Developing a Projection Tool for Otowi Index Supply and Elephant Butte Effective Index Supply

Submitted by:
New Mexico Interstate Stream Commission
407 Galisteo Street
Bataan Memorial Building
P.O. Box 25102
Santa Fe, NM 87504-5102

Project Manager:
Shalamu Abudu. Ph.D.
Water Resources Modeling Chief
Rio Grande Bureau, New Mexico Interstate Stream Commission
5550 San Antonio Drive, NE
Albuquerque, NM 87109-4127
PH: (505) 383-4046
FAX: (505) 383-4045
shalamu.abudu@state.nm.us

TABLE OF CONTENTS

List of Figures:

List of Tables:

LIST OF ACRONYMS

Acronym	Definition
ABCWUA	Albuquerque Bernalillo County Water Utility Authority
AMO	Atlantic Multidecadal Oscillation
ANN	Artificial Neural Networks
AOP	Annual Operating Plan
ARIMA	Autoregressive Integrated Moving Average
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
CDC	Climate Prediction Center
DM&AI	Data Mining and Artificial Intelligence
DMI	Data Management Interface
EB	Elephant Butte
EBEIS	Elephant Butte Reservoir Effective Index Supply
EBID	Elephant Butte Irrigation District
ENSO	El Niño-Southern Oscillation
LFCC	Low Flow Conveyance Channel
MRG	Middle Rio Grande
MRGCD	Middle Rio Grande Conservancy District
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Policy Act
NMSU	New Mexico State University
NetCDF	Network Common Data Form
NLDAS	North American Land Data Assimilation System
NMISC	New Mexico Interstate Stream Commission
NOAA	National Oceanic and Atmospheric Administration
Noah-LSM	Noah Land Surface Model
NRCS	Natural Resources Conservation Service
NWM	National Water Model
OIS	Otowi Index Supply
PDO	Pacific Decadal Oscillation
PDSI	Palmer Drought Severity Index
PLSR	Partial Least Squares Regression
PRMS	Precipitation Runoff Modeling System
Reclamation	Bureau of Reclamation
RF	Random Forest
SOI	Southern Oscillation Index
SVR	Support Vector Regression
TFN	Transfer function-noise
URGWOM	Upper Rio Grande Water Operations Model
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WRF-Hydro	Weather Research and Forecasting Hydrological model

TECHNICAL PROPOSAL AND EVALUATION CRITERIA

1. Executive Summary

New Mexico Interstate Stream Commission (NMISC), headquartered in the City and County of Santa Fe, New Mexico, submitted this proposal on October 28, 2019 to Bureau of Reclamation's WaterSMART Applied Science grant program - 2019 FOA (BOR-DO-19-F012). The project entitled ***"Developing a Projection Tool for Otowi Index Supply and Elephant Butte Effective Index Supply"*** will be directed by Dr. Shalamu Abudu, with co-principal investigators Chris Stageman, Page Pegram, and Cindy Stokes.

In the Rio Grande Basin of Colorado and New Mexico, the water management challenges posed by a highly variable and extremely limited water supply have been exacerbated by prolonged drought. Particularly, in the Middle Rio Grande (MRG) Basin of New Mexico, a variety of water management objectives become increasingly challenging as the region adjusts to declines in water supply and increases in water demand. To respond to these challenges, it is critical to develop improved water management strategies to increase water supply reliability, flexibility in water operations in this three-state (and international) basin. The goal of this project is to investigate obtaining better skills in water supply forecasts in the Rio Grande basin within New Mexico as shown in **Figure 1** (e.g., Otowi, San Marcial, Below Elephant Butte (EB) Dam), and develop a long-range streamflow projection tool for Otowi Index Supply (OIS) and the Elephant Butte Effective Index Supply (EBEIS) that are critical for water management in the MRG. Benefits of a projection tool are improved water supply forecasts, which will benefit water users in the Middle Rio Grande (MRG) basin, including agriculture, municipalities and endangered species.

The specific objectives and research efforts for the proposed project are: 1) conduct a literature review, create a data inventory and gain a better understanding of the impacts of climate variability on streamflow in the Rio Grande. 2) explore various modeling techniques and the current resources available (e.g., data mining and artificial intelligence (DM&AI) techniques, and Natural Resources Conservation Service (NRCS)'s water supply outlooks in New Mexico) for long-range projection to gain better forecasting skill. 3) investigate the integration of the outputs from precipitation-runoff models that are available in the basin into the Upper Rio Grande Water Operation Model (URGWOM). Also, explore the inclusion of climate scenarios and forecasts in watershed models and URGWOM to improve reservoir inflow projection with monsoon precipitation runoff as input. 4) perform model selection and combination of multi-models for projection of flows, and develop a user-friendly spreadsheet-based tool for combining forecasts and assisting decision-making regarding water management in the MRG. These objectives are addressed in six tasks in the research work plan and the project will be completed within two years from the time of award, or approximately January 2020 to December 2021. The project is not located on a federal facility. We are requesting a total of $141,271.92 federal funding and will contribute $147,038.11 of non-federal funding as cost share to complete the project **(Table 2).**

The product of this project, the improved long-range forecasting approaches and a spreadsheet-based streamflow projection tool, will assist water managers in the basin to make informed water management decisions, increase water supply reliability, and enhance resiliency in water management. The proposed project directly addresses Reclamation's research objectives and priorities as listed in 2019 FOA (BOR-DO-19-F012): 1**)** *Develop or improve hydrologic information, water management tools, and modeling and forecasting capabilities. Results from* *these projects will be used by water managers to increase water supply reliability, provide flexibility in water operations, and improve water management* **(Section C.3.).** 2). *Enhance modeling capabilities to improve water supply reliability and increase flexibility in water operations* **(Section C.3.1. (1)).** 3) *Improve or adapt forecasting tools and technologies to enhance management of water supplies and reservoir operations* **(Section C.3.1. (3)).**

2. Technical Project Description and Milestones

2.1 Background and Introduction

In recent years, New Mexico's ability to meet a variety of water management objectives has become increasingly difficult as the region adjusts to climate change, declines in water supply, and increased water demands. Hydrological changes and frequent extreme droughts in the basin have been causing economic losses, depletion of regional aquifers, and other negative impacts on community development and ecosystem health. These challenges motivated many researchers and water managers to seek better water management strategies to increase water resiliency in the basin. Many studies have been conducted in understanding streamflow patterns and their variations with a changing climate and reliable prediction of future hydrologic variations and drought conditions in the basin (e.g., Abudu et al., 2011; Chavarria and Gutzler, 2018). At present, NRCS's water supply outlooks at Otowi and San Marcial gages provide snowmelt season (March-July) streamflow forecasts for water management in the MRG.

Based on the historical water supply outlook records, the Otowi gage forecast is relatively accurate and has been utilized extensively by water managers in the MRG. However, the accurate projection of EB inflow or EBEIS is challenging. First, the EBEIS is defined as the release from EB Dam plus the change in storage in EB Reservoir which is difficult to predict since it is entirely regulated flow. Secondly, EB Reservoir is located at the most southern end of the MRG. Although snowmelt runoff in the basin dominates the EB Reservoir inflow, the contribution from monsoon precipitation runoff between Otowi gage and EB Dam can also be significant. In an average year, tributary inflows between Otowi gage and EB Dam total about 100,000 acre-feet plus an unknown amount from minor ungaged tributaries (Gaume, 1999). Extreme precipitation events substantially contribute to the total runoff in the MRG (Towler et al., 2019). However, the prediction of precipitation events during the monsoon season and its contribution to the annual runoff at EB Reservoir with acceptable accuracy is extremely difficult.

