Enhancing Surface Water Evaporation Monitoring in Texas
to
Improve Reservoir Evaporative Loss Estimates

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List of acronyms

ADSC	Agua del Sol Consultants, LLC
ASR	Aquifer Storage and Recovery
CFEP	Collison Floating Evaporation Pan
CRLE	Complementary Relationship Lake Evaporation
DRI	Desert Research Institute
NCEI	National Centers for Environmental Information
NWS	National Weather Service
TWDB	Texas Water Development Board
USWB	U.S. Weather Bureau
WAM	Water Availability Model
WRAP	Water Rights Allocation Package

Technical Proposal and Evaluation Criteria

Enhancing Surface Water Evaporation Monitoring in Texas to Improve Reservoir Evaporative Loss Estimates

1. Executive Summary

March 25, 2019
Texas Water Development Board
Austin, Travis County, Texas

The Texas Water Development (TWDB) is the state agency charged with collecting and disseminating water-related data, assisting with regional water planning, and preparing the state water plan for the development of the state's water resources. As part of its charge under Section 16.012 of the Texas Water Code, the Texas Water Development Board collects, compiles and disseminates reservoir evaporation data. Since 1998, the reservoir evaporation data compiled by the TWDB have been used by the Texas Commission on Environmental Quality and regional water planning groups as one of the key input datasets to Texas' Water Availability Models (https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html), which are the operational water allocation models used for water rights permitting and regional water planning in the state. The regional water planning process is the main drought planning mechanism in Texas.

Accurate estimates of reservoir evaporation are critically important for determining surface water availability. Unfortunately, current operational practices for observing or estimating surface water evaporation in Texas, primarily using Class A evaporation pans, have large uncertainties. Furthermore, many areas of the state do not have evaporation observations. Such gaps in observations result in large uncertainties in water availability estimates, which in turn have implications for water rights permitting, water planning, drought contingency planning, etc. With the paucity of evaporation observations that feed into the reservoir evaporation data set used for water rights permitting and regional water planning, and the uncertainties inherent in the current operational practice of using pan evaporation rates to infer reservoir evaporation rates, it is imperative that the state takes steps to improve the evaporation dataset used for water permitting and drought planning.

We are proposing a multi-pronged approach to enhance surface water evaporation monitoring in Texas using state-of-the-art technology for:

1) measuring actual evaporation over water using buoy stations on four reservoirs (i.e. Lake Meredith, Red Bluff Reservoir, Choke Canyon Reservoir, and Lake Buchanan) located in the northern, western, south central and southern areas of the state,
2) installing a floating pan evaporation station on Twin Buttes reservoir in west central Texas,

3) upgrading Class A pan evaporation stations managed by TWDB cooperators to include automated data readings, pan refills, and collect meteorological measurements needed for the computation of pan evaporation,
4) installing new Class A pans with automated readings, pan refills and meteorological sensors in areas with no current evaporation observations, and
5) deriving computed evaporation for all upgraded and new pan evaporation sites, identifying currently unmonitored regions where the computed evaporation could be applied using meteorological measurements, and estimating computed evaporation for these regions.

The multi-pronged approach builds on on-going evaporation monitoring research the TWDB is conducting at Lake Limestone, and will enable us to improve existing information on how pan evaporation rates can be adjusted to represent true lake evaporation, ensure that more areas of the state are covered by the evaporation observation network, and enable us to provide more accurate estimates of reservoir evaporation loss. The improved reservoir evaporation datasets will be used to provide daily estimates of evaporative water loss at all monitored reservoirs in Texas via the reservoirs page on Water Data for Texas (https://waterdatafortexas.org/reservoirs/statewide). The TWDB evaporation dataset used as input to the states Water Availability Models will be updated. The reservoir firm yield — that is the maximum amount of water a reservoir can supply annually during a repeat of the worst drought experienced in the area of concern — for the reservoirs at which the buoy stations and the floating pan are located will be re-estimated using the improved dataset to assess implications for surface water availability over the next 50-year time horizon.

By improving the accuracy of reservoir evaporation data used for water planning and water permitting, the project will provide information that water managers and water planners can use to determine the degree to which evaporative water loss has been accurately accounted for in existing management plans and in long-term water supply plans. By providing daily estimates of reservoir evaporation loss at monitored reservoirs in the state, the project will provide reservoir operators with information needed for daily reservoir operations and, during drought periods, provide information critical for decisions related to the implementation of drought contingency triggers on these reservoirs. Therefore, the project will help decrease vulnerability to drought by giving water managers flexibility with water supply options in times of low water supply.

The project fits within Task B – i.e. Projects to Improve Water Management through Decision Support Tools, Modelling, and Measurement – listed as eligible for funding under Reclamation's Drought Resiliency solicitation. It can specifically be classified as a project for: "***Developing water management and modeling tools to help communities evaluate options and implement strategies to address drought", and "Installing water measurement equipment and monitoring instrumentation devices to accurately track water supply conditions"***.

The project length is three years and the estimated completion date is September 30, 2022.

The proposed project is not located on a Federal facility.

2. Background data

The annual statewide water use for Texas in 2016 was estimated at 14.23 million acre-feet (www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/data/2016TexasWaterUseEstimatesSummary.pdf). Water demand is projected to increase from about 18.4 million in 2020 to about 21.6 million in 2070. Current water users (percent of total use) include: irrigation (55%), municipal (31%), manufacturing (8%), power (3%), livestock (2%), and mining (1%). Irrigation is the primary use. Major crops cultivated include: corn, rice, wheat, sorghum, cotton, forage hay pasture, sugarcane, and alfalfa (Texas Water Development Board, 2016).

Existing water supply is estimated at 15.2 million acre-feet for 2020. Existing sources of water are surface water, groundwater, and reuse water. Surface water contributes 7.5 million acre-feet or about 49% of total water supply (Texas Water Development Board, 2016). According to the 2017 State Water Planning Database, it is estimated that approximately 75% of surface water supply comes from surface water reservoirs and small unnamed surface water sources in the state. Most major municipalities in the state, except for San Antonio, El Paso, Amarillo and Lubbock, depend on surface reservoir storage for their supply (Texas Water Development Board, 2016).

Estimating how much water will be available to meet user needs includes an assessment of both water availability and existing supply. Water availability refers to the maximum volume of raw water that could be withdrawn annually from a water source (such as a reservoir or an aquifer) **during a repeat of the drought of record**. Water availability does not account for whether the supply is connected to, or legally authorized for use by, a water user group.

Surface water availability is determined using the Texas Commission on Environmental Quality's surface Water Availability Models (WAM), which are based on permitted water supplies within each river basin. The WAM uses the Water Right Analysis Package (WRAP) developed by Texas A&M University (Wurbs 2015). WRAP simulates management of water resources of river basin(s) under a priority-based water allocation system with river basin hydrology represented by sequences of naturalized stream flows (i.e. streamflow that factors out upstream human influence) and reservoir net evaporation rate at pertinent locations. These models determine the monthly and annual volumes of water that could be diverted each year during drought of record conditions. The TWDB is responsible for the compilation of the net evaporation dataset (the .eva input file) that is used in the WAMs (Wurbs, 2013).

The TWDB estimates that the average annual gross evaporation (i.e. where rainfall over the reservoir is not accounted for) from the 188 major water supply reservoirs in Texas at 6.89 million acre-feet per year, or about 55 percent the available surface water. During the 2011, the worst one-year drought on record in the state, statewide net evaporation (i.e. where rainfall is factored in) from surface water reservoirs is estimated at 5.83 million acre-feet. This estimate of reservoir evaporative water loss exceeds the highest ever recorded total annual municipal water use of 4.98 million acre-feet, which was also recorded in 2011 (TWDB Historical Water Use Summary Estimates, http://www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/index.asp). These estimates of increased evaporative water loss during times of drought, when water demand is highest, underscores the importance of accurate estimates of surface water evaporation for improved drought and water management measures.

As little as a 15 percent error in total annual gross evaporation estimates equates to more than 1,000,000 acre-feet of water per year. Class-A pan measurements, which are the basis of the current evaporation monitoring network, have been found to have errors of 50 percent or more, typically over-estimating evaporation by large amounts during the critical summer months (e.g. Freidrich et al. 2018, Sumner and Jacobs, 2005, Eichinger et al. 2003). Therefore, better data on evaporation could change calculations of surface water availability in Texas by as much as a million acre-feet per year.

3. Project Location

The project location is Texas state-wide (Figure 1). Buoy stations will be deployed on Lake Meredith, Red Bluff Reservoir, Choke Canyon Reservoir, and Lake Buchanan (black squares). A floating evaporation pan will be deployed on Twin Buttes Reservoir (red diamond), Class A evaporation pans will be upgraded at Lake J.B. Thomas, O.H. Ivie Reservoir, Lake Livingston, Lake Tawakoni, and Eagle Lake (blue circles), and new Class A pans will be deployed at Greenbelt Lake, Lake Balmorhea, and Upper Nueces Lake (green circles).

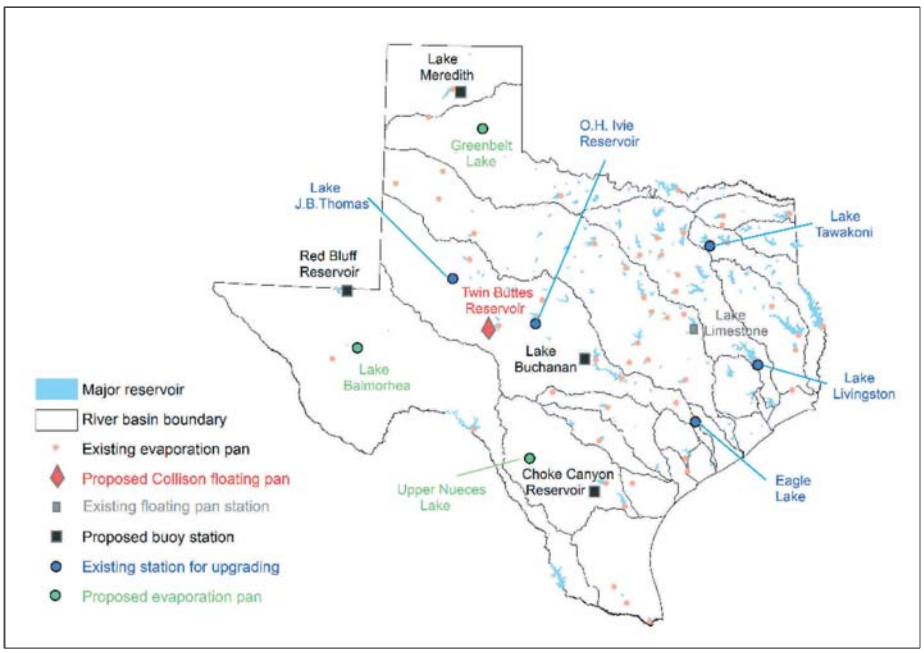

Figure 1: Map of project location with the locations of the proposed buoy deployment stations, floating evaporation pan deployment, Class A pan evaporation upgrades, sites for new Class A pan deployments, and existing TWDB floating pan station.

Past working relationships with Reclamation

The TWDB has collaborated with the Oklahoma-Texas Area Office on research projects on desalination and water reuse to advance innovative water technologies in the state since 2002. Past collaborative projects with a Reclamation Principal Investigator are listed below (Table 1):

Table 1: Past collaborative projects with Reclamation and TWDB

Project Title	Reclamation Principal Investigator	Status
Refining Interpretation Techniques for Determining Brackish Aquifer Water Quality	Bethany Jackson	TWDB staff are reviewing draft final report.
An innovative constructed wetland design for attenuating endocrine disruptor compounds (EDCs) from reclaimed wastewater	Michelle Chapman/Denise Hosler	Additional funds received, but project was terminated due to site development issues that would increase the cost of constructing the wetland significantly.
Developing a deterministic model for cleaning reverse osmosis membranes	Frank Leitz	Final report is being prepared.
Comparing the performance of NF and RO membranes for desalinating brackish groundwater in Texas	Katie Guerra	Project completed and report titled “Treating Brackish Groundwater in Texas: A Comparison of Reverse Osmosis and Nanofiltration” was published in May 2015
Developing a cost curve for brackish groundwater desalination in Texas	Andrew Tiffenbach	Project completed and report titled “Developing a cost curve for brackish groundwater desalination in Texas” was published in July 2014
Variable source salinity desalination	Michelle Chapman	Project completed and report titled “Variable Salinity Desalination” was published in August 2013
Developing a temporary emergency drought planning tool	Michelle Chapman	Project completed and tool published in 2013

In 2015, the TWDB was awarded WaterSMART Drought Resiliency Funding (R15AP00184, FY2015) to develop a Drought Early Warning Project. Through this project several online tools — e.g. automated county-level probabilistic forecasts of May–July rainfall available at lead times from 6.5-months through 3-months (www.waterdatafortexas.org/drought/rainfall-forecast), experimental deterministic forecasts of May–July reservoir evaporation rate for all major water supply reservoirs in Texas (https://waterdatafortexas.org/drought/evaporation-forecast), and experimental reservoir storage forecasts for three water supply reservoirs in the Brazos river basin — were developed to aid with drought early warning and drought contingency planning in Texas. The project was completed on September 30, 2017.

In February 2019, the TWDB and the Lower Colorado River Authority jointly hosted a workshop on Surface Water Evaporation Monitoring in Texas – Current and Future Technologies (22Feb2019_evaporation_workshop_agenda and Annex 1). Dan Broman and Subhrendu Gangopadhyay from Reclamation's Technical Service Center (Denver) presented on *Open Water Evaporation with Application to Reclamation Projects* at the workshop. Mark Treviño from the Reclamation's Oklahoma-Texas Area Office attended the workshop in person, and Kenneth Nowak from Reclamation's Research and Development Office-Science and Technology Program attended the workshop remotely.

Since December of 2018, TWDB staff have met four times with Oklahoma-Texas Area Office staff, in person and via teleconference, to discuss areas for collaborating on hydrology topics of relevance to both Reclamation and TWDB. A teleconference to discuss options for operationalizing surface water evaporation monitoring in Texas and the West has been scheduled for April 18, 2019 at the request of Reclamation's Technical Service Center. Entities and organizations that have been invited to participate on this call include the U.S. Army Corps of Engineers – Fort Worth District (Water Resources), U.S. Geological Survey North Texas Water Science Center, Desert Research Institute, and several river authorities in Texas (i.e. Lower Neches Valley Authority, Lower Colorado River Authority, Trinity River Authority, and Tarrant Regional Water District).

4. Project Description and Milestones

Introduction

The Texas Water Development Board was created by the Texas Legislature in 1957, in response to the drought of the 1950s, to develop water supplies and prepare plans to meet the state's future water needs. In 1997, the 75th Texas Legislature established a "bottom-up" consensus-driven approach to water planning. Sixteen regional water planning areas (Figure 2) were charged with developing regional water plans every five years to address how to meet water needs during a repeat of the drought of record. The state water plan is based on the 16 regional water plans. The state and regional water planning process in Texas is, therefore, the main drought planning mechanism in the state.

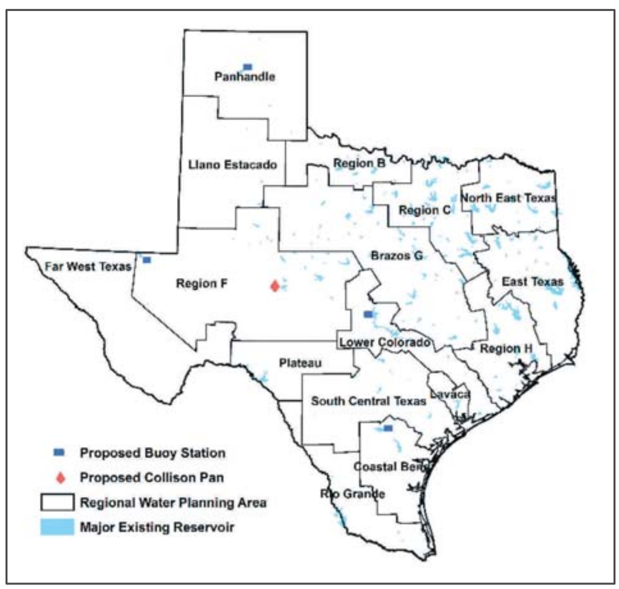

Figure 2: Map of the regional water planning areas in Texas.

As part of its charge under Section 16.012 of the Texas Water Code, the Texas Water Development Board collects, compiles and disseminates reservoir evaporation data. Since 1998, the reservoir evaporation data compiled by the TWDB have been used by the Texas Commission on Environmental Quality and regional water planning groups as one of the key input datasets to Texas' Water Availability Models, which are the operational water allocation models used for water rights permitting and regional water planning in the state.

Accurate estimates of reservoir evaporation are critically important for accurate estimates of surface water availability. Unfortunately, current operational practices for observing or estimate surface water evaporation, primarily using Class A pans, have large uncertainties and limited spatial coverage. Current pan-to-lake coefficients are based on observations that are more than 60 years old and represent a sparse sampling of measurement sites at that time. Re-assessment of these coefficients is sorely needed. Furthermore, many areas of the state do not have evaporation observations (Figure 3). Such gaps in observations result in large uncertainties in the estimates of available surface water, which in turn affect the accuracy of water rights permitting, water planning, and drought contingency planning.

The TWDB is actively exploring enhancements to the existing Class-A pan network. The TWDB has operated an evaporation monitoring system on Lake Limestone (Figure 1), in the Brazos River Basin, since October 2018. The floating platform includes meteorological instrumentation, lake temperature sensors, and an eddy covariance system. A floating pan was originally included in the design but failed shortly after deployment and is scheduled for replacement later in the spring of 2019. Data from the floating system is being evaluated in conjunction with a shore-based Class A pan and meteorological data. The results will be used to reassess the pan-to-lake coefficient for Lake Limestone as well as the applicability and performance of different methods of calculating lake evaporation from meteorological data sets. This proposal seeks to leverage our experience with the Lake Limestone site at additional reservoirs representing the different geographic regions of Texas.

