Title:
WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs

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Executive Summary

Applicant:

October 17, 2023
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Project summary:

Utah State University, with the support of NOAA Colorado Basin River Forecast Center, Salt Lake City Department of Public Utilities, Central Utah Water Conservancy District, Southern Nevada Water Authority, Institute of Land, Water, and Air, and Utah Climate Center will advance a platform to provide multi-year-to-decadal forecasting products for the Colorado River water supply. The project will use dynamical climate forecasting systems on seasonal-to-decadal timescales, such as North American Multi-Model Ensemble and CMIP6 decadal climate prediction experiments, leveraging the web-based platform housed at the Utah Climate Center. The multi-year forecasting products developed here will provide a future perspective on the initiation, duration, and ending of multi-year wet/dry periods, which will inform water managers and reservoir operators about the persistent drought threats, support the development of a management and strategic plan for next several years or a decade, and improve reservoir operating policies, such as Lake Powell, Great Salt Lake, and Bear Lake.

Project length and completion date:

Two years from October 1, 2024, to September 30, 2026.

Federal facility:

The proposed project is not located in a Federal facility.

Technical Project Description and Milestones

Category B applicant

This project team is categorized as the Category B applicant (*universities*) partnering with the state agencies in Utah (Category A). The partner agencies include NOAA Colorado Basin River Forecast Center, Salt Lake City Department of Public Utilities, Central Utah Water Conservancy District, Southern Nevada Water Authority, and Institute of Land, Water, and Air. Those agencies express their keen interest in our multi-year-to-decadal drought forecasting product because the water supply is a fundamental source for their activities. Moreover, members of this project have collaborated with them on other projects previously. These partner agencies committed in-kind contributions (see the letters of participation). Those partner agencies will contribute to this project by providing their information and knowledge to translate scientific outcomes into a user-friendly interface and format. Because of the broad applications in our project outcomes, potential partners in this project will include a wide range of agencies in the Intermountain West, such as water and natural resources, hydropower, agriculture, and the economy.

Project Goal

This project's primary objective is to advance and enhance the web-based platform for multi-year-to-decadal Colorado River water supply forecasts accessible through the Utah Climate Center. The specific focus of this endeavor is to extend the existing forecasting horizon from 2 years to a decade. This will be achieved by leveraging the capabilities of publicly available dynamical climate prediction systems and the forecasting tool developed by the project team. By attaining this goal, the project aspires to give water managers comprehensive insights into forthcoming wet or dry periods and the availability of water reservoirs over the upcoming decade.

Problem Statement

Water Scarcity Challenges in the Intermountain West:

The Intermountain West region is grappling with pressing water scarcity challenges that demand immediate attention from decision-makers and stakeholders. The region's continuous population growth over the past six decades, particularly in Utah, has intensified the strain on available water resources (Perlich et al. 2017). This growth trajectory is alarming, given the long-term decline in snowpacks and the recurrence of drought events due to climate change (Lukas and Payton 2020; McCabe and Wolock 2007; Udall and Overpeck 2017). Recent executive orders declaring states of emergency in response to severe droughts underscore the critical nature of the problem. These orders not only underscore the resulting natural disasters, including heightened wildfire risks and compromised air quality, but also emphasize the far-reaching impacts of prolonged droughts across critical sectors, such as agriculture, energy, food security, and tourism (Grigg 2014; Littell et al. 2016; Chikamoto et al. 2023).

Demand for Reliable Multi-Year-to-Decadal Water Supply Forecasts:

In preparation for timely responses to impending drought conditions, water resource managers carefully and consistently monitor hydroclimate conditions and reservoir levels from the past, present, and future. This comprehensive monitoring includes river streamflow, lake elevation, and precipitation outlooks on daily-to-seasonal timescales. Beyond seasonal timescales, the annual mean product of the Colorado River water supply, estimated by the BOR from streamflow data at Lees Ferry, Arizona, is a significant implication for regional water resource availability. This critical metric directly informs the management of expansive reservoirs such as Lake Powell, Great Salt Lake, and Bear Lake. Despite the substantial demand from water managers for early warnings of prolonged drought events, the challenge remains in accurately forecasting their onset, duration, and intensity. Operational products detailing Colorado River Basin system conditions, issued by the BOR, provide 2- and 5-year projections for Lake Powell's elevation. However, these projections are based on climatological conditions derived from historical minimum-to-maximum streamflow ranges. Regrettably, this approach lacks the precision required to assess forthcoming water deficits. To facilitate sustainable water management planning, the evident need for more precise multi-year-to-decadal forecasts, extending beyond mere projections, underscores the necessity for ensuring timely and informed decision-making.

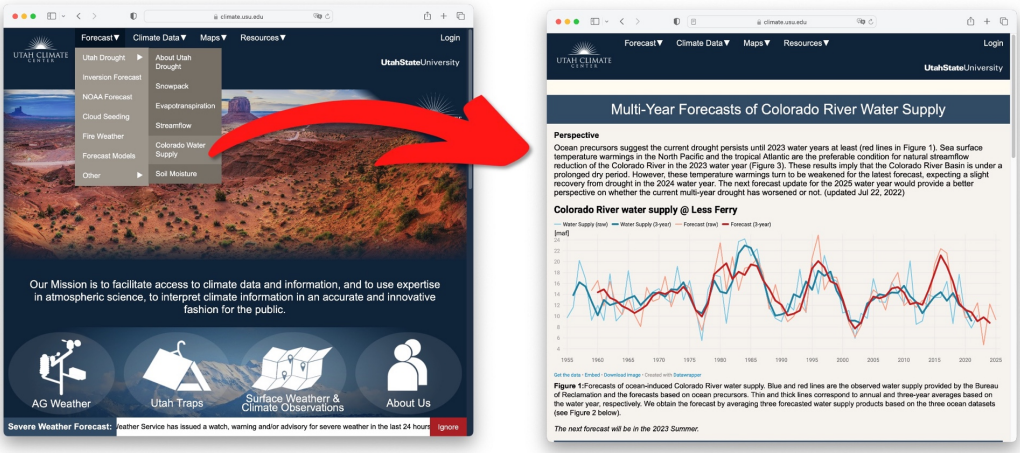


Figure 1: The current web-based platform hosted by the Utah Climate Center, highlighting a menu bar on the top page (left: https://climate.usu.edu/) and the multi-year forecast of the Colorado River water supply (right panels). This forecast provides up to two years of lead time. The proposed project aims to extend this time horizon up to a decade.

Building on Past Successes for Enhanced Forecasting:

Building on our past successes, we have embarked on a journey to develop more advanced forecasting capabilities. In our previous project (BoR WaterSMART grant: R18AC00018), we constructed a comprehensive web-based platform for disseminating integrated drought information across Utah. This collaborative effort was made possible by the dedicated work of the Utah Climate Center. In our following project (BoR WaterSMART grant: R19AP00149), we developed a pioneering forecasting tool for the Colorado River water supply, leveraging ocean precursors. Our tool demonstrated a high predictive skill for wet-dry cycles over interannual to decadal timescales, providing semi-operational insights into the Colorado River water supply for

up to two years (as shown in Figure 1). While this forecasting tool holds immense potential for enhancing our understanding of multi-year drought occurrences, its current two-year lead time falls short in assessing imminent or ongoing wet/dry periods. Encouragingly, recent advances in seasonal-to-decadal climate prediction endeavors (see dynamical climate prediction system below) empower us to extend this prediction horizon to a decade. This extension will allow us to deliver semi-operational forecasting products for the Colorado River water supply and the consequential water availability within large lakes—reservoirs that are continuously monitored by water resource managers and operators.

