Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas

Principal Investigator: Yu Zhang, Associate Professor, Dept of Civil Eng, Univ. of Texas at Arlington, Arlington, TX 76019, Email: yu.zhang@uta.edu, Phone: 817-272-1874
Co-Principal Investigator: Dong-Jun Seo, Professor, Dept of Civil Eng, Univ. of Texas at Arlington, Arlington, TX 76019, Email: djseo@uta.edu, Phone 817-272-5063
Co-Principal Investigator: Nelun Fernando, Manager, Water Availability Program, Texas Water Development Board; Email: nelun.fernando@twdb.tx.gov, Phone: 512-475-0454
Co-Principal Investigator: John Zhu, Senior Hydrologist, Water Availability Program, Texas Water Development Board; john.zhu@twdb.tx.gov Phone: 512-471-7847
Co-Principal Investigator: Bridget Scanlon, Senior Research Scientist, Univ. of Texas at Austin Bureau of Economic Geology; Email: bridget.scanlon@beg.utexas.edu; Phone: 512-471-8241

Consultant: David Curtis, WEST Consultants, dcurtis@westconsultants.com

Collaborators: Jerry Cotter, Chief of Water Resources, USACE Fort Worth District, Email: Jerry.L.Cotter@usace.army.mil,
Aaron Abel, Water Services Manager, Brazos River Authority, aaron.abel@Brazos.org
Kris Lander, Acting Hydrologist in Charge, NWS West Gulf River Forecast Center, Email: Kris.Lander@noaa.gov

Authorized Institutional Representative:

Institutional Representative:
Sarah Panepinto
Director, Grant and Contract Services
The University of Texas at Arlington
Box 19145
Arlington, TX 76019-0145
Tel: 817-272-2105

Principal Investigator (Lead PI):
Dr. Yu Zhang
Associate Professor of Civil Engineering
The University of Texas at Arlington
Box 19308
Arlington, TX 76019-0308
Tel: 817-272-1873

Technical Proposal and Evaluation Criteria:

1. Executive Summary

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University of Texas at Arlington (UTA)
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UTA is a public (state) university and Category B applicant. The PI (Yu Zhang) at UTA is partnering with two state agencies and Category A applicants, namely the Texas Water Development Board (TWDB) and the Brazos River Authority (BRA), to adapt and assess ensemble forecast products from the National Weather Service (NWS). Dr. Nelun Fernando from the TWDB, who is leading the Forecast Informed Reservoir Operation (FIRO) initiative at the TWDB, serves as a co-PI for this project. The project will be conducted in close coordination with the US Army Corps of Engineers – Fort Worth District (USACE-SWF) and the NWS West Gulf River Forecast Center (WGRFC). Letters confirming participation and support from TWDB, BRA, USACE-SWF, and WGRFC can be found in the attachment. The overarching goal of this work is to adapt forecast products for a reservoir system in the Brazos River Basin, Texas to facilitate operational use of forecasts by BRA and USACE-SWF with the ultimate aim of improving water supply reliability in the state.

The proposed initiative will focus on a system of reservoirs in the Brazos River Basin, where rapid population growth over the past decades has put serious strain on water supplies. BRA and USACE-SWF, which manage the conservation and flood pools of these reservoirs, respectively, are interested in examining the skills of NWS ensemble streamflow forecasts and potentially adopting these products to support operational decisions. The project will involve hindcast and integration tests to determine the operational readiness of the products and potential gains in water supply reliability through their adoption. The project will produce adapted forecast systems that can be immediately implemented at WGRFC and a set of climate index-constrained inflow traces to be delivered to BRA to assist with operational planning. The project will also yield three operation-specific decision support tools for partnering agencies: 1) a forecast-based guide on periodic use of a portion of the flood pools for water supply storage and associated changes in flooding risk, 2) a forecast-based planning tool for BRA's planning and operations, and 3) a forecast-driven scenario tool for drought contingency planning. The adaptation effort and integration tests will expedite the adoption of forecasts by reservoir operators, and the initiative addresses the second water management objective listed in the NOFO: *improve or adapt forecasting tools and technologies to enhance management of water supplies and reservoir operations*. Further, it will provide critical information about the potential enhancements in water supply reliability that can be achieved through the use of forecast information. The project goals are precisely aligned with the vision articulated in a recent TWDB report entitled "*Forecast-informed Reservoir Operations (FIRO) and Water Resources Management in Texas*".

The two-year project is expected to start in September of 2021, and it will NOT take place in a federal facility.

2. Technical Project Description

2.1 Background

The state of Texas has experienced rapid population growth in recent decades and features some of the fastest growing urban areas in the nation. The state, however, is highly vulnerable to weather and climate extremes with floods and droughts simultaneously posing large threats to growth and expansion. Reservoirs, particularly multiuse reservoirs, have played a critical role in alleviating the risks of floods and droughts alike in many regions of the state. Major reservoir operators include the US Army Corps of Engineers (USACE), river authorities, and regional water utilities. USACE is the largest reservoir operator in the state: its three districts (Fort Worth, Tulsa, and Galveston) operate 32 multiuse reservoirs across Texas (Fig. 1). For each reservoir, USACE is responsible for managing flood pool operations, whereas raw water suppliers, typically river authorities, manage the conservation pools.

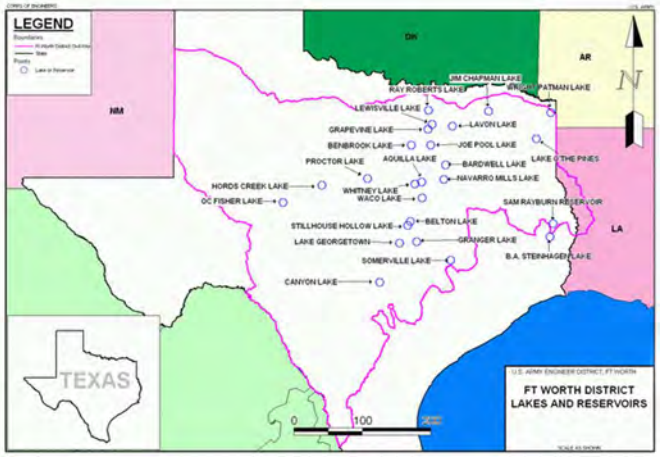

Figure 1: Service area of USACE-SWF and reservoirs the district operates.

Among the river basins in Texas, water supply within the Brazos River Basin is of national interest because of significant petrochemical production at the lower end of the basin that is highly dependent upon upstream water supplies in the basin. In addition, demand for water along the basin has increased sharply as a result of population growth near urban centers such as Austin and Houston. These collectively result in severe stress on water supplies: during the 2010–2014 drought, downstream senior water rights holders petitioned the Texas Commission on Environmental Quality (TCEQ) to curtail water use by upstream junior rights holders. For example, Dow Chemical Corporation made priority calls to the TCEQ in 2011, 2012, and 2013 to maintain the water supply at their facility in Freeport along the Gulf Coast.

Figure 2: Brazos River Basin, and water supply reservoirs managed by BRA (red circles) and USACE SWF(yellow circles).

The Brazos River Authority (BRA) is the largest raw water supplier in the region, and serves municipal, industrial, mining, and agricultural interests. It currently owns and operates three

water supply reservoirs (Fig. 2) and partners in managing the conservation pools of another eight multiuse reservoirs owned and operated by the USACE. As described above, the BRA has been grappling with the challenge of maintaining sufficient water supplies and works actively with partners to plan the construction of new pipelines that allow diversions and transfers and new reservoirs as means to improve water supply reliability (TWDB 2017).

Over recent years, there has been increasing recognition by water resource planners and managers that judicious use of forecast information could lead to more efficient management of reservoir operations, thereby reducing near-term gaps in water supply and demand. To determine the current state of forecast utilization in reservoir operations and identify pathways to facilitate forecast use, the TWDB, UT Arlington, and NOAA National Integrated Drought Information System (NIDIS) jointly convened a workshop in 2019 at UTA. The workshop, entitled "*Forecast-informed Reservoir Operations (FIRO) and Water Resources Management in Texas and Oklahoma*", produced a comprehensive report published in 2020 (TWDB 2020). The report offers a detailed overview of current FIRO practice in the state, forecast products used by major reservoir operators, and existing and emerging forecast products from the National Weather Service (NWS).

A critical gap identified by the workshop is that, few, if any of the reservoir operators in Texas actively employ ensemble streamflow forecasts produced by NWS with the Ensemble Streamflow Prediction (ESP) scheme and the Hydrologic Ensemble Forecast Service (HEFS). These systems were conceived specifically to assist with water supply management and reservoir operations. Relative to deterministic forecasts, they offer the key advantage of representing forecast uncertainties that allow for risk-based decisions. The workshop calls for partnerships between forecast providers and reservoir operators to facilitate the operational adoption of NWS forecast products and recommends that pilot studies be undertaken to determine the skills of NWS ensemble streamflow forecasts and establish their use cases in reservoir operations.

In light of the water supply challenges in the Brazos River Basin, USACE-SWF, the BRA, and the TWDB are all interested in adopting FIRO as a mechanism to address these challenges. At present, under situations where drought is a concern, USACE-SWF allows modest deviations from the water control manual by temporarily storing water in reservoir flood pools to improve water supply reliability. Such decisions are typically based on drought severity and persistence, precipitation climatology and forecaster experience. USACE-SWF is interested in integrating ensemble streamflow forecasts at the seasonal scale to inform its deviation practice. BRA is also interested in incorporating forecasts in its operational planning, and both the BRA and the TWDB are interested in the use of forecast to inform the implementation of drought contingency plans.

2.2 Project Overview

The proposed initiative is a synergistic effort led by UT Arlington, the TWDB, and UT Austin Bureau of Economic Geology (UT-BEG) to adapt NWS ensemble streamflow forecasts, with the overarching aim of paving the way for their adoption for routine reservoir operations. The project will be undertaken in partnership with two reservoir operators, USACE-SWF and BRA, and with the WGRFC. WGRFC will be the primary recipient of the adapted forecast

systems from the project and will implement these systems to produce official forecast information beyond this project. There are four major thrusts of the proposed work:

1. adapting NWS ensemble streamflow forecasts to facilitate their operational adoption by reservoir operators
2. performing hindcast experiments to determine skill level of adapted ensemble streamflow forecasts at different lead times and corresponding operational use cases
3. integrating ensemble forecasts with reservoir models to increase the readiness of forecasts for day-to-day operations at USACE-SWF and BRA
4. developing decision rules and pathways for implementing forecast-based drought trigger implementation and associated drought contingency plans.

