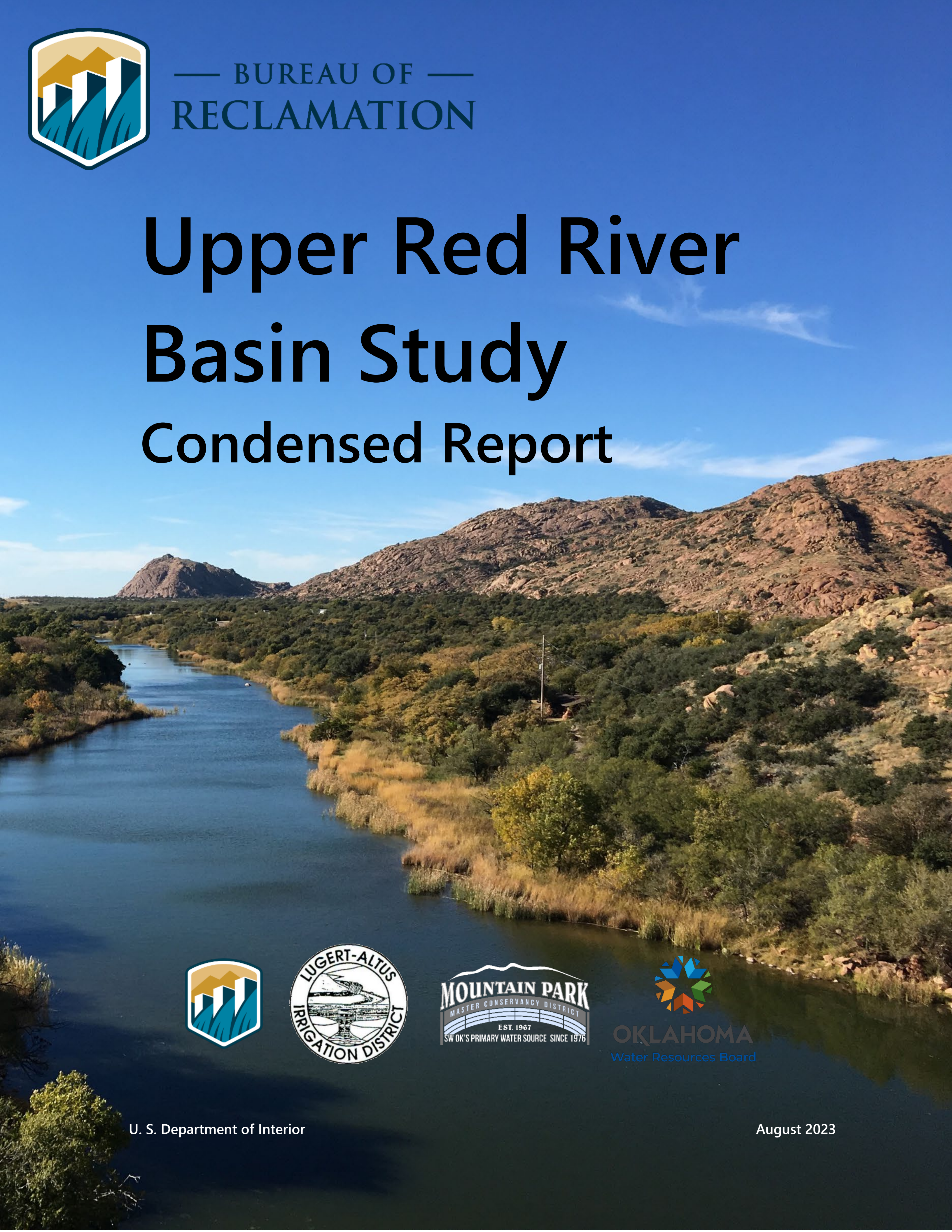
BUREAU OF RECLAMATION

Upper Red River Basin Study

Condensed Report



LUGERT-ALTUS IRRIGATION DISTRICT

MOUNTAIN PARK MASTER CONSERVANCY DISTRICT EST. 1967 SW OK'S PRIMARY WATER SOURCE SINCE 1976

OKLAHOMA Water Resources Board

U. S. Department of Interior

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.

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Acronyms and Abbreviations

Acre-feet per year	Acre-ft/yr
Air Force Base	AFB
Basin Study Program	Program
Bureau of Reclamation	Reclamation
Environmental Quality Plan	EQ Plan
Equal proportionate share	EPS
Hydrologic Unit Code	HUC
IMpact analysis for PLANning	IMPLAN
Lugert-Altus Irrigation District	Lugert-Altus ID
Maximum Annual Yield	MAY
Mountain Park Master Conservancy District	MPMCD
Municipal and Industrial	M&I
Net irrigation water requirement	NIWR
North Fork Red River	NFRR
Oklahoma Comprehensive Water Plan	OCWP
Oklahoma Water Resources Board	OWRB
Operation and Maintenance	O&M
Palmer Drought Severity Index	PDSI
Principles and Requirements for Federal Investments in Water Resources	PR&Gs
Reclamation Reservoir Yield	RRY
Red River Compact	Compact
Surface Water Allocation Model	SWAM
Southwest Oklahoma Water Supply Action Plan	SWAP
Standardized Precipitation Index	SPI
Technical Memorandum	TM
Upper Red River Basin Study	URRBS
United States	U.S.
United States Geological Survey	USGS
Wildlife Management Area	WMA

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Abstract

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. This 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 junior permitted upstream diversions. 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.

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.

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.

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].

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

Content Organization

This Executive Summary Report synthesizes this large body of work into a condensed publication that targets a general audience. The URRBS Full Report totaled 667 pages in body text, as well as 14 Appendices totaling 1,817 pages as listed below. Each Appendix targeted specific technical aspects of the URRBS and was published as a separate technical memorandum in support of this URRBS per the description below.

1. Appendix A: Legal Review of Water Rights and Adaptation Strategies: Issues, and Constraints and Options (Kershen, 2021) (291 pp.). Describes background law and legal issues related to the adaptation strategies identified and evaluated in Chapters 7 and 8 of the URRBS Full Report.

2. Appendix B: North Fork Red River Aquifer Study (Smith et al., 2017) (124 pp.). Describes the methods and results of the groundwater model developed by the United States Geological Survey (USGS) for the URRBS. Supported the integrated groundwater and surface water modeling analyses used to evaluate status-quo conditions and to evaluate adaptation strategies as described in Chapters 6, 7, and 8 of the URRBS Full Report.

3. Appendix C: North Fork of the Red River System Model Naturalization Update (Lynker Technologies, 2022) (106 pp.). Describes the methods and results of the network basin-wide stream-water model commissioned by the OWRB for the URRBS. Supported the integrated groundwater and surface water modeling analyses used to evaluate status-quo conditions and to evaluate adaptation strategies as described in Chapters 6, 7, and 8 of the URRBS Full Report.

4. Appendix D: Lugert-Altus Reservoir Yield Analysis (Reclamation, 2021) (137 pp.). Describes the methods and results of the Lugert-Altus Reservoir yield model developed by Reclamation for the URRBS. Supported the integrated groundwater and surface water modeling analyses used to evaluate status-quo conditions and to evaluate adaptation strategies as described in Chapters 6, 7, and 8 of the URRBS Full Report.

5. Appendix E: Tom Steed Reservoir Yield Analysis (Reclamation, 2021) (178 pp.). Describes the methods and results of the Tom Steed Reservoir yield model developed by Reclamation for the URRBS. Supported the integrated groundwater and surface water modeling analyses used to evaluate status-quo conditions and to evaluate adaptation strategies as described in Chapters 6, 7, and 8 of the URRBS Full Report.

6. Appendix F: Technical Memorandum No. 86-68210-2016-05, Upper Red River Basin Study Climate and Hydrology Projections (Reclamation,

2016) (32 pp.). Describes the methods and results of the climate change sensitivity analysis developed by Reclamation for the URRBS as described in Chapter 6.5 of the URRBS Full Report.

7. Appendix G: Technical Memorandum No. 86-68210-17-04, Estimation of Climate Change Impacts on Future Agricultural Irrigation and Municipal and Industrial Water Demands (Reclamation, 2017) (41 pp.). Describes the methods and results of the climate change sensitivity analysis developed by Reclamation for the URRBS as described in Chapter 6.5 of the URRBS Full Report.

8. Appendix H: Technical Memorandum No. ENV-2019-087, Supplemental Agricultural Irrigation Demand Estimates for the Upper Red River Basin Study (Reclamation, 2019) (21 pp.). Describes the methods and results of the climate change sensitivity analysis developed by Reclamation for the URRBS as described in Chapter 6.5 of the URRBS Full Report.

9. Appendix I: Economic Impacts of Drought on Recreation and Irrigated Agriculture (Reclamation, 2018) (89 pp.). Describes the impacts of status-quo conditions on the local and regional economy that depends on Lugert-Altus and Tom Steed reservoirs as described in Chapter 6.6 of the URRBS Full Report.

10. Appendix J: Formulation of Hydrologic Thresholds to Support Water Management in the Lugert-Altus Reservoir Hydrologic Basin (Reclamation and OWRB, 2022) (254 pp.). Described the approach, assumptions, and methods for selecting a range of hydrologic indicators and thresholds that could be used to manage stream water rights in the basin and to protect the yield of Lugert-Altus Reservoir during drought periods as described in Chapter 8.2.5 of the URRBS Full Report.

11. Appendix K: Formulation of Stream-Water Rights Management Alternatives in the Tom Steed Reservoir Hydrologic Basin (Reclamation and OWRB, 2020) (186 pp.). Described the approach, assumptions, and methods for selecting a range of hydrologic indicators and thresholds that could be used to manage stream water rights in the basin and to protect the yield of Tom Steed Reservoir during drought periods as described in Chapter 8.3.2 of the URRBS Full Report.

12. Appendix L: Cable Mountain Reservoir Hydrology and Costs (15 pp.). Describes the hydrology and preliminary-level design and cost estimates of a new reservoir to supplement water supplies for the Lugert-Altus Irrigation District as described in Chapter 8.2.6 of the URRBS Full Report.

13. Appendix M: Water Availability Modeling Results for the Tom Steed Hydrologic Basin (268 pp.). Described the impacts on water availability

in the Tom Steed Reservoir hydrologic basin from curtailing junior stream permits based on the hydrologic thresholds selected through the URRBS as described in Chapter 8.3.2 of the URRBS Full Report.

14. Appendix N: Peer Review Report (75 pp.). Described the approach and outcome of an independent peer review conducted in accordance with Reclamation's Policy CMP P14, "Peer Review of Scientific Information and Assessments". Because the URRBS models, analyses, and findings produced by Reclamation have the potential to change water policy and inform regulatory decision-making by the OWRB, they were considered to be scientific information that is "influential" pursuant to Section 4.A. of CMP P14. The scientific information supporting the URRBS that was subjected to peer review comprised of seven technical memorandums (TMs) identified as Appendix C, Appendix D, Appendix E, Appendix J, and Appendix K above.

Two additional TMs specifically related to the methods, assumptions, and results associated with water availability modeling of "status quo" management conditions were peer reviewed, but the contents of the TMs were embedded in their entirety directly into Chapter 6.4 of the URRBS and thus, did not warrant a separate appendix.

Regarding the other appendices supporting the URRBS: Appendix B was peer reviewed independently by USGS; and the climate change TMs (Appendix F, Appendix G, and Appendix H) underwent an independent technical sufficiency review by Reclamation's Technical Services Center.

Study Area and Overview of Features

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 primarily provides water to the Lugert-Altus ID for agricultural purposes, as well as to the city of Altus, Oklahoma for municipal and industrial (M&I) purposes. Tom Steed Reservoir provides M&I water to the cities of Altus, Snyder, and Frederick; Altus Air Force Base (AFB); several rural water districts; and to the Hackberry Flat Wildlife Management Area (WMA) 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 (Figure 1). 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.

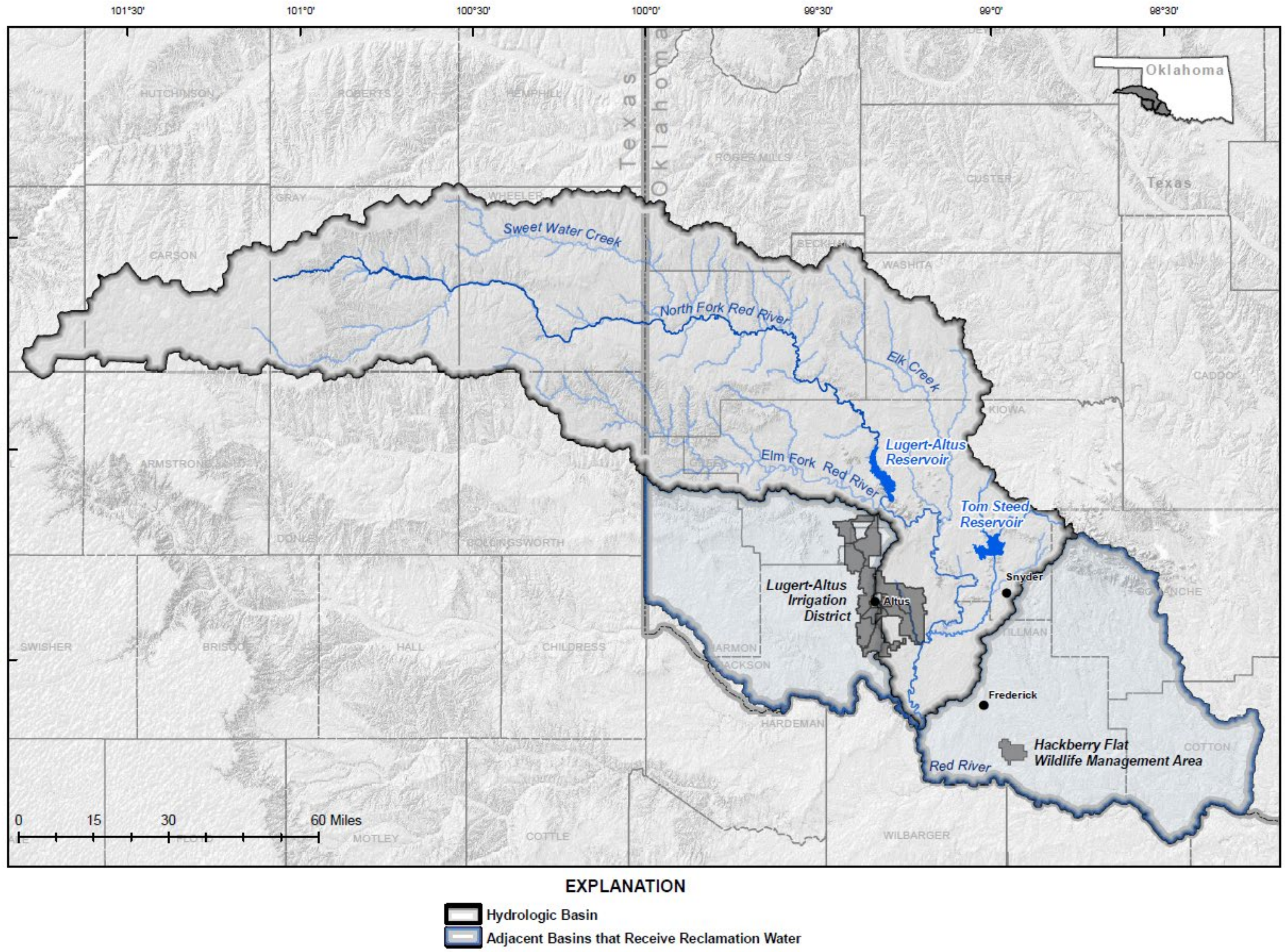


Figure 1. URRBS study area, including Lugert-Altus and Tom Steed reservoirs, customers, the NFRR hydrologic basin, and adjacent basins that receive Reclamation water.

Lugert-Altus Reservoir is the principal feature of the W.C. Austin Project, which is a water supply project constructed by Reclamation in Greer, Kiowa, and Jackson counties, Oklahoma (Figure 2). The dam, along with a series of five dikes, impound the natural flows from the NFRR. The W.C. Austin Project was authorized by Public Law 75-761 on June 28, 1938, for the purposes of flood control and irrigation, and it was constructed in the 1940s. The W.C. Austin Project is owned by the U.S. and is administered by Reclamation. Operation and maintenance (O&M) responsibility for the project has been transferred to the Lugert-Altus ID through a contract with the U.S (Contract No. I1r-1375).

Figure 2. Altus Dam, W.C. Austin Project.

Irrigation benefits are provided through an irrigation water right that was granted to the Lugert-Altus ID by the State of Oklahoma in 1939 (OWRB Water Right No. 39-23). This appropriation allows the Lugert-Altus ID to divert up to 85,630 acre-feet per year (acre-ft/yr) from the NFRR for irrigation purposes. The water is conveyed through a 270-mile-long system of canals and laterals (Figure 3), where it is used to support a diverse array of crops, primarily cotton. M&I benefits are provided through a 4,800 acre-ft/yr water right held by the U.S. that was contracted to the city Altus in exchange for Reclamation's assurance of a water supply from Lugert-Altus Reservoir[2]. The original water right was recognized by the OWRB for M&I use with a priority date of December 29, 1925 (Oklahoma Water Right No. 26-6)[3]. When the W.C. Austin Project was constructed in the 1940's, the city of Altus entered into a water supply contract with the U.S. to use Lugert-Altus Reservoir to store and deliver 4,800 acre-ft/yr of water to the city of Altus. To this end, a Settlement Agreement was later signed in 1954 between the city of Altus and Lugert-Altus ID that requires the reservoir to be operated in a manner that protects the senior M&I water right. Today, Tom Steed Reservoir serves as the primary water supply source for the city of Altus, but when supplemental water is needed from Lugert-Altus Reservoir, it is conveyed from Lugert-Altus Reservoir through the irrigation canals and diverted into Altus Lake which is owned by the city of Altus.

[2] Contract between the United States and the City of Altus for a Municipal Water Supply, Clauses 3 and 5 (May 2, 1941).

[3] The OWRB set forth the City of Altus and the LAID water rights in the OWRB Final Order No. 4 (July 14, 1964).

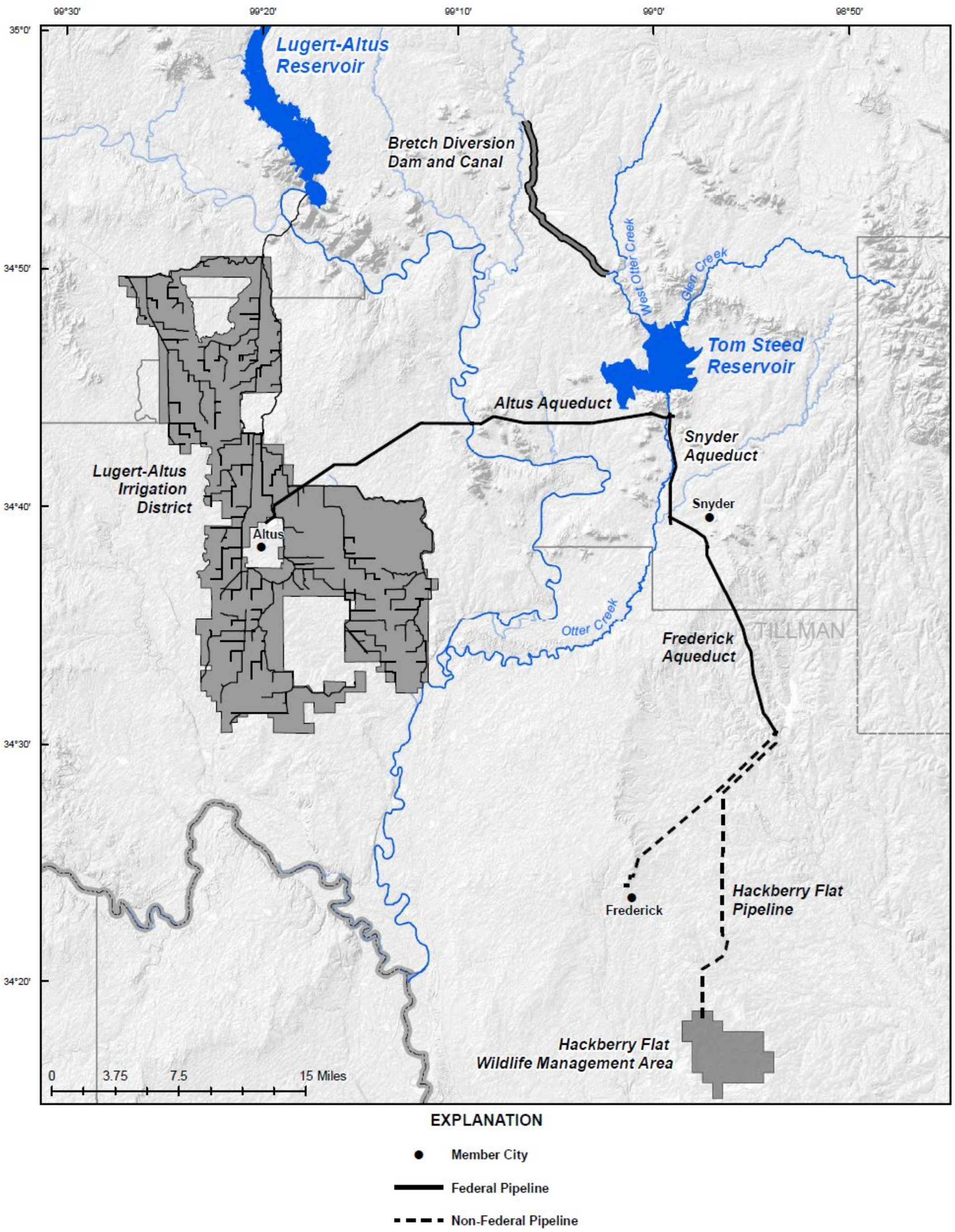


Figure 3. Features and member cities of the Mountain Park Project that receive M&I water, as well as the Hackberry Flat WMA which receives water for EQ benefits.

Tom Steed Reservoir is the principal feature of the Mountain Park Project, which is a water supply project constructed by Reclamation in Jackson, Kiowa, and Tillman counties, Oklahoma (Figure 4). Inflow into Tom Steed Reservoir comes naturally from West Otter Creek and Glen Creek, as well as from diversions from Elk Creek through the Bretch Diversion Dam and Canal (Figure 3). The Mountain Park Project was authorized under Public Law 90-503 on September 21, 1968, for the purposes of providing water for M&I use, conserving and developing fish and wildlife resources, providing outdoor recreation, and controlling floods. Title IV of Public Law 103-434 (Mountain Park Project Act of 1994) dated October 31, 1994, added environmental quality (EQ) benefits to the Mountain Park Project. The Mountain Park Project was constructed in the 1970s. It is owned by the U.S. and administered by Reclamation, and O&M responsibility for the project has been transferred to the MPMCD through a contract with the U.S (Contract No. 14-06-500-1794).

Figure 4. Mountain Park Dam, Mountain Park Project.

The M&I benefits are provided through a water right that was granted to the MPMCD by the State of Oklahoma in 1967 (Oklahoma Water Right No. 67-671) and amended in 1983. This appropriation allows the MPMCD to divert up to 16,100 acre-ft/yr from Elk and Otter Creeks for domestic, municipal, and industrial purposes. Of this amount, 13,748 acre-ft/yr is allocated to the MPMCD member cities of Altus, Snyder, and Frederick for M&I purposes. These three entities act as wholesale water providers to 26 public and private water customers spread across a 2,000 square mile area covering seven counties (Figure 5). About 43,000 people are served by Tom Steed Reservoir. The EQ benefits are provided in accordance with an EQ Plan that was signed in April 1995 following the authorizing legislation. The EQ Plan reallocated 60 percent of the city of Frederick's contractual share of the annual project water supply to the ODWC for use at the Hackberry Flat WMA as an appropriate EQ activity in exchange for an adjustment to Frederick’s share of the MPMCD’s repayment and O&M obligations. A water supply contract has since been signed by the MPMCD and ODWC which allows the MPMCD to deliver up to 2,352 acre-ft/yr to the WMA.

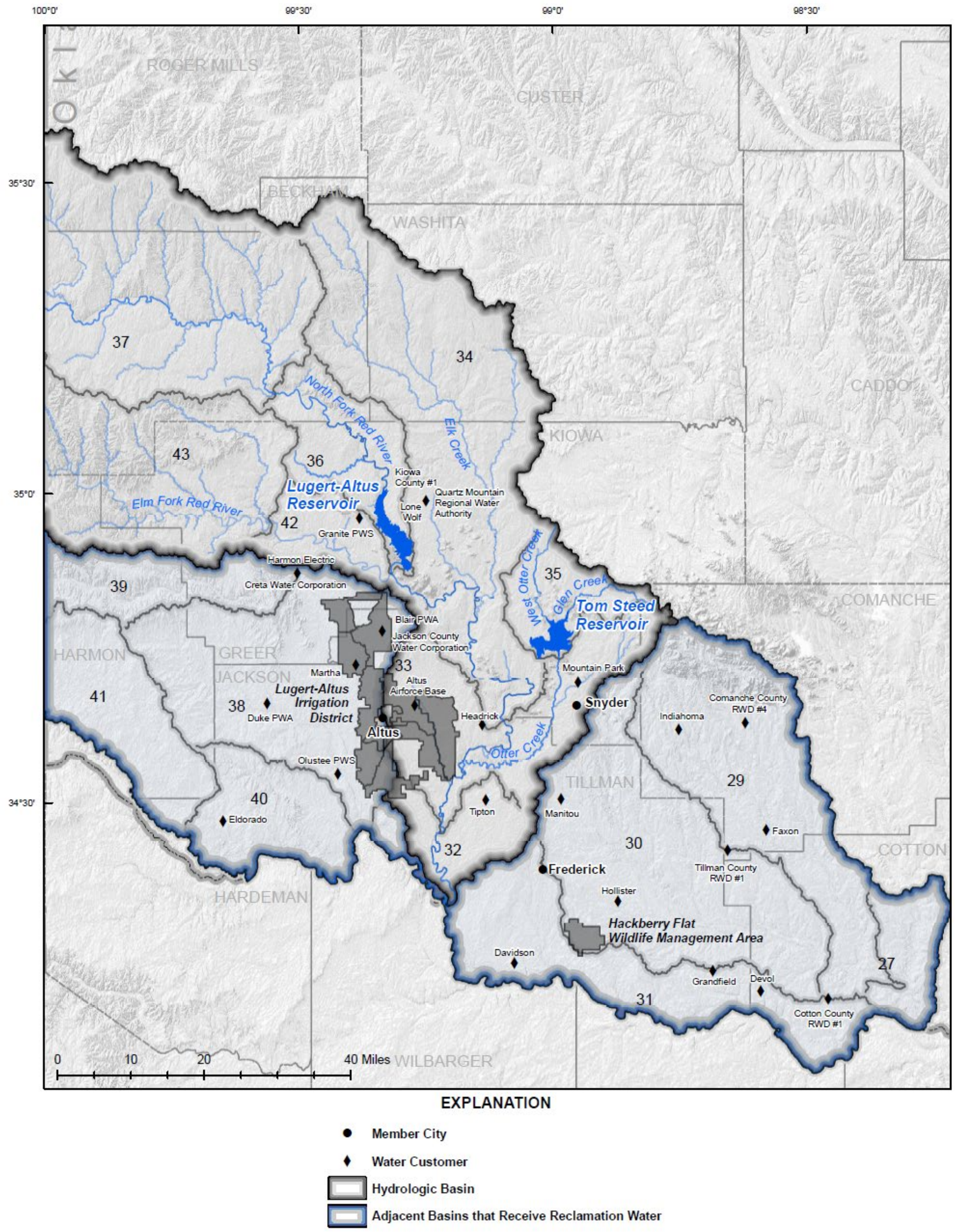


Figure 5. Member cities and customers as of 2018 that receive water from Tom Steed Reservoir, Mountain Park Project.

Problems and Needs

Overview

Southwest Oklahoma experienced a record-breaking drought between 2010 and 2015 (a.k.a., 2010s Drought of Record; Figure 6). 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. An aerial photograph of Lugert-Altus Reservoir both before and during the drought illustrates the severity of the drought (Figure 7). The drought also had severe impacts on recreation and fish and wildlife. A popular board walk at the Quartz Mountain Resort Arts and Conference Center at Lugert-Altus Reservoir was left exposed during the drought (Figure 8), as were many of the reservoirs' boat docks, severely restricting access to boating, fishing, and recreation sports (Figure 9). Around this time, the entire fishery at Lugert-Altus Reservoir, an estimated 350,000 fish[4], was killed by toxic Golden Algae which had bloomed after the reservoir's low storage volume increased the concentration of salts in the reservoir. Municipal and industrial water deliveries from Tom Steed Reservoir were restricted by over 40 percent, and EQ deliveries to Hackberry Flat WMA were discontinued.

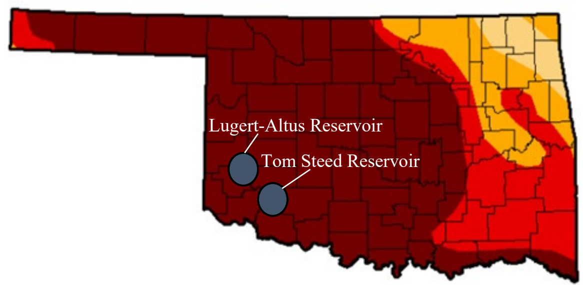


Figure 6. Oklahoma, U.S. Drought Monitor 2014.

[4] http://newsok.com/article/3843485.

Figure 7. Arial photo of Lugert-Altus Reservoir in December 2016 (left) at 60 percent full and in March 2014 (right) during the 2010s Drought of Record when the reservoir was only 12 percent full.

Figure 8. A boardwalk at the Quartz Mountain Resort extends over a dry Lugert-Altus Reservoir (left); low reservoir levels sparked a Golden Algae bloom that killed thousands of fish (right; photo provided by Oklahoma Department of Wildlife Conservation).

Figure 9. A boat ramp and courtesy dock at Tom Steed Reservoir during the 2010s; compliments of State Impact, NPR, Logan Layden Feb 24, 2015.

Several pressing needs emerged during the record-breaking drought, the details of which are described in Chapter 2 of the URRBS Full Report. This included needs for:

- 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 (Chapter 2.2.3 of the URRBS Full Report).
- 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. Figure 10 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 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 almost fully depleted. 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.

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 junior permitted stream diversions; by curtailing junior upstream permits, more water could be available to store in Reclamation's reservoirs during drought periods. 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.

As all of these challenges converged during the 2010 Drought of Record, the opportunity arose for Reclamation, OWRB, Lugert-Altus ID, and MPMPCD to collaborate through the URRBS to address them. Next, a brief overview of Oklahoma water law is described to provide context to the challenges related to permitted withdrawals upstream of the reservoirs.

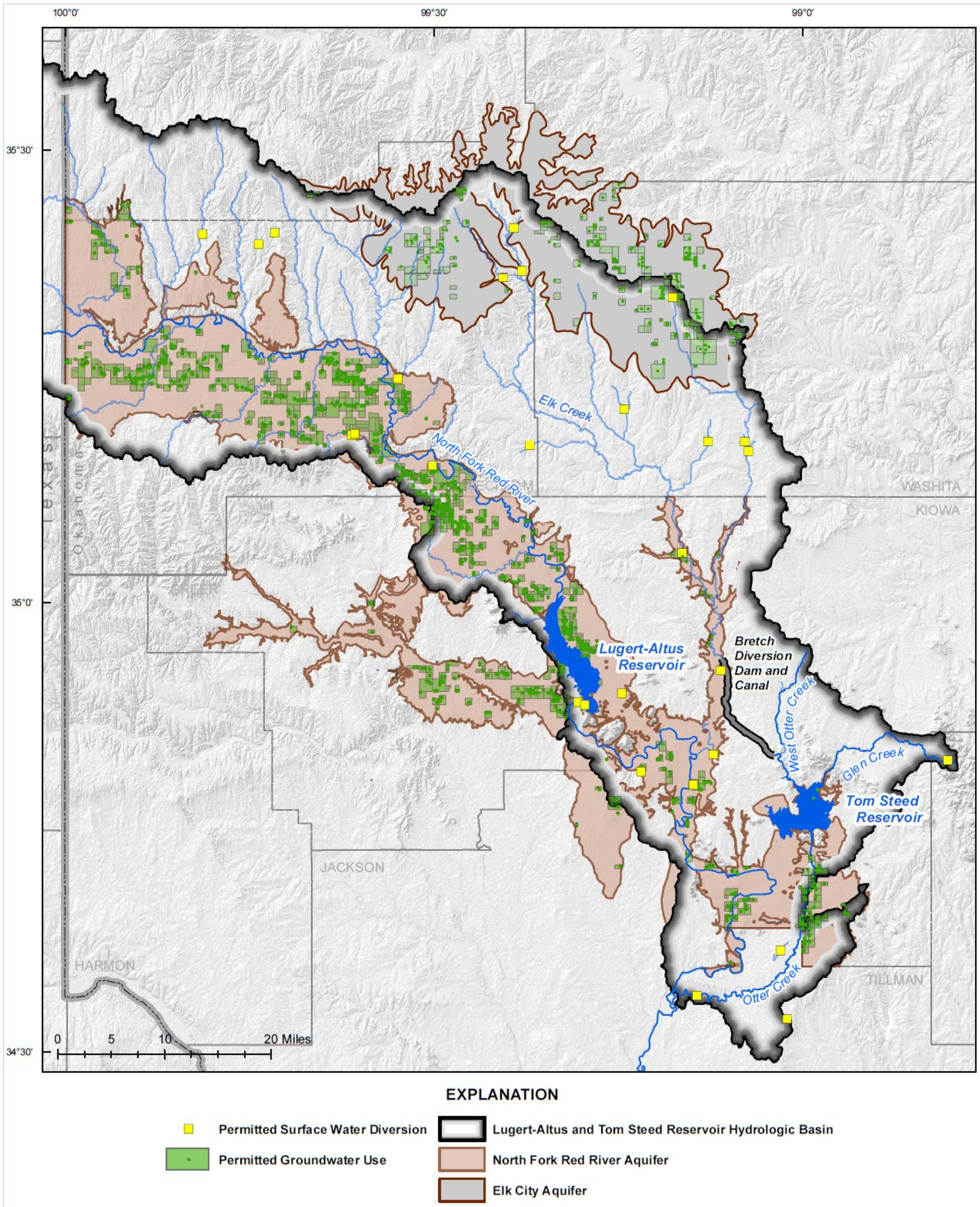


Figure 10. Distribution of permitted surface water diversions within the Lugert-Altus and Tom Steed hydrologic basins, as well as permitted groundwater use within the NFRR and Elk City aquifers.

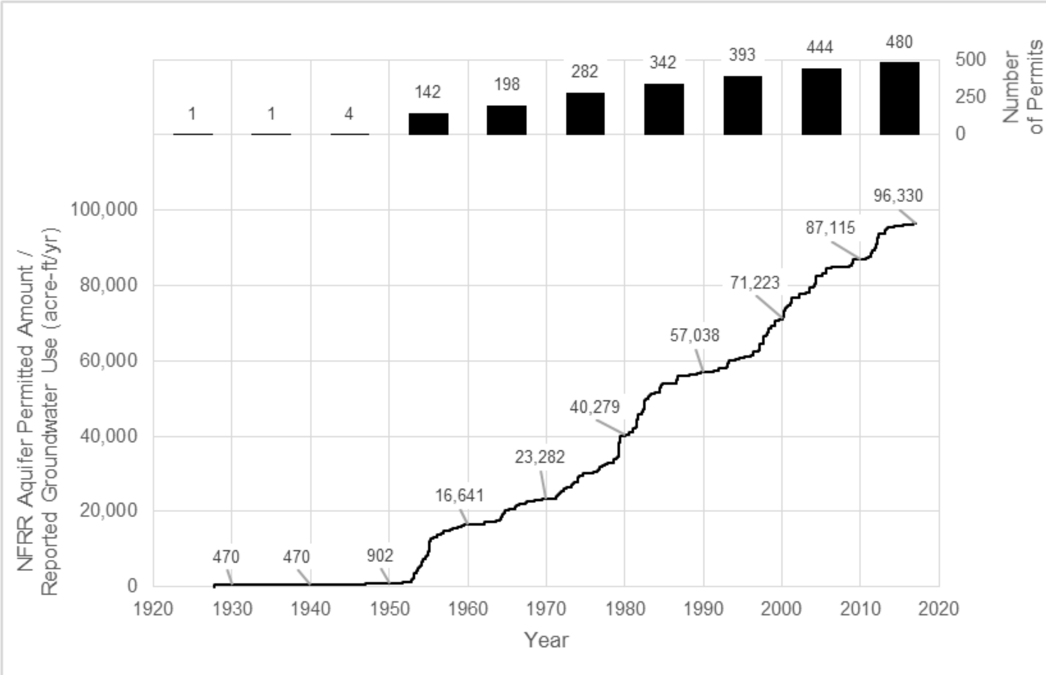


Figure 11. Groundwater permits issued in the NFRR aquifer, including number of permits and cumulative permitted volumes.