Objective and Tasks

To advance the web-based platform for multi-year forecasts of the Colorado River water supply, this project is dedicated to developing a sophisticated forecasting tool. This tool seamlessly integrates the statistical model, hinged on ocean precursors, with dynamical climate forecasting products, all refined by the ensemble optimization technique. Our path to this achievement is paved by the following three pivotal tasks, each elaborated upon in the subsequent planned work section:

- Task 1: Developing the Forecasting Tool for Ocean Precursors through Dynamical Climate Prediction Systems
- Task 2: Enhancing Predictive Skills of Ocean Precursors through Ensemble Optimization Technique
- Task 3: Advancing the Multi-Year Forecasting Product Platform at the Utah Climate Center

Scientific Background and Completed Work

Colorado River water supply and lake elevation:

According to the water budget equation, the Colorado River water supply primarily balances the time tendency of water reservoir volume (Plucinski et al. 2019). Figure 2 illustrates the monthly lake elevation time series for October (left panel), highlighting the corresponding tendencies (elevation differences between the current and previous years' Octobers) and the water year mean of the Colorado River water supply (right panel). The augmented water supply in the Colorado River stems from a precipitation surplus in the Upper Colorado River Basin (Chikamoto et al. 2020), contributing to the elevation rise in lakes. This phenomenon establishes a noteworthy correlation between the Colorado River water supply and lake elevation tendencies, resulting in correlation coefficients of R = 0.69 for Lake Powell, 0.78 for Great Salt Lake, and 0.64 for Bear Lake (Fig. 2b). Notably, these correlations unveil the presence of decadal wet-dry cycles (Wang et al. 2018), a characteristic that becomes apparent through the application of a 3-year running mean filter. Leveraging the water budget equation, it becomes feasible to extrapolate multi-year-to-decadal Colorado River water supply forecasts into corresponding lake elevations for the ensuing decade. This translation proves particularly valuable for reservoir operators in their management endeavors.

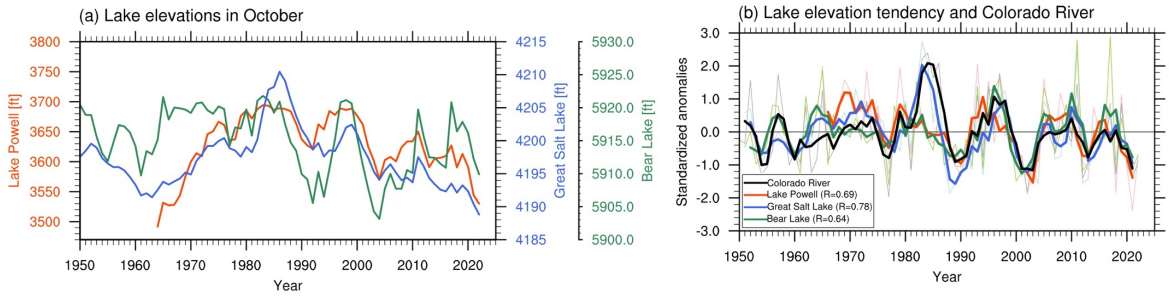


Figure 2: Time series of (a) lake elevations for Lake Powell (red), Great Salt Lake (blue), and Bear Lake (green) in October and (b) their tendencies (time derivatives) along with the water-year average of the Colorado River water supply (black line). The tendencies and the Colorado River water supply are standardized and depicted with both a no-time filter (thin lines) and a 3-year running mean filter (thick lines).

Ocean precursors:

The prior BOR WaterSMART project (R19AP00149) led by the PI identified and harnessed two ocean precursors, resulting in the development of a Colorado River water supply forecasting tool through a multi-linear regression model. These ocean precursors correspond to the area-averaged sea surface temperature anomalies from 29 months ago in the western North Pacific and 44 months ago in the southern tropical Atlantic (as indicated by the black boxes in Fig. 3). Importantly, these ocean precursors received robust validation through a previous study (Chikamoto et al. 2020). The forecasted time series generated from these ocean precursors shows a good agreement with the observed Colorado River water supply (Fig. 3), particularly evident in capturing decadal wet-dry cycles, a feature underscored by a 3-year running mean filter (R=0.71). Notably, the current forecasting tool exclusively utilizes observational products, enabling forecasts only for up to two years. However, the potential extension of this forecast-horizon lies within the ambit of the dynamical climate prediction system, expounded upon below.

Dynamical climate prediction system:

Two distinct climate prediction systems hold wide accessibility for the public: the North American Multi-Model Ensemble (NMME), catering to seasonal predictions (Kirtman et al. 2014), and the CMIP6-Decadal Climate Prediction Project (DCPP), dedicated to decadal predictions (Boer et al. 2016). These two projects (NMME and CMIP6-DCPP) offer ensemble hindcasts and forecasts for sea surface temperature, spanning lead times of up to 12 months and 10 years, respectively. Presently, as of August 2023, four systems stand operative within NMME (CanCM4i-IC3, GEM5-NEMO, COLA-RSMAS-CCSM4, and GFDL-SPEAR), and an equivalent number within CMIP6-DCPP (CMCC-CM2-SR5, CanESM5, EC-Earth3, and HadGEM3-GC31-MM). These systems update the forecasted products operationally and stand poised for deployment in extending our ocean precursor forecasting time horizon. They not only serve scientific research purposes but also find application in operational tools. For instance, they contribute to seasonal El Niño Southern Oscillation (ENSO) forecasts (https://www.cpc.ncep.noaa.gov/products/NMME/), visualized through the Niño3.4 index plumes, and facilitate annual-to-decadal surface temperature forecasts disseminated by the World Meteorological Organization Lead Centre for Annual-to-Decadal Climate Prediction (https://hadleyserver.metoffice.gov.uk/wmolc/).

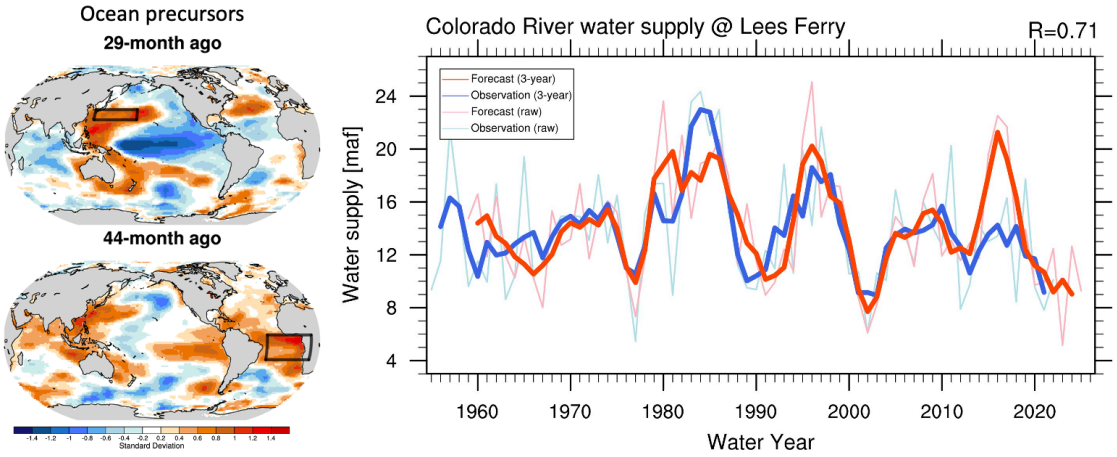


Figure 3: Map of sea surface temperature anomalies characterized by ocean precursors (left) and time series of observed and forecasted products of the Colorado River water supply (right panels).

Ensemble optimization technique (Bayesian updating):

Generally, the forecast skills of the multi-model ensemble mean outperform those of individual models. However, in cases where a limited number of models are involved, the poorly performed model can significantly deteriorate the predictive skills of the multi-model ensemble mean. To tackle this challenge, model weights for multi-model ensembles can be refined based on their respective performances, such as the Bayesian updating method demonstrated by the co-PI for forecasting the ENSO indices (Zhang et al. 2017). This method was proven effective to improve the predictive skill of ocean precursors. This Bayesian updating framework optimizes the model's weight to maximize the predictive skills of multi-model ensemble using the Bayesian theorem by updating the probability distribution of a variable (e.g., the Niño 3.4 index in NMME) with new observed information (e.g., observation-based Niño 3.4 index). Demonstrably, Bayesian-updating predictions have outperformed predictions based on models assigned equal weights for several seasons (Zhang et al. 2017). Drawing inspiration from the effectiveness of Bayesian updating in refining ENSO forecasts, this project strategically applies Bayesian updating to optimize the multi-model ensemble mean within NMME and CMIP6 DCPP to forecast ocean precursors.

