WaterSMART Applied Science Grant Application

Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Reclamation's Lake Thunderbird, Oklahoma

Lake Thunderbird Spillway Intake, 2013

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Technical proposal and Evaluation criteria

Executive Summary

1) Project Title

Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Reclamation's Lake Thunderbird, Oklahoma

Applicant	Eligible Project Type	Region	State	Requested Funding	In-Kind Contributions
cbalcombe @usbr.gov	Type I – Using Improved Modeling Tool Type II – Using Improved Water & Sediment	Arkansas-Rio Grande-Texas Gulf	TX	$200,000 (82%)	$45,055 (18%)

2) Project Summary

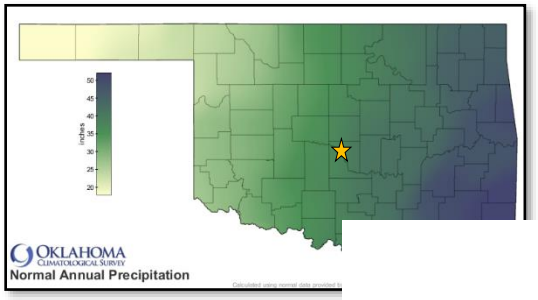

Figure 1. Precipitation gradient across the state. Yellow star denotes Lake Thunderbird.

Reclamation maintains ownership and has oversight responsibilities of the Norman Project (Lake Thunderbird) (Figure 1). Lake Thunderbird is managed by the Central Oklahoma Master Conservancy District (COMCD) under a repayment/O&M contract with Reclamation. COMCD is responsible for protecting water supplies and day-to-day operations and maintenance of the Norman Project. Lake Thunderbird provides municipal and industrial (M&I) water supplies to approximately ***250,000 people in three cities that make up the COMCD: Norman, Midwest City, and Del City***. Oklahoma is a state that is plagued by constant cycles of drought. Reclamation recently performed a supply analysis on Lake Thunderbird and found that the yield is not sufficient to deliver the full 21,600 acre-feet per year permitted water right during critical drought periods. In fact, during a repeat of the 1950s ***drought of record (DOR)***, Reclamation found that the reservoir can only supply 10,400 acre-ft per year, ***which is less than 50 percent of its permitted volume***. This volume is insufficient to meet the combined demands of the three member cities. Norman, whose needs are particularly pressing, has and continues to utilize its entire water right allocation on an annual basis, and this will only worsen as its demands are expected to double over the next 40 years. Given Reclamation's recent findings, COMCD is asking ***three very important questions***: (1) What are the chances that the next drought may be worse than the three critical droughts observed on record, and if the next drought is worse, how severe could it be?; (2) Depending on the drought, how much would deliveries from Lake Thunderbird need to be curtailed in order to prevent the reservoir from going dry?; (3) Are there preferred thresholds COMCD could or should use to curtail deliveries or to augment Lake Thunderbird storage?; and (4) How do the results above affect COMCD's decisions related to new investments in supplemental supplies?

This project will build on previous work completed under Reclamation's Reservoir Operations Pilot Program and ongoing Applied Science work in Texas to develop an ***"Enhanced Drought Response and Reservoir Operations (EDRRO) Model"*** for Lake Thunderbird. The EDRRO

Model will simulate reservoir yield under a range of called "***paleo-droughts***" that are known to have occurred (but not directly observed) over centuries based on data collected from tree rings. The EDRRO Model also will evaluate "what if" demand management scenarios and identify the associated risks of Lake Thunderbird going dry based on the type of drought you may be experiencing. Next, the project will build on work from the ongoing ***Upper Red River Basin Study (URRBS)*** to identify a range of ***"Drought Response Thresholds" (DRTs)*** that that could be used to trigger response actions during a drought. A DRT is comprised of one or more drought indicators [e.g., reservoir storage, inflow, Palmer Drought Severity Index (PDSI), etc.] and a range of thresholds for that indicator (e.g., reservoir storage < 70 percent full; inflow < 15,000 acre-ft; or PDSI < -1.0). For the URRBS, a range of DRTs were developed by study partners as an adaptive strategy to curtail basin-wide "junior" streamwater rights that are permitted under Oklahoma's Prior Appropriation Doctrine (i.e., "first in time – first in right"). This applied science study will apply the same statistical approach developed for the URRBS to Lake Thunderbird, but the focus will be on informing a broad set of drought response actions by users of Lake Thunderbird users as opposed basin-wide stream permit management as in the case of the URRBS. Ultimately, study findings will be used by the COMCD to develop a future ***drought contingency plan*** that will be funded as a separate activity.

As a testament to this project's credibility and potential value to Oklahoma, the state of Oklahoma's lead water planning and financing agency, the ***Oklahoma Water Resources Board (OWRB), is a collaborator*** on this effort. The OWRB is one of the key study partners in the URRBS and was a major contributor to the methods developed to develop and test DRT performance as part of the URRBS. In partnering with the OWRB, the project will provide a test case by which OWRB and Reclamation can collaboratively apply the URRBS approach to Lake Thunderbird and support drought response planning at the local level.

3) Performance Period: *January 2022 to December 2023*

Statement of Work

This study consists of seven main tasks. Details are provided under Criterion C below.
Task 1 – Establish objectives and compile reservoir/basin-specific data
Task 2 – Develop an EDRRO Model for Lake Thunderbird
Task 3 – Evaluate Baseline Reservoir Inflow Scenarios Assuming No Drought Response Actions
Task 4 – Identify Drought Response Indicators and Thresholds
Task 5 – Identify Planning Scenarios
Task 6 – Evaluate Impacts of Drought Response Indicators-Thresholds on Water Availability
Task 7 – Document and Disseminate Results

1) Data Management: *See Criterion C.8.*

Project Team

1) Reclamation Team

Oklahoma-Texas Area Office (OTAO) – Lead Office (**in-kind contribution: $19,690**)

- **Oversight:** Collins Balcombe (Supervisor, Planning & Project Development Division)

- **Management:** Anna Hoag, P.E.; (Civil Engineer)
- **Tasks 1-3:** Anna Hoag
- **Task 4-7:** Collins Balcombe; Anna Hoag
- **Peer Review**: Matthew Warren, P.E. (Supervisor, Engineering & Infrastructure Services Division) and James Allard, P.E. (Deputy Area Manager)

Technical Services Center (TSC)

- **Task 2-4, 7:** Subhrendu Gangopadhyay, Ph.D., P.E. (Civil Engineer, Water Resources Engineering & Management)

2) Reservoir Partners Team (in-kind contribution: $14,400)

- **Task 1, 3, 5, 7:**
  - Kyle Arthur, Manager, Central Oklahoma Master Conservancy District (COMCD)
  - Chris Mattingly, Utility Director, City of Norman
  - Geri Wellborn, Plant Manager, City of Norman
  - Paul Streets, Director of Public Works, City of Midwest City
  - Jay Snapp, Plant Manager, City of Del City

3) Oklahoma Water Development Board (OWRB) Team (in-kind contribution: $10,965)

- **Tasks 4:**
  - Chris Neel, Chief of Water Rights and Administration Division
  - Elise Sherrod, Environmental Programs Specialist in the Water Rights and Administration Division

Evaluation Criteria

Criterion A: Project Benefits (30 Points)

1) Benefits to Reservoir Operations and Water Deliveries

The primary objective of this investigation is to benefit ***reservoir operations and water deliveries***. Norman Project (Lake Thunderbird) is a Reclamation project constructed in the early 1960s. As a "transferred work"[1], Lake Thunderbird is managed in partnership with ***Central Oklahoma Master Conservancy District (COMCD)*** which has repayment/O&M contractual responsibilities with Reclamation to protect water supplies and operate and maintain the reservoir and associated infrastructure. COMCD holds a M&I water right of 21,600 acre-ft/yr out of Lake Thunderbird. This water right is allocated among COMCD's three member entities: Norman 9,460 acre-ft/yr (44%), Midwest City 8,730 acre-ft/yr (40%), and Del City 3,410 acre-ft/yr (16%). Together, ***250,000 people within the three cities depend on Lake Thunderbird as their principal supply source.*** The proposed project will provide a ***quantified, scenario-based risk analysis*** of Lake Thunderbird's supply; as well, it will identify ***Drought Response Thresholds (DRTs***) that can inform decision-making on how to operate Lake Thunderbird and manage water deliveries to prevent the reservoir from going dry under the various supply risk scenarios. Sustaining Lake Thunderbird during critical drought periods will provide a sizeable

[1] Transferred works are operated and maintained by a local managing entity/partner under contract with Reclamation who generally maintains all or some ownership of multi-purpose infrastructure.

economic benefit to the cities that depend on Lake Thunderbird. The supply information also will be critical towards helping stakeholders identify the role Lake Thunderbird plays relative to alternative supplies (e.g., groundwater, out-of-basin water purchases) that either are or may be available to COMCD as part of its larger supply portfolio. This can inform ***future investments*** in new water supplies in terms. The DRTs will provide water users with much-needed predictability in an otherwise unpredictable environment; for example, in a recent drought between 2010-2015, water users were surprised by a water delivery curtailment notice given by COMCD, the basis of which was somewhat vague. The COMCD has since hired a new general manager who is adopting a forward-thinking approach that includes garnering support by its member entities to proactively identify drought response trigger points. By having a set of ***pre-determined trigger points***, COMCD and its customers would have a predictable, agreed-upon mechanism by which to ***inform delivery curtailments***. Furthermore, the trigger points can inform the timing and magnitude of supply augmentation projects (e.g., mixing treated wastewater effluent with water stored in Lake Thunderbird) that are currently being contemplated.

As discussed under No. 3 below, benefits of this project also will result to ***recreation, fish, and wildlife***. Like most Reclamation reservoirs across the west, Lake Thunderbird provides multi-purpose benefits such as M&I supply, recreation, fish and wildlife, and flood control. Having a better understanding of Lake Thunderbird's supply, as well as thresholds to either curtail deliveries or augment the reservoir, will enhance reservoir storage and improve recreation and fish and wildlife benefits during critical drought periods when storage is needed the most. In addition to multi-purpose project benefits, Reclamation has an interest in preserving single-purpose M&I benefits because doing so can ***facilitate project repayment*** (in the case of transferred works). Finally, Reclamation's collaborative partnership with COMCD promotes an overall spirit of collaboration and positive stewardship of water and land resources that benefits Reclamation, COMCD, and its customers not only technically and economically, but politically as well.