Major anticipated benefits of incorporating forecasts include improved water supply reliability, water delivery efficiency, and drought management. These benefits will be examined through thrusts 3 and 4. The proposed initiative is perfectly aligned with the vision laid out in the aforementioned workshop report in that it answers the call for a pilot study to determine the skills of NWS ensemble streamflow forecasts and facilitate their adoption by reservoir operators. The initiative builds on previous UTA-WGRFC collaborations that led to the operationalization of HEFS for the Upper Trinity River Basin (Kim et al. 2018, Limon et al, 2019). The planned adaptation effort complements, and will expedite, WGRFC's efforts to deploy HEFS for the entire service area as described herein.

2.3 NWS ensemble streamflow forecasts and adaptations

There are three ensemble forecast systems operational at various RFCs: the ESP, HEFS, and the Meteorological Model-based Ensemble Forecast System (MMEFS), among which the first two have been deployed or are being deployed on a national level. A brief overview of each system is provided below along with the plans for adaptation.

Ensemble Streamflow Prediction (ESP)

The ESP system, previously known as the Extended Streamflow Prediction system, was first used at the NWS California-Nevada River Forecast Center (CNRFC) in the early 1970s. It was formally incorporated into the NWS River Forecast System (NWSRFS) by NWS Hydrologic Research Laboratory (a predecessor to the National Water Center) in the mid-1970s (Curtis and Schaake, 1979; Day 1985). A schematic of the ESP is shown in Fig. 3. Two flavors of ESP exist: the conditional forecast entails initializing the states of a hydrologic model using current conditions (e.g., soil moisture, streamflow, reservoir level and snowpack) and running the NWS Sacramento Soil Moisture Accounting (SAC-SMA; Burnash et al., 1973), snow accumulation and ablation, and other

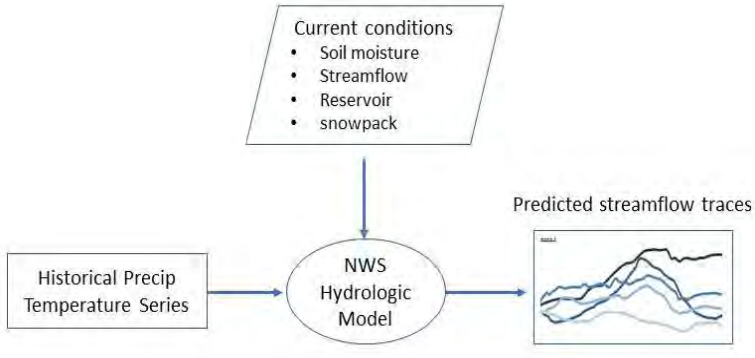

Figure 3: Schematic of the NWS Ensemble Prediction System (with conditional simulation).

models using historical traces of precipitation and temperature for lead times up to 1 year. Alternatively, ESP can be configured to perform unconditional forecasting by using historical conditions to initiate model runs. The ESP schemes have been widely applied in drought forecasting (Twedt et al., 1978; Sheer 1980; Smith et al., 1983).

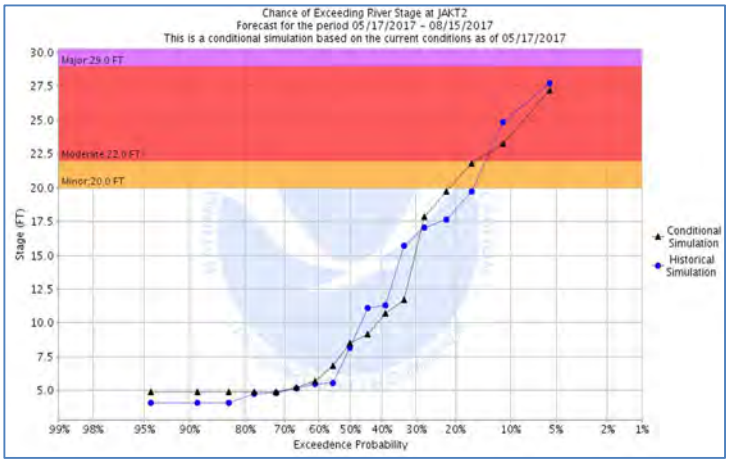

Figure 4: Probabilities of stage exceeding various thresholds based on ESP conditional vs. historical simulations.

At present, ESP is configured as a part of the Community Hydrologic Prediction System (CHPS) at WGRFC. Its major product is the probability of river stage exceeding various thresholds at different lead times (Fig. 4). ESP's adoption in Texas has been slow, primarily due to operators' concern of limited skill of the forecasts. This lack of skill is partly attributed to the fact that the historical precipitation and temperature sequence for each year is assumed to occur with identical probabilities. This shortcoming has long been noted by NWS. As a remedy, Smith et al. (1992) introduced a generic, nonparametric ESP framework which allows for the incorporation of climate information as weights to the ESP traces. This inspired the development of more recent variants of ESP, including the climate index-weighted ESP scheme developed by Werner et al. (2004) for the Colorado River Basin River Forecast Center. The authors demonstrated that weighting ESP by El Niño Index 3.4 leads to overall improvements in the skill of seasonal runoff forecasts for test basins in Colorado, Wyoming, and Arizona.

For the state of Texas, it is widely known that annual precipitation is strongly modulated by El Niño Southern Oscillation (ENSO). The 2011-2014 drought, for example, was nearly coincidental with the intense La Niña (Fig. 5), whereas the transition from La Niña to El Niño in 2015 was immediately followed by a wet episode. In the proposed project, the ESP will be adapted for WGRFC by weighting traces using a distance measure similar to the methodology developed by Warner et al., (2006) but based on the difference in the Multivariate ENSO Index (MEI; Wolter and Timlin, 1993).

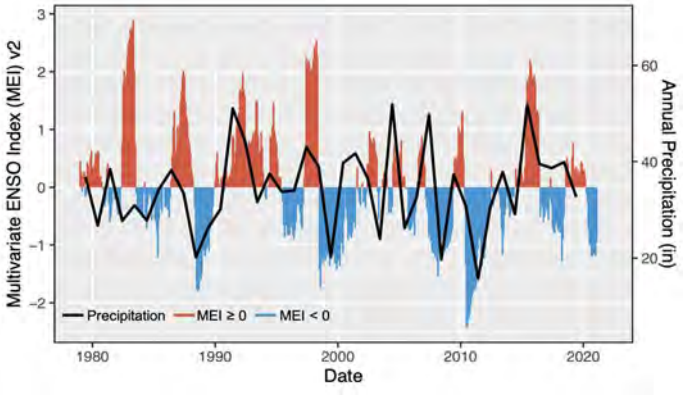

Figure 5: Time series of Multivariate ENSO Index and annual precipitation in central Texas.

Hydrologic Ensemble Forecast Service (HEFS)

HEFS was developed in the NWS Office of Hydrologic Development (OHD) in the mid-2000s in recognition of the limited skills of climatology-based, medium-range (1-15 days) forecasts and the potential advantages of numerical weather prediction (NWP) model precipitation and temperature forecasts. The current HEFS configuration (Fig. 6) consists of three major components: namely the Meteorological Ensemble Forecast Processor (MEFP), the hydrologic model, and Ensemble Postprocessor (EnsPost). HEFS also offers a verification module - the Ensemble Verification System (EVS).

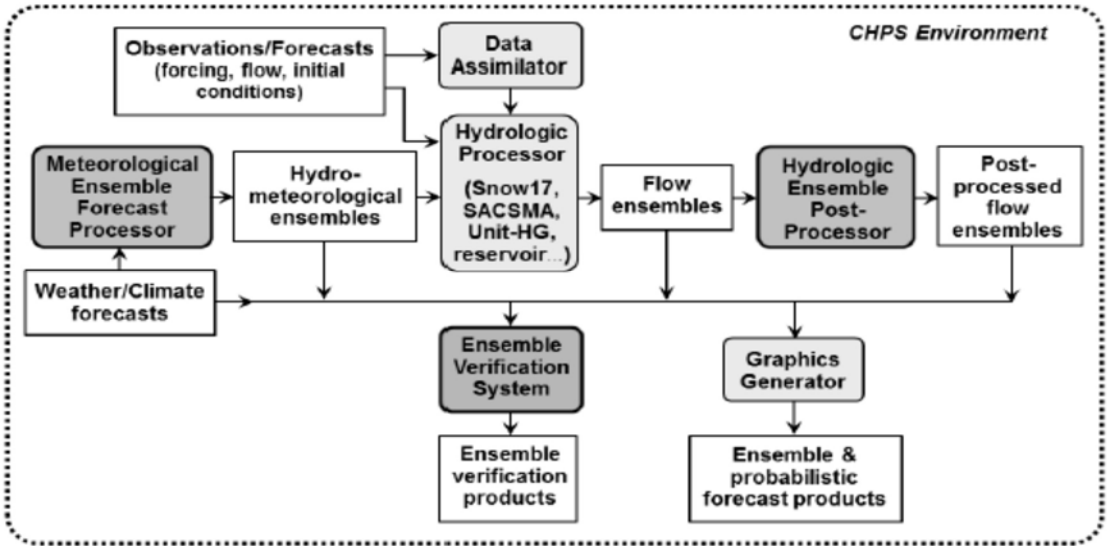

Figure 6: Schematic of the HEFS in NWS CHPS environment (Demargne et al. 2014).

The role of MEFP is to generate calibrated ensemble precipitation and temperature forecasts from raw NWP forecasts. At most of the RFCs, MEFP is configured to use the forecasts from the Global Ensemble Forecast System (GEFS) for lead times from 1 to 15 days; beyond that it uses forecasts from the Climate Forecast System-Version 2 (CFSv2) for lead times up to 270 days and climatology for lead times up to 1 year. In order to account for the decay of forecast accuracy with lead times, it computes precipitation totals over prescribed temporal windows, known as the canonical events (Roundy et al., 2015). MEFP processes NWP forecasts in three steps. First, it establishes a bivariate distribution of forecast and observations via the Mixed Meta-Gaussian Distribution (MMGD; Wu et al., 2011), which then serves as the basis to create conditional (predictive) distributions of precipitation and temperature. Second, the predictive distribution is sampled to create a finite ensemble of precipitation and temperature forecasts for each forecast point. Third, these forecasts over different locations are re-arranged to restore the climatic correlation of one forecast variable or among forecast variables using the Schaake Shuffle (Clark et al., 2004). The reshuffled ensemble traces of precipitation and temperature are used to drive the NWS lumped hydrologic model to produce ensemble traces of streamflow forecasts, which then undergo postprocessing using the EnsPost to correct for bias and account for uncertainties in the forecasts. EnsPost employs an autoregressive-1 model with a single exogenous variable (ARX-1; Seo et al., 2006) to blend model simulated flows for the current and future steps and observed flows from the previous step.