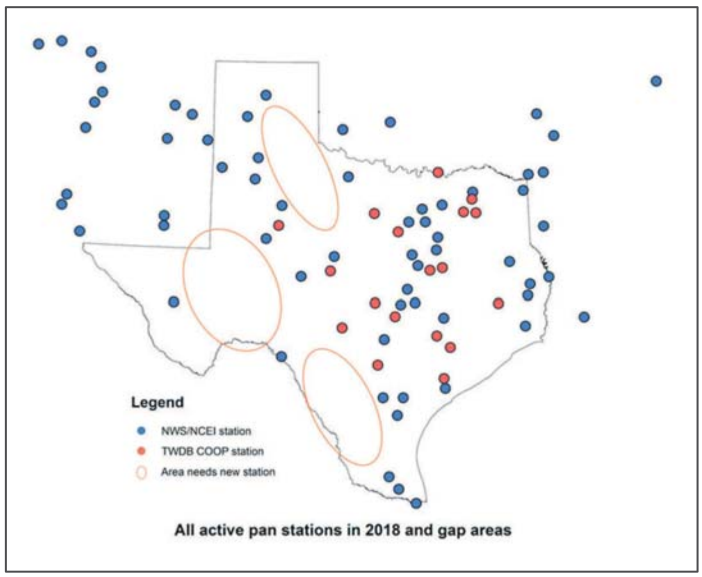

Figure 3: All active pan evaporation stations in 2018. Stations maintained by the National Weather Service (NWS), where data collected are obtained from the National Centers for Environmental Information (NCEI) are shown in blue and stations maintained by TWDB cooperators are shown in red. The brown ovals highlight areas that have no surface water evaporation station.

While the Class A evaporation pan has well-documented shortcomings, the long period-of-record measurements made with the technique and the extensive water management and planning systems developed using these data argue against a hasty conversion to any alternative measurement system. Our goal is to establish a long-term effort to strengthen evaporation monitoring in Texas and build the correlations between the last 60-plus years of monitoring and a 21st century program that takes advantage of the new technologies now available. To accomplish this goal, we need to make direct measurements of reservoir evaporation from floating platforms on the reservoir. Previous projects at the TWDB, and work by other researchers, have demonstrated that various calculations using shore-based meteorological measurements can be used to replicate Class A pan readings with moderate to excellent accuracy (Harwell, 2012; Friedrich et al. 2018; TWDB, 2018), but correlating these shore-based measurements with actual lake evaporation remains a challenge. Differences in micro-meteorological conditions between the lake and shore sites, and the complex energy storage and release dynamics in large reservoirs suggest that accurate estimation of reservoir evaporation requires some measurements from on the lake.

We are proposing a multi-pronged approach to enhancing surface water evaporation monitoring in Texas. We propose:

1. measuring actual evaporation over water using buoy stations on four reservoirs (i.e. Lake Meredith, Red Bluff Reservoir, Choke Canyon Reservoir, and Lake Buchanan) located in the northern, western, south central and southern areas of the state,
2. installing a Collison Floating Evaporation Pan (CFEP) station on Twin Buttes reservoir,
3. upgrading Class A pan evaporation stations managed by TWDB cooperators to include automated data readings, pan refills, and collect meteorological measurements needed for the computation of pan evaporation,
4. installing new Class A pans with automated readings, pan refills and meteorological sensors in areas with no current evaporation observations, and
5. deriving computed evaporation for all upgraded and new pan evaporation sites, identifying currently unmonitored regions where the computed evaporation could be applied using meteorological measurements, and estimating computed evaporation for these regions.

By establishing paired sites of shore-based and lake-based measurements we will be able to verify pan-to-lake coefficients for several sites around Texas. Data collected from the floating pan and buoy systems over two years of operation will support recalculating pan to lake coefficients specific to these sites. We plan to re-deploy the buoy systems and continue data collection at additional sites so that we can update coefficients for additional reservoirs in the state. The floating evaporation pan system included as part of this proposal will serve as our primary standard for actual lake evaporation against which other methods can be rated. The CFEP, with quarterly flux chamber calibrations, is the closest approximation to a weighing lysimeter available for lake studies. Weighing lysimeters are generally considered the standard of comparison for land-based evaporation studies (Burt et al. 2018). Evaporation rates calculated from meteorological data collected by buoy systems and instruments on the CFEP, using aerodynamic and combination equations, will be compared to the CFEP evaporation data to assess the accuracy of various calculation procedures.

In the longer term, we seek to develop a reservoir evaporation monitoring network combining a reduced suite of direct lake measurements with TexMesonet (www.texmesonet.org, the mesonet in Texas that is being developed and maintained by the TWDB) observations of local meteorology and satellite-based observations of water surface temperature, allowing us to estimate evaporation at multiple locations across large reservoirs and for all major reservoirs throughout the state. Continued partnership with the OpenET network (www.etdata.org), in which the TWDB has participated since 2018, will be crucial to calibrating and validating the tools and methodologies needed for this 21st century network. Buoy data in particular will be important for measuring the lake energy balance and validating satellite-derived estimates of lake surface temperature.

The multi-pronged approach will enable us to improve existing information on how pan evaporation rates can be adjusted to represent true lake evaporation, ensure that more areas of the state are covered by the evaporation observation network, and enable us to provide more accurate estimates of reservoir evaporation loss. The improved reservoir evaporation datasets will be used to provide daily estimates of evaporative water loss at all monitored reservoirs in Texas via the reservoirs page on Water Data for Texas (https://waterdatafortexas.org/reservoirs/statewide). The TWDB evaporation dataset used as input to the state's Water Availability Models will be updated. The reservoir firm yield — that is the maximum amount of water a reservoir can supply annually during a repeat of the worst drought experienced in the area of concern —for the reservoirs at which the buoy stations and the floating pan are located will be re-estimated using the improved dataset to assess implications for surface water availability over the next 50-year time horizon.

Specific activities

Task 1: Install four (4) data buoys with telemetry for computation of open water evaporation. The TWDB proposes to deploy instrumented buoys on Red Bluff Reservoir, Lake Meredith, Lake Buchanan, and Choke Canyon Reservoir to collect in-situ data on relevant lake conditions. The buoys will be paired with onshore pan evaporation stations to facilitate comparison between traditional pan measurements and instrument-based evaporation calculations using on shore and on lake data. A TWDB eddy covariance system will be available for quality control of buoy stations.

Task 2: Installation of a Collision Floating Evaporation Pan (CFEP) on Twin Buttes with telemetry and quarterly data quality control. As part of our proposal, Agua del Sol Consultants, LLC will install, operate, and maintain a CFEP system in Twin Buttes reservoir for a two-year period. The CFEP will serve as a reference standard for our other evaporation rate estimates derived from pan measurements or calculations from micro-meteorological data.

Task 3: Upgrading five (5) pan evaporation stations to include automated readings, meteorological readings, and automated refill features. Existing Class A pan evaporation stations at Lakes Livingston, J.B.Thomas, O.H. Ivie, Eagle and Tawakoni (Figure 1) will be upgraded to improve the accuracy and reliability of evaporation measurements and equipped with auxiliary sensors as recommended by the National Weather Service.

Task 4: Installing three (3) pan evaporation stations to include automated readings, meteorological readings, and automated refill features. We propose installing new Class A pan evaporation stations at Greenbelt Lake, Lake Balmorhea, and Upper Nueces Lake in an effort to fill the existing gaps in the TWDB reservoir evaporation monitoring network.

Task 5: Development of new pan-to-lake coefficients at the five (5) lakes with on-water evaporation measurements. Daily evaporation measurements from shore-based and on-lake instruments will be used to generate new pan-to-lake coefficients for the five sites where buoy systems are installed.

Task 6: Derivation of computed evaporation for using the Complementary Relationship Lake Evaporation (CRLE) method and the modified U.S. Weather Bureau method. **Subtask A:** Use the Complementary Relationship Lake Evaporation (CRLE, Morton 1986) method to compute monthly lake evaporation for the lakes with data buoys deployed through this project. **Subtask B:** Compute daily reservoir evaporation at all upgraded and new pan evaporation sites using the U.S. Weather Bureau (USWB) method (Kohler et al. 1955). Identify currently unmonitored regions of the state where the computed reservoir evaporation could be applied to estimate reservoir evaporative water loss using meteorological measurements at existing TexMesonet or other National Weather Service Stations.

Task 7: Providing near-real time (daily) estimates of evaporative water loss at all monitored reservoirs in Texas via the reservoirs page on Water Data for Texas. Daily evaporation estimates for each monitoring major reservoir will be provided via www.waterdatafortexas.org/reservoirs/statewide. The mean daily reservoir elevation (or water level) will be computed from real-time reservoir monitoring dataset.

Task 8: Update quadrangle evaporation data files and the .eva files used in WAM. Run reservoir firm yield reliability estimates for 5 selected reservoirs, assess implications for surface water availability over the next 50-year time horizon, and rerun seasonal reservoir storage forecasts for select reservoirs with the updated .eva files. We will update the statewide gridded reservoir evaporation dataset that is used as input to the WAM files using updated pan-to-lake coefficients from Task 5. Current and future (50 years) reservoir firm yields will be re-simulated using the relevant TCEQ WAM model for Lake Meredith (Canadian WAM), Choke Canyon Reservoir (Nueces WAM), Twin Buttes Reservoir (Colorado WAM for Region F), Lake Buchanan (Colorado WAM for Region K), and Red Bluff Reservoir (Rio Grande WAM for Region F). The short-term water availability forecasts we provided to inform the implementation of drought contingency triggers on Lake Limestone, Lake Aquilla and Proctor Lake in the Brazos River Basin, as part of the WaterSMART Drought Resiliency Grant of FY15 (Zhu et al. 2016, Fernando et al. 2017), will be updated using revised .eva input files.

Data sets generated by this project will include:

1. Direct measurement data from the CFEP, consisting of pan water levels and associated meteorological data at daily and 5-minute intervals. Data from quarterly flux chamber measurements will be used to calibrate the CFEP dataset.
2. Meteorological measurements from buoy weather stations at daily and 5-minute intervals. Meteorological data will be post-processed to calculate evaporation rates. Eddy covariance data will be collected at one or more of the buoy sites as a validation dataset. The 10 HZ eddy covariance data will be collected on an 8 GB data card that will be manually downloaded on a monthly basis.
3. Computed daily reservoir-specific lake evaporation rate data, calculated using modified USWB, CRLE, and other methods, based on project data and other available meteorological data.
4. Updated pan-to-lake coefficient dataset for Texas.
5. Updated net reservoir evaporation (.eva) input file for Texas WAM models.
6. Updated current and 50-year reservoir firm yield estimates for Lake Meredith, Red Bluff Reservoir, Twin Buttes Reservoir, Lake Buchanan, and Choke Canyon Reservoir.

5. Performance measures

We hope to quantify the project's performance by using the following measures:

1. 95 percent or greater completeness of observational records for all new and upgraded measurement sites over at least a 24-month period.

2. On Google Analytics:
    a. Count usage for updated gridded lake evaporation data.
    b. Count usage for near-real time estimates of evaporative water loss at monitored reservoirs on deployment of dataset. Revisit count every six months to gauge interest in the dataset and to track who uses the dataset.

3. Undertake a survey of regional water planning groups on their use of the updated .eva input files for the Texas WAM models. Include the following questions:
    a. Did using the updated evaporation files in WAM simulations result in an increase surface water availability over the 50-year planning horizon? Please quantify the increase in the current term and over each decade in the 50-year planning horizon.
    b. Did using the updated evaporation files in WAM simulations result in a decrease surface water availability over the 50-year planning horizon? Please quantify the decrease in the current term and over each decade in the 50-year planning horizon.
    c. How will water management strategies, including drought management strategies, change over the next regional water planning cycle given the increased/decreased surface water availability estimates?

6. Evaluation criteria

E.1.2 Evaluation Criterion A – Project Benefits

- **How will the project build long-term resilience to drought? How many years will the project continue to provide benefits?** Regional water planning groups in Texas will be able to accurately estimate water availability over the 50-year planning horizon using the updated net reservoir evaporation dataset imbedded in the WAM. This benefit will extend into future planning cycles as the plans are updated every five years. The project will enhance existing reservoir firm yield simulations and provide more accurate estimates of surface water availability for the regional and state water planning process. Accurate lake evaporation data will help lake owners evaluate available water management strategies to minimize water loss from their lakes. These strategies can then be adopted by regional water planning groups, incorporated in the State Water Plan, and become eligible for low-cost water infrastructure funding from the TWDB.

- **Will the project improve the management of water supplies?** If evaporation is currently overestimated by pan measurements, improved reservoir evaporation measurements can free up additional available water with existing infrastructure, while if evaporation is currently underestimated, Texas water users and environmental assets face the risk of water shortage during a repeat of the drought of record.

Better data will help drive better management. During drought, reservoir evaporation is a significant water loss affecting the firm yield from a reservoir. For example, over the 4/1968-4/1982 period, 37% of inflow to Lake Kemp (located on the Wichita River in north Texas) was lost to evaporation (Kennedy Resource Company, 2011). If we assume a five percent increase in net evaporation over the Canadian River Basin, the firm yield for Lake Meredith, simulated by the TWDB using the TCEQ WAM RUN3 for the Canadian River Basin, would decrease by 2% or 1,423 acre-feet per year. These examples demonstrate the critical role of evaporation on surface water availability and highlight the need for improved accuracy in the input evaporation datasets if surface water availability is to be accurately estimated. Aquifer storage and recovery (ASR) systems offer greater flexibility in managing evaporation, with the conjunctive use of surface water from reservoirs with water stored in ASR systems being an option to extend the life of existing surface water supplies. The availability of accurate surface water evaporation would provide critical information for cost benefit analyses for the siting and design of ASR systems.

- **Will the project have benefits to fish, wildlife, or the environment? If so, please describe those benefits.** Improved estimates of reservoir evaporation, and revision of the net evaporation dataset used as input to the WAM used for water rights permitting and planning, will aid in the assessment of whether environmental flow standards adopted for specific river basins in Texas can be realistically met.

- **Additional information for Metering/Water Measurement Projects.** The proposed floating pan and buoy systems are modeled on evaporation monitoring efforts currently implemented by the Reclamation at other reservoirs in the western U.S. and follow recommendations developed at a 2015 workshop on evaporation in the western U.S. (Friedrich et al. 2018). These systems have demonstrated capacity to accurately measure lake evaporation. The CFEP is currently deployed on Lake Powell and Lake Cochiti. The applicability of tools for calculating evaporation from meteorological measurements are also well documented. Huntington and others (2015) used the CRLE method to estimate operational reservoir and lake evaporation for sites in the Western U.S. with limited climatic and heat storage information. Harwell (2012) found that relatively simple calculations, such as the U.S. Weather Bureau method, yielded reasonable evaporation estimates.

The near-real-time reservoir evaporation loss estimates will alert reservoir operators on the likely risk of water storage dropping below certain drought response thresholds. Such early information would allow water managers to effect water conservation measures – e.g. enacting outdoor lawn water restrictions – earlier on. This would help minimize the reduction in available water supply as the summer approaches and extend the time before further water use restrictions, as determined by drought trigger levels, need to be implemented. Such an implementation plan would minimize the economic impacts resulting from the non-delivery of committed water supplies from a given source.

E.1.2 Evaluation Criterion B – Drought Planning and Preparedness

The Texas State Water Plan, which is based on regional water plans from the 16 regional water planning areas in the state, addresses the needs of all water user groups in the state — i.e. municipal, irrigation, manufacturing, livestock, mining, and steam-electric power — **during a repeat of the 1950s drought of record**. The state and regional water planning process in Texas is, therefore, the main drought planning mechanism in the state. The proposed project will revise the net evaporation datasets that are a key input dataset to the Water Availability Models that regional water planning groups use to estimate surface water availability for their respective regional water plans. As such the proposed project will directly impact the assessment of surface water availability for each regional water plan. We provide Chapter Six of the State Water Plan (see Drought Plan – section 1) to demonstrate how surface water availability fits into the assessment of water supply for drought planning purposes in the state. We also include Section 3.2 – Evaluation of Surface Water Availability of the *General Guidelines for the fifth cycle of regional water planning in Texas* (see Drought Plan – Section 2, pages 24–27) to describe the methodology that regional water planning groups are required to follow when assessing surface water availability water supply for the next 50-year planning horizon.

While the state and regional water planning does not explicitly consider the impact of climate change on water resources or drought, it plans for the worst-case scenario as experienced in the historical record. Recognizing that the 1950s drought of record may not be the worst event for each planning area, regional water planning groups are permitted to use the concept of safe yield (i.e. planning for one- or two-year buffer water supply from reservoir) instead of firm yield (where the reservoir goes dry after meeting all permitted water allocations during a repeat of the drought of record) when estimating surface water availability (Texas Water Development Board, 2018).

E.1.3 Evaluation Criterion C – Severity of Actual or Potential Drought Impacts to be addressed by the Project

Texas is no stranger to drought. The seven-year drought of record in the 1950s was a turning point in Texas history that led to the formation of the Texas Water Development Board. Since then, Texas has faced several droughts, including its most recent and severe drought, which began in the fall of 2010 and lasted through winter 2014/2015. In 2011, Texas suffered the worst one-year drought in the instrumental record going back to 1895. The economic impact of this drought on Texas is estimated at 7.6 billion dollars (Fannin 2012) primarily from crop and livestock losses. Dry conditions were also accompanied by record heat in the summer with a mean June through August (JJA) temperature of 30.4 °C, exceeding the long term mean by 2.9 °C (Hoerling et al. 2013). The rapid spring intensification of the 2011 drought caused statewide reservoir storage to drop to 58% in November 2011, the lowest since 1978 (Fernando et al. 2016 and references there-in). Furthermore, several reservoirs dried up, including Lake Meredith and O.C. Fisher Lake. The extremely low water levels in the Wichita Falls area lead to emergency funding to the city by the TWDB for direct reuse of the city's sewer water. With the record low reservoir storage levels during the 2010–2015 drought, particularly over west and south-central Texas, the Lower Colorado River Authority, which manages the Lakes Travis and Buchanan in the south-central region of the state, cut off interruptible water from these lakes in 2012, 2013, and 2014. Such measures affected downstream irrigation customers near the Texas coast (Kloesel et al. 2018).

Real-time evaporation data, included in this proposal, would help water managers quantify the impact of developing droughts.

