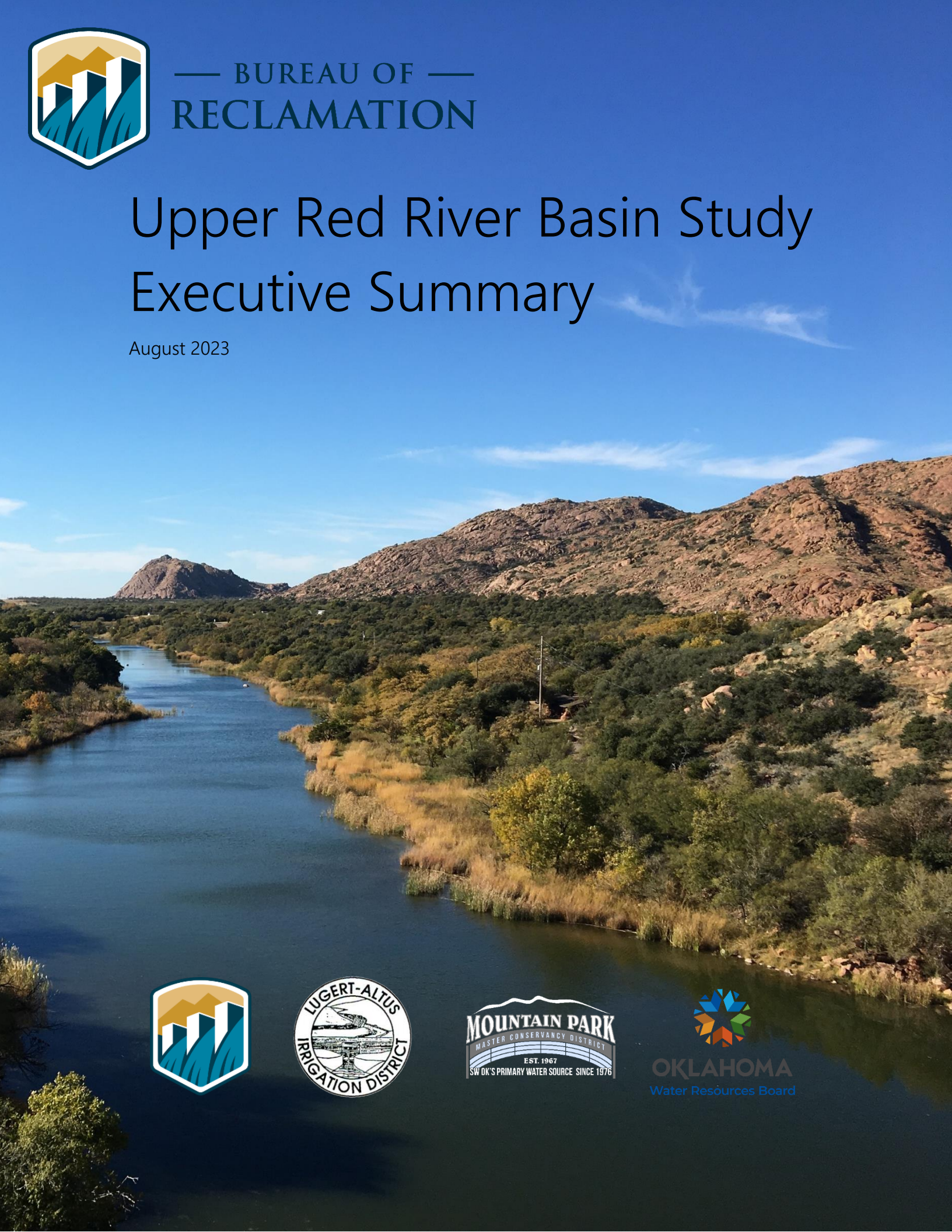
BUREAU OF RECLAMATION

Upper Red River Basin Study Executive Summary

August 2023



Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

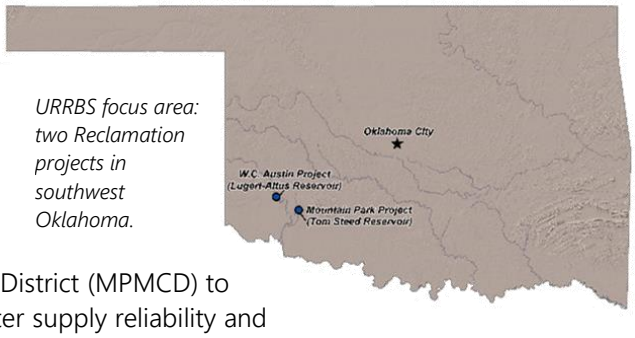
Table of Contents

Acronyms and Abbreviations

Bureau of Reclamation	Reclamation
Equal proportionate share	EPS
Lugert-Altus Irrigation District	Lugert-Altus ID
Maximum Annual Yield	MAY
Mountain Park Master Conservancy District	MPMCD
Municipal and Industrial	M&I
North Fork Red River	NFRR
Oklahoma Comprehensive Water Plan	OCWP
Oklahoma Water Resources Board	OWRB
Operation and Maintenance	O&M
Reclamation Reservoir Yield	RRY
Southwest Oklahoma Water Supply Action Plan	SWAP
Upper Red River Basin Study	URRBS
United States	U.S.
United States Geological Survey	USGS

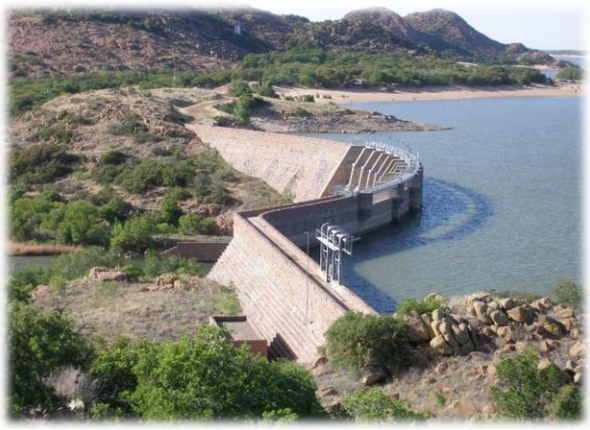
(Page intentionally left blank)

Introduction



URRBS focus area: two Reclamation projects in southwest Oklahoma.

The Upper Red River Basin Study (URRBS) was a collaborative effort between the Bureau of Reclamation (Reclamation), Oklahoma Water Resources Board (OWRB), Lugert-Altus Irrigation District (Lugert-Altus ID), and Mountain Park Master Conservancy District (MPMCD) to evaluate strategies that improve water supply reliability and drought resiliency of two Reclamation reservoirs in southwest Oklahoma: Lugert-Altus Reservoir and Tom Steed Reservoir. Launched in 2014 amidst a record-breaking drought and increasing conflict over limited water supplies, the URRBS performed a comprehensive examination of the numerous pressing water supply, infrastructure, and operational challenges facing Reclamation's reservoirs. Chief among the broad array of issues analyzed in the URRBS was how to define "interference" under Oklahoma's Prior Appropriation Doctrine on surface water, which states that when interference occurs, senior stream-water right permit holders have priority access to water over junior permit holders. Through the URRBS, study partners identified a range of hydrologic indicators and thresholds that could define when interference is occurring, such that when those thresholds have been met during a drought, they could trigger the curtailment of permitted upstream diversions that are junior to the Districts' more senior rights to water stored in Reclamation reservoirs. An evaluation of the impacts of curtailments on water availability demonstrated that the hydrologic thresholds could improve reservoir supply reliability during severe drought periods while not overly restricting upstream permitted diversions. These findings were made possible through a large body of scientific studies conducted jointly by Reclamation and the OWRB, including the development of new groundwater, surface water, and reservoir yield models, all of which were subjected to an independent peer review.



