state and federal law, to State Water Resources Control Board decisions, court decisions, Federal Energy Regulatory Commission licenses and orders, and various water right licenses, permits, and contractual agreements. Both agencies are obligated to meet multiple operating objectives, including providing municipal water supply, streamflow regulation, fishery/public trust interests, recreation, hydropower generation, flood control, temperature management, and release obligations to downstream diverters.

The Mokelumne, like other maritime mountainous watersheds, is prone to ROS events. These midwinter ROS events can produce 85% higher peak flows than spring snowmelt and have resulted in the most catastrophic flooding in the region (Hatchett et al., 2020; Henn et al., 2020; Kattlemann, 1997; Mccabe et al., 2006). The need for improved decision support for ROS events is accelerating with recent research suggesting portions of the Sierra Nevada are approaching a period of "peak ROS," with the greatest projected impacts at the headwaters of the Mokelumne. Peak ROS results from the juxtaposition of a warming climate experiencing more precipitation falling as rain but before warming inhibits the accumulation of persistent and deep snowpacks as we approach a low-to-no snow future (Siirila-Woodburn et al., 2021). Water resource managers are confronted with numerous challenges in their efforts to optimize water resources while simultaneously minimizing flood risk, particularly as the region approaches its peak ROS period. These challenges will be further exacerbated by the increasing demand for consumptive water uses and regulatory environmental obligations, emphasizing **an urgent need for midwinter snowpack runoff decision support to optimize water resource management**. Although high-impact ROS events are rare, minor ROS events generate increased midwinter streamflow, which gives water managers the opportunity to put the water to beneficial use either through storage in surface water reservoirs, regional groundwater basins or pulse flows for ecological benefit. Sequential minor events can also become high impact as soils become saturated, reservoirs reach the flood pool, and the snowpack warms and becomes more capable of increasing runoff by contributing snowmelt.

Effectively and reliably managing the water supply system is critical. However, skillfully forecasting ROS events remains a significant challenge. Annual water supply and near-term runoff forecasting tools generally use long records of precipitation, snow water content, river flow, and air temperature to calibrate and forecast expected runoff. However, the effects on runoff from other parameters within the snowpack and the underlying soils are either not currently measured or have only recently been measured, and therefore they are difficult to incorporate into forecasting systems that depend on the extensive records of readily available input parameters. The lack of operational guidance for forecast points relevant to decision-making, specifically ROS, creates a need for tools that can provide situational awareness and decision support in both transitional (ephemeral) and snow-dominated regions like the Mokelumne.

A2-Describe the concerns or outcomes if this water management challenge is not addressed?

After the historic past winter (water year 2023), EBMUD has expressed concerns that they are unsure what would have happened if a 1997 event (warmer storm event with significant flooding) had occurred on the historic, low-elevation snowpack. Without addressing these concerns, water management will remain reactive to inflows rather than having increased lead times and higher confidence in outcomes by observing real-time changes at the upper reaches of the watershed before those changes reach the lower elevation reservoirs and through a basin assessment of historical conditions that contribute to major floods. Although the occurrence of such a flooding event may appear rare because of the limited sample size, it is crucial not to overlook the likelihood that it could happen in the future and the potential impacts it could entail. This is an important opportunity to improve water resource management by improving the modeling of ROS events to increase confidence by decreasing uncertainty around how the antecedent snowpack and soil moisture will respond to the approaching event.

A3-Explain how your project will address the water management issues identified in your response to the preceding bullets and provide support for your response.

The project will support the refinement of a watershed forecast decision support tool to help reservoir operators manage runoff from the Mokelumne watershed more efficiently. The refinements will balance the need to mitigate extreme runoff events with the need to maximize water supply during droughts for all beneficial watershed uses, such as municipal and industrial drinking water, environmental stewardship, downstream irrigators, and hydropower generation.

The project will provide a better understanding of the antecedent conditions and forecasted atmospheric rivers, which will in turn generate more accurate predictions of the anticipated runoff expected in the Mokelumne Watershed. Because runoff in the watershed is heavily regulated by multiple reservoirs and dams, having an improved and accurate forecast allows for more effective water management by all dam owners. Improved forecasting means managers can meet the primary objectives and multiple needs of the water systems, including the municipal and industrial demands of the East Bay area that serves approximately 1.4 million people, as well as the stewardship objectives of the Mokelumne River, which provides recreational services for the public and generates hydropower to help meet state and federal green energy objectives. Effective water management through improved forecasting could also help dampen the effects of extreme conditions, whether drought or flooding, because the data would support a more adaptive operations management approach such as Forecast Information Reservoir Operations (FIRO).