Planned Work

Based on the scientific background as described above, the water-year average of the Colorado River water supply is predictable using two ocean precursors: sea surface temperature anomalies in the western North Pacific and the southern tropical Atlantic. The current forecasting tool utilizes only observational products, limiting the time horizon to two years. However, NMME and CMIP6 DCPP have the potential to extend this time horizon up to a decade. This project plans to pursue three tasks as described below to advance the web-based platform for multi-year forecasts of the Colorado River water supply. The project timeline and milestones will be found in Evaluation Criteria C below.

Task 1: Developing the forecasting tool

First, we will collect the hindcast/forecast products of sea surface temperature from the dynamical climate prediction systems NMME and CMIP6 DCPP. Although the model-simulated sea surface temperature includes climatological drift and initialization shocks, these artificial biases are removed using the climatology defined from hindcast experiments spanning over 30 years. Consequently, the indicated climatology becomes a function of the lead time, initial month, and prediction system. Next, we will separately produce the forecasted ocean precursors for up to 1 year in NMME and a decade in CMIP6 DCPP. We will calculate the ensemble mean for each model system first and then obtain the multi-model ensemble. Due to the limited models, we will use the minimum-to-maximum range to estimate the multi-model ensemble spread. These ocean precursor forecasts will be integrated into the web-based platform for multi-year-to-decadal Colorado River water supply forecasts. Lastly, we will obtain the multi-year-to-decadal forecasts of the Colorado River water supply by combining the ocean precursor forecasts with the multilinear regression model. The predictive skills associated with the forecast lead time will be assessed to demonstrate the reliability of the forecasted products.

Task 2: Optimizing multi-model ensemble

This task will apply Bayesian updating to optimize the weights of the multi-model ensemble and maximize the predictive skills for the ocean precursors and the resultant water supply forecast. The outcome of this approach includes enhancing the forecast skills of the Colorado River water supply obtained in Task 1, as well as identifying the best and poorest performers in the multi-model ensemble. We will test several skill metrics to validate this approach's accuracy, reliability, and usefulness, such as anomaly correlation coefficient, root-mean-square error, standard deviation ratio, and probabilistic Brier skill score (Zhang et al. 2017). Specifically, we will carefully assess the model's performance in predicting decadal wet-dry cycles, ultimately contributing to better water resource management in the Intermountain West region.

Task 3: Advancing the platform

The final task revolves around disseminating project outcomes by enhancing the web-based platform for multi-year forecasting products in collaboration with the Utah Climate Center. This entails the implementation of a semi-automated process to regularly update forecasted products, the provision of explanatory resources such as visualizations, short videos, method descriptions, and fact sheets, active participation in conferences, workshops, meetings, and webinars, as well as offering training opportunities for project partners. The Utah Climate Center will contribute in-kind support for web development costs, including server maintenance and programming. Notably, the Utah Division of Water Resources conducts bi-monthly drought webinars for weather feedback, with active involvement from members of the Utah Climate Center who provide weather updates. By capitalizing on these activities, our project is poised to effectively disseminate its outcomes. Furthermore, our collaboration with the Institute of Land, Water, and Air will enable us to share our findings with a wider audience of water resource managers, ensuring a broader impact across Category A and beyond partner institutions.

Project Location

This project focuses on the Colorado River water supply provided by the BOR's streamflow estimations at Lees Ferry, Arizona, and the levels of three major reservoirs: Lake Powell, Great Salt Lake, and Bear Lake. These water resources serve as reliable indicators for regional water supply in the Upper Colorado River basin and the NOAA Colorado Basin River Forecast Centers. The map displays their geographical locations, and the shapefiles for these regions are generally available through federal and state agencies but will be listed through the web-based platform hosted by the Utah Climate Center.

Data Management Practices

The products generated by this project (listed in Section C-3 below) will be made freely available and accessible through the web-based platform hosted at the Utah Climate Center. Users will have the capability to download images and data related to the Colorado River water supply forecasts. These downloads will be offered in standard formats such as Portable Network Graphics (PNG) for images and Comma Separated Value (CSV) for data files. The project intends to maintain the utilization of these established formats and procedures. To compile the observed and forecasted datasets, this project will draw from publicly available data sources. These sources will be comprehensively listed on the web-based platform developed under this project, complete with accessible links.

Evaluation Criteria:

Criteria A – Water Management Challenges

A-1. Describe the water management challenge(s).

Prolonged multi-year drought presents significant challenges for water management, which this project aims to alleviate by providing early insights into drought threats. The diminished water supply of the Colorado River reduces inflow to water reservoirs, leading to substantial drops in water levels. As a result, water reservoir operators face formidable tasks in ensuring water availability for vital purposes such as drinking water supply, hydropower generation, irrigation, and recreation. Additionally, multi-year droughts exacerbate water scarcity, impacting both surface water and groundwater resources. As the available water supply dwindles, demand from sectors like agriculture, municipalities, industries, and ecosystems can surpass available resources, intensifying water shortages. Water managers are tasked with maintaining the reliability of water supply systems, allocating water resources efficiently, and prioritizing water usage across competing demands, including the delicate balance between human consumption, ecosystems, industry, and agriculture. Addressing these challenges effectively and building resilience against future drought events necessitates

the development of drought contingency plans, the promotion of water conservation measures, and the integration of climate variability and change into planning efforts. Collaborative endeavors involving water managers, policymakers, scientists, and the public are pivotal for establishing a comprehensive and proactive approach. The web-based platform advanced in this project contributes to fostering collaboration by providing multi-year-to-decadal forecasts of the Colorado River water supply and its wet-dry cycles.

A-2. Describe the concerns or outcomes if this water management challenge is not addressed?

If the water management challenge of the prolonged multi-year drought is not adequately addressed, several concerning outcomes can arise, impacting both human and natural systems. Without effective water management strategies during droughts, water shortages can become more severe and widespread, leading to inadequate water supply for essential needs such as drinking water, agriculture, industry, and ecosystem support. The consequences are far-reaching, with economic losses hitting various sectors, particularly agriculture and tourism, causing financial hardships for farmers and related industries and affecting local and regional economies. Neglecting this challenge risks social conflicts, environmental harm, and compromised livelihoods. The implications are serious as ecosystems degrade, water quality suffers, and human health is at risk due to limited access to clean drinking water and sanitation facilities. The ability to generate hydropower may be compromised, impacting energy production and potentially increasing energy costs. Additionally, the lack of preparedness for future droughts undermines resilience and leaves communities vulnerable to recurring water crises. Addressing the water management challenge during multi-year droughts is crucial to minimizing these negative outcomes and ensuring the sustainable use and conservation of water resources for present and future generations. Implementing proactive strategies, such as drought contingency planning, water conservation measures, and collaborative efforts, can enhance resilience and mitigate the impacts of prolonged drought on both human and environmental systems, safeguarding water availability and stability for the long term.

A-3. 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 multi-year-to-decadal forecasts of the Colorado River water supply provided in this project will be crucial in improving drought management activities (d). Anticipating future water supply during prolonged multi-year droughts will enhance preparedness and response measures, allowing water managers to proactively implement drought contingency plans and conservation measures to minimize the impacts of water scarcity. This will ensure a more stable, sustainable, and reliable water supply for essential needs, including municipal, agricultural, tribal, environmental, and recreational water uses (a). Reliable information about future water supply will enable water reservoir operators and stakeholders to plan and coordinate water deliveries more effectively to different users (b). Understanding future water availability will also help in the optimal utilization of both ground and surface water sources, supporting the conjunctive use of ground and surface water (e). This, in turn, will enhance water

trading and market activities, facilitating more efficient water allocation among stakeholders (c). Additionally, multi-year-to-decadal forecasts will be valuable in water rights administration (f), allowing for better planning and allocation of water rights based on anticipated water supply conditions, leading to a more equitable distribution of water resources among various water rights holders. These forecasts will empower water managers with critical information to make informed decisions, promote water resource sustainability, and ensure effective water management in the Colorado River region.

Criteria B – Project Benefits

B-1. Describe how the need for the project was identified.

The need for multi-year-to-decadal forecasts of the Colorado River water supply has arisen through collaborative efforts involving water resource managers, scientists, and a diverse group of stakeholders. This collective approach integrates various sources of expertise. For instance, the 'Colorado River Basin Climate and Hydrology: State of the Science 2020' report emphasizes the necessity for extended lead forecasting beyond one year (Lukas and Payton 2020). It underscores the importance of input from scientific experts and stakeholders, quoting recommendations such as: 'Invest in the analysis and development of watershed-scale climate forecasts through empirical and dynamical methods as operational climate forecasting capabilities gradually evolve.' It also suggests supporting further research in post-processing CBRFC forecasts to create climate-forecast-informed, use-specific streamflow forecasts, and develop decision support tools that connect climate forecasts to water resource decision-making.