Additionally, there are no resources or tools available to project post-snowmelt season (August-December) streamflow volume in the MRG. URGWOM Annual Operating Plan (AOP) runs use the hydrograph that is generated from the closest historical year based on the NRCS's most updated March-July seasonal volume forecast at Otowi gage (URGWOM Technical Team, 2018). During an AOP run, the local inflows between Cochiti and EB reservoirs are set to zero due to high uncertainty of local inflow volumes within this reach. Based on our initial analysis, the URGWOM AOP runs in recent years underestimated the annual EBEIS projection by 50,000-100,000 acre-feet. Currently, water managers rely on other methods, e.g., simple average of the three most hydrologically similar years, exceedance probability analysis of historic EBEIS, and expert guidance to project EBEIS to inform decision-makers and stakeholders. Therefore, the existing resources and tools regarding EBEIS projections in New Mexico need to be updated and improved to allow the NMISC to accurately predict the streamflow at Otowi gage and flow arriving at Elephant Butte Reservoir. The more accurate prediction of OIS and EBEIS will greatly improve the State's ability to estimate EBEIS earlier in the year and to determine what management strategies should be taken to manage water deliveries. The improved forecasting methods and runoff forecasts can also be used to develop more accurate water supply outlooks in the region, empowering stakeholders in the basin to manage and plan their water use more effectively.

2.2 Project Objectives

The overarching goal of this proposed project is to investigate obtaining better skills in water supply forecasts at the Middle Rio Grande basin (Otowi, San Marcial, below EB Dam), and to develop a long-range streamflow and reservoir inflow projection tool for OIS and EBEIS. NMISC will use these improved modeling and forecasting capabilities to inform water management decisions. The specific objectives for the proposed project are:

- Conduct data collection and analysis, data update and fusion, create a data inventory; perform a literature review and gain a better understanding of the impacts of climate variability on streamflow in the Rio Grande. Identify and explore the spatial and temporal connections between various oceanic-atmospheric climate indices and local climate variables with hydrologic drought and surplus in the basin.
- Explore various modeling approaches for improving the long-range projection of Otowi natural flow and OIS, San Marcial natural flow and EBEIS using the current resources and modeling techniques available, such as improved NRCS water supply outlooks, statistical and DM&AI techniques.
- Investigate the integration of the outputs from precipitation-runoff models that are currently available in the MRG into URGWOM. Also, explore the inclusion of climate scenarios and forecasts into watershed models and URGWOM to improve EBEIS projection with the inclusion of monsoon precipitation runoff in the streamflow projection.
- Perform selection procedures on the models in the previous tasks and identify potentially better approaches and combinations of multi-models for the projection of OIS and EBEIS. Finally, develop a simple and user-friendly interface within a customized spreadsheet-based tool for combining forecasts and assisting decision-making regarding water management in the MRG.

2.3 Project Tasks and Deliverables

This study will explore parametric and non-parametric DM&AI approaches, and distributed watershed models (e.g., Noah Land Surface Model (Noah LSM) and Precipitation-Runoff Modeling System (PRMS)) and their linkage with URGWOM. These approaches will help to characterize and predict streamflows at Otowi and San Marcial gages, and EB Reservoir inflow which shape water operations and management decisions within the MRG. To accomplish the above-mentioned objectives, we propose the following tasks and approaches:

Task 1: Assessment of Hydrologic Models and Hydrologic Data for the Projection of OIS and EBEIS

Phase 1. Literature review, a survey of on-going research projects and hydrological models that are associated with tracking flow in the MRG

- *Conduct a literature review on seasonal streamflow forecasting*

In recent decades, there have been significant advances in long-range streamflow forecasting in the United States and worldwide. Numerous forecasting techniques, including multivariate statistical models, physically based hydrologic models, time series analysis, and soft computing (e.g., artificial neural networks (ANNs), support vector regression (SVR), and model trees), have been developed to simulate hydrological time series. In this project, we will conduct a comprehensive literature review on the currently available techniques, and research results for long-range seasonal streamflow and reservoir inflow forecasting in the western United States and worldwide. Through a literature search, we will identify advances in improving forecast accuracy and summarize strengths and weaknesses of different approaches and their applicability in the snowmelt-dominated arid river basins, and propose the most suitable methods that can be used in the MRG for improving current tools in long-range streamflow forecasting in the basin.

- *Investigate and summarize hydrologic models and research projects in the MRG*

A number of different models have been developed in the MRG for water management and long term planning and environmental law compliance. We will conduct a detailed survey on publicly available surface-water models, groundwater models, and river and reservoir operation models. In addition, we will communicate with Reclamation, the NRCS, the National Weather Service (NWS), the National Center for Atmospheric Research (NCAR) National Aeronautics and Space Administration (NASA)'s Hydrological Sciences Laboratory, the National Oceanic and Atmospheric Administration (NOAA)'s Office of Hydrological Development (OHD), and NOAA's Climate Prediction Center (CPC) and the United States Geological Survey (USGS) to explore their on-going efforts with long-range streamflow forecasting, quantifying monsoon precipitation runoff, coupling of hydrometeorological and hydrological models, and linkage with river and reservoir operation models in the Rio Grande basin. Based on the survey, we will review and document relevant characteristics of all hydrologic models in the basin including model features, model assumptions, applicability and possible weak points for future improvement. Finally, we will suggest the best suitable models that can be utilized to address the objectives of this project.

Phase 2: Identifying, gathering, updating and compiling hydrologic data

- *Identify hydrological data needs and establish a data inventory for OIS and EBEIS projection*

The foundation of water supply forecasting is data. To accomplish project objectives, the first step is to identify various hydrological data that are needed for the specific purpose of this project. Based on the hydrologic model survey and literature review of Phase 1 of Task 1, we will identify data types that are needed and create a data inventory with an annotated list of datasets that will enable us to locate, manage, use and share data effectively. The main data source for the purpose of this project is snowpack and climate monitoring stations in the snow telemetry (SNOTEL) system. Other data sources commonly used in forecast development are the NRCS manual snow course network, the NWS's cooperative climate network, and the USGS's streamgaging network. Additional data types may include local climate and hydrological elements such as temperature, drought indices, groundwater levels, and soil water content and large-scale climate teleconnections such as El Niño-Southern Oscillation (ENSO) related to future weather and streamflow.

- *Construct an automated data retrieval system for ensuring timely data updating and operational projection of OIS and EBEIS*

Based on the data inventory created in the previous step, we will develop a spreadsheet-based tool to extract the most recent hydrometeorological and hydrological data in the basin from various online sources into Microsoft Excel®, perform quality assurance and quality control (QA/QC), compiling, formatting, fusion, conversion and archiving. This is important for the execution of later tasks to prepare high quality input data for the OIS and EBEIS projection, data manipulation, reporting, and dissemination. We will also explore the possibility of managing data in cloud services with web services to allow stakeholders direct access to the OIS and EBEIS projection data toward the end of a year. The process enables integration of important federal, state, and local datasets by leveraging recent progress on open data access and standards, which will make the data shareable. This step will also complement the spreadsheet-based OIS and EBEIS projection tool, which will be completed in Task 5.

Deliverables:

- A survey and literature review report categorizing the advantages and drawbacks of currently available technical resources in the MRG that can be utilized to improve prediction of OIS and EBEIS.
- A detailed data inventory that is needed to develop the OIS and EBEIS projection tool.