EBMUD provides high-quality drinking water for approximately 1.4 million customers in Alameda and Contra Costa Counties. It operates Pardee and Camanche Reservoirs as an integrated system to achieve multiple objectives, including **municipal water supply, flood control, hydropower, minimize drought impact, environmental stewardship, and releases for other downstream obligations**. This project will develop a decision support framework for water resource managers to **optimize water resources while simultaneously minimizing flood risk**, especially during midwinter ROS events. The project framework has the potential to be transferred and applied to other mountainous watersheds in the western US, which will **improve regional water supply reliability**. Therefore, this project will explicitly address the following water management issues: water supply reliability for municipal, agricultural, tribal, environmental, or recreational water uses; drought management activities; water rights obligations, ability to meet endangered species requirements; and conservation and efficiency.

Evaluation Criterion B—Project Benefits

B1-Describe how the need for the project was identified.

ROS events have resulted in the most catastrophic flooding in the Sierra Nevada and skillfully forecasting ROS events remains a significant challenge (Henn et al., 2020; Musselman et al., 2018). This long-standing historic decision support need is accelerating as the climate warms and ROS events are expected to become more frequent. This unmet need led to this project being identified through a collaborative process with the entities involved in this proposal. EBMUD became aware of the ROS relationship research and forecast tool that was developed and being tested on the watershed north of Mokelumne and initiated the discussion with Desert Research Institute and other stakeholders to look at developing one for the Mokelumne watershed which is a flashy system and improved forecasting would lead to more effective operational management. EBMUD and PG&E guided the scope of the project to include a spatially relevant model (BCM) and long-term planning decision support tool (SST). To enhance the project, EBMUD wanted to leverage internal modeling experience with HEC-HMS to run in parallel to BCM and begin to develop the necessary HEC-HMS dataset that can be applied to the SST in future collaborative efforts beyond this project. PI Heggli also meets regularly with the CNRFC to discuss the ongoing research approach in anticipation of implementing the SR-DSS for forecast operations.

B2-Describe how the tool, method, or information will be applied and when will it be applied.

Reliable hydrometeorological data in mountain regions benefit society when applied to decision-support tools at relevant scales. The instruments will immediately start gathering data that can be integrated into the SR-DSS the very first winter. This information can support the decision-making process to allocate valuable and limited water resources. By the second winter the SST and BCM forecasts will be ready for a pseudo-operational assessment of the integrated tools.

B3-Describe, in detail, the extent of benefits that can be expected to occur upon implementation of the project, and provide support for your responses.

A successful project would: 1) provide a better understanding of the likelihood for ROS to cause extreme runoff, 2) facilitate situational awareness and operational readiness for ROS events, and 3) provide avenues to integrate this new information into existing processes and models. The challenge that this project seeks to address is the effects on runoff from other parameters within the snowpack and the underlying soil that are either not currently measured or have only recently been measured and are difficult to incorporate into the forecasting systems that depend on extensive records of readily available input parameters. As precipitation patterns become more extreme, dry spells more extended, and ROS events more common, we anticipate that these previously unmeasured parameters will provide a good mechanism to monitor changing water deficit and surplus dynamics. Therefore, they will play a larger role in detecting changes to help maintain runoff forecast accuracy. In the Mokelumne watershed, good forecast accuracy translates to good planning and a delicate balance of many water management objectives, including but not limited to safely responding to flood flows and minimizing high-flow damage and ensuring the health of riparian ecosystem, reliability of water supply allocations and water use decisions, optimization of hydroelectric energy dispatch, and maximization of recreational opportunities.

Who will use the tool or data developed under this proposal and how will they benefit from the project?

These tools are being designed for EMBUD and PG&E to optimize water resources management during midwinter runoff events. Our team is also working closely with the CNRFC to make these tools available for their forecast operations and assess the potential benefit of applying these tools beyond the Mokelumne watershed. **Their interest is detailed in their support letter**.

How will the project improve water management decisions?

Currently, there is only one streamflow forecast location at the base of the Mokelumne for inflows into Pardee Reservoir. The integration of our tools will not only provide real-time situational awareness of changes across elevation bands in the Mokelumne, but it will also provide streamflow forecasts from the integration of the BCM at the points of interest for PG&E and EBMUD water management decision-making. The SST will estimate the probability of synthetic extreme rainfalls and communicate to EBMUD and PG&E what that event would look like in their watershed to help with long-term planning for high-impact ROS events. The continuous HMS model will assist EBMUD in looking into the uncertain future to help do long term planning for water supply and dam safety. The refined forecasting by CNRFC provides increased confidence that will lead to more effective water operational decisions.

Describe if the results of your project will be applicable elsewhere.