- **Describe any projected increases to the severity or duration of drought in the project area resulting from climate change.** Tree ring records indicate that Texas has experienced droughts of longer duration, in the pre-instrumental record extending back to 1500, than the 1950s drought of record (Cleveland et al. 2011). If the 2010–2015 drought had persisted for two more years it would have vied for first place on the worst-drought-in-the-instrumental-record spectrum. The paleoclimate record, and recent drought and pluvial episodes, indicate that the climate of Texas is highly variable and droughts with durations and intensities exceeding the 1950s drought of record could occur in the future due to natural climatic variability. Projected increases in temperature due to climate change are expected to increase aridity in the Southern Great Plains, with an increase in evapotranspiration and decrease in soil moisture (Kloesel et al. 2018). In addition, Fort Hood and Joint Base San Antonio, in Texas, are threatened by current and potential climate-related events of recurrent flooding, drought, and wildfire (Department of Defense, 2019). The City of Austin water plan (City of Austin, 2018) examines climate change adjusted demands over the next 100 years. The Austin Water Forward plan finds that longer, more severe droughts are likely under climate change scenarios, as are high-intensity precipitation events. As a response to predicted increases in evaporation, and to diversify water supplies, the Austin plan includes an aquifer storage and recovery component.

- **Describe ongoing or potential drought impacts to specific sectors in the project area if no action is taken.** The 2017 State Water Plan estimates that if recommended water supply projects and management strategies are not implemented, water user groups in the state face a potentially shortage of 8.9 million acre-feet in 2070. The annual economic losses from not meeting the water supply need ranges from $73 billion in 2020 to $151 billion in 2070.

E.1.4 Evaluation Criterion D – Project Implementation

Task implementation

Task 1: Install four (4) data buoys with telemetry for computation of open water evaporation. A NexSense CB-650 data buoy will be deployed at each site. The buoys will be equipped with sensors to measure aerodynamic and radiative parameters influencing evaporation, as listed below. Buoy design is based on input from the Desert Research Institute (DRI) research team and their experience with lake monitoring activities on Lake Mead and other large reservoirs in the western U.S. Data will be collected using a Campbell Scientific CR-1000 datalogger. Near real-time data transmission using a cell modem will connect the data buoys to the TexMesonet network website.

The CB-650 is small enough to be launched from TWDB boats, but large enough to provide a stable platform for the instrumentation, communications, and power supply. The buoy will be anchored with a two-point mooring for stable sensor orientation. Buoys will be placed near the center of the reservoirs to allow adequate fetch under prevailing winds so that conditions are representative of the lacustrine environment. Mooring design will include tension systems to accommodate reservoir level fluctuations and break-away systems to prevent submergence in case of major floods. The buoys will be equipped with warning lights and will have marker buoys around the perimeter to ensure the safety of watercraft operating in the vicinity.
DRI collaborators will provide expertise and guidance on buoy design and operations based on their experience with similar systems on Reclamation sites in the western U.S. An existing TWDB eddy covariance system will be available to calibrate and cross-check buoy measurements. The TWDB eddy covariance system is a Campbell Scientific IRGASON 3-D anemometer and gas analyzer connected to a Campbell Scientific CR-6 datalogger. A Lord-MicroStrain 3DM-GX5-25 attitude and heading reference system (AHRS) is mounted near the IRGASON sensor and measures platform motions at a 10 HZ frequency to correct anemometer data to a stable-earth basis. Additional sensors mounted on the platform measure 2-D wind speed and direction, air temperature and relative humidity, net radiation, barometric pressure, precipitation, and water temperature at multiple depths. Zero and span calibrations will be performed on the eddy covariance system before deployment.

Task 2: Install a Collision Floating Evaporation Pan (CFEP) on Twin Buttes Reservoir with telemetry and quarterly data quality control. As part of our proposal, Agua del Sol Consultants will install, operate, and maintain a CFEP system in Twin Buttes reservoir for a two-year period.

The CFEP consists of a floating pan system designed to measure open water evaporation. The CFEP is installed semi-submerged in the reservoir and is equipped with a wave-guard and interior baffle to prevent wave-overtopping and sloshing, a guided float system for measuring water level height in the pan, and micrometeorological sensors to measure wind speed/direction, air temperature, relative humidity, barometric pressure, solar radiation, and water surface temperature both inside and surrounding the pan. The CFEP also has a cellular transmitter that allows real-time acquisition of data and is equipped with a pump for automatic pan refilling as needed. High thermal conductivity all aluminum construction helps the water in the pan maintain the same temperature as the surrounding water, which reduces bias in evaporation measurements. Agua del Sol will perform quarterly flux chamber evaporation tests as part of their quality assurance/quality control program.

Task 3: Upgrading five (5) Class A pan evaporation stations to include automated readings, meteorological readings, and automated refill features. The Class A pan sites by Lake Livingston, J.B. Thomas, O. H. Ivie, Eagle, and Tawakoni) will be equipped with a pressure transducer to measure water level in the pan and meteorological sensors to separately calculate evaporation and provide a basis for comparing shore-based with on-lake environments, as specified below. The pan sites will be equipped with a CR-300 datalogger and a cellular modem providing near real-time connection to the TWDBs TexMesonet system. The upgraded pans also will be plumbed for automated re-filling using a float valve system.

Task 4: Installing three (3) pan evaporation stations to include automated readings, meteorological readings, and automated refill features. The proposed new Class A pan evaporation stations will be installed and operated at Greenbelt Lake, Lake Balmorhea, and Upper Nueces Lake in cooperation with the relevant lake operators. These sites will be equipped with a Class A Pan, a pressure transducer to measure water level in the pan and meteorological sensors to separately calculate evaporation and provide a basis for comparing shore-based with on-lake environments, as specified in Task 3. The new pan sites will also be equipped with a CR-300 datalogger and a cellular modem providing near real-time connection to the TWDBs TexMesonet system. The new pans will be plumbed for automated re-filling using a float valve system.

Task 5: Development of new pan-to-lake coefficients at the five (5) lakes with on-water evaporation measurements. Daily evaporation measurements from shore-based and on-lake instruments will be used to generate new pan-to-lake coefficients for the five sites where buoy systems are installed. Two years of continuous monitoring will generate approximately 60 daily measurements for each month of the year. Monthly pan-to-lake coefficients will be calculated as the average of the daily pan-to-lake ratios for each monthly interval. The statistical distribution of evaporation data and meteorology for the two-year monitoring period will be reviewed to assess the need for longer period of record measurements for establishing new pan-to lake coefficients.

Task 6: Derivation of computed evaporation using the Complementary Relationship Lake Evaporation (CRLE) method and the modified U.S. Weather Bureau method. ***Subtask A:*** Use CRLE model to compute monthly lake evaporation at lakes with buoy stations. Water temperature observations from the buoy stations will be used to estimate the heat storage term required to derive CRLE. The CRLE method uses land-based temperature and humidity measurements, adjusted to simulate open water conditions, to calculate lake evaporation rates using the principles of energy and mass conservation. This method requires land-based meteorological data and measured or estimated lake heat storage (Morton et al. 1985; Morton 1986; Hobbins and Huntington 2016). The CRLE method is suitable for regions with limited weather data and has been applied extensively for the modelling of open water evaporation (Huntington et al. 2015 and references there-in). ***Subtask B:*** We will identify unmonitored regions of the state that are co-located with an existing TexMesonet station or a National Weather Service station (that collects air temperature, relative humidity, wind speed, and solar radiation data). For each of these locations we will compute daily pan/lake evaporation using the modified U.S. Weather Bureau (USWB) (Kohler et al. 1955) method.

Task 7: Providing (near-) real-time (daily) estimates of evaporative water loss at all monitored reservoirs in Texas via the reservoirs page on Water Data for Texas. Using real-time reservoir evaporation data (from Tasks 1 through 5), and computed evaporation data from Task 6, daily volumetric reservoir evaporation loss will be estimated by multiplying the net evaporation rate (evaporation minus rainfall over a lake) by a reservoir's surface area. The mean daily elevation (or water level) will be computed from real-time reservoir stage measurements from the U.S. Geological Survey for 115 monitored reservoirs. The daily mean surface area will be derived from reservoir elevation area capacity rating curves. These estimates will be provided for each of the 115 monitored reservoirs through https://waterdatafortexas.org/reservoirs/.

Task 8: Update quadrangle evaporation data files and the .eva files used in WAM. Run reservoir firm yield reliability estimates for 5 reservoirs selected and assess implications for surface water availability over the next 50-year time horizon and rerun seasonal reservoir storage forecasts for select reservoirs with the updated .eva files. Using revised pan-to-lake coefficients, we will update the gridded reservoir evaporation dataset that the TWBD compiles. Current and future (50-year) reservoir firm yields will be re-simulated using the relevant TCEQ WAM model for Lake Meredith, Choke Canyon Reservoir, Twin Buttes Reservoir, Lake Buchanan (insert relevant WAM), Red Bluff Reservoir. We will compare the new simulations with existing current and future firm yield estimates for these reservoirs and assess the implications for surface water availability. We will document our findings in a TWDB technical note as guidance to regional water planning groups. We will update the seasonal reservoir storage forecasts we provided to inform the implementation of drought contingency triggers on Lake Limestone, Lake Aquilla and Proctor Lake in the Brazos River Basin, as part of the WaterSMART Drought Resiliency Grant of FY15 (Zhu et al. 2016, Fernando et al. 2017), using updated .eva input files. We will use the Conditional Reliability Modeling routine of WAM-Water Rights Allocation Package to derive the seasonal reservoir storage forecasts.

Major tasks, milestones, and dates

Major tasks and milestones	Date
Task 1:	
Installation of four (4) data buoys with telemetry for computation of aerodynamic mass transfer estimates of open water evaporation	September 2020
Task 2:	
Installation of a Collision Pan on Twin Buttes with telemetry and quarterly data quality control.	September 2020
Task 3:	
Upgrade 5 existing pan stations with automatic system	September 2020
Task 4:	
Install 3 new evaporation pans and automatic weather stations.	January 2021
Task 5:	
Development of new pan-to-lake coefficients at the five (5) lakes with on-water evaporation measurements. Further update pan-to-lake coefficient for all quadrangles.	December 2021
Task 6:	
Derivation of computed evaporation using the Complementary Relationship lake Evaporation (CRLE) method and the modified U.S. Weather Bureau method.	
Subtask A: Use CRLE method to compute monthly lake evaporation for the lakes with data buoys being deployed through the project.	September 2021
Subtask B: a) Identify currently unmonitored areas where computed reservoir evaporation could be applied to estimate reservoir evaporative water loss using meteorological measurements at existing TexMesonet or other National Weather Service Station. b) Compute daily reservoir evaporation for these unmonitored areas. Use modified USWB method to compute daily lake evaporation for all lakes having weather station. c) Compute daily reservoir evaporation at all upgraded pan evaporation sites. d) Compute daily reservoir evaporation at new pan evaporation sites.	 January 2020 March 2020 October 2020 February 2021
Task 7:	
Provide near-real time (daily) estimates of evaporative water loss at all monitored reservoirs in Texas via the reservoirs page on Water Data for Texas.	January 2022
Task 8:	
Update quadrangle evaporation data files and the .eva files used in WAM. Run WAM to simulate reservoir firm yield for the 5 reservoirs and assess implications for surface water availability over the next 50 year horizon.	March 2022
Subtask A: Publish TWDB technical note documenting implications for water availability arising from the revision of the reservoir evaporation data files.	September 2022
Subtask B: Update seasonal reservoir storage forecasts for Lake Limestone, Proctor Lake, and Lake Aquilla in the Brazos River Basin using the updated .eva files as input.	April 2022

Data post-processing, evaporation computation, data transfer, and data sharing

The eddy covariance data will be post-processed for motion corrections using the methods of Edson and others (1998). After the data are converted to a stable platform basis, EddyPro software will be used for standard processing and data corrections to calculate 30-minute moisture fluxes. Python-based routines to calculate evaporation from meteorological data will be integrated with the TexMesonet system. The OneRain Contrail platform hosting TexMesonet offers a built-in ET function based on the Penman-Montieth equation. Programming to implement other evaporation calculations using available meteorological data will be completed as part of this project. We are taking steps to ensure that the sensors and data transmission equipment that will be purchased through the grant conform to TexMesonet equipment standards so that some of the ongoing maintenance could be covered by the TexMesonet program. TexMesonet is connected to FirstNet, the public safety dedicated broadband high-speed wireless network. Project data will be stored on TWDBs servers, which are managed by Amazon Web Services. All reservoir evaporation data collected and computed through this project will be shared through the TexMesonet Viewer. The updated gridded evaporation dataset that the TWDB compiles and provides will be posted to: https://waterdatafortexas.org/lake-evaporation-rainfall. We will also provide the revised net reservoir evaporation (.eva) input files for Texas WAM models to the Texas Commission for Environmental Quality and disseminate it via a new tab at https://waterdatafortexas.org/lake-evaporation-rainfall.

Steps for contacting lake owners/operators for the installation of monitoring stations

We have contacted Reclamation's Oklahoma-Texas Area Office to obtain details on Twin Buttes Reservoirs (e.g. availability of boat docks, risk of vandalism, etc.). We will contact the City of San Angelo to obtain permission to install and operate the Collision Floating Evaporation Pan. We will work with Texas Parks and Wildlife, which manages the recreational use of the reservoir, to coordinate security checks on the floating evaporation pan. The TWDB already has a cooperative agreement with Texas Parks and Wildlife Department for the operation and maintenance of coastal water quality observation network along the Texas Gulf Coast. We will contact the Canadian River Municipal Water Authority to request permission to install a buoy station on Lake Meredith, the City of Corpus Christi and the Nueces River Authority to request permission to install a buoy station on Choke Canyon, and the Red Bluff Water Power Control District to request permission to install a buoy station on Red Bluff Reservoir. We have already contacted the Lower Colorado River Authority about the possibility of installing a buoy station on Lake Buchanan. We have contacted TWDB cooperators who provide pan evaporation data and the five stations listed for upgrades are maintained by cooperators who have expressed interest in having their existing stations upgraded. We have also reached out to lake owners in unmonitored areas of the state. Reservoir operators at the three reservoirs identified for the installation of new pan evaporation stations have already expressed interest in having a new pan evaporation station installed. If grant funding is secured, we will proceed with developing and executing access agreements with the relevant lake owners. The TWDB has experience with developing and executing these agreements through the TexMesonet Program.

Steps for proceeding with contractual agreements for professional services

We will follow state and federal procurement procedures for obtaining the services of Agua del Sol Consultants, LLC and the Desert Research Institute. We anticipate using contract examples from the TexMesonet Program as a basis for developing contracts with Agua de Sol Consultants, LLC and the Desert Research Institute.

E.1.5 Evaluation Criterion E – Nexus to Reclamation

- **How is the proposed project connected to a Reclamation project or activity?** By improving the accuracy of reservoir evaporation data used for water planning and water permitting, the project will provide the information that water managers and water planners can use to determine the degree to which evaporative water loss has been accurately accounted for in existing management plans and in long-term water supply plans. By providing daily estimates of reservoir evaporation loss at monitored reservoirs in the state, the project will provide reservoir operators with information needed for daily reservoir operations and, during drought periods, provide information critical for decisions related to the implementation of drought contingency triggers on these reservoirs. The project will help decrease vulnerability to drought by giving water managers flexibility with water supply options in times of low water supply. The project promotes a proactive approach to drought, which places it well within the goals of Reclamation's Drought Response Program.

- **Is the project on Reclamation project lands or involving Reclamation facilities?** The project will install equipment on three Reclamation Projects. A floating pan evaporation monitoring stations will be installed on Twin Buttes Reservoir. Data buoys for the collection of data to compute evaporation using the aerodynamic flux formula will be deployed on Choke Canyon, and on Lake Meredith. These Reclamation Projects are still federally owned. The proposed project represents an extension of recent evaporation work sponsored by Reclamation on reservoirs in Arizona, California, Oregon, Nevada, and New Mexico (e.g. Stannard et al. 2013, Moreno and Swancar, 2013, Huntington et al. 2015). These previous Reclamation projects demonstrated the usefulness of the proposed techniques. Applying them to Texas reservoirs will extend the benefits of the technology that Reclamation has helped to develop.

E.1.6 Evaluation Criterion F – Department of the Interior Priorities

The current evaporation monitoring system in Texas uses century-old technology. Using modern tools to acquire and disseminate real-time data on evaporation will help bring the Texas system into line with best practices for water resource management. Consistent, accurate and timely data is essential for building trust with resource managers and decision-makers and provides a basis for assessing how a changing climate impacts Texas water resources. Data from the current pan-based evaporation monitoring system are difficult to validate and quality control, and apparent long-term trends in the existing gridded evaporation data sets compiled by the state are suspect. More defensible measurement systems, such as those included in this proposal, are needed to document changes in reservoir evaporation in response to climate forcing. The project, therefore, supports Interior's priority of ***'Creating a conservation stewardship legacy second only to Teddy Roosevelt'.***

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Project Budget

Funding Plan

Table 1: Total Project Cost Table

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$360,631.27
Costs to be paid by the applicant	$360,632.27*
Value of third party contributions	$0
TOTAL PROJECT COST	**$721,263.54**

*in-kind support

Table 2: Summary of Non-Federal and Federal Funding Sources

FUNDING SOURCE	AMOUNT
Non-Federal Entities	
1. Texas Water Development Board	$360,632.27
Non-Federal Subtotal	$360,632.27
Other Federal Entities	
1. U.S. Bureau of Reclamation	$360,631.27
Other Federal Subtotal	$360,631.27
REQUESTED RECLAMATION FUNDING	**$721,263.54**

Budget proposal

Table 3: Budget proposal

Budget Item Description	Computation		Quantity Type	Total Cost ($)
	$/hour	Quantity	(hours)	
Salaries and wages				
Nelun Fernando	34.52	2880	hours	99,417.60
John Zhu	27.90	2880	hours	80,352.00
Andrew Weinberg	35.51	1200	hours	42,612.00
Nathan Leber	35.44	240	hours	8,505.60
Maureen Sanders	22.54	480	hours	10,819.20
Total base salary				***241,706.40***
Fringe benefits				
Nelun Fernando			28.73%	28,562.68
John Zhu			28.73%	23,085.13
Andrew Weinberg			28.73%	12,242.43
Nathan Leber			28.73%	2,443.66
Maureen Sanders			28.73%	3,108.36
Total fringe				***69,442.25***
Equipment				
buoys with water temperature sensors, etc.	26,534.00	4	data buoys	106,136.00
pan evaporation station upgrades	7,545.00	5	pan station upgrades	37,725.00
new pan systems (1500 + 7545)	9,045.00	3	new pan stations	27,135.00
Total equipment				***170,996.00***
Contractual				
Collison pan and data package ($55000/year)	55,000.00	2	years	***110,000.00***
Desert Research Institute (software support and code transfer for buoy evaporation measurements)	95.06	60	hours	***5,703.60***
Total contractual				***115,703.60***
Other				
Total Direct Costs (only base salaries)				241,706.40
Indirect Costs - 51.06%				***123,415.29***
Total Study Costs (Direct, Indirect, Fringe, and Contractural)				**721,263.54**

Budget narrative

The proposed project budget covers 50 percent of partial salary costs and associated fringe benefits for five full-time staff members from the Texas Water Development Board (TWDB), indirect costs (at the rate of 51.06 percent that is approved by the U.S. Environmental Protection Agency, see Annex No. 2), equipment costs, and contractual costs. The total project cost for the three-year period, from 1 October 2019 to 30 September 2022, is estimated at $721,263.54. The Texas Water Development Board will provide 50 percent of the total cost – i.e. $ 360,632.27 – as in-kind support to the project. The total cost for year 1 (FY 2019) is $354,526.72, with a federal cost of $177,262.86. The total cost for year 2 (FY 2020) is $232,097.12, with a federal cost of $116,048.06. The total cost for year 3 (FY 2021) is $134,639.70, with a federal cost of $67,319.35.

