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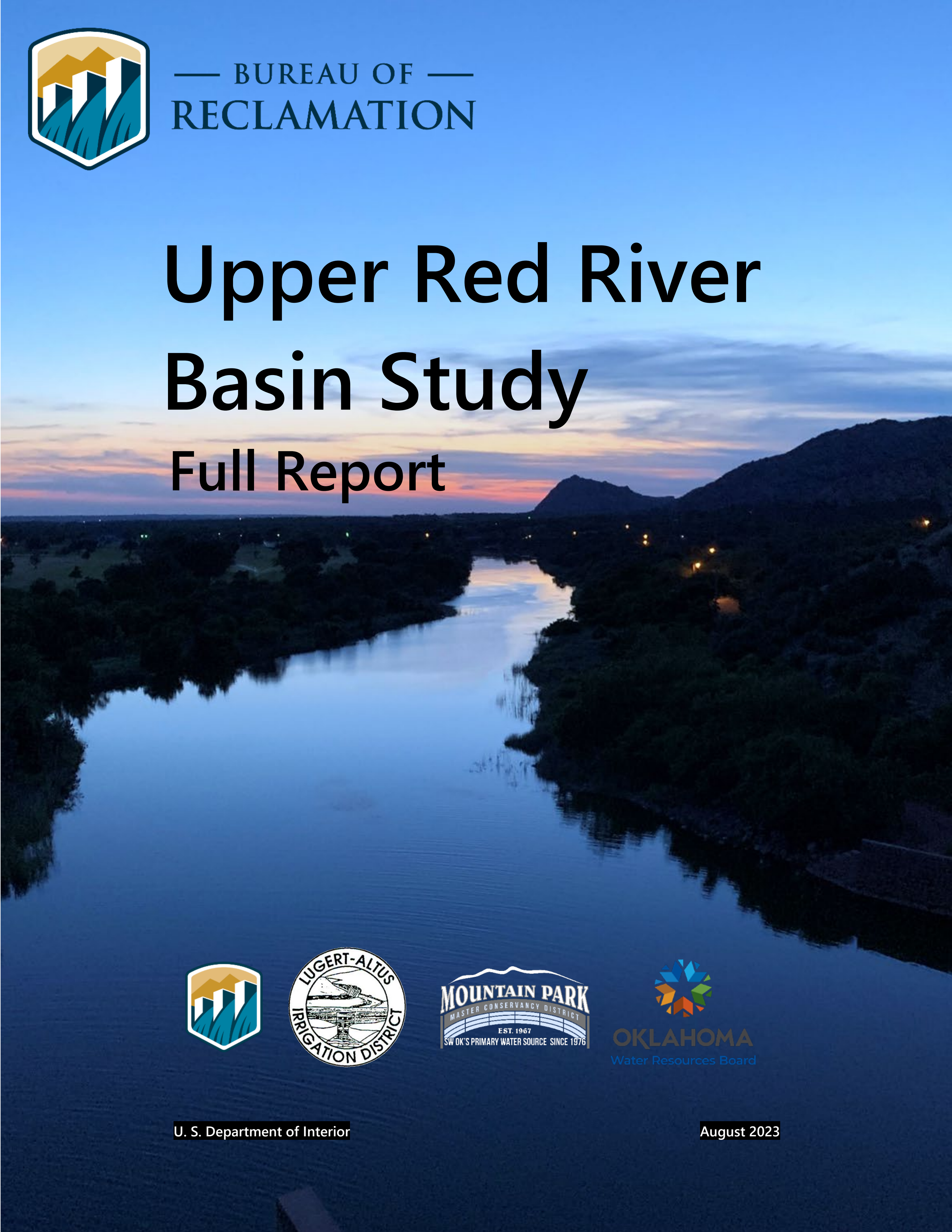

Upper Red River Basin Study

Full 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	Acre-ft
Acre-feet per year	Acre-ft/yr
Air Force Base	AFB
Arc GIS-Based Water Rights	Arc-GIS
Basin Study Program	Program
Bureau of Reclamation	Reclamation
Central Resource Allocation Model	CRAM
Climate Adaptation Science Center	CASC
Climate Divisions	CD
Cost Estimating	FAC
Coupled Model Intercomparison Project	CMIP
Cubic feet per second	Cfs
Definite Plan Report	DPR
Directives and Standards	D&S
Ditch Rider Districts	DRDs
Environmental Quality Plan	EQ Plan
Equal proportionate share	EPS
Evapotranspiration	ET
feet	ft
Focus Area Study	FAS
Gallons Per Capita Day	GPCD
Global climate models	GCMs
Gridded Climate Divisional Dataset	CLIMDIV
High-Density Polyethylene	HDPE
Hydrologic Unit Code	HUC
Hydrologic and meteorological monitoring stations	HydroMet
IMPact analysis for PLANning	IMPLAN
Lugert-Altus Irrigation District	Lugert-Altus ID
Maximum Annual Yield	MAY
milligrams per liter	mg/L