In the preceding BOR WaterSMART project (R19AP00149), ongoing discussions with Dr. James Prairie, a Hydrologic Engineer at the Bureau of Reclamation, along with other critical partners such as the Utah Division of Water Resources, Salt Lake City Department of Public Utilities, and Utah Farm Bureau, consistently highlighted the essential requirement for multi-year-to-decadal forecasts. Within that project, the PI surveyed the web-based platform at the Utah Climate Center in September 2021, targeting individuals with potential connections to the Colorado River. Out of the 400 surveys sent out, we received 58 responses from institutions, including Universities (64.9%), State Agencies (10.5%), Federal Agencies (7%), Private Sector (3.5%), and others (14.4%). Most of the survey responders first learned about our webpage through email invitations for the survey (75.9%), and many had never used an ocean precursor for forecasting the Colorado River water supply (93.1%), finding our webpage to be useful (87.9%). These results suggest a significant demand for multi-year Colorado River water supply forecasts.

Further valuable insights for the proposed project were gathered from discussions held in webinars, meetings, and significant scientific conferences. Notable among these meetings are the Colorado River Climate and Hydrology Work Group, Societally-Relevant Multi-Year Climate Predictions Workshop, Utah Water Conservation Forum, Climate Prediction Applications Science Workshop, Drought in the Southwest Current Conditions and Outlook, and Spring Runoff Conference. These interactions provided platforms for stakeholders, experts, and interested parties to provide feedback, offer suggestions, and contribute innovative ideas. These engagements played a pivotal

role in refining and shaping the proposed project, ensuring its alignment with the authentic needs of stakeholders and advancements in the scientific domain.

B-2. Describe how the tool, method, or information will be applied and when will it be applied.

The project outcomes offer insights into the potential occurrence of multi-year droughts by translating scientific findings into a user-friendly interface that includes observed and forecasted time series of the Colorado River water supply. This interface has already been established as a web-based platform at the Utah Climate Center, readily accessible for use by water resource managers. Our approach involves regularly updating the forecasted product, expanding its forecasting time horizon, and adding the multi-year-to-decadal elevation forecasts for the large lakes. Furthermore, we are dedicated to continuously improving the tool's functionality to ensure its ongoing advancement and relevance.

B-3. Describe, in detail, the extent of benefits that can be expected to occur upon implementation of the project, and provide support for your responses.

The project's outcomes offer significant benefits, notably by providing multi-year-to-decadal forecasts of the Colorado River water supply. The Intermountain West region faces pressing concerns regarding prolonged droughts, impacting not only water resource managers but also the general public. Our scientifically validated approach has the potential to establish a comprehensive framework for predicting water availability over the next decade. This forecasted information will prove invaluable in facilitating discussions around proactive management strategies among diverse stakeholders, including policymakers, water resource managers, and scientists. The demand for such forecasts is evident from our engagement efforts. Responses for each sub-question are described below.

B-3 (i) Who will use the tool or data developed under this proposal and how will they benefit from the project?

The tool and data produced through this project will serve as valuable resources for a range of stakeholders, particularly water resource managers and reservoir operators. Entities like the Salt Lake City Department of Public Utilities, NOAA Colorado Basin River Forecast Center, Central Utah Water Conservancy District, and Southern Nevada Water Authority have expressed support for this project, highlighting the benefits they anticipate from these multi-year-to-decadal forecasts of the Colorado River water supply. However, the utility of our products extends beyond these immediate users. Policymakers, water reservoir operators, farmers, ranchers, recreation managers, and even the general public will find value in the longer-term insights provided by our forecasts due to their broader timescale perspective. This diverse set of beneficiaries underscores the wide-reaching impacts of this project in enhancing decision-making, resource management, and preparedness for the challenges posed by the shortage of the Colorado River water supply and water reservoirs in the Intermountain West.

B-3 (ii) How will the project improve water management decisions?

The project will significantly enhance water management decisions by providing multi-year-to-decadal forecasts for the Colorado River water supply. These forecasts will offer long-term insights into wet-dry cycles, which will help water resource managers and decision-makers to plan and allocate water resources effectively. The project's products will also aid in optimizing reservoir operations, scheduling water releases, implementing conservation measures, and developing informed and strategic policy. Ultimately, the project's contribution to improved water management decisions will foster greater resilience and adaptive capacity in the face of the challenges posed by Colorado River water supply dynamics.

B-3 (iii) Describe if the results of your project will be applicable elsewhere.

As the Colorado River water supply serves as a pivotal indicator of naturally provided water resources across the Intermountain West, the results derived from our project hold potential applicability for forecasting multi-year-to-decadal changes in other reservoirs and unregulated streamflows within this region. To facilitate this broader application, further steps would be essential. These steps may encompass gathering historical data specific to the target reservoirs and streamflows, conducting an in-depth analysis to establish correlations between their water supplies and the Colorado River's, and evaluating the feasibility and relevance of implementing our forecasting methodology in these distinct contexts. By considering these additional measures, we could make our project outcomes more transferable and valuable beyond the immediate scope.

B-3 (iv) To what extent will the project address the water management challenges?

This project will provide multi-year-to-decadal forecasts of the Colorado River water supply through the web-based platform at Utah Climate Center, which gives a time buffer for water resource managers to develop proactive management plans against ongoing and upcoming drought threats. This product targets naturally provided water supply only, therefore excluding human-caused threats, such as water use. We will translate our forecasted product and resources into a user-friendly interface for water managers, such as time series visualizations, forecasted lake elevations, video tutorials, and fact sheets. By offering these tools, the project directly addresses the challenge of effective water resource management by providing advanced notice of potential drought conditions, enabling timely and strategic decision-making to mitigate water scarcity impacts. Currently, water resource managers carefully monitor daily-to-seasonal drought outlooks to conduct water operations. Our products will provide them with additional long-term options for their decision-making processes, enhancing their ability to plan and allocate water resources more effectively.

B-4. Explain how your project complements other similar efforts in the area where the project is located

The project's approach not only complements but also adds substantial value to existing efforts in the area by addressing a critical timescale gap beyond seasonal forecasting. In the realm of daily to monthly timescales, federal agencies such as NOAA and BOR offer shorter-term predictions encompassing variables like precipitation, temperature, streamflow, and lake elevations. However, these forecasts are primarily

used for monitoring purposes due to their limited reliability, often constrained by atmospheric short-term predictability, typically spanning less than two weeks (Krishnamurthy 2019).

The distinct contribution of this project lies in extending the forecasting horizon to multi-year-to-decadal timescales, a domain that has posed significant challenges. This initiative builds upon the successes and insights garnered from our previous BOR WaterSMART project (R19AP00149), which focused on multi-year forecasting of the Colorado River water supply with an emphasis on ocean precursors and statistical modeling. The proposed project equips us to elevate the predictive time horizon and enhance forecast reliability, capitalizing on advancements in seasonal-to-decadal climate prediction projects undertaken by both federal and non-federal institutions worldwide. Furthermore, this project leverages the well-established collaboration network among universities, federal and state agencies, and water resource managers, developed by the previous project.

While several research institutions have attempted to predict decadal streamflow variability using decadal and multi-decadal ocean oscillations, such as the Pacific Decadal Oscillation (McAfee 2014; Wise 2015), Atlantic Multi-decadal Oscillation (Gray et al. 2004; Hidalgo 2004; McCabe et al. 2004), and Quasi-Decadal Oscillation (Nowak et al. 2012; Meko et al. 2007; Wang et al. 2018), these attempts have been accompanied by debates regarding dynamic understanding (Lukas and Payton 2020) and applying heavy time-smoothing approaches (e.g., 10-year averages). While these ocean oscillations showcase coherent multi-decadal wet-dry cycles in the Intermountain West, their translation into forecasting products has remained contentious. This project seeks to bridge this gap by employing a unique approach that harnesses ocean precursors combined with a statistical model to offer skillful predictions while minimizing model biases for precipitation forecasts.