Oklahoma Water Law Basics

To better understand the needs in the study area, some key points about Oklahoma water law are worth highlighting:

- With the exception of the Arbuckle-Simpson aquifer in southeast Oklahoma, groundwater and surface water are regulated separately in Oklahoma. The OWRB has the authority to issue groundwater and surface water permits for uses above and beyond domestic and household uses, which are exempt of permitting requirements. Regardless of whether water is used for domestic purposes or is permitted, it must be put to beneficial use and not be wasted.
- Groundwater permits are issued based on land owned or leased by applicants such that each acre of land overlying an aquifer is allocated an EPS of the aquifer's 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 almost fully depleted, with the remaining portion of the aquifer's saturated thickness reserved for domestic use. If the domestic reserve was fully utilized in combination with the aquifer's MAY, the aquifer would be fully depleted. Importantly, the MAY and EPS are

determined based on legally-mandated investigations that the OWRB must undertake at least every 20 years.

- 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.
- As previously mentioned, surface water in Oklahoma is managed under Prior Appropriation, although Riparian management also is integrated into surface water regulation. The term "Riparian" refers to the right of smaller users to withdraw surface water for domestic and household uses without a permit. Uses above and beyond domestic purposes require a permit, which are managed under a "Prior Appropriation" system. Often referred to as "first in time, first in right", this means that the older a permit's application date, the more "senior" the water right is relative to a "junior" water right that has a more recent application date. Under Oklahoma's joint Prior Appropriation/ Riparian system, a domestic reserve is set aside in the stream and excluded by the OWRB when calculating the volume of unappropriated surface water available for new permits.
- Pursuant to Oklahoma regulations, for direct diversions from a stream, the determination of water available for appropriation takes into consideration the average annual rainfall run-off in the watershed above the point(s) of diversion, the average annual flow, stream gauge measurements, domestic uses, and all existing appropriations and other designated purposes in the stream system. Importantly, the OWRB may consider other evidence or laws relating to streamflow or elevation to determine unappropriated surface water.
- These considerations are accounted for by the OWRB in an equation that aims to maximize the use of the stream while avoiding interference with senior water right holders. In doing so, the equation subtracts only the downstream reservoir's permit volume from average annual streamflow to determine unappropriated water availability, in part because regulations state that water in reservoir storage above the permitted amount is considered public water and subject to appropriation by the OWRB.

This chapter 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.

Related Activities and Opportunities

Chapter 3 of the URRBS provides a detailed accounting of previous and ongoing efforts that have either been recently completed or are underway to address challenges facing the study area, and thus provides basis for the collaborative state, local, and Federal partnership that spearheaded this URRBS.

State-Led Efforts

In 2012, the state of Oklahoma presented its official long-range strategy for managing and protecting water supplies for the next 50 years (Figure 12). The OCWP, compiled with the help of an extensive public involvement campaign, contains a wealth of technical data, tools, and information, along with a variety of policy recommendations that are manifested in an Executive Report, 13 Watershed Planning Region Reports, and many other supporting technical publications[5]. Since its publication, the OCWP has and continues to serve as an indispensable resource for helping water resource managers make informed decisions about water use and management through 2060 and beyond.

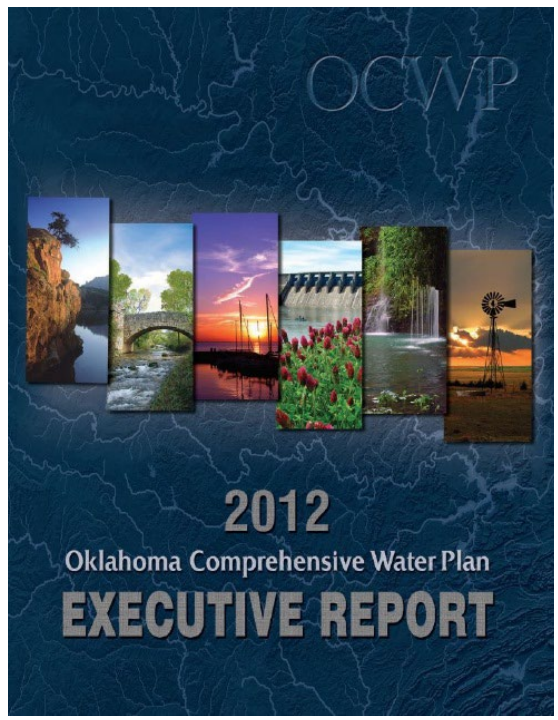


Figure 12. Cover page, OCWP 2012 Update Executive Report.

Some notable quotes from the OCWP's Executive Report are worth pointing out:

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

On the need to have reliable data and tools to quantify and manage groundwater and surface water supplies:

> "Recognizing that information is the foundation for sound decision-making related to the development and protection of Oklahoma's water supplies, the State of Oklahoma must not only reestablish its dwindling base of reliable water data but expand the network of tools necessary to quantify, manage, and allocate surface and groundwater resources confidently. In light of the anticipated stress on water supplies, unless the declining trend is reversed through the combined efforts of elected officials and the agencies and entities associated with managing and protecting Oklahoma's water, managers will lack the required information to justify extremely consequential and potentially costly decisions."
> - OCWP Executive Report Foreword, Page 1

On the need to reevaluate existing water laws and procedures to promote conservation while maximizing water rights and water reliability:

> "Based upon recommendations from the public and OWRB staff, several aspects of the state's current approach to water management require the evaluation of new or enhanced management schemes – including the possible implementation of new policy and clarifications to existing statues and rules – that promote conservation to maximizing existing water rights and create assurance that water resources will be available when and where required."
> - OCWP Executive Report, Page 15

On the need to develop mechanisms during drought periods to protect the yield of reservoirs and manage upstream junior water rights:

> "Additional concerns have been raised about protecting the yield of reservoirs, particularly by some appropriation right holders that authorize use of water from storage reservoirs constructed by federal agencies. During low flow or drought conditions, there is no good mechanism currently in place to notify junior upstream appropriators if interference is occurring or to enforce curtailment of ongoing diversions, thus reducing the dependability of many reservoirs..."
> - OCWP Executive Report, Page 15

Recognizing the aforementioned needs, the OCWP included several priority recommendations across various areas, including but not limited to water conservation, efficiency, and reuse; water supply reliability; instream/environmental flows; and infrastructure funding. The priority recommendations related to “Water Supply Reliability” were particularly relevant to the needs set forth in this URRBS and are thus quoted in full:

> “To address projected increases in water demands and related decreases in availability, as well as to ensure the fair, reliable, and sustainable allocation of Oklahoma’s water supplies, the State legislature should provide stable funding to the OWRB to implement the following recommendations:
>
> 1. Address by 2022 the growing backlog of statutorily-required maximum annual yield studies and overdue 20-year updates on groundwater basins within the state, including consideration of any interactions between surface and groundwater sources, to accurately determine water available for use.
> 2. Develop surface water allocation models on all stream systems within the state to assess water availability at specific locations, manage junior/senior surface water rights under various drought scenarios, and anticipate potential interference between users, and evaluate impacts of potential water transfers.
> 3. Utilize water use stakeholders (including input from the recommended Regional Planning Groups), researchers, and other professionals to develop recommendations, where appropriate, regarding:
>   - Consideration of a seasonal (rather than annual) stream water allocation program to address seasonal surface water shortages and water rights interference.
>   - 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.
>   - 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 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, allocation banking coupled with an accurate method of accounting, irrigation practice improvements, and adoption of new irrigation technology.”

Stakeholder-Led Efforts

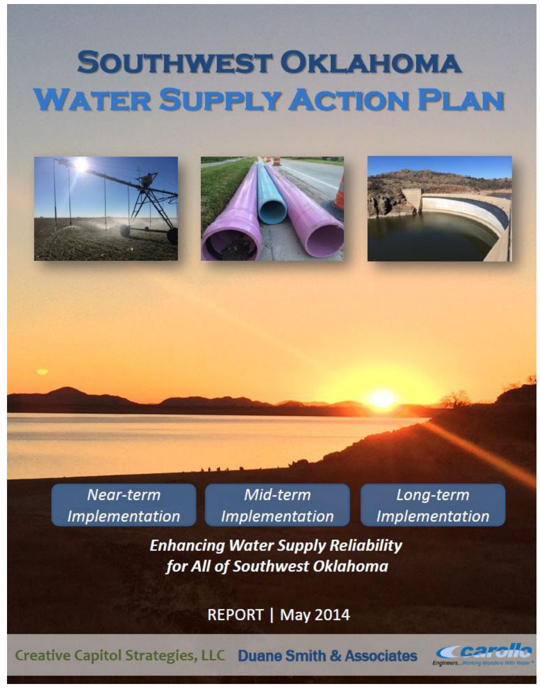


Figure 13. The Southwest Oklahoma Water Supply Action Plan was completed in 2014 and identified a variety of strategies to address water supply vulnerabilities.

In the midst of the 2010s Drought of Record, water users representing diverse interests formed an Advisory Committee that launched the development of a Southwest Oklahoma Water Action Plan (SWAP; Figure 13). The Advisory Committee, comprised primarily of users of Lugert-Altus and Tom Steed reservoirs, identified several near -, mid -, and long-term strategies to address a variety of water supply issues and vulnerabilities in the region.

Near-term strategies focused on enhanced drought contingency planning, water conservation, and on improving the treatment and delivery of local M&I and agricultural water supplies. They also included near-term investigations on groundwater, including the impacts of upstream groundwater pumping on reservoir yield, as well as on the availability of additional groundwater supplies to either extend or augment existing reservoir supplies. Mid-term strategies focused on enhancing existing supplies through the rehabilitation and operations of existing infrastructure, interconnections, and through water recycling and reuse. Long-term strategies focused on the expansion/development of new supplies through more complex activities such as interbasin transfers, raising the dams of Lugert-Altus and Tom Steed reservoirs, and construction of a new reservoir. The SWAP has since been updated and identifies this URRBS (i.e., "Red River Study") as a yet-to-be-completed future strategy (Duane Smith and Associates, 2018).

Federal-Led Efforts

Together, the OCWP and SWAP charted a course at the state and local levels to take actions that improve collaboration and readiness to prepare for and respond to drought. Within these road maps also emerged the role of the Federal government to help address needs of the area. With its authorities, ownership, and interest in Lugert-Altus and Tom Steed reservoirs, Reclamation was viewed by state and local officials as uniquely positioned to participate and lead investigations to address key areas of need, especially areas where the solutions, such as those related to management of water rights, were complex and could potentially result in changes in water law, regulations, policy, or management. In doing so, Reclamation could function as a neutral third party that could unite stakeholders and facilitate the development of solutions that were both credible and defensible. Reclamation's Basin Study Program appeared to provide the necessary vehicle for such collaboration.

Purpose, Goals, and Objectives

The goal of this URRBS was to address many of the challenges outlined in Chapter 2 of the URRBS Full Report, with the purpose of improving supply reliability and drought resiliency of Lugert-Altus and Tom Steed reservoirs. At the same time, the goal was to consider all users in the basin and provide information to help achieve win-win outcomes.

In doing so, other prominent goals of this study are noted below:

1. To incorporate an unbiased approach that is in the public interest.
2. To utilize the best available data, and to develop new models and tools based on sound scientific and engineering principles, thus ensuring that methods and results are credible, replicable, and defensible.
3. To 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:

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 URRBS Full Report. This chapter also defines future groundwater and surface water demand (i.e., 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.

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 for the purpose of determining a MAY for the NFRR aquifer and was conducted by the 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 URRBS Full Report.

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.**

   Overall, 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 development of two Reclamation Reservoir Yield (RRY) models, one for Lugert-Altus Reservoir and one for Tom Steed Reservoir. Although the surface water models were developed separately, Reclamation and 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 URRBS Full Report.

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 URRBS Full 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 URRBS Full 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 URRBS Full 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*.

Basin-Wide Demands and Supplies

Chapter 5 of the URRBS Full Report provides a detailed characterization and inventory of existing water supplies, as well as existing and future demands in the URRBS study area. Because water supply availability is dependent in large part upon the local climate, as well as on the demands placed on those supplies, Chapter 5 of the URRBS Full Report begins with climate characteristics and water demands. For demands, current (i.e., existing) demands on both groundwater and surface water are presented, focusing primarily on permitted and reported use volumes. The analysis includes both "run-of-the-river" demands within the Lugert-Altus and Tom Steed reservoir hydrologic basins, as well as demands from users of the two reservoirs. The discussion then turns to available groundwater and surface water supplies that exist under current demand pressures. For surface water, these pressures are caused not only from direct withdrawals, but also potentially by groundwater withdrawals from adjoining aquifers. Projecting into the future, Chapter 5 of the URRBS presents various future demand scenarios that may be placed on groundwater and surface water supplies, including both permitted demands and non-permitted domestic uses.

Future Supplies, System Reliability, and Status-Quo Impact Assessment

Chapter 6 of the URRBS Full Report provides a detailed analysis on the impacts of groundwater and surface water demand scenarios on future basin-wide water supplies. The analysis was conducted under a range of assumed future "Status-Quo" conditions. As described below, status-quo development assumed that current OWRB water management practices would continue into the future or that reasonably foreseeable changes in OWRB practices could occur within existing Oklahoma water law. This chapter also describes the groundwater and surface water models used to simulate the demand-supply system, as well as the performance metrics selected to evaluate water supply reliability. Finally, consideration was given towards how demands and supplies may change under a range of variable climate patterns relative to baseline conditions that represent the observed, historical record.

Status-Quo Conditions

The fundamental assumption underlying the development of groundwater and stream water demand scenarios for this study was that the future is constrained by existing Oklahoma water law and current OWRB regulations and water policy, except as specifically noted in the following sections. 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 URRBS Full Report, respectively.

Future Groundwater and Stream-Water Demand Scenarios

Future groundwater demand scenarios were formulated and defined based on the status-quo assumptions described in Chapter 6.1.1 of the URRBS Full Reports, as well as by the USGS study on the NFRR aquifer (Smith et al., 2017). The URRBS adopted the four USGS groundwater use scenarios for the NFRR aquifer, presented in order of increasing growth and development as: "Naturalized", "Existing", "New", and "Full" (Table 1 and Table 2). Future stream-water demand scenarios were formulated and defined based on the status-quo assumptions described in Chapter 5.4.2, Chapter 6.1.2, and Chapter 6.2.3 of the of the URRBS. Eight stream-water development scenarios were formulated for the Lugert-Altus Reservoir hydrologic basin, and 24 stream-water development scenarios were formulated for the Tom Steed Reservoir hydrologic basin, including a "Naturalized" scenario. For both groundwater and stream water, the "Naturalized" scenarios assumed no permitted use from existing or future permits holders.

A summary of the groundwater and stream-water demand scenarios are summarized in Table 1 and Table 2 for the Lugert-Altus and Tom Steed reservoir hydrologic basins, respectively.

Table 1. Summary of groundwater and stream-water modeling scenarios for the Lugert-Altus Reservoir hydrologic basin.

	Modeling Conditions	GW Permits	SW Permits	Lugert-Altus Reservoir	SW Domestic
Increasing Growth and Development	Naturalized	Naturalized	Naturalized	-	-
	Existing GW Permits, Existing Domestic SW, Existing SW Permits	Existing	Existing	Full	Existing
	New GW Permits, Existing Domestic SW, Existing SW Permits	New	Existing	Full	Existing
	Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	Existing	Full	Existing
	Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	Existing	Full	New (Low)
	Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	Full	Full	New (Low)
	Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	Existing	Full	New (High)
	Full GW Permits, New Domestic SW (High), Full SW Permits	Full	Full	Full	New (High)

Table 2. Summary of groundwater and stream-water modeling conditions for the Tom Steed Reservoir hydrologic basin.

Increasing Growth and Development

Modeling Conditions	GW Permits	SW Permits	Tom Steed Reservoir	SW Domestic
Naturalized	Naturalized	Naturalized	-	-
Existing GW Permits, Existing Domestic SW, Existing SW Permits	Existing	Existing	Existing / Mid / Full	Existing
New GW Permits, Existing Domestic SW, Existing SW Permits	New	Existing	Existing / Mid / Full	Existing
Existing GW Permits, Existing Domestic SW, Existing and New SW Permits (Low)	Existing	New (Low)	Existing / Mid / Full	Existing
New GW Permits, Existing Domestic SW, Existing and New SW Permits (Low)	New	New (Low)	Existing / Mid / Full	Existing
Existing GW Permits, Existing Domestic SW, Existing and New SW Permits (High)	Existing	New (High)	Existing / Mid / Full	Existing
New GW Permits, Existing Domestic SW, Existing and New SW Permits (High)	New	New (High)	Existing / Mid / Full	Existing
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	Existing	Full	Existing
Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	Existing	Full	New (Low)
Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	Full	Full	New (Low)
Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	Existing	Full	New (High)
Full GW Permits, New Domestic SW (High), Full SW Permits	Full	Full	Full	New (High)

Groundwater Demand Scenarios

For the purposes of the URRBS, future groundwater demands were defined based on USGS (Smith et al., 2017), which identified four 50-yr groundwater use scenarios for the NFRR aquifer: "Naturalized", "Existing", "New", and "Full". Under all four scenarios, the following are assumed: (a) Pumping lasts for 50 years, beginning in 2013 and ending in 2062; and (b) hydrogeology is simulated under "baseline" (observed, historic) climate conditions[6]. The scenarios differed in their assumptions related to regular groundwater permit conditions and permit use, where:

1. ***"Naturalized"*** use: Assumed a 50-yr period with no existing or future groundwater pumping of the NFRR aquifer. No additional demands are assumed on the Elk City aquifer beyond what already exists.
2. ***"Existing"*** use: Assumed a 50-yr pumping rate of 22,988 acre-ft/yr over the entire NFRR aquifer. This was the amount of groundwater use reported in the year 2013 during the 2010s Drought of Record.
3. ***"New***" use: Assumed a 50-yr pumping rate of 27,678 acre-ft/yr over the entire NFRR aquifer. This represents a 20.4 percent growth rate on top of the "Existing" groundwater use based on population/growth projections cited in the OCWP 2012 Update.
4. ***"Full***" use: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS.

Stream-Water Demand Scenarios

For clarity, the demand scenarios are listed again here as follows and are shown in Table 1 and Table 2 for the Lugert-Altus and Tom Steed reservoir hydrologic basins, respectively:

Lugert-Altus Reservoir Hydrologic Basin

1. ***"Naturalized"***: Assumed no diversions from existing or future stream-water permits[7] and no groundwater pumping.
2. ***"Existing GW Permits, Existing Domestic SW, Existing SW Permits"***: Assumed full use of existing stream water permits of 1,422 acre-ft/yr, as well as a 50-yr pumping rate of 22,988 acre-ft/yr over the NFRR aquifer. Assumed no new stream permits would be issued.

[6] The impact of potential changing climate conditions on supplies are addressed in Chapter 6.5 of the URRBS Full Report.
[7] Observed domestic stream-water use is automatically in gage data, meaning under the naturalized condition domestic stream-water use is occurring.

3. ***"New GW Permits, Existing Domestic SW, Existing SW Permits"***: Assumed full use of existing stream water permits, as well as an increased 50-yr pumping rate of 27,678 acre-ft/yr over the NFRR aquifer. Assumed no new stream permits would be issued.
4. ***"Full GW Permits, Existing Domestic SW, Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; and full use of existing stream-water permits of 1,422 acre-ft/yr, with no increase in future domestic stream use or the issuance of new stream water permits.
5. ***"Full GW Permits, New Domestic SW (Low), Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream-water permits of 1,422 acre-ft/yr; and an assumed new domestic stream use totaling 5,000 acre-ft/yr[8]. Assumed no new stream permits would be issued.
6. ***"Full GW Permits, New Domestic SW (Low), Full SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 1,422 acre-ft/yr; an assumed new domestic stream use totaling 5,000 acre-ft/yr; and full development of all remaining stream water, meaning the full appropriation of all remaining average annual naturalized flows above 90,430 acre-ft/yr[9].
7. ***"Full GW Permits, New Domestic SW (High), Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 1,422 acre-ft/yr; and an assumed new domestic stream use totaling 20,000 acre-ft/yr[10]. Assumed no new stream permits would be issued.
8. ***"Full GW Permits, Future Domestic SW (High), Full SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 1,422 acre-ft/yr; an assumed new domestic stream use totaling 20,000 acre-ft/yr; and full development of all remaining stream water, meaning the full appropriation of all remaining average annual naturalized flows above 90,430 acre-ft/yr.

[8] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3 of the URRBS Full Report.

[9] Results regarding availability of new stream-water permits are provided in Chapter 6.2.3 of the URRBS Full Report. When calculating unappropriated water availability, OWRB's current practice aims to maximize the use of the stream while avoiding interference with senior water right holders. Under this practice, for any new permit application upstream of Lugert-Altus Reservoir, an equation is used by OWRB which, among other considerations, subtracts only the downstream reservoir's permit volume (i.e., 90,430 acre-ft/yr combined Lugert-Altus ID and city of Altus) from average annual stream flow to determine unappropriated water availability.

[10] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3 of the URRBS Full Report.

Tom Steed Reservoir Hydrologic Basin

1. **"*Naturalized*":** Assumes no diversions from existing or future stream-water permits[11] and no groundwater pumping.
2. **"*Existing GW Permits, Existing Domestic SW, Existing SW Permits*"**: Assumed full use of existing stream water permits of 6,649 acre-ft/yr, as well as a 50-yr pumping rate of 22,988 acre-ft/yr over the NFRR aquifer. Assumed no new stream permits would be issued. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).
3. **"*New GW Permits, Existing Domestic SW, Existing SW Permits*"**: Assumed full use of existing stream water permits, as well as an increased 50-yr pumping rate of 27,678 acre-ft/yr over the NFRR aquifer. Assumed no new stream permits would be issued. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).
4. **"*Existing GW Permits, Existing Domestic SW, Existing and New SW Permits (Low)*"**: Assumed full use of existing stream water permits of 6,649 acre-ft/yr, as well as a 50-yr pumping rate of 22,988 acre-ft/yr over the NFRR aquifer. Assumed 2,500 acre-ft/yr would be issued in new stream permits. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).
5. **"*New GW Permits, Existing Domestic SW, Existing and New SW Permits (Low)*"**: Assumed full use of existing stream water permit of 6,649 acre-ft/yr, as well as an increased 50-yr pumping rate of 27,678 acre-ft/yr over the NFRR aquifer. Assumed 2,500 acre-ft/yr would be issued in new stream permits. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).
6. ***"Existing GW Permits, Existing Domestic SW, Existing and New SW Permits (High)*"**: Assumed full use of existing stream water permits of 6,649 acre-ft/yr, as well as a 50-yr pumping rate of 22,988 acre-ft/yr over the NFRR aquifer. Assumed 5,000 acre-ft/yr would be issued in new stream permits. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).
7. **"*New GW Permits, Existing Domestic SW, Existing and New SW Permits (High)*"**: Assumed full use of existing stream water permits of 6,649 acre-ft/yr, as well as an increased 50-yr pumping rate of

[11] Observed domestic stream-water use is automatically in gage data, meaning under the naturalized condition domestic stream-water use is occurring.

27,678 acre-ft/yr over the NFRR aquifer. Assumed 5,000 acre-ft/yr would be issued in new stream permits. Assumed three different demand scenarios on Tom Steed Reservoir: "Existing" (12,700 acre-ft/yr); "Mid" (14,400 acre-ft/yr); and "Full" (16,100 acre-ft/yr).

8. ***"Full GW, Existing Domestic SW, Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; and full use of existing stream-water permits of 6,649 acre-ft/yr, with no increase in future domestic stream use or the issuance of new stream water permits.
9. ***"Full GW, New Domestic SW (Low), Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream-water permits of 6,649 acre-ft/yr, and an assumed new domestic stream use totaling 5,000 acre-ft/yr[12]. Assumed no new stream permits would be issued.
10. ***"Full GW, New Domestic SW (Low), Full SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 6,649 acre-ft/yr; an assumed new domestic stream use totaling 5,000 acre-ft/yr; and full development of all remaining stream water, meaning the full appropriation of all remaining average annual naturalized flows above 16,100 acre-ft/yr[13].
11. ***"Full GW, New Domestic SW (High), Existing SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 6,649 acre-ft/yr; and an assumed new domestic stream use totaling 15,000 acre-ft/yr[14]. Assumed no new stream permits would be issued.
12. ***"Full GW, New Domestic SW (High), Full SW Permits"***: Assumed a 50-yr pumping rate of the NFRR aquifer's MAY given a 20-, 40-, and 50-year EPS; full use of existing stream water permits of 6,649 acre-ft/yr; an assumed new domestic stream use totaling 15,000 acre-ft/yr; and full development of all remaining stream water, meaning the full appropriation of all remaining average annual naturalized flows above 16,100 acre-ft/yr.

[12] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3 of the URRBS Full Report.
[13] When calculating unappropriated water availability, OWRB's current practice aims to maximize the use of the stream while avoiding interference with senior water right holders. Under this practice, for any new permit application upstream of Tom Steed Reservoir, an equation is used by OWRB which, among other considerations, subtracts only the downstream reservoir's permit volume (i.e., 16,100 acre-ft/yr) from average annual stream flow to determine unappropriated water availability.
[14] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3 of the URRBS Full Report.

Groundwater and Surface Water Modeling Approach

Groundwater and surface water models were developed to evaluate impacts of future demand scenarios under status-quo management. Each model played an important role in the analysis, with each model's outputs contributing to the 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 (Figure 14). Following a robust model calibration process performed by the OWRB and Reclamation as part of the URRBS, Reclamation and OWRB came to a consensus on a number of important model inputs and outputs. A detailed discussion on groundwater modeling methods and surface water modeling methods is provided in Chapter 6.2.1 and Chapter 6.2.3 of the URRBS Full Report, respectively.

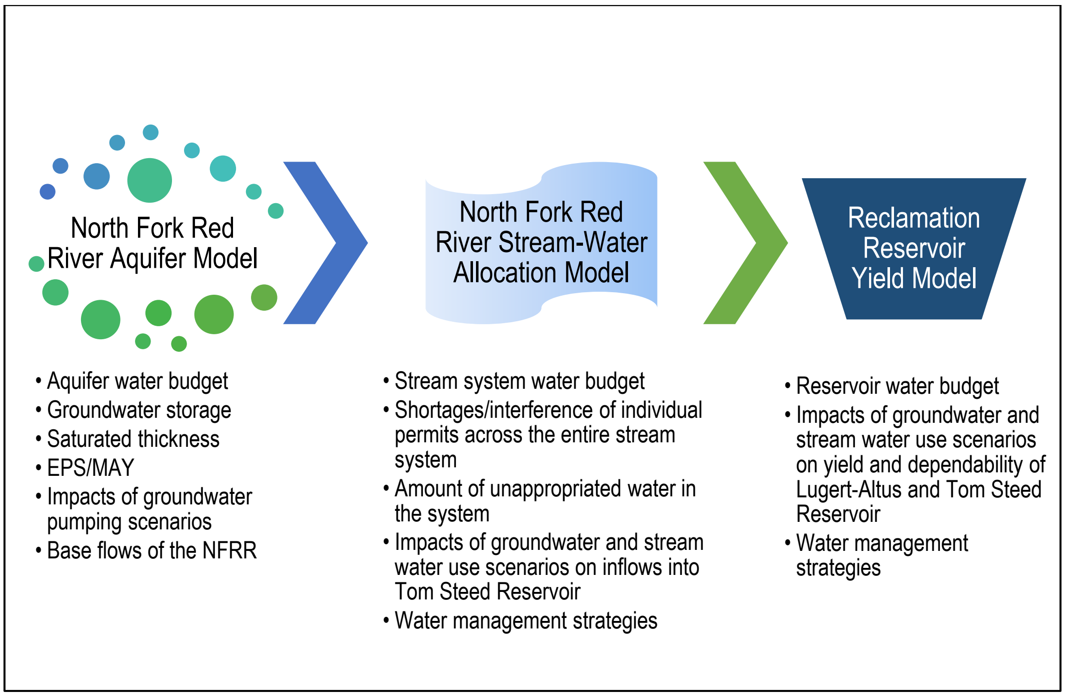


Figure 14. Key components of and relationship between the NFRR aquifer model, NFRR SWAM, and the RRY Models.

Performance Metrics

Chapter 6.3 of the URRBS Full Report describes in detail the performance metrics used to evaluate water supply availability under the range of future groundwater and surface water demand scenarios presented above. The same performance measures under status-quo management were then used to evaluate impacts of adaptation strategies. The performance metrics encompass an integration and progression of impacts, including impacts on the aquifer, streams, reservoirs, and on the hydrologic basins as a whole (Figure 15).

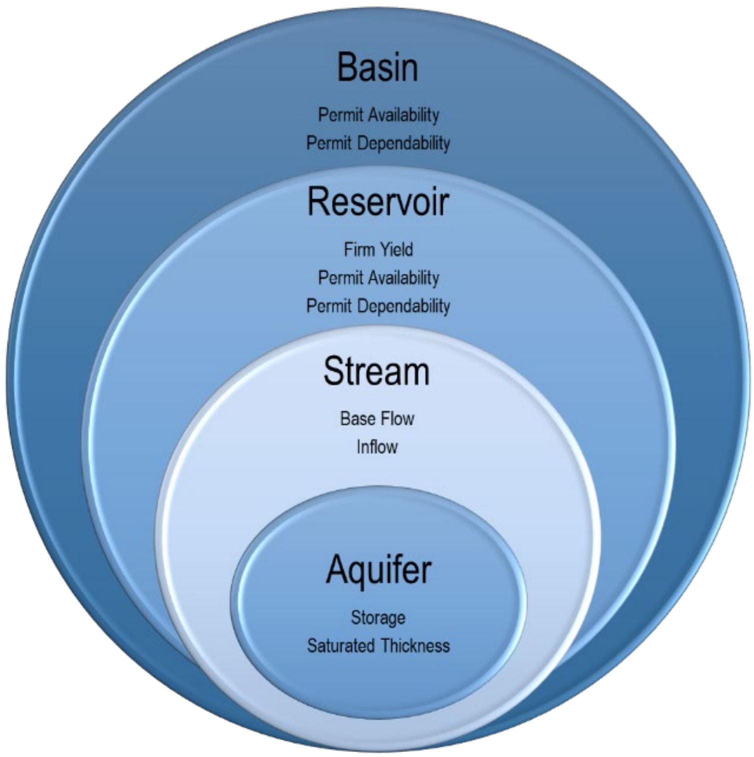


Figure 15. Conceptual illustration and relation of performance metrics evaluated under status quo water system reliability analysis in the URRBS.

Impacts of Status Quo under Baseline Climate

Aquifer EPS and MAY

Recall the aforementioned discussion in the Water Law Basics section on the regulation of permitted groundwater withdrawals in Oklahoma. According to Smith et al. (2017), the amount of NFRR aquifer storage at the end of each scenario corresponding to the definition of "aquifer life", where 50 percent of the aquifer retains a saturated thickness of at least 5 ft, was 948,000 acre-ft under a 50-yr EPS pumping rate and 951,000 acre-ft under the 20-yr EPS pumping rate. The 50-yr and 20-yr EPS pumping rates were 0.52 and 0.59 acre-ft/acre/yr, respectively. Given the 497,582-acre aquifer area, these rates correspond to MAYs of about 259,000 acre-ft/yr and 294,000 acre-ft/yr, respectively.

Impacts on Aquifer Storage, Aquifer Saturated Thickness, and Base Flow

A detailed accounting of impacts on aquifer storage, saturated thickness, and base flow are provided in Chapter 6.4.2 of the URRBS Full Report. According to Smith et al. (2017), at the end of the "Naturalized" scenario, groundwater storage in the NFRR aquifer after 50 years of no pumping was 2,606,000 acre-ft, and under the "Existing" and "New" groundwater pumping rates, groundwater storage in the NFRR aquifer was reduced to 2,398,000 acre-ft and 2,361,000 acre-ft, respectively (Table 3). As previously mentioned, after groundwater withdrawals at the 50-yr and 20-yr EPS pumping rates, groundwater storage in the NFRR aquifer were 948,000 acre-ft and 951,000 acre-ft, respectively (Table 3). Under the "Naturalized" scenario, saturated thickness was 43.6 ft, and after the "Existing" and "New" groundwater pumping rates, average saturated thickness was reduced to 40.1 ft and 39.5 ft, respectively. After groundwater withdrawals at the 50-yr and 20-yr EPS pumping rates, average saturated thickness was reduced to 15.9 ft.

Smith et al. (2017) also revealed the physical extent of the NFRR aquifer. The NFRR aquifer primarily underlies the NFRR; however, a relatively small portion of the NFRR aquifer was found to extend underneath Elk Creek upstream of the Bretch Diversion. Base flows in Elk Creek originate partly from the NFRR aquifer around the proximity of the Bretch Diversion Dam, but also from the Elk City aquifer further upstream in Washita and Beckham counties (Smith et al., 2017).

Regarding impacts on base flow of the NFRR above Lugert-Altus Reservoir, under the “Naturalized” scenario, base flow was 56,683 acre-ft/yr (Smith et al., 2017). Under the “Existing” and “New” groundwater pumping rates, base flow was 43,983 acre-ft/yr (22 percent reduction) and 42,272 acre-ft/yr (25 percent reduction), respectively (Table 3). Under the 50-yr and 20-yr EPS groundwater pumping rates of 0.52 acre-ft per acre and 0.59 acre-ft per acre, respectively, base flows in the NFRR were zero acre-ft/yr (100 percent reduction) (Table 3). The similarity between the “Existing” and “New” use scenarios reflects the minor growth in groundwater development anticipated by 2060 relative to the growth which has already occurred.

Table 3. Simulated changes in groundwater storage and saturated thickness of the NFRR aquifer, along with corresponding changes in base flows above Lugert-Altus Reservoir under five groundwater pumping scenarios.

50-yr Groundwater Pumping Scenario	Groundwater Storage (acre-ft)	Mean Saturated Thickness (ft)[a]	Base Flow (acre-ft/yr)	Change in Base Flow (acre-ft/yr)	Change in Base Flow (Percent)
Naturalized	2,606,000	43.6	56,683	-	-
Existing	2,398,000	40.1	43,983	- 12,700	- 22
New	2,361,000	39.5	42,272	- 14,411	- 25
Full (50-yr EPS)[b]	948,000	15.9	0	- 56,683	- 100
Full (20-yr EPS)[c]	951,000	15.9	0	- 56,683	- 100

[a] Derived from data provided USGS SIR 2017-5098, Smith et al., 2017.
[b] Guarantees a 50-yr life of the NFRR aquifer, where 50 percent of the NFRR aquifer retains a saturated thickness of at least 5 ft pursuant to Oklahoma law.
[c] Guarantees a 20-yr life of the NFRR aquifer, where 50 percent of the NFRR aquifer retains a saturated thickness of at least 5 ft pursuant to Oklahoma law.

Regarding impacts on base flow of Elk Creek at the Hobart streamgage above the Bretch Diversion, under the “Naturalized” scenario, base flow was 22,300 acre-ft/yr (Smith et al., 2017). Under the “Existing” and “New” groundwater pumping rates, base flow remained unchanged (Table 4). After 50 years of groundwater withdrawals at the 50-yr and 20-yr NFRR aquifer EPS pumping rates, base flow of Elk Creek was 15,600 acre-ft/yr (30 percent reduction) and 14,800 acre-ft/yr (34 percent reduction), respectively (Table 4).

Upon fully depleting the NFRR aquifer under the “Full” scenarios, the remaining 70 percent and 66 percent of Elk Creek’s base flow, respectively, were assumed to be derived from the Elk City aquifer. As previously stated, a numerical groundwater model has not been developed for the Elk City aquifer, so impacts of groundwater pumping out of the Elk City aquifer could not be simulated by the NFRR SWAM. That said, pursuant with OWRB’s existing EPS pumping rate of 1.0 acre-ft/acre/yr, Elk Creek’s base flows also could be assumed to be fully depleted to zero. This assumption was consistent with simulated impacts of NFRR aquifer EPS pumping rates on base flows of the NFRR upstream of Lugert-Altus Reservoir (Smith et al., 2017), as well as similar investigations on other major aquifers within Oklahoma (Beaver-North Canadian

Alluvial Aquifer SIR 2015-5183 (Ryter and Correll, 2016) and Central Oklahoma (Garber-Wellington) Aquifer SIR 2013-5219 (Mashburn et al., 2014).

Table 4. Simulated changes in groundwater storage and saturated thickness of the NFRR aquifer, along with corresponding changes in base flows of Elk Creek at the Hobart streamgage above Tom Steed Reservoir under five groundwater pumping scenarios.

50-yr Groundwater Pumping Scenario	Groundwater Storage (acre-ft)	Mean Saturated Thickness (ft)[a]	Base Flow (acre-ft/yr)	Change in Base Flow (acre-ft/yr)	Change in Base Flow (Percent)
Naturalized	2,606,000	43.6	22,300	-	-
Existing	2,398,000	40.1	22,300	0	0
New	2,361,000	39.5	22,300	0	0
Full (50-yr EPS)[b]	948,000	15.9	15,600	- 6,700	- 30
Full (20-yr EPS)[c]	951,000	15.9	14,800	- 7,500	- 34

[a] Derived from data provided USGS SIR 2017-5098.
[b] Guarantees a 50-yr life of the NFRR aquifer, where 50 percent of the NFRR aquifer retains a saturated thickness of at least 5 ft pursuant to Oklahoma law.
[c] Guarantees a 20-yr life of the NFRR aquifer, where 50 percent of the NFRR aquifer retains a saturated thickness of at least 5 ft pursuant to Oklahoma law.