The SR-DSS coupled with the BCM can be applied to any location with SNOTEL stations or networks that observe air temperature, precipitation, snow water equivalent, snow depth, and soil moisture. Forecast information of air temperature and precipitation alone could communicate the potential for snowpack runoff, expanding the application of this project well beyond locations with observational data. Since SST will develop a regional rainfall catalog, these storms can be efficiently used to perform frequency analyses for other watersheds within the transposition domain (Figure 3b).

To what extent will the project address the water management challenges described in E.1.1.?

The project will lead to filling in critical data gaps, specifically at the transition between snow and rainfall. The data will benefit both watershed management and state operations management because water resources in the state are all connected. The data will support the development of a forecasting tool (already developed for the Upper Carson watershed), for the Mokelumne Watershed that will allow for more confidence in expected runoff, and therefore more efficient management of the reservoirs. Improved water management allows for more effective mitigation of downstream flooding during extreme events and would support an adaptive operations management approach like FIRO to help address climate change impacts.

B4-Explain how your project complements other similar efforts in the area where the project is located.
This project is an integration of the SR-DSS, BMC, and SST, which have all previously been developed and applied in other watersheds but will be combined to establish comprehensive decision support tools from real-time situational awareness to long-term planning. The project augments existing instruments in the watershed and will fill in data gaps at the elevations of transition from snow to rainfall. The data would be shared among all stakeholders and archived and accessible through the state's existing database.

Evaluation Criterion C—Project Implementation

C1-Briefly describe and provide support for the approach and methodology that will be used to meet the objectives of the project.
To accomplish the tasks related to Objective 1, we are leveraging the partnership with EBMUD to upgrade stations so there is data continuity across all seven stations. DRI will download historical data for the stations that have the necessary parameters and calibrate the SR-DSS for those stations using the python code and methods developed by Heggli et al., 2022. During year 1, we will refine the data collection and dissemination process to communicate the real-time changes and snowpack potential for runoff in the Mokelumne. These data and the calibrated SR-DSS threshold for snowpack runoff potential will be integrated into the BCM.

To accomplish the tasks related to Objective 2, the USGS will refine an existing BCM model (Flint et al., 2021) for the Mokelumne watershed by locally calibrating to streamflow, snowpack, evapotranspiration, and soil moisture in year 1. The calibrated model will be run using results from Objective 4 to translate a higher range of historical precipitation conditions into hydrologic response during year 1. Comparisons to historical data and sensitivity analyses to antecedent moisture conditions and snowpack will provide insight into the spatially heterogeneous processes controlling runoff generation in the watershed. In year 1, we will also integrate BCM with the SR-DSS tool from Objective 1 to provide spatially explicit snowpack runoff situational awareness across the entire watershed. During years 2 and 3, a daily forecast integrated with CNRFC precipitation forecasts will be developed, and all BCM data will be reviewed and disseminated consistent with USGS policy.

To accomplish the tasks related to Objective 3, EBMUD will work with DRI to modify the existing event-based HEC-HMS model to be a calibrated continuous HEC-HMS model. The initial parameters from the event-based model will be modified as appropriate, e.g. soil accounting and snowmelt component. The long-term HEC-HMS simulation using the re-calibrated parameters will be evaluated in conjunction with the BCM long-term simulation for the Mokelumne.

To accomplish the tasks related to Objective 4, DRI will use the Analysis of Record for Calibration precipitation data (AORC; Fall et al., 2023) and an open-source SST software, RainyDay (Wright et al., 2017). The AORC precipitation data are derived from a combination of gage observations, ground-based weather radar, and satellite remote sensing and are available from 1979 to the present. The spatial and temporal resolutions for the AORC are 30-arc-second (approximately 800 m) and hourly, respectively. RainyDay, a Python-based SST software, will be used in combination with the AORC precipitation data and the results from Objectives 1 and 2 will be used to develop the risk-based decision support tool for the Mokelumne River watershed.

To accomplish the tasks related to Objective 5, we will hold quarterly meetings with EBMUD and PG&E. These will be especially important for the co-production of data visualization, allowing the water managers to guide the data visualization based on their decision-making needs. Once we have refined the data visuals, we will work to improve the efficiency of the workflow to make the visuals available to the water managers in real-time during the pseudo-operational assessment. The workflow and dissemination packages may change between now and the assessment as we learn more about EMBUD, PG&E, and CNRFC current operations. We want to establish our workflow to run parallel to current operations for an easy transition at the end of the grant.

C2-Describe the work plan for implementing the proposed scope of work.
Table 1 provides a Gantt chart for each project task and its associated tasks. Objective 0 has been added to assure that we have scheduled meetings for built in collaboration time and ensure that the necessary data management practices are in place before starting the project. We included a non-numbered objective to close the project with the necessary tech transfer and reporting.