Task 2: Develop Monthly, Seasonal and Annual Streamflow Forecasting Models Using Statistical and DM&AI Techniques

Phase 1. Investigate relationships between streamflow and oceanic-atmospheric climate indices and local climate variables

Previous research has shown the relationship between the streamflow variations of the western United States and climate variability in the form of oceanic-atmospheric oscillations, e.g., ENSO, Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO). Several studies have sought to identify the relationships between these oscillations and streamflows in the Rio Grande basin. Redmond and Koch (1991) suggested that there is a negative correlation between the averaged June-November Southern Oscillation Index (SOI) and average monthly October-March streamflow and precipitation for the southwest United States. NRCS (1997) completed an analysis of the correlation of SOI with spring and summer runoff volume in the western United States and found that the Rio Hondo and Lower Rio Grande March-July flow have the highest correlation coefficients with previous October-December SOI index. Abudu (2009) reported that the EB Reservoir March-July flow has significant correlations with previous October- December SOI index, and the correlation coefficients are less than -0.35 in some parts of the MRG. The signal strength of these oscillation indices may vary spatially in the basin. It is thus important to identify the influential oscillation indices, or their combinations, and corresponding lead times that can be used to develop the best prediction models, and couple them with the streamflow projection analysis to improve long-range prediction accuracy of streamflow variability in the basin.

To identify potential predictors and their significant lag time for natural flows at Otowi and San Marcial gage stations, we will carry out a cross-correlation and predictivity analysis for the time periods when sufficient data are available between the oceanic-atmospheric climate indices, local precipitation, temperature and streamflows at Otowi and San Marcial gage stations at seasonal and annual time scales. This will give us some insights into the linear relationships between time series, and allow us to select preliminary predictors and significant lag time, and possible prediction lead time. We can also examine decision tree and nearest neighbor methods that can capture the nonlinear relationships between these climate indices and streamflow. Skilled predictors for seasonal streamflow forecasting will be identified for both snowmelt season (March-July) and post-snowmelt season (August-December) in the MRG. These indices may include, but are not limited to, ENSO, PDO, AMO, NAO, precipitation, temperature, zonal wind speed, meridian wind speed, geopotential height, relative humidity, soil moisture, palmer drought severity index (PDSI), and Z-index (ZNDX). Once we initially identify possible skilled predictors, they will be used to develop forecasting equations and models by performing detailed variable selection procedures using Partial Least Squares Regression (PLSR) and Random Forest (RF) approaches in the following Phases of Task 2.

Phase 2. Develop improved seasonal streamflow forecast equations similar to NRCS's operational water supply outlooks for snowmelt season at Otowi and San Marcial gage stations

Water supply outlooks in the western United States are issued jointly by the NWS River Forecast Centers (RFCs) and NRCS. They are significant components in effective water management and are utilized by a broad spectrum of users for a variety of purposes, ranging from irrigated agriculture, flood control, municipal water supply, endangered species protection, power generation, and recreation (Pagano, 2005). The primary operational method of seasonal streamflow forecasting in the western United States is the regression of seasonal streamflow volume on indicator variables, primarily point observations of snow-water equivalent (Wood and Lettenmaier, 2006). The principal components regression has been the standard methodology used by NRCS.

In this project, we will employ more robust modeling techniques including PLSR and RF approaches to develop a new set of forecasting equations and models for Otowi natural flow and San Marcial natural flow as comparable to NRCS forecast equations at these streamgage points. The attractive feature of PLSR is that the regression is based on the principal components of both predictors and response variables. Tootle et al. (2007) and Abudu et al., (2010) applied the PLSR in long lead-time seasonal streamflow forecasting, and their research suggests that the PLSR could provide strong forecast skill in long lead-time seasonal runoff volume forecasts. Random Forest is a non-parametric approach that is very robust in preventing overfitting problem and has the functionality of searching for significant predictor variables. The application of PLSR and RF approaches in the seasonal streamflow forecasting is starting to draw the attention of hydrologists in recent years due to the fact that the PLSR could improve model forecasts by dealing with multicollinearity issues, while RF could improve forecast accuracy by modeling nonlinear relationships between input and output variables efficiently without any normality and linearity assumption of the streamflow processes.

We will develop parametric and non-parametric seasonal forecast models from January 1st to June 1st of each year. They include linear statistical forecasting equations developed by PLSR and nonlinear, non-parametric models developed by RF approach for Otowi natural flow and San Marcial natural flow. We will generate snowmelt season (March-July) streamflow volume forecasts similar to NRCS's current water supply outlooks at these two gage stations as an alternative option for improved URGWOM AOP runs in Task 4.

Phase 3. Develop monthly, seasonal and annual forecast models to complement snowmelt season water supply outlooks

NRCS's water supply outlooks are for snowmelt season (March- July) and there are no official forecasts for post-snowmelt season (August-December) streamflow in the MRG. URGWOM AOP runs use the post-snowmelt season hydrograph that is generated from the closest historical year based on the NRCS's most updated March-July seasonal volume forecast at Otowi gage. Previous research indicates that the central and southern parts of New Mexico are influenced by the North American Monsoon during summer, which results in significant contributions to annual precipitation (Gutzler 2013). Towler et al. (2019) reported that although monsoon season streamflow volumes vary from year-to-year, they are an important contribution to annual water supply in New Mexico. To account for the impacts of monsoon precipitation and other climate variables on the Rio Grande streamflow, we will explore the following methodologies to create prediction models for OIS and EBEIS, test model accuracies, and operationality.

- *Develop stochastic time series models for monthly and seasonal rolling forecast updates*

Time series analysis is one of the most popular forms of data-driven modeling for streamflow forecasting. In this phase of work, we will explore the application of monthly and seasonal time series models in the basin. We will develop monthly and seasonal time series models that both include univariate time series models (e.g., Autoregressive Integrated Moving Average (ARIMA)) that account for streamflow persistency, and Transfer function-noise (TFN) models with exogenous variables (e.g., precipitation, snowpack or temperature). The predictor variables will be selected based on the work in Phase 1 of Task 2 and the principle of developing a parsimonious model. The ARIMA and TFN models are linear models that cannot account for nonlinear relations between predictors and predictand. To overcome this, we will also explore ANN and RF approaches using the same predictor variables that are identified in Phase 1 of Task 2 and time series modeling procedure. Based on the updated real-time data in the basin, we will generate one-to three-months ahead, and one-season ahead forecasts on the first day of each month to update the monthly flow hydrograph through the end of a year.

- *Develop regression and non-parametric models for the post-snowmelt season and annual streamflow volume*

Based on the analysis in Phase 1of this Task, we will explore the application of DM&AI techniques (e.g., PLSR, ANN, and RF) to project post-snowmelt season (August-December) and annual streamflow volume including OIS and EBEIS in the basin. We will perform jack-knife, k-fold cross validation techniques to overcome the small sample size and overfitting issues in developing these models. We will use forecast results from these models with combinations of monthly and seasonal forecast updates from time series models (previous step) to update the monthly hydrograph when the new data are available. The updated monthly hydrograph will also be imported to the URGWOM model in Task 4 to update URGWOM AOP runs and update EBEIS projection through the end of a calendar year.

Deliverables:

- A summary report on the significant atmospheric and local climate variables that have impacts on the streamflow in MRG.
- A group of modified forecast equations and models similar to NRCS's equations for operational water supply outlooks for snowmelt season.
- A group of monthly and seasonal time series models; regression and non-parametric models for post-snowmelt and annual streamflow for natural flow at Otowi and San Marcial gage stations, OIS and EBEIS.

Task 3. Analysis and Utilization of Simulated Ungaged Runoff Results from Watershed Models

Based on the outcomes from Task 1, we will identify and select several currently available precipitation-runoff watershed models for the Rio Grande basin. We will use these models to generate ungaged historical local rainfall runoff into the Rio Grande main stem or utilize the local runoff data that were already generated from these calibrated watershed models as input to URGWOM.

Phase 1. Analyze and utilize historical ungaged runoff simulation results from watershed models in the MRG

We will investigate the characteristics and accuracy of historical ungaged runoff datasets simulated from watershed models in the MRG. These datasets will be evaluated by comparing archived model results to the historical flows at USGS gaging locations within the basin.