TWDB staff commitment

TWDB staff time estimates proposed for this project includes the following:

Technical staff

- N. Fernando, Manager – Water Availability Program
  – 18 months (6 months per year in years 1 through 3)

- J. Zhu, Senior Hydrologist – Water Availability Program
  – 18 months (6 months per year in years 1 through 3)

- A. Weinberg, Geoscientist – Groundwater Technical Assistance Program
  – 7.5 months (3 months per year in years 1 through 2, 1.5 months in year 3)

- N. Leber, Manager – TexMesonet and Hydro Survey
  – 1.5 months (0.5 months year in years 1 through 3)

- M. Sanders, Meteorologist – TexMesonet and Hydro Survey
  – 3 months (1 month per year in years 1 through 3)

The hourly rates of compensation for Dr. Fernando, Dr. Zhu, Mr. Weinberg, Mr. Leber, and Ms. Sanders are provided in Table 2 (above). These rates include base salary and longevity pay. The fringe benefit rate is 28.73 percent of the base salary. This rate is approved by the U.S. Environmental Protection Agency. The indirect cost of the project, calculated on base salaries, is $123,415.29.

Justification for labor hour estimate for N. Fernando based on previous experience

Dr. Nelun Fernando, Manager of the Water Availability Program at the TWDB, will be a Principal Investigator on the project, the project manager and contact person on the grant. She will be responsible for project and technical oversight, and program administration and reporting. Compiling reservoir evaporation datasets, and technical support to the regional water planning process in Texas are some of the key responsibilities of the Water Availability Program. The proposed project will expand and enhance the network for collecting evaporation data, establish contractual agreements with contractors, cooperators, and lake owners, develop several new datasets that will be shared in near-real time, and address questions of the accuracy of existing surface water availability estimates in regional water plans, etc. Dr. Fernando will have overall responsibility for developing contracts for procuring the services of contractors on this project, for developing land/lake access agreements with cooperators/reservoir operators, for providing technical oversight to Dr. Zhu, and for leading and coordinating the efforts of the TWDB team on the project.

In **year one**, we estimate that two months of Dr. Fernando's time will be allocated for contract and project management duties associated with the professional services contracts and equipment procurement required for this project. Dr. Fernando has extensive experience with developing agency contracts for contracted studies and she is a Certified Texas Contract Manager (CTCM CTCM02091702). Our estimate of two months in year one for contract and project management duties are based on Dr. Fernando's experience with developing such contracts and her participation in TWDB's internal Contract Assessment and Innovation Team. An additional two months of Dr. Fernando's time will be allocated for the provision of technical oversight for Dr. Zhu's implementation of Task 6-Subtask B [steps a) through c)]. One month of Dr. Fernando's time in year one will be allocated to assist Mr. Andrew Weinberg in the implementation of Tasks 1 through 3, including reviews of initial datasets transmitted from the buoy stations and the floating pan evaporation stations. One more month of Dr. Fernando's time in year one will be allocated to project reporting.

In **year two**, we estimate that two months of Dr. Fernando's time will be allocated for the provision of technical oversight for Dr. Zhu's implementation of Task 5 and Task 6-Subtask A. One month of Dr. Fernando's time will be allocated for the provision of technical oversight for Dr. Zhu's implementation of Task 6-Subtask B [c)]. Dr. Fernando will lead the implementation of Task 7 and we estimate that two months of her time will be needed in year two for coordinating the information technology application development activities needed for the full implementation of the task by January 2020. In addition, one month of Dr. Fernando's time will be spent on program administration and reporting in year two.

In **year three**, two months of. Dr. Fernando's time will be allocated for the provision of technical oversight for Dr. Zhu's implementation of Task 8. One month of her time will be allocated for technical reporting on Task 8, as co-author on the technical note. One month of her time will be allocated to implementation of Task 7. One month of her time will be allocated to assisting Mr. Weinberg on data quality control/quality assurance tests on the real-time data collected by the buoy stations and the floating pan evaporation station. One month of her time will be allocated for project administration and reporting.

The estimate of time needed for Dr. Fernando's technical oversight of task implementation, for the coordination of information technology application development activities, and for program administration and reporting are based on her experience with developing the automation of the May–July rainfall forecast and associated online tools for the project funded by the WaterSMART Drought Resiliency Funding (R15AP00184) in FY2015.

Justification for labor hour estimate for J. Zhu based on previous experience

Dr. John Zhu, Senior Hydrologist in the Water Availability Program at the TWDB, will be a Principal Investigator on this project and will have overall responsibility for leading the implementation of Task 5, Task 6, and Task 8. Dr. Zhu will be lead author on the technical note assessing the implications of incorporating the revised evaporation datasets on estimates of surface water availability. He will provide field assistance to Mr. Andrew Weinberg as needed on Tasks 1 through 4. He will also assist Dr. Fernando in the implementation of

Task 7. Dr. Zhu is currently responsible for compiling and updating the reservoir evaporation datasets, based on pan evaporation data, that the TWDB provides. These datasets are updated annually. Dr. Zhu is also responsible for providing technical assistance to the regional water planning process, including running the WAM models to assess surface water availability for near-term and long-term forecasts. It takes approximately 1-month per year of Dr. Zhu's time to collect, compile, QA/QC, and post the dataset each year. The proposed updates to existing pan-to-lake coefficients, the computation of reservoir evaporation based on meteorological observations at currently unmonitored locations, the near-real time computation of reservoir evaporation loss for all major monitored reservoirs, etc., expand the breadth of the evaporation datasets currently provided by the TWDB.

In **year one**, we estimate needing five months of Dr. Zhu's time for the completion of Task 6-Subtask B [steps a) through c)]. We also estimate that one month of Dr. Zhu's time will be provided as field assistance, as needed, for the execution of Task 1 and Task 3.

In **year two**, we estimate needing one month of Dr. Zhu's time for the implementation of Task 6-Subtask A, four months of Dr. Zhu's time for implementation of Task 5, and one month of Dr. Zhu's time for field assistance, as needed for the implementation of Task 3.

In **year three**, we estimate needing 5.5 months of Dr. Zhu's time for the implementation of Task 8, including developing the technical note (as lead author). We anticipate needing 0.5 months of Dr. Zhu's time for the provision of assistance to Dr. Fernando on Task 7, primarily related to the review of the content and form of the near real-time reservoir evaporative loss estimate application.

The estimates of the time needed for Dr. Zhu's contribution to the project come from current estimates of the time needed for updating the existing evaporation dataset and from past experience on the development of experimental reservoir storage forecasts for the project funded by the WaterSMART Drought Resiliency Funding (R15AP00184) in FY2015.

Justification of labor hour estimate for Andrew Weinberg

Mr. Weinberg, P.G., Geoscientist in the Groundwater Technical Assistance Program at the TWDB., will be a principal investigator on this proposal. He will lead the implementation Task 1, Task 3, and Task 4. He will also be responsible for coordinating with Agua del Sol Consultants on Task 2.

In **year one**, we estimate needing three months of Mr. Weinberg's time for the coordination of all equipment purchases and field installations needed for Tasks 1 and 3.

In **year two**, we estimate needing one month of Mr. Weinberg's time for the installation of the new pan evaporation stations and two months of his time for data validation tests for the buoy station data and for quality assurance tests on the data from the Collison Floating Evaporation Pan.

In **year three**, we estimate needing one month of Mr. Weinberg's time for reporting and quality assurance/quality control tests on the real time reservoir evaporation data being collecting via the project. We also estimate needing 0.5 month of Mr. Weinberg's time in year three for ongoing equipment maintenance on the upgraded and new pan evaporation stations.

The estimate of Mr. Weinberg's time needed on the proposed project is based on his experience with leading the implementation of TWDB's experimental floating evaporation pan station on Lake Limestone, his experience with installing TexMesonet field stations, and his experience with managing a field monitoring campaign to assess water availability in the Playa Lake systems of Texas.

Justification of labor hour estimate for Nathan Leber

Mr. Nathan Leber, Manager of the TexMesonet and Hydro Survey Program at the TWDB, will be a co-principal investigator on this proposal and provide technical oversight and program support to his staff member, Maureen Sanders, for the field assistance being provided by the TexMesonet Program to the proposed project. In **years one through three**, we estimate needing 0.5 months per year of Mr. Leber's time. The estimate of time needed for Mr. Leber's contribution to this project is based on this experience of managing the TexMesonet Program and its extensive field installation component.

Justification of the labor hour estimate for Maureen Sanders

Ms. Maureen Sanders, Meteorologist in the TexMesonet and Hydro Survey Program at the TWDB, will be a co-principal investigator on this project. She will provide field assistance to Mr. Weinberg on Tasks 3 and 4. In **years one through two**, we estimate needing one month/year of Ms. Sander's time for field assistance on Tasks 3 and 4. In **year three**, we estimate needing one month of Ms. Sander's time for assistance to Mr. Weinberg on ongoing equipment maintenance on the upgraded and new pan evaporation stations. The estimate of time needed for Ms. Sanders' contribution to this project is based on Mr. Leber's estimate of the time that TexMesonet staff will be able to devote to this project.

Equipment costs

1. **Buoy stations**

Table 4: Equipment costs for a buoy station

Buoy and mooring	**Cost ($)**
NexSens CB-650 Data Buoy	9,970.00
2-point mooring (chain, rope, anchor blocks)	750.00
warning light, etc	1,000.00
2 x 28 AH battery	178.00
Data logger	**Cost ($)**
CR1000 datalogger	1,700.00
205 cell modem	450.00
32262 omni antenna	98.00
coax cable	35.00
wiring and connectors	15.00
Meteorological and water temperature sensors	**Cost ($)**
EE-181 air temperature/relative humidity sensor	478.00
cable	8.00
radiation shield	180.00
RM Young 05103 Wind monitor	1,112.00
SI-111SS infrared water surface sensor	771.00
CNR4 net radiometer	6,948.00
CS225-10 temperature sensor string w 8 sensors	2,850.00
Total estimated cost for a buoy station	**26,543.00**

2. Pan evaporation station upgrades

Table 5: Equipment costs for upgrading a pan evaporation station

Equipment	Cost
CR1000 data logger	1,377
Sierra Wireless MP70 (FirstNet compatible)	759
Campbell enclosure boxes	800
enc mounting	65
31128 Yagi	87
coax cable	86
surge protection	225
cables and connectors	15
HMP 60 Temperature/Relative Humidity sensor	300
cable	7.9
RM young 41003-5 template sheild	130
MetOne 380D tipping bucket rain gauge	552.5
cable	10
mounting bracket	150
OTT pt transducer	1200
RM Young 05108-5A wind monitor	1084
mounting bracket	32
cable	14
60 watt solar panel	70
PV mounting bracket	160
84 AH battery	235
MorningStar Sunsaver SS-10-12v charge controller	80
grounding rod	12
6 ga grounding wire	12
ground clamp	3.75
15 ft 1.66" galv post	60
concrete, 4 x 80 lb	17.4
Total	**7,545**

3. New pan evaporation station installations

The cost of new pan installations includes the cost of a new Class A Pan, which is $1,500.00 plus the equipment needed for upgrading a pan evaporation station to include automated data transmission and meteorological sensors (Table 5, above).

Contractual costs

1. Desert Research Institute (DRI) participation on buoy station implementation and data coding
DRI will serve in an advisory capacity to the Texas Water Development Board to assist with the design and implementation of near-real time reservoir evaporation monitoring by the aerodynamic mass transfer method. Specifically, DRI will provide design review related to buoy fabrication, environmental sensor selection, and datalogger programming and set-up. Additionally, DRI will provide python-based scripts to estimate reservoir evaporation via the aerodynamic mass transfer approach. DRI will assist with general set-up and execution of the aerodynamic code-base for near-real time application and presentation.

The DRI will provide 60 hours of Chris Pearson's (Assistant Research Hydrologist) time for system design review (20 hours) and code transfer and software support (40 hours) at the rate of $95.06 per hour. The original proposal from DRI is included in Annex No. 3.

Desert Research Institute Cost Estimate

Sponsor: Texas Water Development Board

Title: Design and Software Support for Aerodynamic Open Water Evaporation Estimates

Period of Performance: 10/2019-9/2020

Principal Investigator: C. Pearson

Table 6: Cost estimate for DRI's contractual services

		System Design Review		Code Transfer and Software Support		TOTAL PROJECT	
	Rate (hr)	Units	Amount	Units	Amount	Units	Amount
PERSONNEL							
Pearson, Chris	95.06	20	1,901	40	3,802	60	5,704
TOTAL PERSONNEL			1,901		3,802		5,704
TOTAL COST			**1,901**		**3,802**		**5,704**

2. Agua del Sol Consultants cost estimate for the Collison Floating Evaporation Pan

Agua del Sol Consultants (ADSC) will install a Collison Floating Evaporation Pan (CFEP) on Twin Buttes Reservoir, TX and monitor, maintain, and perform quarterly hemispherical validation tests starting October 1, 2019 and ending September 30, 2021. TWDB will provide site access and any necessary permits. ADSC will provide TWDB quarterly reports of QA/QC data within 3 weeks of the end of each quarter. The costs and fees below are based on the estimated 8-10 site visits per year, with each site visit lasting between 4-7 days. Salary costs will cover field technician site visits and hydrologists costs for performing QA/QC on the collected data. The original quote from ADSC is included in Annex No. 4.

Table 6: Cost estimate for ADSC's contractual services

	Year 1		Year 2	
	10/01/2019-09/30/2020		10/01/2020-09/30/2021	
Cell Modem on Pan	$	1,000	$	1,000
Camper Usage Fee	$	5,000	$	5,000
Boat Usage Fee	$	5,000	$	5,000
Truck Usage Fee	$	5,000	$	5,000
Mileage, Gas ($0.58/mile)	$	6,000	$	6,000
M&E for Site Visits	$	4,000	$	4,000
Salary	$	24,000	$	24,000
Facilities and Administrative %		10%		10%
Facilities and Administrative Cost	$	5,000	$	5,000
Total Yearly Budget	$	55,000	$	55,000

Environmental Compliance

- Will the project impact the surrounding environment (e.g., soil [dust], air, water [quality and quantity], animal habitat)? Please briefly describe all earth-disturbing work and any work that will affect the air, water, or animal habitat in the project area. Please also explain the impacts of such work on the surrounding environment and any steps that could be taken to minimize the impacts.
  No, the project will not impact the surrounding environment

- Are you aware of any species listed or proposed to be listed as a Federal threatened or endangered species, or designated critical habitat in the project area? If so, would they be affected by any activities associated with the proposed project?
  Yes, there are federally listed threatened and endangered species in the project area. The full list is available at http://www.keepingtexasfirst.org/species/listed.php. They would not be affected by any of the activities associated with the proposed project.

- Are there wetlands or other surface waters inside the project boundaries that potentially fall under CWA jurisdiction as "Waters of the United States?" If so, please describe and estimate any impacts the project may have.
  Yes, there are wetlands and surface waters within Texas that could potentially be classified as "Waters of the United States". The project does not have any foreseeable impact on these water bodies.

- When was the water delivery system constructed?
  Not applicable.

- Will the project result in any modification of or effects to, individual features of an irrigation system (e.g., headgates, canals, or flumes)? If so, state when those features were constructed and describe the nature and timing of any extensive alterations or modifications to those features completed previously.
  No.

- Are any buildings, structures, or features in the irrigation district listed or eligible for listing on the National Register of Historic Places? A cultural resources specialist at your local Reclamation office or the State Historic Preservation Office can assist in answering this question.
  Yes, there are. A complete listing by county is available at:
  http://www.nationalregisterofhistoricplaces.com/tx/state.html

- Are there any known archeological sites in the proposed project area?
  Yes, there are.