2) Connecting to the Objectives

a) Support decision-making under uncertain hydrologic conditions

Reclamation recently performed a yield analysis on Lake Thunderbird and found that while the yield is sufficient to deliver the full 21,600 acre-ft/yr water right during most years, the yield is ***not sufficient during three critical drought periods*** (1930s, 1950s, and 1960s) (**Error! Reference source not found.**). While the 1950s DOR resulted in the largest cumulative shortage of 11,200 acre-ft[2] (Figure 3), during 1960s drought, the greatest single-year shortage was 10,400 acre-ft in 1966; this is less than 50 percent of its permitted volume. Permit volume aside, the availability of water is far less than what is currently being used and what is expected to be needed based on future demand projections. Over the last decade, Norman has exceeded its allocation multiple times, and the three cities usage together ranged from 72% to 82% of their total 21,600 acre-ft/yr water right (Table 1). This usage, for example, would exceed the supply that would be available under a repeat of 1966 conditions by 5,200 acre-ft (***33% deficit***) and 7,400 acre-ft (***42% deficit***), respectively. The situation will only worsen as cumulative demands

[2] 21,600 acre-ft/yr permit minus 10,400 acre-ft/yr, which is what could be delivered

of the three member cities is projected to be about 33,000 acre-ft/yr by the year 2060[3], which is ***three times the volume*** available under a repeat of 1966 conditions.

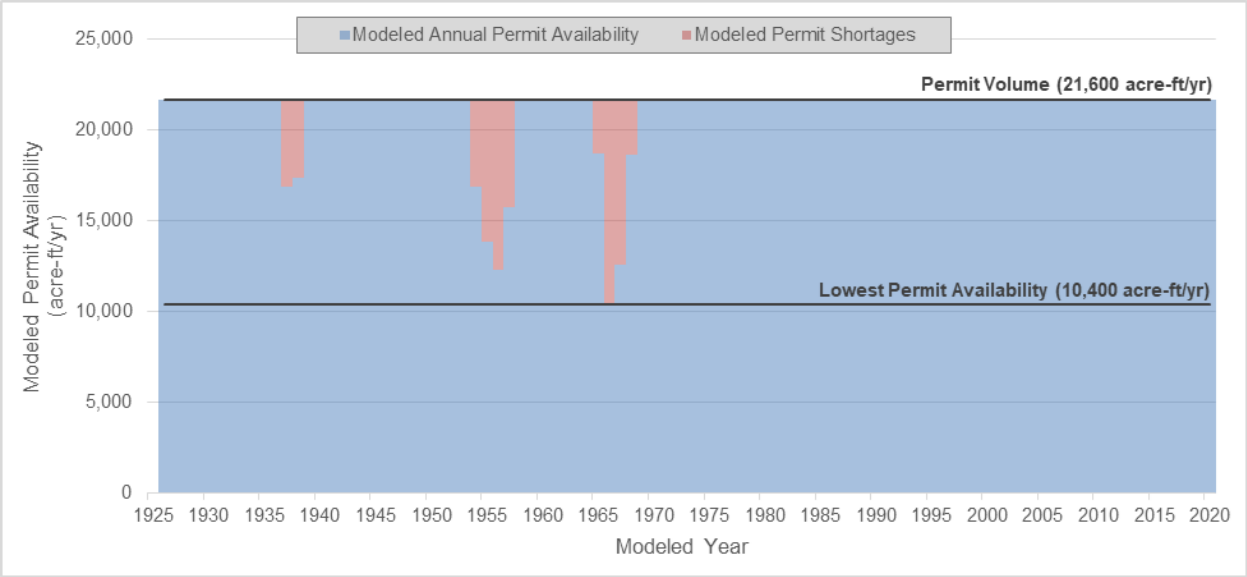

Figure 2. Volume of modeled permit availability and permit shortages over the 95-year model period, 2065 sediment conditions.

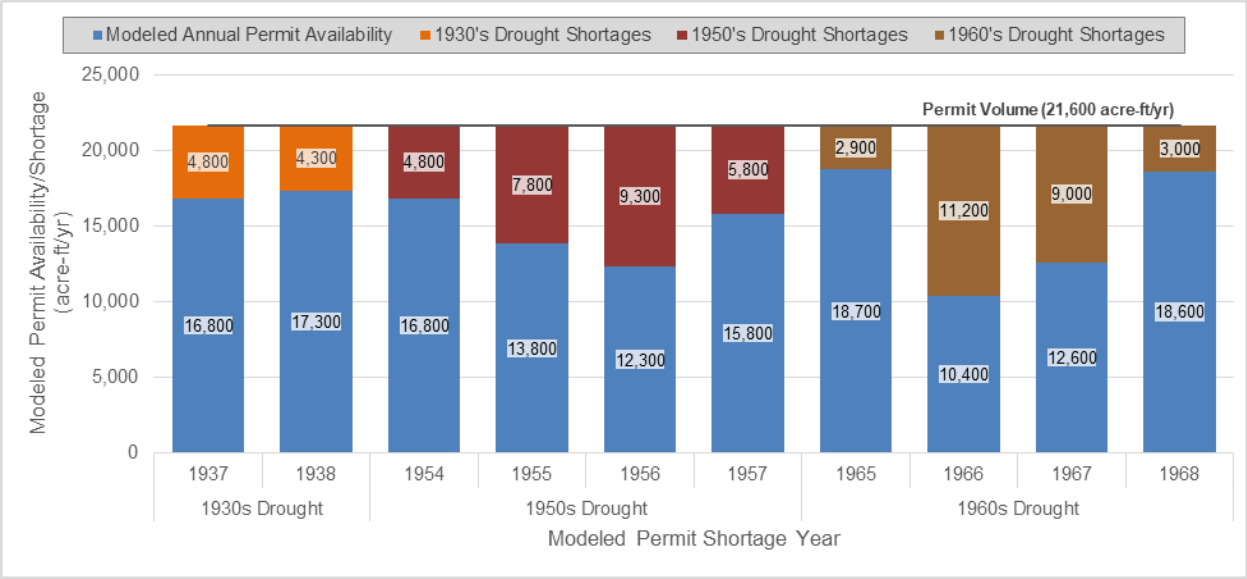

Figure 3. Volume of permit water shortages (orange/red/brown) and availability (blue) during the ten years when permit shortages occurred over the 95-year model period, 2065 sediment conditions.

[3] Oklahoma Comprehensive Water Plan Update (2012)

Table 1. Water deliveries from Reclamation's Lake Thunderbird (2011 to 2020). Black bold font denotes years 95% of the allocation was met or exceeded. Red bold font denotes years the full allocation was met or exceeded.

Reclamation Reservoir Water Deliveries Lake Thunderbird (acre-ft/yr / percent of allocation)				
Year	Norman	Midwest City	Del City	Total
2011	8,800 / 93%	6,900 / 79%	1,700 / 50%	17,300 / 80%
2012	**9,200 / 97%**	6,100 / 70%	1,700 / 50%	17,000 / 79%
2013	**9,300 / 98%**	5,100 / 58%	1,300 / 38%	15,600 / 72%
2014	**10,600 / 112%**	4,800 / 55%	1,300 / 38%	16,700 / 77%
2015	**9,400 / 99%**	5,000 / 57%	1,500 / 44%	16,000 / 74%
2016	**9,100 / 96%**	5,600 / 64%	1,400 / 41%	16,100 / 75%
2017	**9,000 / 95%**	6,500 / 74%	1,400 / 41%	16,900 / 78%
2018	8,800 / 93%	5,700 / 65%	1,400 / 41%	15,900 / 74%
2019	**11,100 / 117%**	5,300 / 61%	1,400 / 41%	17,800 / 82%
2020	**10,200 / 108%**	5,100 / 58%	1,300 / 38%	16,600 / 77%

The findings noted above has left COMCD asking the following questions:

1. What are the chances that the next drought may be worse than the three critical droughts observed on record? If the next drought is worse, how severe could it be? And how would this affect Lake Thunderbird storage availability?
2. Depending on the drought, how much would deliveries from Lake Thunderbird need to be curtailed in order to prevent the reservoir from going dry?
3. Are there preferred thresholds COMCD could or should use to curtail deliveries or to augment Lake Thunderbird storage?
4. How do the results above affect COMCD's decisions related to new investments in supplemental supplies?

This project will develop a tool and framework for answering these questions. Beginning with ***Questions 1 & 2,*** if one compares observed ***Palmer Drought Severity Index (PDSI)*** alongside PDSI reconstructed over a 600-year period using tree ring data, it becomes evident that the droughts observed over the relatively short 95-year period are far less severe than the so called "paleo droughts" that have occurred throughout the last millennium[4]. This project will develop an ***"Enhanced Drought Response and Reservoir Operations (EDRRO) Model"*** that uses these data to develop a probability distribution of reservoir yield estimates, enabling a quantifiable assessment of supply reliability risk ("risk exposure") for Reclamation's Lake Thunderbird. For example, the Reservoir Operations Pilot Study on Reclamation's Washita Basin Project (Reclamation, 2018[5]) used a stochastic resampling methodology to generate inflow sequences of over 1,000 paleo droughts, which in turn, generated a like number of reservoir yield projections for two case study reservoirs in Oklahoma. When comparing known yields that occurred during the DOR with the calculated reservoir yields under paleo droughts, the study found that the firm yield of Fort Cobb and Foss Reservoirs were actually only ***90 percent and 70 percent firm***, respectively (Figure 4 for Foss Reservoir). In other words, their ***risk exposure (i.e., risk of going dry) was 10 and 30 percent***, respectively.

[4] Cook, E.R., et al. 2004. North American Summer PDSI Reconstructions, IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2004-045, NOAA/NGDC Paleoclimatology Program, Boulder CO; URL to access data, ftp://ftp.ncdc.noaa.gov/pub/data/paleo/drought/pdsi2004/.