- *North American Land Data Assimilation System (NLDAS-2) Noah Land Surface Model (Noah LSM) Results*

The main NLDAS Phase 2 product is an hourly 30-year (January 1979 to present, in near real-time with a four-day lag) 1/8th-degree surface meteorology and hydrology dataset over the contiguous United States, southern Canada, and northern Mexico. We will explore hydrologic data (e. g., ungaged local arroyos in the MRG if available) from this dataset. We will be collecting hourly NLDAS runoff and baseflow data downloaded from https://ldas.gsfc.nasa.gov/nldas as text files for the period 1/1/1980-present. These data will be downloaded, labeled (with the latitude and longitude of the inflow point), aggregated to daily time-step data, and analyzed using scripts written in the R language. The results of these analyses will be stored in Microsoft Excel® spreadsheets. These text files will be automatically downloaded with extensive metadata. We will check data quality and availability for possible input for URGWOM recalibration in Task 4.

- *Precipitation-Runoff Modeling System (PRMS) Model Results*

Precipitation-Runoff Modeling System (PRMS) is a modular, physically-based, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on surface-water runoff and general basin hydrology. USGS's New Mexico Water Science Center is currently collaborating with Reclamation's Albuquerque Area Office on Rio Grande Basin Study. They will be using the PRMS model along with climate projections running up to 2099 as inflows for the URGWOM. The PRMS model is being calibrated for the Rio Grande watershed from the headwaters to Fort Quitman, Texas to predict the naturalized flow. USGS is utilizing a unique multi-step hierarchical calibration plan (to calibrate multiple facets of streamflow volume, flashiness, and timing) that was validated in several subbasins scattered throughout the basin (that have little to no withdrawals or infrastructure thus representing near-native or a naturalized flow regime). USGS is planning to release a published report, data, and archived model by the end of December 2019 (Charles Moeser, USGS, personal communication). In this effort, we will also utilize the PRMS model results for Rio Grande watershed upstream from EB Dam once the calibrated model results are publicly available. We will collect historical runoff data in the basin, identify and locate inflow points for ungaged local arroyo runoff if available, and through performing certain reformatting and data processing, prepare historical daily local precipitation runoff data for analysis and input for URGWOM in Task 4. We will collaborate with USGS and Reclamation to keep updating the PRMS model with up-to-date climatic data to provide an estimate of daily streamflow in near real-time so that we will be able to use the quantity and timing of streamflow data at ungaged local arroyos for updating URGWOM input and the OIS and EBEIS projection tool that will be developed in Task 5.

Phase 2. Future projection of ungaged precipitation runoff for URGWOM inputs

In support of the projection tool for OIS and EBEIS that will be developed in Task 5, we need to project local ungaged precipitation-runoff and include them in URGWOM AOP runs in Task 4. To accomplish this, we will select and evaluate National Water Model (NWM)'s 30-day ensemble output to determine if it is applicable, and we will also use a simple resampling method to generate different scenarios to run URGWOM for probabilistic projections:

- *Evaluate and utilize the NWM's 30-day ensemble output*

The National Water Model (NWM) is a hydrologic modeling framework that simulates observed and forecasted streamflow over the entire continental United States. The NWM is a collaborative effort among several academic and federal research partners, and is a streamflow forecasting tool based on the Weather Research and Forecasting Hydrological model (WRF-Hydro) and Noah LSM frameworks developed by the NCAR. We will evaluate and utilize NWM's 30-day ensemble output product, which cycles four times per day and produces a daily 16-member 30-day ensemble forecast. The 30-day ensemble forecast streamflow data will be downloaded from NOAA's website https://nomads.ncep.noaa.gov/ as Network Common Data Form (NetCDF) files for the current day through 30 days in the future. We will develop an automated tool to retrieve and summarize streamflow forecasts from the NWM. These data will be downloaded, labeled, and analyzed using scripts written in the R language, and the results of these analyses will be stored in Microsoft Excel® spreadsheets for later use as inputs to URGWOM for updated EBEIS projection.

- *Resampling of historical ungaged runoff data to generate stochastic scenarios*

To project local ungaged precipitation runoff for URGWOM inputs in Task 4, we will utilize a simple resampling of historical ungaged local inflow data from the NLDAS2 dataset and PRMS model results to generate stochastic scenarios for several months ahead. To overcome the lack of current conditions of the basin and climate in this approach, we will also test using aforementioned DM&AI methods to generate an ensemble of previous years' precipitation-runoff based upon a statistical comparison of current climate indices to those of prior years, to project streamflow for the next several months. The combination of the short-term physical-process-based forecast using NWM output or similar and statistical-based longer-term forecast will provide the seasonal runoff forecasts necessary for enhancement of EBEIS accounting projections in Task 4.

Deliverables:

- A report on the currently well-developed precipitation-runoff models in MRG, their strengths and weaknesses related to the development of ungaged local precipitation data, and possible improvement in the future.
- Historical ungaged local precipitation runoff database and stochastic scenarios for the MRG.

Task 4: Update and Modify the URGWOM for Improved EBEIS Projection

URGWOM is an operations model of the Rio Grande basin, beginning at its headwaters in the San Juan Mountains of Colorado, and ending 700 miles downstream in Hudspeth County, Texas. The URGWOM is a rule-based, daily or monthly computational model, which simulates physical processes and operations of facilities in the Rio Grande basin, including reservoir storage, releases, and flood control, flow routing, open-water evaporation and precipitation, riparian evapotranspiration, seepage, baseflow, deep groundwater flow, river diversions, canal flow, irrigation, groundwater pumping, crop consumptive use, irrigation return flows, municipal and industrial diversions and return flows, and much more. Water managers use URGWOM as an accounting model to track reservoir operations, diversions and depletions with actual year-to-date data, which is updated approximately every 1 to 5 days. Water managers also use URGWOM with operating rules in conjunction with NRCS's water supply outlooks for AOP runs to project what the status of deliveries to different users will be and what future reservoir storage could be in a calendar year. The URGWOM technical team, which formed from many different agencies, meets monthly to discuss URGWOM development and the results of URGWOM model runs. The URGWOM technical team has a shared FTP site hosted by the USGS where the official model, databases, and documentation are maintained, with older versions archived. In this proposed project, we will utilize this powerful tool as a primary method for improved EBEIS annual projection through performing model updates, modification of rules, recalibration, and validation.

Phase 1. Recalibration of URGWOM using historical ungaged local runoff database

We will configure URGWOM to run in calibration mode, using daily historical data from 1980-2017. Currently, URGWOM models zero ungaged local runoff between Cochiti and EB Reservoirs. Therefore, we will include the historical ungaged local runoff database for the MRG developed during Task 3 for this calibration. We will recalibrate the physical parameters of URGWOM on the river reach between Cochiti and EB Reservoirs. It is expected that this will result in more accurate AOP runs. These physical calibration parameters will include riverbed hydraulic conductivities, river open water evaporation coefficients, groundwater parameters (such as hydraulic conductivity, specific yield, anisotropy ratios), and canal seepage coefficients. The physical calibration targets will include river and canal gage data, and groundwater level observations. The methods used, the calibration parameters, the calibration targets, and calibration results will be documented and shared with URGWOM technical team and other stakeholders.

Phase 2. Utilizing ungaged local runoff projections in URGWOM AOP runs

We will utilize the URGWOM's AOP run platform each year to project what the natural flow (flow adjusted for storage in upstream reservoirs and trans-mountain diversions) at Otowi will be, and what the delivered flow at EB Reservoir will be. EBEIS is a function of these two variables. In order to improve the URGWOM AOP projection of the delivered flow at EB Reservoir, more accurate projections of the ungaged local runoff between Otowi and EB are necessary. Therefore, we will take the 30-day dynamical runoff forecast outputs and the subsequent ensemble of statistically derived multi-month forecasts described in Task 3, and plug these into the URGWOM AOP run. The model updates and AOP run results will also be shared with URGWOM technical team and other stakeholders.