The NWS ensemble streamflow forecasts have been adopted by several reservoir operators nationally, most notably in California and New York. In the Lake Mendocino and Folsom Dam FIRO pilot projects in California, operators actively employ HEFS forecasts at the medium range (0-15 days) to determine temporary deviation of storage (Delaney et al., 2020). The New York City's Department of Environment Protection (NYCDEP) also uses HEFS forecasts at a range of lead times in the operation and planning of their water supply systems. The operators have employed the ensemble forecasts in supporting a wide range of decisions including drought declaration, repairs and maintenance, and flood controls (Fig. 7).

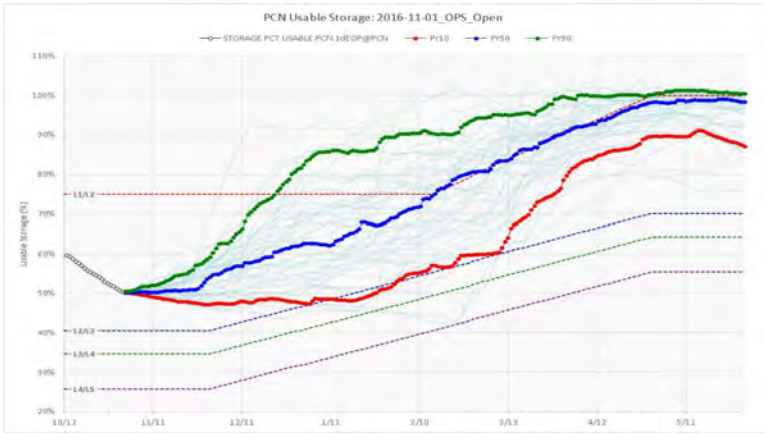

Figure 7: Ensemble pool elevation forecasts generated by New York City Department of Environment based on streamflow forecasts by HEFS that served as the basis for drought declaration.

In a previous project funded by NOAA Climate Program Office, UTA partnered with WGRFC to establish HEFS for the Upper Trinity River Basin (Fig. 8), to assess the skills of HEFS forecasts and to experimentally couple HEFS forecasts with a reservoir simulation model of Tarrant Regional Water District, a major water supplier for the Dallas-Fort Worth Metroplex. The outcome of the project suggests that i) the HEFS forecasts exhibit higher skills than climatology for lead times up to 30 days and ii) postprocessing of streamflow forecasts via EnsPost is *a major source* of skill gains for lead times up to 90 days.

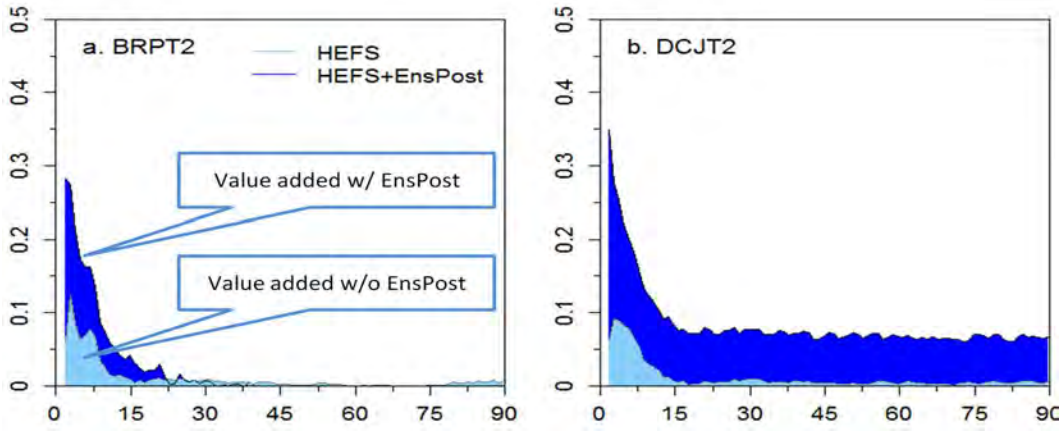

Figure 8: Skills of HEFS streamflow forecasts as characterized by Continuously Ranked Probability Skill Scores (CRPSS) for two forecast points in the UTRB. Light and dark blue lines represent skills for HEFS without and with postprocessing, respectively (Kim et al., 2019).

WGRFC has configured 70 forecast points in Sabine, Neches, San Jacinto, and Trinity River Basins and is planning on deploying HEFS for the remaining forecast points in Texas by the end of 2021. WGRFC will focus on calibration of HEFS using a new version of GEFS, i.e., GEFS version 12 (GEFSv12), that has come online since 2019. The GEFSv12 reforecast database comprises two distinct datasets. The first one is issued daily for lead times up to 15 days (medium range) and consists of 5 ensemble members, whereas the second is issued weekly with 11 members for lead times up to 35 days (subseasonal). The planned effort complements WGRFC's plan in three major respects: 1) adapting the subseasonal forecasts rather than medium range forecasts as planned by WGRFC, 2) calibrating the MEFP using CFSv2 forecast for lead times beyond 65 days, and 3) calibrating the EnsPost.

The UTA team will acquire a stand-alone version of CHPS along with mean areal precipitation (MAP) series from WGRFC. The MAP series are created for each forecast segment from hourly, gridded radar-gauge multi-sensor precipitation estimates produced by the Multisensor Precipitation Estimator (MPE; Seo et al., 2010; Zhang et al., 2011). Prior to the calibration of MMGD; canonical events in MEFP will be determined according to forecast accuracy and climatology using all forecast-observation pairs in the historical record. The calibration of the MMGD scheme will be done following the parameter estimation approach described in Wu et al. (2011).

2.4 Hindcast and integration tests

Hindcast experiments will involve running ESP and HEFS to generate ensemble streamflow forecast traces for selected forecast points along the Brazos River and its tributaries as described in the subsequent section. ESP will be run to produce streamflow hindcasts for 1990-2020, whereas HEFS will be calibrated separately for two periods, 2000-2009 and 2010-2019. The calibration-validation strategies are outlined in Table 1. In each calibration-validation test, both postprocessed probabilistic quantitative precipitation forecasts (PQPFs) and ensemble streamflow traces generated using calibrated modules will undergo validation against observations in the validation window.

Table 1: Hindcast experiments and calibration-validation strategies

Forecast System	Time window for testing	Calibration-validation scheme
ESP (baseline)	1990-2020	5-fold cross-validation
ESP (MEI-weighted)		
HEFS (baseline)	2000-2019	2-fold cross-validation
HEFS w/ EnsPost		

Three integration tests will be performed to determine the operational readiness of the ensemble streamflow forecasts produced by the two forecast systems. The first test was developed in consultation with USACE-SWF, which has indicated that one of its primary needs for integrating forecast information arises from the concern of flooding risks in determining requests for deviations. These requests are made by water suppliers to enhance water supply reliability and proactively mitigate potential impacts of droughts. As illustrated in Fig. 9, this test entails ingesting ensemble streamflow traces from ESP into the NWS Joint Reservoir Simulation Model (RES-J) for the entire Brazos River Basin.

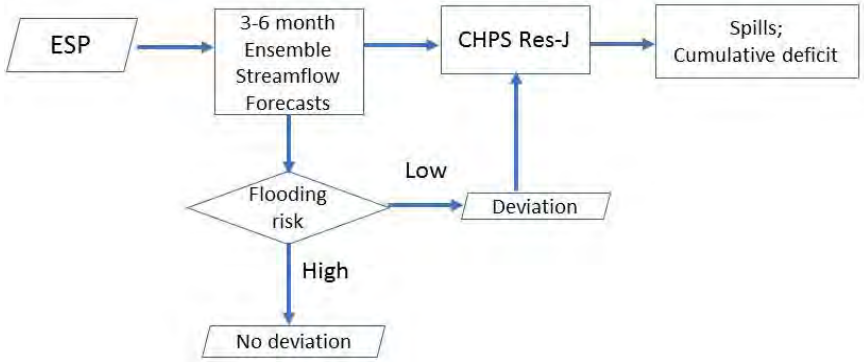

Figure 9: Integration test with USACE-SWF reservoir system represented in RES-J. Hypothetical scenarios of forecast-informed deviation that mimic current USACE practice are introduced to examine the operational readiness of forecasts.

The RES-J will serve as a proxy for the reservoir modeling system maintained by the USACE-SWF. In order to verify that RES-J closely resembles the USACE-SWF's reservoir modeling system, the project team will partner with the latter to extract and compare operational rules against those of the latter, and any discrepancies will be fixed. Then, a trigger for deviation will be introduced to RES-J to mimic USACE-SWF operations. This trigger will be set in the fall and activated when the risk of flooding in the upcoming 3-6 months is sufficiently low (below a minimum percentage threshold) on the basis of ensemble traces. This threshold will be set to 15, 10, and 5% exceedance levels calculated from ESP traces per Smith et al. (1992). This temporary deviation will then be incorporated into RES-J with other operational policies intact. The resulting model will then be used to produce simulations of reservoir pool levels and spillage. The results on risks and benefits will be shared with USACE-SWF.

The second integration test entails coupling HEFS forecasts with an operational model managed by BRA, the Williamson County Regional Raw Water System (WCRRWS). The WCRRWS consists of a planning simulation model (PSM) and an operations optimization model (OOM). Both models calculate the reservoir pool level using the mass balance model shown in Fig. 10. The PSM is actively used for pump station design and operations planning at 3-60 month time horizon. It helps users assess plans such as new pump selections, alternative operating rules, energy pricing structures, and projected water use. In its present configuration, it is able to ingest historical inflow series and produce simulations of pool elevations, spills, supply shortages, and energy consumption. It offers three simulation modes, i.e., period of record, mid-term, and batch modes. In the integration test, the PSM will be upgraded to ingest user-specified inflow series and run in a batch mode that ingests the ESP traces. In order to evaluate the impacts of potential improvements in forecasts, both the baseline (unconstrained) and MEI-constrained ESP traces will be fed to the PSM. Resulting supply shortages and pumping costs will be compared.

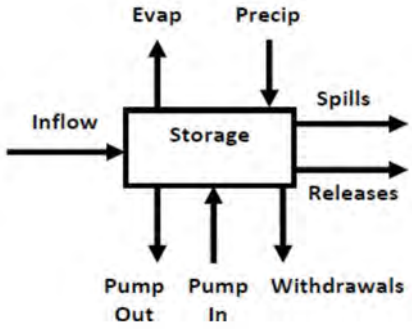

Figure 10: Reservoir mass balance model used in WCRRW modeling system.