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

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

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

Existing Drought Plan

Section 1: State Water Plan – Chapter Six (Water Supplies)

Section 2: General Guidelines for Regional Water Planning (Section 3.2) – *Evaluation of Surface Water Availability*

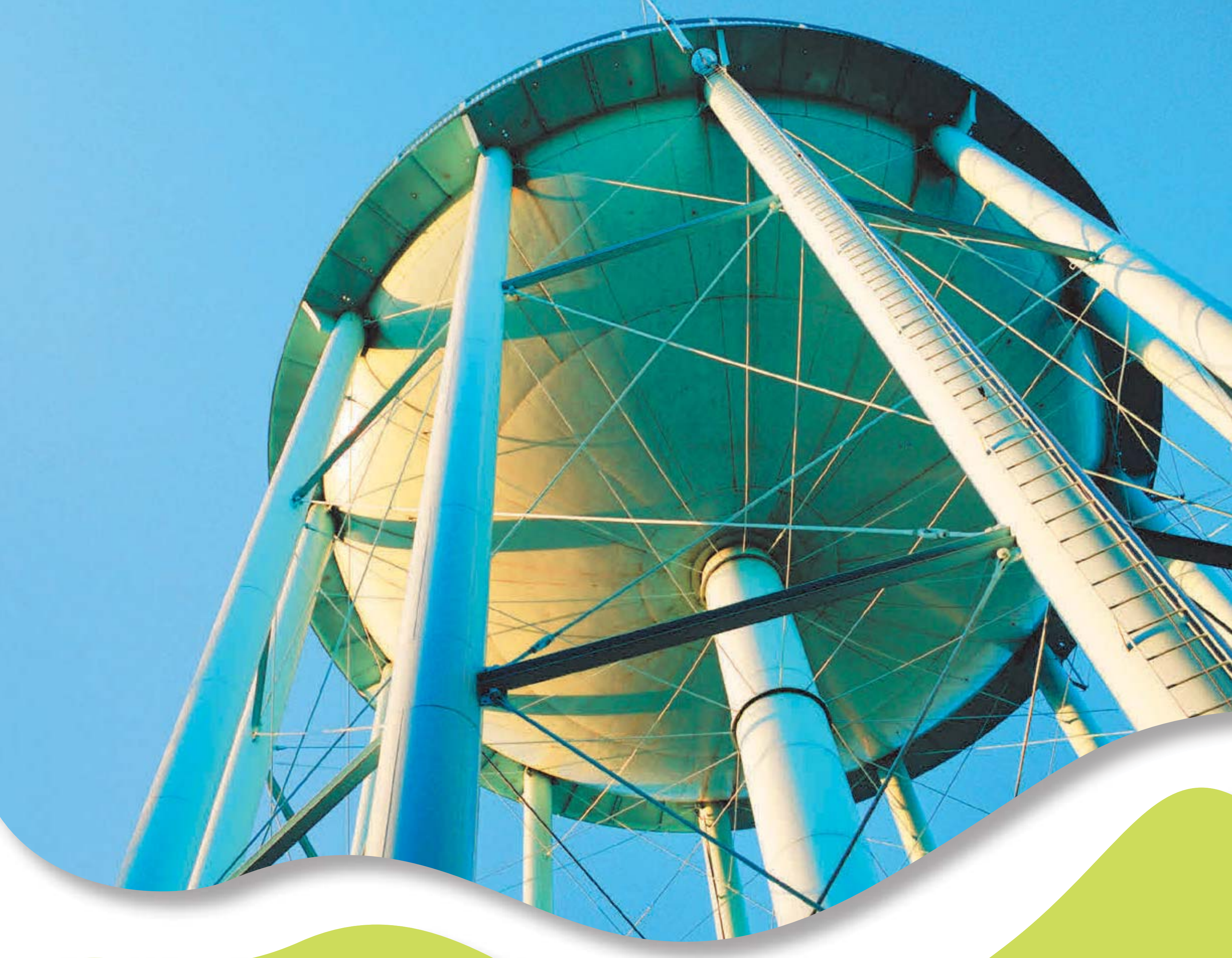
Annexes

Annex 1: Agenda for TWDB/LCRA evaporation workshop (Feb. 22, 2019)

Annex 2: EPA approved rates for FY 2019

Annex 3: Proposal from the Desert Research Institute for contractual services

Annex 4: Quote from Agua del Sol Consultants for contractual services



6

Water supplies

Quick facts

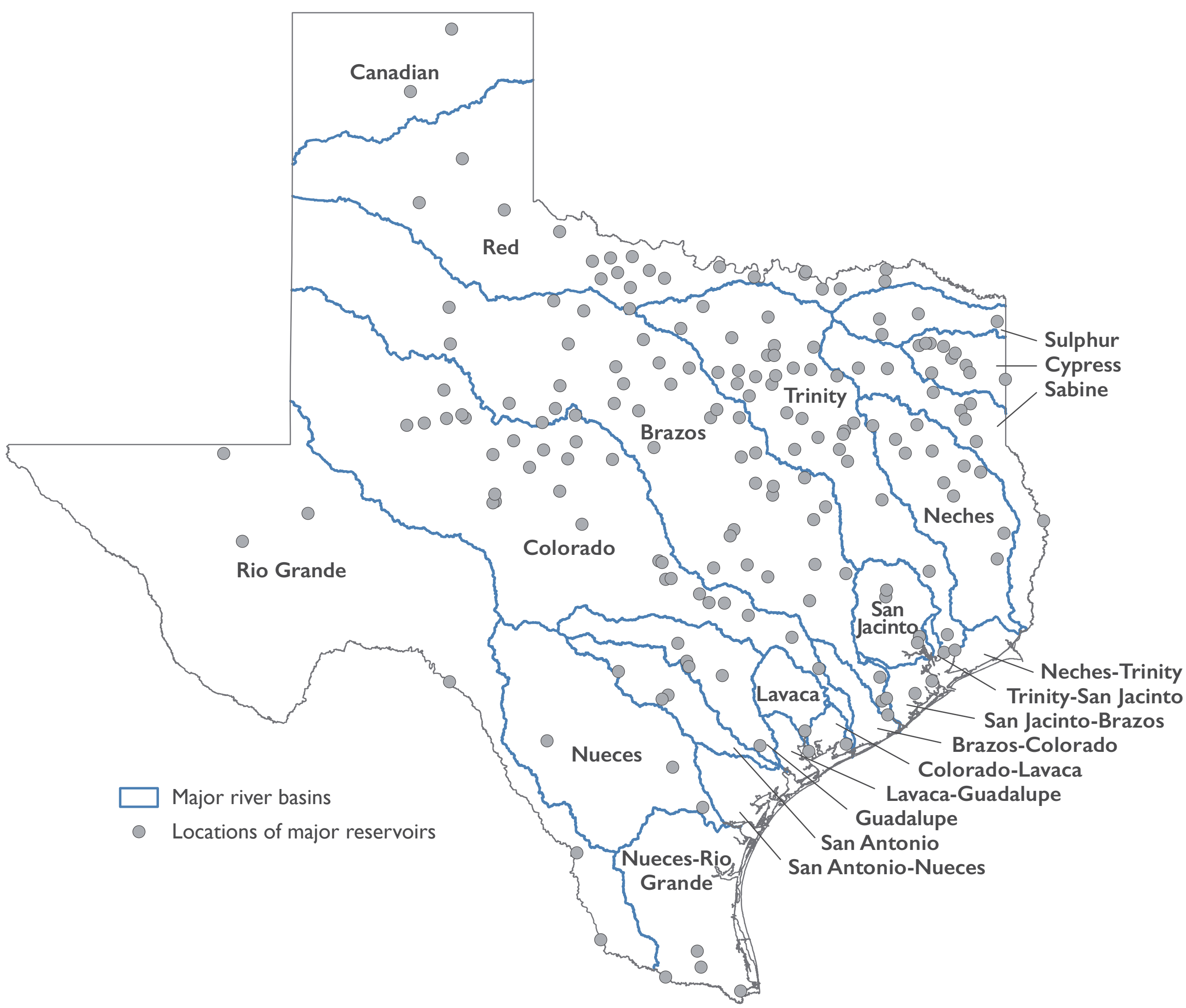
Total surface water and groundwater availability are lower by approxi mately 4 percent in 2020 and 5 percent in 2060 than in the 2012 State Water Plan.

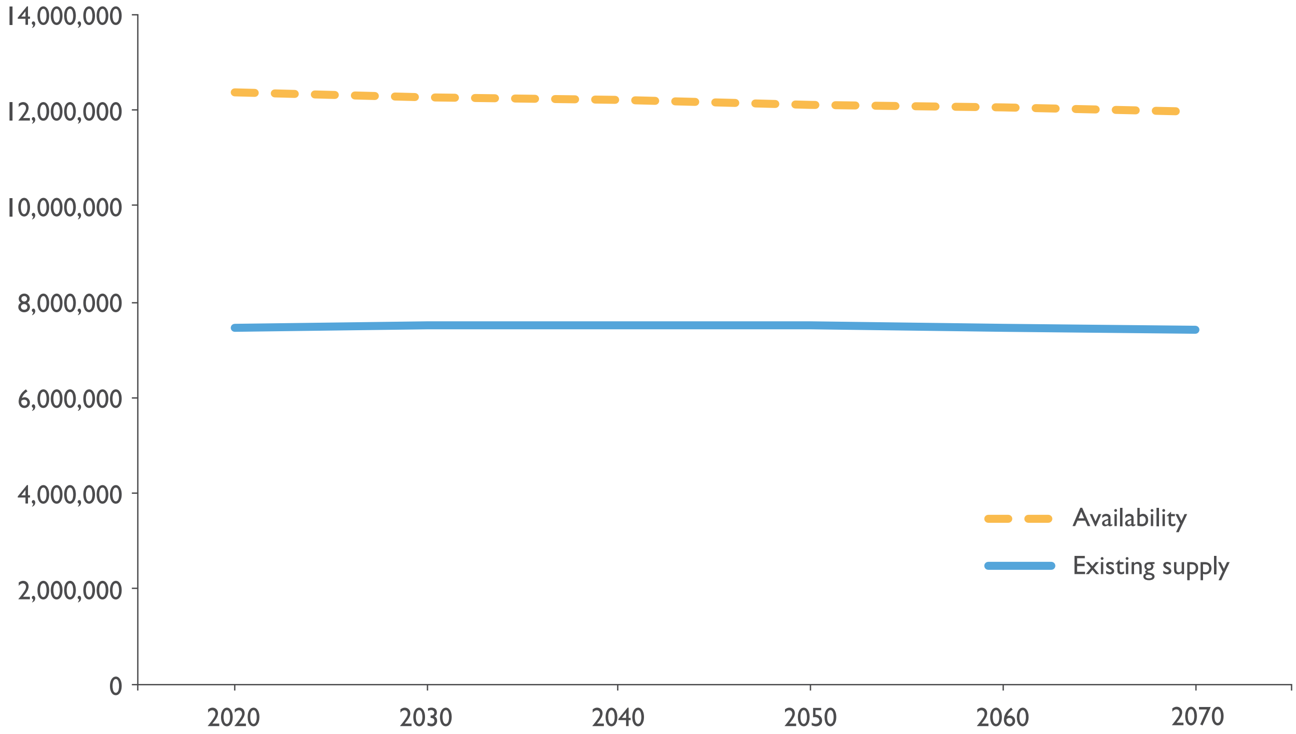
Texas' existing water supplies those that can already be relied on in the event of drought are ex pected to decline by approximately 11 percent between 2020 and 2070, from 15.2 to 13.6 million acre feet per year.

T

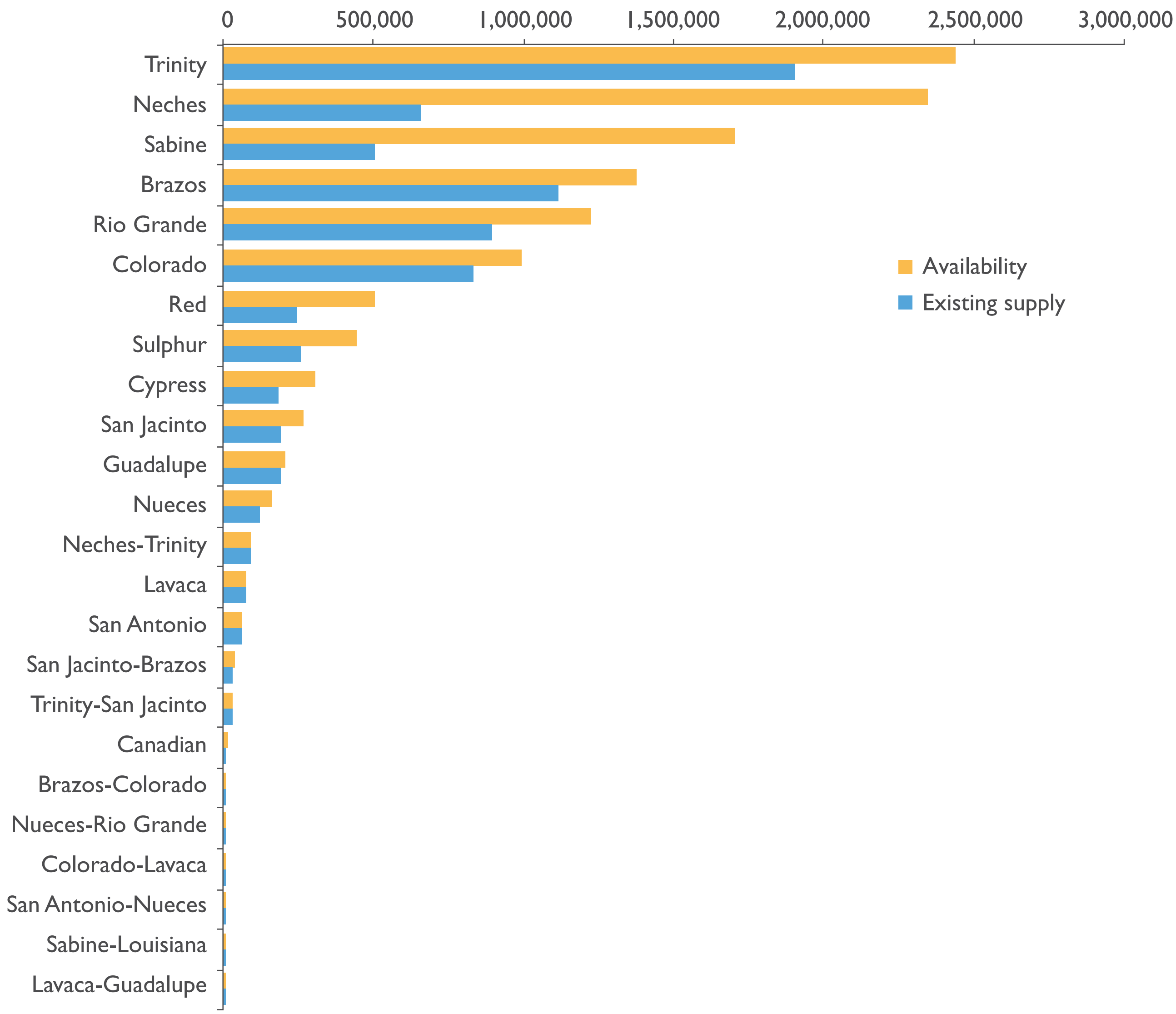
6.1 Evaluating water resources for planning

6.2 Surface water availability within river basins





6.3 Future surface water availability


0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
Trinity
Neches
Sabine
Brazos
Rio Grande
Colorado
Red
Sulphur
Cypress
San Jacinto
Guadalupe
Nueces
Neches-Trinity
Lavaca
San Antonio
San Jacinto-Brazos
Trinity-San Jacinto
Canadian
Brazos-Colorado
Nueces-Rio Grande
Colorado-Lavaca
San Antonio-Nueces
Sabine-Louisiana
Lavaca-Guadalupe
Availability
Existing supply

6.4 Groundwater availability of aquifers

Groundwater in Texas comes from nine major and 21 minor aquifers as well as other formations around the state. Major aquifers produce large amounts of water over large areas (Figure 6.4), whereas minor aquifers produce minor amounts of water over large areas or major amounts of water over small areas (Figure 6.5). Groundwater availability is estimated through a combination of policy decisions, made primarily by groundwater conservation districts, and the ability of an aquifer to transmit water to wells.

Groundwater is generally governed by the rule of capture, which may be modified where groundwater conservation and groundwater subsidence districts exist (Figure 6.6). Districts may issue permits that regulate pumping of groundwater and spacing of wells within their jurisdictions.

In 2005, the 79th Texas Legislature passed House Bill 1763, which fundamentally changed the process of how groundwater availability is determined. Prior to House Bill 1763, planning groups determined groundwater availability with input from groundwater conservation districts. House Bill 1763 shifted that responsibility to groundwater