Deliverables

- A new version of the official URGWOM model with new data management interfaces (DMIs) to automatically bring in the 30-day dynamical runoff forecast, and multi-month statistical forecast developed during Task 3. The updated URGWOM model will also have recalibrated physical parameters. The URGWOM technical team will maintain this new model on their shared FTP site.
- A report documenting the new additions to the URGWOM model, and calibration results using the historical ungaged local runoff database developed in Task 3.

Task 5: Develop a Spreadsheet-Based Tool for Combining Forecasts and Reporting Projection Results

Streamflow prediction, particularly the long-range projection of streamflow volume, is a challenging task due to the complexity of the hydrologic system. There is no single streamflow prediction model that provides better forecast results under all circumstances with respect to alternative competing models. Every model has some degree of uncertainty, including structure and parameter uncertainty (Shamseldin et al., 1997). Therefore, the reliance of a single model in streamflow prediction may result in considerable risk in water management if that model fails to provide reliable predictions. A possible approach to overcome this deficiency is the combination of forecasts from different individual models and integration of these models which may provide better forecasting solutions than a single model. The forecast combination and/or integration of different model results are a viable option to improve prediction accuracy. In this proposed work, we will utilize several forecast combination approaches to combine/integrate the forecast results of different models to improve the accuracy of long-range projection of OIS and EBEIS. This will be carried out by developing and utilizing a spreadsheet-based projection tool.

Phase 1. Develop a spreadsheet-based tool for forecast combination

We will develop a simple and user-friendly interface to create a customized spreadsheet-based model in Microsoft Excel® that combines different forecast approaches as described in Tasks 2, 3, and 4 in order to improve the projection accuracy and decrease model prediction bias. We are envisioning that the tool is capable of performing the following functions:

- To retrieve hydrological and meteorological data from online sources and collectively update, combine and compile inputs for forecasting both OIS and EBEIS.
- To provide data visualization and QA/QC before and after feeding the data into the approaches developed in the previous tasks.
- To combine/integrate the prediction results of different approaches in the previous tasks using a simple-average, weighted average and nearest neighbor methods for the final official forecast with the inclusion of expert advice as well.
- To assist in final reporting and decision-making concerning OIS and EBEIS within NMISC's Rio Grande Basin Bureau.

The spreadsheet tool will be developed using an Excel® workbook environment. We will create a user-friendly Excel® dashboard and reporting tool by utilizing online automatic data acquisition, data QA/QC, input data into different models, running the model/or retrieving results from other hydrological models, combining results, and final reporting. Simple average methods, weighted-average methods, and nearest neighbor models will be utilized to combine/integrate the prediction results of different approaches to improve the accuracy of long-range prediction OIS and EBEIS and to construct an operational forecasting/projection tool for early projection of EBEIS for assisting active water management. The user will update the tool with the most recent hydrological and meteorological data and click some designed buttons, and almost immediately, the user will be able to see the numerical forecast results with probabilistic distributions and associated graphs for visualization and further analysis and dissemination.

Phase 2. Stakeholder outreach and dissemination

Utilizing the spreadsheet-based tool developed in Phase 1 of this Task, we will create and implement an outreach plan to encourage water managers to be aware of EBEIS status when making daily water management and long-term planning decisions. The data visualization and reporting system functions of the tool will facilitate the timely sharing of information among stakeholders and will help them make informed decisions on active water management in the MRG. The project team will share the research findings with stakeholders through URGWOM technical team meetings and other technical presentations and discussion meetings when necessary. The data and information will be shared with the USGS, Reclamation, other water resources researchers, and regional water users, through technical reports, webinars and presentations. Fact sheets and annual projections will be delivered and shared with the water administrators in the three Rio Grande basin States. The results of the project will be shared with other research institutions, federal agencies such as Reclamation, NRCS, USGS, NOAA/NWS, and NCAR, through water supply forecast workshops and seminars for gathering comments and suggestions for future improvement and updates.

Deliverables:

- A user-friendly spreadsheet-based tool for operational projection of OIS and EBEIS, data visualization, reporting, and dissemination.
- Final project report with the user's manual and documentation of the tool.

Task 6: Reporting

This task involves the preparation of Quarterly Technical Progress Reports to update the Reclamation project manager with the project's progress, as well as Draft-Final and Final Reports following the requested format.

2.4 Project Schedule and Milestones

The project schedule and milestones are illustrated in Table 1. The project will be initiated with a kick-off meeting with Reclamation's project manager and the research team in the second month of the project timeline. The important milestones of the projects are literature review, survey of hydrologic models, identifying hydrologic data needs and creating data inventory, development of a group of models, evaluation and assessment of existing watershed models in the basin, recalibration of URGWOM and development of a spreadsheet tool for model combination, reporting and dissemination, quarterly progress reports, and final reports. The first progress report will include datasets and data sources, and currently available technical resources in the MRG that can be utilized to improve prediction of OIS and EBEIS. Progress of the subsequent Tasks, including development of a group of models, evaluation and assessment of existing watershed models in the basin, recalibration of URGWOM and development of a spreadsheet tool for model combination, reporting and dissemination will be summarized in the 2nd, 3rd, 4th, 5th, and 6th quarterly progress reports. The draft final report will summarize the overall progress throughout the project. Based on the feedback and comments on the draft final report, we will submit the Final Report at the end of the project.

Table 1: Project Schedule and Deliverables

Year		**2020**												**2021**											
Month		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Task1	Phase 1																								
	Phase 2																								
Task2	Phase 1																								
	Phase 2																								
	Phase 3																								
Task3	Phase 1																								
	Phase 2																								
Task4	Phase 1																								
	Phase 2																								
Task5	Phase 1																								
	Phase 2																								
Task 6				*			*			*			*			*			*				ǀ		‖

Note: *- Quarterly progress report; ǀ - Draft final report; ‖ - Final Report

2.5 Anticipated Challenges

As with any data-driven modeling process, the project team anticipates numerous challenges related to both data complexity and availability in this highly-regulated complex basin. These challenges may include: 1) the proper identification of skillful predictor variables from a pool of large scale and local-scale climate variables, and monthly and seasonal projection of warm-season precipitation in the basin. Additionally, the reliability of local ungaged precipitation runoff from the NLDAS2 dataset and calibrated PRMS-based watershed models need to be evaluated before being utilized as inputs to URGWOM or other tools. These challenges will be gradually addressed, along with an improved understanding of the drivers and the extent of changes in precipitation events in the MRG. 2) the projection tool developed in this project is anticipated to rely on federal databases, especially the USGS, NWM, and NLDAS databases. The recalibrated URGWOM AOP runs will also rely on several different federal databases to produce ungaged local runoff forecasts between Cochiti and EB Reservoirs. These databases include the oceanic-atmospheric climate indices and local climate division database used in Task 2. If these data are not produced (e.g., federal government shutdown), the NMISC and the URGWOM technical team will need to rely on some assumptions to continue with their simulations of the URGWOM AOPs. 3) with so many stakeholders working on the URGWOM model and documentation simultaneously, NMISC needs to work together with the rest of the URGWOM technical team to make sure that the Task 4 deliverables are integrated into the most up-to-date, official URGWOM model and associated documentation.

3. Project Location

The geographic area of focus for this project is the Rio Grande basin between the USGS Otowi Bridge gage (near Española, NM: 35°52'28.2", 106°08'32.8") and the USGS below EB Dam gage (near Truth or Consequences, NM: 33°08'54.64", 107°12'24.42"). The Rio Grande basin upstream from Otowi gage is also included in the project to investigate the connections between oceanic-atmospheric climate indices and local climate variables with Otowi natural flow and improve Otowi gage seasonal volume forecasts. (Figure 1.) The variables and flows at stream gages in this project are:

- Otowi natural flow
- Otowi Index Supply (OIS)
- San Marcial natural flow
- EB Effective Index Supply (EBEIS)

The time scales that are considered in this project: Daily, Monthly, Seasonal, and Annual.