[5] United States Bureau of Reclamation. (2018). Reservoir Operations Pilot Study, Washita Basin Project, Oklahoma. https://www.usbr.gov/watersmart/pilots/docs/reports/Final_Reservoir_Operations_Pilot_Report-Washita_Basin_Project_OK.pdf

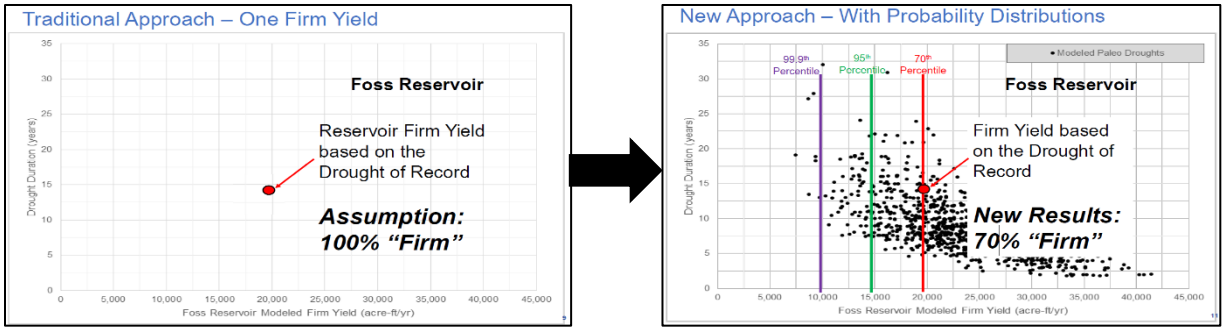

Figure 4. Before the EDRRO Model, Foss Reservoir firm yield assumed to be 18,000 acre-ft/yr is based on the observed DOR. The EDRRO Model simulation of yield under 1,000 paleo drought scenarios indicates that 18,000 acre-ft/yr is, in fact, only 70% firm. The colored lines (right graphic) correspond to reservoir yields that result when exposed to paleo droughts of three alternative sample risk exposure levels (results from Reclamation, 2018).

How would this benefit a water manager planning ahead to ensure predictable, reliable supplies? Understanding reservoir risk exposure can inform ***long-term investments*** (e.g., building a supplemental supply) and ***drought contingency planning*** (e.g., demand management). It does this by framing an understanding on ***"risk tolerance"***. Risk tolerance is a measure of how reliable the supply needs to be. In the case cited above, is 10 and 30 percent an acceptable level of risk? Tolerance is driven both by the amount and type of users and by the availability of supplemental supplies. If water deliveries are primarily for residential lawn irrigation, risk tolerance may be higher relative to a situation where deliveries are largely for manufacturing – or for compact or biological opinion compliance. Risk tolerance also is driven by the availability of supplemental supplies. For drought planning purposes, the EDRRO Model helps identify ***the extent to which a gap exists between risk exposure and risk tolerance,*** which provide a signal for actions to be taken to mitigate those risks and improve reliability of long-term water deliveries. If a gap does *not* exist, officials may have a sustainable supply. If a gap *does* exist, steps to mitigate likely depend on the size of the gap. In some cases, demand management alone (taken through drought contingency planning) can close the gap. In other cases, even with aggressive demand management, a gap still exists, and actions may be needed to secure supplemental supplies to ensure predictable, reliable deliveries - although now ***a manager has a quantifiable basis to inform these investments, which can be extremely important because investments are often costly, both financially and politically***. For example, recall above that in Reclamation (2018), risk exposure at Foss Reservoir was found to be 30 percent. Believing this to be unacceptable, in planning for the next drought, ***stakeholders selected a risk tolerance of 5.0 to 0.1 percent***, meaning that they wanted to be 95 to 99.9 percent "sure" that the paleo drought they plan for would not be surpassed by an even worse drought. The risk tolerance selected provided a conservative range of the most severe paleo drought scenarios, which if properly planned for, would pose the most minimal chance of the reservoirs going dry. As expected, Reclamation (2018) found that to withstand these paleo droughts, significant demand curtailments (***up to 66 percent***) would be required (Figure 4). Armed with an understanding of

the magnitude and frequency of these curtailments, stakeholders now had a framework for improved drought contingency planning to assess who, what, when, where, and how demand curtailments can be managed to achieve win-win outcomes.

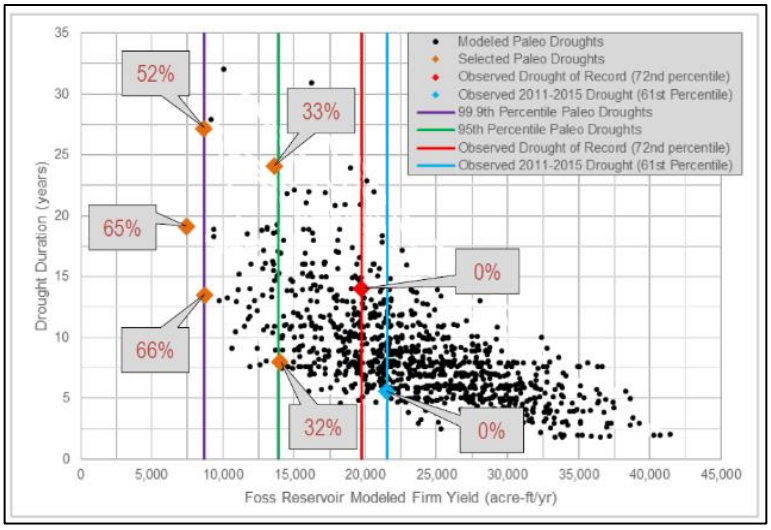

Figure 5. Percent demand curtailments (gray boxes) needed under to prevent water shortages at Foss Reservoir under seven drought scenarios simulated using the EDRRO Model; assumes full permitted demands (Reclamation, 2018)

COMCD will benefit from this type of analysis because unlike the Oklahoma case studies cited above, Lake Thunderbird is unable to deliver either current demands or the full permitted water right under the DOR without strategic and proactive supply/demand management. The EDRRO model will not only provide the quantitative risk analysis needed, it also can be used to simulate how ***DRTs can sustain reservoir storage through a range of critical drought periods***. The question noted under No. 1: *How do other available supplies play into these deliveries*, ***remains unanswered*** in the context of the need and benefit of the EDRRO Model. This is one of the biggest challenges (and benefits!) to developing an EDRRO Model for Reclamation's reservoir.

Regarding ***Question No. 3*** above, a famous quote by World War II supreme allied commander Dwight D. Eisenhower is worth noting: "*plans are useless, but planning is indispensable*". While a key strength of the EDRRO model lies with its capabilities of making more informed predictions about future long-term supplies and risk, the reality is, when the next drought comes, an additional benefit of the EDRRO model lies in its ability to simulate demand management strategies to ensure reliability of current water deliveries to COMCD's customers. In effect, the EDRRO Model is enhancing drought response as a redundancy measure to mitigate any uncertainty left with enhanced drought preparedness. The EDRRO Model can incorporate predetermined reservoir elevation triggers (i.e., DRTs) such as Watch, Warning, and Emergency Levels, that can be used to test how various delivery curtailments can affect reservoir storage and prevent shortages under a ***drought contingency planning framework***[6]. Another key challenge (and benefit!) of this project will be incorporating supplemental supply sources into the EDRRO Model's drought response interface. Case in point: Norman is currently evaluating the merits of mixing highly treated wastewater effluent with stored water in Lake Thunderbird to improve supply reliability.

[6] The COMCD plans to develop a drought contingency plan using the results of this applied science study, but to be clear, this project would not include development of the drought contingency plan itself.

b) Increase the availability of data

This project will utilize the stochastic resampling methodology described in Prairie et al. (2008)[7] to develop ***new inflow sequences*** that will be run in the EDRRO Model to simulate reservoir yield. The Prairie et al. (2008) algorithm is a conditional Markov Chain (MC)[8] simulation framework that uses time varying (i.e., transient) transition probabilities and nonparametric K-nearest neighbor (K-NN) resampling to develop inflow sequences (Figure 5). In summary, this framework consists of three steps: (1) develop the transient transition probabilities from the reconstructed Palmer Modified Drought Index (PMDI)[9] data; (2) generate a hydrologic state to initialize (i.e., starting point) along with the selection of the transient transition probabilities for use in MC simulation; and (3) MC simulation to generate flows conditionally using K-NN resampling. A more detailed description of this method is provided in Prairie et al. (2008), where it is referred to as "***nonparametric paleoconditioning***".

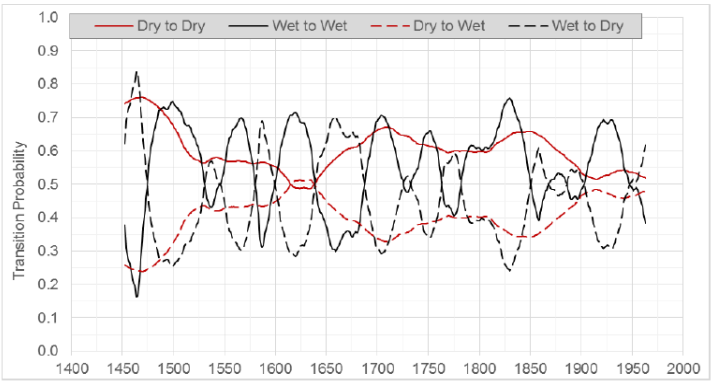

Figure 6. Two-state transient transition probability with four transitions derived from PDSI data (Reclamation, 2018).

c) Improve the ability to respond to stakeholder concerns

This project responds to ***COMCD and its member city's concerns*** about reducing uncertainty and making more informed, defensible water-related management decisions that ensure supply reliability during times when it is most needed and to the customers that need it most. What we have not discussed yet are concerns by another important stakeholder: ***Oklahoma Water Resources Board*** (OWRB). As a testament to the EDRRO Model's credibility and potential value to Oklahoma, the state of Oklahoma's lead water planning and financing agency, OWRB is an important collaborator on this effort. ***Reclamation's OTAO considers OWRB a key stakeholder*** because our respective missions and interests have tremendous overlap, prompting a long history of collaborative activities. In partnering with the OWRB, the project will provide a test case in helping state officials build technical capacity in the development of DRTs that could inform local water planning. To be clear, the OWRB does not have a desire or legal authority to require COMCD to implement DRTs or otherwise instruct COMCD how to operate Lake Thunderbird. Rather, the OWRB's interests are strictly technical in nature in terms of helping provide decision-support tools that improve water supply reliability.