Figure 6.4 - Major aquifers of Texas

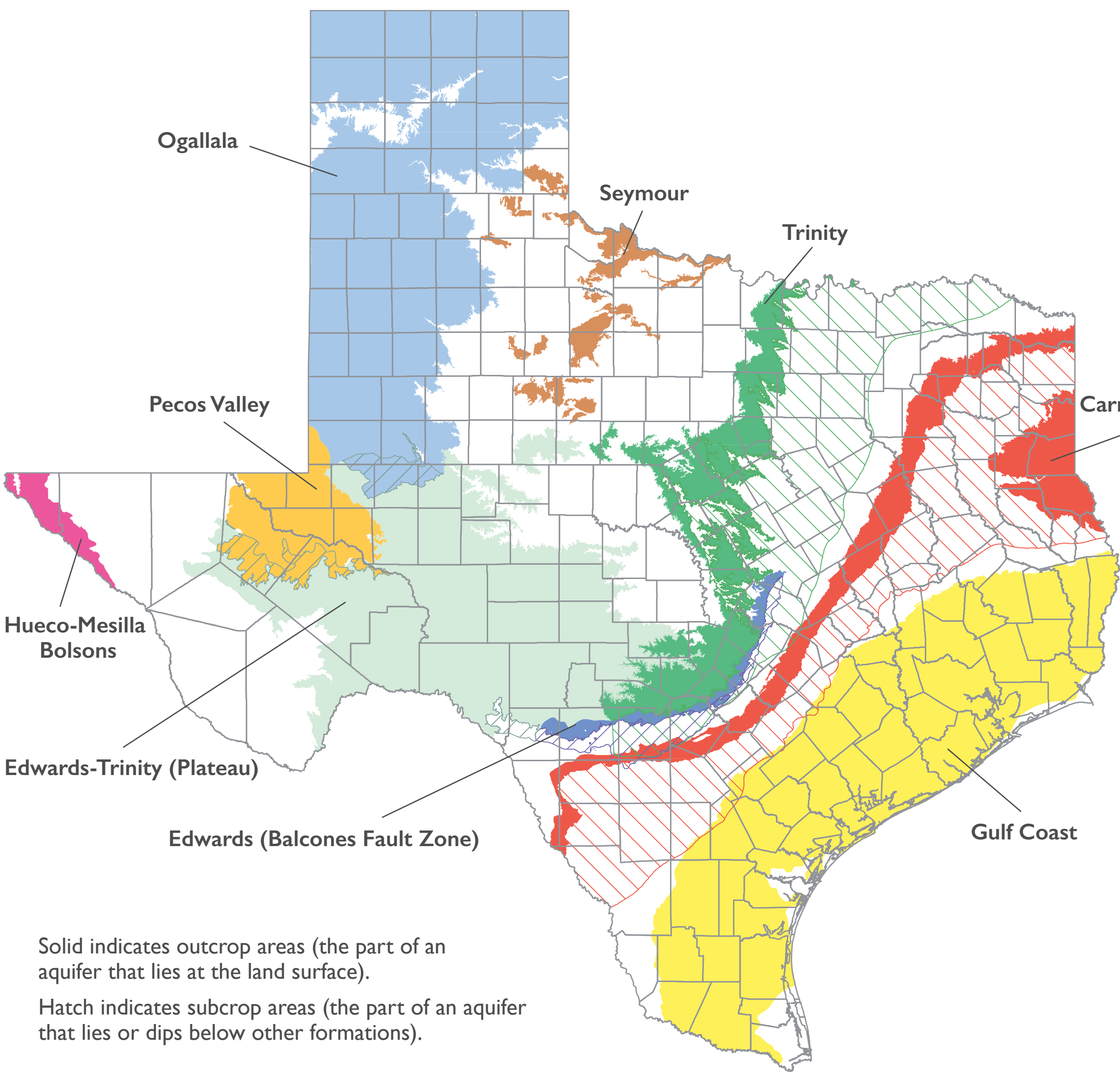
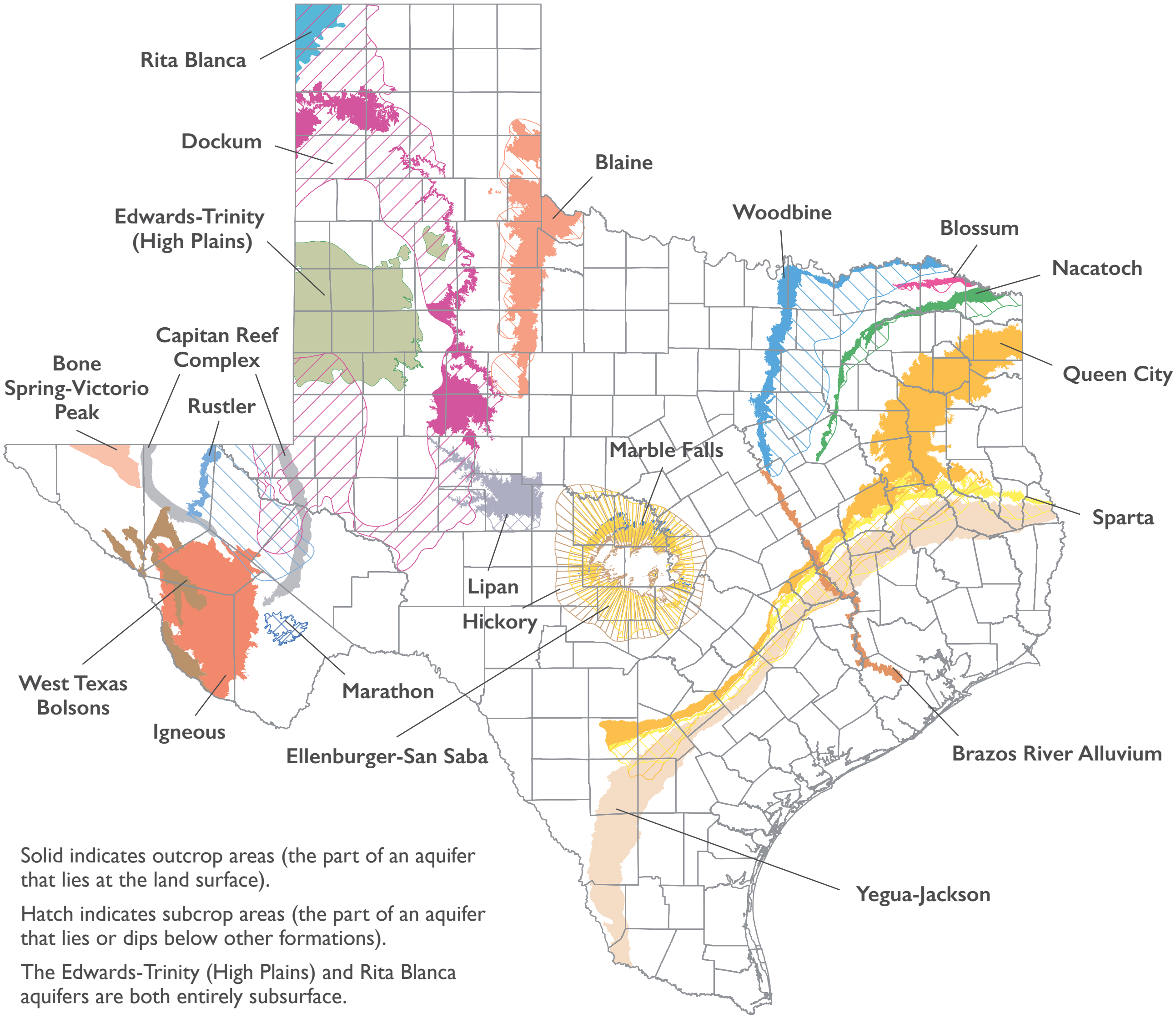


Figure 6.5 - Minor aquifers of Texas



conservation districts by requiring districts within groundwater management areas to work together to establish the desired future conditions of relevant aquifers within that area.

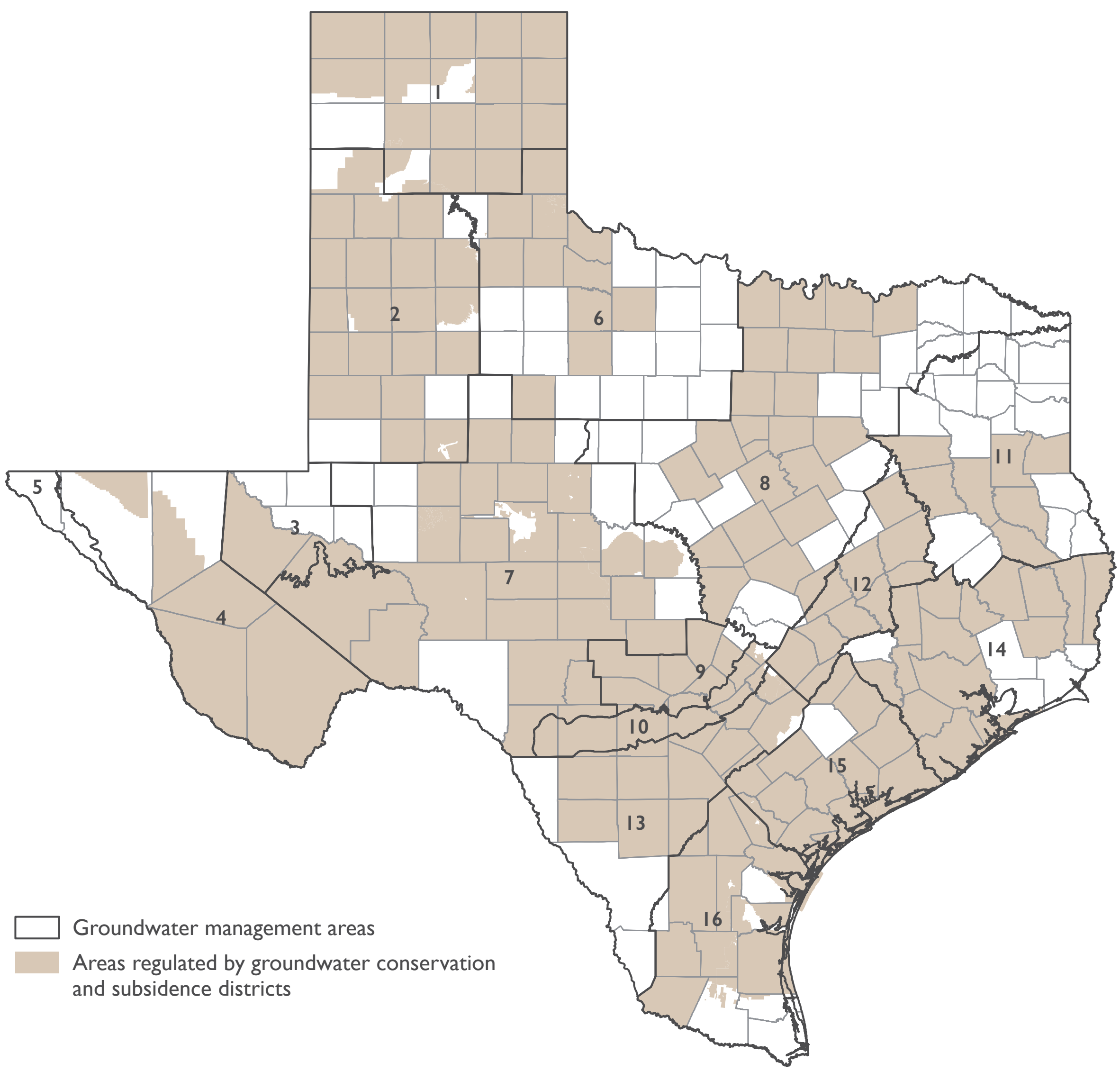
Desired future conditions are the desired, quantified conditions of groundwater resources (such as water levels, water quality, spring flows, or storage volumes) at a specified time in the future or in perpetuity. The TWDB uses desired future conditions to determine a modeled available groundwater value for an aquifer or part of an aquifer in the groundwater management area. A modeled available groundwater value is the volume of groundwater production, on an average annual basis, that will achieve the desired future condition. These values are independent of existing pumping permits and may, depending on the aquifer characteristics and how the desired future conditions are defined, include a variety of water quality types, including brackish groundwater. Depending on the aquifer and location, the inclusion of brackish groundwater in modeled available groundwater values might be subject to local and regional supply evaluations.

This is the first state water plan that is based on modeled available groundwater volumes for all relevant aquifers, statewide. Modeled available groundwater volumes account for the vast majority of groundwater availability considered in this plan. For aquifers and portions of aquifers that did not have modeled available groundwater values, planning groups determined availability with input from groundwater conservation districts. Senate Bill 1101, passed by the 84th Texas Legislature in 2015, allows a regional water planning group to define all groundwater availability as long as there are no groundwater conservation districts within the regional water planning area. This applies to Region D only.

On a statewide basis, total groundwater availability is projected to decline by approximately 20 percent from 2020 to 2070 (Figure 6.7). This decrease is primarily due to declines in the Ogallala and Gulf Coast aquifers.

Annual statewide groundwater availability in 2020 is estimated to be 12.3 million acre-feet. More than half of that comes from the Ogallala and Gulf Coast aquifers (Figure 6.8, Appendix B.2).

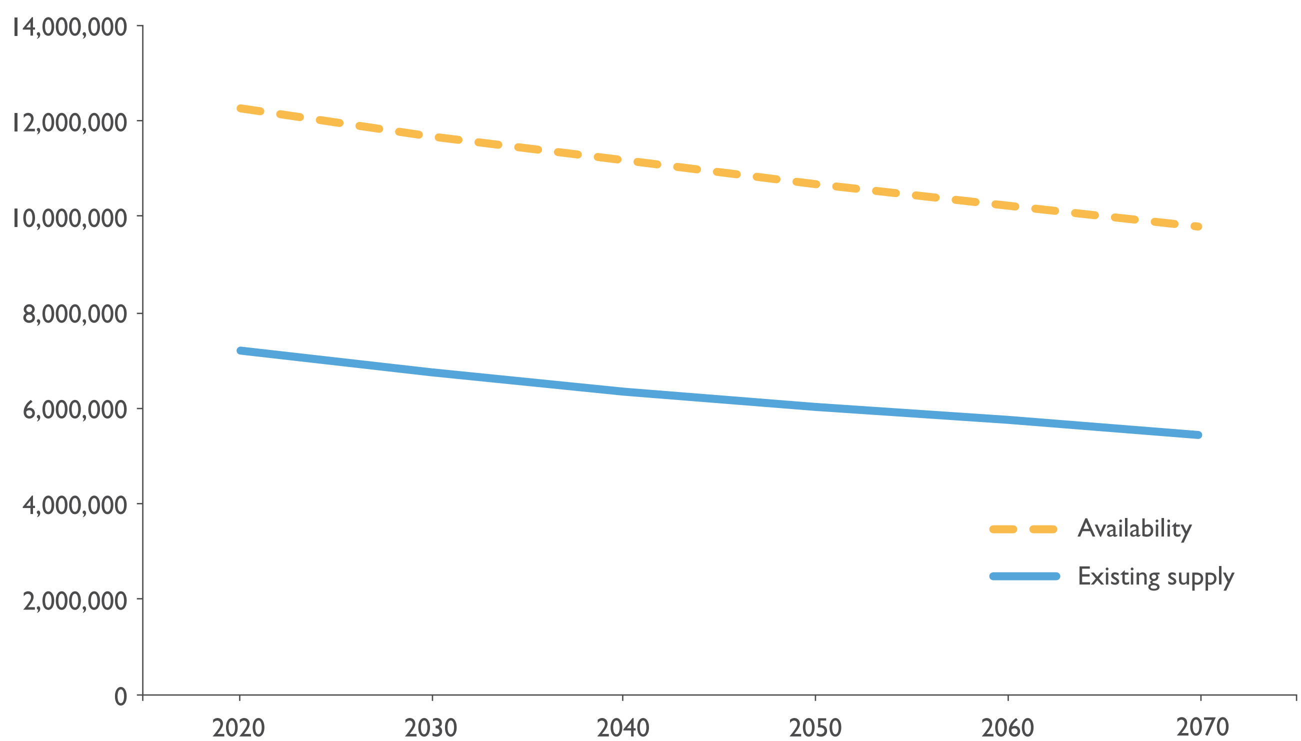
Figure 6.6 - Locations of groundwater conservation or subsidence districts and 16 groundwater management areas