Minimum Desirable Streamflows	MDS
Mountain Park Master Conservancy District	MPMCD
Municipal and Industrial	M&I
National Drought Resilience Partnership	NDRP
National Environmental Policy Act	NEPA
Natural Resources Conservation Service	NRCS
Net irrigation water requirement	NIWR
North Fork Red River	NFRR
Oklahoma Comprehensive Water Plan	OCWP
Oklahoma Department of Wildlife Conservation	ODWC
Oklahoma-Texas Area Office	OTAO
Oklahoma Tourism and Recreation Department	OTRD
Oklahoma Water Resources Board	OWRB
Operation and Maintenance	O&M
Palmer Drought Severity Index	PDSI
Plan of Development	POD
Principles and Requirements for Federal Investments in Water Resources	PR&Gs
Provisional Temporary	PT
Reclamation Reservoir Yield	RRY
Surface Water Allocation Model	SWAM
Southwest Oklahoma Water Supply Action Plan	SWAP
Standardized Precipitation Index	SPI
Technical Memorandum	TM
Trihalomethanes	THMs
Red River Compact	Compact
Upper Red River URRBS Basin Study	URRBS
United States	U.S.
United States Geological Survey	USGS
United States Department of Agriculture	USDA
Variable Infiltration Capacity	VIC
Western Federal Agency Support Team	WestFAST

Western States Water Council	WSWC
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 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.

Content Organization

The full URRBS Report totaled 675 pages in body text, as well as 14 Appendices totaling 1,687 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 in the next section. This Executive Summary Report synthesizes this large body of work into a condensed publication that targets a general audience.

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 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 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 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 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 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 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 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 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 Report.

10. Appendix J: Formulation of Hydrologic Thresholds to Support Water Management in the Lugert-Altus Reservoir Hydrologic Basin (Reclamation and OWRB, 2022) (264 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 Report.

11. Appendix K: Formulation of Stream-Water Rights Management Alternatives in the Tom Steed Reservoir Hydrologic Basin (Reclamation and OWRB, 2020) (151 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 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 Report.

13. Appendix M: Water Availability Modeling Results for the Tom Steed Hydrologic Basin (172 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 Report.

14. Appendix N: Peer Review Report (66 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.

Chapter 1. Introduction

1.1. Authority and Purpose

The Upper Red River Basin Study (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. The Bureau of Reclamation (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]. Under the Program, four key elements must be included in the URRBS:

1. Projections of future supply and demand, including risk factors such as future changes in climate, hydrology, and groundwater recharge and discharge.
2. An analysis of how existing water and power operations and infrastructure will perform in the face of various risk factors, such as during times of drought and under potential supply imbalances.
3. Development of adaptation and mitigation strategies to meet current and future water demands.

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

4. A trade-off analysis of strategies in terms of their ability to meet study objectives, including the extent to which they minimize water supply and demand imbalances.

Regarding the trade-off analysis, WTR 13-01 states that the following is required:

> *"A quantitative or qualitative trade-off analysis of the adaptation and mitigation strategies identified. Such analysis will examine all proposed strategies in terms of their ability to meet the study objectives, the extent to which they minimize imbalances between water supply and demand and address the possible impacts of climate change, the level of stakeholder support, the relative cost (when available), the potential environmental impacts, or other attributes common to the strategies."*[2]

The term "trade-off analysis" of "attributes common to the strategies" could be interpreted by some as meaning all adaptation strategies must be compared to one another based on a common set of criteria, and that the result will be one or more strategies that is selected as the best solution(s) for implementation. While that type of analysis is warranted and even required for Federal planning investigations that culminate in recommendations for action or result in an official position of the agency, what sets basin studies apart from those types of planning investigations is that basin studies, including the URRBS, are explicitly *prohibited* from making recommendations or from making findings that represent a position of the agency. According to WTR 13-01, a basin study is defined as follows:

[2] Reclamation's Directives and Standards on Basin Studies (WTR 13-01); https://www.usbr.gov/recman/wtr/wtr13-01.pdf.