The third integration test involves the Water Availability Model (WAM) for the Brazos. WAMs are maintained by TCEQ and are used for water rights permitting and regional water planning in Texas. WAMs include a feature called Conditional Reliability Modeling (CRM) for supporting drought management and operational planning (Fig. 11). The TWDB has developed a simple quantile mapping mechanism that combines seasonal rainfall forecasts for May, June, and July (MJJ) and CRM simulations to produce reservoir storage forecasts. This mechanism has been previously implemented for three reservoirs in the Brazos River Basin, namely Aquilla Lake, Lake Limestone, and Proctor Lake. In this project, this scheme will be augmented to allow the use of ESP cumulative inflow volume forecast in lieu of TWDB seasonal rainfall forecasts as the basis for producing reservoir storage forecasts. For each designated reservoir, forecasted probability of exceedance of inflow volumes will be calculated using historical ESP traces as the reference, and this probability will be used to retrieve the corresponding historical trace produced by CRM simulations to yield the forecasted storage. Both the baseline ESP and MEI-weighted ESP traces will be tested, and the resulting storage forecasts will be shared with BRA to guide the implementation of drought contingency plans. Note that this integration test complements the first test based on RES-J in that the WAM/CRM features a more comprehensive set of water use scenarios (permitted diversions), and therefore the results are more informative to drought planning.

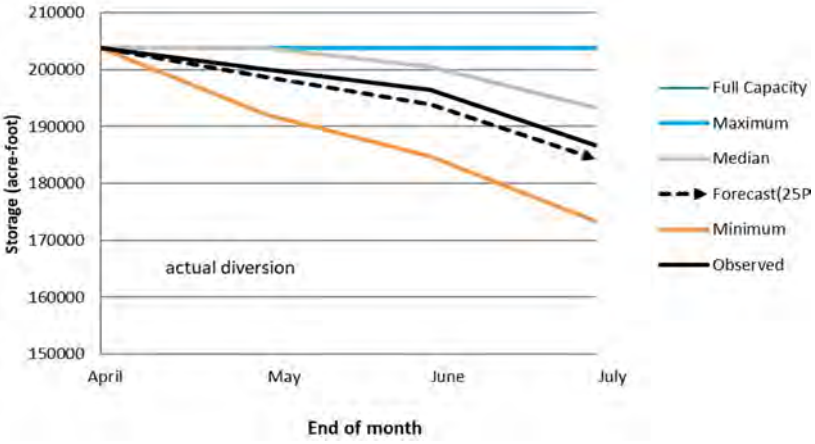

Figure 11: An example of output from the CRM simulation with Brazos WAM. For Lake Limestone (TWDB, 2017)

2.5 Tasks

This proposed project consists of the following seven tasks:

Task 1: Adopting and configuring NWS WGRFC CHPS

The UTA team will acquire a stand-alone version of CHPS from WGRFC on a UTA High Performance Cluster (HPC) managed by the PI. The CHPS configuration includes boundaries and connectivity among forecast segments along the entire Brazos River Basin, parameters for the SAC-SMA, unit hydrographs and routing models for each forecast segment in the basin. The team will also examine reservoir operation rules implemented in the RES-J model against those maintained by USACE-SWF and will modify the former as necessary.

Task 2: Establishing and testing MEI-weighted ESP for selected forecast points

In this task, UT-BEG will acquire MEI from NOAA Physical Science Laboratory, and will create schemes for weighting ESP traces using MEI in computing the exceedance probability as illustrated in Fig. 4. The weighting schemes will broadly mimic those described in Werner et al. (2004); it will be based on the similarity between current and historical MEI. In order

to capture the relative ENSO phase, the similarity measure will be calculated on the basis of difference in the MEI values as well as its relative position in the current ENSO phase measured as the time lapse from the onset of the transition.

Task 3: Configuring and adapting HEFS

UTA will collaborate with WGRFC to configure HEFS for selected forecast points in the Brazos River Basin. WGRFC will set up the MEFP, the hydrologic models, and the EVS, and the UTA team will work on calibrating the MEFP using the subseasonal (GEFS) and seasonal (CFSV2) forecast and on configuring the EnsPost. The calibration of MEFP will involve identification of the canonical events, computing the temporally aggregated rainfall series (based on forecasts and observations) for each canonical event, and estimating the parameters of MMGD. The calibration of EnsPost will entail regression analysis for USGS headwater stations to derive the autoregressive coefficients for each forecast point. The calibrated MEFP and EnsPost will be shared with WGRFC.

Task 4: Producing hindcasts and skill assessments

UTA will lead this task with assistance from UT-BEG. The task is divided into three subtasks. The first subtask involves computing streamflow hindcasts using the baseline ESP and will be carried out by UTA. The second subtask will be led by UT-BEG and entails configuring the MEI-weighted ESP and creating streamflow hindcasts. The hindcasts based on both ESP systems will be for lead times of 1 to 12 months for the period of 1991-2020. The third subtask will focus on creating the HEFS hindcasts for 2000-2019 using the WGRFC configuration (without EnsPost) and using the UTA configuration (with EnsPost). The UTA team will perform a comprehensive assessment of forecast skills using the EVS. The forecasts to be assessed are summarized in Table 2, and the precipitation and streamflow forecasts will be assessed against observations. The results will be shared with all partners.

Table 2: Forecasts to undergo skill assessments

Forecast System	**Forecast types**	**Lead Time**
GEFSv12	Precip. and temp ensemble	Day 1-35
CFSv2	Precip. and temp lagged ensemble	Month 1-6
ESP (baseline/MEI-weighed)	Streamflow ensemble	Month 1-12
HEFS	Probabilistic precipitation forecasts, ensemble streamflow forecasts	Day 1-270

Task 5: Testing ensemble forecast-informed reservoir operation using RES-J

This task will be carried out by the UTA team in coordination with WGRFC and USACE-SWF and with participation from a consultant from WEST Consultants (Curtis) who is closely familiar with USACE's reservoir system model. It will produce a decision support tool for USACE-SWF to determine the risk associated with temporary deviation on the basis of seasonal streamflow forecasts. The task will consist of the following three elements:

- calculating the percentage exceedance of inflow rates for lead times of 3-9 months from the ensemble forecasts produced by the baseline and the MEI-weighted ESP
- applying daily and monthly inflow volumes associated with a range of non-exceedance probabilities of flow as the reference threshold to trigger the decision of deviation in the fall

- ingesting ESP ensemble streamflow traces to the NWS RES-J to yield total spillage and the duration the pool level stays below conservation storage level

The results of the integration test will be shared with USACE-SWF and BRA.

Task 6: Testing ensemble forecast-informed reservoir operation using WCRRWS and daily Brazos WAM/Conditional Reliability Modeling routine

This task will be carried out by UT-BEG in consultation with BRA and WEST Consultants. The task will involve the following steps:

- configuring the WCRRWS to allow the ingest of ESP traces;
- feeding both baseline and MEI-weighted monthly ESP ensemble traces to the WCRRWS PSM to calculate total pumpage and cumulative deficit; and comparing the results derived by applying existing historical traces;
- developing monthly forecast of reservoir storage with the daily Brazos WAM/CRM in conjunction with ESP inflow forecasts

This task will yield a decision support system for BRA to assist with its planning and operation and forecasted storage from WAM/CRM.

Task 7: Producing drought triggers for drought contingency plan

This task will be led by UTA in cooperation with UT-BEG and the TWDB. The latest drought contingency plan developed by BRA in 2019 relies on a combination of pool levels, combined volumes, and pumping duration and transfer (BRA, 2019). In the contingency plan, TWDB seasonal rainfall prediction, which is produced using the statistical scheme of Fernando et al. (2019), serves as one of the references (https://waterdatafortexas.org/drought/rainfall-forecast). The forecast-driven implementation of drought contingency plan will be developed on the basis of storage forecast produced by WAM/CRM. Incidence when the triggers are activated will be computed for the period of hindcast (2000-2019) and compared with actual issuance of contingency measures.

3. Project Location

As shown in Fig. 12, the test domain for the hindcast experiments and integration tests covers the central portion of Texas north of the Austin metropolitan area. There are four major reservoirs situated in the study area, Lake Georgetown, Stillhouse Hollow Lake, Belton Lake, and Granger Lake (Fig. 12; Table 3); all located in the Brazos River Basin. Lake Georgetown and Granger Lake are situated along the San Gabriel River, a tributary to the Brazos River, with Granger Lake situated downstream of Georgetown. Among these, Lake Georgetown features the smallest surface area and storage (2 mi^2). Its area of service covers the cities of Georgetown, Brushy Creek, and Round Rock. These reservoirs

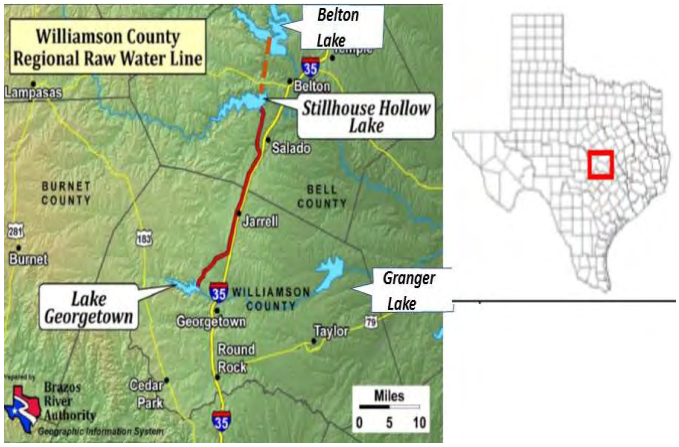

Figure 12: Locations of Lake Georgetown and Stillhouse Hollow Lake in central Texas. The red solid line represents the pipeline system that connects the two reservoirs.

are considered in the Williamson County Regional Raw Water Supply System (WCRRWS).

Table 3: Reservoirs in central Texas considered for the proposed study

Reservoir	Drainage (mi^2)	Surface Area (mi^2)	Inflow Source	Year of Impoundment
Georgetown	247	2	San Gabriel River	1979
Stillhouse Hollow	1,313	10	Lampasas River	1968
Belton	3,570	19	Leon River	1954
Granger	730	6	San Gabriel River	1980

The forecast points of interest for this project are shown in Table 4 where each forecast point is designated by NWS Standard Hydrological Exchange Format (SHEF) ID.

Table 4: NWS forecast points in the domain of interest

NWS SHEF ID	USGS ID	Drainage Area (mi^2)	Downstream Reservoir
KEMT2	08103800	818	Stillhouse Hollow Lake
PICT2	08101000	455	Belton Lake
GAST2	08100500	2342	Belton Lake
BLET2	08102500	3582	N/A
LRIT2	08104500	5228	N/A
GETT2	08104900	133	Granger Lake
RLRT2	08106350	6959	N/A

Another 5 reservoirs in the Brazos River and associated forecast points will be incorporated in integrating ensemble streamflow forecast with RES-J.