Impacts in the Lugert-Altus Reservoir Hydrologic Basin

Base flow results for all four groundwater use scenarios presented in the previous section were combined with the eight stream-water use scenarios and input into the NFRR SWAM and RRY model to evaluate surface water availability in the Lugert-Altus Reservoir hydrologic basin. Impacts were evaluated in terms of the surface water, reservoir, and basin-wide metrics described in Chapter 6.3 of the URRBS Full Report.

Reservoir Inflow and Average Annual Water Availability

An illustration of reservoir inflow sequences generated by the SWAM under all eight scenarios is provided in Figure 16. Over the entire period of record, average annual inflow into Lugert-Altus Reservoir was 116,000 acre-ft/yr under the "Naturalized" scenario (Figure 16; Figure 17). Average annual inflow was reduced to between 92,000 acre-ft/yr (21 percent reduction) and 71,000 acre-ft/yr (39 percent reduction) depending on the development scenario (Figure 16; Figure 17).

The cumulative impacts of groundwater use, domestic use, and existing stream-water permits resulted in average annual inflows of 77,000 acre-ft/yr and 71,000 acre-ft/yr depending on whether future new domestic use was low or high, respectively. The calculation used to determine the availability of water for future new stream-water permits are discussed in Chapter 2.5.6 of the URRBS Full Report. These average annual volumes do not exceed the permitted volume of

90,430 acre-ft/yr out of Lugert-Altus Reservoir. Therefore, no water was found to be available for new stream-water permits in the Lugert-Altus Reservoir hydrologic basin. As such, impacts from the two "Full SW" scenarios were no different than impacts from the two "Existing SW" scenarios that included new domestic use.

During the 2010s Drought of Record, average annual inflow into Lugert-Altus Reservoir was 38,000 acre-ft/yr under the "Naturalized" scenario (Figure 16; Figure 17). Average annual drought-of-record inflow was reduced to between 12,000 acre-ft/yr (68 percent reduction) and 6,000 acre-ft/yr (84 percent reduction) depending on the development scenario (Figure 16; Figure 17). Regarding reservoir yield, the average annual yield of Lugert-Altus Reservoir for irrigation purposes was 58,300 acre-ft/yr under the "Naturalized" scenario. The average annual yield was reduced to between 45,900 acre-ft/yr (21 percent reduction) to 34,200 acre-ft/yr (41 percent reduction) depending on the development scenario (Figure 18).

A comparison of the *incremental* reductions in reservoir inflow between scenarios revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be evaluated in terms of their relative impacts on reservoir inflow (Table 5). For example, over the period of record, the largest reduction in average annual inflow was caused by the "Existing GW Permits" variable (21 percent), while the smallest reduction in average annual inflow was caused by the "Existing SW Permits" and "Full SW Permits" scenarios [(zero percent) (Table 5)]. During the drought of record, the largest reduction in average annual inflow was caused by the "Existing GW Permits" scenario (68 percent reduction), while the smallest reduction in average annual inflow was caused by the "Existing SW Permits" and "Full SW Permits" scenarios [(zero percent each) (Table 5)]. The incremental reductions associated with each variable making up the range of development scenarios for both the period of record and drought of record is provided in Table 5.

Inflows were the highest under the "Naturalized" scenario because there is no upstream use. Inflows into the reservoir were reduced as development/use increased. These results suggest that impacts on reservoir inflows were attributable to groundwater pumping and that surface water development has had no measurable impact on inflows. Results also show that reservoir inflows have been impacted more by existing groundwater pumping ("Existing GW") than by future groundwater pumping ("New GW" and "Full GW"). Finally, the "Existing GW" and "New GW" scenarios appear to result in similar impacts. This is because the OCWP-projected development of the NFRR aquifer through 2060 was relatively minor.

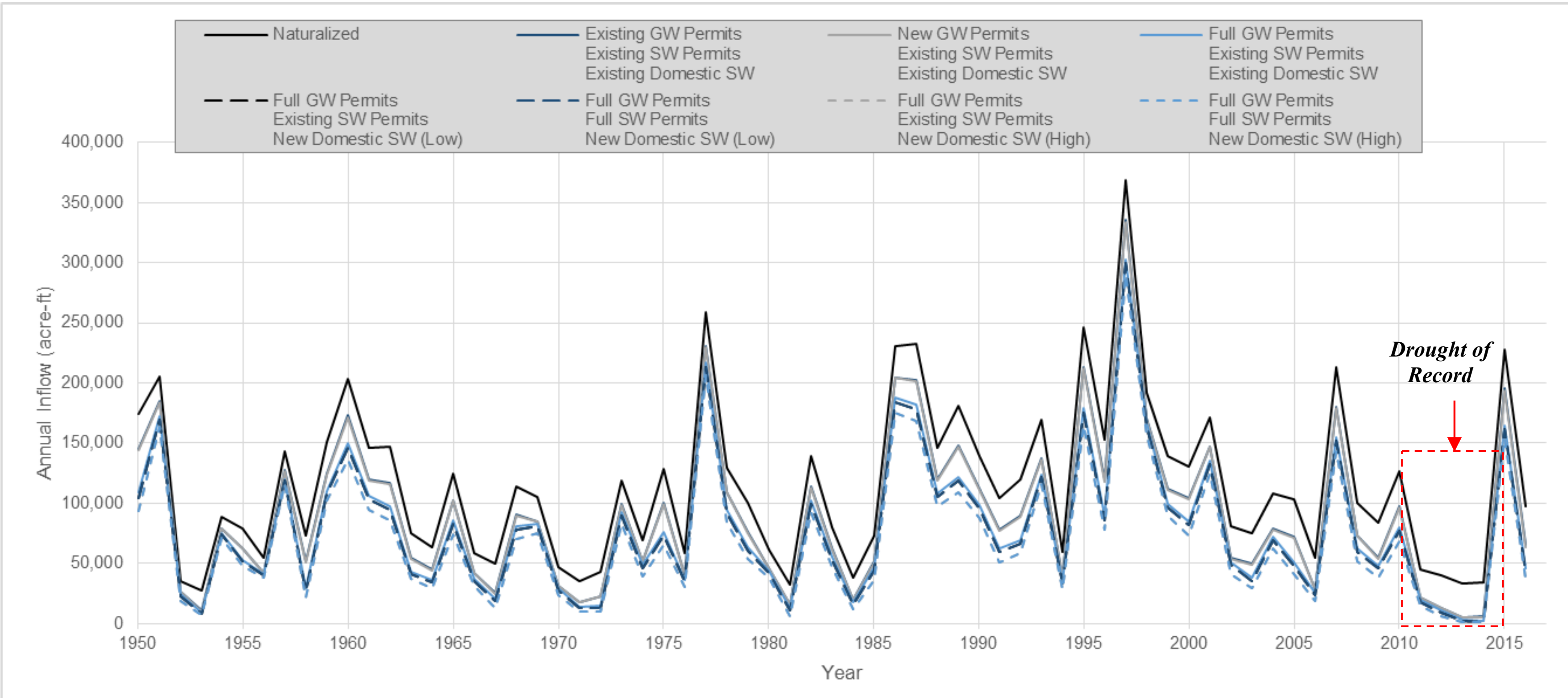


Figure 16. Annual inflows into Lugert-Altus Reservoir under a range of groundwater and stream- water use scenarios, 1950-2016.

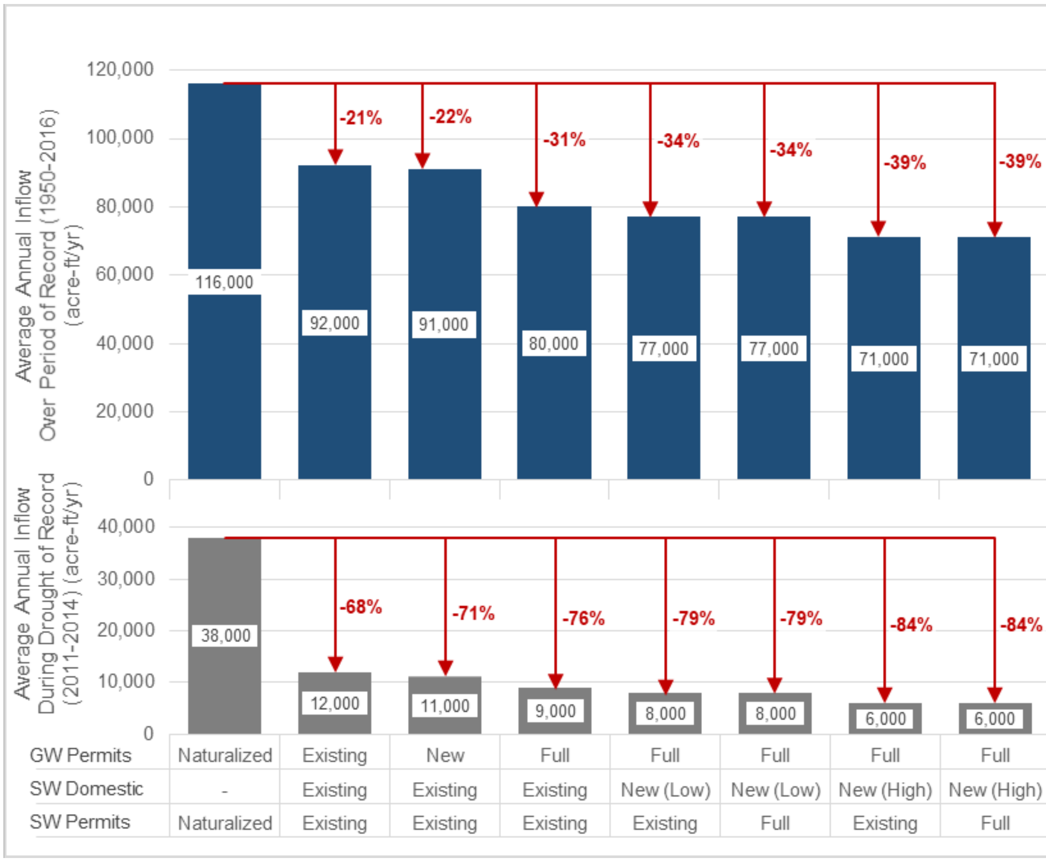


Figure 17. Average annual inflows into Lugert-Altus Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016) and during the drought of record (2011-2014).

Table 5. Incremental impacts of development-scenario variables on average annual inflow into Lugert-Altus Reservoir.

Development Scenario Variable	Incremental Impact on Average Annual Inflow over Period of Record (1950-2016)	Incremental Impact on Average Annual Inflow during the Drought of Record (2011-2014)
Existing GW Permits	21%	68%
Existing SW Permits	0%	0%
New GW Permits	1%	3%
Full GW Permits	10%	8%
New Domestic SW (Low)	3%	3%
New Domestic SW (High)	8%	8%
Full SW Permits	0%	0%

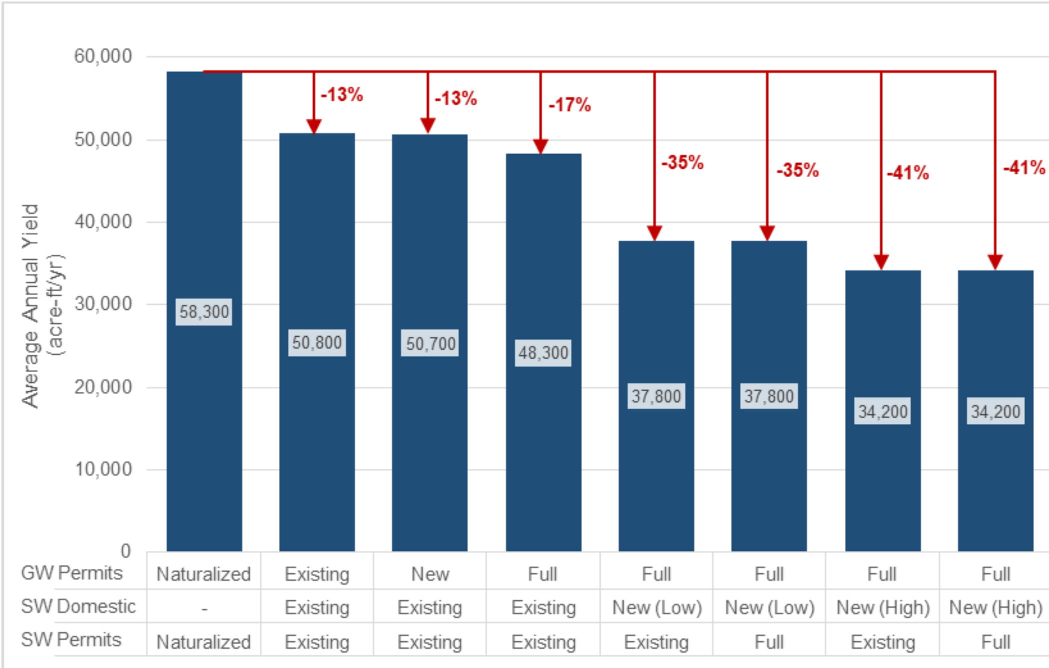


Figure 18. Average annual yield of Lugert-Altus Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016), 2060 sediment condition.

Reservoir Irrigation and M&I Permit Dependability

Under the "Naturalized" (no use) scenario, the full permitted M&I volume of 4,800 acre-ft/yr from the reservoir was available 100 percent of the time, but the full permitted irrigation volume of 85,630 acre-ft/yr was available only 31 percent of the time (Figure 19). The irrigation permit availability was reduced to between 19 percent and 27 percent of the time depending on the development scenario, and the M&I permit availability was reduced to between 93 percent and 94 percent of the time under all development scenarios (Figure 19).

The dependability of a range of irrigation supplies that could be delivered by the Lugert-Altus ID, in ten percent increments up to its existing irrigation permit volume, also was evaluated under the full range of development scenarios (Figure 20). Under the "Naturalized" scenario, 61,100 acre-ft/yr was available 50 percent of the time, and a minimum of 4,700 acre-ft/yr was available 100 percent of the time (i.e., at least 4,700 acre-ft/yr was available for irrigation every year modeled). Depending on the development scenario, the analysis showed that between 28,200 acre-ft/yr and 53,700 acre-ft/yr was available for irrigation 50 percent of the time; a minimum of 1,900 acre-ft/yr to 4,900 acre-ft/yr was available 90 percent of the time; and no amount of irrigation water was available 100 percent of the time. For comparison purposes, the full range of irrigation supply dependability is also displayed in Figure 20.

A comparison of the *incremental* reductions in average annual yield and dependability of the full permit volumes between scenarios revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be ordered from smallest to largest in terms of their impacts on reservoir availability Table 6). For example, the largest reduction in average annual yield and irrigation permit dependability was caused by the “New Domestic SW (High)” scenario (24 percent reduction and eight percent reduction, respectively), while the smallest reduction in average annual yield and irrigation permit dependability was caused by the “New GW Permits” and “Existing and Full SW Permits” scenarios [(zero percent) (Table 6)]. The incremental reductions associated with each variable making up the range of development scenarios is provided in Table 6. For M&I permit dependability, the largest reduction was caused by the “Existing GW” scenario (four percent reduction, while the smallest reduction in average annual yield and irrigation permit dependability was caused by the “New GW Permits” and “Existing and Full SW Permits” scenarios [(zero percent) (Table 6)]

These results showed that reservoir dependability has been impacted more by existing groundwater permits (the “Existing GW” scenario) than by new groundwater permits (“New GW” or “Full GW” use scenarios). Results also showed that the “Existing GW” and “New GW” use scenarios appear to result in similar impacts. This is because the OCWP-projection for additional development of the NFRR aquifer through 2060 is relatively minor.

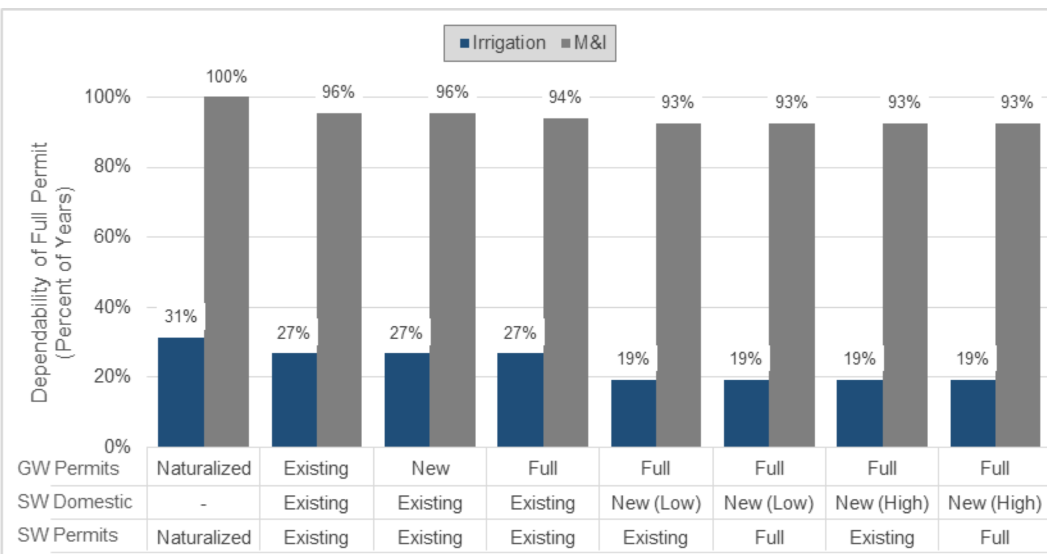
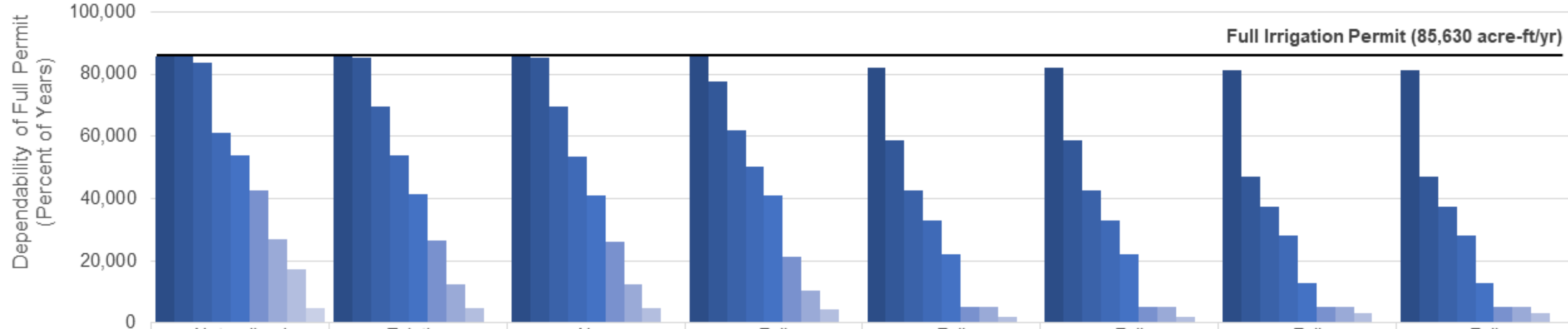


Figure 19. Dependability of the full volume of irrigation water permitted to Lugert-Altus ID (85,630 acre-ft/yr) and the 4,800 acre-ft/yr of M&I water permitted to the United States for use by the city of Altus based on modeled storage of Lugert-Altus Reservoir under a range of groundwater and surface-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Table 6. Incremental impacts of development-scenario variables on average annual yield of Lugert-Altus Reservoir, as well as the dependability of irrigation and M&I permits over the period of record (1950-2016), 2060 sediment condition.

Development Scenario Variable	Incremental Impact on Irrigation Permit		Incremental Impact on M&I Permit Dependability of Full Permit
	Average Annual Yield	Dependability of Full Permit	
Existing SW Permits	0%	0%	0%
Full SW Permits with New Domestic SW (Low)	0%	0%	0%
Full SW Permits with New Domestic SW (High)	0%	0%	0%
New GW Permits	0%	0%	0%
Full GW Permits	4%	0%	2%
Existing GW Permits	13%	4%	4%
New Domestic SW (Low)	18%	8%	1%
New Domestic SW (High)	24%	8%	1%



GW Permits	Naturalized	Existing	New	Full	Full	Full	Full	Full
SW Domestic	-	Existing	Existing	Existing	New (Low)	New (Low)	New (High)	New (High)
SW Permits	Naturalized	Existing	Existing	Existing	Existing	Full	Existing	Full
Dependability of Full Permit	58,300 31%	58,300 27%	58,300 27%	58,300 27%	58,300 19%	58,300 19%	58,300 19%	58,300 19%
20% Dependable	85,630	85,630	85,630	85,630	82,200	82,200	81,400	81,400
30% Dependable	85,630	85,100	85,100	77,500	58,700	58,700	47,000	47,000
40% Dependable	83,600	69,700	69,500	61,700	42,400	42,400	37,300	37,300
50% Dependable	61,100	53,700	53,500	50,200	32,900	32,900	28,200	28,200
60% Dependable	54,000	41,400	41,100	41,100	22,000	22,000	12,900	12,900
70% Dependable	42,500	26,600	26,000	21,300	5,200	5,200	5,200	5,200
80% Dependable	26,900	12,500	12,400	10,500	5,200	5,200	5,200	5,200
90% Dependable	17,100	4,900	4,800	4,200	1,900	1,900	3,100	3,100
100% Dependable	4,700	0	0	0	0	0	0	0

Figure 20. Dependability of available irrigation supplies that could be delivered by the Lugert-Altus ID, up to its existing irrigation permit, based on modeled storage of Lugert-Altus Reservoir under a range of groundwater and surface-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Basin-Wide Permit Availability

Impacts on the frequency of water availability for existing regular stream-water permits in the Lugert-Altus Reservoir hydrologic basin are presented below. For reference, stream-water permits are listed in Chapter 6.2.3 of the URRBS, including permit seniority date, type, volume, and consumptive demand, and the location of these permits within the basin are illustrated in Chapter 5.2.2 of the URRBS Full Report. The "Naturalized" use scenario was considered not applicable to this metric because under naturalized conditions, no permits would exist. Results are displayed for each permit within their respective ten-digit Hydrologic Unit Codes (HUCs) and are generally listed in order of upstream to downstream where applicable. The metrics presented are basin-wide average annual permit availability of existing permits, both cumulatively for all existing permits combined (Figure 21) and for existing individual permits (Table 7). Chapter 6.4.3 of the URRBS Full Report includes additional details for individual permits in the basin, namely the percent of years when at least some portion of each individual permit volume was available and the percent of years when the full volume of each individual permit was available.

Overall, future development had little to no impacts on the cumulative average annual yield of existing stream permits or on the frequency of individual permit availability. The basin-wide cumulative average annual availability of existing stream permits (excluding water permitted out of Lugert-Altus Reservoir) ranged from 1,380 acre-ft/yr (97 percent of the full permitted volume of 1,422 acre-ft/yr) to 1,330 acre-ft/yr (93 percent of the full permitted volume of 1,422 acre-ft/yr) depending on the development scenario (Figure 21). Similar trends were observed for the average annual yield of each individual stream permit (Table 7), and there were no differences in average annual water availability between permits upstream versus downstream of Lugert-Altus Reservoir.

A comparison between development scenarios and the incremental reductions in average annual availability of existing junior stream permits revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be ordered from smallest to largest in terms of their impacts on reservoir firm yield (Table 8). For example, the largest reduction in average permit availability of existing junior permits was caused by the New Domestic SW (High) scenario, which caused a four percent reduction in average annual water availability; while the smallest reduction in permit availability was caused by the "New GW Permits", "Full GW Permits", and "Full SW Permits" scenarios [(zero percent) (Table 8)]. It is important to note that modeling assumed all New SW Permit scenarios were downstream of existing upstream junior SW permits and therefore result in zero incremental impact, so additional modeling would be needed to assess other locations and associated impacts on existing upstream junior SW permits if desired.

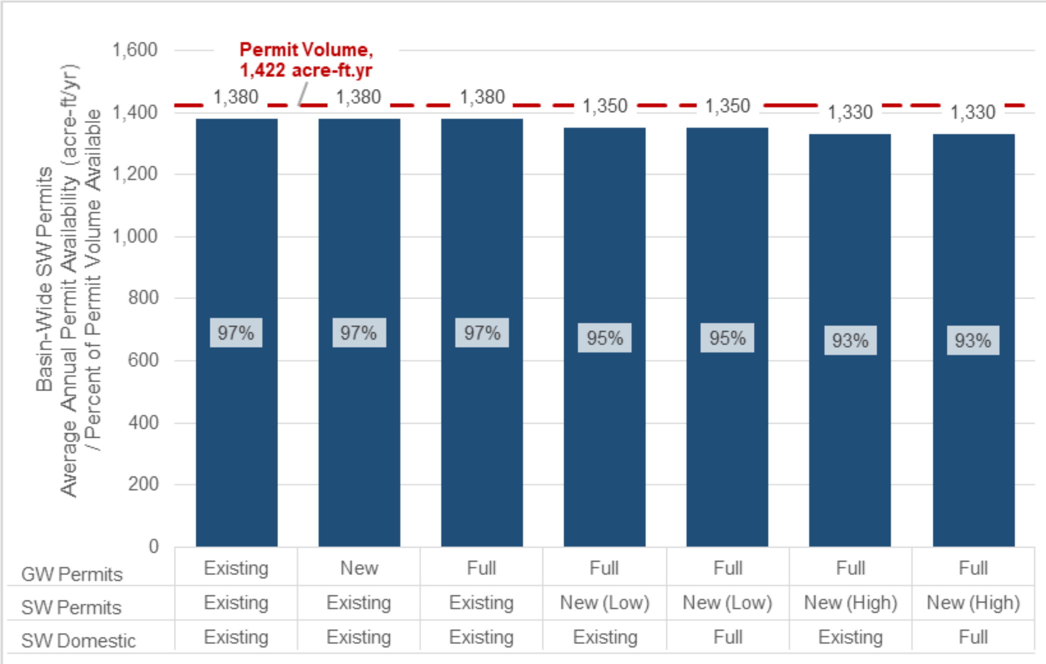


Figure 21. Basin-wide SW Permits average annual permit availability (excluding LAID and city of Altus) within the Lugert-Altus Reservoir hydrologic basin over the period of record (1950-2016), 2060 sediment condition.

Table 7. Average annual permit water availability of existing regular stream water permits in the Lugert-Altus Reservoir hydrologic basin under seven groundwater and stream-water use scenarios over the period of record (1950-2016), 2060 sediment condition.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Average Annual Permit Water Availability (acre-ft/yr)***						
				Existing GW Permits Existing Domestic SW Existing SW Permits	New GW Permits Existing Domestic SW Existing SW Permits	Full GW Permits Existing Domestic SW Existing SW Permits	Full GW Permits New Domestic SW (Low) Existing SW Permits	Full GW New Domestic SW (Low) Full SW Permits	Full GW Full Domestic SW (High) Existing SW Permits	Full GW Permits Full Domestic SW (High) Full SW Permits
Upstream of Reservoir	30203	19470003	84	84	84	83	69	69	48	48
		19600140	150	140	140	140	140	140	140	140
		19620010	110	94	94	94	94	94	93	93
	30204	19660220	53	49	49	49	49	49	49	49
		20020003	442.5	438	438	438	435	435	435	435
		19950037A	80	78	78	78	76	76	76	76
		19740253	11	11	11	11	10	10	10	10
Lugert-Altus Reservoir		19260006	4,800	4,640	4,640	4,580	4,490	4,490	4,450	4,450
		19390023	85,630	50,800	50,700	48,300	37,800	37,800	34,200	34,200
Downstream of Reservoir	30204	19900029	100	99	99	99	91	91	90	90
	30304	19850022C	56.5	56	56	56	56	56	56	56
		19650245	15	15	15	15	15	15	15	15
		20060062	320	317	317	317	317	317	317	317

Table 8. Incremental impacts of development-scenario variables on the average annual availability of existing upstream junior stream-water permits over the period of record (1950-2016), 2060 sediment condition.

Development Variable	Incremental Impact to Existing Upstream Junior Stream-water Permits Average Annual Permit Availability
New GW Permits	0%
Full GW Permits	0%
Full SW Permits with New Domestic SW (High)	0%
Full SW Permits with New Domestic SW (Low)	0%
New Domestic SW (Low)	2%
New Domestic SW (High)	4%

Impacts in the Tom Steed Reservoir Hydrologic Basin

Similar to Lugert-Altus Reservoir, the base flow results for all groundwater use scenarios presented in the previous section were combined with the surface water use scenarios and input into the NFRR SWAM and the RRY model to evaluate impacts on surface water availability in the Tom Steed Reservoir hydrologic basin. Impacts were evaluated in terms of the surface water, reservoir, and basin-wide metrics described in Chapter 6.3 of the URRBS Full Report.

Reservoir Inflow

An illustration of inflow sequences generated by the SWAM under all development scenarios is provided in Figure 22. Over the entire period of record, average annual inflow into Tom Steed Reservoir was 80,000 acre-ft/yr under the "Naturalized" scenario, of which 34,000 acre-ft/yr was derived from West Otter and Glen Creeks and 46,000 acre-ft/yr from Elk Creek (Figure 23; Figure 24). Average annual inflow was reduced to between 53,000 acre-ft/yr (34 percent reduction) and 44,000 acre-ft/yr (45 percent reduction) depending on the development scenario (Figure 23 and Figure 24). Average annual inflow was reduced to between 52,000 acre-ft/yr (35 percent reduction) and 50,000 acre-ft/yr (38 percent reduction) for the "New Domestic SW (Low)" and "New Domestic SW (High)" scenario (Figure 23 and Figure 24). These volumes exceeded the permitted volume of 16,100 acre-ft/yr out of Tom Steed Reservoir by

35,900 acre-ft/yr and 33,900 acre-ft/yr, respectively. Therefore, 35,900 acre-ft/yr and 33,900 acre-ft/yr of water, respectively, were assumed to be available for new permits under the "Full SW Permits" scenario (the calculation used to determine the availability of water for future new stream-water permits that are discussed in Chapter 2.5.6 of the URRBS Full Report)[15]. Under "Full SW Permits", average annual inflows were reduced to 45,000 acre-ft/yr (44 percent reduction) and 44,000 acre-ft/yr (45 percent reduction).

During the drought of record, average annual inflow into Tom Steed Reservoir was 21,700 acre-ft/yr under the "Naturalized" scenario, of which 14,000 acre-ft/yr was derived from West Otter and Glen Creeks and 7,700 acre-ft/yr from Elk Creek. This was reduced to between 18,400 acre-ft/yr (15 percent reduction) and 9,400 acre-ft/yr (57 percent reduction) depending on the development scenario (Figure 23).

A comparison of the *incremental* reductions in reservoir inflow between scenarios revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be evaluated in terms of their relative impacts on reservoir inflow (Table 9). For example, over the period of record, the largest reduction in average annual inflow was caused by the "Existing SW Permits" variable (34 percent), while the smallest reduction in average annual inflow was caused by the "Existing GW Permits" and "New GW Permits" scenarios [(zero percent) (Table 9)]. During the drought of record, the largest reduction in average annual inflow was caused by the "Full SW Permits (Low)" scenario (33 percent reduction), while the smallest reduction in average annual inflow was caused by the "Existing GW Permits" and "New GW Permits" scenarios [(zero percent) (Table 9)]. The incremental reductions associated with each variable making up the range of development scenarios for both the period of record and drought of record is provided in Table 9.

Inflows were the highest under the "Naturalized" scenario because there was no permitted upstream use. Inflows into the reservoir were generally reduced as development increased, with the exception of "Existing GW Permits" and "New GW Permits" scenarios, neither of which showed any measurable impacts on inflow during the drought of record. Recall that results from Smith et al. (2017) showed that permitted groundwater withdrawals out of the NFRR aquifer at 2013 pumping rates had no measurable impact on base flows of Elk Creek. Furthermore, there were no measurable differences in impacts between the "Existing GW Permits" and "New GW Permits" scenarios. This is because the OCWP-projected development of the NFRR aquifer through 2060 was relatively minor. A more thorough discussion of these impacts is included under Planning Objectives in Chapter 7.2 of the URRBS Full Report.

[15] Based on the hydrology in the Tom Steed Reservoir hydrologic basin, about 25 percent of the new stream-water permit volume was distributed to Elk Creek, and 75 percent was distributed to the West Otter-Glen Creek watershed.

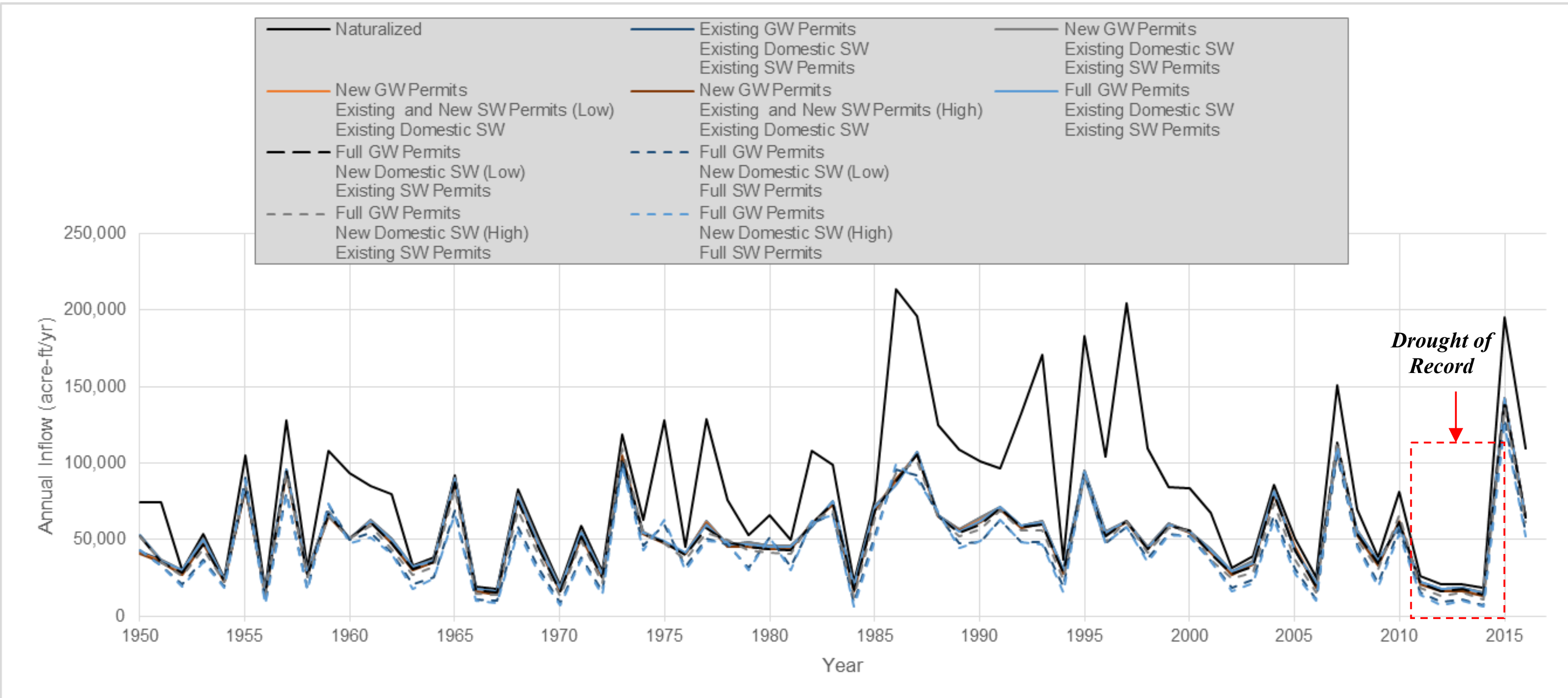


Figure 22. Annual inflows into Tom Steed Reservoir under a range of groundwater and stream- water use scenarios, 1950-2016.