Altus Dam, Lugert-Altus Reservoir.

Beyond the significant findings related to the management of permitted stream-water rights, the URRBS provided up-to-date estimates of current and future demands on Lugert-Altus and Tom Steed reservoirs, including how those demands could be met and managed within existing contractual agreements, operational constraints, and legal commitments and obligations. The URRBS also evaluated vulnerabilities of existing infrastructure and operations; the benefits of modifying existing infrastructure and operations; and the extent to which new infrastructure may be needed to supplement existing reservoir supplies. Finally, the URRBS analyzed the complex suite of water-related legal and policy issues that drive water management affecting Reclamation's reservoirs, and it explored how adaptation strategies identified in the URRBS could be implemented within existing legal and policy frameworks or whether changes in water law or policy may be warranted.

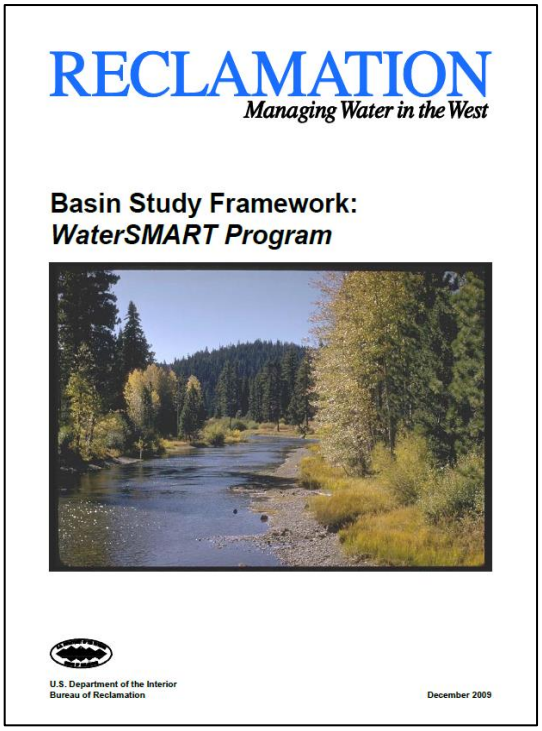
Mountain Park Dam, Tom Steed Reservoir.

The URRBS is a reflection of the tremendous acts of leadership, commitment, and perseverance demonstrated by study partners to deliver a legacy body of work that not only helps secure the water supplies of Lugert-Altus and Tom Steed reservoirs, but that could inform water resource planning and management in Oklahoma for decades to come. The URRBS took seven years to complete at a cost of approximately three million dollars.

Irrigated cotton, Lugert-Altus Irrigation District, W.C. Austin Project.

Authority and Purpose

The URRBS was conducted under the authority of the 2009 SECURE Water Act [(Act) (P.L. 111-11)]. The Act directed the United States (U.S.) Department of the Interior to develop a sustainable water management policy that included an evaluation of water supply risks across the western U.S., as well as strategies to adapt and mitigate those risks. Reclamation subsequently developed the Basin Study Program (Program) to fulfill this directive. Under the Program, eligible entities can compete for federal cost-share funds that are used by Reclamation (or its contractors) to undertake investigations (a.k.a., "Basin Studies") to analyze solutions to water resource management needs on a basin-wide scale. The requirements under the Program are set forth in a Basin Study Framework (Reclamation, 2009) and Reclamation's Directive and Standard on Basin Studies (WTR 13-01)[1].



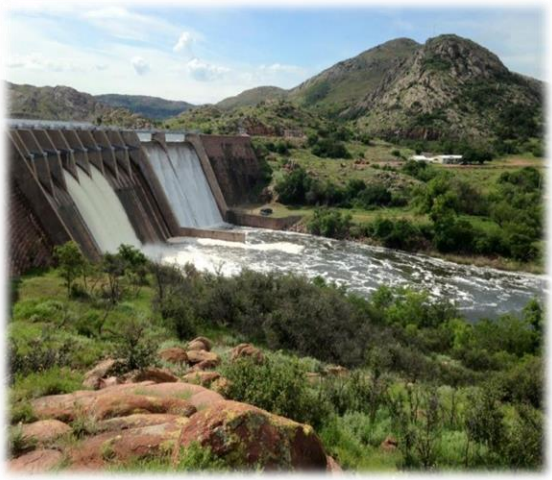
Reclamation's Basin Study Framework.

The URRBS body of work is comprised of: (1) Full Report and Appendices; (2) Condensed Report; and (3) Executive Summary. The Full Report (670 pages) and Appendices (14 Technical Memorandums totaling 1,600 pages) target a relatively small audience seeking the most complete understanding of the URRBS. Together, they contain a highly detailed analysis of the needs, objectives, methods, and strategies, thoroughly documenting all definitions, methods, assumptions, disclosures, and disclaimers; as such, the Full Report and Appendices were prepared to withstand the highest level of technical, procedural, or legal scrutiny. Given the size and complexity of the Full Report and its Appendices, a Condensed Report (143 pages) was prepared that targets a wider audience seeking a less detailed yet comprehensive understanding of the URRBS. While the Condensed Report is less detailed than the Full Report, its content and structure were organized to address all of the Program elements required under WTR 13-01.

The Executive Summary presented here (25 pages) targets an audience seeking only a cursory overview of the URRBS. A crosswalk table is provided in Appendix A that cross references applicable Program study elements as required by in WTR 13-01 with corresponding chapter and section locations within the Full Report.

[1] https://www.usbr.gov/recman/wtr/wtr13-01.pdf.