3) Benefits to Recreation, Fish & Wildlife, Federally-Listed Species

Although the focus of this project is on improving reliability of M&I and irrigation deliveries, ancillary benefits would undoubtedly result to other Federally authorized benefits including recreation and fish and wildlife. Lake Thunderbird is a popular destination for hunting, boating, fishing, camping, etc. Lake Thunderbird, and associated lands, are designated as a ***State Park***

[7] Prairie, J., K. Nowak, B. Rajagopalan, U. Lall, and T. Fulp. 2008. A stochastic nonparametric approach for streamflow generation combining observational and paleoreconstructed data, Water Resources Research, 44, W06423, doi:10.1029/2007WR006684
[8] Haan, C.T. 1977. Statistical Methods in Hydrology, the Iowa State University Press, Ames, IA, 378 pp.
[9] Cook, E.R., Seager, R., Heim, R.R., Vose, R.S., Herweijer, C., and Woodhouse, C. (2010). Megadroughts in North America: Placing IPCC projections of hydroclimatic change in a long-term paleoclimate context. Journal of Quaternary Science, 25(1), 48-61. doi: 10.1002/jqs.1303

that are managed by the Oklahoma Tourism and Recreation Department. Lake Thunderbird State Park is one of the most visited parks in the state of Oklahoma. In the last five years alone (2016-2020), the ***state park has hosted ~5.3 million visitors and generated ~$5.7 million in revenue***[10]. Indeed, advancing this project would lead to better management of reservoir storage during critical droughts when the reservoir centered recreation benefits are needed most. Lake Thunderbird State Park provide substantial fish habitat with ~5,500 surface area, ~7,944 acres of state park and wildlife habitat[11]. It also supports a number of federally listed species, including the piping plover *(Charadrius melodus)*, red knot *(Calidris canutus rufa)*, and whooping crane *(Grus americana)*[12].

Criterion B: Project Relevancy: Need for Project and Applicability of Project Results and Project Fit with Program Priorities (30 Points)

1) Explain how your project will result in readily useful applied science tool(s) that meet an existing need

a) Project Need and Urgency

As discussed above, based on recent water usage of COMCD customers, under a repeat of 1960s drought conditions, ***demands exceed supply by between 33% and 42%***. Recognizing the inevitability of a recurrence of such a severe drought, ***the water supply need is significant and immediate***. With cumulative demands of the three member cities projected to triple by the year 2060[13], the situation becomes even more dire. Worse yet, it is reasonable to assume that this need grossly underestimates the supply imbalance that would occur under a 30-50 year paleo drought. Returning to our previous example, Foss Reservoir's firm yield under the DOR was 19,700 acre-ft/yr. Reclamation (2018) found that the Foss Reservoir's firm yield could be 30 percent (14,000 acre-ft/yr; 95th percentile/five percent occurrence) to 70 percent lower (7,400 acre-ft/yr; 99.9th percentile/0.1 percent occurrence) depending on the severity (intensity/duration) of simulated paleo droughts (recall that the observed DOR for Foss fell within the 70th percentile/30 percent occurrence). These findings have proven to be of tremendous value to managers of Foss Reservoir. ***A need exists*** to apply the same methodology to quantify water availability risk of Lake Thunderbird. Adding the DRT analysis and the resulting curtailment triggers into the equation will make the tool that much more powerful and applicable to COMCD and beyond.

b) Immediacy of Tool Application

The data provided by this project will be ready for application immediately upon completion. In fact, the COMCD is applying for a FY 22 ***Drought Contingency Planning (DCP)*** grant under Reclamaiton's WaterSMART program that, if awarded, would be used to develop a DCP concurrently with this project. The DCP will include the supply and DRT analyses developed through this project. In Oklahoma, as opposed to many other states, wholesale water suppliers, irrigation districts, and retail water suppliers are not required to maintain a drought contingency plan that describes response actions that entities will/could take during critical droughts. The basis for establishing thresholds that trigger response actions vary tremendously, and when the

[10] Reported annually as part of Recreation Use Data Report (RUDR).
[11] Lake Thunderbird State Park Resource Management Plan, Oklahoma State University, 2019
[12] US Fish and Wildlife Service IPac 9-21-2021
[13] Oklahoma Comprehensive Water Plan Update (2012)

onset of drought appears imminent, challenges with near-term forecasting complicate efforts to predict the severity of the drought and to react accordingly. ***A need exists*** to incorporate real-time storage and water use and to test how various delivery curtailments affect reservoir storage and prevent shortages under a ***drought contingency planning framework***. For example, Reclamation (2018) found that 84 months into a hypothetical drought, a 45 percent demand reduction would be needed to sustain reservoir storage under even the most severe paleo drought scenario (Figure 7). COMCD recognizes the need for this type of proactive and informed approach and intends to integrate the information obtained in this project to into the development of a drought contingency plan. COMCD has demonstrated the immediacy of this project by prioritizing it submitting a grant proposal to Reclamation for the development of a Drought Contingency Plan.

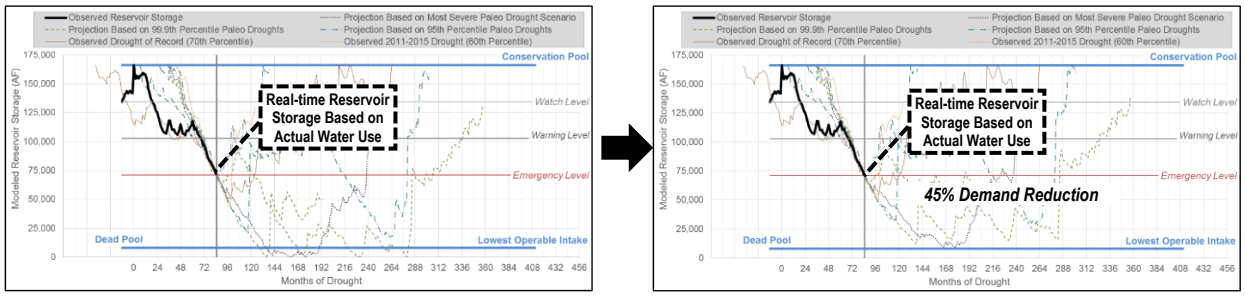

Figure 7. Modeled Reservoir Storage interface of the EDRRO model. This interface illustrates how Watch, Warning, and Emergency thresholds can be used during a drought to curtail demands based on drought-scenario projections to maximize use of the reservoir and prevent shortages (Reclamation, 2018).

c) Applicability to other Reclamation offices and/or water managers within service area

This project has broad applicability to any decisionmaker that depends on a reservoir as part of its water supply portfolio. Reclamation currently delivers M&I water supplies to an estimated 31 million people. This need will expand substantially by 2060, which highlights the applicability of developing a tool and decision framework that helps ensure reliable water deliveries during severe droughts that could be worse than the observed DOR. During OTAO's Reservoir Operations Pilot briefing with ***Commissioner Brenda Burman***, she acknowledged the importance of meeting M&I deliveries, but also stressed how the EDRRO Model and risk assessment framework could be applied towards meeting other types of mission-critical obligations, namely those related to Federally-listed species.

While many communities have developed drought contingency plans with associated curtailment goals, few have developed such a robust statistical analysis towards identification of DRTs. This project has applicability to provide a ***template for other communities to evaluate risk*** exposure and to identify and test DRTs to reduce risk to an acceptable level.

2) Project fit with program priorities and project eligibility criteria.

a) Will the project increase technical capacity?

1. This Project will apply a new-and-improved tool/approach by building and adding value to existing applied science tools and/or water resources information currently used. OTAO's traditional approach has been to use its Reservoir Yield Model to calculate a single firm yield estimate based on the observed DOR. The EDRRO Model is essentially a ***"new and improved"*** version of this existing model, but much more powerful.

2. This EDRRO Model will increase the technical capacity of Reclamation's Project Operating Partners and stakeholders. The EDRRO Model will be ***open source tool*** available to the public. A key strength of the model lies not only with making informed predictions about water availability risk exposure, but in managing demands and system operations to ensure supply reliability while in the midst of the drought. It also could enhance and inform the vulnerability assessment and mitigation actions for drought contingency planning.
3. Development of DRTs will further build technical capacity at OTAO, TSC, and the OWRB. Reclamation and OWRB developed DRTs as part of the URRBS, but applying the statistical methods and approach to Lake Thunderbird would provide a ***valuable test case for replicating this approach for a different application***.
4. This Project will contribute to modernization or increased consistency across Reclamation's service area by extending the paleo-informed supply projections being developed under Reclamation's updated ***West-Wide Risk Assessment (WWRA) to Oklahoma***. The WWRA currently underway will incorporate the widely-available paleo-informed PMDI reconstructions in the supply projections of Reclamation's reservoirs across the major basins within our jurisdiction.
5. This Project will complement other similar efforts rather than duplicate or complicate those efforts. While the Reservoir Operations Pilot Project in Oklahoma focused on single-source reservoir systems, ***this effort will build upon the Pilot*** and develop and test drought thresholds. The project also will ***complement COCMD's future drought contingency planning efforts***. It also is worth noting how this project would complement efforts to quantify risks associated with future climate change. Over the past decade, there has been much work done in Oklahoma, Texas, and across the west using ***global climate models (GCMs)*** to project how changes in climate may affect future supplies[14]. Most of OTAO's reservoirs have climate change factors built into their long-range yield projections, much like Reclamation's reservoirs residing within the major river basins evaluated within our WWRA completed in 2011[15]. The use of GCMs continues to be a powerful tool in assessing potential water availability risks, yet research continues on how assumptions related to initial conditions, future greenhouse gases emissions, and atmospheric and ocean dynamics may affect future drought resiliency. That said, the use of tree rings has been garnering recent attention as another method to account for hydrologic uncertainty, and it ***should complement GCM projections to provide an even more comprehensive analysis of water availability risk***.

b) Will the project result in the application of a tool, method, or information?