"A comprehensive study, or update of an existing study, that identifies imbalances between water supply and demand and includes the development of mitigation and adaptation strategies in direct response to current or future water supply and demand imbalances resulting from climate change and other stressors. Basin studies are technical assessments and do not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the funding partners. Basin studies do not propose or address the feasibility of any specific project, program, or plan and do not represent a commitment for provision of Federal funds."[3]

With the two aforementioned provisions in mind, it should be stated clearly that this study does include a trade-off analysis of adaptive strategies, but the analysis is cursory and qualitative in nature, and it does not culminate in a recommendation by Reclamation or any of the study partners on implementation of any particular strategy over another. To the extent possible and applicable, comparisons among strategies were made in terms of their relative ability to meet planning objectives and improve water supply availability, but in some cases, the strategies are either too different or not mutually exclusive to warrant a meaningful comparison. By not being mutually exclusive, this study means two or more strategies could be implemented at the same time rather one strategy being selected over another (e.g., a legal or administrative strategy could be pursued alongside an infrastructure strategy).

In Fiscal Year 2014, the Oklahoma Water Resources Board (OWRB), Lugert-Altus Irrigation District (Lugert-Altus ID), and Mountain Park Master Conservancy District (MPMCD) were awarded $640,000 in federal funds to undertake the URRBS. These funds were matched by the non-federal entities with $795,500, bringing the total study cost to $1,435,500 at the time of initiation;

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[3] Reclamation's Directive and Standard on Basin Studies (WTR 13-01); https://www.usbr.gov/recman/wtr/wtr13-01.pdf.

the Federal/non-federal cost-share percentage was 45/55. A detailed "Plan of Study" was developed by study partners, which outlined five overarching objectives of the URRBS. These objectives were tailored to address local needs while fulfilling previously mentioned Program requirements:

1. Characterize and quantify existing and future water supplies and demands of Lugert-Altus Reservoir and Tom Steed Reservoir;
2. Conduct investigations to determine the amount of groundwater available for future appropriations in areas that could impact Lugert-Altus Reservoir and Tom Steed Reservoir;
3. Develop a surface water allocation model to evaluate how groundwater and surface water management options affect the water supplies of Lugert-Altus Reservoir and Tom Steed Reservoir;
4. Assess the current and future capability of existing infrastructure and operations to meet demands, including risks and reliability of Lugert-Altus and Tom Steed reservoir's water supplies; and
5. Evaluate strategies to address infrastructure and water supply issues facing Lugert-Altus and Tom Steed reservoirs, both now and in the future.

The Plan of Study was subsequently incorporated into a Memorandum of Agreement that was signed in January 2015 by the OWRB, Lugert-Altus ID, and the MPMCD, as well as by Reclamation's Oklahoma-Texas Area Office (OTAO)[4]. Since that time, additional funds on both sides have been allocated to study modifications that meet the evolving needs on the ground. Overall, the URRBS was completed at a total cost of $2,820,000. The Federal share was $1,395,000; the non-federal share was $1,425,000, bringing the federal/non-federal cost-share percentage to 49/51[5].

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[4] The Memorandum of Agreement and Plan of Study are available in OTAO's central files.
[5] The non-Federal contributions are considered draft until the URRBS report is finalized.

1.2. 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, as well as 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 1-1). 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.