4. Data Management Practices

The project will utilize publicly available datasets and public-domain software systems maintained by the NWS and BRA. It will produce intermediate and final datasets, software tools and documentation, which include the hindcasts, scripts for performing the calibration and skill assessments, and configurations of HEFS and ESP to be shared with WGRFC. These final datasets will be stored on the UTA server for 2 years after project completion, and will be shared with partners upon request. With concurrence from partners, some of the final datasets will be published in a public domain archive (e.g., hydroshare.org). The UTA PI will also establish a UTA project web portal (hydromet.uta.edu) where a catalog of key datasets will be published. Table 5 summarizes the final datasets and management plans.

Table 5: Final tools/datasets and sharing plan

Product	Format	Archive Location	Sharing Platform
MEI-weighted ESP	Python, xml	UTA	Hydroshare
HEFS config for GEFSv12	Python (or Java), xml	UTA	Hydroshare
ESP/HEFS hindcasts	Ascii	UTA	Google drive, Hydroshare
Integration test results	Ascii	UTA	Google drive, Hydroshare
HEFS + WCRRW integration test results	Ascii	UTA	Google drive, Hydroshare

5. Evaluation Criteria

E.1.1. Evaluation Criterion A — Benefits to Water Supply Reliability

1. Regional water supplies are increasingly stressed by both population growth and droughts. The population of the service area of Lake Georgetown has more than doubled in the last two decades and is expected to increase by more than 50% in the next decade (Fig. 13). Due to its small size, Lake Georgetown is particularly vulnerable to overdraft. In both 2008 and 2010, pool levels dropped to near historical lows (Fig. 14). To augment the limited capacity of Lake Georgetown and ensure reliability in water supply, the Williamson County Regional Raw Water Line (WCRRWL) was constructed to transfer water from Stillhouse Hollow Lake to Lake Georgetown. Since the onset of its operation, the WCRRWL has steadily increased pumpage/transfers. To further improve water supply reliability, an additional potential pipeline is planned between Belton and Stillhouse Hollow Lakes.

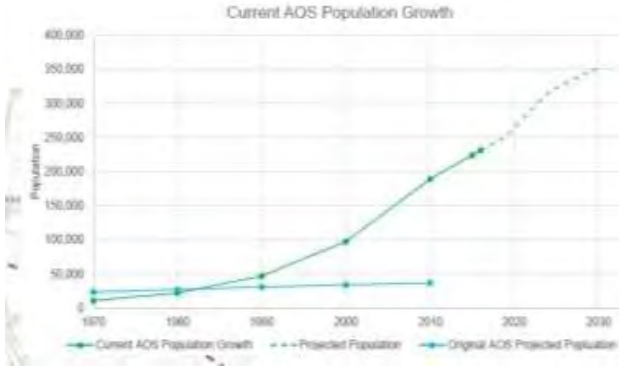

Figure 13: Population trend in Lake Georgetown's area of service.

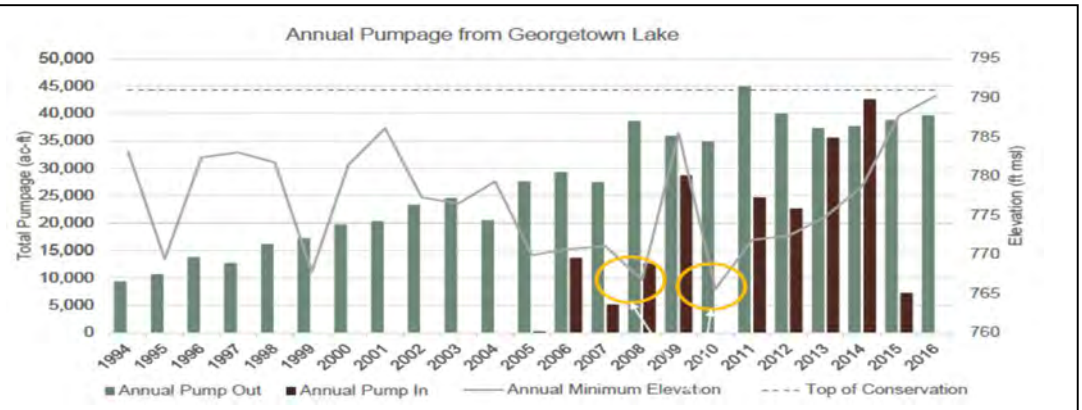

Figure 14: Pool level of Lake Georgetown and annual pumpage from Stillhouse Hollow to Lake Georgetown.

The adaptation of ensemble streamflow forecasts and testing their use in reservoir operation will help address the following water supply objectives: a) water supply reliability, b) management of water deliveries, and c) drought management activities. Specifically, the use of ensemble streamflow forecasts at lead times of 3-6 months can enable USACE-SWF to objectively assess the risk associated with temporary use of flood storage for Stillhouse Hollow Lake that is currently decided using a combination of climatology and operator judgement. Understanding the risk of temporary holding of flood water to benefit water availability under different forecasted scenarios will help USACE-SWF develop a more consistent, objective deviation strategy that will

translate into reduced deficit in the conservation pool and improved water supply reliability. The integration of forecasts with BRA's planning tool will help BRA more efficiently manage its pumping and water delivery operations. This addresses the objective of water delivery operation by BRA. The project will also yield WAM/CRM storage forecasts under different water use scenarios that will serve as a reference for implementing drought contingency plans to help proactively manage the impacts of droughts.

2. The proposed work will produce sizable and measurable benefits to all three aforementioned management objectives. The availability of ensemble streamflow forecasts at the seasonal scale will help inform USACE-SWF's decision on temporary storage of flood water which in turn can substantially benefit water supply reliability and help proactively alleviate impacts of droughts; these benefits will be quantitatively assessed through the hindcast experiment. Likewise, the ability to constrain ensemble streamflow forecasts at seasonal scales according to similarity in prevailing climate conditions will directly help BRA plan pumping operations, which, at present, relies on a historical ensemble of inflow conditions indiscriminately. In addition, the project will augment a current planning tool by BRA to allow examination of forecast-driven and operation and planning decisions and a forecast-based drought planning tool based on the WAM maintained by the TWDB.

3. The project will complement and contribute to ongoing efforts by WGRFC to implement and deploy HEFS for its entire service area in that 1) it calibrates MEFP using the GEFSv12 weekly reforecasts for lead times 1-35 days and using the CFSv2 forecast for lead times between 65 and 270 days, 2) it establishes EnsPost parameters for the Brazos River Basin. These elements are not included in WGRFC's plan and will lead to the implementation of complementary, critical tools to ensure water supply reliability via operationalization of forecast products.

E.1.2. Evaluation Criterion B — Need for Project and Applicability of Project Results

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

a. The need for forecast products to inform reservoir operations has been expressed by multiple operators across the state including the USACE-SWF and the BRA (see letters attached). The TWDB has a vested interest in promoting the adoption of forecast products as a potential mechanism for improving water supply reliability across the state as enunciated in the FIRO report described earlier (TWDB, 2020). USACE-SWF, through its normal operation, has identified the need for forecast information to determine deviation strategies that can minimize the risk of flooding while improving water supply reliability. The BRA already uses an operational and planning model capable of ingesting historical hydrology, and is interested in using the MEI-weighted ESP if its skills can be demonstrated. Both agencies express keen interests in understanding and quantifying the skill of inflow forecasts from different systems and the potential utility of forecasts in different aspects of reservoir operations.

b. The project will yield the following tools that can be **immediately implemented** in WGRFC's CHPS and adopted by reservoir operators including the USACE-SWF and BRA: 1) MEI-weighted ESP scheme and configuration, and MEI-constrained ESP traces; 2) HEFS with EnsPost, and calibrated parameters for GEFS and CFSv2 susbseasonal and seasonal forecasts. The MEI-constrained ESP traces will be delivered to the BRA.

   The HEFS forecasts and skill assessments will also be reviewed by USACE-SWF for adoption. In addition, the project will produce two simple decision support tools that **can be immediately used by partnering agencies**. The first tool ingests either climatology or ensemble streamflow forecast as the guide to determine the risk of deviation. This tool will be made available to USACE-SWF and the BRA. The second is a forecast-based planning tool based on WCRRWS that will be shared with the BRA by project completion. It will also yield a tool for forecasting seasonal reservoir storage using WAM/CRM based on ensemble streamflow forecast that will augment the existing framework developed by the TWDB to guide the implementation of drought contingency plans for water supply reservoirs.

c. The forecasts and decision support tools will be readily transferable to other reservoir operators in the state. The TWDB, in collaboration with USACE-SWF, is hosting a quarterly FIRO seminar series that serves as an ideal platform to demonstrate the tools to participants. The TWDB co-PI will help reach out to water suppliers including the Lower Colorado River Authority and Trinity River Authority to assess interest in similar pilot projects.

d. The project team includes a co-PI from the TWDB (Fernando) responsible for water availability modeling for the state, and the project planning has been done with input and direction from USACE-SWF and the BRA. USACE-SWF Chief of Water Resources Jerry Cotter first brought to the attention of the project team the widening water demand-supply gap in the Lake Georgetown region. Cotter also described in detail the deviation practice, the forecast lead times of interest, and specific types of rainfall events that would most likely lead to flood operations. BRA representatives Aaron Abel and Phil Price provided detail and clarity regarding conditions under which deviation requests are made, described the specific considerations in scheduling the pumping operations, and helped identify the need for a modified ESP conditioned on the climatological conditions. In executing the project, the operators from USACE-SWF and BRA will be continually engaged through regular check-in meetings; any change in plan will be discussed with the partnering agencies first to reach consensus.

E.1.3. Evaluation Criterion C — Project Implementation

1. The adaptation of the ESP by incorporating climate information will follow the framework outlined in Smith et al. (1992) and the method established in Werner et al. (2004). In implementing the MEI-weighting scheme for conditional ESP traces, the

project team will calculate the weights assigned to the ESP traces on the basis of similarities in the MEI associated with each trace to the present condition.

The HEFS adaptation will follow the well-established methodology previously described, which entails identifying the canonical events, calibrating the Mixed-type Meta-Gaussian Distribution (MMGD; Wu et al., 2011) for the ensemble mean of the 35-member weekly precipitation and temperature forecasts, and establishing the parameters for the EnsPost. The hindcast experiments and skill assessments will be done using the EVS. Metrics involved include the Brier Skill Score (BSS), Continuous Ranked Probability Skill Score (CRPSS), and reliability diagrams.