This Project will result in the application of the EDRRO Model to quantify risk exposure for a Reclamation reservoir in central Oklahoma. Results can be ***applied immediately to enhance drought preparedness and response*** as discussed above in the Benefits Criterion. Following project completion, COMCD will take the risk exposure and drought threshold analysis and work with their member cities to develop a detailed drought contingency plan. This plan, including the DRTs that make up the plan, will provide a template for other communities within the state and across the country.

[14] Brekke, L. D., Pruitt, T., & Smith, D. (2010). Climate Change and Hydrology Scenarios for Oklahoma Yield Studies. US Department of the Interior, Bureau of Reclamation.
[15] United States Bureau of Reclamation. (2016). SECURE Water Act Section 9503(c) — Reclamation Climate Change and Water 2016. https://www.usbr.gov/climate/secure/docs/2016secure/2016SECUREReport.pdf

Criterion C: Project Implementation Plan and Likelihood of Success (20 Points)

1) Project Objectives

Policy/Management Objective: The overarching objective is to improve how we quantify risk exposure of water supplies during severe droughts by considering variations in climate beyond those observed on record. If risk estimates are too low, investments could be made in supplemental supplies to withstand a drought that may never come to fruition. If estimates are too high, it could lead to a false sense of security or inaction, and investments that should have been made to withstand a severe drought are overlooked. Once risk exposure is known, COMCD and its member cities can assess whether it is an acceptable risk, and if not, use these data to build consensus and justify investments that could be costly, both technically and politically. We will also test a variety of strategies, such as DRTs to determine the role of conservation and the integration of augmented supplies in improving Lake Thunderbird supply reliability for customers that depend on it.

Technical Objectives:

1. Develop an EDRRO Model for Lake Thunderbird using methods carried out by Reclamation (2018) that incorporate paleo-reconstructed PSDI data in the development of new reservoir inflow datasets based on a range of paleo droughts.
2. Identify drought indicators and response thresholds (i.e., DRTs) that could be used to trigger drought response actions.
3. Use the EDRRO Model to evaluate the impacts of "what if" supply and demand management scenarios on operations, drought thresholds, and supply augmentation alternatives under a range of paleo drought scenarios, as well as the observed critical drought periods.

2) Project Workplan, Budget, and Timeline

See table on the next page.

3) Availability of Existing Data and Models

The existing EDRRO Models completed under Reclamation (2018) will provide the foundation to build the EDRRO Models for Lake Thunderbird. The Models the R programming language and Microsoft® Office Excel and have no licensing or accessibility limitations. No field measurements are required. All other data will be collected under Task 1 and are available as follows (sources indicated as in parentheses):

1. ***Paleo-reconstructed PSDI data***, with multiple grid points in TX (Cook et al., 2010; National Oceanic Atmospheric Administration; Figure 8[16]).

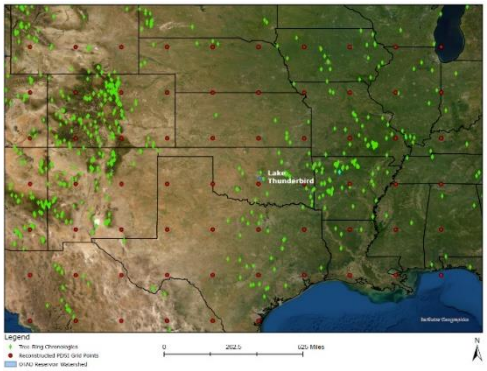

Figure 8. Reconstructed PDSI grid points relative to Reclamation's reservoirs and watersheds in Texas. Tree-Ring Chronologies illustrated by green diamonds.

[16] This figure illustrates tree-ring chronologies found in Cook et al. (2004). This project will use finer resolution grid points of tree-ring chronologies developed in developed in Cook et al. (2010).

Proposed Tasks	FY2022 2Q	3Q	4Q	FY2023 1Q	2Q	3Q	4Q	24 1Q	Total Cost
Task 1 – Establish planning objectives and compile reservoir/basin-specific data (Reclamation, COMCD, member cities)									
a) Host kickoff meeting.									$6,320
b) Meet with COMCD to identify needs and planning objectives; water supply portfolios; and planning/operational considerations Lake Thunderbird.									$11,360
c) Collect/update reservoir supply data including but not limited to precipitation, evaporation, sedimentation; reservoir releases; seepage; streamflow; inflow; and paleo-reconstructed Palmer Modified Drought Index (PMDI) data.									$3,840
Task 2 – Develop EDRRO Model for Lake Thunderbird (Reclamation)									
a) Use the observed, historical period of record and available tree-ring-reconstructed PMDI data (potentially starting year 1400) to develop a range of reservoir inflow sequences that correspond to various paleo drought scenarios. The stochastic resampling methodology used to develop inflow sequences will follow the algorithm described in Prairie et al. (2008).									$14,080
b) Develop reservoir platform based on physical conditions and limitations.									$8,960
c) Develop a demand platform that will be able to adjust water use based on maximum reliable reservoir supply available under varying hydrologic conditions, as well as supply availability from other sources such as groundwater or IPR.									$10,160
Task 3 – Evaluate Baseline Reservoir Inflow Scenarios Assuming No Drought Response Actions (Reclamation)									
a) Use the observed hydrologic record alone to simulate Lake Thunderbird firm yield and availability of the full permitted volume of 21,600 acre-ft/yr.									$1,280
b) Use a large number (1,000+) of paleo inflow sequences to simulate Lake Thunderbird firm yield and permit availability.									$7,680
c) Quantify probability distribution of reservoir firm yield and magnitude and frequency of permit shortages.									$6,400
Task 4 – Identify Drought Response Thresholds (DRTs) (Reclamation and OWRB)									
a) Identify range of indicators (e.g., reservoir storage, inflow, PDSI, etc.) and thresholds that could be used to trigger drought response actions.									$3,931
b) Identify range of drought scenarios for indicator-threshold performance testing. A minimum of ten drought definitions would be selected.									$17,003
c) Evaluate indicator-threshold performance in terms of predicting observed, historical droughts.									$15,541
d) Select best performing drought response indicator-threshold combinations for further analysis.									$11,611
Task 5 – Identify Planning Scenarios (Reclamation, COMCD, member cities)									
a) Select paleo inflow sequences and demand scenarios that address planning needs and risk tolerance of COMCD and member entities. For example, inflow sequences that contain the 99th, 95th, and/or 90th percentile droughts may be									$6,920

Proposed Tasks	FY2022 2Q	3Q	4Q	FY2023 1Q	2Q	3Q	4Q	24 1Q	Total Cost
selected, as well as sequences that capture high intensity-short duration droughts and low intensity-long duration droughts. The observed period of record also will be selected for comparison. Demand scenarios may include historic use, peak use, and full permitted use.									
Task 6 – Evaluate Impacts of Drought Response Thresholds on Water Availability (Reclamation, COMCD, member cities)									
a) Evaluate impacts of drought response indicator-threshold combinations on Lake Thunderbird storage under the range of inflow and demand scenarios selected in Task 5. Compare impacts to those from existing water conservation triggers that are currently in place, if applicable.									$5,120
b) Quantify reservoir demand curtailment percentages needed to prevent shortages (note: a shortage occurs when reservoir storage drops below inactive pool.									$6,400
b) Identify range of supplemental supply source scenarios (e.g., groundwater pumping and/or indirect potable reuse at a rate of A, B, or C). These supplies could be used in lieu of Lake Thunderbird depending on tolerance to reservoir curtailment percent.									$9,480
c) Host a demonstration for COMCD of various EDRRO Model runs. Model runs will include both drought preparedness and drought response scenarios. Determine if additional scenarios can be evaluated using the EDRRO Models.									$8,880
d) Run additional scenarios if needed after demonstration using the model.									$6,400
Task 7 – Document and Disseminate Results (Reclamation, COMCD, member cities)									
a) Prepare a draft Technical Memorandum (TM) that describes the need, constraints, methods, results, and findings.									$25,520
b) Perform a peer review of EDRRO Model and TM. The review would be considered "discretionary" in accordance with Reclamation D&S.									$12,800
c) Finalize and disseminate the TM to COMCD, member cities, and others.									$6,320
d) Develop and disseminate Summary Bulletin (similar to Operations Pilot bulletin).									$6,400
e) Prepare and deliver PowerPoint presentation to COMCD.									$10,080
g) Host a webinar internal to Reclamation in coordination with Policy & Administration, R&D, and TSC.									$6,400
h) Submit abstracts and give presentations at relevant Oklahoma-based conferences.									$2,560
i) Publish results in relevant peer-reviewed water journals.									$8,960
Travel associated with Task 1 and Task 7									$4,650
Total									**$245,055**

2. Use of ***stochastic resampling methodology*** to develop inflow sequences following algorithm described in Prairie et al. (2008), which is a conditional Markov Chain (MC)[17] simulation framework that uses time varying (i.e., transient) transition probabilities and nonparametric K-nearest neighbor (K-NN) resampling to develop inflow sequences
3. ***Lake Thunderbird data*** including but not limited to precipitation, evaporation, sedimentation; reservoir releases; seepage; streamflow; inflow (Hydromet; OTAO files/records; Reservoir Operating Partners)
4. ***The DRTs will be analyzed using proven atmospheric science methods used to test meteorological forecasting.***
5. ***Demand data*** including but not limited to historical population, water deliveries, and water use; projected population, water deliveries, and water use (U.S. Census; Oklahoma Comprehensive Water Plans; Reservoir Operating Partner and Member Cities).
6. ***Supply augmentation data*** including but not limited to indirect potable reuse estimates from the City of Norman (Reservoir Operation Partner and Member Cities).