The project's distinctive methodology aligns with and complements ongoing efforts, reinforcing its potential to amplify the impact of the entire spectrum of forecasting endeavors in the area. By leveraging and enhancing the strengths of previous projects, our initiative ensures a coherent and mutually reinforcing approach, thereby avoiding unnecessary duplication or complication. This collaborative orientation will facilitate a holistic understanding of hydroclimate dynamics and enhance the effectiveness of water resource management decisions.

Criteria C – Project Implementation

C-1. Briefly describe and provide support for the approach and methodology that will be used to meet the objectives of the project.

A methodological strength of this project lies in its adoption of forecasted sea surface temperature (SST) data from dynamical climate prediction systems, a departure from relying solely on precipitation. While precipitation is pivotal for water supply forecasts, current dynamical models exhibit significant biases in simulating land precipitation patterns and intensity (Hosseinzadehtalaei et al. 2017), limiting their predictability primarily to seasonal timescales driven by major El Niño-Southern Oscillation (ENSO) signals. In contrast, SST predominantly influences the lower-frequency component and offers greater predictability over longer timescales (Chikamoto et al. 2019). The prior project (R19AP00149) demonstrated high reliability in

forecasting the Colorado River water supply for up to a two-year lead time using observed SST data combined with a multilinear regression model. Thus, by integrating SST forecasts from dynamical climate prediction systems with the statistical model that translates these into predictions for the Colorado River water supply, we anticipate significantly improved predictive capacities. Furthermore, the multi-model approach allows us to provide forecast uncertainties, a critical factor in evaluating forecast reliability.

C-2. Describe the work plan for implementing the proposed scope of work.

The proposed project is envisioned to span a total duration of two years. The estimated project schedule, along with milestones for each major task and the anticipated duration for each task, is summarized in Figure 4 and presented according to the quarterly timeline. The primary costs for Task 1 and Task 2 encompass project personnel salaries, wages, and fringe benefits. Task 3 necessitates dissemination costs, which include expenses related to project personnel travel and web-server maintenance fees. Further details regarding the work plan and associated costs are provided in the budget sections.

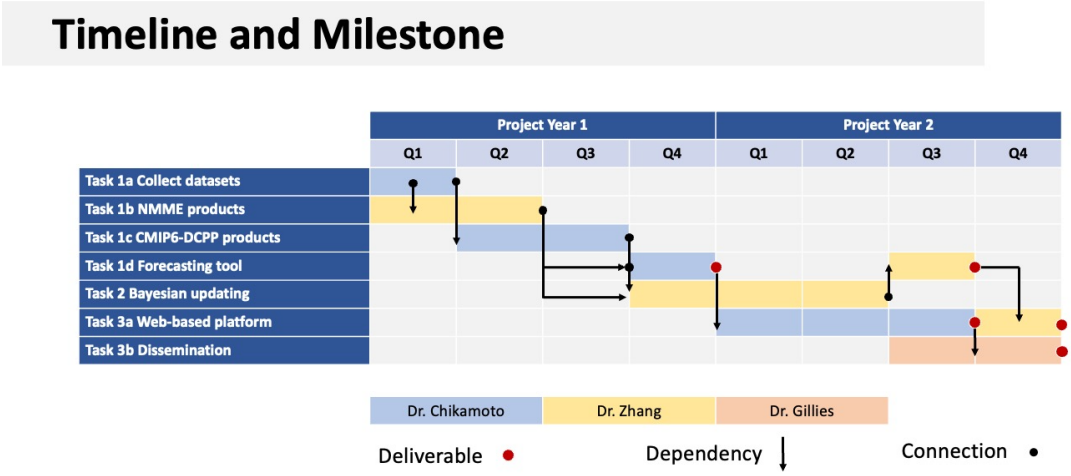


Figure 4: Project timeline and milestone.

C-3. Provide a summary description of the products that are anticipated to result from the project. Note: using a table to list anticipated products is suggested.

Type	**Description**
Data	A historical and future record for the water-year mean of the forecasted Colorado River water supply and ocean precursors
	Lake level forecasts translated from the Colorado River water supply forecast
Metadata	Detailed information about data sources, methodologies, and models.
Digital Products	A Web-based platform for multi-year-to-decadal forecasts
	User-friendly interface to visualize the forecasted data
Reports	Semi-annual project reports to provide to the BOR
Publications	Research articles in peer-reviewed journals relating to our project
	Graduate student thesis/dissertation
	Presentations and abstracts for webinars, meetings, and conferences
	The factsheet of our project targeted stakeholders and the general public

C-4. Who will be involved in the project as project partners? What will each partner or stakeholder's role in the project be? How will project partners and stakeholder be engaged in the project and at what stages? If you are a Category B applicant, be sure to explain how your Category A partners will be engaged in the project.

The project's collaborative network comprises a range of federal, state, regional, and local water-related organizations situated in Utah, Colorado, and Nevada. These esteemed partners include the NOAA Colorado Basin River Forecast Center, Salt Lake City Department of Public Utilities, Central Utah Water Conservancy District, Southern Nevada Water Authority, and Institute of Land, Water, and Air. Each partner brings unique expertise and capacities to the project:

- The NOAA Colorado Basin River Forecast Center and Southern Nevada Water Authority play pivotal roles as water authorities and agencies. They will contribute by actively participating in discussions on the operational aspects of utilizing forecasted information, engaging in training sessions, webinars, and workshops, providing valuable feedback, and supporting the project through in-kind contributions.
- The Central Utah Water Conservancy District and Salt Lake City Department of Public Utilities, representing regional and local water interests, will offer insights and perspectives specific to their areas. They will participate in discussions regarding the practical applicability of project outcomes, attend training and collaboration sessions, and contribute to the development of water management strategies.
- The Institute of Land, Water, and Air, as a regional and research-focused partner, will provide scientific expertise and broader insights into water management challenges. They will contribute by participating in project discussions, providing valuable feedback, and assisting in the dissemination of project outcomes through their established communication channels.

Engagement with project partners and stakeholders will occur throughout the project's lifecycle. Regular interactions, meetings, and workshops will ensure that their input shapes the project's direction, ensures the applicability of the products, and enhances their effectiveness in addressing water management challenges. By involving Category A partners in this project, their engagement will be integrated into the project's activities and decision-making processes to ensure a cohesive and collaborative effort in achieving the project's goals.

C-5. Identify staff with appropriate credentials and experience and describe their qualifications.

The project team comprises experts at different career stages, ensuring well-balanced and highly qualified professionals in seasonal-to-decadal climate forecasts, ensemble optimization techniques, web-based system development, outreach activities, and stakeholder engagement. Our team members and their specific roles are outlined below.

- Lead PI: Dr. Yoshimitsu Chikamoto (associate professor at Utah State University and a member of the Utah Climate Center) possesses expertise in seasonal-to-decadal climate prediction. He has authored numerous impactful papers showcasing the capability of Earth system modeling in predicting prolonged droughts in the southwestern US and the Colorado River water supply. His role includes leading the project, coordinating planned work, conducting associated tasks, and mentoring two graduate students.
- Co-PI: Dr. Wei Zhang (assistant professor at Utah State University and a member of the Utah Climate Center) specializes in seasonal prediction, statistical and dynamical downscaling, and dynamical modeling (snow and climate). He has developed several statistical-dynamical climate prediction schemes, including the Bayesian updating method applied to the El Niño Southern Oscillation based on the NMME forecasts. Working closely with the lead PI, Dr. Zhang will contribute to the planned work, associated tasks, and co-supervise two graduate students.
- Co-I: Dr. Robert Gillies (professor at Utah State University and director of the Utah Climate Center) is an expert in remote sensing, synoptic meteorology, and mountain climatology. As a director at the Utah Climate Center, he has developed a collaborative network with water agencies and planners in Utah and the Intermountain West. He will provide mentoring to all project members, including the PIs, and disseminate the project outcomes through outreach activities at the Utah Climate Center.
- Other personnel: Two graduate students (TBD) will execute all tasks proposed by this project under the guidance and supervision of the PIs (Chikamoto, Zhang) and Co-I (Gillies). The selection process and criteria align with the standard protocol for graduate student recruitment at Utah State University.

C-5a. Have the project team members accomplished projects similar in scope to the proposed project in the past either as a lead or team member?