Study Area



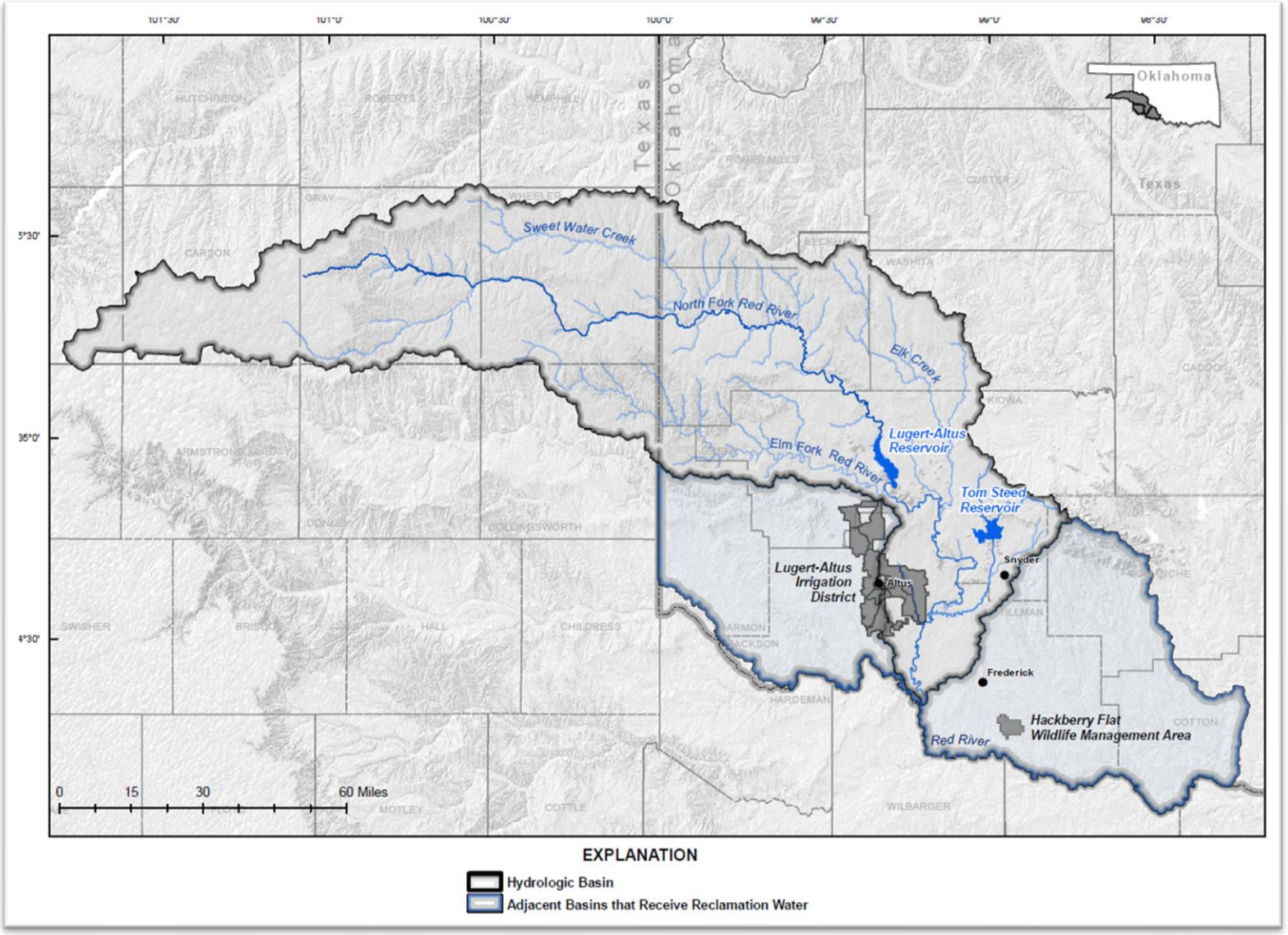
Altus Dam, W.C. Austin Project.

The purpose of the URRBS was to help improve supply reliability and drought resiliency of Lugert-Altus and Tom Steed reservoirs in a manner that considers all water users in the basin. Lugert-Altus Reservoir, the principal feature of the W.C. Austin Project, primarily provides water to the Lugert-Altus ID for agricultural purposes, as well as to the city of Altus for municipal and industrial (M&I) purposes. Tom Steed Reservoir, the principal feature of the Mountain Park Project, provides M&I water to the cities of Altus, Snyder, and Frederick; Altus Air Force Base; several rural water districts; and to the Hackberry Flat Wildlife Management Area for environmental quality purposes. Together, the two reservoirs provide storage for 99 percent of the surface water supplies within the study area, including M&I water to 43,000 people and irrigation water for 48,000 acres of land. Both reservoirs are located within the North Fork Red River (NFRR) Basin (i.e., "hydrologic basin"), which encompasses approximately 5,100 square miles in all or part of nine counties in southwest Oklahoma, and a southeast portion of the Texas panhandle. The study area also includes an additional 4,000 square miles encompassing five counties within adjacent basins that receive water from Reclamation's two reservoirs.

Mountain Park Dam, Mountain Park Project.

Bretch Diversion, Mountain Park Project.

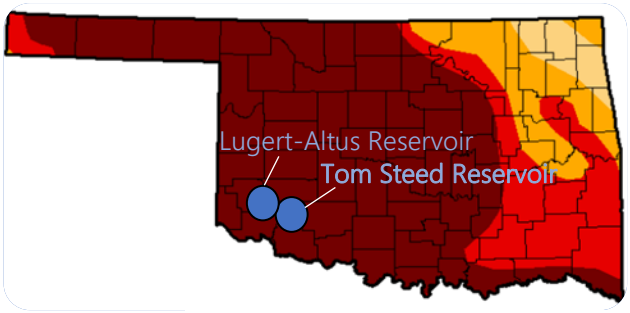
Main canal, Lugert-Altus Irrigation District, W.C. Austin Project.



URRBS study area, including Lugert-Altus and Tom Steed reservoirs, customers, the NFRR hydrologic basin, and adjacent basins that receive Reclamation water.

Needs and Opportunities

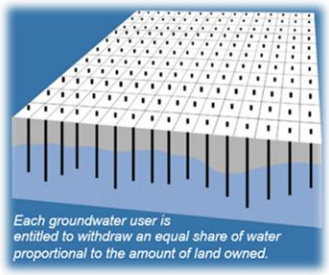
Southwest Oklahoma experienced a record-breaking drought between 2010 and 2015 (a.k.a., 2010s Drought of Record). The storage of both Tom Steed Reservoir and Lugert-Altus Reservoir fell to record lows. Agricultural irrigation deliveries from Lugert-Altus Reservoir were discontinued for the first time since reservoir construction in the 1940s. M&I water deliveries from Tom Steed Reservoir were restricted by over 40 percent. There were severe impacts on recreation, fish and wildlife, and across all economic sectors that depend on the reservoirs. Several pressing needs emerged during the record-breaking drought, the details of which are described in Chapter 2 of the Full URRBS Report. This included needs for:



Oklahoma, U.S. Drought Monitor 2014.

- Improved understanding of the factors affecting the water supplies of Lugert-Altus and Tom Steed reservoirs, including the current and future climate and hydrology, as well as sedimentation.
- Improved understanding of the impacts of permitted groundwater and surface water withdrawals upstream of both reservoirs, the subject of which was a primary focus of this URRBS.
- Improved estimates of current and future demands on the reservoirs, including how those demands can be met and managed within existing contractual frameworks, operational constraints, and legal commitments and obligations.
- Improved understanding of vulnerabilities in existing infrastructure and operations, and the extent to which operational changes or infrastructure modifications may be warranted or whether new infrastructure is required to supplement existing reservoir supplies.
- Improved access to data and models that are collected and developed using sound scientific practices that can quantify the groundwater and surface water supplies in the Lugert-Altus and Tom Steed Reservoir hydrologic basins. This entailed quantifying the impacts of permitted groundwater and surface water withdrawals on Lugert-Altus and Tom Steed reservoirs under a range of future "status quo" growth and development scenarios. It also entailed quantifying and evaluating how well adaptation strategies could mitigate or eliminate those impacts or otherwise impact water availability for users upstream of the reservoirs.
- Improved understanding of water-related legal and policy frameworks. This included a review of Western water law and Oklahoma water law to determine how adaptation strategies could be implemented within existing legal and policy frameworks, or whether strategies may require changes in law or policy or warrant a new legal or policy framework altogether.