4) Team credentials and qualifications

The majority of the work will be conducted in-house by Reclamation staff. The team has vast experience in project management, planning, engineering, and hydrologic modeling. Although numerous staff will be involved in various forms (see Reclamation Team above), a sample of the qualifications of key personnel on the Project Team are as follows:

1. ***Collins Balcombe*** (OTAO Supervisor, Planning & Project Development Division): 18 years of experience; oversees OTAO's water resources planning and environmental compliance activities, water conservation planning, drought management, tribal affairs, inter-state compacts; study manager of the Reservoir Operations Pilot Project; study manager of the Lower Rio Grande Valley and Republican River Basin Studies; current study manager of the Upper Red River and Upper Washita River Basin Studies; Science & Technology and Title XVI Coordinators for Missouri Basin and Arkansas-Rio Grande-Gulf Coast Regions; four peer-reviewed publications; Commissioner's Superior Service Award.
2. ***Subhrendu Gangopadhyay, Ph.D., P.E.*** (TSC Civil Engineer and Technical Lead, Water Resources Engineering & Management): 27 years of experience as a water resources engineer (Civil Engineer-Hydrologic) in academia, private, and public sectors; expertise in water resources planning and management, stochastic hydrology, applied statistics, hydroclimatology, numerical modeling in hydrology – surface and ground water, scientific computing, research and development, project management, operations management, teaching, and consulting; registered professional engineer in the states of Kentucky and Colorado; 36 peer-reviewed publications; Reclamation's 2014 Engineer of the Year Award.
3. ***Anna Hoag, P.E.***; (OTAO Civil Engineer): Eight years of experience and lead Hydrologist at OTAO; participated in dozens of planning and technical activities; lead modeler for the Reservoir Operations Pilot Project and ongoing Basin Studies in OK; expertise in reservoir operations and hydrologic modeling; co-investigator on seven Science & Technology research projects; registered professional engineer in the state of Oklahoma; Reclamation's 2019 Engineer of the Year Award.
4. ***Matthew Warren, P.E.*** (OTAO Supervisor, Engineering & Infrastructure Services Division); 17 years of experience; oversees OTAO dam safety and inspection programs, flood operations, emergency management, hydrology, design, and construction; served as an

[17] Haan, C.T. 1977. Statistical Methods in Hydrology, the Iowa State University Press, Ames, IA, 378 pp.

independent peer reviewer on the Reservoir Operations Pilot Project; registered professional engineer in the state of Oklahoma.

5. ***James Allard, P.E.*** (OTAO Deputy Area Manager): 32 years of experience; oversees all OTAO planning, infrastructure, engineering, and lands activities; has served/serves as an independent peer reviewer on most high-profile OTAO planning/modeling activities, including the Reservoir Operations Pilot Project and ongoing basin studies; registered professional engineer in the state of Oklahoma; 2009 John Keys Award.
6. ***Kyle Arthur*** (COMCD Manager): Kyle has worked professionally in the environmental field for the past 27 years including time at the Oklahoma Department of Environmental Quality, the OK Water Resources Board, Chesapeake Energy and currently COMCD. During this time, he has worked in a variety of federal and state environmental programs.
7. ***Chris Neel*** (OWRB Division Chief): Chris began working at the OWRB in 2007 on hydrologic investigations to determine groundwater availability of Oklahoma's aquifers. He started managing the program in 2012 and has since served as the Planning and Management Division's Assistant Division Chief before serving in his current capacity beginning in March 2021. Chris has a Bachelor and Master of Science in Geology from Oklahoma State University. His most notable projects include the Arbuckle-Simpson, Garber-Wellington, and Rush Springs hydrologic investigations. In addition, he has collaborated with OWRB staff, the U.S. Geological Survey, and U.S. Bureau of Reclamation on numerous groundwater and surface water investigations.
8. ***Elise Sherrod*** (OWRB Environmental Programs Specialist): Elise works within OWRB's Water Rights Administration Division. She holds a M.S. in Environmental Studies from the College of Charleston. She has been working on models of surface water quantity and water rights allocation for nine years, having received formal training in SWAT, Excel CRAM, STELLA, and RiverWare platforms. Elise has partnered with the Bureau of Reclamation on multiple basin studies since 2015 and contributed to development of the methodology used to identify drought response thresholds for the Upper Red River Basin Study.

5) *Team selection for tasks that have not yet been assigned?* N/A.

6) *Have team members accomplished projects similar in scope to the proposed project?*

Yes, the same team that led and completed the Reservoir Operations Pilot Study on the Washita Basin Project (Reclamation, 2018) will lead and complete this Applied Science Project.

7) *Can team proceed within the proposed project?*

Yes, all participants, both internal and external, are available and ready to proceed.

8) *Descriptions of products anticipated to result from the project; data management; how the peer review process and/or guidelines will be applied to the project.*

The Project Team has an exceptional record in the completion of high-quality, well-written products. The following products are expected:

a) Three ***EDRRO Models*** are built in Microsoft Excel, are digital, and transferrable to Reservoir Operating Partners and to the TWDB.
b) ***One TM*** on the Lake Thunderbird EDDRO Model that describes the need, constraints, methods, results, and findings; digital and bound hard copies.
c) ***One Summary Bulletin*** (similar to Operations Pilot bulletins); digital and hard copies.

d) ***PowerPoint presentations*** in support of product dissemination internally to Reclamation; to COMCD and its member cities; and to the OWRB. PowerPoint presentations at relevant Oklahoma-based conferences including Oklahoma Governors Water Conference.
e) ***Publications in relevant peer-reviewed water journals***: Water Resources Research (from American Geophysical Union), Journal of Hydrologic Engineering (from ASCE), and Hydrology and Earth Systems Sciences (from European Geological Union).

Peer review of each EDRRO Model and TM will be completed in accordance with Reclamation D&S CMP 14, Peer Review of Scientific Information and Assessments. Review will be considered "discretionary"; performed by OTAO's Matt Warren, P.E and James Allard, P.E.(credentials provided above).

Criterion D: Project Partners and Dissemination of Results (10 Points)

1) Describe how this project include partner involvement

Yes, we have secured partners within Reclamation and outside Reclamation at both the state and local levels. See Project Team section above.

a) Have the appropriate internal and external partners committed to participate in this project? Have they submitted letters of support?

Yes, we have received verbal commitment from all partners and team members to participate in this project. We also have received letters of support from COMCD and OWRB[18].

b) Are the partners contributing cost-share (cash or in-kind)? Are partners contributing other resources (e.g., expertise, or input and feedback to the project)?

See Project Team section above.

c) Are there team members from these partners involved in the project?

Yes, a list of project tasks and assigned team members is included on page 2-3 of this proposal. Total Partner In-Kind Contributions/Match: $45,055 (18% of Funding Request).

2) Describe how the project results be made available and communicated to project partners, to Reclamation staff, and to interested stakeholders an d water resources managers in the area, if appropriate*: :*

The EDRRO Models and supply reliability findings will be disseminated and communicated as follows.

a) Externally to Reservoir Operating Partners and TWDB, each will receive the following:

1) A digital copy of the EDRRO Model (platform, interface, etc.). It is recognized that the EDRRO Model would need to be adapted to meet local conditions for other reservoirs.
2) A digital and three spiral-bound copies of the TM summarizing the need, constraints, methods, results, and findings digital and bound hard copies.
3) A digital copy of a one- or two-page Summary Bulletin.
4) A face-to-face workshop/PowerPoint presentation, both during Tasks 1 and 5.

b) Externally beyond Applied Science Project Partners:

1) ***National Oceanic Atmospheric Administration (NOAA):*** coordinate with the Interdisciplinary Research and Applications Working Group for the ***National Integrated Drought Information System (NIDIS)*** Southern Plains Drought Early Warning System;

[18] This project has the support of Corpus Christi, but due to time constraints, a support letter could not be secured at the time of this submittal.

seeks to optimize the expertise to make climate and drought science readily available, easily understandable and usable for decision makers; and to improve the capacity of stakeholders to better monitor, forecast, plan for and cope with the impacts of drought.

2) ***Western States Water Council***: coordinate with Deborah Lawler, Federal liaison officer to WestFAST, and the ***National Drought Resiliency Partnership***. Note: this project meets multiple goals outlined by the NDRP[19]. We would view this as one of the key outreach opportunities for this work.
3) ***R&D Office Network***: present in one of the monthly R&D Webinars, Operations and Planning Series (hosted by K. Nowak). About 100 people are on the list, mostly internal across regions and TSC with some external representation (e.g., NOAA/NIDIS).
4) PowerPoint presentations at relevant ***Oklahoma-based conferences*** (see Criterion C.8.d).
5) ***Publications in relevant peer-reviewed water journals*** (see Criterion C, 8.e).

Evaluation Criterion E—Department of the Interior and Bureau of Reclamation Priorities (10 Points)

1) Climate Change

Over the past decade, there has been much work done in Oklahoma, Texas, and across the west using global climate models (GCMs) to project how changes in climate may affect future supplies. Most of OTAO's reservoirs have climate change factors built into their long-range yield projections, much like Reclamation's reservoirs residing within the major river basins evaluated within our WWRA completed in 2011. The use of GCMs continues to be a powerful tool in assessing potential water availability risks, yet research continues on how assumptions related to initial conditions, future greenhouse gases emissions, and atmospheric and ocean dynamics may affect future drought resiliency. That said, the use of tree rings has been garnering recent attention as another method to account for hydrologic uncertainty, and it should complement GCM projections to provide an even more comprehensive analysis of water availability risk.

2) Disadvantaged or Underserved Communities

Engagement with the TWDB and Regional Water Planning Group will be driven to be responsive to local interests. The last thing we want is for local water users to perceive the Federal government as interfering with local water resources planning efforts. Reclamation maintains an excellent collaborative relationship with our Reservoir Operating Partners in Texas, and solid foundation of trust already exists that we can build upon to maximize positive outcome on this effort. Their support will help build trust with local water users during the initial phases of this work.

3) Tribal Benefits

There are 38 recognized Tribes in Oklahoma. The tribes are generally very active in terms of water resources planning and management, in particular the Chickasaw and Choctaw Nations, which have expressed an interest in development of their own DRTs that replicate the statistical methods and approach developed by Reclamation and OWRB in support of the URRBS. The EDRRO Model and development of DRTs could be used by Tribes to provide a robust analysis of water storage at reservoirs within tribal jurisdictions that could help inform future efforts to

[19] https://obamawhitehouse.archives.gov/sites/default/files/docs/drought_resilience_action_plan_2016_final.pdf

mitigate and adapt to supply vulnerabilities which would help resolve potential conflicts and competition over water supplies.