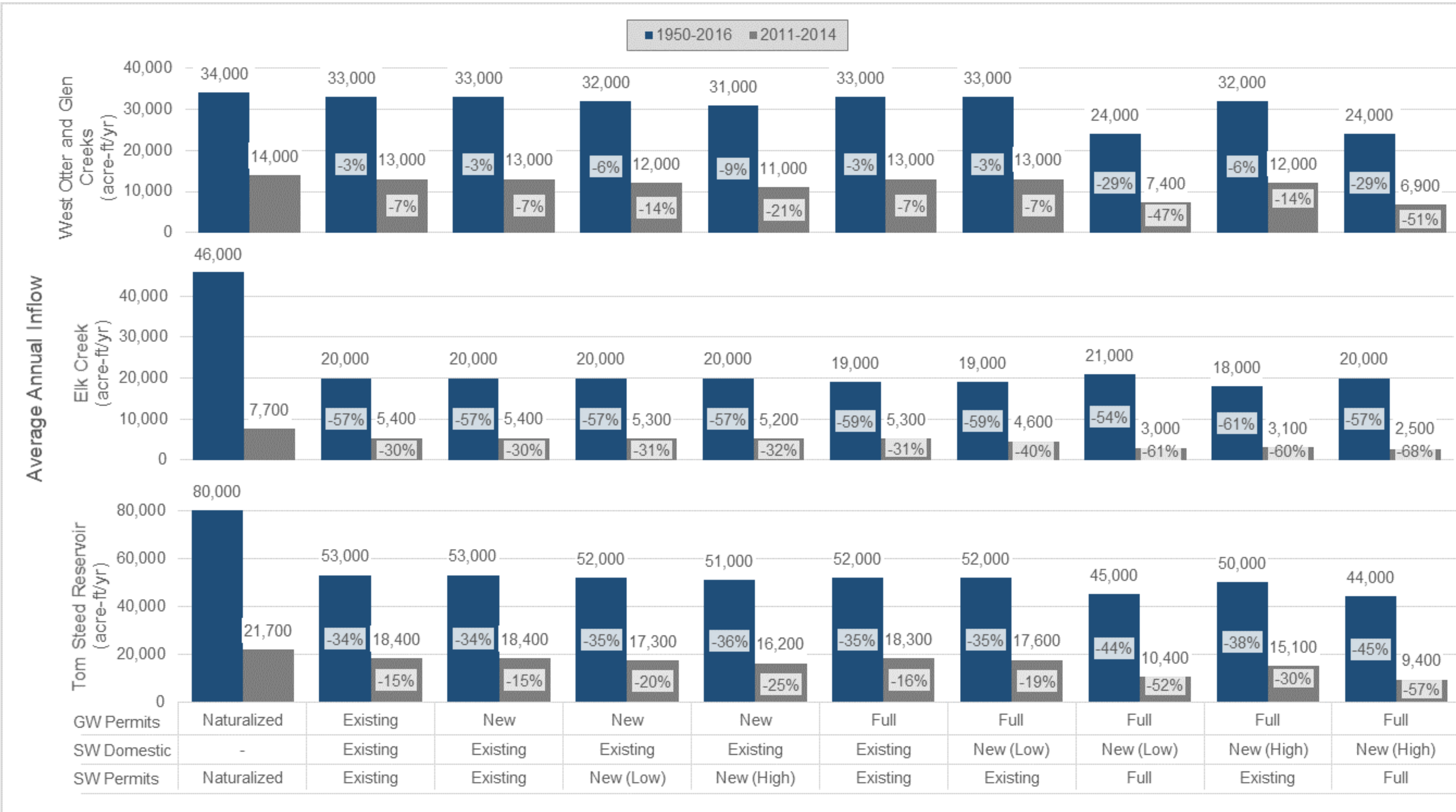


Figure 23. Average annual inflows into Tom Steed Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016) and during the drought of record (2011-2014).

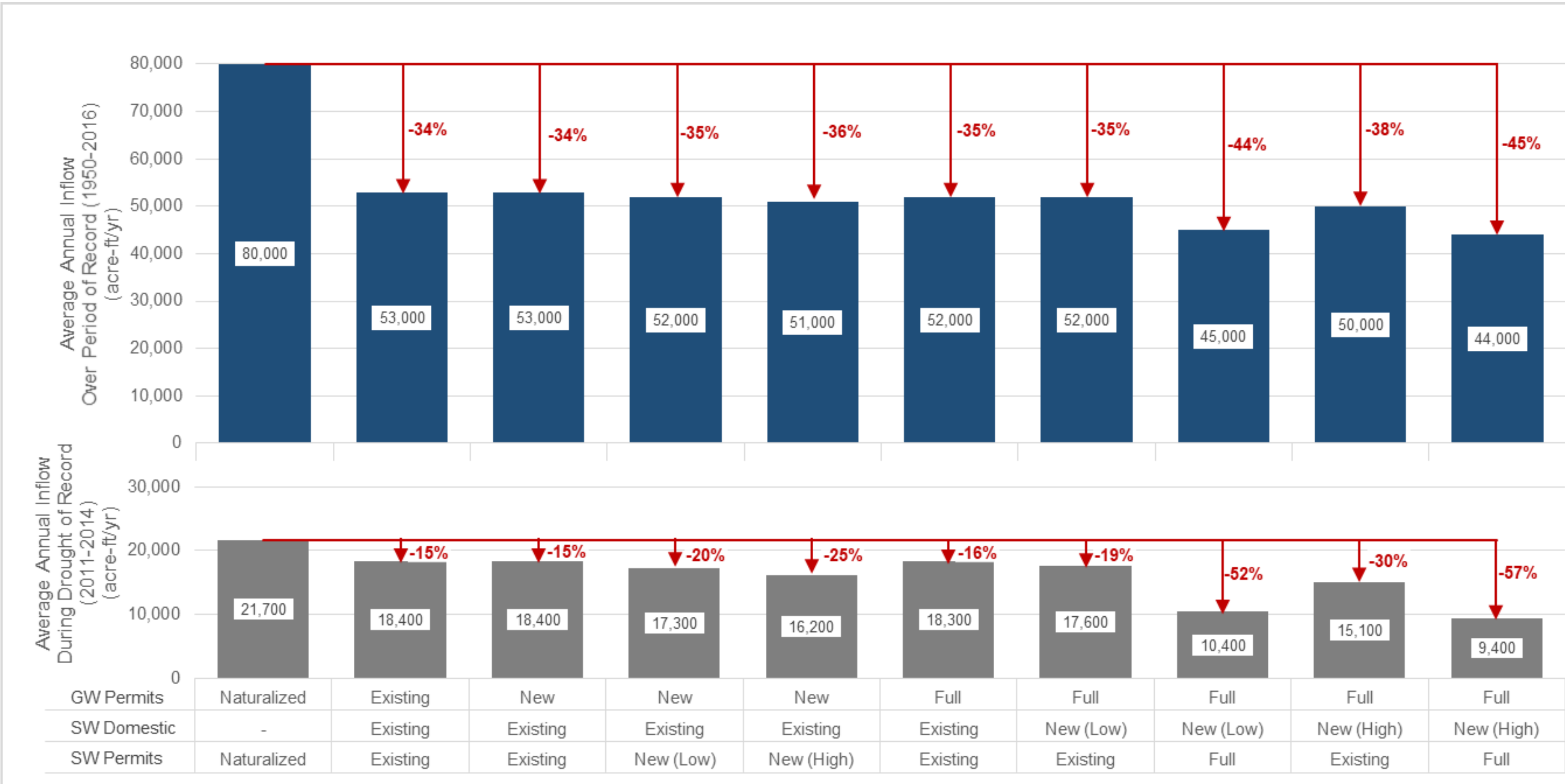


Figure 24. Average annual inflows into Tom Steed Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016) and during the drought of record (2011-2014).

Table 9. Incremental impacts of development-scenario variables on average annual inflow into Tom Steed Reservoir over the period of record (1950-2016), 2060 sediment condition.

Development Scenario Variable	Incremental Impact on Average Annual Inflow over Period of Record (1950-2016)	Incremental Impact on Average Annual Inflow during the Drought of Record (2011-2014)
Existing SW Permits	34%	15%
Existing GW Permits[a]	0%	0%
New GW Permits	0%	0%
New SW Permits (Low)	1%	5%
New SW Permits (High)	2%	10%
Full GW Permits	1%	1%
New Domestic SW (Low)	0%	3%
Full SW Permits with New Domestic SW (Low)	9%	33%
New Domestic SW (High)	3%	14%
Full SW Permits with New Domestic SW (High)	7%	27%

Reservoir Firm Yield

Under the "Naturalized" scenario, reservoir firm yield was 16,100 acre-ft/yr. Firm yield was reduced to between 13,400 acre-ft/yr (17 percent reduction) and 5,000 acre-ft/yr (69 percent reduction) depending on the development scenario (Figure 25).

A comparison of the *incremental* reductions in reservoir firm yield between scenarios revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be ordered from smallest to largest in terms of their impacts on reservoir firm yield (Table 10). For example, the largest reduction in firm yield was caused by the "Full SW Permits (Low)" scenario (39 percent reduction), while the smallest reduction in firm yield was caused by the "Existing GW Permits" and "New GW Permits" scenarios [(zero percent each) (Table 10)]. The incremental reductions associated with each variable making up the range of development scenarios is provided in Table 10.

As expected, reservoir firm yield was the largest under the "Naturalized" scenario because there was no permitted upstream use. Reservoir firm yield was reduced as development increased, with the exception of "Existing GW Permits" and "New GW Permits" scenarios, neither of which showed any measurable impacts on inflow during the drought of record. Recall that results from Smith et al. (2017) showed that permitted groundwater withdrawals out of the NFRR aquifer at 2013 pumping rates had no measurable impact on base flows of Elk Creek. Furthermore, there were no measurable differences in impacts between the "Existing GW Permits" and "New GW Permits" scenarios. This is because the OCWP-projected development of the NFRR aquifer through 2060 was relatively minor. A more thorough discussion of these impacts is included under Planning Objectives in Chapter 7.2.

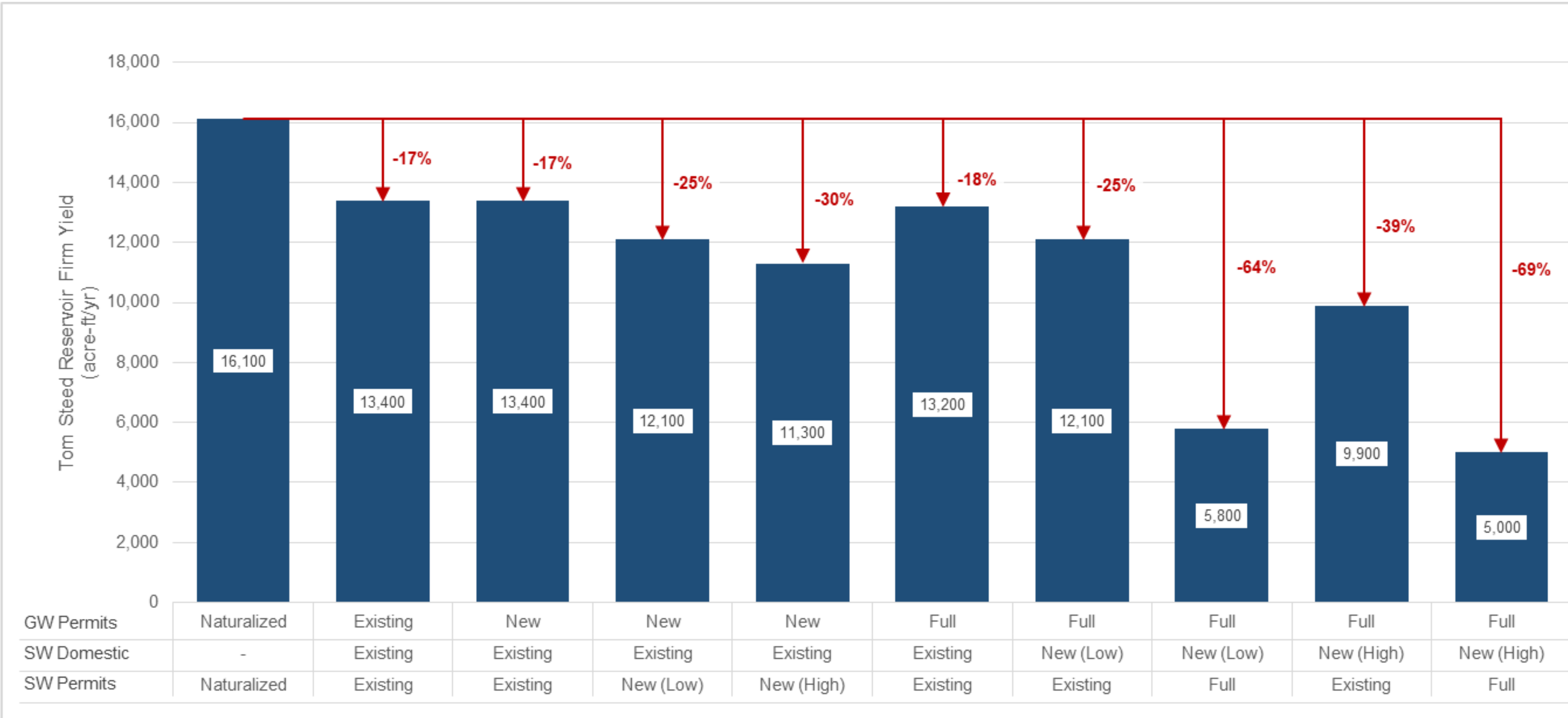


Figure 25. Tom Steed Reservoir firm yield under a range of groundwater and surface-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Table 10. Incremental impacts of development-scenario variables on Tom Steed Reservoir firm yield over the period of record (1950-2016), 2060 sediment condition.

Development Variable	Incremental Impact to Tom Steed Reservoir Firm Yield
Existing GW Permits	0%
New GW Permits	0%
Full GW Permits	1%
New Domestic SW (Low)	7%
New SW Permits (Low)	8%
New SW Permits (High)	13%
Existing SW Permits	17%
New Domestic SW (High)	21%
Full SW Permits with New Domestic SW (High)	30%
Full SW Permits with New Domestic SW (Low)	39%

Reservoir Supply Dependability

The dependability of three reservoir-use conditions ("Existing", "Mid", and "Full") were evaluated across the range of groundwater and stream-water development scenarios. Recall that the "Existing" use scenario assumed a reservoir demand of 12,700 acre-ft/yr; the "Mid" use scenario assumed a reservoir demand of 14,400 acre-ft/yr; and the "Full" use scenario assumed a reservoir demand of the full permit volume of 16,100 acre-ft/yr.

The reservoir had sufficient water in storage to meet "Existing" reservoir demands between 100 percent and 98.5 percent of all years and 100 percent and 99.8 percent of all months depending on the development scenario; the reservoir had sufficient water in storage to meet a "Mid" reservoir demands between 98.5 percent and 97.0 percent of all years and 99.9 percent and 99.4 percent of all months; and the reservoir had sufficient water in storage to meet the "Full" permit demand between 97 percent and 89.6 percent of all years and 99.5 percent and 95.4 percent of all months depending on the development scenario (Table 11).

Reservoir supply shortages ranged from zero acre-ft/yr to 11,600 acre-ft/yr depending on the reservoir use and development scenario (Table 11). The maximum volume of calendar-year shortages corresponding to "Existing" reservoir demands was between zero acre-ft/yr and 1,000 acre-ft/yr; the maximum volume of calendar-year shortages corresponding to "Mid" reservoir demands was between 200 acre-ft/yr and 2,000 acre-ft/yr; and maximum volume of calendar-year shortages corresponding to "Full" reservoir demands was between 2,000 acre-ft/yr and 11,600 acre-ft/yr depending on the development scenario (Table 11).

A visual representation of reservoir supply shortages across the range of development scenarios assuming "Full" reservoir use is provided in Figure 26. Supply shortages also were compared among the three reservoir use scenarios ("Existing", "Mid", and "Full") under the three different stream permitting scenarios ["Existing SW", "New SW (Low)", and "New SW (High)"] where development was limited to Existing or New GW Permits and Existing Domestic SW. The visual illustrations of the reservoir use comparisons among the three stream permitting scenarios are provided in Chapter 6.4.4 of the URRBS Full Report.

Some key findings are worth pointing out. First, similar to inflow and firm yield, results showed that current groundwater pumping from the NFRR aquifer has had no measurable impact on permit water availability; and the "Existing GW Permits" and "New GW Permits" use scenarios resulted in the same impacts because according the OCWP-projected development of the NFRR aquifer through 2060 was relatively minor. Second, with the exception of the "Full SW Permits" scenario, MPMCD's full permitted volume of 16,100 acre-ft/yr was 100 percent dependable through multiple severe droughts that were known to occur in the 1950s, 1960s, and 1970s[16]. This highlights the severity of the 2010s Drought of Record; and although single-calendar-year

[16] A cursory discussion on observed, historical droughts was provided in Chapter 2.2.1 of the URRBS Full Report. A more extensive discussion is provided in Chapter 8.4.2 of the URRBS Full Report.

permit shortages were noted in Figure 26, the shortages actually extended over two calendar years under most of the development scenarios, and under the "Full SW Permits" scenario, shortages extended over three calendar years. Third, for the "Existing" reservoir use scenario, no shortages existed under either the "Existing SW Permits" or "New SW Permits (Low)" scenarios, but shortages did exist under the "New SW Permits (High)" scenario. Under the "Mid" and "Full" reservoir use scenarios, shortages existed under all three stream permitting scenarios.

Table 11. Tom Steed Reservoir supply dependability, as well as the maximum calendar-year permit shortage, based on modeled storage of Tom Steed Reservoir under a range of groundwater and stream-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Modeling Scenarios for the MPMCD	Tom Steed Reservoir Use	Tom Steed Reservoir Supply Dependability		Maximum Calendar-Year Permit Shortage	
		(Percent of Calendar Years)	(Percent of Months)	(acre-ft/yr)	(Percent Permit Shortage)
Naturalized	-	100	100.0	0	0
Existing or New GW Permits, Existing Domestic SW, Existing SW Permits	Existing	100	100.0	0	- [a]
	Mid	98.5	99.9	200	-
	Full	97.0	99.5	2,000	12
Existing or New GW Permits, Existing Domestic SW, Existing and New SW Permits (Low)	Existing	100	100.0	0	-
	Mid	97.0	99.5	1,900	-
	Full	97.0	99.3	2,300	14
Existing or New GW Permits, Existing Domestic SW, Existing and New SW Permits (High)	Existing	98.5	99.8	1,000	-
	Mid	97.0	99.4	2,000	-
	Full	97.0	99.1	3,300	20
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	97.0	99.5	2,000	12
Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	97.0	99.4	2,500	16
Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	89.6	96.4	11,100	69
Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	97.0	98.8	5,900	37
Full GW Permits, New Domestic SW (High), Full SW Permits	Full	89.6	95.4	11,600	72

[a] Because simulated reservoir demands were lower than the permit volume, no shortage exists.

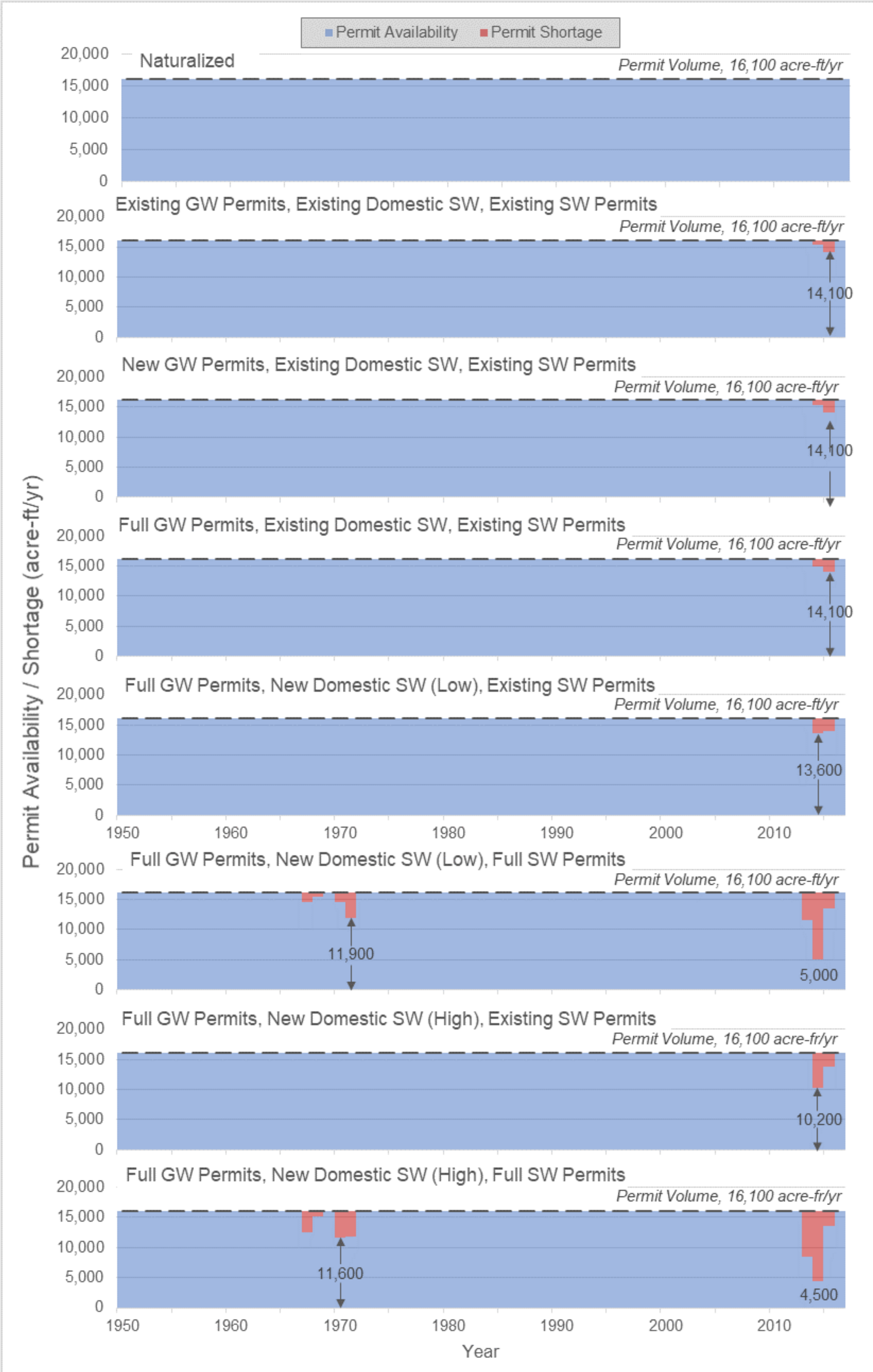


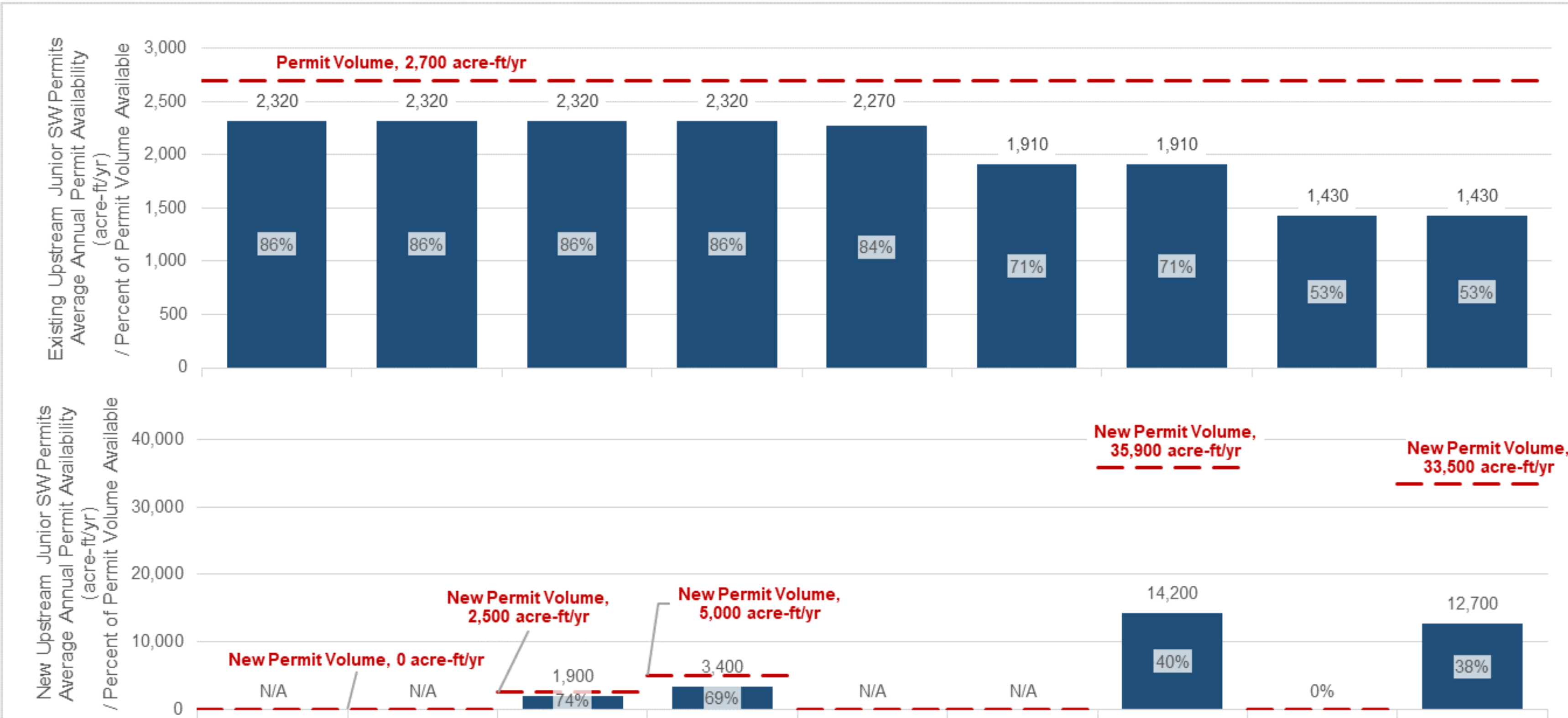
Figure 26. The dependability of Tom Steed Reservoir supply in delivering the "Full" permit demands on the reservoir for each calendar year under a range of groundwater and surface-water development scenarios, 2060 sediment condition.

Basin-Wide Permit Availability

The impacts on the water availability of existing regular stream-water permits in the Tom Steed Reservoir hydrologic basin are presented below. For reference, stream-water permits are listed in Chapter 6.2.3 of the URRBS, including permit seniority date, type, volume, and consumptive demand, and the location of these permits within the basin are illustrated in Chapter 5.2.2 of the URRBS Full Report. The "Naturalized" use scenario was considered not applicable to this metric because under naturalized conditions, no permits would exist. Results are displayed for each permit within their respective ten-digit HUCs and listed in order of upstream to downstream where applicable. The metrics presented are upstream existing and new junior permits average annual availability (Figure 27) and basin-wide average annual permit availability for individual permits (Table 12). Chapter 6.4.4 of the URRBS Full Report includes additional details for individual permits in the basin, namely the percent of years when at least some portion of each individual permit volume was available and the percent of years when the full volume of each individual permit was available.

For existing upstream junior stream permits, the overall basin-wide average annual availability ranged from 2,320 acre-ft/yr (86 percent of the cumulative full permitted volume of 2,700 acre-ft/yr) to 1,430 acre-ft/yr (53 percent of the cumulative full permitted volume of 2,700 acre-ft/yr) depending on the development scenario. For new stream permits, the average annual availability ranged from 1,900 acre-ft/yr [(74 percent of the full permitted volume of 2,500 acre-ft/yr under the "New SW (Low)" scenario)] to 14,200 acre-ft/yr [(40 percent of the full permitted volume of 35,900 acre-ft/yr under the "Full SW (Low)" scenario)] depending on the development scenario (Figure 27).

A comparison between development scenarios of the incremental reductions in average annual availability of existing junior stream permits revealed which of the three variables making up each development scenario (GW Permits, SW Permits, SW Domestic) was the source of the reduction; as such, the variables could be ordered from smallest to largest in terms of their impacts on reservoir firm yield (Table 13). For example, the largest reduction in average permit availability of existing junior permits was caused by the "New Domestic SW (High)" scenario (31 percent reduction), while the smallest reduction in permit availability was caused by the "New GW Permits", New SW Permits (low), New SW Permits (High), Full SW Permits with New Domestic SW (High), and Full SW Permits with New Domestic SW (Low)" scenarios [(zero percent) (Table 13)]. It is important to note that modeling assumed all New SW Permit scenarios are downstream of existing upstream junior SW permits and therefore result in zero incremental impact, additional modeling is needed to assess other locations and associated impacted to existing upstream junior SW permits if desired. The incremental reductions associated with each variable making up the range of development scenarios is provided in Table 13.



GW Permits	Existing	New	New	New	Full	Full	Full	Full	Full
SW Domestic	Existing	Existing	Existing	Existing	Existing	New (Low)	New (Low)	New (High)	New (High)
SW Permits	Existing	Existing	New (Low)	New (High)	Existing	Existing	Full	Existing	Full

Figure 27. Average annual permit availability of upstream junior permits within the Tom Steed Reservoir hydrologic basin under a range of groundwater and stream-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Table 12. Average annual permit availability of existing regular and new stream water permits in the Tom Steed Reservoir hydrologic basin under a range of groundwater and stream-water development scenarios over the period of record (1950-2016), 2060 sediment condition.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Average Annual Permit Water Availability (acre-ft/yr)***							
				Existing or New GW Permits Existing Domestic SW Existing SW Permits	Existing or New GW Permits Existing Domestic SW Existing and New SW Permits (Low)	Existing or New GW Permits Existing Domestic SW Existing and New SW Permits (High)	Full GW Permits Existing Domestic SW Existing SW Permits	Full GW Permits Future Domestic SW (Low) Existing SW Permits	Full GW Permits Future Domestic SW (Low) Full SW Permits	Full GW Permits Future Domestic SW (High) Existing SW Permits	Full GW Permits Future Domestic SW (High) Full SW Permits
Upstream of Reservoir	30301	19550353	8	7	7	7	7	6	6	4	4
		19600053	108	103	103	103	103	90	90	59	59
		19650249	800	663	663	663	568	544	544	471	471
		20030029	100	95	95	95	95	82	82	54	54
		19740306	20	19	19	19	19	17	17	11	11
		19641018	160	152	152	152	149	133	133	125	125
		20060043	1,470	1,240	1,240	1,240	1,190	970	970	720	720
	30302	19650553	149	116	116	116	116	88	88	68	68
		19970006	1,100	958	958	958	955	836	836	645	645
		19320051	631	595	595	595	593	544	544	411	411
		New Permits	Varies[a]	N/A[b]	539	1,060	N/A	N/A	5,420	N/A	4,140
	30303	19820113	10	9	9	9	9	8	8	7	7
		New Permits	Varies[c]	N/A	1,320	2,390	N/A	N/A	8,790	N/A	8,590
Tom Steed Reservoir		19670671L	16,100	16,100[d]	16,100[d]	16,000	16,100[d]	16,000	15,700	15,700	15,600
Downstream of Reservoir	30302	19970010	297	171	167	157	156	137	108	123	97
		19980025	1,338	1,200	1,202	1,199	1,200	1,130	1,130	1,010	990
	30304	20060062	320	317	317	317	317	317	317	317	317
	30303	20090008	46	46	46	46	46	46	46	46	46
		19960036	15	15	15	15	15	15	15	15	15
		19520414	77	77	77	77	77	77	77	77	77

[a] The total volume of new SW permits on Elk Creek varies from none to 625 acre-ft/yr (Low), 1,250 acre-ft/yr (High), 9,000 acre-ft/yr (Full Low), and 8,500 acre-ft/yr (Full High).
[b] N/A = Not Applicable.
[c] The total volume of new SW permits on West Otter-Glen Creek varies from none to 1,875 acre-ft/yr (Low), 3,750 acre-ft/yr (High), 26,900 acre-ft/yr (Full Low), and 25,400 acre-ft/yr (Full High).
[d] Results rounded to the permit amount after shortages observed in only a few years.

Table 13. Incremental impacts of development-scenario variables on the average annual availability of existing upstream junior stream-water permits over the period of record (1950-2016), 2060 sediment condition.

Development Variable	Incremental Impact to Existing Upstream Junior Stream-water Permits Average Annual Permit Availability
New GW Permits	0%
New SW Permits (Low)[a]	0%
New SW Permits (High)[a]	0%
Full SW Permits with New Domestic SW (High)[a]	0%
Full SW Permits with New Domestic SW (Low)[a]	0%
Full GW Permits	2%
New Domestic SW (Low)	13%
New Domestic SW (High)	31%

[a] New stream-water permits were considered “junior” to existing stream-water permits in the basin, meaning modeled diversions from existing permits would be removed from the system prior to diversions from new permits; furthermore, the impacts of those new permits were modeled by distributing a lump sum diversion amount immediately upstream of the Bretch Diversion on Elk Creek and on West-Otter and Glen Creeks.

New stream permits had little to no impact on the average annual availability of existing stream permits. This is because the modeled diversions from the new stream permits were located downstream from existing upstream permits, effectively allowing existing upstream permits priority access to available water. This assumption was intended to simplify the modeling process in light of the uncertainty associated with the location of potential new stream permits. In reality, any potential new stream permits would likely be widely distributed throughout the basin, and assuming status-quo management persists, then those potential new stream permits would likely have impacts on existing stream permits.

Impacts of Status Quo under Climate Change

In accordance with the requirements set forth in Reclamation's Basin Study Framework (Reclamation, 2009) and Reclamation's Directive and Standard on Basin Studies (WTR 13-01), one of the key elements that must be included in the URRBS is an analysis on the impacts of future changes in climate and hydrology on water supply and demands. Reclamation (2016), Reclamation (2017), and Chapter 6.5 of the URRBS Full Report provides a detailed discussion on the methods, assumptions, and results associated with climate change impacts in the Lugert-Altus and Tom Steed reservoir hydrologic basins.

Climate Change Scenarios

A total of 231 projections of average annual temperature and precipitation encompassing the years 2045 to 2074 were compared to average annual historical ("baseline") temperature and precipitation conditions encompassing the years 1950 to 1999. The 231 climate projections were then condensed down to three climate scenarios by averaging the ten individual temperature and precipitation projections that fall closest to the intersections of the 10^{th}, 50^{th}, and 90^{th} percentiles of change relative to the baseline, resulting in three climate change scenarios: (1) *warm-wet*; (2) *median*; and (3) *hot-dry*. Table 14 presents average annual temperature and precipitation for the three climate change scenarios relative to baseline conditions for each of the four HUCs and for the basin study area as a whole.

Table 14. Projected change in future (2045-2074) temperature and precipitation under three climate change scenarios relative to baseline (1950-1999) conditions for the four HUCs making up the URRBS study area.

Sub-basin (HUC)	Baseline	Warm-Wet	Median	Hot-Dry
	Average Annual Temperature	(Percent Change)		
Upper NFRR (11120301)	59°F	+ 5%	+ 8%	+ 12%
Middle NFRR (11120302)	60°F	+ 9%	+ 12%	+ 16%
Lower NFRR (11120303)	63°F	+ 5%	+ 7%	+ 11%
Elm Fork (11120304)	60°F	+ 5%	+ 8%	+ 12%
Weighted Basin Mean	*60°F*	*+6%*	*+9%*	*+13%*
	Average Annual Precipitation	(Percent Change)		
Upper NFRR (11120301)	20 in	+ 11%	+ 6%	- 5%
Middle NFRR (11120302)	24 in	+ 11%	+ 5%	- 5%
Lower NFRR (11120303)	27 in	+ 11%	+ 5%	- 5%
Elm Fork (11120304)	22 in	+ 11%	+ 6%	- 6%
Weighted Basin Mean	*22 in*	*+ 11%*	*+ 6%*	*- 5%*

Water Supply Modeling Approach

Basin study partners deliberated on how to evaluate the impacts of future climate change scenarios on water supplies in the Lugert-Altus and Tom Steed reservoir hydrologic basins. One option considered was to use the NFRR SWAM to evaluate the impacts of climate change on water availability under all future groundwater and stream-water development scenarios. However, this option would have effectively added up to 30 additional modeling scenarios to an already complicated status-quo analysis[17], and study partners were concerned that such a large number of modeling scenarios could create confusion among stakeholders and subsequently reduce the probability of implementing adaptation strategies that were themselves complicated and sensitive. Study partners also expressed concerns about the financial and staffing resources needed for the OWRB to run the NFRR SWAM and process the results. The preferred option selected by basin study partners was for Reclamation to lead the analysis and to use its RRY model to simulate impacts of climate change specifically on the reservoirs (as opposed to reservoir and basin-wide permit availability) and to use only one baseline hydrologic record: the observed period of record.

[17] Ten groundwater and stream-water development scenarios multiplied by three climate change scenarios = 30 modeling scenarios.

With this decision in mind, the impacts of climate change on Lugert-Altus and Tom Steed reservoirs were simulated on a monthly time step using Reclamation's RRY model, and the weighted basin mean percent change factors for each of the three climate change scenarios identified in Table 14 were applied to the observed period of record between Jan 1926 to Dec 2016.

Impacts on Lugert-Altus Reservoir Supply and Demand

Overall, impacts on Lugert-Altus Reservoir varied depending on the future climate change scenario considered, but generally speaking, the Hot-Dry climate change scenario reduced water supplies, while both the Median and Warm-Wet climate change scenarios increased water supplies. Using the observed period of record, average annual inflow into Lugert-Altus Reservoir was 108,000 acre-ft/yr (Figure 28). Average annual inflow was reduced to 90,000 acre-ft/yr (17 percent reduction) under the Hot-Dry climate change scenario; increased to 125,000 acre-ft/yr (16 percent increase) under the Median climate change scenario; and increased to 145,000 acre-ft/yr (34 percent increase) under the Warm-Wet climate change scenario (Figure 28). The average annual yield of Lugert-Altus Reservoir was 52,900 acre-ft/yr based on the observed period of record, and was decreased to 45,000 acre-ft/yr (15 percent reduction) under the Hot-Dry scenario; increased to 57,700 acre-ft/yr (nine percent increase) under the Median scenario; and increased to 62,800 acre-ft/yr (19 percent increase) under the Warm-Wet scenario (Figure 29). Similar trends resulted when evaluating the impacts of future climate change on dependability of both the irrigation and M&I permits (Figure 30), as well as a range of available irrigation supplies (Figure 31).