Objectives	Tasks								2025												2026					Cost
		Q3				Q4			Q1			Q2			Q3			Q4			Q1			Q2		
		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	
0 Project Initiation	1. Collaborator Meetings		■			■			■			■						■			■			■		$ 39,376.32
	2. Set up Data Management	■																								$ 7,876.62
	3. Environmental Review	■																								$ 14,139.27
1 SR-DSS	1. Upgrade Stations	■	■	■																						$ 29,949.62
	2. Operational Workflow		■	■																						$ 22,358.21
	3. SR-DSS Calibration			■	■	■	■																			$ 20,315.06
	4. Probabilistic Forecast Integration							■	■	■	■	■	■													$ 17,097.67
	5. BCM Integration			■	■	■	■	■	■	■	■	■	■													$ 15,898.31
2 BCM	1. Initialize & Calibrate	■	■	■	■	■	■	■																		$ 4,153.22
	2. Sensitivity Tests					■	■	■																		$ 31,183.61
	3. Historical Comparisons					■	■	■	■	■	■	■	■	■												$ 20,766.08
	4. Daily Forecast Integration												■	■												$ 8,306.43
3 HEC-HMS	1. Initialize & Calibrate					■	■	■	■	■	■	■	■													$ 20,639.25
	2. Evaluate Model Performance													■	■	■	■	■	■	■						$ 20,639.25
4 SST	1. Delienating Rainfall Homogenous Domain							■	■	■																$ 20,364.96
	2. Develop a Regional Rainfall Catalog									■	■	■														$ 14,255.47
	3-4. Monte Carlo Simulation											■	■	■	■	■										$ 14,255.47
	5. Apply SR-DSS to Simulated Results																		■	■	■	■	■	■	■	$ 29,121.89
5 Pseudo Operational Assessment	1. Create operational visualizations													■	■	■	■	■								$ 31,398.33
	2. Test Workflow																■	■	■							$ 37,696.55
	3. Run Psuedo Operational Tool																			■	■	■	■	■	■	$ 55,944.48
Project Close	1. Tech Transfer																					■	■	■	■	$ 50,322.54
	2. Publication/Reports																					■	■	■	■	$ 44,188.13
	3. Presentation																								■	$ 4,656.03
																									TOTAL:	$ 574,902.77

Table 1. Gantt chart outlining the milestones for each project objective and task with the associated cost per task.

C3-Provide a summary description of the products that are anticipated to result from the project.

This project will produce calibrated thresholds to identify present weather and antecedent snowpack conditions that can communicate the potential for snowpack runoff during ROS events. This information coupled with the station data will disseminate these changes through a map display. When coupled with the BCM, the SR-DSS will be able to disseminate what percent of the watershed has the potential to produce ROS runoff and provide streamflow forecasts as select locations of interest to EBMUD and PG&E. These two visualizations will be available in near real-time through ArcGIS and cloud-based repositories during year two of the project. The results of the products will be reviewed with the CNRFC to assess the feasibility of integrating this information into their operational products and forecasts. The coupled BCM and SST will provide frequency analyses of reservoir inflows of different duration for the Mokelumne watershed. The refined HEC-HMS long-term continuous simulation will provide benchmark for the BCM simulation.

C4-Who will be involved in the project as project partners?

The main applicant, Desert Research Institute (**DRI; Category B**), is partnering with East Bay Municipal Utility District (**EBMUD; Category A**), Pacific Gas & Electric (**PG&E; Category A**), and the United States Geological Survey (USGS; subcontractor of Category B) to work on this project. Other partner agencies, who will not be directly funded by this project, include the California-Nevada River Forecast Center (CNRFC). EBMUD and PG&E are the two primary reservoir managers in the Mokelumne River watershed. DRI will collaborate with EBMUD, USGS, and CNRFC to enhance the SR-DSS by integrating field observation and providing data for the BCM. Model forcings for the BCM will be shared by USGS with EBMUD for their work on HEC-HSM. The calibrated BCM will provide data to DRI for the SST. PG&E will provide guidance for model setup, basin delineation, and revision of model performance. DRI, USGS, EBMUD, PG&E, and CNRFC will work collaboratively and iteratively to refine the workflow and visualizations for the decision support tool leading into the year two pseudo-operational assessment. Throughout the project, EBMUD and PG&E will actively contribute their extensive knowledge and expertise in reservoir operations and emergency management. Their input and immediate feedback will be invaluable to enhancing the robustness and effectiveness of this project.

C5-Identify staff with appropriate credentials and experience and describe their qualifications.