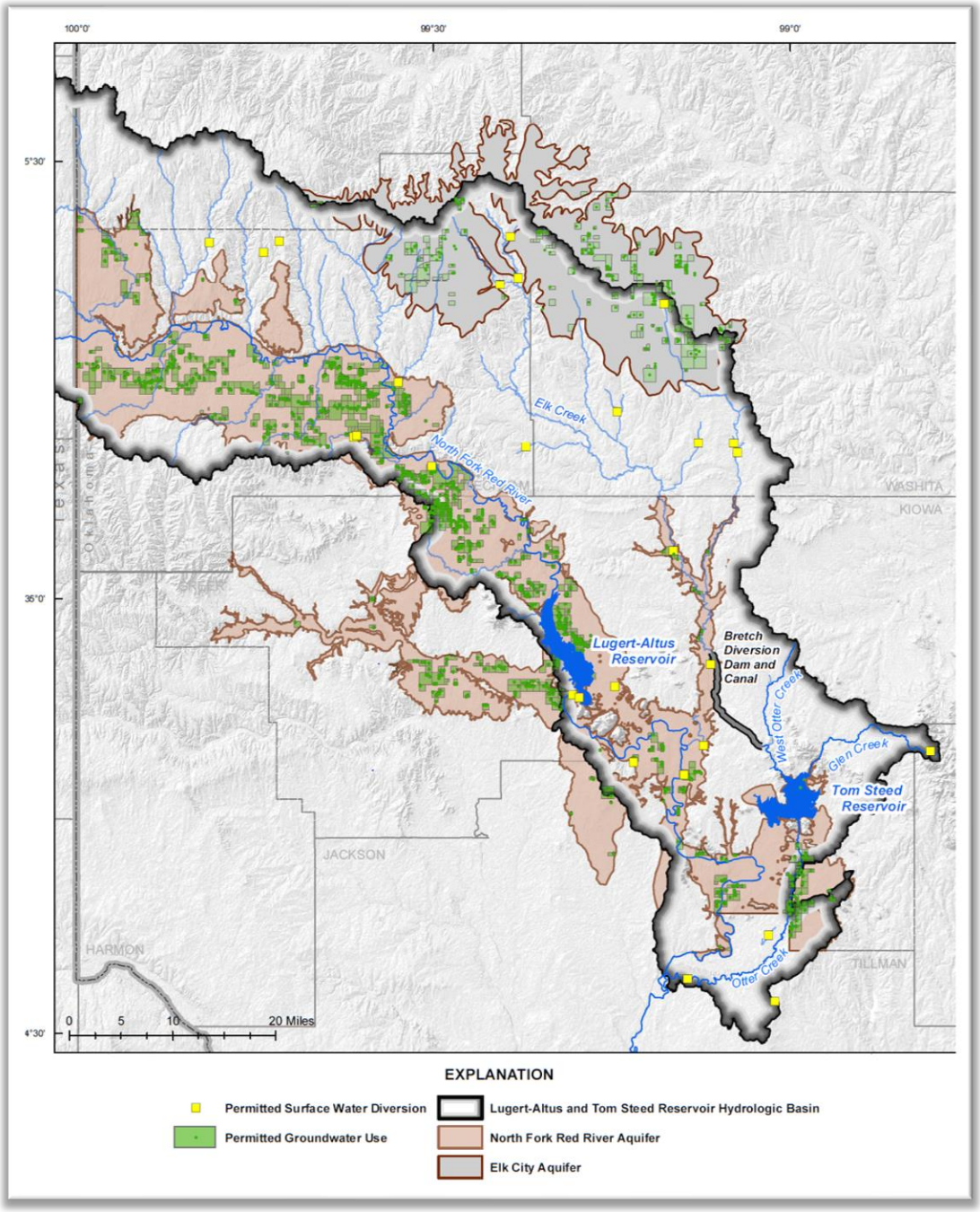
Chief among the needs identified above was the challenge to quantify the impacts of current and projected permitted groundwater and stream-water withdrawals upstream of Lugert-Altus and Tom Steed reservoirs. The figure on the next page illustrates permitted groundwater and surface water use within the Lugert-Altus and Tom Steed reservoir hydrologic basins. The OWRB has planning, financing, and regulatory permitting authority over waters of the state. It is important to note that groundwater and surface water are largely regulated separately in Oklahoma.



Groundwater is considered to be a property right in Oklahoma, and well permits are issued by the OWRB based on land owned or leased by applicants such that each acre of land overlying an aquifer is allocated an equal proportionate share (EPS) of the aquifer's maximum annual yield (MAY). The MAY is the amount of water the aquifer can provide for beneficial use in any given year in order to ensure that the life of the aquifer will be maintained at least 20 years. In other words, if each and every acre overlying the aquifer was to experience a withdrawal of its EPS over a 20-year period, the aquifer would be considered depleted in accordance with Oklahoma law. One of the key concerns expressed by Lugert-Altus ID and MPMCD was the potential for groundwater depletion to reduce the base flow of connecting surface waters that contribute inflow into Lugert-Altus and Tom Steed reservoirs. These base flows serve as the principal source of water to sustain reservoir storage during extended drought periods.

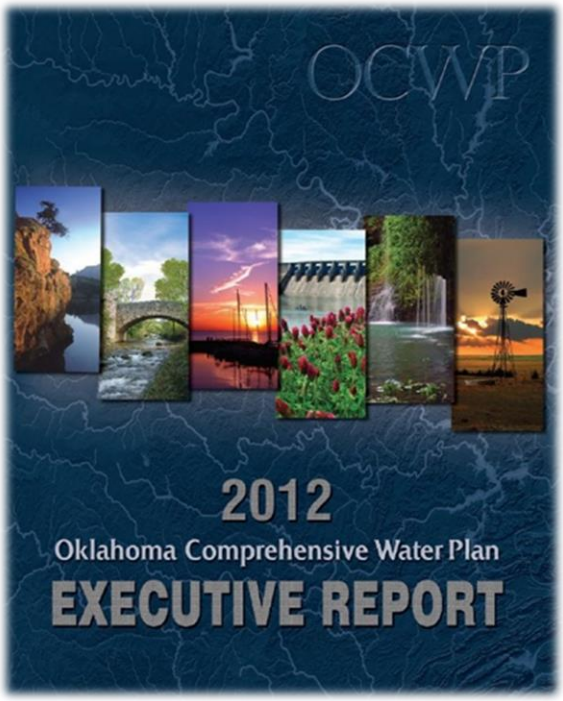
Surface water permits are regulated under Prior Appropriation Doctrine. Often referred to as "first in time, first in right", the Doctrine generally states that older, more "senior" permits have priority access to water over newer, more "junior" permits. One of the key concerns expressed by Lugert-Altus ID and MPMCD during the drought of record was that junior upstream permits were reducing inflows into Reclamation's reservoirs, and as such, were interfering with the Districts' more senior permits to water stored in Reclamation's reservoirs. Furthermore, the Districts raised concerns that a definition of "interference" under state law did not exist, and as such, the state lacked a mechanism to trigger the curtailment of junior stream permits under the state's Prior Appropriation Doctrine during future droughts. There also was a lack of data and decision-support tools available at the time to measure and quantify the impacts of permitted withdrawals upstream of Lugert-Altus and Tom Steed reservoirs, and to determine if those impacts were interfering with the Districts' water rights. In addition, without these decision-support tools in place, it was unclear how the OWRB could effectively regulate permitted water withdrawals within Oklahoma's existing legal and policy framework.

Bretch Canal, Mountain Park Project.



Distribution of permitted surface water diversions within the Lugert-Altus and Tom Steed reservoir hydrologic basins, as well as permitted groundwater use within the NFRR and Elk City aquifers.