The impacts noted above do not include a quantified assessment on the impacts of future climate change on groundwater (i.e., the NFRR aquifer), which is known to contribute base flow to the NFRR which flows into Lugert-Altus Reservoir. A study completed by USGS found that compared to the baseline climate scenario, annual base flow in the NFRR was reduced by 15.9 percent under the Hot-Dry scenario; reduced by 10.8 percent under the Median scenario; and increased by 15.7 percent under the Warm-Wet scenario (Labriola et al., 2020). Importantly, the USGS groundwater study used a different baseline reference period (1980-2009) than that used by Reclamation (1926-2016) for the surface water analysis; however, the findings are useful in that they provide an approximation of the cumulative impacts of climate change on groundwater and surface water in the Lugert-Altus Reservoir hydrologic basin.

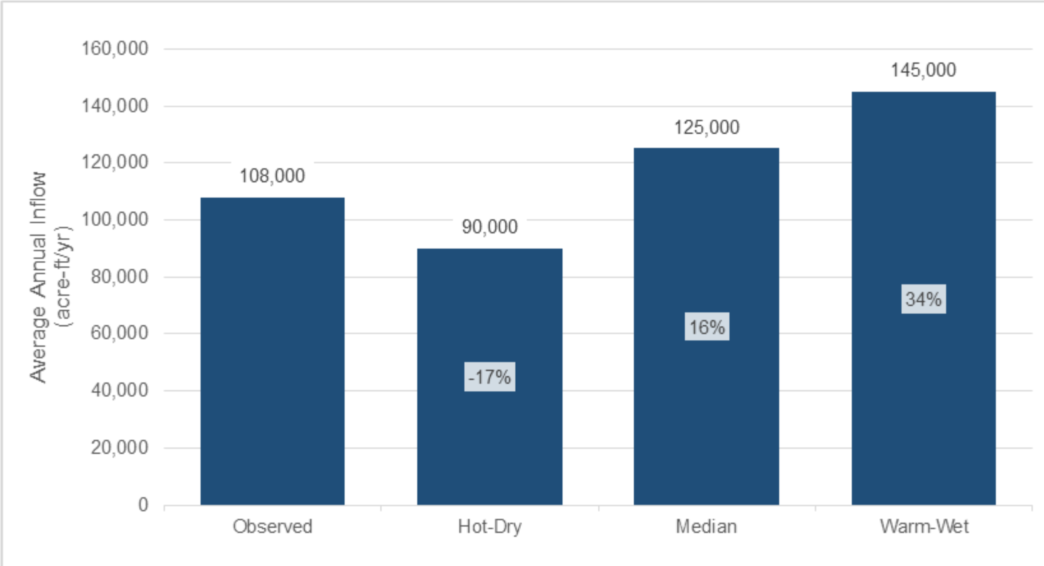


Figure 28. A comparison of average annual inflow into Lugert-Altus Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

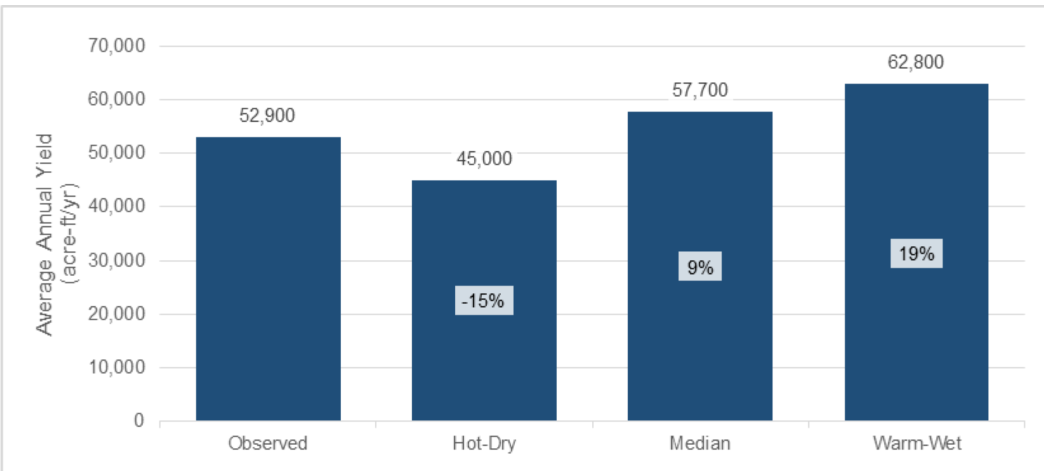


Figure 29. A comparison of average annual yield of Lugert-Altus Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

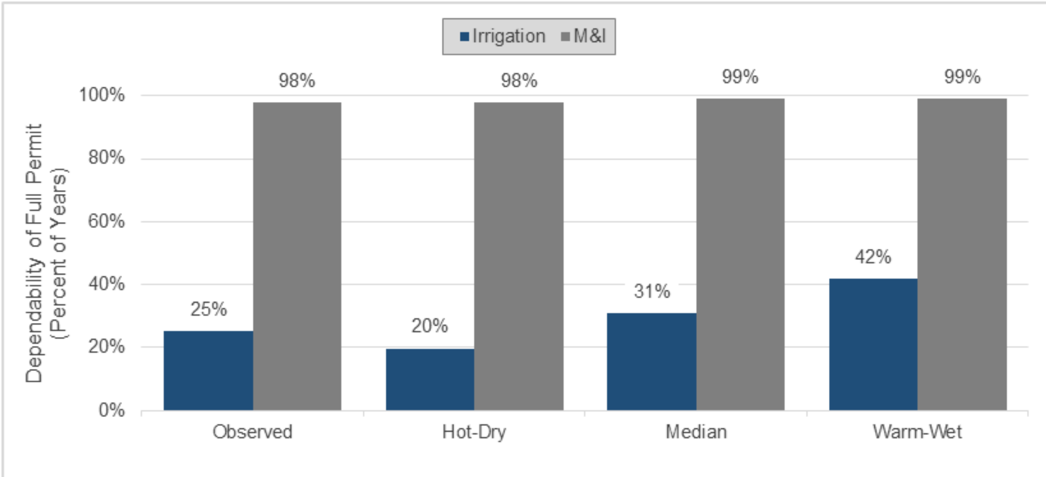
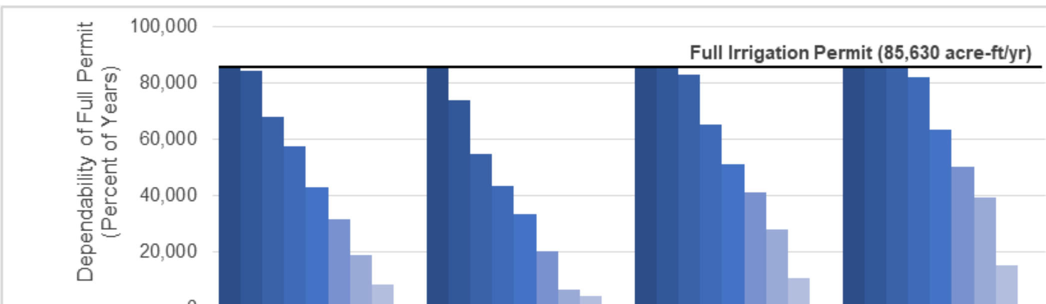


Figure 30. A comparison of the dependability of the full volume of irrigation water permitted to Lugert-Altus ID (85,630 acre-ft/yr) and the 4,800 acre ft/yr of M&I water permitted to the United States for use by the city of Altus based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).



	Observed	Hot-Dry	Median	Warm-Wet
20% Dependable	85,630	85,500	85,600	85,600
30% Dependable	84,680	73,800	85,600	85,600
40% Dependable	67,900	54,900	83,100	85,600
50% Dependable	57,600	43,700	65,200	82,100
60% Dependable	43,000	33,400	51,300	63,700
70% Dependable	31,700	20,100	41,300	50,300
80% Dependable	18,800	6,700	28,000	39,400
90% Dependable	8,200	4,200	10,500	15,300
100% Dependable	0	0	0	0

Figure 31. A comparison of the dependability of available irrigation supplies that could be delivered by the Lugert-Altus ID, up to its existing irrigation permit, based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

Climate change also was found to have a potential impact on future water demands on Lugert-Altus Reservoir. Relative to agricultural irrigation demands, M&I demands are likely less vulnerable to the effects of climate change, so the discussion below centers on agricultural irrigation demands with a brief discussion on M&I demands included in Chapter 6.5.6 of the URRBS Full Report. Details on the approach and findings can be found in two documents. Reclamation (2017) and Reclamation (2019). Details, including assumptions and uncertainties, also can be found in Chapter 6.5 of the URRBS Full Report.

Crop Net Irrigation Water Requirement (NIWR) estimates were calculated for each of the basin's four HUCs. Baseline climate conditions were evaluated for the period 1950-1999 and similar to the water supply analysis, the future climate change period was 2045-2074. According to the Evapotranspiration Demands Model, under baseline conditions, the average annual basin-wide NIWR was 660,900 acre-ft, corresponding to a NIWR depth of 32 inches per acre (Table 15). The projected change in NIWR ranges from a one percent decrease to a 21 percent increase relative to baseline conditions, with the weighted basin-wide mean NIWR projected to increase from one to 15 percent (Table 15). Putting this into perspective, this means that the future groundwater demands discussed in Chapter 5.4.1 of the URRBS Full Report, which were comprised almost entirely of agricultural irrigation, may underestimate future demands on groundwater by between one and 15 percent. It also means that all other factors being equal, farmers of either permitted or domestic wells may need to irrigate more to produce the same type/volume of crops they otherwise could under baseline conditions. Future stream-water demand estimates discussed in Chapter 5.4.2 of the URRBS Full Report, on the other hand, would not be affected because those demands were capped by permit and/or domestic water availability. That said, farmers using stream water may face the same challenges as those using groundwater in terms of needing to irrigate more to satisfy an increased NIWR that produces the same type/volume of crops.

Table 15. Projected change in future (2045-2074) average annual NIWR (depth and volume) under three climate change scenarios relative to baseline (1950-1999) conditions for the four HUCs making up the URRBS study area.

Sub-basin (HUC)	Baseline		Warm-Wet	Median	Hot-Dry
	Average Annual NIWR Depth	Average Annual NIWR Volume	(Percent Change)		
Upper NFRR (11120301)	33 in/acre	176,500 acre-ft	+ 2%	+ 7%	+ 17%
Middle NFRR (11120302)	32 in/acre	226,700 acre-ft	- 1%	+ 4%	+ 9%
Lower NFRR (11120303)	32 in/acre	174,100 acre-ft	+ 3%	+ 10%	+ 21%
Elm Fork (11120304)	29 in/acre	83,600 acre-ft	+ 3%	+ 9%	+ 17%
Basin-Wide	*32 in/acre*	*660,900 acre-ft*	*+ 1%*	*+ 7%*	*+ 15%*

Impacts on Tom Steed Reservoir Supply and Demand

The discussion here focuses on Tom Steed Reservoir supply because impacts on M&I demands were found to be fairly negligible (Reclamation, 2017; Chapter 6.5.8 of the URRBS Full Report). Overall, impacts on Tom Steed Reservoir varied depending on the future climate change scenario considered, but generally speaking, similar to Lugert-Altus Reservoir, the Hot-Dry climate change scenario reduced water supplies, while both the Median and Warm-Wet climate change scenarios increased water supplies. An illustration comparing annual inflow based on the observed record versus the three future climate change scenarios is provided in Figure 32. Using the observed period of record, average annual inflow into Tom Steed Reservoir was 67,000 acre-ft/yr (Figure 33). Average annual inflow remained unchanged under the Hot-Dry climate change scenario; increased to 79,000 acre-ft/yr (18 percent increase) under the Median climate change scenario; and increased to 90,000 acre-ft/yr (34 percent increase) under the Warm-Wet climate change scenario (Figure 33). Observed average annual inflow and reservoir firm yield during the 2010s Drought of Record was 20,000 acre-ft/yr and 13,300 acre-ft/yr, respectively (Figure 33*;* Figure 34). Drought of record inflow and firm yield decreased to 19,000 acre-ft/yr (five percent decrease) and 13,200 acre-ft/yr (one percent decrease), respectively, under the Hot-Dry scenario; increased to 24,000 acre-ft/yr (20 percent increase) and 18,200 acre-ft/yr (37 percent increase), respectively under the Median scenario; and increased to 27,000 acre-ft/yr (35 percent increase) and 22,800 acre-ft/yr (71 percent increase), respectively, under the Warm-Wet scenario (Figure 33*;* Figure 34). Similar trends resulted when evaluating the impacts of future climate change on dependability of MPMCD's water right permit (Table 16).

Similar to Lugert-Altus Reservoir, the impacts noted above did not include a quantified assessment on the impacts of future climate change on groundwater (i.e., the NFRR aquifer), which is known to contribute base flow to Elk Creek which flows into Tom Steed Reservoir. The USGS study cited in the Lugert-Altus Reservoir section (i.e., Labriola et al., 2020) quantified the impacts of climate change on NFRR aquifer and NFRR base flow, but the study did not quantify how impacts on the NFRR aquifer could impact base flow of Elk Creek. That said, the USGS study did show that the mean annual percent change in NFRR aquifer storage was −3.2, −2.7, and +3.0 percent under the Hot-Dry, Median, and Warm-Wet climate change scenarios (Labriola et al., 2020). Although only a small portion of the NFRR aquifer interacts with Elk Creek (Chapter 6.4.2), some cumulative impacts from groundwater and surface water would be expected on Tom Steed Reservoir. As previously discussed, the USGS groundwater study used a different baseline reference period (1980-2009) than that used by Reclamation (1926-2016) for the surface water analysis; however, the findings are useful in that they provide an approximation of the cumulative impacts of climate change on groundwater and surface water in the Tom Steed Reservoir hydrologic basin.

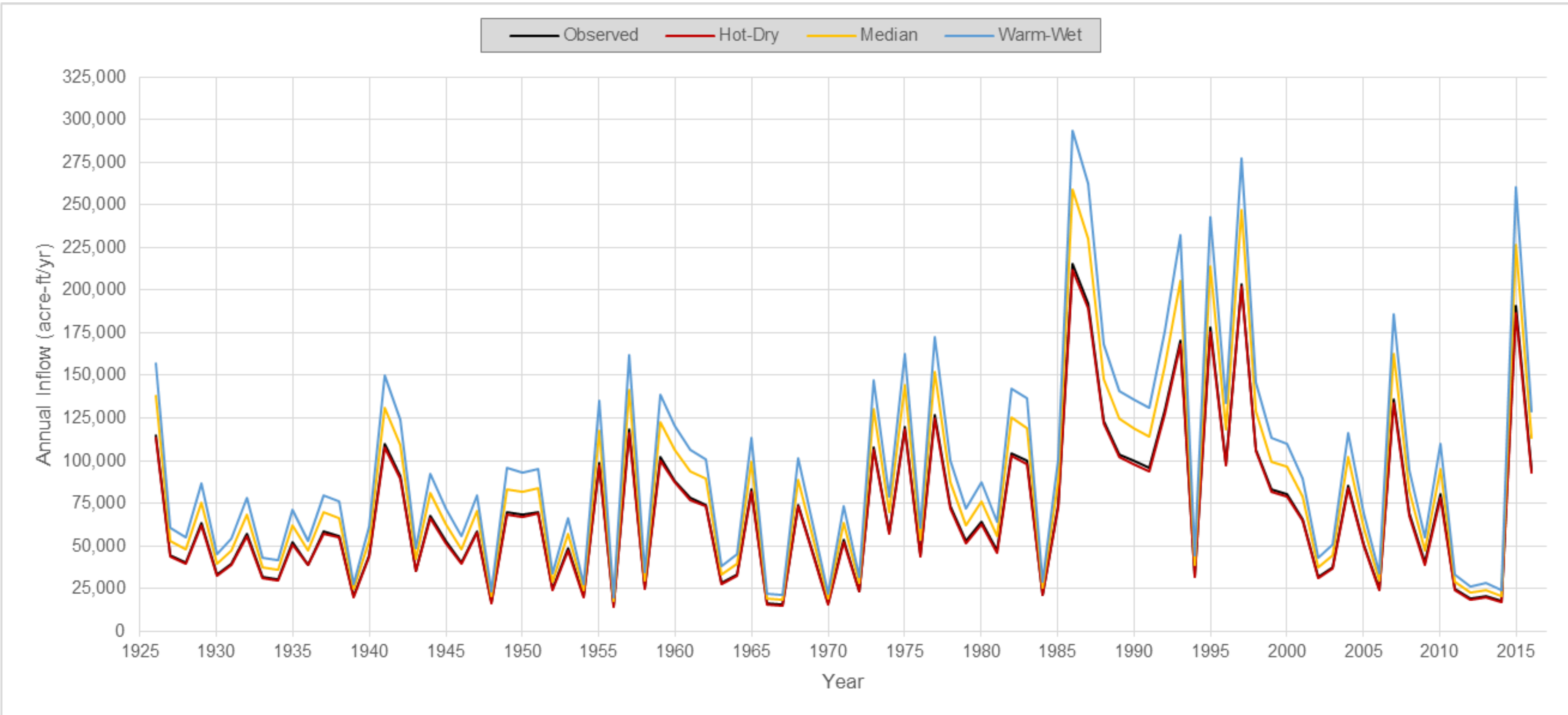


Figure 32. A comparison of annual inflows into Tom Steed Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

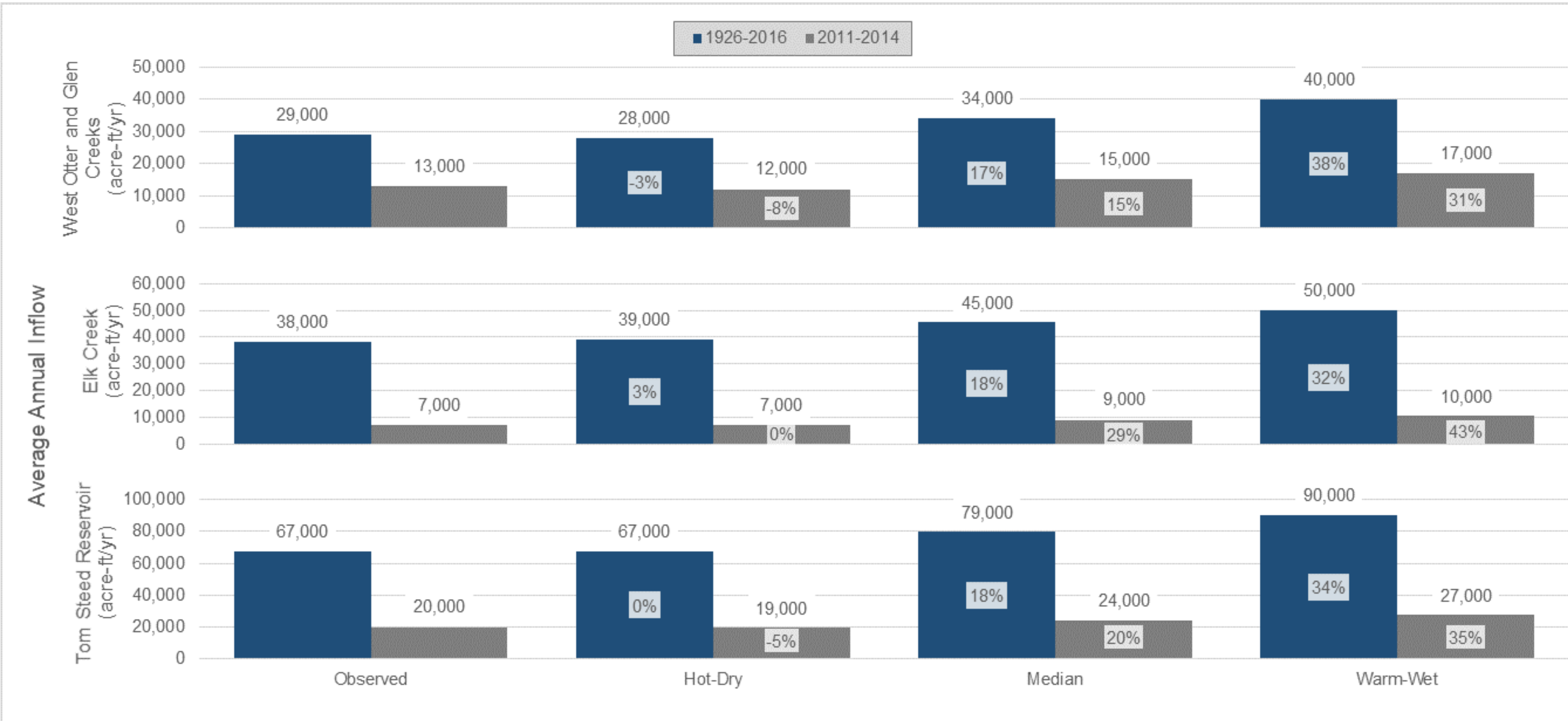


Figure 33. A comparison of average annual inflow into Tom Steed Reservoir based on the observed record (1926-2016) and during the drought of record (2011-2014) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

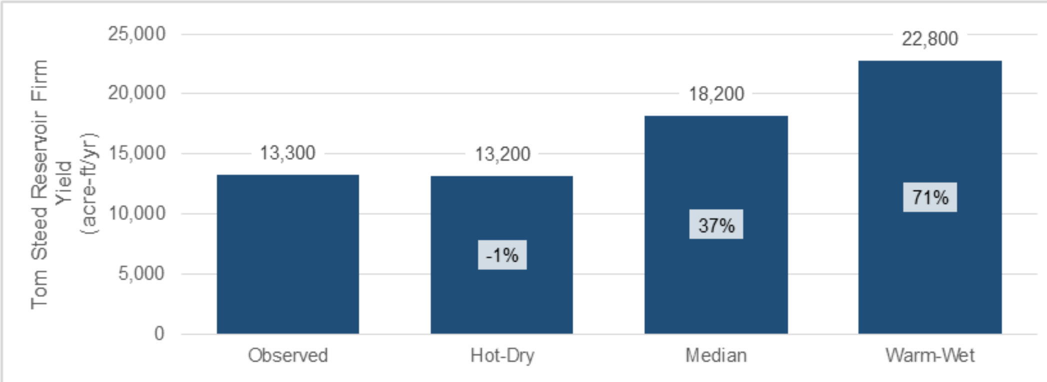


Figure 34. A comparison of Tom Steed Reservoir firm yield based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

Table 16. A comparison of the dependability of the full volume of water permitted to Mountain Park Master Conservancy District (16,100 acre-ft/yr) each calendar year, as well as lowest volume of permit water available, based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

	Permit Volume Dependability		Lowest Calendar-Year Permit Availability	
	Percent of Years	Percent of Months	(acre-ft/yr)	(Percent of Permit)
Observed	97.8	99.7	13,300	83
Hot-Dry	97.8	99.3	13,200	82
Median	100.0	100.0	16,100	100
Warm-Wet	100.0	100.0	16,100	100

Impacts of Status-Quo on the Local and Regional Economy

In this section, the impacts of status-quo conditions on the economic benefits of Lugert-Altus and Tom Steed Reservoir are presented. The discussion summarizes the methods and results presented in Reclamation (2018). The reader also is encouraged to review Chapter 6.6 of the URRBS Full Report for a detailed discussion of the methods and results.

Modeling Approach

Visitation regression models were developed to evaluate the impact of changes in reservoir elevation on recreation at two recreation facilities (i.e., Quartz Mountain State Park and Lodge at the W.C. Austin Project; Great Plain State Park at the Mountain Park Project) and associated benefits. The dollar value of recreation benefits was estimated and subsequently multiplied by visitation data and input into the regression models to predict impacts from changes in reservoir elevation on recreation visitation and values.

A regression model was developed to evaluate the impact of changes in reservoir elevation on irrigation water deliveries. The model was developed using historical irrigation releases (June through September), lake elevation, precipitation, and temperature data. Irrigation deliveries and benefit values were obtained from Reclamation's 2015 Altus Safety of Dams, Irrigation Benefits Technical Report (Reclamation, 2015); this report used a farm budgeting approach to estimate costs, returns, and net farm income for a representative farm operation both with and without irrigation production, the difference of which was attributed to the application of irrigation water, including irrigation water benefits. The estimated irrigation benefits were subsequently multiplied by estimated changes in irrigation deliveries and input into the regression model to predict impacts from changes in reservoir elevation on irrigation deliveries and benefits.

The regional economic impact analysis evaluated the impacts of cumulative changes in expenditures associated with recreation visitation and crop production caused by changes in reservoir elevation. The underlying assumption was that changes in recreation and agricultural production would have impacts on many sectors in the regional economy, including impacts on income, employment, and the overall economic output produced in the region. Regional recreation impacts were estimated using the IMpact analysis for PLANning (IMPLAN) model.

In addition to the analyses provided above, a separate estimate of agriculture benefits was calculated using the most recent available crop revenue data provided by the Lugert-Altus ID for the years 2015 to 2021 (after the drought of record).

Results

Recreation Benefits

Recreation at Lugert-Altus and Tom Steed reservoirs provides benefits to the local and regional economy. The average recreation benefit of Tom Steed Reservoir (i.e., Great Plains State Park) was estimated to be $3.07 million annually. Regression modeling results showed that a one-foot change in Tom Steed Reservoir elevation resulted in a change of $41,280 in recreation benefits or 1.3 percent of the total recreation benefit. For Lugert-Altus Reservoir, the average recreation benefit was estimated to be $1.4 million annually. Regression modeling results showed that a one-foot change in Lugert-Altus Reservoir elevation resulted in a change of $14,400 in recreation benefits for both Quartz Mountain Lodge and State Park or one percent of the total recreation benefit.

Irrigated Agriculture Benefits

The total benefit of irrigation in the Lugert-Altus ID was estimated to be $68.50 per acre-foot or $5.22 million annually. Total revenues from agricultural sales associated with crop production were estimated to be 47,841 acres multiplied by average estimated revenues of $855 per irrigated acre or $40.9 million annually. The impacts from a one-foot change in reservoir elevation were estimated to be $72,100 annually or 1.4 percent of the total irrigation benefit of the Lugert-Altus ID. The impact on crop revenue was estimated to be $566,000 annually or 1.4 percent of the total crop revenues associated with the Lugert-Altus ID.

In addition to the analyses provided above, a separate estimate of agriculture benefits was calculated using the most recent available crop revenue data provided by the Lugert-Altus ID for the years 2015 to 2021 (after the drought of record). According to the Lugert-Altus ID, crop revenues over the seven-year period averaged $1,355 per acre[18]. Multiplying this value by the 48,000 acres irrigated by Lugert-Altus ID resulted in an economic value of $65 million annually. Recall that 115,000 acre-ft/yr was determined by this study to be the effective storage needed to deliver the combined M&I and irrigation water rights of 90,430 acre-ft/yr. Therefore, a storage deficit occurs when the storage of Lugert-Altus Reservoir falls below 115,000 acre-ft. If one assumes that the storage volume deficit is directly proportional to a loss in economic value, then one could approximate the economic losses caused by prolonged drought. For example, if reservoir storage was 50 percent below the 115,000 acre-ft target storage in a given year, then by this logic, there could be a corresponding 50 percent reduction in crop production, which could result in a 50 percent loss that year in total revenue (i.e., $32.5 million) generated by the Lugert-Altus ID.

[18] Personal communication, Tom Buchanan Lugert-Altus ID Manager on Dec 19, 2022.

Impacts on Regional Economy

For Tom Steed Reservoir, results showed that direct, indirect, and induced recreation benefits totaled $4.0 million annually, including 60 jobs and $1.2 million in income. The total regional impact of a one-foot change in Tom Steed Reservoir elevation was estimated to be $54,000 annually.

For Lugert-Altus Reservoir, results showed that direct, indirect, and induced recreation benefits totaled $3.3 million annually, including 43 jobs and $898,400 in income; the total regional impact on recreation of a one-foot change in Lugert-Altus Reservoir elevation was estimated to be $28,400 annually. Regional irrigation benefits from Lugert-Altus ID crop sales totaled $57.4 million annually, including 451 jobs and $26.6 million in income; the total regional impact on agricultural production of a one-foot change in Lugert-Altus Reservoir elevation was estimated to be $794,000 annually. For Lugert-Altus Reservoir, the combined recreation and agricultural benefits totaled $60.7 million annually, and a one-foot change in reservoir elevation corresponded to a combined total of $822,400 annually. These results likely underestimate the benefits provided by Lugert-Altus Reservoir because they do not consider the year 2015-2021 crop revenue data provided by Lugert-Altus ID, which was significantly higher than the crop revenue data used in the above results. In fact, when using the data provided by Lugert-Altus ID, the agricultural benefits alone are $65 million annually, which is higher than the combined agricultural and recreation benefits calculated by Reclamation.

Impacts of the Altus AFB on the Regional Economy

Although this URRBS economic analysis focused on the impacts of water supply conditions on economic outputs in the region, it is important to recognize the economic benefits provided by the Altus AFB and acknowledge that water supply shortages could threaten the viability of AFB operations. A Fiscal Year 2016 Altus Air Force Base Economic Impact Statement (Altus Air Force Base, 2018) indicated that there was a total of 3,164 military personnel and dependents and 1,507 civilian personnel associated with the Air Base. Total construction and operations expenditures on the Air Base were a little over $60.8 million and total payroll was about $230.6 million. A 2011 report evaluating the economic impact of five Oklahoma military installations, including Altus AFB (Oklahoma Department of Commerce and The State Chamber of Oklahoma, 2011), indicated an annual employment impact of about 7,500 jobs over the 2011 to 2015 time period. A more up to date 2017 report by the Oklahoma Aeronautics Commission, estimated that the Altus Air Force Base directly and indirectly accounts for nearly 8,890 jobs per year in the region. The estimated employment impact of Altus AFB was used to estimate the potential contributions by the AFB towards recreation in the area. Using methods described in Chapter 6.6.3 of the URRBS Full Report, the cursory analysis found that the Altus AFB increased recreation visitation by 0.33 percent or 445 recreation visits per year. In the event of a severe drought that impacts recreation, this would represent a loss in regional economic benefits in addition to the loss of jobs and income described above.

Planning Objectives and Adaptation Strategies

The water supply imbalances identified through the System Reliability Analysis on status-quo results (detailed in Chapter 6 of the URRBS Full Report) were used to develop specific planning objectives for each of the two reservoirs. The planning objectives for Lugert-Altus Reservoir and Tom Steed Reservoir are discussed extensively in Chapter 7.2 and Chapter 7.3 of the URRBS Full Report, respectively. Chapter 7 of the URRBS Full Report also presents a range of adaptation strategies that could address the planning objectives, along with the justification and process by which these strategies were identified and formulated. 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. In Chapter 8 of the URRBS Full Report, these strategies were evaluated to determine how well they perform at meeting planning objectives in terms of reducing water supply deficits and improving overall water supply reliability.

Lugert-Altus Reservoir: Planning Objectives and Strategies

Planning Objectives

The planning objective for Lugert-Altus Reservoir was to *maximize the volume of water held in storage such that 115,000 acre-ft is available at the beginning of the irrigation season*. This is the volume needed in storage to meet the full permitted volumes of 85,630 acre-ft/yr for irrigation purposes and 4,800 acre-ft/yr for M&I purposes, including the agreed-upon storage reserve[19]. Overall, results supported the potential need for both an administrative strategy that would address human-induced issues related to groundwater and/or stream-water management, as well as new infrastructure and supplemental water supplies to build additional resilience. Results revealed two important findings: (1) the leading causes of water supply imbalances in the Lugert-Altus Reservoir

[19] A detailed discussion on how the agreed-upon storage reserve was calculated is provided in Chapter 2.3.1 of the URRBS Full Report.

hydrologic basin appeared to be caused by the climatological limitations of the basin, followed by permitted groundwater pumping; and (2) existing permitted groundwater pumping showed a more pronounced impact on Lugert-Altus Reservoir than future groundwater pumping. A detailed discussion on how these findings were derived is provided in Chapter 7.2 of the URRBS Full Report.

To address the planning objective of having 115,000 acre-ft of water in storage in Lugert-Altus Reservoir at the beginning of each irrigation season, these findings highlighted the need for an adaptive strategy that addresses groundwater pumping, in particular pumping from existing permit holders, as well as a strategy, namely Cable Mountain Reservoir, that could provide water to supplement the water supply provided from Lugert-Altus Reservoir and the NFRR watershed. This is not to say that stream-water management strategies should be abandoned altogether. In fact, Kershen (2021) explored two stream-water management options, namely protecting existing water rights and applying for additional water rights to Lugert-Altus Reservoir.

Adaptation Strategies

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 legal review performed by Dr. Kershen that was discussed earlier in this chapter: (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 through voluntary dry-year lease or purchase agreements; (6) Conjunctive Management through a conservation-oriented redetermination of aquifer maximum annual yield; (7) Reclassification of alluvial groundwater to stream-water; (8) Cable Mountain Reservoir; and (9) Water conservation. The first five strategies are discussed extensively in Kershen (2021), which includes dozens of supporting footnotes and references that detail the case law/juris prudence, correspondence, and other documentation of events. Readers are strongly encouraged to review Kershen (2021) in its entirety. A thorough description of these strategies also is provided in Chapter 7.2 of the URRBS Full Report.

Tom Steed Reservoir: Planning Objectives and Strategies

Planning Objectives

The primary planning objective identified in the URRBS was for *Tom Steed Reservoir to deliver a firm yield of 16,100 acre-ft/yr*, which is the full volume of MPMCD's permit. Regarding run-of-the-river stream-water permit holders, the planning objective was to maximize beneficial use and avoid futile curtailments. Although the primary objective for Tom Steed Reservoir was to deliver 16,100 acre-ft/yr, it is important to note that lesser demands on Tom Steed Reservoir were considered as a means of adding flexibility into the adaptation strategies in terms of testing their ability to protect the volume within the MPMCD permit that was either currently being put to beneficial use or could be put to beneficial use during prolonged and severe droughts. As such, two additional planning objectives were formulated for MPMCD. The first objective was to protect 12,700 acre-ft/yr, which was the maximum historical reported use of water by MPMCD out of Tom Steed Reservoir; and the second objective was to protect 14,400 acre-ft/yr, which was a mid-point volume between the maximum historical reported use of 12,700 acre-ft/yr and the full permitted volume of 16,100 acre-ft/yr, and as such represented a reasonable future demand on the reservoir given some increase in growth[20]. All three reservoir demand scenarios were included in surface water availability modeling analyses performed by the NFRR SWAM.

Overall, status-quo results revealed two important findings: (1) climate-related hydrologic factors, namely a new drought of record, have had a significant impact on Tom Steed Reservoir supply – so significant, that supplemental water would be needed for Tom Steed Reservoir to reliably deliver the full permit volume of 16,100 acre-ft/yr; and (2) the leading causes of human-induced water supply imbalances appeared to be future stream-water development (including both future domestic use and permitted use), followed by existing stream-water development (including both domestic use and permitted use).

[20] The mid-point volume is very close to 14,950 acre-ft/yr, which was MPMCD's projected year 2060 demands on Tom Steed Reservoir according to the OCWP 2012 Update.

Adaptation Strategies

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 legal review performed by Dr. Kershen that was discussed earlier in this chapter: (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 through voluntary dry-year lease agreements; (6) Conjunctive management through a conservation-oriented redetermination of aquifer MAY; (7) Reclassification of alluvial groundwater to stream-water; (8) Addressing EQ beneficial use issues at Hackberry Flat WMA; (9) Expansion of the Bretch Diversion and Canal; (10) Development of Supplemental Groundwater Supplies; and (11) Water conservation. The first seven strategies were discussed extensively in Kershen (2021), which includes dozens of supporting footnotes and references that detail the case law/juris prudence, correspondence, and other documentation of events. Readers are strongly encouraged to review Kershen (2021) in its entirety. A thorough description of these strategies also is provided in Chapter 7.2 of the URRBS Full Report.

Evaluation of Adaptation Strategies and Trade-off Analysis

Overview and Approach

Chapter 8.2 and Chapter 8.3 of the URRBS provides a thorough evaluation of each adaptation strategy identified for Lugert-Altus Reservoir and Tom Steed Reservoir, respectively. Specifically, the adaptation strategies were evaluated to determine how well they perform in addressing the planning objectives identified for the Lugert-Altus and Tom Steed reservoir hydrologic basins, including the extent to which they could eliminate imbalances between water supplies and demands. In addition to performing a thorough evaluation of adaptation strategies, the URRBS performed a cursory trade-off analysis comparing the portfolio of strategies among one another, which was a requirement set forth by Reclamation's Basin Study Program in WTR 11-01. The trade-off analysis for Lugert-Altus Reservoir and Tom Steed Reservoir is provided in Chapter 8.2.9 and Chapter 8.3.9, respectively.