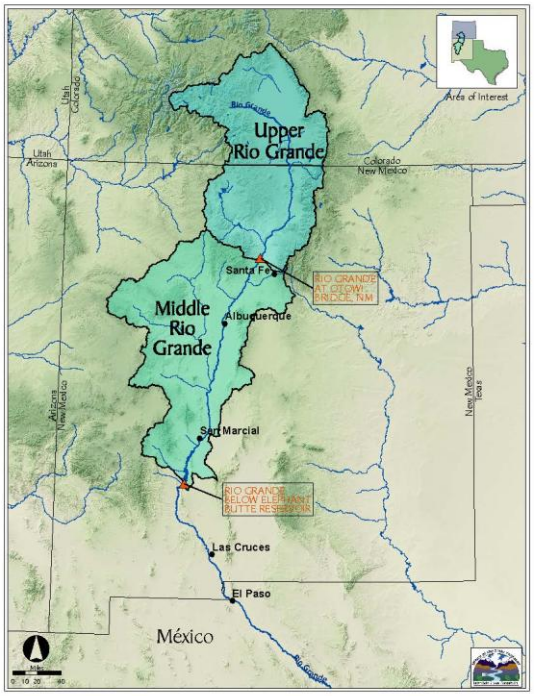

Figure 1. Project Location

4. Data Management Practices

This project is data-intensive. We will identify the hydrologic data needs for the project and develop a data inventory. All the data will be collected in various formats from different sources and converted, compiled and stored in Microsoft Excel® format in the spreadsheet-based projection tool that will be developed in Task 5.

- The first type of data to be collected will be hourly NLDAS runoff and baseflow data, downloaded from https://ldas.gsfc.nasa.gov/nldas as text files for the period 1/1/1980 - present. These data will be downloaded, labeled (with the latitude and longitude of the inflow point), aggregated to daily, and analyzed using scripts written in the R language, and the results of these analyses will be stored in Microsoft Excel® spreadsheets. These text files will be automatically downloaded with extensive metadata.
- The second type of data to be collected will be hourly and daily global climate indices downloaded from https://ldas.gsfc.nasa.gov/nldas as Network Common Data Form, version 4 files for the period 1/1/1980-present. These data will be downloaded, labeled, and analyzed using scripts written in the R language, and the results of these analyses will be stored in Microsoft Excel® spreadsheets.
- The third type of data to be collected will be the NWM model daily streamflow data, downloaded from nomads.ncep.noaa.gov as Network Common Data Form files for the current day through 30 days in the future. These data will be downloaded, labeled, and analyzed using scripts written in the R language, and the results of these analyses will be stored in Microsoft Excel® spreadsheets.
- The fourth type of data to be collected will be daily flow and reservoir storage data from the URGWOM, for the period 1/1/1950-present, stored in Microsoft Excel® spreadsheets.
- The fifth type of data to be collected will be Vector data, stored in shapefiles, which are read using ArcGIS.

- The sixth type of data to be collected will be Raster data, stored as TIFF files, which are read using ArcGIS.

Data produced will include daily streamflow forecasts for the next several months and resulting EBEIS projections, all in Microsoft Excel® data formats. Secondary data produced will include URGWOM model simulations, which include the streamflow forecasts in RiverWare model file format and can be read by any interested stakeholders using the no-cost RiverWare Viewer software. All preliminary data will be accessible by the NMISC and consultants via a shared FTP site and may be backed up locally. All final data will be public and obtainable through the NMISC.

5. Evaluation Criteria

5.1 Evaluation Criterion A — Benefits to Water Supply Reliability

Describe how your project will benefit water supply reliability:

1. Describe the water management issue(s) that your project will address.

In recent years, hydrological changes and frequent extreme droughts in the Rio Grande basin have caused economic losses, depletion of regional aquifers, and other negative impacts on community development and ecosystem health. A variety of water management objectives in the MRG will continue to be challenging as the region adjusts to a changing environment, declining water supply, and increasing water demand. In response, the existing resources and tools regarding hydrologic forecasting and projection in New Mexico should be updated and improved to allow the State of New Mexico to more accurately predict the streamflow arriving at EB Reservoir. The improved forecasting methods and a streamflow projection tool that will be delivered through this proposed research project can be used to develop more accurate water supply outlooks in the region, empowering stakeholders in the basin to manage and plan their water use more effectively. The expected outcome from this project will also be beneficial for water managers in the region for developing and utilizing improved water management strategies to increase water supply reliability and enhance flexibility in water operations in the MRG.

2. Explain how your project will address the water management issues identified in your response to the preceding bullet.

It is anticipated that with the modified and updated databases and existing models, and with the newly developed models and approaches in the basin through this proposed research project, we can identify skillful oceanic-atmospheric climate indices and local climate variables that have significant influence on the streamflow conditions, and the best combinations of these variables for improved long-range streamflow and reservoir inflow prediction in the MRG. The identified relationships between streamflow and local and regional climate variables would enable us to incorporate impacts of climate variations into a prediction of streamflow/reservoir inflow variability and the frequency and severity of hydrologic extremes in the basin.

As an outcome of this project, the projection tool for OIS and EBEIS helps assist New Mexico's active water management. Added benefits of a forecasting tool are improved water supply forecasts, which will also assist with reliability and management of water deliveries in the MRG. This will help us propose and move toward more reliable/improved long lead-time streamflow prediction approaches. The streamflow projection tool will provide an improved water supply projection for increasing water supply reliability and ability to meet endangered species requirements, improved management of water deliveries, flexibility in water operations, and implementation of drought contingency plans in the MRG.

3. Describe to what extent your project will benefit one of the water management objectives listed in the preceding bullets.

Water development and management organizations are expected to need future streamflow and reservoir inflow projection information for water resources planning and management. With this project, water managers along the Rio Grande in New Mexico and Texas will improve their ability to manage water supplies because they will have easy access to a local inflow database in the 200 mile stretch between Otowi and EB. For example, the State of New Mexico will more efficiently manage water operations because they will be able to project OIS and EBEIS several months ahead of time. Also, farmers below EB Reservoir will be better able to plan their crops because they will have a better prediction of their water supply for the upcoming year. The expected product from this project, the improved OIS and EBEIS forecasts methods together with a user-friendly projection tool will assist water managers in the basin make informed water management decisions and increase water supply reliability and resiliency in water delivery management under drought or surplus conditions.

4. Explain how your project complements other similar applicable to the area where the project is located.

This proposed project complements existing efforts on water resources studies that cover the same geographic area. Reclamation has conducted the **"Upper Rio Grande Impact Assessment"** project to determine baseline risks to water supplies and demands to establish a foundation for more in-depth analyses and the development of adaptation strategies. The study was conducted by the Bureau of Reclamation in partnership with Sandia National Laboratories and the United States Army Corps of Engineers (USACE). USGS National Water Census has initiated the **"Upper Rio Grande Basin Focus Area Study".** This study seeks to improve estimates of selected water budget components to assess water availability and use in the Upper Rio Grande Basin of Colorado, New Mexico, and Texas. The above two research projects are in the same geographical area with this proposed project. The expected outcome of this project also complements these research projects.

Recently, Reclamation has launched **"The Rio Grande Basin Study in New Mexico"** that is focused on the MRG from the Colorado-New Mexico border to EB Reservoir. The basin study will enhance existing models and data to evaluate infrastructure and operations. It will also develop strategies to improve water supply reliability and improve stakeholder collaboration and water management in an area of competing needs. NMISC is a partner in this project and is actively participating in the research efforts. The proposed project outcome will complement a long-range streamflow forecasting component of the Rio Grande Basin Study. Additionally, Reclamation is actively collaborating with NCAR on the project titled **"Detecting, Interpreting, and Modeling Hydrologic Extremes to Support Flexible Water Management and Planning."** In this research effort, the researchers are performing extreme-value analysis for the characterization of extremes in water resources and its application on New Mexico monsoon precipitation (Towler et al., 2019). The results of this project are very useful for projection of monsoon precipitation in the MRG and will benefit the proposed project. This project can be a testbed for evaluating the results of the aforementioned project.