The project team will include two assistant research professors currently employed by DRI, one research scientist currently employed by USGS, two water supply engineers currently employed by EBMUD, and two hydrologists currently employed by PG&E. There are no plans to fill new positions or request technical assistance from USBR. The project team has substantial experience in conducting water resources projects and is capable of proceeding with the tasks in the proposed project immediately upon entering into a financial assistance agreement. A brief biosketch for each team member is shown below:

Dr. Anne Heggli (DRI; PI) – Dr. Heggli is a research scientist at DRI with expertise in rain-on-snow processes. Dr. Heggli has a background in water resource management with over 8 years of experience as a consultant and 7 years of experience in the research and development of snow monitoring instrumentation. Dr. Heggli's PhD was spent building the framework for the SR-DSS to improve situational awareness and enhance decision support during rain-on-snow events in the Sierra Nevada. Prior to pursuing her PhD in atmospheric sciences, Dr. Heggli spent her career working directly with stakeholders like PG&E and EBMUD.

Dr. Guo Yu (DRI; Co-I) – Dr. Yu holds the position of assistant research professor at DRI and is also a licensed professional engineer in the state of Nevada. Dr. Yu has a PhD in civil and environmental engineering from the University of Wisconsin-Madison and over 10 years combined academic and industrial experience in the fields of hydrology, hydrometeorology, and climate change impact studies. Dr. Yu has had a long-term working relationship with the USBR working on issues related to watershed hydrologic processes, flood risk, and dam safety. One noteworthy achievement is Dr. Yu's involvement in a USBR-funded project that received the Science and Technology Project of the Year Award in 2020 (Project ID: 1735).

Michelle Stern (USGS; Co-I) – Michelle Stern is a hydrologist at the California Water Science Center, USGS. She has over 15 years of experience in hydrology and hydrologic modeling and has over 10 years of experience developing and applying the Basin Characterization Model (BCM). Her research focuses on fine-scale regional water resources studies assessing the effects of climate and land use changes, with an emphasis on integrating measurements and modeling to improve process understanding and model accuracy. Stern has partnered with USBR on two WaterSMART projects that assess post-wildfire changes on hydrology and sediment transport.

Priyanka Jain (EBMUD) – Priyanka Jain is a Senior Civil Engineer in the Water Resources Planning Division of EBMUD with over 25 years' experience in water resources planning and where, for the last 18 years, she has been responsible for administering the federal hydropower license including dam safety and emergency preparedness, overseeing the hydrologic and hydraulic modeling for EBMUD dams, spillways and appurtenances, in addition to doing leading long term water resources planning which incorporates climate change analysis. Ms. Jain is a registered professional civil engineer in the State of California.

Christopher Potter (EBMUD) – Mr. Potter leads the Water Supply Engineering Section of EBMUD as senior civil engineer, supporting the management of the municipal raw water supply system for the past 7 years. Mr. Potter received both bachelor's and master's degree in civil engineering and is a registered civil engineer with 22 years of professional experience, with expertise in hydraulic and hydrologic modeling. His proficiency with numerical modeling and database development has been applied to perform water supply operations analyses, such as runoff forecasting, scheduling operations of water supply reservoirs, aqueducts, and pumping plants, and managing official operations records.

Eric Toth (EBMUD) – Mr. Toth is an associate civil engineer in the Water Resources Planning Division at EBMUD where he has worked for the last 10 years performing hydrologic and hydraulic modeling to support EBMUD's dam safety program. Mr. Toth is a registered civil engineer in the state of California and earned both bachelor's and master's degrees in civil engineering from San Jose State University.

Annie Zaccarin (PG&E) – Annie Zaccarin is a hydro scheduling consultant in the water management group at PG&E. This role supports Mokelumne watershed operations with forecasting, water conveyance, and reservoir operations. Annie Zaccarin has a master's in civil engineering from the University of Washington, with a background in environmental science, hydrology, and snow.

Kevin Richards (PG&E) – Kevin is Principal Hydrologist in the Water Management group at PG&E. He is a registered Civil Engineer in California with bachelor's and master's degrees in civil & environmental engineering. He has over 20 years of experience in water supply modeling and engineering, with a focus on information systems supporting operations.

Evaluation Criterion D—Dissemination of Results

D1-Describe how the tools, frameworks, or analyses developed under the proposed scope of work will be disseminated, communicated, or made available to water resources managers who may be interested in the results.

We have been and will continue to meet with the CNRFC to continue to refine the product so that it can be integrated into NWS forecast operations, which would have the largest reach because the CNRFC is a first-stop resource for most water resource managers. We met with the CNRFC on September 18, 2023, to update them on the current progress of the SR-DSS and our plans for the WaterSMART grant in the Mokelumne. They offered guidance to refine our approach and we plan to give a presentation to the CNRFC and California Forecasters upon completion of the project to move the development of the tool forward toward operations.

D2-If the applicant is the primary beneficiary of the project, explain how the project results will be communicated internally.

N/A

D3-If the applicant is not the primary beneficiary of the project (e.g., universities or research institutes), describe how project results will be communicated to project partners and interested water resources managers in the area.