To address the Districts' interference concerns, study partners evaluated a range of thresholds that could be used to define when interference is occurring, and thus when reached during drought periods, could trigger the curtailment of permitted stream diversions that are junior to the Districts' more senior rights. While such a solution had been proposed by the Districts in concept, what was lacking was a scientific analysis supporting the identification of defensible parameters and thresholds that could be used to define interference. The curtailment thresholds evaluated during this study provide a range of pre-determined science-driven definitions of interference for consideration and use by the OWRB when promulgating administrative rules for permitting and enforcement within the hydrologic basins containing Lugert-Altus and Tom Steed reservoirs.



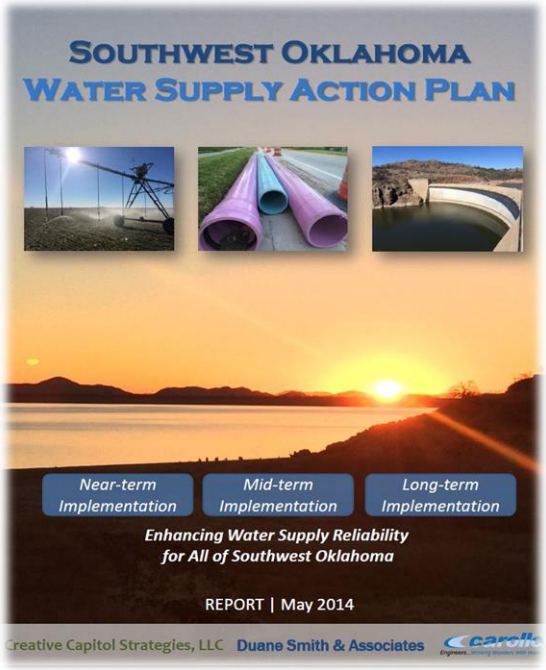
Cover page, OCWP 2012 Update Executive Report.

As all of these challenges converged during the 2010s Drought of Record, the opportunity arose for Reclamation, the OWRB, Lugert-Altus ID, and MPMCD to collaborate through the URRBS to address them. In 2012, the OWRB presented the state's long-range strategy for managing and protecting water supplies for the next 50 years through its Oklahoma Comprehensive Water Plan (OCWP)[2]. Specifically, the OCWP recommended that stakeholders develop management frameworks that address the following:

- Conditioning junior water use permit holders to discontinue their diversion of water during predetermined periods of shortage (i.e., "trigger" points) to enhance the availability of dependable yields in appropriate reservoirs and minimize interference between riparian users and users of reservoir storage.
- Consideration of a conjunctive management water allocation system to address the potential decline in surface water flows and reservoir yields resulting from forecasts of increased groundwater use in areas where these sources are hydrologically connected.
- Consideration of a more conservation-oriented approach in the calculation of groundwater basin yields and allocation of groundwater use permits, including the consideration of more sustainable use and development of groundwater supplies.

[2] https://www.owrb.ok.gov/supply/ocwp/ocwp.php.

These recommendations provided a significant footing for scoping the URRBS. Around the same time, local stakeholders primarily comprised of users of Lugert-Altus and Tom Steed reservoirs, formed an Advisory Committee that launched the development of a Southwest Oklahoma Water Action Plan (SWAP). The SWAP Advisory Committee identified several strategies to address a variety of water supply issues and vulnerabilities in the region, including the aforementioned challenges related to groundwater and stream-water permitting. Completion of the URRBS was one of the key recommendations made by the SWAP.



Cover page, Southwest Oklahoma Water Supply Action Plan.

This section concludes with a brief discussion on legal and policy challenges arising from Oklahoma water law. Understanding these challenges is necessary because some water-related adaptation strategies may be implemented within existing legal frameworks while others may require changes to those frameworks. There is no universal agreement on how to interpret these legal frameworks, both on matters of general principle and in their applications in specific situations. Complicating matters further is that one's legal interpretation is often reflective of the institutions he or she represents (and constituencies they serve); this has understandably resulted in opposing viewpoints on legal matters tied to water-related issues, particularly the administration of water rights in the URRBS study area.

Recognizing these challenges, this URRBS was initiated with a commitment by study partners at the Federal, state, and local level to identify a range of solutions that could potentially achieve win-win outcomes, and to avoid solutions that may result in a significantly disproportionate benefit to one constituency over another. Fulfilling this commitment included recognizing that a thorough legal analysis of these solutions by an outside party was needed. This outside party would represent the public good and not advocate for any particular entity or position. The outside party also would be uniquely qualified and have an acute understanding of law from the U.S. (Federal law), law from the State of Oklahoma (state law), and law from other states in the western U.S. (Western law), because each of these three sources of water law provide policies, statutes, regulations, and judicial opinions that influence the understanding of water rights associated with Lugert-Altus and Tom Steed reservoirs, along with our judgements about specific issues related to those water rights.

With these criteria in mind, URRBS study partners analyzed prospective candidates and selected Dr. Drew L. Kershen, Emeritus Professor of Law at the University of Oklahoma, as the outside party to conduct the legal review for this URRBS. Dr. Kershen was tasked with performing an academic review and preparing a report on the history and evolution of the

fundamental statutes and case law that govern groundwater and stream water in a manner that has affected or could affect Oklahoma Reclamation projects. The report was comprised of a "Background Law" chapter that provided legal context for the broad water-related issues at hand, as well as chapters focusing specifically on Lugert-Altus and Tom Steed reservoirs. The reservoir-specific chapters included a detailed review of constraints and opportunities, within both existing and new legal frameworks, to implement a range of potential water management solutions associated with each reservoir. The Legal Review in its entirety is provided in Appendix A of the Full URRBS Report.

Lugert-Altus Irrigation District, W.C. Austin Project.

Downstream of Mountain Park Dam, Mountain Park Project.

Study Goals and Objectives

Building upon a shared understanding of the needs to improve water supply reliability in the Lugert-Altus and Tom Steed reservoirs, study partners identified the following goals:

- Incorporate an unbiased approach that is in the interest of the public.
- Utilize the best available data, and to develop new models and tools based on sound scientific and engineering principles that are subject to independent peer review, thus ensuring that methods and results are replicable, credible, and defensible.
- Inform stakeholders and decision-makers about the problems and needs in the basin, and on a range of potential solutions and outcomes. The goal was *not* to make recommendations, nor was it to select one or more adaptation strategies as preferred over others. Ultimately, implementation of strategies considered herein must be led by the state or at the local level with the input of stakeholders, boards of directors, council members, policy makers, or other decision-makers.

More specifically, at the onset of the URRBS, study partners identified four key study objectives as follows:

Objective 1: Characterize and quantify existing and future water demands and supplies in the Lugert-Altus and Tom Steed reservoir hydrologic basins.

A detailed inventory and characterization of existing groundwater and surface water supplies and demands is provided in Chapter 5 of the Full URRBS Report. Chapter 5 also defines future groundwater and surface water demand (i.e., growth and development) scenarios under an assumed range of future "Status Quo" conditions. The impacts of these development scenarios on future water supply availability in the basins was evaluated using newly-developed groundwater and surface water models, which were the subject of Objectives No. 2 and 3 below.

Objective 2: Develop a numerical groundwater model for the NFRR aquifer and evaluate the impacts of groundwater pumping on aquifer storage and on the base flows of adjoining streams that flow into Lugert-Altus and Tom Steed reservoirs.