The analysis of flood risk incurred by deviation will adapt methodology developed by Delaney et al. (2020) including running the ESP and HEFS forecast traces through a reservoir model and computing the total spillage with and without deviation. The integration test with the WCRRWS PSM will be carried out by feeding the model with MEI-constrained ESP traces, and the results will be compared with the baseline (equal probability for each trace). The forecast-informed implementation of drought contingency plans will be tested against drought declarations documented by BRA.

2. Work plan

Tasks and Milestones	**Organizations**	**Year 1**				**Year 2**			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Kickoff Meeting	All								
CHPS adoption	UTA, WGRFC								
ESP adaptation	UT-BEG, UTA, TWDB								
HEFS adaptation	UTA, WGRFC								
Hindcast and Tuning	UTA, UT-BEG, TWDB								
Workshop 1	All								
Site visit to BRA	UTA, UT-BEG								
Y1 Report	All								
Integration test	UTA, UT-BEG, TWDB								
Workshop 2	All								
Y2 Report and plan for future operation	All								

3. Anticipated end products from the project

Product	**Type**	**Users**
MEI-weighted ESP configuration	Code and doc.	WGRFC, BRA
Adapted HEFS	Code and doc.	WGRFC
Hindcasts and skill assessments	Data and report	USACE, BRA, TWDB
Integration test outcomes/ reports	Data and report	USACE, BRA, TWDB
Drought trigger implementation	Data and report	BRA, TWDB

4. Credentials and responsibilities of investigators

The project will be led by Drs. Yu Zhang and Dong-Jun Seo at UTA, both of whom are veterans of the NWS Hydrology Program and have worked extensively on the calibration and improvement of ensemble weather and streamflow forecasts. Dr. Zhang is leading a NASA-funded project titled *"Integrating NASA Satellite Soil Moisture and Precipitation Products with Operational Hydrologic Prediction Capabilities of River Authorities in the State of Texas"*, which focuses on improving reservoir inflow forecasts through the ingest of NASA soil moisture products. He has contributed to the improvement of HEFS over the years (Wu et al., 2017; Ghazvinian et al., 2020, 2021). Dr. Zhang will oversee the project execution and coordination between project teams and partners. Dr. Seo was the primary architect of the HEFS that is operational today. He led a NOAA-funded project titled *"Climate forecast-aided drought decision support for North Central Texas"*, which led to the establishment of HEFS for forecast points along the Upper Trinity River Basin and helped assess the utility of ensemble streamflow forecast to inform the management of a reservoir system owned by the TWRD. Dr. Seo will guide the UTA team in setting up the forecast systems, producing hindcasts, and performing integration tests.

The TWDB co-PI Dr. Nelun Fernando has expertise in seasonal climate prediction and in the provision of technical assistance for water availability assessments. She is the PI for a current USBR Drought Response Program project entitled "Enhancing Surface Water Evaporation Monitoring in Texas to Improve Reservoir Evaporative Loss Estimates". Dr. Fernando will participate in forecast adaptation, coordination with BRA and USACE-SWF, and will help with dissemination of findings to reservoir operators and the public through the quarterly FIRO webinars hosted by the TWDB. Dr. John Zhu is a senior hydrologist who has worked extensively with reservoir modeling. Dr. Zhu will work on combining ESP inflow forecasts with WAM/CRM simulations to produce storage forecast.

The UT-BEG co-PI Dr. Bridget Scanlon is a world leading expert on hydrologic systems and modeling and a member of National Academy of Engineering. Dr. Scanlon will guide a postdoctoral researcher to help tailor the ESP for central Texas and test forecast-driven pumping operations. A consultant Dr. David Curtis is a renowned water resource scientist and engineer, an early contributor to the development of ESP, and a current contributor to the Lake Folsom FIRO effort. Dr. Curtis will guide the integration test with reservoir operation models and will help disseminate results to USACE-SWF.

E.1.4. Evaluation Criterion D — Dissemination of Results

The project outcomes will be disseminated to partners, reservoir operators, and the public through the following channels.

- Project team will hold bi-weekly meetings with the BRA and USACE to share results and solicit input, and the team will visit the BRA in Y2 to discuss project status.
- TWDB will share the results through its newsletter and social media outlets
- UTA will establish a project webpage at hydromet.uta.edu to disseminate resources related to project objectives and findings.

- Project team will present the results at national and state conferences, e.g., American Society of Civil Engineers (ASCE) Environment and Water Resource Institute 2023 Annual Conference and the 2022 Water for Texas Conference.
- Project team will give a joint presentation at the quarterly seminar hosted by TWDB;
- Project team will host a series of (2 or 3) joint workshops through the course of the project to help operators understand and adopt the forecast products. These workshops will be attended by USACE water management staff, forecasters from WGRFC, TWDB water availability team members, and will involve forecasters from NWS Climate Prediction Center and Weather Prediction Center.

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Funding Plan

The non-federal share of project costs will be obtained through the University of Texas at Arlington (applicant), the University of Texas at Austin (subaward), and the Texas Water Development Board (Category A partner).

The University of Texas at Arlington will provide cost-share through personnel salaries, fringe, and associated indirect costs. The Department of Civil Engineering will provide cost-shared effort for the PI (1.11 months in Y1 and 1.78 months in Y2), co-PI (0.24 months in Y1 and 0.23 months in Y2), and graduate research assistant (4.8 months in Y1). This effort has cost-shared fringe and indirect costs associated with it for each person. The total cost-share provided is $119,860

The University of Texas at Austin will provide cost-share from personnel effort performed on the Faculty and Research Scientists Appointments (FRSA). The PI will cost-share 0.59 months of salary for each of the two years. The total cost-share provided is $44,820.

The Texas Water Development Board will provide cost-share in the form of staff hours (560 total) and associated indirect costs. The total cost-share provided is $34,981.

Please see attached for the letters of funding commitment.

OFFICE OF SPONSORED PROJECTS
THE UNIVERSITY OF TEXAS AT AUSTIN
3925 West Braker Lane, Suite 3.340 •Mail Stop A9000 • Austin, TX 78759
(512)471-6424 • Fax (512)232-6649 • osp@austin.utexas.edu

Letter of Intent to Establish a Consortium Agreement

Date: 4/15/2021

UT Austin PI: Bridget Scanlon, PhD
Prime Agency Name: The University of Texas at Arlington
Application Title: *Adopting Ensemble Inflow Forecasts to Inform Flood Pool Allocation Strategies for a System of Reservoirs along the Brazos River in Central Texas*
OSP #: 202100978-001

Project Information

Organization Name: **The University of Texas at Austin**
DUNS #: **170230239**
Congressional District: **TX-025**
Project Dates: **08/31/2021 to 08/30/2023**

Funds Requested		**Cost Share**		**Total Project Costs**	
Direct Costs	$ **28,278**	Direct Costs	$ **28,283**	Direct Costs	$ **56,561**
F&A Costs	$ **16,542**	F&A Costs	$ **16,546**	F&A Costs	$ **33,088**
Total Costs	$ **44,820**	Total Costs	$ **44,829**	Total Costs	$ **89,649**

The in-kind cost share will be available during the period of performance of the prime award.

Are Animals Applicable to this Proposed Project? ☐ Yes ☒ No
Are Humans Applicable to this Proposed Project? ☐ Yes ☒ No

Attached to this Notice of Intent:

Statement of Work	☒	**Budget Justification**	☒	
Biosketch(es) / Key Personnel	☐	Click here to enter text.	☐	
Budget	☒	Click here to enter text.	☐	

The University of Texas at Austin is participating in the FDP Expanded Clearinghouse Pilot. Relevant subaward information is located on The University's entity profile located at https://fdpclearinghouse.org/organizations/66.

The appropriate programmatic and administrative personnel of The University of Texas at Austin involved in this grant application are aware of the pertinent Federal regulations and policies and are prepared to establish written inter-organizational agreements that will ensure compliance with all such policies.

Please note that The University of Texas at Austin reserves the right to negotiate the terms and conditions of any awarded grant or contract. As an institution of higher education, The University of Texas at Austin intends to perform the work under any awarded grant or contract as fundamental research and reserves the right to: 1) require that the provider notify the University if it is to provide any export controlled information; 2) to deny receipt of any export controlled materials; and 3) to reject any restrictions on the University's right to publish or otherwise disseminate information relating to this research.

The University of Texas at Austin has implemented, and elects to follow, an institutional financial conflicts of interest policy that complies with 42 CFR Part 50 (http://www.policies.utexas.edu/policies/promoting-objectivity-research-managing-reducing-or-eliminating-financial-conflicts) AND is registered in the FDP FCOI Clearinghouse.

AUTHORIZED OFFICIAL

Elena V. Mota, BA, CRA, Assistant Director, Office of Sponsored Projects
The University of Texas at Austin

ADDITIONAL CONTACTS

Administrative and budgetary matters regarding the proposal:
Ryan Rousch, Proposal Analyst
The University of Texas at Austin
Office of Sponsored Projects
Phone: (512) 232-5651
Email: rousch@austin.utexas.edu

Negotiation and execution of consortium agreement:
The University of Texas at Austin
Office of Sponsored Projects
3925 W. Braker Lane, Suite 3.340 (Mail Code A9000)
Austin, Texas 78759-5316
Phone: (512) 471-6424; FAX: (512) 232-6649
Email: osp@austin.utexas.edu

Texas Water Development Board

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.texas.gov
Phone (512) 463-7847, Fax (512) 475-2053

April 21, 2021

Prof. Yu Zhang, Ph.D
Associate Professor
Department of Civil Engineering,
The University of Texas at Arlington
Box 19308, 416 Yates St. Arlington, TX 76019-0308

Dear Dr. Zhang:

Thank you for the invitation to collaborate on the proposal titled *Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas* that you are submitting in response to the U.S. Bureau of Reclamation's WaterSMART Applied Sciences funding opportunity for Fiscal Year 2021.

We consider it important that the Texas Water Development Board (TWDB) collaborates with you on this project, because it will: 1) develop a pilot project to determine the skills of National Weather Service ensemble streamflow forecasts and facilitate their adoption by reservoir operators, which was a key recommendation from the 2019 workshop on *Forecast-Informed Reservoir Operations (FIRO) and Water Resources Management in Texas and Oklahoma* that we co-hosted with the University of Texas at Arlington and the National Integrated Drought Information System; and 2) develop methodologies for ingesting adapted ensemble streamflow forecasts to inform reservoir operations that will, in turn, provide reservoir operators with the tools to quantify improvements to water supply reliability that can be realized by adopting aspects of FIRO.