4) Ecological Value

By improving how we quantify risk exposure of available water supplies to severe droughts worse than the DOR, managers can assess whether it is an acceptable risk, and if not, use these data to build consensus and justify investments that could be costly, both technically and politically. This helps enhance ecological value by improving reservoir storage during critical drought periods when ecological communities need the water most. Furthermore, this could help water users comply with water-related regulations, whether involving Federally-listed species, Clean Water Act commitments, etc.

Project Budget

Total Project Costs

The proposed project is requesting funding for $200,000 (82%) and has commitments to provide $45,055 (18%) in matching contributions from two external partners and one Reclamation offices. Table 2 provides a summary of contributions.

Table 2. Total Project Cost Table.

SOURCE	AMOUNT
Costs to be reimbursed with the requested funding	$200,000
Cost share contributions by applicant	
OTAO	$19,690
Cost share contributions by partners	
Central Oklahoma Master Conservancy District	$14,400
Oklahoma Water Resource Board	$10,965
TOTAL PROJECT COST	**$245,055**

Budget Proposal Table

A detailed budget table is described on the next page. Table 3 provides a summary of the costs for each Reclamation Office for each fiscal year of the study. No funds will be transferred to external partners during this project. OWRB and the Operating Partners budgets are also included as labor costs in the detailed budget table to show where their expertise will be used.

Table 3. Summary of Reclamation costs by funding Directorate.

Reclamation Office	Fiscal Year 1	Fiscal Year 2	Total
OTAO	$51,550	$109,500	$161,050
TSC	$24,560	$34,080	$58,640
Total	$76,110	$143,580	$219,690

BUDGET ITEM DESCRIPTION	COMPUTATION			Quantity Type	Reclamation Funds	Matching Funds		Fiscal Year 1	Fiscal Year 2	Total Cost
	$/Unit	OTAO Quantity	TSC Quantity			OWRB	Operating Partners			
Labor Costs										
Task 1 – Establish planning objectives and compile data										
a) Host kickoff meeting.	$160	24	8	hr	$5,120	-	$1,200	$6,320	-	$6,320
b) Identify needs and planning objectives	$160	48	8	hr	$8,960	-	$2,400	$11,360	-	$11,360
c) Collect/update reservoir supply data	$160	24	-	hr	$3,840	-	-	$3,840	-	$3,840
Task 2 – Develop EDRRO Model for Lake Thunderbird										
a) Develop a range of reservoir inflow sequences based on paleo drought scenarios.	$160	8	80	hr	$14,080	-	-	$14,080	-	$14,080
b) Develop reservoir platform	$160	48	8	hr	$8,960	-	-	$8,960	-	$8,960
c) Develop a demand platform	$160	48	8	hr	$8,960	-	$1,200	$10,160	-	$10,160
Task 3 – Evaluate Baseline Reservoir Inflow Scenarios										
a) Use the observed hydrologic record alone to simulate firm yield	$160	8	-	hr	$1,280	-	-	$1,280	-	$1,280
b) Use 1,000+ of paleo inflow sequences to simulate firm yield/permit availability.	$160	48	-	hr	$7,680	-	-	$7,680	-	$7,680
c) Quantify probability distribution of reservoir firm yield	$160	24	16	hr	$6,400	-	-	$6,400	-	$6,400
Task 4 – Identify Drought Response Thresholds										
a) Identify range of indicators and thresholds	$160	8	8	hr	$2,560	$1,371	-	-	$3,931	$3,931
b) Identify range of drought scenarios for indicator-threshold performance testing	$160	40	32	hr	$11,520	$5,483	-	-	$17,003	$17,003
c) Evaluate indicator-threshold performance	$160	48	32	hr	$12,800	$2,741	-	-	$15,541	$15,541
d) Select best performing drought response indicator-threshold combinations	$160	40	24	hr	$10,240	$1,371	-	-	$11,611	$11,611
Task 5 – Identify Planning Scenarios										
a) Select paleo inflow sequences and demand scenarios	$160	32	-	hr	$5,120	-	$1,800	-	$6,920	$6,920
Task 6 – Evaluate Impacts of Drought Response Thresholds										
a) Evaluate impacts of drought response indicator-threshold combinations	$160	32	-	hr	$5,120	-	-	-	$5,120	$5,120
b) Quantify reservoir demand curtailment percentages	$160	40	-	hr	$6,400	-	-	-	$6,400	$6,400
b) Identify range of supplemental supply source scenarios	$160	48	-	hr	$7,680	-	$1,800	-	$9,480	$9,480
c) Host a demonstration for COMCD	$160	48	-	hr	$7,680	-	$1,200	-	$8,880	$8,880
d) Run additional scenarios	$160	40	-	hr	$6,400	-	-	-	$6,400	$6,400
Task 7 – Document and Disseminate Results										
a) Prepare a draft Technical Memorandum (TM)	$160	120	32	hr	$24,320	-	$1,200	$6,380	$19,140	$25,520
b) Perform a peer review of EDRRO Model and TM.	$160	40	40	hr	$12,800	-	-	$3,200	$9,600	$12,800
c) Finalize and disseminate the TM	$160	32	-	hr	$5,120	-	$1,200	-	$6,320	$6,320
d) Develop and disseminate Summary Bulletin	$160	32	8	hr	$6,400	-	-	-	$6,400	$6,400
e) Prepare and deliver PowerPoint presentation to COMCD.	$160	32	16	hr	$7,680	-	$2,400	-	$10,080	$10,080
g) Host a webinar internal to Reclamation	$160	32	8	hr	$6,400	-	-	-	$6,400	$6,400
h) Submit abstracts and give presentations	$160	16	-	hr	$2,560	-	-	-	$2,560	$2,560
i) Publish results in relevant peer-reviewed water journals.	$160	40	16	hr	$8,960	-	-	-	$8,960	$8,960
Travel Costs										
OTAO Travel associated with Task 1 and Task 7	$350	3	-	Trip	$1,050	-	-	$350	$700	$1,050
TSC Travel associated with Task 1 and Task 7	$1,200	-	3	Trip	$3,600	-	-	$1,200	$2,400	$3,600
TOTAL Estimated Project Costs					**$219,690**	**$10,965**	**$14,400**	**$81,210**	**$163,845**	**$245,055**

Budget Narrative

The vast majority of the proposed project's budget is for labor costs. Labor costs for all entities were estimated by hour for each task scoped for the project. The scope and level of effort required was based on previous experience on similar projects, such as the Reservoir Operations Pilot Study on the Washita Basin Project (Reclamation, 2018). The project manager and team that will complete each task are listed below. The staff day estimated for the team is approximately $1,280.

1) Reclamation Team

Oklahoma-Texas Area Office (OTAO) – Lead Office

- **Oversight:** Collins Balcombe (Supervisor, Planning & Project Development Division)
- **Management:** Anna Hoag, P.E.; (Civil Engineer)
- **Tasks 1-3:** Anna Hoag
- **Task 4-5:** Collins Balcombe
- **Peer Review**: Matthew Warren, P.E. (Supervisor, Engineering & Infrastructure Services Division) and James Allard, P.E. (Deputy Area Manager)

Technical Services Center (TSC)

- **Task 2-4:** Subhrendu Gangopadhyay, Ph.D., P.E. (Civil Engineer, Water Resources Engineering & Management)

Research & Development Office (R&D)

- **Task 5, Peer Review:** Ken Nowak, Ph.D. (Water Availability Research Coordinator)

The modeling software used by Reclamation for this project (R programming language and Microsoft® Office Excel) both have no licensing or accessibility limitations. The only costs associated with non-labor for all of the entities involved in the project will be for travel. Three in-person meetings will be held with the operating partner at the beginning and end of the project (Task 1 and 7). Travel costs for these meetings with the operating partner was determined based on the previous costs from meetings (Table 4). Since the facility is a Reclamation projects, the travel costs for OTAO and TSC to travel to these sites are well-known.

Table 4. Estimated travel costs.

	OTAO Travel Estimate
GOV from Oklahoma City GOV from Austin Lodging Per Diem M&IE Per Diem (one day there and one travel day)	$10.73 per day + 34 miles [$0.221/mile for GSA + $1.58/gallon/(20mpg)] = $21 $10.27 per day + 378 miles [$0.208/mile for GSA + $1.58/gallon/(20mpg)] = $119 $96 $59 for two days
Estimate for OTAO Travel:	~$350 per trip
	TSC Travel Estimate
Transportation from Denver Lodging Per Diem M&IE Per Diem	$950 roundtrip (includes baggage, mileage, etc) $96 $59 for two days
Estimate for TSC Travel:	~$1,200 per trip

No environmental compliance is needed for this project. No contracts are needed for this project.

Cost-Share Contributions

As previously described, this project has cost share-contributions from one internal Reclamation partner and two external entities. The specific time and associated costs for each entity is shown in the detailed budget table to clearly denote the tasks and effort of each contributing entity by subtask.

1) Reclamation Team

Oklahoma-Texas Area Office (OTAO) – Lead Office (**in-kind contribution: $19,960**)

- Collins Balcombe, cbalcombe@usbr.gov, OTAO in the Arkansas-Rio Grande-Texas Gulf Region, Federal Government, In-Kind Firm.

2) Reservoir Operating Partners Team (in-kind contribution: $14,400)

Central Oklahoma Master Conservancy District: Kyle Arthur, District Manager

- Kyle Arthur, karthur@comcd.net, COMCD, Non-Federal Government, In-Kind Firm.

3) Oklahoma Water Resources Board (OWRB) Team (in-kind contribution: $10,965)

Chris Neel, Division Chief, Water Rights Administration Division and Elise Sherrod, Senior Hydrologist, Water Availability Section.

- Chris Neel, chris.neel@owrb.ok.gov, OWRB, Non-Federal Government, In-Kind Firm.

Environmental and Cultural Resources Compliance

No environmental compliance is needed for this project.

Required Permits or Approval

No permit or approval is needed for this project.