We have built in quarterly meetings with the project partners to assure that we will have regular meetings to update each other with the collaborative objectives though meetings are not limited to quarterly. We will also prepare a final report and presentation in collaboration with EBMUD and PG&E. EBMUD has reached out to the Buena Vista Rancheria of Me-Wuk Indians who are interested and supportive of this project. Per their request we will keep them informed of our progress and final products.

D4-Describe how the project results will be shared with other water managers in the West that could use the information to support water management objectives.

To reach other water managers in the West, we anticipate presenting at the operationally focused Western Snow Conference and we will request to present at the California Cooperator Snow Conference and California Extreme Precipitation Symposium. Our team will leverage the media outreach at DRI to publish blog posts and press releases of advances in the project that can also be leveraged by EBMUD and PG&E's media reach. We also intend to publish a minimum of one paper to an applied science journal, such as the *Journal of Hydrologic Engineering*.

Evaluation Criterion E—Presidential and Department of the Interior Priorities

E1-Climate Change: E.O. 14008 emphasizes the need to prioritize and take robust actions to reduce climate pollution; increase resilience to the impacts of climate change; protect public health; and conserve our lands, waters, oceans, and biodiversity.

The surface air temperature over the Pacific Southwest, including land and ocean, has markedly increased over the past few decades and such a warming trend is projected to persist into the future (Byrne & O'Gorman, 2018; Reidmiller et al., 2017). A warmer climate will increase the variability in the hydrologic system, enhancing the frequency of hydroclimatic extreme events (e.g., droughts and floods). It is foreseen that precipitation will increasingly fall as rain rather than snow, causing the transition from snowmelt-dominated to rain-on-snow and rainfall-driven runoff processes in mountainous watersheds such as the Mokelumne River watershed (Musselman et al., 2018).

Assessments were made to identify the potential impacts of climate change to EBMUD operations:

- In water supply, decreased runoff and timing of runoff affect carryover storage.

- Water demand and usage could increase as a result of warmer climate, as well as result in increased frequency of rationing due to water supply shortages.
- Water quality could decrease as a result of warmer air temperatures shifting spring runoff and increasing peak runoff. Managing cold water pool levels in Camanche and Pardee Reservoirs becomes more challenging with more frequent droughts and warming rivers and reservoirs. Any modifications to temperatures in the river could affect fisheries.
- Climate change could negatively affect hydropower generation because of changes in runoff timing and patterns, and management of cold-water pools.

E2-Disadvantaged or Underserved Communities:
The Mokelumne watershed includes disadvantaged communities as identified by the Climate and Ecological Justice Screening Tool. These include tract numbers 06009000300, 06009000400, 06005000102, and 06003010000 in Calaveras, Amador, and Alpine Counties. Although no disadvantaged communities were identified in the EBMUD service area, they do have recreational areas and mobile home parks.

E3-Tribal Benefits:
EBMUD has relations with Tribal communities in the region and is in the process of developing partnerships with them where they would be using the watershed to support their needs. In anticipation of this project EBMUD has reached out to Buena Vista Rancheria of Me-Wuk Indians who are in support of this project. If flows can be forecasted, and the dam releases can be managed from a functional flow perspective this could be beneficial to the ecosystem by enabling floodplain inundation and flows that trigger geomorphic processes important to the river. Having improved water supply/operations management would benefit regional Tribes. For example, they would like to use the Mokelumne Day Use Area that is directly downstream of Camanche Dam and access to the area is sometimes constrained by the high releases. Understanding and forecasting what can be released, as well as how and when, would allow community members to be aware and know when they can safely use the area for their rituals and events.

PROJECT BUDGET

FUNDING SOURCES	AMOUNT
Non-Federal Entities	
East Bay Municipal Utility District	$220,723
Pacific Gas & Electric	$38,500
Desert Research Institute	$28,228
Non-Federal Subtotal	$287,451
REQUESTED RECLAMATION FUNDING	**$287,451**

ENVIRONMENTAL AND CULTURAL RESOURCES COMPLIANCE

Will the proposed project impact the surrounding environment?

Our work leverages data from the existing SNOTEL and California Statewide Monitoring networks. All station upgrades are being done through the cooperative agreements between the USBR and the State of California with the appropriate permits and environmental assessments.

Are you aware of any species listed or proposed to be listed as a Federal threatened or endangered species, or designated critical habitat in the project area? If so, would they be affected by any activities associated with the proposed project?