For the purposes of this Executive Summary Report, the evaluation of adaptation strategies is presented only in terms of the trade-off analysis required in WTR 11-01. 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, which is the case for Federal planning investigations governed by the Principles and Requirements for Federal Investments in Water Resources (PR&Gs)[21]. 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. The requirements for such studies are quite rigorous. However, unlike Federal planning investigations governed by the PR&Gs, basin studies (including this URRBS) are explicitly *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.

[21] For the purposes here, Federal planning investigations are defined as studies governed by the Principles and Requirements for Federal Investments in Water Resources (https://www.doi.gov/ppa/principles-and-guidelines), as well as Reclamation's CMP 09-02 on Water and Related Feasibility Studies (https://www.usbr.gov/recman/cmp/cmp09-02.pdf).

For this URRBS, the goal of the trade-off analysis was to provide Lugert-Altus ID and MPMCD, and (to some extent) OWRB, with guidance on some key criteria to consider when assessing the viability or preferability of one or more strategies evaluated in this URRBS. While each strategy was assigned a qualitative "score" indicating its relative performance for each criterion, two items are important to note. First, even though relative performance could be interpreted as indicating one strategy should be selected over another strategy, multiple strategies may be pursued either jointly or concurrently. Second, the scores were largely subjective and based on numerous assumptions. For most strategies, the legal review by Kershen (2021) was taken into consideration. This entailed weighing the merits of each strategy based on a subjective interpretation of the contents, claims, and opinions provided by Dr. Kershen. This subjective interpretation does not represent the official opinion, endorsement, or agreement by study partners on any aspect of the legal review. Dr. Kershen was solely responsible for the contents and opinions presented in the legal review. In light of this, the trade-off analysis should be viewed with caution and should be considered for guidance purposes only.

Evaluation Criteria

Even though basin studies are not governed by the PR&Gs, this study used the PR&Gs as guidance in determining how to perform the required trade-off analysis of alternative strategies identified in this URRBS. The PR&Gs require alternatives to be compared to one another based on four screening criteria: *Effectiveness*, *Efficiency*, *Acceptability*, and *Completeness*. These criteria were adopted for the trade-off analysis here and modified to meet the purpose and context of the URRBS. The four criteria were defined as follows:

Effectiveness: This criterion measured the relative extent to which the strategy meets the planning objectives identified in the URRBS. For Lugert-Altus Reservoir, the planning objective was to maximize the volume of water held in storage such that 115,000 acre-ft is available at the beginning of the irrigation season. This is the volume needed in storage to meet the full permitted volumes of 85,630 acre-ft/yr for irrigation purposes and 4,800 acre-ft/yr for M&I purposes, including the agreed-upon storage reserve. 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[22]. For Tom Steed Reservoir, the planning objective was to maximize water deliveries through prolonged and severe droughts, including and up to the volume of MPMCD's water right permit of 16,100 acre-ft/yr. Similar to Lugert-Altus Reservoir, if a strategy was effective at maximizing water deliveries

[22] Recall that WTR 13-01 requires the trade-off analysis to include an evaluation of the extent to which strategies minimize water supply imbalances and address the potential impacts of climate change. This study assumed increased water supply availability correlated to reduced supply-demand imbalances and conditions that would be more resilient to potential future supply reductions caused by climate change.

up to 16,100 acre-ft/yr, then it was assumed that the strategy also was effective at minimizing water supply imbalances and addressing potential impacts of climate change. To add flexibility into the adaptation strategies that could be considered, a secondary planning objective for Tom Steed Reservoir was adopted, which was to protect the volume within the MPMCD permit that is being put to beneficial use or could be put to beneficial use, even during prolonged and severe droughts. This includes consumptive beneficial use (i.e., M&I use), as well as non-consumptive beneficial uses (i.e., EQ, fish and wildlife, and recreation). 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 do not result in meaningful improvements in water availability at Tom Steed Reservoir).

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 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.

Scoring Rubric

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 17*).

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

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

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

Table 17. Scoring rubric for the trade-off analysis of adaptation strategies to improve water supply reliability of Lugert-Altus Reservoir.

Favorable	↑
Neutral	→
Less Favorable	↓

Trade-Off Analysis Results

Lugert-Altus Reservoir

The evaluation criteria and scoring rubric were applied to each of the nine adaptation strategies. A summary table of trade-off analysis results is provided in Table 20. Following this summary, a discussion is provided on how each strategy performed in the trade-off analysis; it includes a brief explanation supporting the score that was given under each evaluation criterion.

Table 18. 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	↑	↑	↑	↑

Clarification of Existing Stream-Water Rights to Lugert-Altus Reservoir

Description

- This strategy proposed clarification on whether a valid claim could be made asserting an existing water right to the top of the conservation pool of Lugert-Altus Reservoir. The reader is encouraged to read Chapter 8.2.1 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- The extent to which this strategy addresses the planning objective of maintaining a 115,000 acre-ft volume in storage at Lugert-Altus Reservoir depends on whether a valid claim could be made asserting an existing water right to the top of the conservation pool of Lugert-Altus Reservoir.
- Based on Kershen (2021), it was assumed that a valid claim may not be made asserting a water right to the top of conservation pool; therefore, this strategy would not be effective at providing 115,000 acre-ft of water in storage.
- If claiming a water right to the top of conservation pool was legally validated or otherwise approved by the OWRB, then this strategy would be effective at achieving the 115,000 acre-ft water in storage target, notwithstanding the natural variations in climate and hydrology that cannot be controlled.

Efficiency: Less Favorable

- It was assumed that this strategy would not receive agreement or approval from the OWRB; therefore, it was assumed that litigation may be required to implement this strategy, which would increase the costs to implement this strategy.

Acceptability: Less Favorable

- It was assumed that this strategy may not receive agreement or approval from the OWRB; therefore, it was assumed that litigation may be required, which may reduce stakeholder support. The unknown outcome of potential future litigation raises additional risks.

Completeness: Less Favorable

- It was assumed that this strategy may not receive agreement or approval from the OWRB; therefore, it was assumed that litigation may be required, which may reduce stakeholder support. The unknown outcome of potential future litigation raises additional risks.

Protection of Existing Stream-Water Rights to Lugert-Altus Reservoir – Regulatory Protection

Description

- This strategy proposed to adopt regulatory interference thresholds that protect Lugert-Altus Reservoir from existing and/or future junior stream-water permits during drought periods. The reader is encouraged to read Chapter 8.2.2 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- Given the relatively minor volume and impact of existing stream-water permits in the Lugert-Altus Reservoir hydrologic basin, it would be difficult to claim those permits create interference with the senior rights to the reservoir; the NFRR watershed above Lugert-Altus Reservoir does not appear to have sufficient water available for new regular stream-water permits, even when calculating permit availability using naturalized flows. The combination of these two factors led study partners to question the merits of going through the complex and time-consuming process of developing an administrative procedure to prevent interference with senior priority rights. Therefore, a determination was made by study partners that an administrative enforcement procedure protecting the senior water rights to Lugert-Altus Reservoir would not meaningfully address the 115,000 acre-ft water in storage planning objective.

Efficiency: Neutral

- The costs to implement this strategy would not be relevant considering a determination was made by study partners that an administrative enforcement procedure protecting the senior water rights to Lugert-Altus Reservoir would not meaningfully address the 115,000 acre-ft water in storage planning objective.

Acceptability: Less Favorable

- Given the ineffectiveness of this strategy at addressing the 115,000 acre-ft water in storage planning objective, this strategy was not considered an acceptable approach by study partners.

Completeness: Less Favorable

- Given the ineffectiveness of this strategy at addressing the 115,000 acre-ft water in storage planning objective, the risks associated with implementing this strategy were considered relatively high.

Protection of Existing Stream-Water Rights to Lugert-Altus Reservoir – Non-Regulatory Protection

Description

- This strategy was comprised of protecting the irrigation right by leasing or converting/assigning the M&I right to an irrigation right held by Lugert-Altus ID. The reader is encouraged to read Chapter 8.2.2 of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- This was considered an effective strategy for at least partially achieving the planning objective of 115,000 acre-ft water in storage. By assigning the existing 4,800 acre-ft/yr M&I water right to an irrigation water right held by Lugert-Altus ID, the total irrigation right could potentially be increased from 85,630 acre-ft/yr to 90,430 acre-ft/yr, and in doing so, free up to 29,000 acre-ft/yr of additional water supply for irrigation that otherwise has to remain in storage to protect the city of Altus' senior right to M&I water. More specifically, this strategy could increase the average annual yield of Lugert-Altus Reservoir by between 20,600 acre-ft/yr (31 percent increase) and 27,200 acre-ft/yr (44 percent increase) depending on the development scenario and could increase the dependability of the full 85,630 acre-ft/yr irrigation permit by between 31 percent (from 21 percent dependable to 52 percent dependable and 23 percent (from 19 percent dependable to 42 percent dependable).

Efficiency: Neutral

- The transaction costs to implement this strategy would depend on a number of factors, including an assessment of the fair market value of the senior M&I water right that is currently assigned to the city of Altus, as well as the outcome of stakeholder outreach and environmental compliance activities.

Acceptability: Neutral

- The transaction would need to be coordinated jointly between the city of Altus and Lugert-Altus ID, and would likely require approval by the U.S. As such, the action would be subject to review in accordance with NEPA, and Reclamation would be required to coordinate with other stakeholders, including recreation and fish and wildlife interests, and the public when evaluating the environmental and socioeconomic impacts of the action.

- The acceptability of this strategy would depend on the capability or willingness of the city of Altus to sell, lease, or otherwise convert/assign their M&I water to Lugert-Altus ID for irrigation purposes; the capability or willingness of Lugert-Altus ID to purchase or lease the water, and other unknown terms and conditions that could affect the viability of a voluntary purchase/lease agreement.

- The acceptability of this strategy also would depend on the outcome of NEPA compliance activities, including coordination with recreation and fish and wildlife stakeholders.

Completeness: Neutral

- The risks for implementing of this strategy would depend on the capability or willingness to pay, other unknown terms and conditions that could affect the viability of a voluntary purchase/lease agreement, the acceptability by stakeholders, and outcome of NEPA compliance activities.

Additional Stream Water Rights for Lugert-Altus ID

Description

- This strategy proposed that Lugert-Altus ID[23] apply for water rights to all of the unappropriated water in the NFRR, effectively gaining a water right to an additional 37,570 acre-ft of water, which is the unused volume above 90,430 acre-ft (the combined volume of the irrigation and M&I rights) and below 128,000 acre-ft (top of conservation pool). The new right could be non-consumptive (for recreation and fish and wildlife purposes), yet would provide additional protections for the consumptive irrigation and M&I rights. The reader is encouraged to read Chapter 8.2.3 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- This strategy would be effective at achieving the reservoir water in storage target of 115,000 acre-ft, albeit only during infrequent and favorable wet conditions when the reservoir can fill above 90,430 acre-ft/yr.
- This strategy could turn the OWRB policy of not granting any new stream permits on the NFRR upstream of Lugert-Altus Reservoir into a legal impossibility because Lugert-Altus ID would have a vested water right for all additional waters from all years.
- If Lugert-Altus ID gained the new right for non-consumptive purposes, it would also indirectly protect the consumptive (irrigation and M&I) water rights. By having a new, non-consumptive water right that is junior to its senior consumptive water rights, Lugert-Altus ID would be protecting the senior water rights from junior interference.

Efficiency: Favorable

- It was assumed that the OWRB could grant Lugert-Altus ID a water right to all unappropriated waters upstream of Lugert-Altus Reservoir at relatively low costs. It assumed that stakeholder support would be largely positive and that the risk of significant protest or prolonged litigation was low.

[23] Kershen (2021) noted that Reclamation also has the authority to apply for rights to all unappropriated water; for the purposes here, it was assumed Lugert-Altus ID would apply for the water rights.

Acceptability: Favorable

- It was assumed that stakeholder support would be largely positive with minimal risk of significant protest or prolonged litigation.
- The OWRB concluded in the OCWP that the basins upstream from Lugert-Altus Reservoir did not have any stream water available for new regular prior appropriation permits, so it would seem that no one should be thinking about applying for a new water right in the Lugert-Altus Reservoir hydrologic basin.
- It may sound contradictory to state that Lugert-Altus ID could apply for water rights in all unappropriated waters when the OCWP stated (and the URRBS verified) that no unappropriated waters exist; however, granting Lugert-Altus ID a water permit for all unappropriated waters could legally effectuate closure of the basins in conformity with the OCWP. Moreover, the OCWP closure appears related to consumptive uses of the waters of these watersheds whereas this strategy assumes Lugert-Altus ID would be applying for non-consumptive beneficial uses for recreation, fish, and wildlife.
- State of Oklahoma statutes require that the OWRB make factual findings for five different criteria before issuing a permit to use surface water. If sufficient evidence does not exist to support each of the criteria, then the permit cannot be issued. The first of these criteria is that "there is unappropriated water available in the amount applied for." Therefore, under current law, OWRB can only issue a permit to the Lugert-Altus ID for additional water if water is available in the stream system based on the requirements of Oklahoma Administrative Code 785:20-5-5(a)(1). 82 O.S. § 105.12.

Completeness: Favorable

- For reasons discussed above, it was assumed that Lugert-Altus ID could face little opposition to its application for all unappropriated waters in the NFRR above Lugert-Altus Reservoir, that stakeholder support would be positive, and that changes in law, regulations, and/or policy would not be required. Therefore, the risks associated with implementing this strategy may be relatively low.
- State of Oklahoma statutes require that the OWRB make factual findings for five different criteria before issuing a permit to use surface water. If sufficient evidence does not exist to support each of the criteria, then the permit cannot be issued. The first of these criteria is that "there is unappropriated water available in the amount applied for." Therefore, under current law, OWRB can only issue a permit to the Lugert-Altus ID for additional water if water is available in the stream system based on the requirements of Oklahoma Administrative Code 785:20-5-5(a)(1). 82 O.S. § 105.12.

Conjunctive Management - Voluntary Dry-Year Lease or Purchase Agreements

Description

- This strategy proposed to purchase existing senior water rights and/or enter into dry-year lease agreements with groundwater permit holders in the NFRR aquifer through voluntary, non-regulated transactions between the Lugert-Altus ID and willing leasers/sellers of groundwater to protect the base flows of the NFRR. The reader is encouraged to read Chapter 8.2.4 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Neutral

- Existing groundwater permits were found to have substantive impacts on Lugert-Altus Reservoir, yet the effectiveness of this strategy in addressing the 115,000 acre-ft water in storage target would depend on the ability to negotiate lease/purchase agreements with groundwater permit holders that have the greatest impacts on NFRR base flow.
- It may be considered impractical for Lugert-Altus ID to reach a dry-year lease/purchase agreement with all 480 groundwater-right holders because of the high transaction costs and the current hydrological uncertainties associated with leasing any specific acreage less than all acres covered by the groundwater permits. Therefore, this strategy would benefit from a more detailed investigation into the localized impacts of groundwater pumping on Lugert-Altus Reservoir. If this strategy could target permit holders that have the greatest impact on the NFRR baseflow (and inflows to the Lugert-Altus Reservoir), then Lugert-Altus ID would have a more manageable number of landowners with whom to negotiate dry-year lease/purchase agreements and have more confidence that these agreements would increase the amount of water in storage in the Reservoir. This is a subject of a separate investigation that is being conducted outside of this URRBS.

Efficiency: Neutral

- The costs of implementing this strategy would depend on the number of groundwater permit holders in the NFRR aquifer that could potentially enter into agreements with Lugert-Altus ID; the number of permit holders would depend on the outcome of further investigations into the localized impacts of groundwater pumping on Lugert-Altus Reservoir.

Acceptability: Neutral

- The acceptability of this strategy would depend on the capability or willingness of groundwater permit holders to lease or sell their water to Lugert-Altus ID, the capability or willingness of Lugert-Altus ID to lease or purchase the groundwater from groundwater permit holders, and other unknown terms and conditions that could affect the viability of voluntary lease/purchase agreements.

Completeness: Neutral

- The risks for implementing of this strategy would depend on the outcome of future investigations into the localized impacts of groundwater pumping on Lugert-Altus Reservoir, and the number of groundwater permit holders and agreements that would be needed to be executed to have meaningful benefit to NFRR base flow and inflows into Lugert-Altus Reservoir.

Conjunctive Management – Conservation-Oriented Maximum Annual Yield Determination

Description

- This strategy proposed the implementation of a conservation-oriented maximum annual yield on the NFRR and Elk City aquifers, as well as the adoption of a lesser EPS for future groundwater permit applicants that protects the base flow of the NFRR and consequently, protects the yield of Lugert-Altus Reservoir. The reader is encouraged to read Chapter 8.2.4 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- The extent to which this strategy could address the 115,000 acre-ft storage volume target depends on numerous factors, including the volume of existing versus future groundwater withdrawals that could actually be reduced. For example, reservoir yield was reduced two times more by existing wells than by future wells, but future groundwater permits still had measurable impacts on the supply of Lugert-Altus Reservoir. Most existing permits are prior rights that cannot be reduced, whereas future well permits could be reduced. Even though new groundwater permits were found to be less impactful on Lugert-Altus Reservoir than existing permits, there were impacts, nevertheless, so adopting a lesser EPS to promote a conservation policy about groundwater use would be preferred by Lugert-Altus ID over an EPS that promotes a policy of depleting the NFRR alluvial aquifer within 20 to 50 years.

Efficiency: Neutral

- The costs to implement this strategy would depend on the level of stakeholder support from existing and future potential groundwater users of the NFRR, and the extent to which a lack of stakeholder support could result in significant protest or prolonged litigation.

- A lesser EPS in the NFRR aquifer would likely be preferred by Lugert-Altus ID over one that reflects the policy of full depletion of the aquifers, but this preference may not be shared by groundwater users. Groundwater users may not view full aquifer depletion as a reasonably foreseeable scenario, and therefore may continue to advocate for a higher aquifer EPS that maximizes water availability for agricultural production, municipal use, energy production, etc.

Acceptability: Neutral

- The acceptability of this strategy would depend on the level of stakeholder support from existing and future potential groundwater users of the NFRR aquifer, and the extent to which a lack of stakeholder support could result in significant protest or prolonged litigation; these factors would ultimately influence the likelihood of the OWRB agreeing to implement a lesser, more conservation-oriented EPS.
- A lesser EPS in the NFRR aquifer would likely be preferred by Lugert-Altus ID over one that reflects the policy of full depletion of the aquifers, but this preference may not be shared by groundwater users. Groundwater users may not view full aquifer depletion as a reasonably foreseeable scenario, and therefore may continue to advocate for a higher aquifer EPS that maximizes water availability for agricultural production, municipal use, energy production, etc.

Completeness: Less Favorable

- While legal arguments exist that support a conservation-oriented EPS, the OWRB noted that a similar strategy in the Arbuckle Simpson Aquifer in southeast Oklahoma required new legislation. Therefore, it was assumed that new legislation may likely be needed for a similar strategy to be implemented in the Lugert-Altus Reservoir hydrologic basin, which would create a barrier towards implementation.

Reclassification of Alluvial Groundwater to Stream Water

Description

- This strategy proposed that under certain conditions, reclassified alluvial groundwater could be managed in accordance with Oklahoma's surface water prior appropriation laws, which would effectively make the surface water permits for water stored in Lugert-Altus Reservoir senior to the groundwater use permitted after the dates of the reservoir permits.
- After reclassification, the newly-classified junior "stream-water" permits could be curtailed during periods of severe drought under the state's existing Prior Appropriation Doctrine.
- Notwithstanding the complex factors associated with implementing this strategy noted in the criteria below, a key component of the URRBS was the identification of hydrologic indicators and corresponding thresholds that could be used to curtail the newly-classified "stream-water" permits under the state's existing Prior Appropriation Doctrine. The details of the analysis can be found in Chapter 8.2.5 of the URRBS Full Report and Reclamation's

Technical Memorandum “Formulation of Hydrologic Thresholds to Support Water Management in the Lugert-Altus Reservoir Hydrologic Basin” [(Reclamation, 2021b) (Appendix J of the URRBS Full Report]. Unlike Tom Steed Reservoir, a water availability modeling analysis was not conducted to evaluate the impacts of implementing the hydrologic thresholds on Lugert-Altus Reservoir. This is because the NFRR aquifer model developed through the URRBS was not robust enough to conduct this type of analysis.[24] As such, the discussion below is limited only to the formulation of hydrologic thresholds.

Formulation of Hydrologic Threshold Alternatives

The analysis was divided into six parts as follows:

Part I: Provides an introduction to the goals of the analysis and key terminology.

Part II: Identified several indicators that exist both nationally and globally, and applied multiple screening criteria to narrow these down to only a few indicators for further consideration. These were evaluated both individually and in combination with one another in Part III.

Part III: Analyzed the indicators selected in Part II in terms of their ability to predict observed, historical droughts, both individually and in combination. Seventeen drought definitions (scenarios) were evaluated. Predictive models were built through logistic regression to evaluate predictive performance. The relative performance of the logistic regression models was tested using standard techniques to assess how well model predictions match up with observed droughts (as defined by the drought scenarios) over seven different model time periods. Through this analysis, the list of indicators selected in Part II was narrowed down to only two for further testing: inflow and Standardized Precipitation Index (SPI).

Part IV: Focused specifically on the logistic regression models derived by the two indicators (inflow and SPI) selected in Part III, and evaluated the impact that each drought scenario and model time period had on model performance. Through this analysis, of the 17 drought scenarios originally considered, only 11 were carried forward for further analysis; and of the seven model periods originally considered, only 4 were carried forward for further analysis.

Part V: Focused on how well the full range of potential inflow-SPI thresholds predicted observed, historical conditions as defined by the droughts and model time periods that are selected in Part IV. Each combination of thresholds was analyzed using proven atmospheric science methods used to test meteorological forecasting. Of the 882 threshold combinations considered, a total of four inflow-SPI thresholds were selected as preferred thresholds that would make up the Hydrologic Threshold Alternatives described in Part VI as follows:

[24] Separate from the URRBS, Reclamation was awarded a grant in Fiscal Year 2022 under Reclamation’s Applied Science Program to increase the robustness of the NFRR aquifer model, and to perform more detailed modeling simulations that could inform future water availability modeling analyses on the impacts of hydrologic thresholds on Lugert-Altus Reservoir. Reclamation has commissioned USGS to perform the analyses.

1. Inflow ≤ 79,100 acre-ft and SPI ≤ -0.01
2. Inflow ≤ 89,100 acre-ft and SPI ≤ -0.35
3. Inflow ≤ 101,500 acre-ft and SPI ≤ -0.12
4. Inflow ≤ 110,000 acre-ft and SPI ≤ -0.23

An illustration of the frequency and duration of events over the observed 90-year period of record when inflow and SPI conditions were at or below the four inflow-SPI thresholds is provided in Figure 35. Next, ten reservoir storage thresholds were selected. Combining the four inflow-SPI thresholds with the ten reservoir storage thresholds, a total of 50 inflow-SPI-reservoir storage threshold combinations were selected as presented in Table 19.

Part VI. This section describes the final formulation of Hydrologic Threshold Alternatives. The Alternatives were derived in part by the indicators and thresholds selected through Parts II-V, but other important factors were considered, namely conditions at the reservoir itself and the timing of Hydrologic Thresholds. Results showed that initiating curtailments between January and June resulted in slightly lower curtailment frequencies than initiating actions between July and December. This was because the onset of drought more often occurred between July and December, thus signaling the potential benefits of initiating action in the latter part of the year. Overall, when comparing results across *all* inflow-SPI thresholds and drought scenarios, results showed that constraining thresholds (i.e., curtailment initiation) to any particular month did *not* have a meaningful impact on the accuracy of predicting drought conditions, nor did it have a significant impact on curtailment frequency and duration when compared to immediately initiating curtailments when thresholds are first reached regardless of the time of year. The overall similarity of predictive performance across timing conditions means that a higher degree of flexibility can be integrated into future curtailment procedures without sacrificing the assumed benefits gained by curtailments. This flexibility should consider the role that water supply risk and uncertainty play in water resources management and incorporate a monitoring and advanced warning process that gives water users sufficient time to plan and prepare ahead of a potential curtailment. Most water users in the basin are farmers, and farmers often make decisions on seed purchase, crop planting, whether or not to apply for crop insurance if applicable, etc.) during the fall or winter prior to the next irrigation season.

Table 19. Occurrence frequency of a range of reservoir storage thresholds alone and when combined with four inflow-SPI thresholds over the period of record, 1926-2016.

		Occurrence Frequency (Percentile)				
		Reservoir Storage Alone	Reservoir Storage Combined with Inflow-SPI			
Inflow		-	≤ 110,000	≤ 101,500	≤ 89,100	≤ 79,100
SPI		-	≤ -0.23	≤ -0.12	≤ -0.35	≤ -0.01
Reservoir Storage Thresholds						
Percent of Conservation Pool	Acre-Feet					
< 100%	106,960	90th	44th	38th	33rd	32nd
≤ 90%	96,000	85th	43rd	38th	33rd	32nd
≤ 80%	86,000	82nd	42nd	37th	32nd	31st
≤ 70%	75,000	76th	41st	36th	32nd	31st
≤ 60%	64,000	68th	38th	34th	31st	30th
≤ 50%	53,000	59th	33rd	30th	27th	27th
≤ 40%	43,000	46th	26th	25th	22nd	22nd
≤ 30%	32,000	31st	20th	19th	18th	18th
≤ 20%	21,000	16th	12th	12th	11th	12th
≤ 10%	11,000	6th	6th	6th	6th	6th

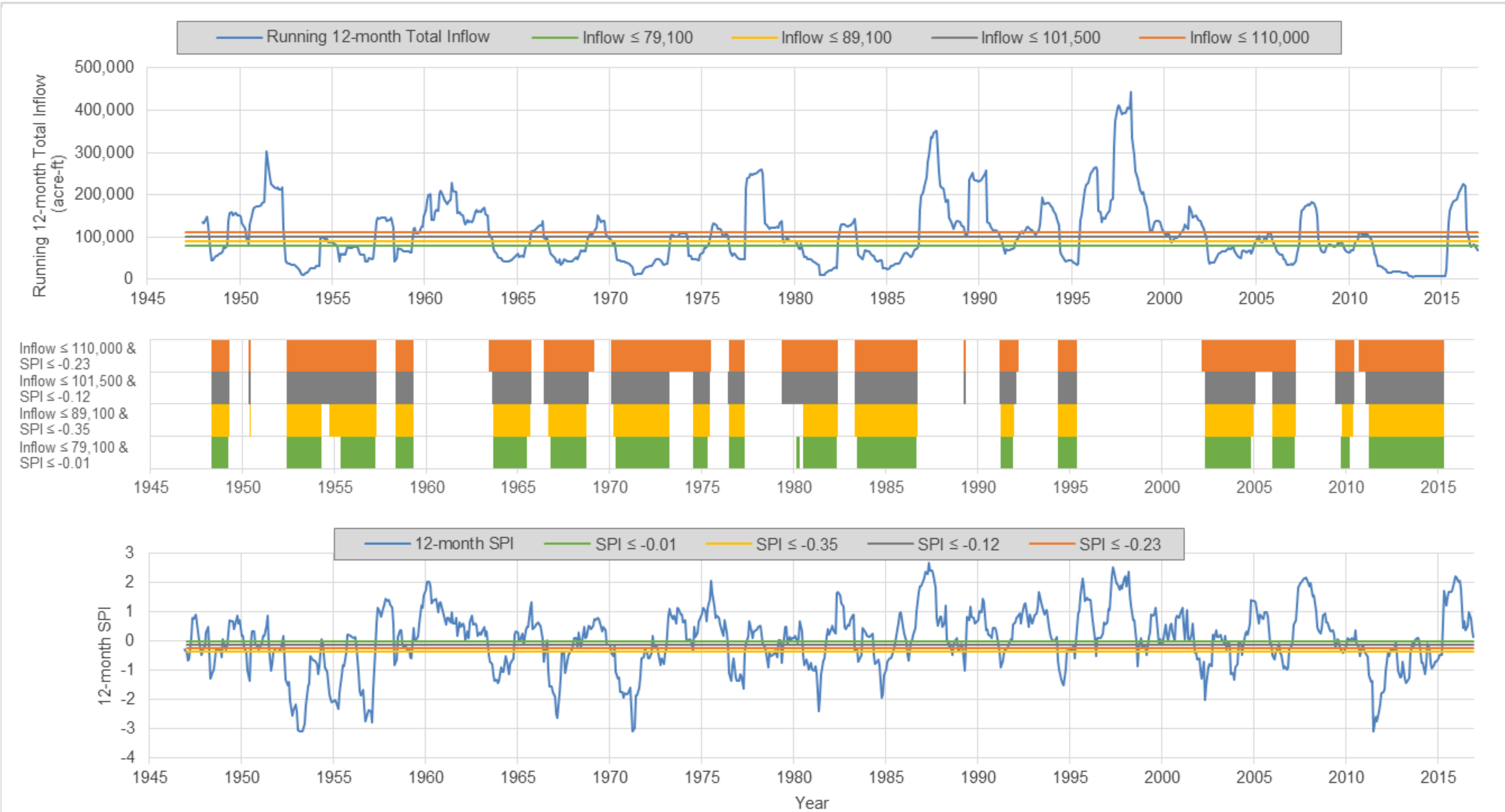


Figure 35. Occurrence frequency of a range of reservoir storage and inflow-SPI thresholds alone and in combination over the period of record, 1926-2016.

Effectiveness: Favorable

- The extent to which this strategy could address the 115,000 acre-ft water in storage target remains uncertain due to the many technical, political, and legal constraints that would need to be overcome if this strategy is pursued by Lugert-Altus ID. The volume of alluvial groundwater that could be reclassified as stream water is large, and legal arguments exist that support reclassification; however, many challenges would need to be overcome in order to implement this strategy.

Efficiency: Neutral

- Multiple legal arguments exist that support reclassification, but such an action may be controversial. Some stakeholders, notably Lugert-Altus ID and users of Lugert-Altus Reservoir, will likely support this strategy, while other stakeholders may protest this strategy resulting in litigation. Therefore, the time and cost to implement this alternative may be significant.

Acceptability: Neutral

- While this action would be effective in restoring the yield and improving the reliability of Lugert-Altus Reservoir, it may be controversial. Lugert-Altus ID and users of Lugert-Altus Reservoir would likely support this strategy, but other stakeholders may protest it resulting in litigation, potentially up to and including a hearing by the Oklahoma Supreme Court. In addition to the time and expense associated with these potential legal proceedings, the unknown outcome of such litigation raises additional uncertainty.

Completeness: Less Favorable

- While legal arguments exist that support reclassification, it was assumed that a lack of stakeholder support may generate significant protests and prolonged litigation, potentially up to and including a hearing by the Oklahoma Supreme Court. The unknown outcome of potential future litigation raises additional risks.

Cable Mountain Reservoir

Description

- This strategy proposed to construct a new reservoir, called Cable Mountain Reservoir, on the NFRR downstream of Lugert-Altus Reservoir to provide supplemental water to Lugert-Altus Irrigation District. The reader is encouraged to read Chapter 8.2.7 of the URRBS Full Report and Appendix I of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- Modeling results showed that the 80 percent dependable yield of Cable Mountain Reservoir for irrigation purposes was 60,700 acre-ft/yr, and the average annual yield was estimated to be 54,800 acre-ft/yr. The firm yield was estimated to be 23,700 acre-ft/yr.

- Cable Mountain Reservoir would improve overall water supply reliability by delivering augmentation water directly to Lugert-Altus ID. The combined average annual yield of both Lugert-Altus and Cable Mountain Reservoirs would range from 100,700 acre-ft/yr to 89,000 acre-ft/yr depending on the development scenario. These volumes are more than sufficient to deliver the full irrigation and M&I permit volume of 90,430 acre-ft/yr to the Lugert-Altus ID and city of Altus.

Efficiency: Less Favorable

- The preliminary estimate of capital costs to implement this strategy was $455 million with annual O&M of $2.5 million. These costs exclude the costs to implement chloride control measures in the Elm Fork of the NFRR upstream of Cable Mountain Reservoir. This strategy was considered to be less favorable given the high costs and risks associated with chloride control measures that were assumed to be needed in order to make this strategy viable.

Acceptability: Neutral

- Despite its relatively high costs and risks to implement, Cable Mountain Reservoir has long been perceived by stakeholders as an important alternative that could provide supplemental irrigation water to Lugert-Altus ID, as well as water for agricultural irrigation and M&I purposes in the region beyond Lugert-Altus ID. As such, both Cable Mountain and chloride control measures have garnered continued support from Lugert-Altus ID and other potential project sponsors over the years. However, other stakeholders, namely some recreation, fish, and wildlife interests, may pose strong opposition to the reservoir and/or chloride control measures.

Completeness: Less Favorable

- Given the extraordinarily complex factors related to planning, permitting, building, operating, and maintaining Cable Mountain Reservoir, and considering the additional complexities associated with planning and implementing the necessary chloride control measures, it was assumed that this strategy would involve numerous high risks to implement.

Water Conservation

Description

- Although water conservation measures can include a variety of District- and on-farm-level measures to improve the delivery, control, measurement, and application of water, for the purposes of this URRBS, the water conservation strategy for Lugert-Altus ID was defined specifically as the entire network of canals identified in the Lugert-Altus ID 2021 WCP Update that could be either lined or converted to enclosed pipelines in the future. A copy of the Lugert-Altus IDs 2021 five-year WCP Update is located in Reclamation OTAO's central files and is available upon request. The reader is encouraged to read Chapter 8.2.8 of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- Although water conservation would not directly address the planning objective of having 115,000 acre-ft of water in storage at the beginning of the irrigation season, it would allow more of the water stored in Lugert-Altus Reservoir to be put to beneficial use. The volume of water savings would depend on the scale and size of future water conservation improvement projects implemented by the Lugert-Altus ID to address water losses, but the potential water savings identified in the Lugert-Altus ID WCP 2021 Update were significant (i.e., at least 15,000 acre-ft/yr).

Efficiency: Favorable

- The capital cost to convert open canals to buried pipelines can be relatively high, especially for larger canals; however, the water savings can be significant. At the time of this URRBS, a cost estimate had not been prepared for the full conversion of the open canal system evaluated in the Lugert-Altus WCP 2021 Update.

Acceptability: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Completeness: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Tom Steed Reservoir

The evaluation criteria and scoring rubric were applied to each of the eleven adaptation strategies. A summary table of trade-off analysis results is provided in Table 20. Following this summary, a discussion is provided on how each strategy performed in the trade-off analysis; it includes a brief explanation supporting the score that was given under each evaluation criterion.

Table 20. 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	→	↑	↑	↑

Clarification of Existing Stream-Water Rights of Mountain Park Master Conservancy District

Description

- Unlike Lugert-Altus Reservoir which focused solely on claiming a water right to the top of conservation pool, this strategy proposed to clarify MPMCD's existing stream-water right with regards to permit volume, beneficial uses, and priority date. The reader is encouraged to read Chapter 8.3.1 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- If MPMCD gained or perfected water rights that account for carriage, evaporative losses, and/or non-consumptive uses, then MPMCD would have a larger volume of permitted (perfected) water rights; consequently, MPMCD could seek protection and assert interference with its water rights sooner (i.e., upon dropping below an average annual inflow threshold of 45,000 acre-ft/yr) than it would otherwise by seeking protection of a permit to only 16,100 acre-ft/yr. The effectiveness of curtailing junior permits at various inflow thresholds is discussed below.
- If MPMCD has a quantified right to store up to 45,000 acre-ft/yr, a "Schedule of Use" for the permit may not be needed because MPMCD would have a right to store 45,000 acre-ft/yr regardless of the amount of water actually conveyed to contractual water users, and would be at less risk of a reduction in its water rights under a "use it or lose it" approach implied by having a Schedule of Use in its water permit.
- Increasing MPMCD's permit to 45,000 acre-ft/yr would significantly reduce and almost eliminate the volume of water available for new stream-water permits upstream of Tom Steed Reservoir.
- Kershen (2021) noted that the year 1955 is actually the priority date of MPMCD's permit, not 1967. This is because 1955 is the year Reclamation wrote to the state of Oklahoma asking for the withdrawal of all unappropriated waters in the Elk Creek and West Otter-Glen Creek watersheds for development of the Mountain Park Project. If MPMCD's permit was assigned a priority date of May 4, 1955, then MPMCD's water right would be senior over all water rights in the OWRB's 1964 Final Order No. 4 that date after May 4, 1955, along with any other permit with an officially-designated priority date after 1967. Precisely how this change could affect the priority of permits is unknown because an adjudication and final order of vested stream rights in the Tom Steed Reservoir hydrologic basin post-1964 has not been performed by the OWRB. That said, changing the priority date of MPMCD's permit to May 4, 1955 could make MPMCD's permit senior to 15 of the 17 stream permits in the Tom Steed Reservoir hydrologic basin, with only two remaining permits (Permit No. 19320051 for 631 acre-ft/yr and Permit No. 19520414 for 77 acre-ft/yr) left as senior to MPMCD's permit. And by

this change, one could speculate that MPMCD's permit would be further protected because an additional 1,225 acre-ft/yr of permits could be subject to curtailment during drought periods if hydrologic thresholds were put into place by the OWRB. It is important to stress again that without a post-1964 adjudication and final order on the priority of vested water rights in the Tom Steed Reservoir hydrologic basin, the impacts of changing MPMCD's permit seniority on real-world water management in the basin was assumed to remain unknown.