Members of the project team have extensive involvement in both previous and ongoing BoR WaterSMART projects that share similarities with the proposed project, particularly in terms of collaborations between universities and state agencies with a focus on drought prediction in the Intermountain West. These projects include:

- The 2013 BoR WaterSMART project titled "Building Decadal Prediction of Extreme Climate for Managing Water in the Intermountain West" (Co-PI: Gillies).
- The 2018 BoR WaterSMART project titled "Synthesizing Drought Characteristics Prediction to Inform Drought Resilience Decisions from Days to Years" (Co-I: Chikamoto, Gillies).
- The 2019 BoR WaterSMART project titled “A Platform Toward an Early Warning System for Shortages in Colorado River Water Supply" (PI: Chikamoto).
- The 2021 BoR WaterSMART project titled “A Platform for Drought Forecast in the Intermountain West with the Optimized Multi-Model Ensemble Approach” (PI: Zhang, Co-I: Chikamoto, Gillies).

These projects collectively demonstrate the team's expertise and experience in conducting applied science related to drought prediction and water resource management in the Intermountain West region.

C-5b. Is the project team capable of proceeding with tasks within the proposed project immediately upon entering into a financial assistance agreement?

Yes, the project team is fully prepared and capable of commencing the tasks outlined in the proposed project as soon as a financial assistance agreement is established. There are no anticipated delays or impediments that would hinder the team's ability to initiate the project promptly.

Criteria D – Dissemination of Results

Explain how project results will be disseminated, including: 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.

The results and products generated within this project (as outlined in Section C-3 above) will be disseminated via the web-based platform hosted by the Utah Climate Center. The Utah Climate Center routinely shares climate-related information through extension activities and engagements with various media channels. These outcomes will be communicated to stakeholders in alignment with their existing service and outreach roles. With an audience of over 11,000 monthly visitors, the Utah Climate Center's data server will offer unrestricted access for the placement and utilization of data on its webpage. The data will be made freely accessible to the general public. Dr. Gillies, as the director and co-I, will oversee the archiving of data in this project. As integral members of the Utah Climate Center, both Dr. Chikamoto (PI) and Dr. Zhang (co-PI) are actively engaged in outreach initiatives encompassing web-based platform development, scientific product communication, stakeholder engagement, and broader collaborative efforts.

To effectively reach a wider audience, this project will conduct outreach activities in close partnership with collaborating institutions, including the Institute of Land, Water, and Air (ILWA) and Southern Nevada Water Authority (SNWA). ILWA, a significant interdisciplinary initiative, seeks to bridge research programs focused on land, water, and air with state, county, and city governments, ultimately achieving positive outcomes for Utah. SNWA is dedicated to providing world-class water services sustainably, adaptively, and responsibly to its customers through reliable and cost-effective systems. These partner institutions maintain their communication networks, comprising newsletters, webinars, and workshops. The outcomes of our project will be actively shared and distributed through these established channels via collaboration with our partner institutions.

Furthermore, the project has forged partnerships with water resource agencies, including the NOAA Colorado Basin River Forecast Center, Salt Lake City Department of Public Utilities, and Central Utah Water Conservancy District. To optimize the usability of our products and project outcomes, they will lend support to our initiative by participating in discussions concerning the technical aspects of an operational application. Their engagement will extend to participation in training webinars, formal

and informal meetings, and larger workshops organized by project members. They will also provide responses to surveys regarding our products, furnish feedback for the web-based platform, and share their historical datasets, if applicable. This collaborative commitment from them will ensure the success of these activities, and they will contribute in-kind support to the project.

Criteria E – Presidential and Department of the Interior Priorities

E. Please address only those priorities that are applicable to your project. If applicable, describe how the project addresses climate change and increases resiliency. How will the project build long-term resilience to drought?

The project presented here, which focuses on multi-year-to-decadal forecasts of the Colorado River water supply, makes a significant contribution to addressing climate change impacts and enhancing resilience in the Intermountain West region. The Intermountain West is currently confronted with pressing challenges stemming from increasing water scarcity, prolonged droughts, and uncertainties related to changing hydroclimate conditions. These challenges may be further exacerbated by the ongoing effects of climate change. While the impacts of climate change are evident in a consistent upward trend in surface air temperature spanning over 50 years, their specific effects on the Colorado River water supply remain unclear due to the presence of decadal wet-dry cycles. Our forecasted product plays a crucial role in understanding the existing conditions of natural variability, aiding in the more accurate detection of climate change signals.

By conducting an extensive analysis of historical data, employing sophisticated modeling techniques, and utilizing advanced forecasting methods, this project aims to provide water resource managers, policymakers, and stakeholders with dependable and cutting-edge insights into future water supply conditions. By extending forecasting capabilities up to a decade in advance, the project empowers these stakeholders to make well-informed decisions and formulate proactive strategies for effective water resource management. This holds particular significance for ensuring the resilience of water supply systems, agricultural practices, energy generation, and other sectors heavily reliant on a consistent and predictable water supply.

The project's impact is significantly enhanced by integrating advanced forecasting models, user-friendly data dissemination through a web-based platform, and strategic partnerships with institutions like the Utah Climate Center and Southern Nevada Water Authority. This initiative directly addresses climate change challenges by providing precise information and enabling stakeholders to proactively plan for water scarcity events. Furthermore, the project collaborates closely with water resource agencies, including the NOAA Colorado Basin River Forecast Center and local utilities, to ensure effective utilization of forecasted insights. The project promotes collaboration through discussions, training, and structured feedback, enhancing water management practices and resilient strategies against climate change.

Budget

FUNDING SOURCES	AMOUNT
Non-Federal Entities	
1. Utah State University (includes Utah Climate Center and Institute for Land, Water and Air)	$146,493.72
2. Central Utah Water Conservancy District	$ 12,000.00
3. Southern Nevada Water Authority	$ 8,730.00
4. Salt Lake City Public Utilities	$ 8,000.00
5. NOAA Colorado Basin River Forecast Center	$ 16,400.00
Non-Federal Subtotal	**$191,623.72**
REQUESTED RECLAMATION FUNDING	**$191,219.63**

Environmental and Cultural Resources Compliance
Not applicable

Required Permits or Approvals
Not applicable

Overlap or Duplication of Effort Statement
Not applicable

Conflict of Interest Disclosure Statement
Not applicable

Uniform Audit Reporting Statement
Not applicable

Disclosure of Lobbying Activities
Not applicable

References

Boer, G. J., and Coauthors, 2016: The Decadal Climate Prediction Project (DCPP) contribution to CMIP6. *Geosci. Model Dev.*, **9**, 3751–3777, https://doi.org/10.5194/gmd-9-3751-2016.

Chikamoto, Y., A. Timmermann, M. J. Widlansky, S. Zhang, and M. A. Balmaseda, 2019: A Drift-Free Decadal Climate Prediction System for the Community Earth System Model. *J. Clim.*, **32**, 5967–5995, https://doi.org/10.1175/JCLI-D-18-0788.1.

——, S.-Y. S. Wang, M. Yost, L. Yocom, and R. R. Gillies, 2020: Colorado River water supply is predictable on multi-year timescales owing to long-term ocean memory. *Commun. Earth Environ.*, **1**, 1–11, https://doi.org/10.1038/s43247-020-00027-0.

——, W. Zhang, L. Hipps, S.-Y. S. Wang, R. R. Gillies, and S. Bigalke, 2023: Interannual variability and trends of summertime PM2.5-based air quality in the Intermountain West. *Environ. Res. Lett.*, **18**, 044032, https://doi.org/10.1088/1748-9326/acc6e0.

Gray, S. T., L. J. Graumlich, J. L. Betancourt, and G. T. Pederson, 2004: A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. *Geophys. Res. Lett.*, **31**, https://doi.org/10.1029/2004GL019932.

Grigg, N. S., 2014: The 2011–2012 drought in the United States: new lessons from a record event. *Int. J. Water Resour. Dev.*, **30**, 183–199, https://doi.org/10.1080/07900627.2013.847710.

Hidalgo, H. G., 2004: Climate precursors of multidecadal drought variability in the western United States. *Water Resour. Res.*, **40**, https://doi.org/10.1029/2004WR003350.