A review of the USFWS IPaC resource list has identified 6 species within the project area. These include Sierra Nevada Red Fox (Ulpes vulpes necator); California Spotted Owl (Strix occidentalis occidentalis), Sierra Nevada Yellow-legged frog (Rana sierrae), monarch butterfly (Danaus plexippus), Bald Eagle (Haliaeetus leucocephalus) and Golden Eagle (Aquila chrysaetos). The only species listed above with a critical habitat designation is the Sierra Nevada Yellow legged frog. The project area does not include critical habitat for the species. An environmental assessment will be performed if necessary for the two stations that will be modified to include soil moisture sensors prior to breaking ground.

The proposed project is an assessment and incorporation of data into software tools and therefore will not affect any species or habitats within the Mokelumne River Watershed.

Are there wetlands or other surface waters inside the project boundaries that potentially fall under CWA jurisdiction as "Waters of the United States"? If so, please describe and estimate any impacts the proposed project may have.

The proposed project is being conducted on the South Fork Mokelumne River, a Water of the United States. The proposed project includes installing sensors and is an assessment and incorporation of data into software tools and therefore will not likely impact any wetlands or other surface waters in the project area.

When was the water delivery system constructed?

For EBMUD's water system in the Mokelumne watershed, Pardee Dam was completed in 1929 and Camanche Dam was completed in 1964. For PG&E's water system, Salt Springs Dam was completed in 1931 and Upper Bear Reservoir was completed in 1900.

Will the proposed project result in any modification of or effects to, individual features of an irrigation system (e.g., headgates, canals, or flumes)? If so, state when those features were constructed and describe the nature and timing of any extensive alterations or modifications to those features completed previously.

No

Are any buildings, structures, or features in the irrigation district listed or eligible for listing on the National Register of Historic Places?

Yes. Due to the confidential nature of information on cultural resources present on EBMUD's owned lands, only a simple response could be provided without elaboration on identity, description, or location of those cultural resources, since one of the conditions posed by the question has been met. In addition, because the project scope is limited to assessing and incorporating data into software tools and absent major construction work, the proposed project will not affect any National Register of Historic Places listed or eligible for listing structures or features within the Mokelumne River Watershed.

Are there any known archeological sites in the proposed project area?
An environmental assessment will be performed for the two stations that will be modified to include soil moisture sensors prior to breaking ground. The remaining portion of the project is an assessment of data that will not impact the land.

Will the proposed project have a disproportionately high and adverse effect on low income or minority populations?
No

Will the proposed project limit access to, and ceremonial use of, Indian sacred sites or result in other impacts on tribal lands?
No

Will the proposed project contribute to the introduction, continued existence, or spread of noxious weeds or non-native invasive species known to occur in the area?
No

REQUIRED PERMITS OR APPROVALS

The installation of the soil moisture sensors requires an environmental assessment (EA) and updated USFS permits. EBMUD is funding the EA and has been working with the USFS to verify that all of the permits are filed. The two stations being upgraded belong to the USBR and EBMUD has also been working with them to receive approvals for the station upgrades.

OVERLAP OR DUPLICATION OF EFFORT STATEMENT

PI Heggli is funded by the Nevada Department of Transportation to implement the SR-DSS in the Upper Carson Watershed. This project will be ending in March 2024. The stations at the crest of the Upper Carson are shared with the Mokelumne so the work from the implementation of the SR-DSS in the Upper Carson will expedite the implementation of the SR-DSS in the Upper Mokelumne. PI Heggli is also funded by the University Corporation for Atmospheric Research to assess the feasibility to integrate probabilistic forecast information into the SR-DSS in collaboration with the NWS Reno, but this project does not include the application of the forecast information to the Mokelumne that is outlined in this project. There is no other overlap between the proposed project and any other active or anticipated proposals.

CONFLICT OF INTEREST DISCLOSURE STATEMENT

No conflict of interest exists.

UNIFORM AUDIT REPORTING STATEMENT

The Desert Research Institute submits a Single Audit on an annual basis as part of a larger comprehensive audit for the Nevada System of Higher Education. DRI's EIN number is 88-6000024. NSHE's Single Audit can be located on the Federal Audit Clearinghouse website.

DISCLOSURE OF LOBBYING ACTIVITIES (IF APPLICABLE)

N/A

LETTERS OF PARTNERSHIP

EAST BAY
MUNICIPAL UTILITY DISTRICT

CLIFFORD C. CHAN
GENERAL MANAGER

October 12, 2023

Subject: Support of the Desert Research Institute application for a U.S. Bureau of Reclamation's WaterSMART Applied Science Grant (R23AS0046)

To Whom It May Concern:

The East Bay Municipal Utility District (EBMUD) is a public utility that provides water to 1.4 million customers in the East San Francisco Bay Area. EBMUD's main water supply is Mokelumne River water from its Pardee and Camanche Reservoirs. The Mokelumne watershed is complex in the hydrologic challenges that exist in combination with the many diverse needs including water supply, flood control, hydropower generation, and environmental needs. With the increasing frequency of Atmospheric Rivers and potential rain-on-snow effects in the watershed, there is a critical need to understand and refine forecast related to runoff responses to help optimize water management operations.