Efficiency: Favorable

- It was assumed that MPMCD's permit could be increased and/or perfected to allow non-consumptive beneficial uses and/or vested to a seniority date of May 4, 1955 at a relatively low cost. This assumed that the OWRB and MPMCD could clarify MPMCD's existing permit on agreeable terms, that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Acceptability: Favorable

- It was assumed that MPMCD's permit could be increased and/or perfected to allow non-consumptive beneficial uses and/or vested to a seniority date of May 4, 1955 with broad stakeholder support.

Completeness: Favorable

- It was assumed that MPMCD's permit could be increased and/or perfected to allow non-consumptive beneficial uses and/or vested to a seniority date of May 4, 1955 with relatively low risks to implementation. This assumed that the OWRB and MPMCD could clarify MPMCD's existing permit on agreeable terms, that stakeholder support would be positive, and that changes in law, regulations, and/or policy would not be required.

Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District – Regulatory Protection

Description

- This strategy proposed to adopt regulatory interference thresholds that protect Tom Steed Reservoir from existing and/or future junior stream-water permits during drought periods.
- A key component of the URRBS was the identification of a range of hydrologic indicators and thresholds that could define when interference is occurring under the state's Prior Appropriation Doctrine, thus triggering the curtailment of permitted upstream diversions that are junior to MPMCD's more senior rights to water stored in Reclamation reservoirs. The details of the analysis can be found in Chapter 8.3.2 of the URRBS Full Report, as well as in Reclamation's Technical Memorandum "Formulation of Stream-Water

Rights Management Alternatives in the Tom Steed Reservoir Hydrologic Basin" (Appendix K of the URRBS Full Report).

- The NFRR SWAM was then used to quantify the impacts of each of the hydrologic indicators and thresholds on water availability in the Tom Steed Reservoir hydrologic basin. A thorough description of the water availability modeling methods and results is provided in Chapter 8.3.2 of the URRBS Full Report, as well as in Appendix M of the URRBS Full Report.
- For the purposes of this Executive Summary Report, the two major bodies of work cited above are summarized below. The first summary focuses on the methods and results related to the identification of hydrologic indictors and thresholds in the basin, and the second summary focuses on the methods and results of the water availability modeling analysis.

Formulation of Stream-Water Rights Management Alternatives

The hydrologic indicators and thresholds were named "stream-water rights management alternatives" in the URRBS Full Report. The analysis was divided into six "Parts" as follows.

Part I: Provided an introduction to the analysis, including strategy goals and definitions of key terminology.

Part II: Identified several drought indicators that exist both nationally and globally, and applied several screening criteria to narrow these down to only a few indicators for further consideration. These were evaluated both individually and in combination in Part III.

Part III: Analyzed the drought indicators selected in Part II in terms of their ability to predict observed, historical droughts, both individually and in combination. Fifteen drought definitions (scenarios) were evaluated. Predictive models were built through logistic regression to evaluate predictive performance. The relative performance of the logistic regression models was tested using standard techniques to assess how well model predictions matched up with observed droughts (as defined by the drought scenarios) over seven different model time periods. Through this analysis, the list of drought indicators selected in Part II was narrowed down to only two indicators [(i.e., inflow and Palmer Drought Severity Index (PDSI)] for further testing.

Part IV: Focused specifically on the logistic regression models derived by the two indicators (inflow and PDSI) selected in Part III, and evaluated the impact that each drought scenario and model period had on model performance. Through this analysis, of the 15 drought scenarios originally considered, only six were carried forward for further analysis, and of the seven model time periods considered, three were carried forward for further analysis.

Part V: Focused on how well the full range of potential inflow-PDSI thresholds predicted observed, historical conditions as defined by the droughts and model periods that were selected in Part IV. Each combination of thresholds was analyzed using proven methods. Of the 441 inflow-PDSI threshold combinations considered, four inflow-PDSI thresholds were selected as preferred thresholds that make up the Stream-Water Rights Management Alternatives described in Part VI. The four inflow-PDSI thresholds were as follows:

1. Inflow ≤ 58,300 acre-ft and PDSI ≤ -0.12
2. Inflow ≤ 72,200 acre-ft and PDSI ≤ -1.66
3. Inflow ≤ 39,700 acre-ft and PDSI ≤ -0.78
4. Inflow ≤ 28,600 acre-ft and PDSI ≤ -0.49

An illustration of the frequency and duration of events over the observed 90-year period of record when inflow and PDSI conditions were at or below four inflow-PDSI thresholds is provided in Table 21 below.

Next, ten reservoir storage thresholds were selected. Combining the four inflow-PDS thresholds with the ten reservoir storage thresholds, a total of 50 inflow-PDSI-reservoir storage threshold combinations were selected as presented in Table 21 and Figure 36[25]:

Table 21. Occurrence frequency of a range of reservoir storage thresholds alone and when combined with four inflow-PDSI thresholds over the period of record, 1926-2016.

		Occurrence Frequency (Percentile)				
		Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI			
Inflow		-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600
PDSI		-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49
Reservoir Storage Thresholds						
Percent of Conservation Pool	Acre-Feet					
< 100%	88,880	83rd	36th	20th	20th	12th
≤ 90%	80,000	58th	33rd	19th	19th	12th
≤ 80%	71,000	40th	28th	18th	18th	12th
≤ 70%	62,000	26th	21st	16th	15th	11th
≤ 60%	53,000	16th	15th	12th	12th	9th
≤ 50%	44,000	8th	8th	7th	7th	6th
≤ 40%	36,000	5th	5th	5th	5th	5th
≤ 30%	27,000	3rd	3rd	3rd	3rd	3rd
≤ 20%	18,000	2nd	2nd	2nd	2nd	2nd
≤ 10%	9,000	1st	1st	1st	1st	1st

[25] It is important to point out that the range of indicator-threshold combinations selected in support of this strategy also could be used to support a "shared shortage" declaration by MPMCD during times of drought in accordance with its water supply contracts with member entities, thus addressing a key operational challenge cited in Chapter 2.4.2 of the URRBS Full Report. In doing so, the threshold could provide MPMCD with a reasonable and defensible basis for ensuring member entities proportionally reduce their water usage during times of drought. The thresholds also could provide a basis for triggering willing, agreed-upon transfers of water among member entities based on their respective allocations, usage, and needs.

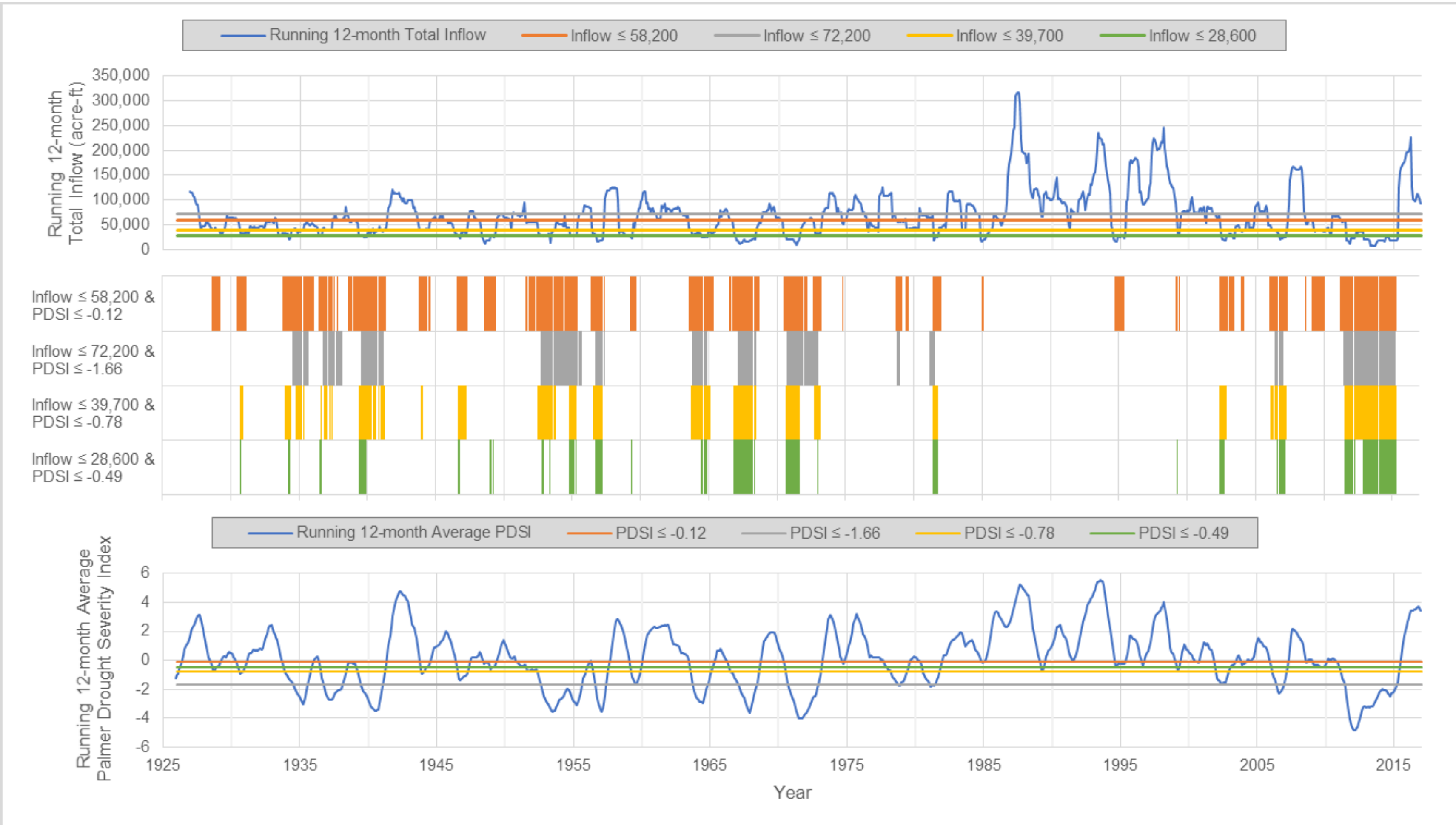


Figure 36. Frequency and duration of events over the observed 90-year period of record when inflow and PDSI conditions were at or below four inflow-PDSI thresholds.

Part VI. Described the final formulation of Stream-Water Rights Management Alternatives. The Alternatives were comprised of the inflow-PDSI-reservoir storage thresholds selected through Parts II-V, as well as two other important factors, namely the *timing* of curtailments (i.e., implementation month) and the *types* of stream-water permits (i.e., existing and/or new junior stream-water permits) to be curtailed. Regarding *timing*, results showed that constraining thresholds (i.e., curtailment initiation) to any particular month did *not* have a meaningful impact on the accuracy of predicting drought conditions, nor did it have a significant impact on curtailment frequency and duration when compared to immediately initiating curtailments when thresholds are first reached regardless of the time of year. This means that a higher degree of flexibility could be integrated into future stream-water rights management procedures without sacrificing the assumed benefits gained by curtailments or without causing unnecessary curtailments on existing or future junior stream permit holders. This flexibility would allow for incorporation of a monitoring and advanced warning process that gives water users sufficient time to plan and prepare ahead of a potential curtailment. Most existing water users in the basin are farmers, and farmers often make decisions on seed purchase, crop planting, whether or not to apply for crop insurance (if applicable, etc.) during the fall or winter prior to the next irrigation season. For this reason, in addition to a "Baseline" timing condition (which would allow curtailments to initiate anytime throughout the year), the month of September was selected as the month when inflow, PDSI, and reservoir storage would be reviewed, and decisions would be made regarding management of stream-water rights and implementation of curtailments if observed conditions are at or below the thresholds previously identified[26]. Regarding permit types, two permit type scenarios were selected. The first scenario proposed curtailment of only new future junior stream-water permits, meaning that existing junior stream permits would be exempt from curtailments. The second scenario proposed curtailment of both existing and new future junior stream-water permits. The final range of Stream-Water Rights Management Alternatives consisted of 200 scenarios that were carried forward for water availability modeling, as follows:

- Fifty inflow-PDSI-reservoir storage thresholds
- Two timing scenarios:
    - Initiate management on any month of the year
    - Initiate management only in September
- Two permit type scenarios:
    - Manage only new future junior stream permits
    - Manage both existing and new future junior stream permits

[26] To reduce the number of modeling scenarios, only two timing scenarios were selected. Although the individual month of September was selected (in addition to any month) for this analysis for reasons previously explained, any individual month could be selected for future water availability modeling.

Water Availability Modeling Results

The NFRR SWAM was used to quantify the impacts of each of the 200 Stream-Water Rights Management Alternatives on water availability in the Tom Steed Reservoir hydrologic basin. These results were compared to the impacts quantified by the NFRR SWAM under Status-Quo management presented in Chapter 6.4.4 for each of the 12 groundwater and surface water development scenarios. When accounting for the 12 development scenarios, both with and without seniority and varying reservoir use conditions, a total of 2,524 modeling scenarios were evaluated. Due to the very large volume of data, only a sub-set of the results are presented below.

Content Organization

This section presents the impacts on water availability in the Tom Steed Reservoir hydrologic basin from curtailing junior stream permits based on the stream-water rights management alternatives previously described. Water availability was evaluated under each of the 12 groundwater and stream-water development scenarios in terms of the resulting Tom Steed Reservoir firm yields, the water supply dependability of Tom Steed Reservoir under a range of reservoir use scenarios, and the average annual water availability of junior upstream permits. A general framework also is provided for how one could approach a trade-off analysis of curtailment thresholds[27]. Because of the large number of modeling scenarios, only summary tables of the results are provided. Within Chapter 7.3.2 of the URRBS Full Report, detailed results are presented and are organized into separate subsections in order of increasing groundwater and surface water development. Impacts under the existing and new groundwater permitting scenarios were combined[28].

In addition to the metrics above, the impacts of curtailments also were evaluated for each individual stream permit in the Tom Steed Reservoir hydrologic basin, including existing permits (both junior and senior to MPMCD's permit), as well as new junior upstream permits. Because of the large number of modeling scenarios, these results also are provided in Appendix M of the URRBS Full Report. Metrics include average annual availability of each existing permit; the percent of years when some portion of each individual permit's water was available; and the percent of years when each individual's full permit water was available.

The summary tables and figures provided here include results for the four inflow-PDSI curtailment thresholds combined with each of the four reservoir curtailment thresholds: (1) < 100 percent full (Top of Conservation Pool); (2) ≤ 90 percent full; (3) ≤ 70 percent full; and (4) ≤ 50 percent full. The discussions throughout this section use the *Top of Conservation Pool* threshold as

[27] The trade-off analysis of hydrologic indicators/thresholds (i.e., stream-water management alternatives) should not be confused with the broader trade-off analysis of adaptation strategies.

[28] Recall that Chapter 7.3 showed that there were no measurable differences in impacts between the "Existing GW Permits" and "New GW Permits" scenarios. This is because the OCWP-projected development of the NFRR aquifer through 2060 was relatively minor.

one example of how results could be evaluated[29]. Furthermore, the discussions highlight impacts caused by the various curtailment thresholds across only a subset of the development scenarios that represent opposite ends of the development spectrum, and thus encompass the full range of impacts that occurred across the development scenarios. Specifically, the results presented here are for two stream water permitting conditions (“None” and “Low”) in combination with the “Existing GW Permits/ Existing Domestic SW” development scenario, and the “Full GW Permits/ New Domestic SW (High)/ Full SW Permits” development scenario. The summary tables and Appendix M of the URRBS Full Report present the results of curtailing upstream junior permits based on the four inflow-PDSI thresholds combined with each of the four reservoir thresholds selected for all 12 development scenarios. To be clear, permits that were considered senior to MPMCD’s permit were not curtailed in this analysis; only junior permits were curtailed[30]. Again, the discussions in this section are limited to a subset of the development scenarios, and the reader is encouraged to carefully review the summary tables presented in this section and the detailed information provided in Appendix M of the URRBS Full Report to develop a full understanding of how implementation of these curtailment thresholds impacts water supply availability both from Tom Steed Reservoir and for the upstream permit holders.

To simplify the presentation and discussion of results, thresholds were color-coded and named according to their assigned color as shown in Table 22. The thresholds are herein referred to by their assigned color.

[29] The decision was made to discuss only the Top of Conservation Pool threshold for practical reasons given the large volume of results. However, results did show that under all 12 development scenarios, there were no measurable differences in reservoir firm yield among the five curtailment thresholds when selecting the 50 percent reservoir full threshold; as well there was no measurable difference among the thresholds when selecting the 70 percent full threshold for all but the full development scenario. This is because as reservoir storage dropped, the inflow-PDSI thresholds were always met before the reservoir storage threshold, and reservoir storage became the only factor influencing curtailment frequency across all four inflow-PDSI thresholds (Table 35; Figure 43), at which point the management of stream-water rights did not provide any benefits to Tom Steed Reservoir.

[30] As discussed in Chapter 6.4.4 and 7.3.1 of the URRBS Full Report and Kershen (2021), MPMCD’s existing permit appears to have a priority date of 1955, not 1967. However, OWRB’s water rights database lists MPMCD’s permit as having a priority date of 1967, which is the year that MPMCD filed its application for the permit. For the purposes of the URRBS, 1967 was selected as the priority date for MPMCD’s permit for all hydrologic modeling analyses. It was considered beyond the scope this URRBS to attempt to reconcile the inconsistent seniority dates; this decision would likely be made by OWRB as part of a potential future adjudication of vested water rights in the Tom Steed Reservoir hydrologic basin.

Table 22. Summary of thresholds and assigned colors for consistent nomenclature.

Threshold Name	Curtailment Threshold
Status Quo	No Threshold
Blue	Reservoir storage alone
Orange	Inflow ≤ 58,300 acre-ft and PDSI ≤ -0.12
Gray	Inflow ≤ 72,200 acre-ft and PDSI ≤ -1.66
Yellow	Inflow ≤ 39,700 acre-ft and PDSI ≤ -0.78
Green	Inflow ≤ 28,600 acre-ft and PDSI ≤ -0.49

Approach to Performing a Trade-Off Analysis of Curtailment Thresholds

The discussions highlight examples of the trade-offs involved when selecting certain curtailment thresholds over others. The approach used here compared proportionate increases in water availability of one metric with proportionate decreases in water availability for the other metric, if applicable. This is not to say, for example, that the water availability of junior upstream permits should be weighted equally to that of a senior permit to water stored in Tom Steed Reservoir. The point here is to highlight the fact that proportionate differences in water availability between the two metrics exist and could be considered in a trade-off analysis comparing the various thresholds.

These discussions are not exhaustive and did not draw any conclusions on whether certain curtailment thresholds may be preferred over others. In fact, the authorities and requirements governing this study explicitly prohibited it from making recommendations on such matters. As such, the discussions provide only a glimpse into the vast array of information contained herein, including how such information could be analyzed. The reader should use these discussions only as a guide in helping the reader perform a more thorough and comprehensive review of all of the data in accordance with each reader's goals and perspectives.

Impacts of Water Rights Management on Water Availability

An adequate understanding of the results on Tom Steed Reservoir in particular is largely predicated on understanding the difference between the modeling approaches used to calculate Tom Steed Reservoir firm yield and MPMCD permit dependability. The reader is encouraged to read in Chapter 6.3.3 of the URRBS for detailed explanation on the difference between these two modeling approaches.

Existing GW Permits; Existing Domestic SW; Existing SW Permits

Under this development scenario, permitted groundwater use, as well as domestic and permitted stream-water use were assumed to reflect existing conditions, and no new stream permits were issued upstream of Tom Steed Reservoir. As such, only the 2,700 acre-ft/yr of existing junior upstream permits above Tom Steed Reservoir were subject to curtailment. Results showed that all five thresholds resulted in similar improvements on the availability of water from Tom Steed Reservoir; however, there was a pronounced difference among the thresholds in terms of the frequency of curtailments they caused and their impacts on the availability of water for the existing permits upstream of the reservoir.

Impacts of Curtailments on Tom Steed Reservoir

The following findings are worth noting for Tom Steed Reservoir:

- Under Status Quo, results showed that Tom Steed Reservoir firm yield was 13,400 acre-ft/yr (Figure 37; Table 23). Curtailing existing upstream permits based on the blue threshold increased reservoir firm yield to 14,300 acre-ft/yr (seven percent increase) (Figure 37; Table 23). Curtailing existing upstream permits based on the orange, gray, yellow, and green thresholds equally increased the firm yield to 14,100 acre-ft/yr (five percent increase) (Figure 37; Table 23).
- Under Status Quo, results showed that Tom Steed Reservoir had sufficient water in storage 100 percent of all years to deliver "Existing" demands on the reservoir with zero shortages (Table 24). Regardless of the threshold selected, curtailing existing upstream permits had no impacts on reservoir storage (Table 24).
- Under Status Quo, the reservoir had sufficient water in storage 98.5 percent of all years to deliver "Mid"-level demands on the reservoir with a maximum calendar-year shortage of 200 acre-ft (Table 24). Regardless of the threshold selected, curtailing existing upstream permits eliminated those shortages and increased the dependability of delivering "Mid"-level demands on the reservoir to 100 percent of all years (Table 24).
- Under Status Quo, the reservoir had sufficient water in storage 97.0 percent of all years to deliver the "Full" permit reservoir demand with a maximum calendar-year shortage of 2,000 acre-ft (Table 24). Regardless of the threshold selected, curtailing existing upstream permits increased the dependability of delivering "Full" reservoir demands to 98.5 percent of all years and reduced MPMCD's maximum calendar-year shortage to 1,500 acre-ft (Table 24).

Impacts of Curtailments on Junior Stream Permits Above Tom Steed Reservoir

- Under Status Quo, results showed that the average water available for upstream permits was 2,320 acre-ft/yr (Table 25). Curtailing existing upstream permits based on the four reservoir storage-inflow-PDSI thresholds decreased average water availability for junior upstream permits to between 2,080 acre-ft/yr (ten percent decrease) and 1,730 acre-ft/yr (25 percent decrease) (Figure 37; Table 25). Curtailing existing upstream permits based on reservoir storage alone decreased average water availability of junior upstream permits to 1,040 acre-ft/yr (55 percent decrease) (Figure 37; Table 25). Overall, the thresholds curtailed upstream permits between eight percent and 69 percent of the time[31] (Figure 37).
- The impacts of curtailments on each individual permit in the Tom Steed Reservoir hydrologic basin are provided in Appendix M of the URRBS Full Report. This includes impacts on the average annual availability of each permit; the percent of years when a portion of each individual permit's water was available; and the percent of years when each individual's full permit water was available.

Threshold Trade-Offs

A few key findings are summarized below:

- While the blue threshold resulted in a larger increase in reservoir firm yield relative to the other four thresholds, the incremental increase in firm yield was only two percent. Yet, the blue threshold resulted in a 41 percent to 61 percent incremental increase in curtailment frequency and a 30 percent to 45 percent incremental decrease in water availability for upstream permits relative to the other four thresholds (Figure 37).
- The orange, gray, yellow, and green thresholds equally improved the firm yield of Tom Steed Reservoir (five percent increase). Yet, the same thresholds curtailed upstream permits between eight percent and 28 percent of the time and reduced average water availability for upstream permits by ten percent to 25 percent. Of the four reservoir storage-inflow-PDSI thresholds, the gray threshold resulted in the smallest decrease in water availability for existing upstream junior permits, despite causing a higher frequency of curtailments relative to both the yellow and green thresholds.

Existing GW Permits; Existing Domestic SW; New SW Permits

Under this development scenario, permitted groundwater use and domestic stream-water use were assumed to reflect existing conditions, but unlike the

[31] This curtailment frequency was based on the modeling results for the reservoir firm yield scenario. Curtailment frequency varies depending on the amount of water delivered from Tom Steed Reservoir.

previous development scenario, this scenario assumed that a range of new stream permitting volumes (i.e., “Low”, “High”, and “Full”) were issued above Tom Steed Reservoir, and that these new permits were subject to curtailment. For the sake of brevity and for reasons previously described, only the results of curtailing a “Low” new stream permit volume are discussed here, which assumed the issuance of an additional 2,500 acre-ft/yr of new junior upstream permits above Tom Steed Reservoir. Results include impacts of curtailing the 2,500 acre-ft/yr of new stream permits alone (existing upstream permits would be “grandfathered” into the management strategy), as well as the impacts of curtailing new upstream permits in combination with the 2,700 acre-ft/yr of existing junior upstream permits (i.e., curtailing a total of 5,200 acre-ft/yr of both existing and new junior upstream permits).

Results showed that the difference among the five thresholds in terms of their impacts on Tom Steed Reservoir was minimal; however, there was a pronounced difference in impacts on the frequency of curtailments and the availability of existing permits upstream of the reservoir.

Impacts of Curtailments on Tom Steed Reservoir

The following findings are worth noting for Tom Steed Reservoir:

- Under Status Quo, results showed that Tom Steed Reservoir firm yield was 12,100 acre-ft/yr (Figure 37; Table 23). When curtailing only new upstream permits, the five thresholds equally increased reservoir firm yield to 13,400 acre-ft/yr (11 percent increase) (Figure 37; Table 23). Curtailing both new upstream permits and existing junior upstream permits resulted in higher increases in reservoir firm yield across all five thresholds, ranging from an increase to 13,900 acre-ft/yr (an incremental increase of four percent relative to curtailing only the new upstream permits) to 14,300 acre-ft/yr (an incremental increase of seven percent relative to curtailing only the new upstream permits) (Figure 37; Table 23).
- Under Status Quo, results showed that Tom Steed Reservoir had sufficient water in storage 100 percent of all years to deliver “Existing” demands on the reservoir with zero shortages (Table 24). Regardless of the threshold selected, curtailing existing upstream permits had no impact on reservoir storage (Table 24).
- Under Status Quo, the reservoir had sufficient water in storage 97.0 percent of all years to deliver “Mid”-level demands on the reservoir with a maximum calendar-year shortage of 1,900 acre-ft (Table 24). Curtailing only the new upstream permits increased the dependability of delivering “Mid”-level demands on the reservoir to 98.5 percent of all years and reduced the maximum calendar-year shortage to between 200 acre-ft and 500 acre-ft (Table 24). Curtailing both new upstream permits and existing upstream junior permits eliminated shortages altogether and increased the dependability of delivering “Mid”-level demands on the reservoir to 100 percent in all years (Table 24).

- Under Status Quo, the reservoir had sufficient water in storage 97.0 percent of all years to deliver the "Full" permit reservoir demand with a maximum calendar-year shortage of 2,300 acre-ft (Table 24). Regardless of the threshold selected, curtailing only the new upstream permits resulted in the same annual dependability as Status Quo (i.e., 97 percent), but it reduced the maximum calendar-year shortage to 2,000 acre-ft (Table 24). Curtailing both the new upstream permits and existing upstream junior permits increased the dependability of delivering "Full" permit demands on the reservoir to 98.5 percent of all years and reduced the maximum calendar-year shortage to between 1,500 acre-ft and 1,900 acre-ft (Table 24).

Impacts of Curtailments on Junior Stream Permits Above Tom Steed Reservoir

- Under Status Quo, results showed that the total average availability of both existing and new upstream permits was 4,180 acre-ft/yr, 2,320 acre-ft/yr of which was for existing upstream permits, and 1,860 acre-ft/yr of which was new upstream permits (Table 25). Curtailing only the new upstream permits decreased total average water availability for upstream permits to between 2,530 acre-ft/yr (39 percent decrease) and 3,860 acre-ft/yr (eight percent decrease). Of these amounts, existing upstream junior permits remained unchanged, and new upstream permits were decreased to between 210 acre-ft/yr and 1,540 acre-ft/yr, respectively (Figure 37; Table 25).
- Curtailing both new and existing upstream junior permits decreased total average water availability for upstream permits to between 1,800 acre-ft/yr (57 percent decrease) and 3,690 acre-ft/yr (12 percent decrease) (Figure 37; Table 25). Of these amounts, water available for existing upstream junior permits decreased to between 1,070 acre-ft/yr and 2,080 acre-ft/yr, and water available for new upstream permits decreased to between 730 acre-ft/yr and 1,610 acre-ft/yr, respectively (Figure 37; Table 25).
- While curtailing both new and existing junior upstream permit use resulted a decrease in total average water availability for upstream permits, the decrease was caused entirely by the decrease in water available for existing upstream junior permits. In fact, water availability for new upstream permits actually increased when existing upstream junior permits were being curtailed because the requirement for new upstream permits to curtail occurred less frequently and/or for a shorter duration, which in turn resulted in an overall decrease in water being "called" from the new upstream permits to make up for the shortages at Tom Steed Reservoir. However, when only new upstream permits were curtailed (i.e., existing junior permits were not curtailed), more water was "called" from those new upstream permits to make up for the shortages at the reservoir, which resulted in a decrease in water availability for the new upstream permits.

Threshold Trade-Offs

A few key findings are summarized below:

- When curtailing only new upstream permits, all five thresholds equally improved the firm yield of Tom Steed Reservoir (11 percent increase). Yet, the same thresholds curtailed the new upstream permits between nine percent and 66 percent of the time and reduced average water availability for new upstream permits by between eight percent and 39 percent (Figure 37). Of the five thresholds, the gray threshold resulted in the smallest decrease in average water availability for new upstream permits, despite causing a higher frequency of curtailments relative to both the yellow and green thresholds.
- When curtailing both new upstream permits and existing upstream junior permits, the blue threshold resulted in a larger increase in reservoir firm yield relative to the other four thresholds, but the incremental increase in firm yield was only two or three percent. Yet, the blue threshold resulted in a 37 percent to 56 percent incremental increase in curtailment frequency for these permits and a 28 percent to 45 percent incremental decrease in average water availability for these upstream permit holders relative to the other four thresholds (Figure 37).
- When curtailing both new upstream permits and existing upstream junior permits, the orange and green thresholds resulted in an incremental increase in reservoir firm yield of one percent relative to the gray and yellow thresholds. Yet, the orange threshold decreased water availability for these upstream permit holders by 17 percent more than the gray threshold and by eight percent more than the yellow threshold; and the green threshold decreased water availability for these upstream permits by 15 percent more than the gray threshold and by six percent more than the yellow threshold. In other words, while the gray threshold resulted in a one percent decrease in reservoir firm yield in comparison to the orange or green thresholds, the gray threshold resulted in 15 percent to 17 percent more water availability for these upstream permits compared to the orange and the green thresholds.
- Under Status Quo, Tom Steed Reservoir had sufficient water in storage 100 percent of all years to deliver “Existing” demands on the reservoir with zero shortages; therefore, a trade-off analysis of thresholds for this scenario was not applicable.
- When delivering “Mid”-level demands from the reservoir, the blue threshold reduced reservoir supply shortages more than the other four thresholds compared to Status Quo, but the benefit occurred when the blue threshold was only curtailing new upstream permits; in that scenario, the blue threshold reduced the maximum calendar-year shortage for Tom Steed Reservoir by an additional 200 acre-ft (compared to the orange and green thresholds) or an additional 300 acre-ft (compared to the gray and yellow thresholds). Furthermore, when delivering the “Mid”-level demands from the reservoir, the orange and green thresholds both reduced the maximum calendar-year

shortage by an additional 100 acre-ft/yr compared to the gray and yellow thresholds.

- When delivering the "Full" permit demand from the reservoir and curtailing only the new upstream permits, all five of the thresholds equally reduced the maximum calendar-year reservoir supply shortage by 300 acre-ft relative to Status Quo. When curtailing both new and existing junior upstream permits, the orange and green thresholds both reduced the maximum calendar-year supply shortage by an additional 100 acre-ft/yr relative to the gray-yellow thresholds.

Full GW Permits; New Domestic SW (High); Full SW Permits

Under this development scenario, permitted groundwater use, as well as domestic and permitted stream-water use were assumed to reflect fully developed conditions, and existing junior stream permits and all new stream permits above Tom Steed Reservoir were subject to curtailment. For the sake of brevity and for reasons previously described, only the results of new "High" domestic stream volume are discussed here; after accounting for a "High" volume of domestic stream use, an additional 33,500 acre-ft/yr of new upstream permits were assumed to be issued above Tom Steed Reservoir. Results include the impacts of curtailing the 33,500 acre-ft/yr of new stream permits alone (existing upstream permits would be "grandfathered" into the management strategy), as well as the impacts of curtailing new upstream permits in combination with the 2,700 acre-ft/yr of existing junior upstream permits (i.e., curtailing a total of 36,200 acre-ft/yr of both existing and new junior upstream permits). This scenario assumed that reservoir demands reflected "Full" permit use of 16,100 acre-ft/yr.

Impacts of Curtailments on Tom Steed Reservoir

The following findings are worth noting for Tom Steed Reservoir:

- Under Status Quo, results showed that Tom Steed Reservoir firm yield was 4,960 acre-ft/yr (Figure 37; Table 23). When curtailing only the new upstream permits under the five thresholds, reservoir firm yield increased to between 8,610 acre-ft/yr (74 percent increase) and 9,880 acre-ft/yr (99 percent increase) (Figure 37; Table 23). When curtailing both the new upstream permits and existing junior upstream permits, reservoir firm yield increased to between 8,850 acre-ft/yr (78 percent increase) and 10,200 acre-ft/yr (106 percent increase) (Table 23). As such, the incremental increase in firm yield from curtailing both new and existing upstream junior permits as opposed to curtailing only new upstream permits was between four percent and seven percent.
- Under Status Quo, results showed that Tom Steed Reservoir had sufficient water in storage 89.6 percent of all years to deliver "Full" permit demands on the reservoir with a maximum calendar-year shortage of 11,600 acre-ft

(Table 24). Curtailing only new upstream permits increased the dependability of delivering "Full" permit demands from the reservoir to between 92.5 percent and 97.0 percent of all years and reduced the maximum calendar-year shortage to between 5,900 acre-ft/yr and 7,600 acre-ft/yr (Table 24). Curtailing both new upstream permits and existing upstream junior permits increased reservoir supply dependability the same as curtailing only new stream permits (i.e., to between 92.5 percent and 97.0 percent of all years), but it reduced the maximum calendar-year shortage to between 5,100 acre-ft/yr and 6,900 acre-ft/yr (Table 24).

Impacts of Curtailments on Junior Stream Permits Above Tom Steed Reservoir

- Under Status Quo, results showed that the total average availability of both existing junior and new upstream permits was 14,010 acre-ft/yr, 1,430 acre-ft/yr of which was for existing junior upstream permits, and 12,580 acre-ft/yr of which was new junior upstream permits (Table 25). Curtailing only new upstream permits decreased total average water availability for upstream permit holders to between 2,020 acre-ft/yr (86 percent decrease) and 11,920 acre-ft/yr (15 percent decrease). Of these amounts, the water availability for existing junior upstream permits remained unchanged, but water availability for new upstream permits decreased to between 590 acre-ft/yr and 10,490 acre-ft/yr, respectively (Figure 37; Table 25).
- Curtailing both new and existing upstream junior permits decreased total average water availability for upstream permits to between 5,150 acre-ft/yr (63 percent decrease) and 12,300 acre-ft/yr (13 percent decrease) (Figure 37; Table 25). Of these amounts, existing water availability for existing upstream junior permits decreased to between 530 acre-ft/yr and 1,300 acre-ft/yr, and water availability for new upstream permits decreased to between 4,620 acre-ft/yr and 11,000 acre-ft/yr, respectively.
- Unlike the two development scenarios presented above, for all but the yellow thresholds, curtailing both new and existing upstream junior permits resulted in an equal or greater total average annual volume of water available for upstream permits (new, existing junior, and senior combined) relative to curtailing only new upstream permits. This is because the requirement for new upstream permits to curtail occurred less frequently and/or for a shorter duration, which in turn resulted in an overall decrease in water being "called" from the new upstream permits to make up for the shortages at Tom Steed Reservoir. However, when only new upstream permits were curtailed (i.e., existing junior permits were not curtailed), more water was "called" from those new upstream permits to make up for the shortages at the reservoir, which resulted in a decrease in water availability for the new upstream permits.

Threshold Trade-Offs

A few key findings are summarized below:

- The incremental impacts on reservoir firm yield and average annual reservoir permit availability among the five curtailment thresholds were generally the same, regardless of whether new upstream permits were curtailed alone or if new permits were curtailed in combination with existing upstream junior permits.
- When curtailing both new upstream permits and existing upstream junior permits, the blue threshold resulted in an incremental increase in reservoir firm yield of 16 percent to 28 percent relative to the other four thresholds. Yet, the blue threshold resulted in a 40 percent to 57 percent incremental increase in curtailment frequency and a 32 percent to 50 percent incremental decrease in average water availability for upstream junior permits relative to the other four thresholds (Figure 37).
- When curtailing both new upstream permits and existing upstream junior permits, the orange and green thresholds resulted in an incremental increase in reservoir firm yield of up to 12 percent relative to the gray and yellow thresholds. The orange and green thresholds also resulted in up to an 18 percent incremental decrease in average water availability of upstream junior permits compared to the gray threshold, and up to a 10 percent incremental decrease in water availability compared to the yellow threshold. In other words, although the gray and the yellow thresholds result in more average water availability for upstream junior stream permits, they provided less benefit to reservoir firm yield compared to the orange and green thresholds.
- In terms of calendar-year reservoir supply shortages, the blue threshold reduced the maximum calendar-year supply shortage by up to 1,800 acre-ft (relative to the gray and yellow thresholds) and by up to 1,200 acre-ft (relative to the orange and green thresholds). The orange and green thresholds equally reduced the maximum calendar-year supply shortage by up to 600 acre-ft/yr relative to the gray and yellow thresholds.