Hosseinzadehtalaei, P., H. Tabari, and P. Willems, 2017: Uncertainty assessment for climate change impact on intense precipitation: how many model runs do we need? *Int. J. Climatol.*, **37**, 1105–1117, https://doi.org/10.1002/joc.5069.

Kirtman, B. P., and Coauthors, 2014: The North American Multimodel Ensemble: Phase-1 Seasonal-to-Interannual Prediction; Phase-2 toward Developing Intraseasonal Prediction. *Bull. Am. Meteorol. Soc.*, **95**, 585–601, https://doi.org/10.1175/BAMS-D-12-00050.1.

Krishnamurthy, V., 2019: Predictability of Weather and Climate. *Earth Space Sci.*, **6**, 1043–1056, https://doi.org/10.1029/2019EA000586.

Littell, J. S., D. L. Peterson, K. L. Riley, Y. Liu, and C. H. Luce, 2016: A review of the relationships between drought and forest fire in the United States. *Glob. Change Biol.*, **22**, 2353–2369, https://doi.org/10.1111/gcb.13275.

Lukas, J., and E. Payton, 2020: *Colorado River Basin Climate and Hydrology: State of the Science*. Western Water Assessment, University of Colorado Boulder, https://doi.org/10.25810/3hcv-w477.

McAfee, S. A., 2014: Consistency and the Lack Thereof in Pacific Decadal Oscillation Impacts on North American Winter Climate. *J. Clim.*, **27**, 7410–7431, https://doi.org/10.1175/JCLI-D-14-00143.1.

McCabe, G. J., and D. M. Wolock, 2007: Warming may create substantial water supply shortages in the Colorado River basin. *Geophys. Res. Lett.*, **34**, https://doi.org/10.1029/2007GL031764.

——, M. A. Palecki, and J. L. Betancourt, 2004: Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. *Proc. Natl. Acad. Sci.*, **101**, 4136–4141, https://doi.org/10.1073/pnas.0306738101.

Meko, D. M., C. A. Woodhouse, C. A. Baisan, T. Knight, J. J. Lukas, M. K. Hughes, and M. W. Salzer, 2007: Medieval drought in the upper Colorado River Basin. *Geophys. Res. Lett.*, **34**, https://doi.org/10.1029/2007GL029988.

Nowak, K., M. Hoerling, B. Rajagopalan, and E. Zagona, 2012: Colorado River Basin Hydroclimatic Variability. *J. Clim.*, **25**, 4389–4403, https://doi.org/10.1175/JCLI-D-11-00406.1.

Perlich, P. S., M. Hollingshaus, E. R. Harris, J. Tennert, and M. T. Hogue, 2017: *Utah's Long-Term Demographic and Economic Projections Summary*. Kem C. Gardner Policy Institute, University of Utah, https://gardner.utah.edu/wp-content/uploads/Projections-Brief-Final.pdf.

Plucinski, B., Y. Sun, S.-Y. S. Wang, R. R. Gillies, J. Eklund, and C.-C. Wang, 2019: Feasibility of Multi-Year Forecast for the Colorado River Water Supply: Time Series Modeling. *Water*, **11**, 2433, https://doi.org/10.3390/w11122433.

Udall, B., and J. Overpeck, 2017: The twenty-first century Colorado River hot drought and implications for the future. *Water Resour. Res.*, **53**, 2404–2418, https://doi.org/10.1002/2016WR019638.

Wang, S.-Y. S., R. R. Gillies, O.-Y. Chung, and C. Shen, 2018: Cross-Basin Decadal Climate Regime Connecting the Colorado River with the Great Salt Lake. *J. Hydrometeorol.*, **19**, 659–665, https://doi.org/10.1175/JHM-D-17-0081.1.

Wise, E. K., 2015: Tropical Pacific and Northern Hemisphere influences on the coherence of Pacific Decadal Oscillation reconstructions. *Int. J. Climatol.*, **35**, 154–160, https://doi.org/10.1002/joc.3966.

Zhang, W., G. Villarini, L. Slater, G. A. Vecchi, and A. A. Bradley, 2017: Improved ENSO Forecasting Using Bayesian Updating and the North American Multimodel Ensemble (NMME). *J. Clim.*, **30**, 9007–9025, https://doi.org/10.1175/JCLI-D-17-0073.1.

D.2.2.18. Letters of Funding Commitment

1. Mikayla Cook, USU Sponsored Programs (letter)
2. Rob Gillies, USU UCC (letter and cost share form for UCC)
3. Brian Steed, USU ILWA (letter and cost share form for ILWA)
4. Bart Leeflang, Central Utah Water Conservancy District (letter and cost share form)
5. Seth Shanahan, Southern Nevada Water Authority (letter and cost share form)
6. Jesse Stewart, SLC Public Utilities (letter and cost share form)
7. Michelle Stokes, NOAA Colorado Basin River Forecast Center (letter and cost share form)

OFFICE OF RESEARCH
UtahStateUniversity

Sponsored Programs

October 10, 2023

Bureau of Reclamation
Columbia-Pacific Regional Office
1150 N. Curtis Road
Boise, Idaho 83706
Attn: Nathan Moeller

RE: Letter of Commitment for Matching Funds – USU No. DP13079
TITLE: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs

To Whom it May Concern:

This letter is being sent to express the willingness of Utah State University ("USU"), 1415 Old Main Hill, Logan, UT 84322-1415, to fulfill the match requirement for the above referenced proposal entitled "Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs." If funded, USU agrees to provide $146,493.72 in in-kind salary & benefits, development of a web-based platform at the Utah Climate Center, and indirect costs on these costs.

I certify that I am an Authorizing Official for USU and this proposal. The Division of Sponsored Programs at USU is responsible for contractual matters. The USU principal investigator for the proposed project will be Dr. Yoshi Chikamoto. *USU requests that any resulting award from this proposal incorporate terms and conditions applicable to its status as a state-owned, non-profit, educational institution.* Please direct questions regarding this proposal to me at mikayla.cook@usu.edu, 435-797-0943. All contractual and/or administrative correspondence, including all award and/or modification documents requiring signature, should be sent to Corinna Knowles, Grant & Contract Officer, Utah State University, Sponsored Programs, 1415 Old Main Hill – Room 64, Logan, UT 84322-1415, via email at corinna.knowles@usu.edu, or by phone at 435-797-9153. Questions of a technical nature or regarding the statement of work should be directed to the Principal Investigator, Dr. Chikamoto, at yoshi.chikamoto@usu.edu, 435-797-0832.

We appreciate the opportunity to apply for funding from the Bureau of Reclamation.

Sincerely,

Mikayla Cook

Mikayla Cook
Grant & Contract Officer

1415 Old Main Hill Logan, UT 84322-1415 PH: (435) 797-1223 FAX: (435) 797-3543 spo.usu.edu

COLLEGE of AGRICULTURE and APPLIED SCIENCES
UtahStateUniversity

UTAH CLIMATE CENTER

Monday, October 2, 2023

Dr. Yoshimitsu Chikamoto
c/o Department of Plants, Soils and Climate
College of Agriculture and Applied Sciences
Utah State University, Logan

Dear Dr. Chikamoto

RE: WaterSMART Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs

If the proposal, as submitted by Dr. Y. Chikamoto, entitled WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs, is selected for funding by BOR, it is our intent to collaborate and/or commit resources to provide in-kind contributions for use as a partial match to the federal Bureau of Reclamation request. The total cost is $16,682, which consists of in-kind support from an assistant state climatologist (190 hours in total) and software engineering service (60 hours in total) as well as indirect costs on UCC. This in-kind contribution will be available throughout the performance period of this grant, beginning on the award date and without other contingency.

Sincerely,

Dr. Robert R. Gillies
Director – Utah Climate Center
State Climatologist – Utah
Professor – Plants, Soils and Climate

4825 Old Main Hill Logan, UT 84322-4825 Phone: (435) 797-2190 Fax: (435) 797-3376
climate.usu.edu

Janet Quinney Lawson
Institute for Land, Water & Air
UtahStateUniversity

September 25, 2023

Yoshimitsu Chikamoto
Associate Professor,
Department of Plants, Soils and Climate
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820

Re: Support for a WaterSMART project

Dear Dr. Chikamoto,

I'm writing this letter to express the commitment of the Janet Quinney Lawson Institute for Land, Water, and Air (ILWA) to support the proposed project titled "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs." We understand that this project involves a collaborative effort between researchers from Utah State University and water agencies in the Intermountain West. Our mission is to guide Utah's land, water, and air policy by connecting decision-makers with high-quality research. The proposed project aims to improve multi-year-to-decadal forecasts of water availability for the Colorado River, Great Salt Lake, and Bear Lake. These products are highly valuable for decision-making processes in state, county, and city governments. Therefore, the ILWA will work on establishing a connection between the researchers in the project teams and water resource agencies across Utah.