Supervisor and Acquisitions Approvals

Written approval was provided by Mark Treviño, Area Manager of the Oklahoma-Texas Area Office, on October 28, 2021. This approval is attached on the first page of the Appendix.

Letters of Support

COMCD and OWRB all provided a letter of support for this project and a description of their firm commitment to provide in-kind contributions. These letters are attached on pages 2-6 of the Appendix.

Appendix

See following pages.

Re: Approval of Two OTAO Applied Science Proposals

Trevino, Mark A <MTrevino@usbr.gov>

Thu 10/28/2021 3:04 PM

To: Balcombe, Collins K <CBalcombe@usbr.gov>
Cc: Hoag, Anna <ahoag@usbr.gov>; Allard, James <JAllard@usbr.gov>

Approved, Looks Good.
Mark

From: Balcombe, Collins K <CBalcombe@usbr.gov>
Sent: Thursday, October 28, 2021 2:56 PM
To: Trevino, Mark A <MTrevino@usbr.gov>
Cc: Hoag, Anna <ahoag@usbr.gov>; Allard, James <JAllard@usbr.gov>
Subject: Approval of Two OTAO Applied Science Proposals

Mark,
Attached are the two applied science proposals we are submitting for FY 22 funding to support the Norman and W.C. Austin Projects. We are required to document Area Manager approval. Would you kindly take a look and provide the necessary approval for us to submit these? The deadline is tomorrow.

Appreciate it.

Collins Balcombe
Supervisor, Planning & Project Development Division
Oklahoma-Texas Area Office
Austin, TX. 78745
512-922-0525 (cell)

From: Hoag, Anna <ahoag@usbr.gov>
Sent: Thursday, October 28, 2021 12:39 PM
To: Balcombe, Collins K <CBalcombe@usbr.gov>
Subject: Applied Science Proposals

Hey Collins,
I wrote Chris Neel a bio as a place holder. I wondered if you wanted to go ahead and send to Mark for his approval? Attached are the latest for both applications.
Thanks,
Anna

JULIE CUNNINGHAM
EXECUTIVE DIRECTOR

KEVIN STITT
GOVERNOR

OKLAHOMA
Water Resources Board

October 25, 2021

Bureau of Reclamation
Water Resources and Planning Office
Attn: Ms. Avra Morgan
P.O. Box 25007, MS 86-69200
Denver, CO 80225

RE: Reclamation FY2021 WaterSMART Program - Applied Science Tools *Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Lake Thunderbird, Oklahoma*

Dear Ms. Morgan,

The Oklahoma Water Resources Board (OWRB) supports the subject application that would fund Reclamation's development of a new modeling tool to simulate Lake Thunderbird's supply under a range of drought scenarios, including paleo droughts that are known to have occurred prior to official record keeping. The proposed project also will develop drought response thresholds that can be used during critical drought periods to help manage water deliveries and augment reservoir storage with outside supply sources in order to improve overall water supply reliability for users that depend on Lake Thunderbird.

The OWRB's mission is to "protect and enhance the quality of life for Oklahomans by managing and improving the state's water resources to ensure clean and reliable water supplies, a strong economy, and a safe and healthy environment". This project is directly aligned with OWRB's mission.

The OWRB is committed to providing $10,965 of in-kind support to provide technical assistance to Reclamation and stakeholders in developing a range of drought response thresholds for local water managers and users to potentially use in managing Lake Thunderbird through critical droughts. The methods used to develop the thresholds will follow a similar approach recently developed by OWRB and Reclamation as part of the Upper Red River Basin Study. The work on Lake Thunderbird would provide an interesting test case for applying this methodology to a different, smaller watershed to support local planning and decision-making.

Sincerely,

for Julie Cunningham, Executive Director
Oklahoma Water Resources Board

CN/mnb

12500 ALAMEDA NORMAN, OKLAHOMA 73026
(405) 329-5228

Bureau of Reclamation
Water Resources and Planning Office
Attn: Ms. Avra Morgan
P.O. Box 25007, MS 86-69200
Denver, CO 80225

Subject: Reclamation FY2021 WaterSMART Program - Applied Science Tools *Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Lake Thunderbird, Oklahoma*

Dear Ms. Morgan,

The Central Oklahoma Master Conservancy District (COMCD) has water right permit of 21,600 acre-ft/yr for water stored in Lake Thunderbird for municipal and industrial purposes. The COMCD operates and maintains the Norman Project, including Lake Thunderbird, in partnership with Reclamation. The COMCD and Reclamation have a shared interest of preserving the authorized benefits of Lake Thunderbird, including ensuring that the reservoir can reliably deliver 21,600 acre-ft/yr, even during critical drought periods.

The COMCD supports the subject application that would fund Reclamation's development of a new modeling tool to simulate Lake Thunderbird's supply under a range of drought scenarios, including paleo droughts that are known to have occurred prior to official record keeping. The proposed project also will develop drought response thresholds that can be used during critical drought periods to potentially curtail water deliveries and augment reservoir storage with outside supply sources in order to improve overall water supply reliability for our customers. The COMCD plans to use Reclamation's analysis to support future drought contingency planning efforts that will be pursued with separate funding opportunities.

The COMCD is committed to providing $14,400 of in-kind support to ensure this project is successful and meets the needs of COMCD and our customers. This includes helping Reclamation collect the necessary data to develop the model, identification of drought and planning scenarios, identification of drought response thresholds, and stakeholder coordination.

Sincerely,

Kyle Arthur
General Manager
Central Oklahoma Master Conservancy District

The City of
NORMAN

201 West Gray C • P.O. Box 370
Norman, Oklahoma 73069 • 73070

DIRECTOR OF UTILITIES
Phone: 405-366-5443
Fax:405-366-5447

Bureau of Reclamation
Water Resources and Planning Office
Attn: Ms. Avra Morgan
P.O. Box 25007, MS 86-69200
Denver, CO 80225

Subject: Reclamation FY2021 WaterSMART Program - Applied Science Tools *Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Lake Thunderbird, Oklahoma*

Dear Ms. Morgan,

The City of Norman depends on Lake Thunderbird as its primary water supply source, and we have a strong interest in ensuring supplies are reliable during critical drought periods.

The City supports the subject application that would fund Reclamation's development of a new modeling tool to simulate Lake Thunderbird's supply under a range of drought scenarios, including paleo droughts that are known to have occurred prior to official record keeping. The proposed project also will develop drought response thresholds that can be used during critical drought periods to potentially curtail water deliveries and augment reservoir storage with outside supply sources in order to improve overall water supply reliability of Lake Thunderbird.

The City provides water to approximately 41,000 residential, commercial, and wholesale accounts. Reclamation recently performed a yield analysis on Lake Thunderbird and found that the yield is not sufficient to deliver the full 21,600 acre-feet per year water right during critical drought periods. The City needs a better understanding of Lake Thunderbird's risk exposure for droughts that could be worse than those recorded over the last 90 years. By knowing Lake Thunderbird's supply risk exposure, the City and District can make informed decisions about investments in supplemental supply sources while also better understanding our own tolerance to potential delivery curtailments from the reservoir.

Sincerely,

Chris Mattingly, P.E.
Utilities Director
City of Norman, Oklahoma

City of Del City
Oklahoma

Bureau of Reclamation
Water Resources and Planning Office
Attn: Ms. Avra Morgan
P.O. Box 25007, MS 86-69200
Denver, CO 80225

Subject: Reclamation FY2021 WaterSMART Program - Applied Science Tools *Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Lake Thunderbird, Oklahoma*

Dear Ms. Morgan,

The City of Del City depends on Lake Thunderbird as its primary water supply source, and we have a strong interest in ensuring supplies are reliable during critical drought periods.

The City supports the subject application that would fund Reclamation's development of a new modeling tool to simulate Lake Thunderbird's supply under a range of drought scenarios, including paleo droughts that are known to have occurred prior to official record keeping. The proposed project also will develop drought response thresholds that can be used during critical drought periods to potentially curtail water deliveries and augment reservoir storage with outside supply sources in order to improve overall water supply reliability of Lake Thunderbird.

The City provides water to approximately 22,000 residential, commercial, and wholesale accounts. Reclamation recently performed a yield analysis on Lake Thunderbird and found that the yield is not sufficient to deliver the full 21,600 acre-feet per year water right during critical drought periods. The City needs a better understanding of Lake Thunderbird's risk exposure for droughts that could be worse than those recorded over the last 90 years. By knowing Lake Thunderbird's supply risk exposure, the City and District can make informed decisions about investments in supplemental supply sources while also better understanding our own tolerance to potential delivery curtailments from the reservoir.

Sincerely,

Mike Cantrell

Mike Cantrell
City Manager
City Of Del City

Bureau of Reclamation
Water Resources and Planning Office
Attn: Ms. Avra Morgan
P.O. Box 25007, MS 86-69200
Denver, CO 80225

Subject: Reclamation FY2021 WaterSMART Program - Applied Science Tools *Evaluation of Risk Exposure and Drought Response Thresholds to Improve Water Supply Reliability: A Case Study at Lake Thunderbird, Oklahoma*

Dear Ms. Morgan,

The City of City of Midwest City depends on Lake Thunderbird as its primary water supply source, and we have a strong interest in ensuring supplies are reliable during critical drought periods.

The City supports the subject application that would fund Reclamation's development of a new modeling tool to simulate Lake Thunderbird's supply under a range of drought scenarios, including paleo droughts that are known to have occurred prior to official record keeping. The proposed project also will develop drought response thresholds that can be used during critical drought periods to potentially curtail water deliveries and augment reservoir storage with outside supply sources in order to improve overall water supply reliability of Lake Thunderbird.

The City provides water to approximately 20,523 residential, commercial, and wholesale accounts. Reclamation recently performed a yield analysis on Lake Thunderbird and found that the yield is not sufficient to deliver the full 21,600 acre-feet per year water right during critical drought periods. The City needs a better understanding of Lake Thunderbird's risk exposure for droughts that could be worse than those recorded over the last 90 years. By knowing Lake Thunderbird's supply risk exposure, the City and District can make informed decisions about investments in supplemental supply sources while also better understanding our own tolerance to potential delivery curtailments from the reservoir.

Sincerely,

Mark Roberts/ Chief Operator