We commit to providing at least $34,980 of in-kind support as state match on this project to cover staff time for Dr. Nelun Fernando (Manager, Water Availability) and Dr. John Zhu (Senior Hydrologist, Water Availability) to undertake the following in support of the proposed project: (a) provision of methodological guidance on proposed Task 7; (b) developing reservoir storage forecasts, by ingesting ensemble streamflow forecasts to the Brazos Water Availability Model (WAM)–Conditional Reliability Modelling routine, as defined in proposed Task 7, (c) participation in virtual project meetings, and (d) peer review of tools and reports. We also hope to disseminate lessons learned through this project via the quarterly FIRO webinar series that the TWDB is co-hosting with the U.S. Army Corps of Engineers–Fort Worth District.

Sincerely,

Carla G Guthrie

Carla G. Guthrie, Ph.D.
Director, Surface Water Division

BUDGET PROPOSAL & BUDGET NARRATIVE

Table 1. Total Project Cost Table

Source	Amount
Costs to be imbursed with the requested Federal funding	$199,656.00
Costs to be paid by the applicant	$119,859.00
Value of third-party contributions	$79,800.00
TOTAL PROJECT COST	$399,316.00

Table 2. UTA Detailed Budget

BUDGET ITEM DESCRIPTION	COMPUTATION		Quantity Type	Total Cost
	$/Unit	Quantity		
Salaries and Wages				
Employee 1	13,828.42	4.03	Month	55,716.00
Employee 2	19,004.33	0.95	Month	18,000.00
Employee 3	2,000.00	12.00	Month	24,000.00
Employee 4	4,000.00	5.00	Month	20,000.00
Fringe Benefits				
Full-Time Employees			30%	28,114.80
Student Employees			10%	2,400.00
Equipment				
Item A				0.00
Supplies and Materials				
Item A				0.00
Contractual/Construction				
UT-BEG				44,820.00
WEST Consultants (Curtis)				15,000.00
Third-Party In-Kind Contributions				
TWDB				34,981.00
UT-BEG				44,820.00
Other				
STEM Tuition				5,200.00
Travel				3,000.00
Total Direct Costs				216,250.00
UTA indirect Costs	54%	191,230	MTDC Base	103,265.00
Total Estimated Project Costs				399,316.00

Budget Narrative- UTA

Salaries and Wages

The total costs will be used to provide salary and fringe benefit for two UTA key personnel: $55,716 for PI Dr. Yu Zhang (Total: 4.0 month) and $18,000 for co-PI Dr. Dong Jun Seo (0.95 month). The respective amounts from UTA cost-share will be $40,716 and $9,000.

The annualized salaries for Zhang and Seo are $165,941 and $228,052, respectively. The funds will also support a 12-month salary for one UTA graduate student research assistant for Y1, whose monthly salary is $2,500. This totals $24,000, of which $12,000 will be from UTA cost-share. The funds will also support 5.18-month salary for one UTA postdoctoral research associate for Y2, whose monthly salary is $3,862.

Task/Personnel-month	Zhang	Seo	GSRA	Postdoc research associate
1	1.0	0.35	4	
2	0.2			
3	1.0	0.3	4	
4	0.8	0.3	4	
5	0.4			3
6	0.4			2
7	0.2			

The total salaries for the UTA team will be $117,716, with $61,716 from UTA cost-share.

Fringe Benefits

The fringe benefits for the senior personnel will be $16,714 for Zhang and $5,400 for Seo, and that for the postdoctoral research associate will be $6,000. These benefits are calculated with the rate of 30%. The fringe benefit for the student will be $2,400, which is calculated using the rate of 10%.

The total fringe benefits for the UTA team will be $30,515, of which $16,115 will be from UTA cost-share.

Travel

The total budget for travel will be $3000.

<u>Trip 1:</u>
Purpose: Attend Water for Texas Conference in 2022
Destination: Austin
Number of travelers: 2
Length of Stay: 2 days
Lodging: $600
Per diem: $322
Vehicle: $278
Misc: $200

Total: $1400

Trip 2:
Purpose: Attend ASCE EWRI Conference
Destination: TBD
Number of travelers: 1
Length of Stay: 3 days
Airfare: $500
Lodging: $400
Per diem: $400
Vehicle: $100
Misc: $200
Total: $1600

Contractual
A subcontractor UT-BEG will be awarded $44,800 to perform Tasks 2 and 6. The detailed budget breakdown can be found in the attached table.

A consultant David Curtis at WEST Consultants will be awarded $15,000. Curtis is a renown expert on reservoir operation and water resources management. He will contribute to Tasks 5 and 6.

Third-Party In-kind Contributions
The TWDB will make an in-kind contribution of $34,980.96. The detailed budget breakdown can be found attached.

UT-BEG will make an in-kind contribution of $44,820. A detailed breakdown of the cost-share can be found attached.

Other Expenses
The requested fund will cover one semester of STEM tuition for the graduate student at the amount of $5200.

Indirect Costs
The indirect rate for UTA is 54% for 2021-2022. This rate applies to the modified direct cost of $191,230.80, and the total indirect cost is $103,264.63.

For the University of Texas at Arlington, year equates to every 12-month period for Senior Personnel from the start date of this project.

Table 3- UT BEG Detailed Budget

View Burden Statement

BUDGET INFORMATION - Non-Construction Programs

OMB Number: 4040-0006
Expiration Date: 02/28/2022

SECTION A - BUDGET SUMMARY

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. R21AS00289	15.557	$	$	$ 44,820.06	$ 44,828.52	$ 89,648.58
2.						
3.						
4.						
5. Totals		$	$	$ 44,820.06	$ 44,828.52	$ 89,648.58

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SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY (1)	(2)	(3)	(4)	Total (5)
	R21AS00289				
a. Personnel	$ 10,201.09	$ 10,609.14	$	$	$ 20,810.23
b. Fringe Benefits	3,152.14	3,331.27			6,483.41
c. Travel					
d. Equipment					
e. Supplies					
f. Contractual					
g. Construction					
h. Other	492.00	492.00			984.00
i. Total Direct Charges (sum of 6a-6h)	13,845.23	14,432.41			$ 28,277.64
j. Indirect Charges					$
k. TOTALS (sum of 6i and 6j)	$ 13,845.23	$ 14,432.41	$	$	$ 28,277.64
7. Program Income	$ 0.00	$ 0.00	$	$	$ 0.00

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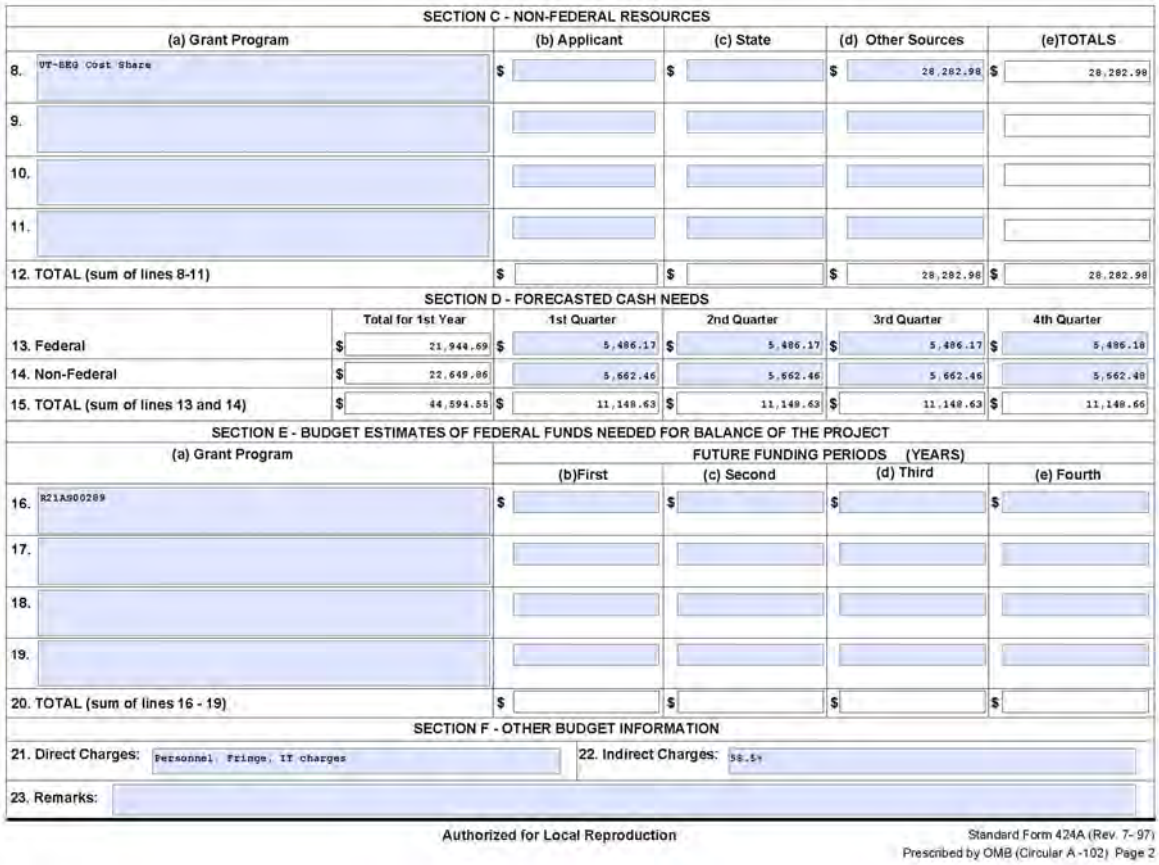

SECTION C - NON-FEDERAL RESOURCES

(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e)TOTALS
8. UT-BEG Cost Share	$	$	$ 28,282.98	$ 28,282.98
9.				
10.				
11.				
12. TOTAL (sum of lines 8-11)	$	$	$ 28,282.98	$ 28,282.98

SECTION D - FORECASTED CASH NEEDS

	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 21,944.69	$ 5,486.17	$ 5,486.17	$ 5,486.17	$ 5,486.18
14. Non-Federal	$ 22,649.86	5,662.46	5,662.46	5,662.46	5,662.48
15. TOTAL (sum of lines 13 and 14)	$ 44,594.55	$ 11,148.63	$ 11,148.63	$ 11,148.63	$ 11,148.66

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT

(a) Grant Program	FUTURE FUNDING PERIODS (YEARS) (b)First	(c) Second	(d) Third	(e) Fourth
16. R21AS00289	$	$	$	$
17.				
18.				
19.				
20. TOTAL (sum of lines 16 - 19)	$	$	$	$

SECTION F - OTHER BUDGET INFORMATION

21. Direct Charges: Personnel, Fringe, IT charges

22. Indirect Charges: 58.5%

23. Remarks:

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Budget Narrative – UT BEG

Salaries and Wages

The total costs will be used to provide salary and fringe benefit for two UT-BEG personnel. The salary includes $3,727.88 for Co-PI Dr. Bridget Scanlon (Total: 0.2 months) and $17,082.35 for postdoctoral researcher Dr. Sarah Fakhreddine (3.08 months). The UT-BEG cost-share will include $21,298.24 in salary for Dr. Scanlon (1 month) and associated fringe and indirect costs. The annualized salaries for Scanlon and Fakhreddine are $210,852.78 and $62,740, respectively.