The purpose of this letter is to express EBMUD's support as part of the partnership with Desert Research Institute, United State Geological Survey, Pacific Gas & Electric, the California-Nevada River Forecast Center, and EBMUD to apply and enhance the Snowpack Runoff Decision Support System (SR-DSS) framework. EBMUD supports this application because we believe this applied science will enhance a comprehensive understanding of rain-on-snow dynamics with improved data collection and refined tools that will not only improve water resources management for the region, but provide a greater understanding of the science for state and national programs.

In support of this project, EBMUD agrees to provide the following equipment and in-kind cost share totaling $220,723, including our indirect costs:

- Purchase and install two soil moisture sensors
- If necessary, contract environmental assessment
- Review data and develop/test new tools
- Set up HEC-HMS for calibration and continuous simulation for Mokelumne Watershed

Thank you for taking the time to consider DRI's application and this letter of support.

Sincerely,

Clifford C. Chan
General Manager

375 ELEVENTH STREET . OAKLAND . CA 94607-4240 . (510) 287-0101

Pacific Gas and Electric Company

Power Generation

300 Lakeside Drive
Suite 210
Oakland, CA 94612-3534

General PO Box:
P.O. Box 28209
Oakland, CA 94612-8209

LETTER OF SUPPORT FOR DRI, WATERSMART GRANT #R23AS00446

Dr. Anne Heggli
Desert Research Institute
2215 Raggio Pkwy
Reno, NV 89512

RE: PG&E Support Letter for WaterSMART Grant #R23AS00446

Dear Dr. Heggli,

This is Pacific Gas and Electric (PG&E) Company's letter of support for DRI's application to the Bureau of Reclamation's WaterSMART Applied Science Grant Application Funding Opportunity Number R23AS00446.

DRI's proposed "Decision Support for Enhanced Water Resource Management Planning of Rain-on-Snow Events in the Mokelumne Watershed" will provide valuable new data and methods in a watershed of interest to PG&E. PG&E owns and operates a fleet of 62 hydroelectric plants in California with a total capacity of 3,800 MWs of carbon free energy for the benefit of our customers and the environment, and the Mokelumne Watershed is a key river system in this fleet.

PG&E's Water Management Team believes that the proposed DRI goal to better monitor and characterize soil moisture and snowpack runoff has the potential to play a key new role in detection of changing water deficit and surplus dynamics to help maintain runoff forecast accuracy under extreme precipitation and drought patterns. In the Mokelumne Watershed, good forecast accuracy translates to good planning and a delicate balance of many water management objectives including but not limited to safety in responding to flood flows and minimization of high-flow damage, heath of the riparian ecosystem, maximization of recreational opportunities, and reliability of water supply allocations and water use decisions in addition to optimization of hydroelectric energy dispatch for our customers.

We are willing to provide an in-kind match of $35,000 for the two years of the project. This would include time participating in stakeholder meetings, providing data and input on work, and performing supporting analyses.

Sincerely,

TC

Tyler Covich

Manager, Water Management

Pacific Gas & Electric Company

LETTERS OF SUPPORT

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
California-Nevada River Forecast Center
3310 El Camino Avenue, suite 227
Sacramento, CA 95821-6373

12 October 2023

Dr. Anne Heggli
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

Dear Dr. Heggli:

I am writing to offer my support of your WaterSMART proposal entitled "**Decision Support for Enhanced Water Resource Management Planning of Rain-on-Snow Events in the Mokelumne Watershed**." We believe that the research proposed and the resulting observations of snowpack changes during Rain on-Snow events will provide important information that could benefit our operations and the end-users in the California-Nevada River Forecast Center (CNRFC) region.

At the CNRFC we provide short-term flood forecasts and seasonal water supply forecasts for the region. Rain-on-Snow events in the Sierra Nevada are most frequently the type of large flood event which pose significant challenges to reservoir operations. Rain-on-Snow events can also produce rapid changes in the total snow water equivalent volume, the most important variable in forecasting snowmelt runoff. We appreciate too the probabilistic approach proposed, in which the SST will simulate different "combinations of rainfall and watershed antecedent conditions by leveraging historical simulated watershed conditions."

We hope that this proposal will be successful as it will help enhance our situational awareness and reservoir inflow forecasts, both short term inflows and longer seasonal forecasts. This proposed work could help not only the immediate forecasts in the Mokelumne watershed, but also enhance other water management entities in the central Sierra.

Sincerely,

Pete Fickenscher
Development and Operations Hydrologist
California-Nevada River Forecast Center

REFERENCES

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