To demonstrate our support for this project, we commit to providing a contribution of $22,127 in total for an in-kind donation ($15,155 for personnel with $6,972 F&A costs) to serve as a partial match for the federal Bureau of Reclamation's funding request. These supports will encompass funding and in-kind contributions with various costs, including staff salaries, fringe benefits, professional insights related to the needs of water agencies, and communication expenses. There are no additional contingencies associated with this funding commitment.

Sincerely,

Brian Steed
Executive Director, JQL Institute for Land, Water, and Air
State of Utah Great Salt Lake Commissioner

October 2, 2023

Yoshimitsu Chikamoto
Associate Professor,
Department of Plants, Soils and Climate
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820

Re: WaterSMART Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs

Dear Dr. Chikamoto,

We are writing to express the Central Utah Water Conservancy District's support for the prospective project proposal, "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs." We understand that the project comprises a team of researchers from Utah State University who require a water manager's perspective regarding the long-term forecasts of the Colorado River water supply and large reservoirs.

Central Utah Water's primary responsibility is to deliver clean, usable water to our customers by managing the Central Utah Project and District network of water facilities. Every day, we work to maintain and improve those systems. We monitor and track precipitation levels and make decisions on how best to serve current customers and store water for future generations. We collaborate with large water users to develop ways to use water more efficiently and engage the public in activities promoting conservation. Additionally, we operate three water treatment facilities, two hydroelectric plants, and nine reservoirs while providing services to participating counties. The multi-year water supply forecasts proposed in this project provide a unique aspect for consideration in our long-term planning process. Therefore, collaborating with the team members in the proposed project is crucial for us to articulate the project outcomes appropriately.

We will provide $12,000 in in-kind contributions to satisfy a partial match to the federal Bureau of Reclamation's request during the project period. This includes the costs related to personnel communication and services for our manager's participation in training, meetings, webinars, and workshops, as well as providing information regarding the needs of the Central Utah Water Conservancy District. The estimated cost consists of personnel salary and fringe benefits at a rate of $100/hour, with an estimated 60 hours each year. There are no other contingencies associated with this funding commitment.

Sincerely,

Bart Leeflang Digitally signed by Bart Leeflang
Date: 2023.10.02 15:00:03 -06'00'

Bart Leeflang
Central Utah Water Conservancy District

SOUTHERN NEVADA WATER AUTHORITY™
100 City Parkway, Suite 700 • Las Vegas, NV 89106
MAILING ADDRESS: P.O. Box 99956 • Las Vegas, NV 89193-9956
702-862-3400 • snwa.com

September 13, 2023

Yoshimitsu Chikamoto
Associate Professor
Department of Plants, Soils and Climate
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820

SUBJECT: LETTER OF SUPPORT AND IN-KIND COMMITMENT

Dear Dr. Chikamoto

I am delighted to write this letter of support for the proposal entitled "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs." The Southern Nevada Water Authority (SNWA) is an active participant in the Colorado River Climate and Hydrology Work Group, a voluntary consortium comprising federal, state, and local water management agencies, along with other contributors who share a common goal:

- Advancing scientific understanding to enhance the accuracy of hydrological forecasts and projections.
- Improving the performance of predictive tools.
- Gaining a better understanding of the uncertainty related to future supply and demand conditions in the Colorado River Basin.

I have reviewed the proposal and believe that it, and other similar efforts, could be helpful for enhancing long-range water supply forecasts for the Colorado River Basin. In support of this project, SNWA commits to providing an in-kind contribution in the form of staff time, not exceeding $8,730 (equivalent to 80 hours at a rate of $75/hour with 45.5% in fringe benefits). This contribution can be used as a partial match for the Bureau of Reclamation's funding request. SNWA is submitting a separate proposal potentially funded by the WaterSMART program and the commitment made here is separate and apart of any other commitment made by SNWA.

I support this proposal and eagerly anticipate the utilization of this information to enhance water management strategies.

Sincerely,

Seth A. Shanahan
Manager, Colorado River Program
Southern Nevada Water Authority

ERIN MENDENHALL
Mayor

DEPARTMENT OF
PUBLIC UTILITIES

September 29, 2023

Yoshimitsu Chikamoto
Associate Professor,
Department of Plants, Soils and Climate
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820

Re: WaterSMART Application for a Science Grant through the Bureau of Reclamation

Dear Dr. Chikamoto

Salt Lake City Department of Public Utilities (SLCDPU) is in support of the proposed project, "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs." This project, led by a team of researchers from Utah State University, seeks input from water planners to advance multi-year-to-decadal forecasts of the Colorado River water supply and Great Salt Lake elevation.

The Salt Lake City Department of Public Utilities proudly serves as the oldest water provider in the Western United States. Our mission is to serve and safeguard our community and environment by equitably, sustainably, and efficiently providing top-quality water, wastewater, stormwater, and street lighting services. The Project will benefit SLCDPU and our mission.

In support of this project, SLCDPU commits to provide $8,000 in in-kind contributions to serve as a partial match for the Federal Bureau of Reclamation's funding request. These contributions will start upon the project's funding approval and will cover various costs, including staff salaries, fringe benefits, professional information regarding the needs of water agencies, and other communications. SLCDPU's personnel will be billed at a rate of $160 per hour, with 25 hours allocated for each year of the project duration. There are no additional contingencies associated with this funding commitment.

Sincerely,

Jesse A. Stewart
Deputy Director

TEL: 801-483-6900 FAX: 801-483-6818

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Colorado Basin River Forecast Center
2242 West North Temple
Salt Lake City, UT 84116

September 7, 2023

Yoshimitsu Chikamoto
Associate Professor,
Department of Plants, Soils and Climate
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820

Subject: Letter of Support for the "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs" Proposal

Dear Dr. Chikamoto,

I am writing to express our wholehearted support for the proposal titled "WaterSMART: Enhancing Multi-Year-to-Decadal Forecasting for the Colorado River Water Supply and Large Reservoirs."

The National Weather Service (NWS) Colorado Basin River Forecast Center (CBRFC) has a longstanding history of providing seasonal water supply forecasts. These forecasts are instrumental for critical decision-making by the Bureau of Reclamation and other key water managers across the Colorado River Basin, with significant economic repercussions for the region.

Our seasonal forecasts at the CBRFC are built upon a foundation of understanding streamflow inputs within our jurisdiction. The proposed application research promises to augment our knowledge and potentially extend our forecasting capabilities to longer-term horizons.

The CBRFC relies on the Ensemble Streamflow Prediction system (ESP) as the cornerstone of our seasonal water supply forecasts. This system generates 30 traces for each forecast site, utilizing historical temperature and precipitation data spanning from 1991 to 2020, applied to the current model states. We continuously look for ways to improve our forecasts, and any improvement is of great value to our stakeholders, who depend on our forecasts to make highly impactful decisions. We are interested in your proposal because it has the potential to improve our forecasts and services, and we have succesfully worked with you in the past.

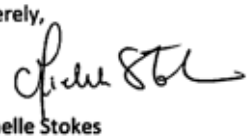
To underscore our support for this project, we are committed to providing an in-kind contribution totaling $16,400. This contribution will serve as a partial match for the federal

Bureau of Reclamation's funding request. Our contribution will encompass various expenses, including staff salaries, fringe benefits, travel expenses, professional insights related to water supply forecasts, and communication costs. Importantly, there are no additional contingencies tied to this funding commitment.

Position	Hours	Hourly Rate with fringe benefits	Total
Hydrologist in Charge	20	$120/hour	$2400
Development and Operations Hydrologist and Service Coordination Hydrologist	80	$100/hour	$8000
Hydrologists	80	$75/hour	$6000
Total	170		$16400

We are looking forward to working with you.

Sincerely,



Michelle Stokes
Hydrologist in Charge, CBRFC