This entailed the development of a groundwater model specific to the NFRR aquifer that quantified inputs and outputs of the aquifer, including the volume of groundwater that could be permitted through current practices under Oklahoma law. The model quantified the volume of base flow of connecting streams that contribute to Lugert-Altus and Tom Steed reservoirs, along with the impacts of groundwater pumping scenarios on those base flows. This objective was led by the OWRB and conducted by the United States Geological

Survey (USGS). A detailed accounting of the NFRR aquifer model and the impacts of groundwater pumping on base flows of the NFRR and water availability in the hydrologic basins is provided in Chapter 6 of the Full URRBS Report.

Objective 3: Develop a basin-wide Surface Water Allocation Model for the NFRR (NFRR SWAM), along with yield models for Lugert-Altus and Tom Steed reservoirs and evaluate the impacts of future groundwater and surface water development scenarios on water availability in the Lugert-Altus and Tom Steed reservoir hydrologic basins.

This objective was led jointly by the OWRB and Reclamation, with each partner responsible for various aspects of the analyses. The OWRB led the development of the NFRR model, which incorporated the results of groundwater pumping scenarios on NFRR base flow that was simulated by the NFRR aquifer model developed by USGS under Objective No. 2. Reclamation led the development of two Reclamation Reservoir Yield (RRY) models, one for Lugert-Altus Reservoir and the other for Tom Steed Reservoir. Although the surface water models were developed separately, Reclamation and the OWRB conducted a rigorous calibration process to ensure the models were integrated appropriately and provided consistent results. The integrated surface-water-modeling analysis on basin-wide water availability was conducted under "Baseline" climate conditions where the future climate conditions were assumed to emulate the observed, historical climate record. A separate analysis on reservoir supply alone was conducted by Reclamation using its RRY models to quantify impacts under a range of assumed changes in future climate conditions. Reclamation also evaluated the impacts of future "status quo" development on the local and regional economies that depend on Lugert-Altus and Tom Steed reservoirs. A detailed description of the surface water models and methods, as well as the simulated impacts of groundwater and surface water development scenarios on future water availability in the hydrologic basins, is provided in Chapter 6 of the Full URRBS Report.

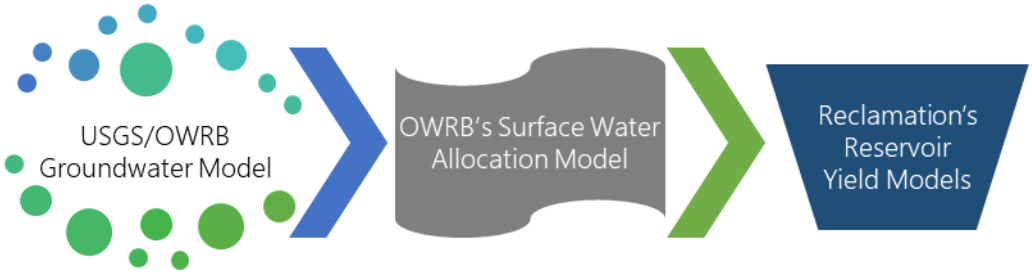
Objective 4: Identify and evaluate adaptation strategies to improve water supply reliability in the Lugert-Altus and Tom Steed reservoir hydrologic basins.

Based on the results of the modeling efforts described under Objectives No. 2 and 3 above, Chapter 7 of the Full URRBS Report outlined planning objectives that were formulated to address water supply and infrastructure needs that were unique and specific to Lugert-Altus and Tom Steed reservoirs. Chapter 7 of the Full URRBS Report identified a range of non-infrastructure and infrastructure adaptation strategies that could be implemented to address these planning objectives. Strategies related to legal, policy, and administrative issues related to water rights drew upon an academic legal review commissioned by Reclamation and conducted by Dr. Drew Kershen from the University of Oklahoma. Other strategies involved the modification of existing infrastructure and operations or construction of new infrastructure to develop supplemental water supplies. Chapter 8 of the Full URRBS Report evaluated these adaptation strategies and performed a trade-off analysis comparing the strategies to one another in terms of four criteria described in Reclamation's WTR 13-01: *effectiveness*, *efficiency*, *acceptability*, and *completeness*.

Water Supply Modeling and Impacts Analysis

Water supply imbalances were quantified over a range of groundwater and surface water development scenarios. These scenarios were formulated under the assumption that the future was constrained by existing Oklahoma water law and current OWRB regulations and water policy. A detailed discussion of the key assumptions and relevant OWRB statutory rules used to guide development of status quo management for both groundwater and surface water is provided in Chapter 6.1.1 and Chapter 6.1.2 of the Full URRBS Report, respectively. The groundwater development scenarios are described in detail in Chapter 5.4.1 and Chapter 6.2.1 of the Full URRBS Report. The stream-water development scenarios are described in Chapter 5.4.2 and Chapter 6.2.2 of the Full URRBS Report.

Groundwater and surface water models were created to quantify the impacts of these development scenarios. Each model played an important role in the analysis, with each model's outputs contributing to subsequent model's inputs. In general, outputs of the NFRR aquifer model were used as inputs into the NFRR SWAM, and outputs of the NFRR SWAM were subsequently used as inputs into the RRY Models for Lugert-Altus and Tom Steed reservoirs. Following a robust model calibration process performed by the OWRB and Reclamation as part of the URRBS, Reclamation and the OWRB came to a consensus on the models, along with supporting methods and assumptions.



Key components of and relationship between the NFRR aquifer model, NFRR SWAM, and the RRY Models.

Quartz Mountains surrounding the North Fork Red River.

Impacts on Lugert-Altus Reservoir

Impacts in the Lugert-Altus Reservoir hydrologic basin were quantified in terms of surface water, reservoir, and basin-wide metrics described in Chapter 6.3 of the Full URRBS Report. Modeling results showed that:

- Existing permitted groundwater use out of the NFRR aquifer has had a significant impact on the supply of Lugert-Altus Reservoir. Although reservoir storage was largely insufficient to meet permitted irrigation demands over the 67-year model period, impacts from groundwater use were particularly pronounced during the drought of record when existing upstream groundwater users increased pumping to irrigate crops.
- Reductions in streamflow and the supply of Lugert-Altus Reservoir will become more pronounced if additional groundwater use is permitted in the future.
- Impacts from existing stream permits were negligible. Modeling was conducted to determine whether stream water was available for the appropriation of future new stream permits. Results showed that stream water was not found to be available for the appropriation of future permits in the Lugert-Altus Reservoir hydrologic basin.
- A primary cause of water supply imbalances in the Lugert-Altus Reservoir hydrologic basin was climatological limitations, particularly during the drought of record when, for the first time since reservoir construction, reservoir storage was insufficient to deliver any water for irrigation.

Lugert-Altus Reservoir, W.C. Austin Project.