Water Availability Modeling Results - Summary Figure and Tables

Water availability modeling results are presented in Figure 37 and Table 23, Table 24, and Table 25.

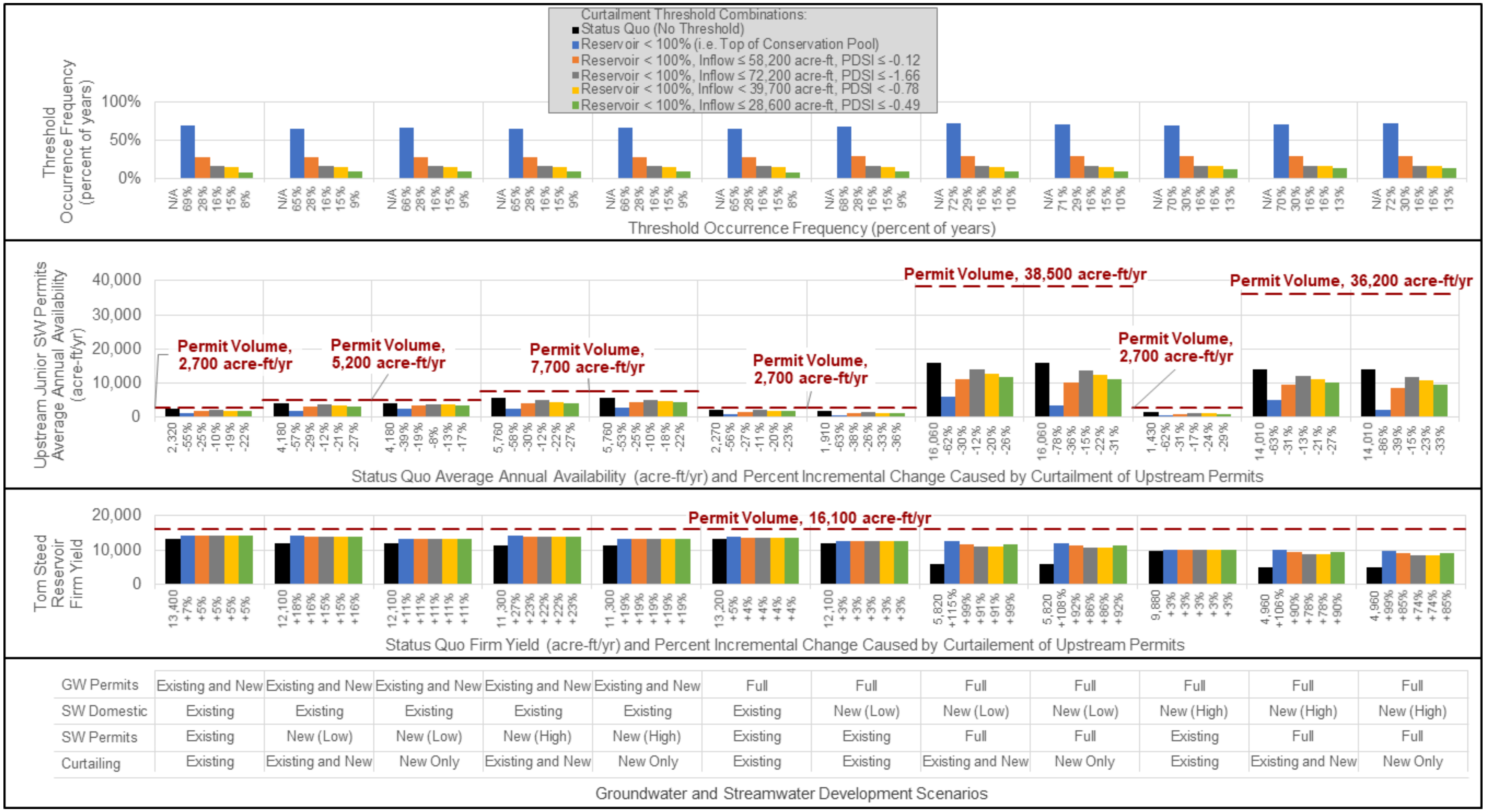


Figure 37. Tom Steed Reservoir firm yield (bottom), junior upstream permit water availability (middle), and threshold occurrence frequency (top) that result from curtailing permits under twelve development scenarios when Tom Steed Reservoir storage is < 100 percent full (below the Top of Conservation Pool) and when both inflow and PDSI are at or below four curtailment threshold combinations over the period of record (1950-2016), 2060 sediment condition.

Table 23. Tom Steed Reservoir firm yield that results from curtailing permits under twelve development scenarios when Tom Steed Reservoir storage is < 100 percent full (below the Top of Conservation Pool) and when both inflow and PDSI are at or below four curtailment threshold combinations over the period of record (1950-2016), 2060 sediment condition.

		Status Quo (No Curtailment)	Curtailing Existing Junior SW Permits					Curtailing New SW Permits and Existing Junior SW Permits					Curtailing New SW Permits Only				
			Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI			
Reservoir Storage Threshold		-	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%
Inflow Threshold		-	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600
PDSI Threshold		-	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49
Scenario	New SW Permits (acre-ft/yr)	Top Row – Tom Steed Reservoir Firm Yield (acre-ft/yr) Bottom Row – Percent Change Relative to Status Quo Conditions															
Existing and New Groundwater Permit Use and Existing Domestic Use Conditions	None	13,400	14,300 +7%	14,100 +5%	14,100 +5%	14,100 +5%	14,100 +5%	-	-	-	-	-	-	-	-	-	-
	Low (2,500)	12,100	-	-	-	-	-	14,300 +18%	14,000 +16%	13,900 +15%	13,900 +15%	14,000 +16%	13,400 +11%	13,400 +11%	13,400 +11%	13,400 +11%	13,400 +11%
	High (5,000)	11,300	-	-	-	-	-	14,300 +27%	13,900 +23%	13,800 +22%	13,800 +22%	13,900 +23%	13,400 +19%	13,400 +19%	13,400 +19%	13,400 +19%	13,400 +19%
Full Groundwater Permit Use and Existing Domestic Use Conditions	None	13,200	13,800 +5%	13,700 +4%	13,700 +4%	13,700 +4%	13,700 +4%	-	-	-	-	-	-	-	-	-	-
Full Groundwater Permit Use and Low Domestic Use Conditions	None	12,100	12,500 +3%	12,500 +3%	12,500 +3%	12,500 +3%	12,500 +3%	-	-	-	-	-	-	-	-	-	-
	Full (35,900)	5,820	-	-	-	-	-	12,500 +115%	11,600 +99%	11,100 +91%	11,100 +91%	11,600 +99%	12,100 +108%	11,200 +92%	10,800 +86%	10,800 +86%	11,200 +92%
Full Groundwater Permit Use and High Domestic Use Conditions	None	9,880	10,200 +3%	10,200 +3%	10,200 +3%	10,200 +3%	10,200 +3%	-	-	-	-	-	-	-	-	-	-
	Full (33,700)	4,960	-	-	-	-	-	10,200 +106%	9,440 +90%	8,850 +78%	8,850 +78%	9,440 +90%	9,880 +99%	9,160 +85%	8,610 +74%	8,610 +74%	9,160 +85%
Average Incremental Changes		-	+4%	+4%	+4%	+4%	+4%	+66%	+57%	+52%	+52%	+57%	+59%	+52%	+47%	+47%	+52%

Table 24. Water supply dependability of Tom Steed Reservoir under three reservoir use scenarios, including maximum calendar-year shortage, that result from curtailing permits under twelve development scenarios when Tom Steed Reservoir storage is < 100 percent full (below the Top of Conservation Pool) and when both inflow and PDSI are at or below four curtailment threshold combinations over the period of record (1950-2016), 2060 sediment condition.

			Status Quo (No Curtailment)	Curtailing Existing Junior SW Permits					Curtailing New SW Permits and Existing Junior SW Permits					Curtailing New SW Permits Only				
				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI			
		Reservoir Storage Threshold	-	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%
		Inflow Threshold	-	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600
		PDSI Threshold	-	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49
Scenario	New SW Permits (acre-ft/yr)	Reservoir Use (acre-ft/yr)	Top Row – Maximum Reservoir Permit Shortage in a Single Calendar Year (acre-ft/yr) Bottom Row – Permit Volume Dependability (Percent of Years Full Permit is Available)															
Existing and New Groundwater Permit Use and Existing Domestic Use Conditions	None	Existing (12,700)	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	-	-	-	-	-	-	-	-	-	-
		Mid (14,400)	200 98.5%	0 100%	0 100%	0 100%	0 100%	0 100%	-	-	-	-	-	-	-	-	-	-
		Full (16,100)	2,000 97.0%	1,500 98.5%	1,500 98.5%	1,500 98.5%	1,500 98.5%	1,500 98.5%	-	-	-	-	-	-	-	-	-	-
	Low (2,500)	Existing (12,700)	0 100%	-	-	-	-	-	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%
		Mid (14,400)	1,900 97.0%	-	-	-	-	-	0 100%	0 100%	0 100%	0 100%	0 100%	200 98.5%	400 98.5%	500 98.5%	500 98.5%	400 98.5%
		Full (16,100)	2,300 97.0%	-	-	-	-	-	1,500 98.5%	1,800 98.5%	1,900 98.5%	1,900 98.5%	1,800 98.5%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%
	High (5,000)	Existing (12,700)	1,000 98.5%	-	-	-	-	-	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%	0 100%
		Mid (14,400)	2,000 97.0%	-	-	-	-	-	0 100%	0 100%	0 100%	0 100%	0 100%	200 98.5%	600 98.5%	600 98.5%	600 98.5%	600 98.5%
		Full (16,100)	3,300 97.0%	-	-	-	-	-	1,500 98.5%	1,900 98.5%	2,000 97.0%	2,000 97.0%	1,900 98.5%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%

Table 24. Continued.

Scenario	New SW Permits (acre-ft/yr)	Reservoir Use (acre-ft/yr)	Status Quo (No Curtailment)	Curtailing Existing Junior SW Permits					Curtailing New SW Permits and Existing Junior SW Permits					Curtailing New SW Permits Only				
				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI			
Reservoir Storage Threshold			-	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%
Inflow Threshold			-	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600
PDSI Threshold			-	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49
			Top Row – Maximum Reservoir Permit Shortage in a Single Calendar Year (acre-ft/yr) Bottom Row – Permit Volume Dependability (Percent of Years Full Permit is Available)															
Full Groundwater Permit Use and Existing Domestic Use Conditions	None	Full (16,100)	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%	2,000 97.0%	-	-	-	-	-	-	-	-	-	-
Full Groundwater Permit Use and Low Domestic Use Conditions	None	Full (16,100)	2,500 97.0%	2,100 97.0%	2,100 97.0%	2,100 97.0%	2,100 97.0%	2,100 97.0%	-	-	-	-	-	-	-	-	-	-
	Full (35,900)	Full (16,100)	11,100 89.6%	-	-	-	-	-	2,100 97.0%	2,300 97.0%	4,600 95.5%	4,300 95.5%	2,300 97.0%	2,500 97.0%	2,900 97.0%	5,000 95.5%	4,800 95.5%	2,900 97.0%
Full Groundwater Permit Use and High Domestic Use Conditions	None	Full (16,100)	5,900 97.0%	5,100 97.0%	5,100 97.0%	5,200 97.0%	5,100 97.0%	5,100 97.0%	-	-	-	-	-	-	-	-	-	-
	Full (33,700)	Full (16,100)	11,600 89.6%	-	-	-	-	-	5,100 97.0%	6,300 95.5%	6,900 92.5%	6,900 92.5%	6,300 95.5%	5,900 97.0%	7,100 95.5%	7,600 92.5%	7,600 92.5%	7,100 95.5%

Table 25. Average annual water availability of existing and/or new junior stream permits above Tom Steed Reservoir that result from curtailing permits under twelve development scenarios when Tom Steed Reservoir storage is < 100 percent full (below the Top of Conservation Pool) and when both inflow and PDSI are at or below four curtailment threshold combinations over the period of record (1950-2016), 2060 sediment condition.

		Status Quo (No Curtailment)	Curtailing Existing Junior SW Permits					Curtailing New SW Permits and Existing Junior SW Permits					Curtailing New SW Permits Only				
			Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI				Reservoir Storage Alone	Reservoir Storage Combined with Inflow-PDSI			
Reservoir Storage Threshold		-	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%	< 100%
Inflow Threshold		-	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600	-	≤ 58,200	≤ 72,200	≤ 39,700	≤ 28,600
PDSI Threshold		-	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49	-	≤ -0.12	≤ -1.66	≤ -0.78	≤ -0.49
Scenario	New SW Permits (acre-ft/yr)	Top Row – Existing Upstream Junior SW Permit Average Annual Availability (acre-ft/yr) Middle Row – New Upstream Junior SW Permit Average Availability (acre-ft/yr) Bottom Row - Total Upstream Junior SW Permit Average Annual Availability (acre-ft/yr)															
Existing and New Groundwater Permit Use and Existing Domestic Use Conditions	None	2,320 0 2,320	1,040 0 1,040	1,730 0 1,730	2,080 0 2,080	1,870 0 1,870	1,820 0 1,820	-	-	-	-	-	-	-	-	-	-
	Low (2,500)	2,320 1,860 4,180	-	-	-	-	-	1,070 730 1,800	1,700 1,250 2,960	2,080 1,610 3,690	1,870 1,420 3,290	1,750 1,320 3,070	2,320 210 2,530	2,320 1,060 3,380	2,320 1,540 3,860	2,320 1,310 3,630	2,320 1,150 3,470
	High (5,000)	2,320 3,440 5,760	-	-	-	-	-	1,050 1,390 2,440	1,700 2,360 4,060	2,080 3,000 5,080	1,870 2,640 4,510	1,750 2,480 4,220	2,320 410 2,730	2,320 1,980 4,300	2,320 2,860 5,180	2,320 2,440 4,750	2,320 2,150 4,470
Full Groundwater Permit Use and Existing Domestic Use Conditions	None	2,270 0 2,270	1,010 0 1,010	1,660 0 1,660	2,030 0 2,030	1,820 0 1,820	1,750 0 1,750	-	-	-	-	-	-	-	-	-	-
Full Groundwater Permit Use and Low Domestic Use Conditions	None	1,910 0 1,910	710 0 710	1,180 0 1,180	1,410 0 1,410	1,280 0 1,280	1,220 0 1,220	-	-	-	-	-	-	-	-	-	-
	Full (35,900)	1,910 14,150 16,060	-	-	-	-	-	690 5,380 6,070	1,390 9,800 11,190	1,720 12,300 14,020	1,560 11,200 12,760	1,440 10,400 11,840	1,910 1,640 3,550	1,910 8,300 10,210	1,910 11,800 13,710	1,910 10,600 12,510	1,910 9,230 11,140
Full Groundwater Permit Use and High Domestic Use Conditions	None	1,430 0 1,430	550 0 550	980 0 980	1,190 0 1,190	1,080 0 1,080	1,010 0 1,010	-	-	-	-	-	-	-	-	-	-
	Full (33,700)	1,430 12,580 14,010	-	-	-	-	-	530 4,620 5,150	1,060 8,580 9,640	1,300 11,000 12,300	1,190 9,880 11,070	1,090 9,170 10,260	1,430 590 2,020	1,430 7,130 8,560	1,430 10,490 11,920	1,430 9,300 10,730	1,430 8,000 9,430

Effectiveness: Favorable

- Although the effectiveness of this strategy at helping Tom Steed Reservoir deliver MPMCD's full permit volume of 16,100 acre-ft/yr was dependent upon on the development scenario and the curtailment threshold(s) adopted for implementation, there were significant potential benefits to reservoir supply.
- Regarding run-of-the-river stream-water permit holders, results showed that curtailment thresholds were effective at demonstrating when MPMCD permit water could be put to beneficial use while avoiding futile curtailments of junior stream-water permits (i.e., administratively-enforced diversion reductions that do not result in meaningful improvements in water availability at Tom Steed Reservoir).

Efficiency: Favorable

- It was assumed that MPMCD and the OWRB could mutually agree on a set of hydrologic thresholds that protect the yield of Tom Steed Reservoir while maximizing beneficial use in the hydrologic basin. It assumed that stakeholder support would be largely positive; and although new regulations and changes in policy would be required, the changes could be made at relatively low costs with minimal risk of significant protest or prolonged litigation.

Acceptability: Favorable

- It was assumed that MPMCD and the OWRB could mutually agree on a set of hydrologic thresholds that protect the yield of Tom Steed Reservoir while maximizing beneficial use in the hydrologic basin, and that stakeholder support would be largely positive with minimal risk of significant protest or prolonged litigation.

Completeness: Favorable

- It was assumed that MPMCD and the OWRB could mutually agree on a set of hydrologic thresholds that protect the yield of Tom Steed Reservoir while maximizing beneficial use in the hydrologic basin. It assumed that stakeholder support would be largely positive; and although new regulations and changes in policy would be required, the changes could be made at relatively low costs with minimal risk of significant protest or prolonged litigation.

Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District – Non-Regulatory Protection

Description

- This strategy proposed to purchase existing senior water rights and/or enter into dry-year lease agreements with senior stream-water permit holders through voluntary, non-regulated transactions between the MPMCD and willing sellers/leasers of water. The reader is encouraged to read Chapter 8.3.3 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Neutral

- The effectiveness of this strategy at helping Tom Steed Reservoir deliver MPMCD's full permit volume of 16,100 acre-ft/yr would depend on the volume of senior water rights purchased or leased.
- The effectiveness of this strategy would be improved if it was combined with other strategies identified in this URRBS that address depletions caused by junior stream permits. This includes existing junior permits and potential new future junior permits.
- If all senior and junior permits in the hydrologic basin were addressed, then only domestic withdrawals would impact reservoir yield.

Efficiency: Neutral

- The transaction costs to implement this strategy would depend on a number of factors, including an assessment of the fair market value of the senior water rights in the Tom Steed Reservoir hydrologic basin.

Acceptability: Neutral

- The acceptability of this strategy would depend on the capability or willingness of senior permit holders to sell or lease their water to MPMCD, the capability or willingness of MPMCD to purchase or lease the water from senior permit holders, as well as other unknown terms and conditions that could affect the viability of voluntary purchase/lease agreements.

Completeness: Neutral

- The risks implementing of this strategy would depend on the capability or willingness to sell or purchase the water, as well as other unknown terms and conditions that could affect the viability of voluntary purchase/lease agreements.
- An important factor to consider would be determining which permit holders are, in fact, senior to MPMCD's permit (i.e., whether it is permits with priority dates before May 4, 1955 or permits with priority dates before August 29, 1967). This further supports the need for a formal adjudication of vested water rights in the Tom Steed Reservoir hydrologic basin that was previously discussed with regards to clarifying the volume and priority date of MPMCD's permit.

Additional Stream-Water Rights of Mountain Park Master Conservancy District

Description

- This strategy proposed that MPMCD[32] to apply for water rights to all of the unappropriated water in Elk Creek and West Otter-Glen Creeks for non-consumptive uses (i.e., for recreation, fish, and wildlife purposes). The reader is encouraged to read Chapter 8.3.3 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- This strategy would protect Tom Steed Reservoir's firm yield from depletions caused by future new stream-water permits, which were found to cause the largest depletions in reservoir firm yield. In doing so, this strategy would protect the firm yield from being reduced beyond that which would occur from existing stream permits and existing/future domestic use. In quantitative terms, this strategy would protect the firm yield from being reduced below a range of between 13,400 acre-ft/yr to 9,880 acre-ft/yr depending on the development scenario.
- By gaining a water right for non-consumptive uses of water for recreation, fish, and wildlife for all remaining unappropriated waters above Tom Steed Reservoir, MPMCD would mitigate the risk of its core water rights being reduced by the OWRB. If MPMCD had water rights to all unappropriated waters in the basin, then MPMCD would preclude any additional junior permits from coming into existence to make a claim for the "lost" water. In other words, by having a new water right for non-consumptive purposes of recreation, fish, and wildlife, MPMCD, in practical terms, converts its potential "lost" water into its permitted non-consumptive water right for recreation, fish and wildlife.
- If MPMCD obtained a water right for all unappropriated waters upstream of Tom Steed Reservoir, MPMCD would have a vested water right to all water in the reservoir. In other words, MPMCD's control over the water in storage in Tom Steed Reservoir would thereafter be a vested water right, not just a storage right. The immediate consequence of having a vested water right for all water in Tom Steed Reservoir would be that no person or entity could apply for a water permit for the "excess" water in storage because there would be no "excess" water in storage (i.e., all water in storage would be included in the permit held by MPMCD).

Efficiency: Favorable

- It was assumed that the effort and resources needed for MPMCD to apply for and for the OWRB to grant a water right for all unappropriated waters

[32] Kershen (2021) noted that Reclamation also has the authority to apply for rights to all unappropriated water for recreation, fish, wildlife, and environmental quality purposes; for the purposes here, it was assumed MPMCD would apply for the water rights.

upstream of Tom Steed Reservoir for non-consumptive purposes would be relatively low. It was assumed that stakeholder support would be largely positive and that the risk of significant protest or prolonged litigation was low.

Acceptability: Favorable

- Other existing senior and junior permit holders in the Tom Steed Reservoir hydrologic basin could benefit if MPMCD had a water right for all unappropriated waters. The URRBS results showed that existing senior and junior permit holders in Elk Creek and West Otter-Glen Creeks already have unstable and unpredictable water rights, so any additional consumptive water rights, even though junior to existing water rights, would increase the instability of these senior water rights. Consequently, what is good for MPMCD in gaining a permit to all unappropriated waters would turn out to be good for the existing senior and junior water rights holders as well. Therefore, it was assumed that stakeholder support would be largely positive with minimal risk of significant protest or prolonged litigation.
- The OWRB concluded in the OCWP that the basins upstream from Tom Steed Reservoir did not have any stream water available for new regular prior appropriation permits, so it would seem that no one should be thinking about applying for a new water right in the Tom Steed Reservoir hydrologic basin.
- Recognizing that the URRBS found that unappropriated water could exist if the OWRB used naturalized flows in lieu of 1951-1980 run-off records, it may sound contradictory to state that MPMCD could apply for water rights in all unappropriated waters when the OCWP stated that no unappropriated waters exist; however, granting MPMCD a water permit for all unappropriated waters could legally effectuate closure of the basins in conformity with the OCWP. Moreover, the OCWP closure appears related to consumptive uses of the waters of these watersheds whereas this strategy assumes MPMCD would be applying for non-consumptive beneficial uses for recreation, fish, and wildlife.

Completeness: Favorable

- For reasons discussed above, it was assumed that MPMCD could face little opposition to its application for all unappropriated waters in Elk Creek and West Otter-Glen Creeks above Tom Steed Reservoir, that stakeholder support would be positive, and that changes in law, regulations, and/or policy would not be required. Therefore, the risks associated with implementing this strategy may be relatively low.

Conjunctive Management - Voluntary Dry-Year Lease or Purchase Agreements

Description

- This strategy proposed to purchase existing senior water rights and/or enter into dry-year lease agreements with groundwater permit holders in the NFRR aquifer through voluntary, non-regulated transactions between the MPMCD and willing sellers/leasers of groundwater to protect the base flows of Elk Creek. The reader is encouraged to read Chapter 8.3.4 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- It was assumed that this strategy would not provide meaningful benefits to the firm yield of Tom Steed Reservoir. The URRBS results showed that existing groundwater permits in the NFRR aquifer had no measurable impact on Elk Creek, and that the impacts of future groundwater permits were negligible.

Efficiency: Less Favorable

- Considering the large number of groundwater permit holders in the NFRR aquifer, the transaction costs to implement this strategy would be relatively high.

Acceptability: Less Favorable

- The acceptability of this strategy would depend on the capability or willingness of groundwater permit holders to sell or lease their water to MPMCD, the capability or willingness of MPMCD to purchase or lease the groundwater from senior permit holders, as well as other unknown terms and conditions that could affect the viability of voluntary purchase/lease agreements.

- Even if all of the groundwater permit holders agreed to sell or lease their water rights to MPMCD, the benefits to Tom Steed Reservoir would be negligible. It is highly unlikely that a large number of groundwater permit holders, let alone all permit holders, would be willing to sell or lease their groundwater rights to MPMCD.

Completeness: Less Favorable

- The risks for implementing this strategy would be relatively high in terms of obtaining enough groundwater permit holders to sell or lease their water such that any meaningful benefit to Tom Steed Reservoir firm yield would result.

Conjunctive Management – Conservation-Oriented Maximum Annual Yield Determination

Description

- This strategy proposed the implementation of a conservation-oriented maximum annual yield on the NFRR and Elk City aquifers, as well as adoption of a lesser EPS for future groundwater permit applicants that protects the base flow of Elk Creek and consequently, protects the firm yield of Tom Steed Reservoir. The reader is encouraged to read Chapter 8.3.4 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- While a lesser EPS in the NFRR and Elk City aquifers would likely be preferred by MPMCD over one that reflects the policy of full depletion of the aquifers, it was assumed that this strategy would not provide meaningful benefits to the firm yield of Tom Steed Reservoir. This is because the URRBS results showed that existing groundwater permits in the NFRR aquifer had no measurable impact on Elk Creek, and that impacts from future groundwater permits were negligible.

Efficiency: Neutral

- The costs to implement this strategy would depend on the level of stakeholder support from existing and future potential groundwater users of the NFRR and Elk City aquifers, and the extent to which a lack of stakeholder support could result in significant protest or prolonged litigation.
- A lesser EPS in the NFRR and Elk City aquifers would likely be preferred by MPMCD over one that reflects the policy of full depletion of the aquifers, but this preference may not be shared by groundwater users. Groundwater users may not view full aquifer depletion as a reasonably foreseeable scenario, and therefore may continue to advocate for a higher aquifer EPS that maximizes water availability for agricultural production, municipal use, energy production, etc.

Acceptability: Neutral

- The acceptability of this strategy would depend on the level of stakeholder support from existing and future potential groundwater users of the NFRR and Elk City aquifers, and the extent to which a lack of stakeholder support could result in significant protest or prolonged litigation; these factors would ultimately influence the likelihood of the OWRB agreeing to implement a lesser, more conservation-oriented EPS.
- A lesser EPS in the NFRR and Elk City aquifers would likely be preferred by MPMCD over one that reflects the policy of full depletion of the aquifers, but this preference may not be shared by groundwater users. Groundwater users may not view full aquifer depletion as a reasonably foreseeable scenario, and therefore may continue to advocate for a higher aquifer EPS that maximizes

water availability for agricultural production, municipal use, energy production, etc.

Completeness: Less Favorable

- While legal arguments exist that support a conservation-oriented EPS, the OWRB noted that a similar strategy in the Arbuckle Simpson Aquifer in southeast Oklahoma required new legislation. Therefore, it was assumed that new legislation may likely be needed for a similar strategy to be implemented in the Lugert-Altus Reservoir hydrologic basin, which would create a barrier towards implementation.

Reclassification of Alluvial Groundwater to Stream Water

Description

- This strategy proposed to reclassify alluvial groundwater as stream water to allow stream waters to be managed in accordance with Oklahoma's surface water prior appropriation laws. The reader is encouraged to read Chapter 8.3.5 of the URRBS Full Report and Kershen (2021) for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- While this strategy would effectively make MPMCD's permit senior to groundwater use permitted after MPMCD's permit priority date, potentially enabling MPMCD to collaborate with the OWRB to develop interference regulations applicable to newly-classified alluvial (stream) waters that protect Tom Steed Reservoir, it was assumed that this strategy would not provide meaningful benefits to the firm yield of Tom Steed Reservoir. This is because the URRBS results showed that existing groundwater permits in the NFRR aquifer had no measurable impact on Elk Creek, and that future groundwater impacts were negligible.

Efficiency: Less Favorable

- While legal arguments exist that support reclassification, it was assumed that a lack of stakeholder support may generate significant protests and prolonged litigation, potentially up to and including a hearing by the Oklahoma Supreme Court. This could potentially make this strategy costly to implement. The unknown outcome of potential future litigation raises additional risks.

Acceptability: Less Favorable

- While legal arguments exist that support reclassification, it was assumed that a lack of stakeholder support may generate significant protests and prolonged litigation, potentially up to and including a hearing by the Oklahoma Supreme Court. The unknown outcome of potential future litigation raises additional risks.

Completeness: Less Favorable

- While legal arguments exist that support reclassification, it was assumed that a lack of stakeholder support may generate significant protests and prolonged litigation, potentially up to and including a hearing by the Oklahoma Supreme Court. The unknown outcome of potential future litigation raises additional risks.

Environmental Quality Beneficial Use

Description

- This strategy proposed a reevaluation of Mountain Park Project benefits, including an assessment of EQ water needs at Hackberry Flat WMA that would include an up-to-date analysis on the management objectives of Hackberry Flat WMA. An optimization assessment also was proposed that identifies opportunities to conserve water through improved water management and instrumentation within the Hackberry Flat WMA complex.
- This strategy also proposed reevaluation of M&I needs, taking into account the best available supply and demand data contained within this URRBS.
- Depending on the outcome of a reevaluation study on the needs and objectives of Hackberry Flat WMA as compared to present-day M&I needs and benefits, if the objective is to resume all or some deliveries of EQ water to Hackberry Flat WMA, then this strategy proposed addressing the viability of the Hackberry Flat Pipeline by either replacing the pipeline or installing a slip-line within the existing pipeline.
- If all or a portion of EQ water remains unused, then this strategy proposed that MPMCD coordinate with its member cities, along with ODWC and Reclamation, to identify and implement steps to reallocate any unused EQ water back to M&I purposes.
- To further inform a formulation of objectives moving forward in terms of delivering all EQ water, some EQ water, or no EQ water to Hackberry Flat WMA, this strategy proposed the delivery of a portion of the needed water to Hackberry Flat WMA from alternative, non-EQ water sources, namely wastewater effluent from the city of Frederick.
- The reader is encouraged to read Chapter 8.3.6 of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Favorable

- Unlike other strategies which aimed to maximize water supply availability and help provide a Tom Steed Reservoir firm yield of 16,100 acre-ft/yr, this strategy proposed to address the planning objective of maximizing the beneficial use of MPMCD's permitted water to Tom Steed Reservoir.

- It was assumed that this strategy, although multi-faceted and complex, could effectively maximize the beneficial use of MPMCD's permitted water.

Efficiency: Favorable

- The costs to implement this strategy would depend on numerous factors, including the outcome of EQ-M&I needs assessments, the formulation of Mountain Park Project objectives, the level of stakeholder support, and the extent to which infrastructure alternatives are needed to achieve desired outcomes. However, the efficiency of this strategy was viewed to be favorable because it could be easily implemented, at least in part without infrastructure changes and at little to no cost, provided that the assessment of EQ water needs at Hackberry Flat WMA indicates that some portion of the EQ water could be converted to M&I.

Acceptability: Favorable

- Provided the EQ-M&I needs assessment indicates that excess EQ water may be available for M&I use, the level of stakeholder support to implement this strategy would likely be high. In addition, this strategy could be at least partially implemented without significant infrastructure changes, so the primary acceptability question would be related to infrastructure requirements for full implementation if the volume of available EQ water was such that infrastructure changes would be needed to achieve desired outcomes.

Completeness: Neutral

- The actual amount of EQ water which may be available for M&I use, if any, is currently unknown, and the risks involved with implementing this strategy would depend primarily on the outcome of EQ-M&I needs assessments. Depending on the formulation of Mountain Park Project objectives and the extent to which infrastructure alternatives are needed to achieve desired outcomes identified during the EQ-M&I needs assessment, additional risks may also exist with regard to the cost to implement a project and the capability-willingness to pay.

Expansion of the Bretch Diversion and Canal

Description

- This strategy proposed to increase the capacity of the Bretch Diversion Dam and Canal system to store and convey additional flows from Elk Creek, and in doing so, increase the firm yield of Tom Steed Reservoir. Eleven storage-canal expansion alternatives were evaluated. The reader is encouraged to read Chapter 8.3.7 of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Less Favorable

- None of the eleven storage-canal expansion alternatives increased the firm yield of Tom Steed Reservoir, so it was assumed that this strategy would not meaningfully address the planning objective of delivering MPMCD's full permit volume of 16,100 acre-ft/yr.

Efficiency: Less Favorable

- The estimated preliminary costs to implement this strategy ranged from $12.2 million to $63.8 million. This strategy was considered cost prohibitive, especially given the absence of firm yield benefits to Tom Steed Reservoir.

Acceptability: Less Favorable

- Given the relatively high costs to implement storage-conveyance expansion alternatives that would result in no benefits to the firm yield of Tom Steed Reservoir, it was assumed that this strategy would unlikely garner support from MPMCD or stakeholders.

Completeness: Less Favorable

- Given the relatively high costs to implement storage-conveyance expansion alternatives that would result in no benefits to the firm yield of Tom Steed Reservoir, it was assumed that MPMCD would unlikely be willing to pay the costs to implement this strategy.

Development of Supplemental Groundwater Supplies

Description

- This strategy proposed to pump up to 2,240 acre-ft/yr in supplemental groundwater from proposed well fields located on Project lands and non-Project lands, and then use existing Project infrastructure to deliver water to its customers.

Effectiveness: Favorable

- This strategy has the potential to provide enough supplemental water for Tom Steed Reservoir to deliver the target firm yield of 16,100 acre-ft/yr through a repeat of the 2010s Drought of Record.

Efficiency: Favorable

- It was assumed that the costs to develop supplemental groundwater supplies would be relatively low when compared with other options.

Acceptability: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Completeness: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required. That said, key steps remain on implementation of this strategy. First, plans need to be developed must be developed both for how the physical connections would be made and for how to integrate supplemental groundwater into Project operations, including the development of criteria or thresholds for volume and timing of groundwater supplementation. Reclamation review and approval of these plans would be required. In addition, coordination is needed to: (1) determine if any contractual changes are required; (2) to formally establish when and how much groundwater will be conveyed; (3) to establish who would be responsible for funding operation and maintenance costs for the groundwater wells; (4) to determine who would hold the groundwater permit from the OWRB; (5) to determine ownership of the wells; and (6) to ensure compliance with the National Environmental Policy Act.

Water Conservation

Description

- This strategy proposed to stretch available water supplies of Tom Steed Reservoir through implementation of water conservation measures to reduce demands on Tom Steed Reservoir during drought periods.
- If demands on Tom Steed Reservoir equaled the full 16,100 acre-ft/yr permit volume, then a 42 percent water conservation rate would result in an assumed reservoir demand of 9,300 acre-ft/yr.
- If demands on Tom Steed Reservoir equaled the (higher) projected year 2060 water demand of 14,950 acre-ft/yr, then a 42 percent water conservation rate would result in an assumed reservoir demand of 8,700 acre-ft/yr.
- If demands on Tom Steed Reservoir equaled the maximum volume of historical deliveries made by MPMCD, which was 12,700 acre-ft/yr, then a 42 percent water conservation rate would result in a reservoir demand of 6,800 acre-ft/yr.
- The reader is encouraged to read Chapter 8.3.8 of the URRBS Full Report for a thorough examination of this adaptation strategy.

Effectiveness: Neutral

- Unlike other strategies which aimed maximize to water supply availability and help Tom Steed Reservoir deliver MPMCD's full permit volume of 16,100 acre-ft/yr, this strategy proposed to stretch available supplies of Tom Steed Reservoir through implementation of water conservation measures.

Efficiency: Favorable

- It was assumed that the direct costs to implement water conservation measures would be relatively low. Indirect impacts on the local economy resulting from reductions in water use were not considered.

Acceptability: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Completeness: Favorable

- It was assumed that stakeholder support would be largely positive, and that changes in law, regulations, and/or policy would not be required.

Conclusions

The record-breaking drought between 2010 and 2015 created a historic milestone in southwest Oklahoma, a milestone where Reclamation, 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.

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 took into account the region's climate and hydrology, as well as inflow depletions from future growth in human development. The URRBS showed that regardless of human development, the region's climate, largely driven by a new drought of record, was such that there was a measurable and finite limit to the volume of water that could be stored and reliably delivered from Lugert-Altus and Tom Steed reservoirs during severe drought periods, particularly during a repeat of the 2010s Drought of Record. Although the updated reservoir supply yields for both reservoirs were less than the supply yields previously calculated by Reclamation during the initial stages of project development back in the 1940s and 1970s, they are important and provide decision-makers with a baseline to prepare for and respond to future droughts. Another key finding was that the depletions in stream flow caused by upstream groundwater and surface water development were measurable and will continue to reduce water supplies in the Lugert-Altus and Tom Steed reservoir hydrologic basins if steps are not taken to change how water is permitted and/or managed during periods of drought. Importantly, this finding applies not only to the two reservoirs, but also to other groundwater and stream water users in the basins as a whole. As such, 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.

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 upon and improve for years to come.

"*Truth* is the end of inquiry"

- anonymous

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