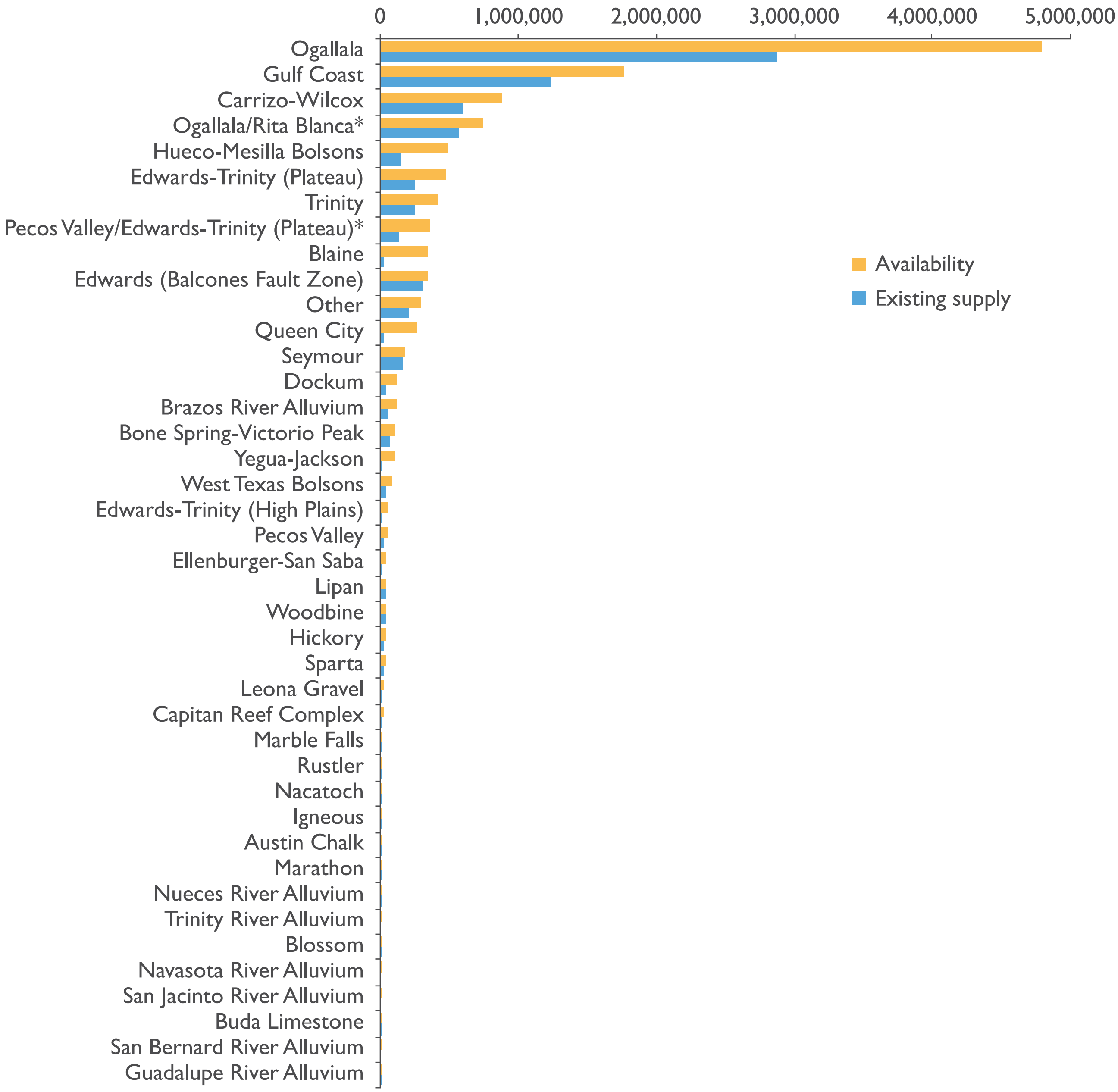


6.5 Future groundwater availability

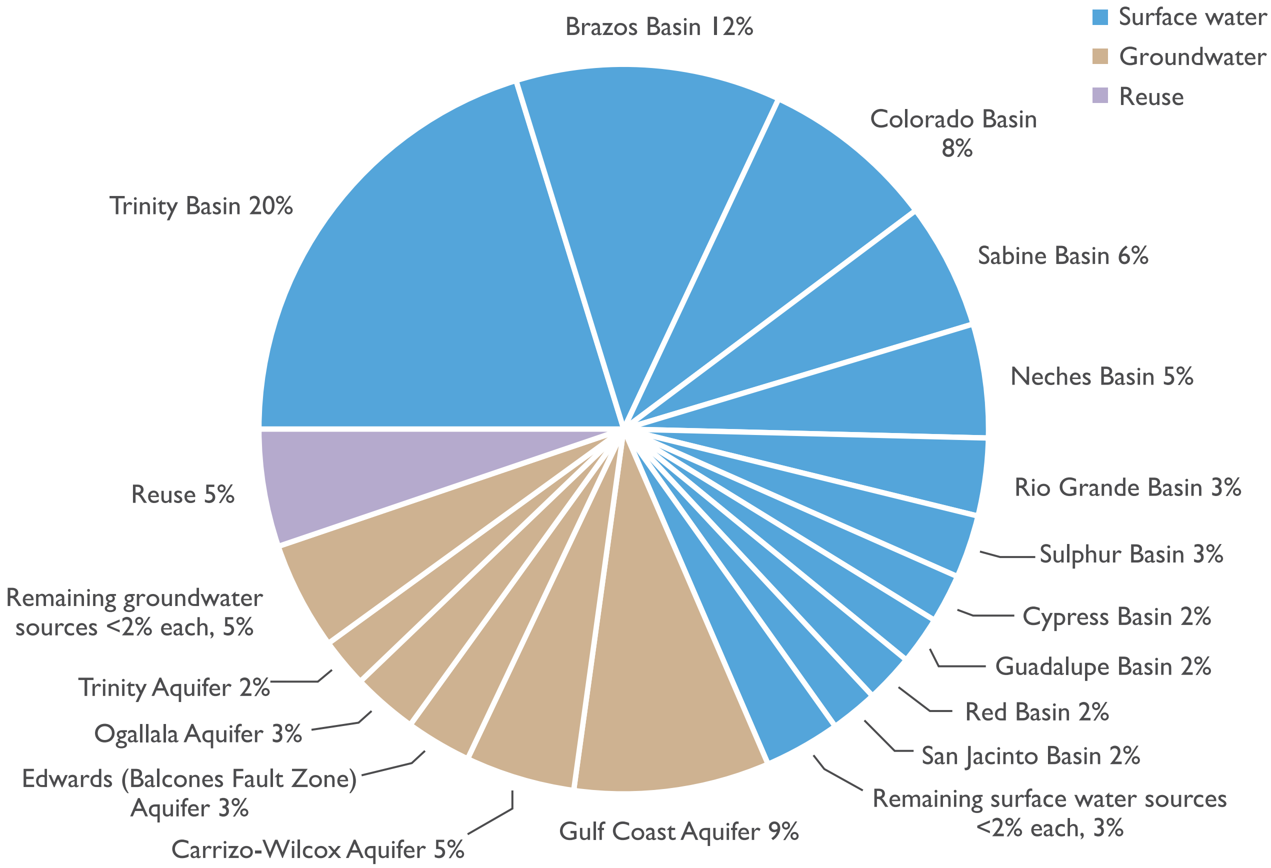
6.7 Existing supplies

6.6 Availability of other sources





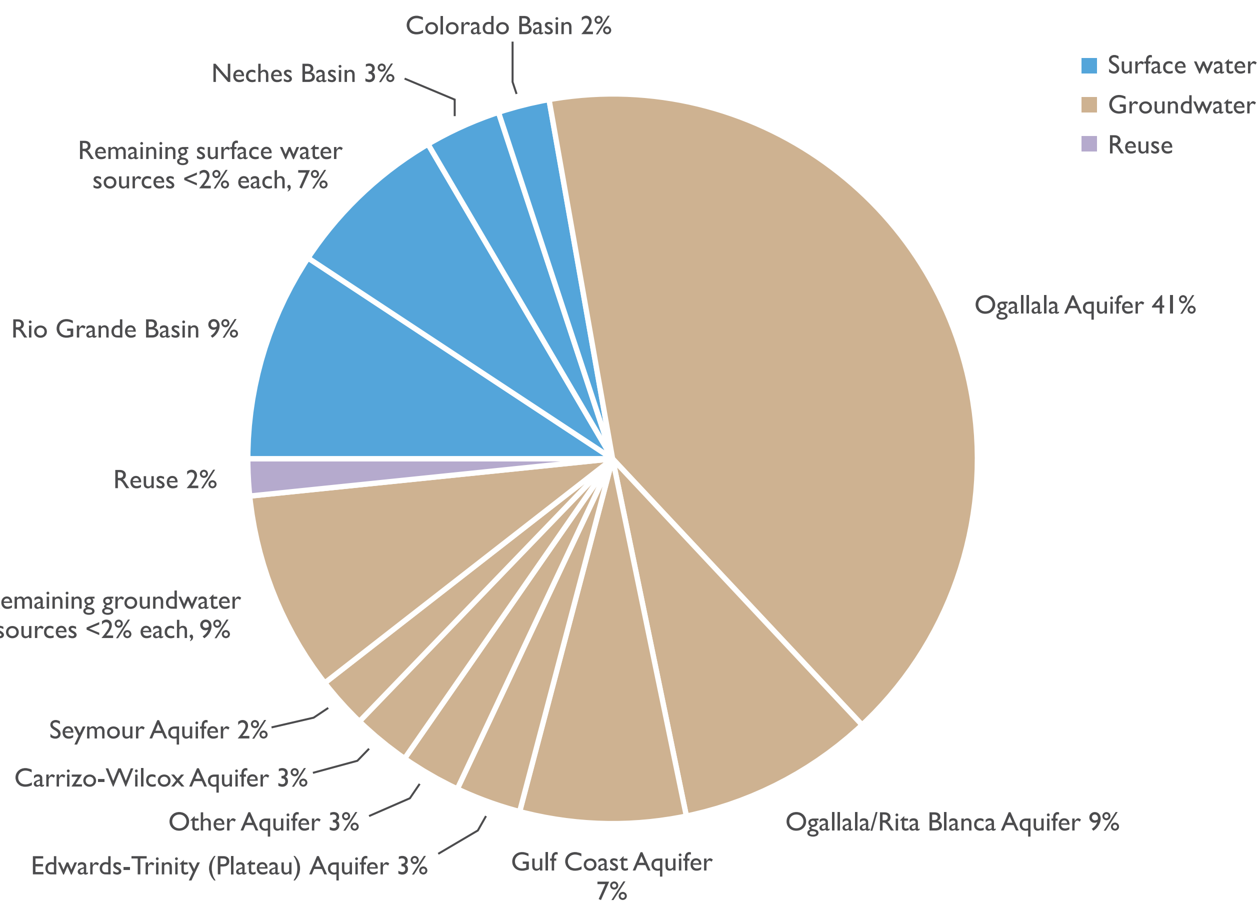
** The Ogallala/Rita Blanca and the Pecos Valley/Edwards-Trinity (Plateau) are aquifer combinations that reflect specific and mutual aquifer properties, undifferentiated groundwater usage, and groundwater availability model characteristics. In these cases, the modeled available groundwater and existing supply values have likewise been developed to honor these aquifer combinations.*

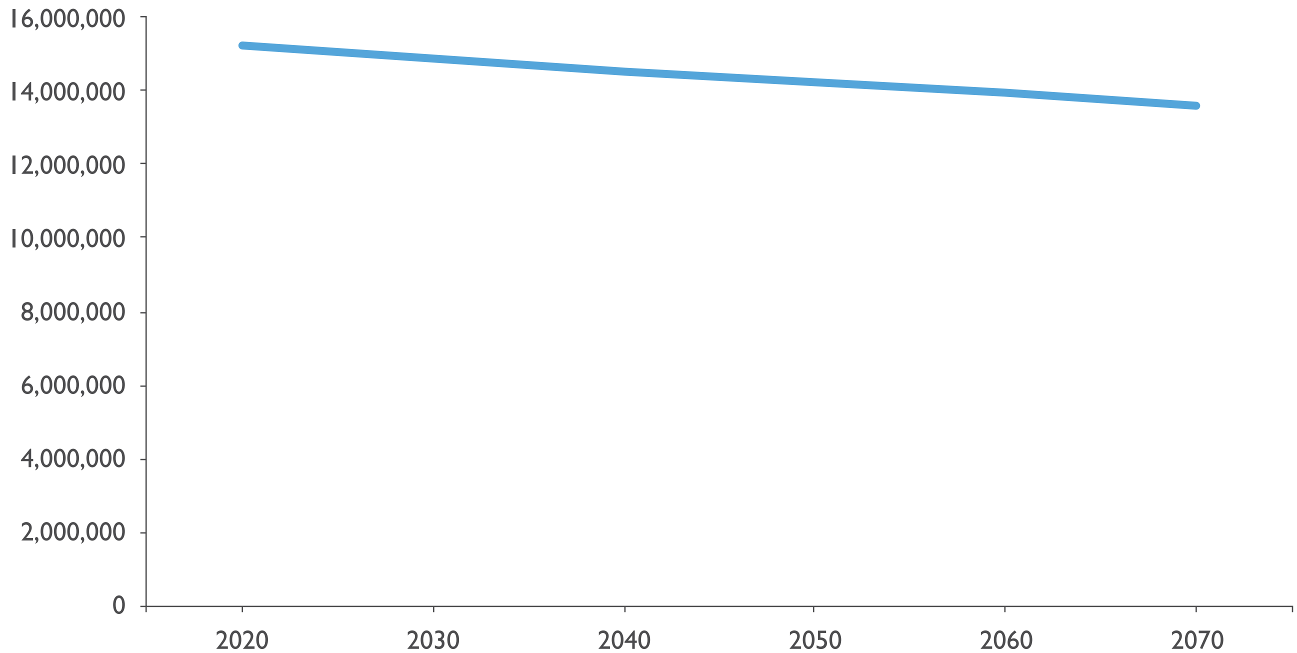

Surface water
Groundwater
Reuse
Brazos Basin 12%
Colorado Basin 8%
Sabine Basin 6%
Neches Basin 5%
Rio Grande Basin 3%
Sulphur Basin 3%
Cypress Basin 2%
Guadalupe Basin 2%
Red Basin 2%
San Jacinto Basin 2%
Remaining surface water sources <2% each, 3%
Gulf Coast Aquifer 9%
Carrizo-Wilcox Aquifer 5%
Edwards (Balcones Fault Zone) Aquifer 3%
Ogallala Aquifer 3%
Trinity Aquifer 2%
Remaining groundwater sources <2% each, 5%
Reuse 5%
Trinity Basin 20%

Groundwater supply

Reuse supply

Surface water supply





** Does not reflect some portions of existing supplies that are associated with purely saline water sources such as untreated seawater*

2020 to 2070. The increase in reuse existing supply is primarily due to an increase in wastewater flows associated with an increasing population and the capacity of existing reuse facilities.

6.8 Comparison to the 2012 State Water Plan

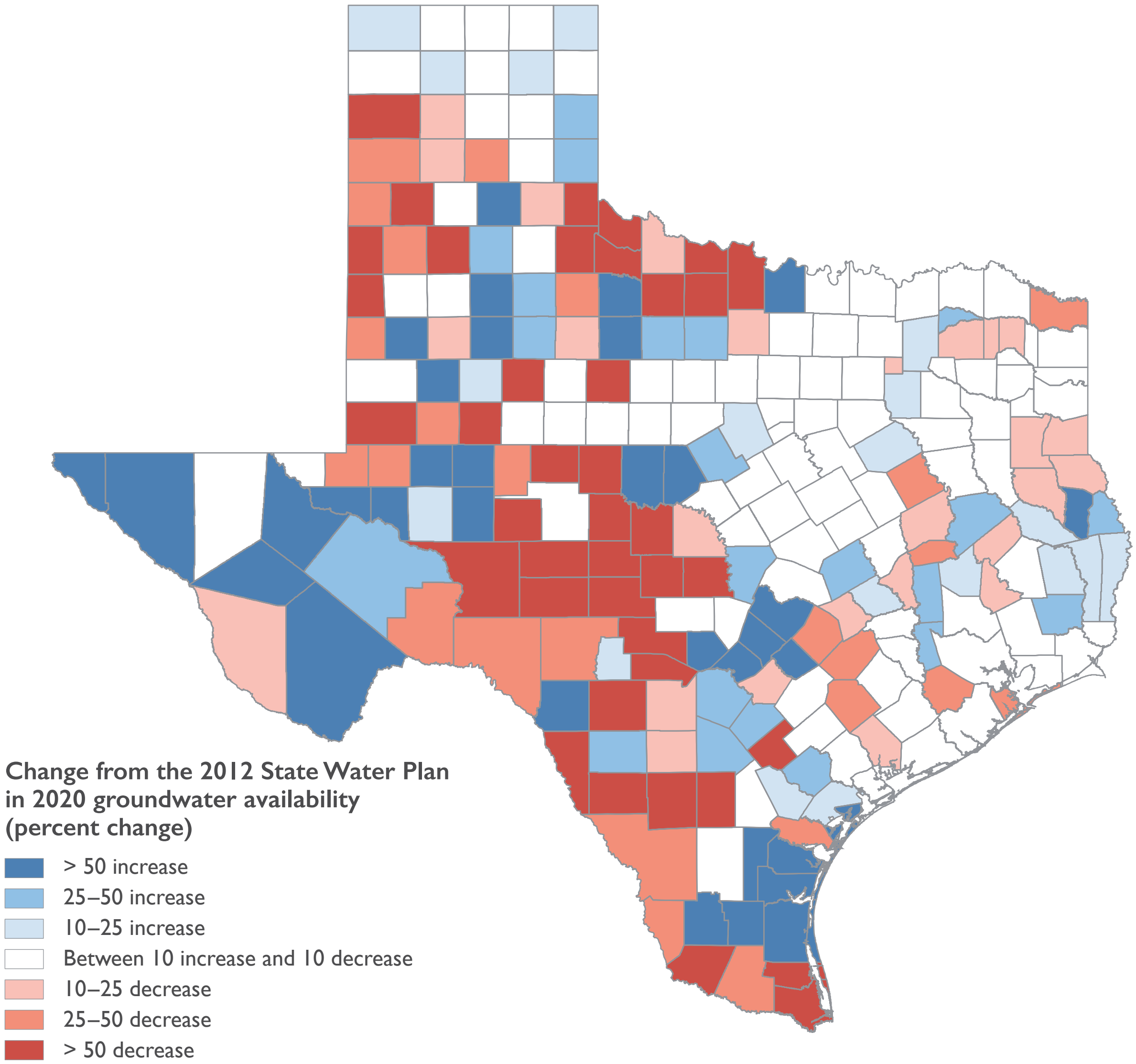
Surface water

Source	2020	2030	2040	2050	2060	2070	Percent change
Groundwater	7,191,000	6,770,000	6,367,000	6,048,000	5,776,000	5,432,000	24
Texas[a]	**15,218,000**	**14,892,000**	**14,503,000**	**14,210,000**	**13,954,000**	**13,572,000**	**11**

Tom Miller Dam, Austin, Texas

Figure 6.12 - Changes from the 2012 State Water Plan in annual surface water availability in 2020

Figure 6.13 - Changes from the 2012 State Water Plan in annual groundwater availability in 2020



decrease in existing surface water supplies in 2060 due partly to reduced availability estimates based on updated historical drought conditions.

Groundwater

There is slightly less groundwater availability statewide in 2020, with considerable variations by county, including relatively more decreases in central/western and southern counties (Figure 6.13). The statewide existing groundwater supply is close to the supply in the 2012 State Water Plan, although it is somewhat higher for the decades from 2030 to 2060. The greatest relative change was an approximate 3 percent increase in statewide groundwater availability in 2040 due to policy decisions made as part of the groundwater management area joint planning process.

Reuse

The existing reuse supply is higher than the supply from the 2012 State Water Plan in each decade from 2020 to 2060.

6.9 Uncertainty of our future water supply

Exhibit C

Second Amended

General Guidelines for Fifth Cycle of Regional Water Plan Development

April 2018

This document is subject to future revision based upon any future Legislative actions.

by modifying a desired future condition (DFC) that changes an annual modeled available groundwater (MAG) volume.

All surface water availability shall be based on water availability model (WAM) runs. For groundwater availability not associated with a MAG, the RWPGs may develop RWPG-estimated groundwater availability and shall include a table summarizing the basis of these RWPG-estimated groundwater availabilities. Reuse availability may be based on a population-dependent infrastructure concept, for example, relying on wastewater from a growing population that is anticipated to already be initially treated and available for additional treatment for reuse purposes.

The water availability at each source and the associated existing water supply information for each WUG and WWP shall be entered into DB22. RWPGs shall report both: a) water availability data; and b) existing water supply data in the Technical Memorandum, IPP, and final adopted RWP for WUGs and MWPs. Note that data for WWPs that the RWPG determines are necessary for purposes of developing their plan will need to be entered into DB22 for purposes of data analysis.[9] Due to recent rule changes, only MWPs rather than WWPs are to be presented in the RWP.

3.2 Evaluation of Surface Water Availability

Regional water planning surface water availability shall be evaluated using the TCEQ's WAMs; specifically, the unmodified RUN3 version, which includes all water rights at full authorization; all applicable permit conditions, such as flow requirements, are met; and, no return flows. All TCEQ unmodified WAM RUN3 models also use the original reservoir capacity, i.e., do not include reservoir sedimentation. However, for regional water planning purposes, inclusion of anticipated sedimentation[10] into the WAM RUN3 models for major reservoirs, defined as greater than 5,000 acre-feet, is a necessary modification[11] to be performed by the RWPGs independent of the hydrologic variance request process. Any further reference to use of an unmodified WAM RUN3 in this document is assumed to include the use of anticipated sedimentation.

Reservoir availability, or firm yield, is defined as the maximum water volume a reservoir can provide each year under a repeat of the drought of record using anticipated sedimentation rates and the following WAM RUN3 characteristics: all senior water rights will be totally utilized, no return flows are included, and, all applicable permit conditions are met. This definition of firm yield does not prevent accounting for run of river firm diversions or firm supplies that rely on multiple surface water sources or conjunctive supplies in the planning process.

"Firm" means that the use-appropriate monthly percentage of the annual firm diversion amount must be satisfied in each and every month of the estimation period (or a shorter period if it is used in the estimation) for all surface water diversions. Unless otherwise approved by the EA, available surface water shall be described by the permitted portion of firm yields for reservoirs and the permitted portion of firm diversions for run of river supplies.