Impacts on Tom Steed Reservoir

Impacts in the Tom Steed Reservoir hydrologic basin were quantified in terms of surface water, reservoir, and basin-wide metrics described in Chapter 6.3 of the Full URRBS Report. Modeling results showed that:

- The leading cause of water supply imbalances in the Tom Steed Reservoir hydrologic basin were climatological limitations caused by the new drought of record, although supply shortages also were observed during other historical droughts over the 67-year model period.
- Impacts from permitted groundwater use (both current and future) on the water supplies of Tom Steed Reservoir appear to be negligible but more modeling may be needed to fully assess impacts.
- Permitted stream diversions (both current and future) had a measurable and pronounced impact on the water supply of Tom Steed Reservoir and on water availability across the entire basin.
- The ability of Tom Steed Reservoir to meet demands depended on the climatological conditions, the magnitude of the demands on the reservoir, and the magnitude of future stream-water permitting in the basin. In terms of future stream-water permitting, modeling showed that water was available for the appropriation of new permits under existing OWRB rules in the NFRR, and that the new stream permits have the potential to cause significant reductions in water availability at Tom Steed Reservoir, more so than existing junior stream permits.
- In some cases, these reductions caused water supply shortages, not only during the drought of record, but during other historical droughts over the 90-year model period. The reservoir supply shortages varied in severity, ranging from levels that are likely manageable (e.g., could be mitigated during droughts through water conservation measures) to levels that are so significant that supplemental supplies would likely be needed in order to meet demands on the reservoir.
- The new stream permits also had a measurable and pronounced impact on existing permitted stream diversions in the basin, highlighting a shared interest between existing users of Tom Steed Reservoir and the NFRR to identify strategies that reduce shortages caused by future stream permits.

Boat ramp extending into Tom Steed Reservoir, Mountain Park Project.

Strategies to Improve Supply Reliability

Results demonstrated a need for administrative and legal strategies that would address water supply imbalances caused by groundwater and stream-water permitting, as well as strategies to develop supplemental water supplies that require the modification of existing infrastructure/operations or construction of new infrastructure.

In addition to performing a detailed evaluation of adaptation strategies, the URRBS performed a qualitative trade-off analysis comparing the portfolio of strategies, which was a requirement set forth by Reclamation's Basin Study Program in WTR 13-01. The term "trade-off analysis" should not be interpreted as meaning that one or more strategies will be selected as a preferred alternative over other alternatives and/or recommended for implementation, as would be the case for a Federal planning investigation governed by the Principles and Requirements for Federal Investments in Water Resources (PR&Gs). The PR&Gs describe the content and analysis requirements for Federal planning investigations that can culminate in a recommendation for action or inaction, or which result in an official position of the agency, and the requirements for such studies are quite rigorous. However, unlike Federal planning investigations governed by the PR&Gs, basin studies (including this URRBS) are *prohibited* from making recommendations or from making findings that represent a position of the agency, and consequently, basin studies are not governed by the PR&Gs. This allows for more flexibility in determining the appropriate level of analysis supporting the comparison of alternatives identified in basin studies.

Sunset behind the Quartz Mountain and Lugert-Altus Reservoir, W.C. Austin Project

Even though basin studies are not governed by the PR&Gs, WTR 13-01 cited the four evaluation criteria included in the PR&Gs as useful to consider in the comparison of strategies evaluated in basin studies: *Effectiveness*, *Efficiency*, *Acceptability*, and *Completeness*. These four criteria were adopted for the trade-off analysis in the URRBS but were modified to meet the purpose and context of the URRBS. The four criteria were defined as follows (see following page):

Evaluation Criteria for Trade-Off Analysis

- **Effectiveness:** This criterion measured the relative extent to which the strategy met the planning objectives identified in the URRBS. If a strategy was effective at meeting this planning objective, then it was assumed that the strategy also was effective at minimizing water supply imbalances and addressing potential impacts of climate change. Regarding run-of-the-river stream-water permit holders, the planning objective was to maximize beneficial use and avoid futile curtailments (i.e., administratively-enforced diversion reductions that did not result in meaningful improvements in water availability).
- **Efficiency:** This criterion measured the estimated or perceived relative costs to implement the strategy. This included potential administrative costs, legal costs, transaction costs, and/or capital and Operations and Maintenance (O&M) costs, if applicable depending on nature of the strategy (i.e., whether it involved infrastructure or not).
- **Acceptability:** This criterion measured the extent to which the strategy could garner support from stakeholders with diverse interests, including but not limited to Lugert-Altus ID and MPMCD and their customers; water users in the hydrologic basins; agricultural, municipal, commercial, industrial, and/or energy-producing stakeholders; and recreation, fish and wildlife, and/or environmental stakeholders.
- **Completeness:** This criterion measured the workability of the strategy and risks associated with implementation. It measured the extent to which the strategy was compatible with existing law, regulations, policies, etc., and the extent to which additional investments may be needed to address risks, including those related to hydrology and engineering; changes in law, regulations, or policy; and/or potential litigation.

Each strategy was assigned one of three qualitative "scores" for each of the four criteria. Each score, defined below, was assigned a unique color and symbol (Table 2).

Favorable: A favorable score meant that the strategy was interpreted as performing more favorably than other strategies.

Neutral: A neutral score meant that the strategy was interpreted as neither performing in a net positive nor negative manner.

Less Favorable: A negative score meant that the strategy was interpreted as performing less favorably than other strategies.

Table 1: Scoring rubric for the trade-off analysis of adaptation strategies.

Favorable	↑
Neutral	→
Less Favorable	↓

Lugert-Altus Reservoir

Nine strategies were identified by study partners, either directly through the formulation of preferred strategies at the onset of the URRBS and/or indirectly through the academic legal review performed described in Kershen (2021). The academic legal review, including dozens of supporting footnotes and references that detail the case law/jurisprudence and correspondence, is provided in Appendix A of the Full URRBS Report. A more condensed description of the legal analysis and strategies for Lugert-Altus Reservoir also is provided in Chapter 7.2 of the Full URRBS Report. In Chapter 8.2 of the Full URRBS Report, each strategy was evaluated to determine how well it performed in addressing planning objectives, including the extent to which they could eliminate imbalances between water supplies and demands. The evaluation criteria and scoring rubric noted above were applied to each of the nine adaptation strategies. A summary table of trade-off analysis results is provided in Table 2. The nine strategies were:

Adaptation Strategies for Lugert-Altus Reservoir:

1. Clarification of existing stream-water rights to Lugert-Altus Reservoir
2. Protection of the existing stream-water rights of Lugert-Altus ID (regulatory protection)
3. Protection of the existing stream-water rights of Lugert-Altus ID (non-regulatory protection)
4. Applying for an additional stream-water right for Lugert-Altus ID
5. Conjunctive management of groundwater and surface water (voluntary dry-year lease or purchase agreements)
6. Conjunctive management of groundwater and surface water (conservation-oriented redetermination of NFRR aquifer MAY)
7. Reclassification of alluvial groundwater to stream water
8. Construction of a new reservoir (i.e., "Cable Mountain Reservoir")
9. Water conservation

Table 2. Trade-off analysis results of nine adaptation strategies to improve water supply reliability of Lugert-Altus Reservoir, W.C. Austin Project, Oklahoma.