Task/Personnel-month	Scanlon	Fakhreddine
2	0.6	1.54
6	0.6	1.54

The total salaries for the UTA team will be $42,108, with $21,298 from UT-BEG costshare.

Fringe Benefits

The fringe benefits for personnel will be $5,321.99 for Fakhreddine and $7,795.15 for Scanlon. These benefits are calculated with the rate of 30.9% for Year 1 and 31.4% for Year 2.

The total fringe benefits for the UT-BEG team will be $13,117.15, of which $6,633.74 will be from UTA cost-share.

Other Expenses
The requested fund will cover materials including cost of computer use for Task 2 ($669) and for Task 6 ($666), of which $351 will come from cost-share.

Indirect Costs
The indirect rate for UT-BEG is 58.5% for 2021-2022. This rate applies to the modified direct cost of $56,561.62, and the total indirect cost is $33,087.96, of which $16,545.54 comes from cost-share.

Table 4- TWDB Detailed Budget

Budget Item Description	Computation		Quantity Type	Total Cost ($)
	$/hour	Quantity	(hours)	(in-kind)
Salaries and wages				
Nelun Fernando	38.81	160	hours	6,209.60
John Zhu	30.86	400	hours	12,344.00
Total base salary				***18,553.60***
Fringe benefits				
Nelun Fernando			29.16%	1,810.72
John Zhu			29.16%	3,599.51
Total fringe				***5,410.23***
Travel to workshops				
Total travel				-
Other				
Total Direct Costs (only base salary)				18,553.60
Indirect costs (on base salary; 59.38%)				11,017.13
Total Study Costs (Direct,Fringe, and Indirect)				**34,980.96**

Personnel and tasks	year_1 (hours)	year_2 (hours)	Total (hours)
Nelun Fernando *(oversight of TWDB involvement in the project, methodological guidance on proposed Task 7, participation in virtual project meetings, and peer review of tools and reports)*	40	40	80
John Zhu *(Task 7: running of WAM-CRM to develop reservoir storage forecasts)*	80	320	400

Budget Narrative- TWDB

TWDB will not receive grant funds, but we will contribute cost-share in the form of staff time and associated IDC.

UNIVERSITY OF TEXAS ARLINGTON
OFFICE OF RESEARCH ADMINISTRATION
GRANT AND CONTRACT SERVICES

April 20, 2021

Ms. Avra Morgan
Program Analyst
Bureau of Reclamation
Water Resources and Planning Division
P.O. Box 25007, MS 86-69200
Denver, CO 80225
dmayhorn@usbr.gov
303-445-2906

Re: R21AS00289: “Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas” – Yu Zhang, PhD

Dear Ms. Morgan:

Enclosed is information relating to The University of Texas at Arlington’s proposal entitled “Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas” to be directed by Dr. Zhang. This letter represents our commitment to the financial and legal obligations associated with receipt of a financial assistance award under this NOFO and verifies the following:

- Authorized Organizational Representative: Sarah Panepinto, Director of Grant and Contract Services.
- The Office of Grant and Contract Services has reviewed and supports the application.
- UTA will provide the sum amount of $119,860 as cash cost-share towards the proposal as referenced in the funding plan and budget documents. This cost share will be provided in the form of salaries, fringe benefits, and associated indirect costs.
- UTA will work with Reclamation to meet established deadlines for entering into a grant or cooperative agreement.

Thank you for your consideration of this proposal.

Sincerely,

Sarah Panepinto

Digitally signed by Sarah Panepinto
Date: 2021.04.20 13:49:12 -05'00'

Sarah Panepinto
Director, Grants and Contracts Services

Brazos River Authority

QUALITY • CONSERVATION • SERVICE

April 20, 2021

Dr. Yu Zhang, Ph.D.
Department of Civil Engineering
The University of Texas at Arlington
416 Yates St
Box 19308
Arlington, TX 76019

Dear Dr. Zhang:

I am writing to confirm the Brazos River Authority's (BRA's) participation and full support in the USBR WaterSMART – Applied Science Grant FY21 proposal: *Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas*. The overarching goal of this work to adapt forecast products for a reservoir system in the Brazos River Basin to facilitate their operational use with the aim of improving water supply reliability, enhancing efficiencies in operations, and developing more effective drought management directly supports BRA's mission to develop, manage, and protect the water resources of the Brazos River basin.

The BRA is the largest provider of wholesale surface water within the Brazos River Basin serving municipal, industrial, mining, and agricultural interests. BRA stores water in three wholly owned and operated reservoirs: Possum Kingdom Lake, Lake Granbury, and Lake Limestone. The BRA also contracts for conservation storage space in eight US Army Corps of Engineers (USACE) reservoirs in the basin: Lakes Whitney, Aquilla, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville. Additionally, BRA operates the Williamson County Regional Raw Water Line (WCRRWL) that transfers water from Stillhouse Hollow Lake to Lake Georgetown through a 28-mile pipeline to further augment water supply for rapidly growing municipalities within Central Texas.

BRA supports forecast informed reservoir operations to more efficiently manage water supply operations, improve water supply reliability, and deliver better tools for drought management. As a partner with the WaterSMART proposal team, BRA commits to support all the activities outlined in the proposal. BRA will provide input and feedback on the adapted forecast systems constrained inflow traces (baseline Ensemble Streamflow Prediction (ESP) and Multivariate ENSO Index (MEI) weighted ESP) produced by the project to assist in BRA operations and drought management activities.

Sincerely,

AARON ABEL
Water Services Manager, Brazos River Authority

4600 Cobbs Drive • P.O. Box 7555 • Waco, Texas 76714-7555
254-761-3100 • FAX 254-761-3202

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
West Gulf River Forecast Center
3401 Northern Cross Blvd
Fort Worth, TX 76137

Date: April 18, 2021

To: Selection Committee
WaterSMART - Applied Science Grant (R21AS00289)
United States Bureau of Reclamation

From: Kris Lander, PE – Acting Hydrologist In Charge - West Gulf RFC

The National Weather Service West Gulf River Forecast Center (WGRFC) fully supports the USBR WaterSMART - Applied Science Grant FY21 proposal: *Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas,* by Dr. Yu Zhang and Dr. Dong-Jun Seo. This project cost-effectively proposes a solution that will deliver a tool to support Forecast-Informed Reservoir Operations (FIRO) in the West Gulf region. Furthermore, this project will support the fulfillment of the NWS' mission of protecting lives and property and enhancing the national economy.

The NWS WGRFC has partnered with this proposal team to further the development and implementation of a suite of predictive tools that will drive Forecast-Informed Reservoir Operations (FIRO) in the West Gulf region. The Ensemble Streamflow Prediction (ESP) system and Hydrologic Ensemble Forecast System (HEFS) have both been designed to drive FIRO-based decisions. HEFS has been successfully deployed and utilized for FIRO decisions in the Western and Eastern regions of the US, and has the potential to provide a framework to drive FIRO decisions in the West Gulf region. Furthermore, the National Weather Service has committed to continue the development and implementation of HEFS to help reservoir operators and water supply agencies make forecast-driven operational decisions in the short-to-long term time frame. This project is well aligned with the NWS' efforts to further HEFS development, as it extends the baseline HEFS capabilities to the subseasonal domain, creates EnsPost parameters and provides a case study for how HEFS may support FIRO in Texas.

With this letter, the NWS WGRFC commits to partner with the WaterSMART proposal team to support all of the activities outlined in the proposal. WGRFC will provide the project team with the CHPS Stand Alone model and the mean areal precipitation data files for input. WGRFC will set up the MEFP, the SAC-SMA, and the EVS for the study area. Finally, WGRFC will immediately implement functional HEFS model components and the MEI-weighted ESP scheme, developed by the project team, into the operational forecast system upon completion of the project.

Thank you for your careful consideration of this proposed effort.

Sincerely,

Kris Lander, PE

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT
P.O. BOX 17300
FORT WORTH, TX 76102-0300

April 21, 2021

Re: Letter of Collaboration for Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas

To whom it may concern:

If the following team of researchers:
Principal Investigator: Yu Zhang, Associate Professor, Dept of Civil Eng, Univ. of Texas at Arlington, Arlington, TX 76019, Email: yu.zhang@uta.edu, Phone: 817-272-1874
Co-Principal Investigator: Dong-Jun Seo, Professor, Dept of Civil Eng, Univ. of Texas at Arlington, Arlington, TX 76019, Email: djseo@uta.edu, Phone 817-272-5063
Development Board; Email: nelun.fernando@twdb.tx.gov, Phone: 512-471-8241
Co-Principal Investigator: John Zhu, Senior Hydrologist, Water Availability Program, Texas Water Development Board; john.zhu@twdb.tx.gov Phone: 512-471-7847
Co-Principal Investigator: Bridget Scanlon, Senior Research Scientist, Univ. of Texas at Austin Bureau of Economic Geology; Email: bridget.scanlon@beg.utexas.edu; Phone: 512-475-0454

are selected to investigate "Adapting Ensemble Inflow Forecasts to Inform Operations of a System of Reservoirs along the Brazos River in Central Texas", it is the intent of the U.S. Army Corps of Engineers (USACE), Fort Worth District, Water Resources Branch, to collaborate and partner with this research team to investigate utilizing forecast products and skills of the NWS to support additional forecast informed reservoir operations within the Brazos River Basin to improve water availability.

Water supply within the Brazos Basin is a critical issue within the State of Texas as was identified in 2011 when the TCEQ issued a senior water call and by emergency water supply planning activities related to the petrochemical industry located at the mouth of the Brazos River along the Texas Coast.

The USACE is in the initial stages of a Forecast Informed Reservoir Operations Viability Assessment for Texas and this research, if completed, will better inform USACE concerning forecast skill and use of forecast products for reservoir operations.

Please let me know if you have any questions or comments.

Sincerely,

Jerry Cotter, P.E.
Chief in Water Resources
U.S. Army Corps of Engineers
Fort Worth District
Email: Jerry.L.Cotter@usace.army.mil
Tel: (817)886-1549