Updating anticipated sedimentation using reservoir volumetric survey data would be a WAM firm yield modification to include new existing area-capacity conditions in the model as provided from an updated scientific volumetric survey performed on a reservoir since the last update to WAM RUN3 or other

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[9] The TWDB will migrate a limited amount of DB17 data to DB22 and confirm lists of WWPs with RWPGs at that time. RWPGs will continue to use WWP information and water transfer points in their data analysis of their plan.
[10] Anticipated sedimentation is the anticipated decreases in a reservoir's area-capacity condition resulting in projected firm yield decreases each decade; the necessary modification to all WAM RUN3 models for inclusion of the anticipated sedimentation for all reservoirs will not require a hydrologic variance.
[11] 31 TAC §357.10(14)

relevant information as deemed appropriate by the RWPG in order to more accurately reflect existing firm yield.

Run of river availability, or firm diversion, evaluated for a municipal sole-source water use (i.e. not firmed up with other sources), is defined as the minimum monthly diversion amount that is available 100 percent of the time during a repeat of the drought of record (i.e., this minimum volume must be available each and every month). Evaluated for all other water users, the firm diversion is defined as the minimum annual diversion, which is the lowest annual summation of the monthly diversions reported by the WAM over the simulation period (lowest annual summation being the calendar year within the simulation that produces the lowest run of river diversion volume). Such run of river availabilities may be determined without the inclusion of reservoir sedimentation modifications if deemed appropriate by the RWPG since sedimentation modification requirements of WAM RUN3 apply to stored water.

For municipal WUGs whose only source of water is from a run of river diversion, it is important that RWPGs do not over-estimate reliable run of river water availability during drought of record conditions, for example, by overlooking the need for additional intra-year storage and/or alternative sources of water supply necessary to bridge potential seasonal water shortages. If an intra-year shortage is identified in WAM RUN3, based on the reasonable monthly diversion distribution pattern, then the annual firm diversion volume to be reported is that for which the monthly diversion amounts are met in each and every month, unless the municipal WUG has supplies from multiple run of river sources or a combination of reservoir and run of river supply that serve to firm up the monthly supply.

In general, for surface waters bordering neighboring states or countries, RWPGs shall analyze and report currently available water supplies taking into account existing legal agreements. For interstate and international reservoirs, RWPGs shall report annual water volumes that are available to Texas according to existing legal agreements. Future availability may be based on strategies.

For surface water withdrawals that do not require permits, such as for domestic and livestock uses, RWPGs will estimate these local annual water availability volumes under drought of record conditions based on the most current accessible information. RWPGs shall document the methodologies utilized for these availabilities in the Technical Memorandum, IPP, and final adopted RWP.

RWPGs should consider requesting model modification for any issue that varies from the base requirements or that is expected to have significant effects on existing supply estimates.

If the use of a potential hydrologic variance for an alternative surface water availability evaluation is approved by the EA, then both the unmodified WAM RUN3 firm yield/firm diversion and the alternative annual availability volume shall be reported for the reservoir, reservoir system, or river source in the hydrologic variance technical documentation. If the approved hydrologic variance allows for use of a different model than the TCEQ WAM, the approved alternative model may be used to calculate the reported firm yield/firm diversion and the alternative annual availability volume. For modifications to reservoir or reservoir system firm yield, the original unmodified firm yield shall be a reported total value in the plan documents while the alternative availability is utilized as the basis for planning in the Technical Memorandum, IPP, final adopted RWP, and DB22. If no hydrologic variance is used for surface water availability, the unmodified WAM RUN3 firm yield/firm diversion shall be reported for the reservoir, reservoir system, or river source and utilized as the basis for planning in the Technical Memorandum, IPP, final adopted RWP, and DB22.

3.2.1 Standard Criteria and Assumptions for TCEQ WAM RUN3

When estimating surface water availability associated with firm yields or firm diversions with the TCEQ's unmodified WAM RUN3, the following criteria must be met if applicable:

1. available inflows to reservoirs are the remainder of naturalized stream flows after upstream (and downstream) senior water rights are met unless the use of lower diversion rates for an upstream right is approved by the EA;
2. downstream senior water rights must be met; however, this does not require releases of legally stored water unless specifically stated in existing water rights;
3. all special conditions of water rights must be considered, including, but not limited to:
    a. bay, estuary, and instream flow requirements;
    b. TCEQ environmental flow standards and associated TCEQ rules (e.g. instream flow set-asides); or
    c. other relevant limitations.
4. minimum allowable reservoir levels are the top of dead pool unless the use of a lower level is approved by the EA (this dead pool limitation applies only to situations where the dead pool is specified in the water right permit or other binding agreement);
5. maximum allowable reservoir levels are the top of conservation pool unless the use of a higher level is approved by the EA;
6. evaporative losses are based on evaporation rate data that best coincide with the location of the reservoir and the period of record and time steps for inflows;
7. annual water supply demands are constant for all years; the distribution of annual demands within a given year are constant in all years and shall reflect the patterns of different types of water use expected; and,
8. model run time steps shall not be longer than one month.

The Technical Memorandum, IPP, and final adopted RWP shall include a written summary of all WAM models on which the surface water availabilities in the RWP are based as well as WAM model(s) input/output files or other model files necessary to support replication of the results used in developing the surface water availabilities.[12] This summary must include:

1. the named/labeled version (including date) of each model used;
2. a summary of any modifications to each model and the date these modifications were approved by the EA;
3. the name of the entity/firm that performed each model run; and,
4. the date of each model run.

3.3 System Availability and Related WMSs

Future water supply sources may be aggregated in a WMS(s) and categorized as a system if they meet one or more of the following criteria:

1. aggregated sources that come from two or more of the following categories: groundwater, surface water, and reuse;
2. several reservoirs are to operate together under permit, so that supplies from a specific reservoir cannot be tracked directly to an end user; and/or,
3. two or more reservoirs are to operate, under permit, as a system resulting in a system gain in firm yield.

For planning purposes, availability for reservoirs operated as a system may be reported as a system in lieu of reporting individual reservoir availability. Such a relationship could include reservoirs owned and operated by the same entity, so long as the operations comply with the existing permit conditions. The

[12] All required model files for WAMs and GAMs used to develop the RWP shall be included as electronic appendices per Section 13.2.1 of this guidance document.

firm yield of the system should be the firm yield during drought of record conditions for the system as a whole.

System gain is the amount of permitted water a system creates that would otherwise be unavailable if the reservoirs were operated independently; and for existing systems, this volume shall be reported separately in the RWPs in addition to the reservoir system firm yield. For multi-reservoir systems, the minimum system gain during drought conditions may be considered additional water available, if it has already been permitted. Total existing water from a system shall not exceed the sum of the system gain plus the firm yields of individual reservoirs in that system.

To report system gain, system operations must produce a measurable system yield greater than the sum of the individual reservoir yields. System gain for system operations that mask individual reservoir yields or that group reservoirs together without a permitted relationship shall not be allowed in the RWPs.

As described above, potential future operation of multiple reservoirs as a new system, or changes to current operational procedures for existing reservoir systems, in order to provide additional yield may be evaluated as a potential WMS. Such a WMS analysis shall adequately describe methods used to calculate these future system gains (to be permitted) and shall include discussion regarding any associated permit changes that would be required.

3.4 Reuse Availability and Related WMSs

For regional water planning purposes, reuse is considered a stand-alone water source type and RWPGs will evaluate reuse availability and supplies separately from conservation, which is classified as a demand reduction associated with a WUG.

Availability cannot exceed the capacity of the existing infrastructure to deliver produced treated water[13] to customers or existing permits. However, it should be clarified that to avoid overestimating reuse availability, the reuse availability will also be dependent upon the associated decade population/demand projections that would determine the amount of wastewater flowing into a wastewater treatment plant (WWTP) on an annual basis. This population-dependent availability would be less than a WWTP's maximum permit capacity and would increase each future decade (as population/demand increases) up to the annual volume restricted by existing infrastructure and/or permit (i.e., WWTP inflow projections could be a more stringent restriction for reuse availability in early planning decades). This same population-dependent concept would hold true for determining future WMS decadal reuse availabilities and can include new capacity from additional strategy WWTP infrastructure.

Direct reuse is process water recirculated within a given system and should be classified as potable or non-potable. The standardized naming convention for a direct reuse source will include the Producer's Name plus the Recipient's Name.[14] For direct reuse, RWPGs shall base their drought of record existing direct reuse analyses on: currently installed wastewater reclamation infrastructure; and the amount of wastewater anticipated to be treated at the WWTP, based on associated decade populations/demands. These amounts shall not exceed the amounts of water available to utilities generating the wastewater. RWPGs shall evaluate potential future sources of direct reuse that will require new permits and additional reclamation infrastructure as WMSs, and shall provide adequate justification to explain

[13] May require additional level of treatment prior to reuse to be included as a WMS.
[14] See TWDB's Contract Exhibit D *Guidelines for Regional Water Planning Data Deliverables* for more details on naming direct reuse sources within DB22 and presented in the RWP.

AGENDA

TWDB & LCRA Workshop on

Surface Water Evaporation Monitoring in Texas - Current and Future Technologies

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Date: February 22, 2019 - Central Standard Time

Room R108, LCRA Redbud Center, 3701 Lake Austin Blvd. Austin, Texas, 78703

11:00	Optional Pre-Workshop Meet and Greet Lunch on your own - Able's on the Lake or Hula Hut - Park at LCRA and walk. Pick up your nametag at Redbud and assemble in groups of 4 or more.
12:30	Welcome Statement – John Dupnik, TWDB Deputy Executive Administrator & David Walker, LCRA Director of River Operations
12:40	*Importance of Accurate Evaporation Data* - Benjamin Livneh, University Colorado Boulder (remote)
1:00	*National Weather Service Station Coverage*, Maren Stoflet National Weather Service- Ft. Worth
1:10	*Monitoring Lake Evaporation at the Texas Water Development Board*, Nelun Fernando & John Zhu, TWDB Water Availability
1:30	*Extending Evaporation Datasets with the Hargreaves Method*, Richard Hoffpauir
1:50	*Potential Applications for Estimating Open Water Evaporation Through the OpenET Platform*, Justin Huntington, Desert Research Institute (remote)
2:10	*Estimating Reservoir Evaporation Losses by Fusing Remote Sensing and Modelling Approaches*, Huilin Gao, Texas A&M University

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2:30	Break – Tour of Redbud Hydromet facilities (weather permitting)

2:50	*New Technologies in Evaporation Monitoring*, Andrew Weinberg, TWDB
3:10	*The Collison Evaporation Pan*, Jake Collison
3:30	*Open Water Evaporation with Application to Reclamation Projects*, Dan Broman and Subhrendu Gangopadhyay, USBR (remote)
3:50	*Evaporation at the USACE* – Jerry, Cotter, Michael Schwind & John Hunter, USACE-SWF
4:10	*Computed Evaporation at USGS*, Glenn Harwell, USGS
4:30	Recap
4:45	Adjourn

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

COGNIZANT AGENCY
NEGOTIATION AGREEMENT

State of Texas
Water Development Board
Austin, Texas

Date: May 23, 2018

Filing Ref: July 6, 2017

The indirect cost rates contained herein are for use on grants and contracts with the Federal Government to which 2 CFR Part 200 applies, subject to the limitations contained in the Circular and in Section II, A below.

SECTION I: RATES

Type	Effective Period From	Effective Period To	Rate	Base
Fixed:				
Release Time	9/1/2018	8/31/2019	18.80%	(a)
Fringe Benefits	9/1/2018	8/31/2019	28.73%	(b)
Indirect Costs	9/1/2018	8/31/2019	51.06%	(b)

Basis for Application
(a) Chargeable salaries (direct salaries and wages excluding vacation, sick, holiday, and other paid absences).
(b) Direct salaries and wages including release time.

Treatment of Fringe Benefits: Release time (vacation, sick, holiday and all other absences) are recovered through the release time rate. Fringe benefits are included in the indirect cost rate listed above.

SECTION II: GENERAL

A. LIMITATIONS: The rates in this Agreement are subject to any statutory and administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the department/agency or allocated to the department/agency by an approved cost allocation plan were included in the indirect cost pool as finally accepted; such costs are legal obligations of the department/agency and are allowable under governing cost principles; (2) The same costs that have been treated as indirect costs have not been claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the department/agency which was used to establish the rates is not later found to be materially incomplete or inaccurate by the Federal Government. In such situations the rate(s) would be subject to renegotiation at the discretion of the Federal Government.

B. CHANGES. The fixed rate contained in this agreement is based on the organizational structure and the accounting system in effect at the time the proposal was submitted. Changes in the organizational structure or changes in the method of accounting for costs which affect the amount of reimbursement resulting from use of the rates in this agreement, require the prior approval of the authorized representative of the responsible negotiation agency. Failure to obtain such approval may result in subsequent audit disallowances.

C. THE FIXED RATES contained in this agreement are based on an estimate of the cost which will be incurred during the period for which the rate applies. When the actual costs for such a period have been determined, an adjustment will be made in the negotiation following such determination to compensate for the difference between the cost used to establish the fixed rates and that which would have been used were the actual costs known at the time.

D. NOTIFICATION TO FEDERAL AGENCIES: Copies of this document may be provided to other Federal agencies as a means of notifying them of the agreement contained herein.

E. SPECIAL REMARKS: Please confirm your acceptance of the terms of the indirect cost rate agreement by signing and returning this letter to me. Please retain a copy for your records.

ACCEPTANCE

The undersigned official warrants that he/she has the proper authority to execute this agreement on the behalf of the State Agency:

(Signature)

Rebecca Trevino
(Name)

Chief Financial Officer
(Title)

Texas Water Development Board
(Agency)

5.24.2018
(Date)

By the Federal Agency:

JACQUELINE SMITH Digitally signed by JACQUELINE SMITH Date: 2018.05.23 15:49:51 -04'00'
(Signature)

Jacqueline Smith, Rate Negotiator
Financial Analysis and
Oversight Service Center
U.S. Environmental
Protection Agency

Negotiated by: Jacqueline Smith
Telephone: (202) 564-5055

Design Review and Software Support for Open Water Evaporation Monitoring

Prepared for:
Texas Water Development Board

Prepared by:
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

March 2019

BACKGROUND INFORMATION:

Evaporation represents a key component of a lake's water budget. Historically, pan-based measurement methods have proven unreliable and systematically flawed. The Desert Research Institute (DRI) in Reno, NV has developed an approach to estimate open water evaporation by the aerodynamic mass transfer method using over water meteorological measurements collected via a buoy-based weather station. The purpose of this agreement is to provide assistance to the Texas Water Development Board related to installation of aerodynamic evaporation monitoring station.

ABOUT DRI

DRI is a recognized world leader in investigating the effects of natural and human-induced environmental change and advancing technologies aimed at assessing a changing planet. For more than 50 years DRI research faculty, students, and staff have applied scientific understanding to support the effective management of natural resources while meeting Nevada's needs for economic diversification and science-based educational opportunities. With more than 500 employees and two main campuses in Reno and Las Vegas, DRI serves as the non-profit environmental research arm of the Nevada System of Higher Education.

DRI's faculty members are non-tenured, entrepreneurial and responsible for their own salaries from external grants and contracts. This blend of academic rigor and private-sector pragmatism has earned DRI a reputation for delivering rapid, high quality environmental science in a businesslike fashion.

SCOPE OF WORK:

DRI will serve in an advisory capacity to the Texas Water Development Board to assist with the design and implementation of near-real time reservoir evaporation monitoring by the aerodynamic mass transfer method. Specifically, DRI will provide design review related to buoy fabrication, environmental sensor selection, and datalogger programming and set-up. Additionally, DRI will provide python-based scripts to estimate reservoir evaporation via the aerodynamic mass transfer approach. DRI will assist with general set-up and execution of the aerodynamic code-base for near-real time application and presentation.

PROPOSED BUDGET:

Desert Research Institute Cost Estimate

Sponsor: Texas Water Development Board

Title: Design and Software Support for Aerodynamic Open Water Evaporation Estimates

Period of Performance: 10/2019-9/2020

Principal Investigator: C. Pearson

		System Design Review		Code Transfer and Software Support		TOTAL PROJECT	
	Rate (hr)	Units	Amount	Units	Amount	Units	Amount
PERSONNEL							
Pearson, Chris	95.06	20	1,901	40	3,802	60	5,704
TOTAL PERSONNEL			1,901		3,802		5,704
TOTAL COST			**1,901**		**3,802**		**5,704**

Consultants, LLC

To whom it may concern,

This is a quote for budgetary use only subject to terms and conditions between Agua del Sol Consultants (ADSC) and Texas Water Development Board (TWDB) for TWDB's fulfilment of Bureau of Reclamation grant BOR-DO-19-F003. ADSC will install a Collison Floating Evaporation Pan (CFEP) on Twin Buttes Reservoir, TX and monitor, maintain, and perform quarterly hemispherical validation tests starting October 1, 2019 and ending September 30, 2021. TWDB will provide site access and any necessary permits. ADSC will provide TWDB quarterly reports of QA/QC data within 3 weeks of the end of each quarter. The costs and fees below are based on the estimated 8-10 site visits per year, with each site visit lasting between 4-7 days. Salary costs will cover field technician site visits and hydrologists costs for performing QA/QC on the collected data.

	Year 1	Year 2
	10/01/2019-09/30/2020	10/01/2020-09/30/2021
Cell Modem on Pan	$ 1,000	$ 1,000
Camper Usage Fee	$ 5,000	$ 5,000
Boat Usage Fee	$ 5,000	$ 5,000
Truck Usage Fee	$ 5,000	$ 5,000
Mileage, Gas ($0.58/mile)	$ 6,000	$ 6,000
M&E for Site Visits	$ 4,000	$ 4,000
Salary	$ 24,000	$ 24,000
Facilities and Administrative %	10%	10%
Facilities and Administrative Cost	$ 5,000	$ 5,000
Total Yearly Budget	$ 55,000	$ 55,000

Agua del Sol Consultants is dedicated to providing turn-key solutions for accurate and precise open-water evaporation measurements for our clients.

Sincerely,

Jake Collison
Agua del Sol Consultants

Po Box 92797 • Albuquerque, New Mexico 87199

505-270-4360 • jake@aguadelsol.org