5.2 Evaluation Criterion B — Need for Project and Applicability of Project Results

Explain how your project will result in readily useful applied science tools that meet an existing need:

1. ***Does your project meet an existing need identified by a water resource manager(s) within the 17 Western States?***

The need for improved forecasting tools in the West is evident because streamflow is becoming less predictable with current tools, temperatures are trending up, and population is increasing. At the start of each year, the NRCS's water supply outlooks at Otowi and San Marcial gage stations are important for all stakeholders and water users in the MRG and Lower Rio Grande basins. Specifically, the accuracy of the Otowi seasonal streamflow forecast is of vital importance in water management and planning in the region. Additionally, Otowi gage seasonal volume forecasts determine the expected EBEIS. Moreover, the accurate projection of EBEIS is extremely difficult due to complexity of the system and the impacts of anthropogenic factors. At present, the NMISC's Rio Grande Bureau relies on other methods, e.g., simple average of the three hydrologically closest years, exceedance probability analysis of historic EBEIS, and expert guidance to project EBEIS to inform decision-makers and stakeholders.

This project is expected to provide improved seasonal water supply forecasts at Otowi and San Marcial gage stations, more accurate monthly, seasonal, and annual OIS and EBEIS projection, and a spreadsheet-based projection tool for decision-making, stakeholder outreach and dissemination. These products will play significant roles in better water management in the basin. Many stakeholders in the region (e.g., Albuquerque Bernalillo County Water Utility Authority (ABCWUA), Reclamation, Elephant Butte Irrigation District of New Mexico (EBID)) have expressed their interest and support for this proposed project and hope to utilize the project outcomes.

2. ***Will the project result in an applied science tool(s) or information that is readily applicable, and highly likely to be used by water resource managers in the West?***

The proposed project will help water managers and policymakers in the region develop contingency plans for extreme hydrologic conditions, active water management, and long-term water plans for regional sustainable development in the MRG. The final product of this project, the spreadsheet-based projection tool, is aimed at integrating and combining results from various modeling approaches into a user-friendly platform for the use of different stakeholders. The results of this project will inform OIS and EBEIS status upon completion of the project. Many stakeholders along the Rio Grande in New Mexico and Texas will immediately benefit from the improved decision-making capabilities allowed by this tool, including the States of New Mexico and Texas, the federal agencies, irrigation districts, Native American Pueblos, municipalities, recreationalists, and environmental groups. Additionally, the methodologies that have been used in the project for seasonal streamflow forecasting and inclusion of local precipitation runoff in the RiverWare-based platform, e.g., URGWOM, can be transferrable to other arid regions in the western United States with similar climate conditions.

5.3 Evaluation Criterion C — Project Implementation

Describe your project implementation plan:

1. ***Describe the objectives of the project and the methodology and approach that will be undertaken. Provide support for your methodology and approach.***

The objectives of the project and the methodology and approach are described in **Section 2.2 Project Objectives** and **Section 2.3 Project Tasks and Deliverables** in detail. Due to space constraints, **Sections 2.2 and 2.3** should be considered the detailed explanation of objectives, methodology, and deliverables requested for evaluation criterion C sub-criteria 1.

2. ***Describe the work plan for the project. Include an estimated project schedule that shows the stages and duration of the proposed work, including major tasks, milestones, and dates.***

The work plan for this project, including detailed project schedule and milestones, are illustrated in **Section 2.4 Project Schedule and Milestones.** Please refer to this section for details of the work plan.

3. Describe the availability and quality of existing data and models applicable to the project.

Please refer to **Section 2.3 Project Tasks and Deliverables** and **Section 4. Data Management Practices** for the description of data and models that are going to be used in this project. Additionally, the project is designed based on the data that are publicly available with good quality from various sources such as USGS, NRCS, NOAA/NWS, and NCAR, to ensure the operationality of the projection tool. Model simulation results data, e.g., local precipitation runoff data from NDALS and PRMS, will be collected from respective agencies as raw data. We will perform QA/QC procedures on the raw data before it is put to use for modeling in this project.

4. Identify staff with appropriate credentials and experience and describe their qualifications.

The project team is very well positioned to deliver on a project of this scale. The project team is comprised of NMISC Rio Grande Bureau staff, engineers from Hydros Consulting Inc., and a Graduate Research Assistant from New Mexico State University (NMSU). The team has extensive experience in the field of work and understands potential challenges in conducting the proposed research.

The project manager and principal investigator (PI) Dr. Shalamu Abudu has extensively been involved in streamflow forecasting on the Rio Grande in New Mexico, both in his dissertation research and postdoctoral work at NMSU and Texas A&M AgriLife Reseach Center. As a PI, Dr. Abudu has accomplished a number of research projects on streamflow forecasting and RiverWare applications. Dr. Abudu will devote 6 months to be involved in all tasks throughout the project and will lead Task 1, Task 2, Task 3 and Task 5 (as shown in Table 4).

The Co-PI Chris Stageman is a hydrogeologist with more than 30 years of experience groundwater and surface water management, including Rio Grande water management. He will devote 2.5 months to support all tasks and will co-lead Task 4 and Task 5 (as shown in Table 4).

The Co-PI Page Pegram is the Rio Grande Bureau Chief of NMISC and an expert in watershed management practices. She is a hydrogeologist with 25 years experience in groundwater and surface water management in both the private sector and state government. As a Co-PI Ms. Pegram will devote 2 months to oversee the project and will lead Phase 2 of Task 5 - Stakeholder outreach and dissemination - Develop a spreadsheet-based tool for combining and reporting projection results (as shown in Table 4).

The Co-PI Cindy Stokes is a surface water hydrologist and GIS expert with extensive expertise in URGWOM. She will devote 3 months to be involved in all tasks and co-lead Task 4 and Task 5 (as shown in Table 4).

Key personnel Anders Lundahl is an experienced hydrologist and has substantial knowledge in the MRG. He will devote 3 months of his time to support project coordination and stakeholder outreach and dissemination (as shown in Table 4).

The Hydros Consulting Collaborators (Contractors) Nicholas Mander, and Taylor Adams have accomplished substantial work in the Rio Grande, including development of URGWOM. They also have expertise in GIS and database technologies, forecasting and climate change, and stochastic hydrology. Nicholas Mander will be working on Task 4, overseeing code development of Task 5, and corresponding task progress reporting in Task 6 (See Table 6). Taylor Adams will be working on model development, and data inventory and watershed model evaluation, specifically on Task 3 and Phase 1 of Task 2, and corresponding task progress reporting in Task 6 (See Table 6).

This project will be supported by a full-time graduate student (18 months) primarily for literature review, hydrologic model survey and creating reports. An NMISC Rio Grande Bureau staff member will also be involved in GIS and data QA/QC work (2 months). Table 4 and Table 6 in the **PROJECT BUDGET Section** summarize the work-hour of the key personnel at NMISC and contractual work-hours and rates of Hydros Consulting engineers.