Adaptation Strategy	Effectiveness	Efficiency	Acceptability	Completeness
1. Clarification of Existing Stream-Water Rights to Lugert-Altus Reservoir	↓	↓	↓	↓
2. Protection of Existing Stream-Water Rights to Lugert-Altus Reservoir (Regulatory Protection)	↓	→	↓	↓
3. Protection of Existing Stream-Water Rights of Lugert-Altus District (Non-Regulatory Protection)	↑	→	→	→
4. Additional Stream-Water Rights of Lugert-Altus Irrigation District	↑	↑	↑	↑
5. Conjunctive Management (Voluntary Dry-Year Lease or Purchase Agreements)	→	→	→	→
6. Conjunctive Management (Conservation-Oriented Maximum Annual Yield Determination)	↑	→	→	↓
7. Reclassification of Alluvial Groundwater to Stream Water	↑	→	→	↓
8. Cable Mountain Reservoir	↑	↓	→	↓
9. Water Conservation	↑	↑	↑	↑

Tom Steed Reservoir

Eleven strategies were identified by study partners, either directly through the formulation of preferred strategies at the onset of the URRBS and/or indirectly through the academic legal review performed described in Kershen (2021). The academic legal review, including dozens of supporting footnotes and references that detail the case law/jurisprudence and correspondence, is provided in Appendix A of the Full URRBS Report. A more condensed description of the legal analysis and strategies for Tom Steed Reservoir also is provided in Chapter 7.3 of the Full URRBS Report. In Chapter 8.3 of the Full URRBS Report, each strategy was evaluated to determine how well it performed in addressing planning objectives, including the extent to which they could eliminate imbalances between water supplies and demands. The evaluation criteria and scoring rubric noted above were applied to each of the eleven adaptation strategies. A summary table of trade-off analysis results is provided in Table 3. The eleven strategies were:

Adaptation Strategies for Tom Steed Reservoir:

1. Clarification of the existing stream-water right of MPMCD
2. Protection of the existing stream-water right of MPMCD (regulatory protection)
3. Protection of the existing stream-water right of MPMCD (non-regulatory protection)
4. Applying for additional stream-water rights for MPMCD
5. Conjunctive management of groundwater and surface water (voluntary dry-year lease or purchase agreements)
6. Conjunctive management of groundwater and surface water (conservation-oriented redetermination of NFRR aquifer MAY)
7. Reclassification of alluvial groundwater to stream water
8. Addressing Environmental Quality beneficial use issues at Hackberry Flat Wildlife Management Area
9. Expansion of the Bretch Diversion and Canal
10. Development of Supplemental Groundwater Supplies
11. Water conservation

Table 3. Trade-off analysis results of 11 adaptation strategies to improve water supply reliability of Tom Steed Reservoir, Mountain Park Project, Oklahoma.

Adaptation Strategy	Effectiveness	Efficiency	Acceptability	Completeness
1. Clarification of Existing Stream-Water Rights of Mountain Park Master Conservancy District	↑	↑	↑	↑
2. Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District - Regulatory Protection	↑	↑	↑	↑
3. Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District – Non-Regulatory Protection	→	→	→	→
4. Additional Stream-Water Rights of Mountain Park Master Conservancy District	↑	↑	↑	↑
5. Conjunctive Management - Voluntary Dry-Year Lease or Purchase Agreements	↓	↓	↓	↓
6. Conjunctive Management - Conservation-Oriented Maximum Annual Yield Determination	↓	→	→	↓
7. Reclassification of Alluvial Groundwater to Stream-Water	↓	↓	↓	↓
8. Environmental Quality Beneficial Use	↑	↑	↑	→
9. Expansion of the Bretch Diversion and Canal	↓	↓	↓	↓
10. Development of Supplemental Groundwater Supplies	↑	↑	↑	↑
11. Water Conservation	→	↑	↑	↑

Conclusions

The record-breaking drought between 2010 and 2015 created a historic milestone in southwest Oklahoma, a milestone where Reclamation, the OWRB, Lugert-Altus ID, and MPMCD decided to cooperate and collaborate on the comprehensive URRBS for the benefit of the public good. Amidst an atmosphere wrought with uncertainty, and despite the myriad of complex and controversial water problems facing the area, study partners embraced the shared goal of developing unbiased, science-driven tools to create a foundation for decision-making that could improve water supply reliability in the Lugert-Altus and Tom Steed Reservoir hydrologic basins.

Irrigated cotton, Lugert-Altus Irrigation District, W.C. Austin Project.

These tools manifested in the form of numerical models that could quantify and simulate the complex interaction between groundwater, stream water, and reservoir storage. Through the URRBS, study partners used these models to provide updated, state-of-the-art calculations on reservoir yield that considered the region's climate and hydrology, as well depletions from existing and future groundwater and surface water development. The URRBS showed that existing upstream permitted groundwater pumping has caused a significant reduction in the supply of Lugert-Altus Reservoir, and future groundwater pumping will cause further declines if current groundwater permitting practices continue. For Tom Steed Reservoir, the URRBS showed that the firm supply of water available from the reservoir through the new 2010s Drought of Record was lower than previous droughts. The URRBS also showed that if new stream permits are issued in the hydrologic basin, those permits could cause significant reductions in the firm supply of Tom Steed Reservoir if steps are not taken to curtail usage of those permits during periods of drought. Overall, results of the URRBS showed that there are shared interests between study partners to implement adaptation strategies that result in win-win solutions that benefit both users of the reservoirs and users of groundwater and stream water in the basins.

North Fork Red River.

To this end, the URRBS examined a range of complex legal, policy, and administrative remedies related to the clarification, acquisition, and management of existing and new water rights. The analysis centered on how the URRBS' newly-developed, science-driven technical findings could relate to and inform these remedies, as well as on how these remedies could be implemented within Oklahoma's legal and policy frameworks. The results of this examination were among several criteria presented in the URRBS that stakeholders could consider as they weigh the trade-offs of implementing one or more adaptation strategies. Undoubtedly, securing a water supply that is predictable and reliable during even the most severe droughts will require a portfolio of strategies.

This URRBS concludes with a statement attesting to the high degree of patience, perseverance, and tenacity displayed by study partners throughout this effort. The URRBS was made possible only through a collective trust that was built among a group of individuals who shared a commitment towards ensuring that the analyses contained in this URRBS represented the highest standards of rigor and professionalism and were in the interest of the public. The URRBS will hopefully serve as an enduring body of work that future stakeholders and professionals can build and improve upon for years to come.

Sunset behind the North Fork Red River.

Appendix A. Program Requirements Cross Walk Table

WTR 13-01, Basin Studies, Required Elements	Location in URRBS Full Report
9.A. Projections of future water supply and demand (2) changes in the timing and quantity of runoff; (3) changes in groundwater recharge and discharge; and (4) any increase in: (a) the demand for water as a result of increasing temperatures; or (b) the rate of reservoir evaporation.	Chapter 5. Basin-Wide Demands and Supplies Chapter 6.5.2. Future Climate Projections
9.B. Analysis of how existing water and power infrastructure and operations will perform given any current imbalances between water supply and demand and in the face of changing water realities due to climate change and population growth, including an analysis of the extent to which changes in the water supply will impact Reclamation operations and facilities, including impacts on: (1) ability to deliver water, including the impacts of drought; (3) recreation; and (4) fish and wildlife habitat.	Chapter 6.4. Impacts of Status Quo under Baseline Climate (Observed Hydrology) Chapter 6.5. Impacts under Climate Change
9.C. Development of adaptation and mitigation strategies (2) development of new water management, operating, or habitat restoration plans; (4) development of new water infrastructure; (6) development or improvement of hydrologic models and other decision support systems; and	Chapter 7. Identification of Adaptation Strategies
9.D. A quantitative or qualitative trade-off analysis of the adaptation and mitigation strategies identified.	Chapter 8. Evaluation of Adaptation Strategies
11.B. Technical Sufficiency Review (List of Reviewers)	Key Contributors (Page vii) Appendix N: Peer Review Report

WTR 13-01, Basin Studies, Required Elements	Location in URRBS Full Report
11.C. Technical Sufficiency Review (Level of Review)	The review of "Influential" scientific information is found in Appendix N: Peer Review Report. Discretionary review of all other scientific information (Page vii)
11.D. Technical Sufficiency Review (Documentation of Results)	Appendix N: Peer Review Report