5. ***Provide a summary description of the products that are anticipated to result from the project. These may include data, metadata, digital or electronic products, reports and publications.***

The expected products and deliverables from the proposed project are documented in **Section 2.3 Project Tasks and Deliverables.** In summary, the following final products are anticipated:

- Data inventory (data sources, data format, metadata)
- A hydrologic model survey and data needs report
- A summary report on the significant atmospheric and local climate variables that have impacts on the MRG streamflow and developed forecasting equations
- A report on the summary of existing watershed models and historical local precipitation runoff database in the MRG
- A new version of the official URGWOM model with new data management interfaces (DMIs) and re-calibrated physical parameters
- A report documenting the new additions to the URGWOM model, and calibration results using the historical ungaged local runoff database
- A spreadsheet-based tool/software for operational streamflow projection
- User's manual and documentation for the spreadsheet-based projection tool

5.4 Evaluation Criterion D — Dissemination of Results

The final products including information and data collected and compiled, developed models, and a spreadsheet-based tool will be shared with the project team frequently for modification, updates and improvement during project execution and after the completion of the project. The project team will be working closely with the Reclamation project manager and scientists to ensure the project process meets the specific requirements of the project in terms of sharing and dissemination of the project outcomes. After the project completion, the projection tool will be immediately put into use within NMISC's Rio Grande Bureau. A staff member from the project team is responsible for producing and sharing estimates of annual OIS and EBEIS volumes and monthly hydrographs, and for updating the projection twice a month (1^{st} and 16^{th} of a month) through email communication. The project team will share the project progress and research findings periodically with stakeholders through URGWOM technical team meetings, and other technical presentations and discussion meetings when necessary. The data and information will be shared with the USGS, Reclamation and other water resources researchers, and regional water users either through an established database or a report. Fact sheets and annual projections will be delivered and shared with the related water administrations. The results of the project will be shared with other research institutions, and federal agencies such as NRCS and NWS through water supply forecast workshops and seminars for gathering comments and suggestions for future improvement.

5.5 Evaluation Criterion E — Department of the Interior Priorities

Explain how your project supports Department of the Interior Priorities (or at least one priority):

The proposed project supports a number of Priorities of Department of Interior including "***Utilize science to identify best practices to manage land and water resources and adapt to changes in the environment"*** and ***"review DOI water storage, transportation, and distribution systems to identify opportunities to resolve conflicts and expand capacity".*** The proposed project will help water managers and policymakers in the region develop contingency plans for extreme hydrologic conditions, engage in active water management under a changing environment, and provide information to help guide water managers when water-related conflicts among Rio Grande basin States arise.

The project area selected in this proposal is consistent with Reclamation's efforts on the operation of EB and Caballo Reservoirs, and indirectly related to the operation of Heron, El Vado and Nambe Reservoirs in the Rio Grande basin. Specifically, the project results may assist better decisions on determining the Caballo Reservoir target storage and releases. Additionally, the proposed project complements the current ongoing research projects in the Rio Grande, including Reclamation's Rio Grande Basin Study in the New Mexico and USGS's"Upper Rio Grande Basin Focus Area Study." Please also refer to **Section 5.1-Benefits to Water Supply Reliability** for a detailed description.

PROJECT BUDGET

1. Funding Plan and Letters of Funding Commitment

1.1 Funding Plan

New Mexico Interstate Stream Commission (NMISC) will be the recipient of the Reclamation funding. The total amount of funds requested from Reclamation for the two-year effort is $141,271.92. The total cost share provided by the recipient amounts to $147,038.11. The funds will be available to the project when Reclamation announces the project start date. There are no other contingencies associated with the funding commitment. The amount of cost share accounts for 51% of the total project costs of $288,310.03 (Table 2).

Table 2. Total Project Cost

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$141,271.92
Costs to be paid by the applicant	$147,038.11
Value of third-party contributions	$0.00
TOTAL PROJECT COST	**$288,310.03**

1.2 Letters of Commitment

The commitment letter from NMISC regarding the cost share funding to the proposed project is attached in Appendix A.

2. Budget Proposal

We have developed a detailed project budget in the suggested format as shown in Table 3. The proposed working period will be completed within two years from the time of award, or from approximately January 1, 2020 – December 31, 2021. The total amount of funds requested from Reclamation for the 2-year effort is 141,271.92. The total cost-sharing is $147,038.11. The breakdown of the budget such as quantity, type, and detailed budget for each category are described in the following sections of the Budget Narrative.

ENVIRONMENTAL AND CULTURAL RESOURCES COMPLIANCE

There is no environmental compliance required for the proposed project.

REQUIRED PERMITS OR APPROVALS

No permits or approvals are required for the proposed project.

LETTERS OF SUPPORT AND LETTERS OF PARTICIPATION

A Letter of Participation from Hydros Consulting Inc. is attached in Appendix A. The letters of support from Reclamation, Albuquerque Bernalillo County Water Utility Authority (ABCWUA), Dr. James King (NMSU), Dr. David Gutzler (UNM), Dr. Nabil Shafike, United States Army Corps of Engineers (USACE), and Elephant Butte Irrigation District (EBID) are attached in Appendix B.

APPENDIX C. REFERENCES

Abudu, S. (2009). "Monthly and Seasonal Streamflow Forecasting in the Rio Grande Basin," Ph.D. Dissertation, New Mexico State University, Las Cruces, New Mexico, Available online at https://nmwrri.nmsu.edu/wp-content/uploads/2015/research/rfp/studentgrants08/reports/Abudu.pdf

Abudu, S., King, J. P., and Bawazir, S. (2011) "Forecasting Monthly Streamflow of Spring-Summer Runoff Season in Rio Grande Headwaters Basin Using Stochastic Hybrid Modeling Approach", Journal of Hydrologic Engineering, 16 (4), 384-390

Abudu, S., J. P. King, and T. C. Pagano, 2010: Application of partial least-squares regression in seasonal streamflow forecasting. *J. Hydrol. Eng.*, 15, 612–623, doi: https://doi.org/10.1061/(ASCE)HE.1943-5584.00

Chavarria, Shaleene B. and Gutzler, David S. (2018). Observed Changes in Climate and Streamflow in the Upper Rio Grande Basin. Journal of the American Water Resources Association (JAWRA) 54(3): 644– 659. https://doi.org/10.1111/1752-1688.12640

Towler, E., Llewellyn, D., Prein, A., Gilleland, E. (2019). Extreme-value analysis for the characterization of extremes in water resources: A generalized workflow and case study on New Mexico monsoon precipitation, *Weather and Climate Extremes (WACE Elsevier)*, in press.

Gaume, N. (1999). "New Mexico's Obligations and Compliance under the Rio Grande Compact-the Rio Grande Compact: It's the Law", WRRI Conference Proceedings, 1999.

Gutzler, D. S. (2013). Climate and drought in New Mexico. In: Water Policy in New Mexico [Brookshire, D.S., Gupta, H.V., and Matthews O.P. (Eds.)]. RFF Press, New York, 72–86.

Natural Resources Conservation Service (NRCS) (1997). Southern oscillation index statistical correlation with spring runoff in the western US. http://www.wrcc.dri.edu/enso/soiwsf2.pdf

Pagano, T. (2005). *The role of climate variability in operational water supply forecasting for the western United States*. Ph.D. dissertation. University of Arizona, Tucson, AZ.

Redmond, K.T. and R.W. Koch, 1991. Surface Climate and Streamflow Variability in the Western United States and Their Relationship to Large-Scale Circulation Indices. Water Resources Research 27(9):2381-2399, doi: 10.1029/91WR00690.

Shamseldin, A. Y., O'Connor, K. M., and Liang, G. C. (1997). "Methods for combining the output of different rainfall-runoff models." Journal of Hydrology, 197, 203–229.

Tootle, G. A., Singh, A. K., Piechota, T. C., and Farnham, I. (2007). "Long lead-time forecasting of U.S. streamflow using partial least squares regression." *Journal of Hydrologic Engineering*, 12(5), 442–451.

URGWOM Technical Team (2018) Upper Rio Grande Water Operations Model Physical Model Documentation: Technical Review Committee Draft.

Wood, A. W., and Lettenmaier, D. P. (2006). "A test bed for new seasonal hydrologic forecasting approaches in the western United States." *Bulletin of the American Meteorological Society*, 87(12), 1699-1712.