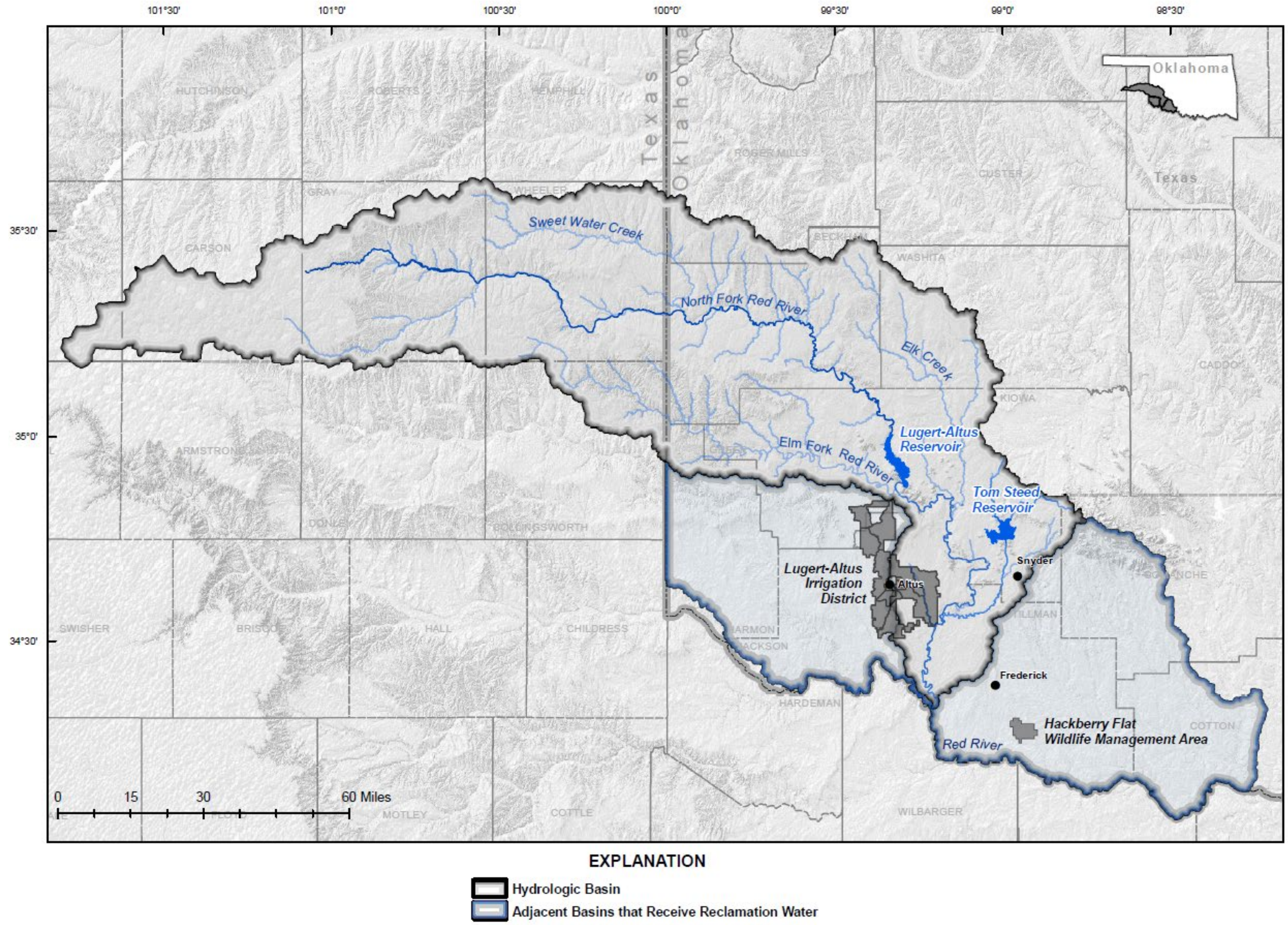

Figure 1-1. URRBS study area, including Lugert-Altus and Tom Steed reservoirs, customers, the NFRR hydrologic basin, and adjacent basins that receive Reclamation water.

1.2.1. Surface and Groundwater Resources

Surface Water Resources in Texas

The two prominent streams in the NFRR basin are the NFRR and the Elm Fork of the NFRR (Elm Fork Red River), both of which form in Texas. The NFRR contributes inflow to Lugert-Altus Reservoir; neither of the two streams contribute inflow to Tom Steed Reservoir, which receives its inflow from other tributaries of the NFRR in Oklahoma (discussed later in this section). The surface waters shared between Texas and Oklahoma are governed by the Red River Compact (Compact). The Compact was signed by neighboring member states AR, LA, OK and TX in 1978 to resolve and prevent disputes over waters of the Red River Basin that are shared between these states and to assure the receipt by the member states of adequate surface flows and releases. While provisions of the Compact specifically identify how much water each state is allowed to develop or store on an interstate stream, the Compact generally provides a means of resolving problems between the member states in an orderly manner, thus preventing the likelihood of litigation in most cases. As part of the Compact, the Red River is divided into "Reaches" both above and below Lake Texoma (Figure 1-2). Reach "I", upstream of Lake Texoma, is further divided into three subbasins, with Subbasin "I" containing the NFRR which flows across the Texas state border into Lugert-Altus Reservoir in Oklahoma. According to Section 4 of the Compact, 60 percent of the surface waters in Subbasin "I" are apportioned to Texas and 40 percent to Oklahoma.

In so far as the development of the apportioned water resources in Texas could affect inflow to Lugert-Altus Reservoir, projected growth and planned development of water resource activities within Subbasin "I" were assessed. According to the Texas Region A Water Plan (Freese and Nichols Inc. et al., 2016), which encompasses Subbasin "I", little to no growth is projected in this area, water supplies are provided almost exclusively by groundwater, and development of surface water supplies are not anticipated. Therefore, this study assumed that no impacts would occur from Texas-based development upstream of either Lugert-Altus Reservoir or Tom Steed Reservoir, and no further collaboration with Texas-based entities was required for the URRBS. That said, surface water flow data were included where applicable for the purposes of hydrologic modeling. The remainder of this report focuses solely on the Oklahoma portion of the URRBS study area.

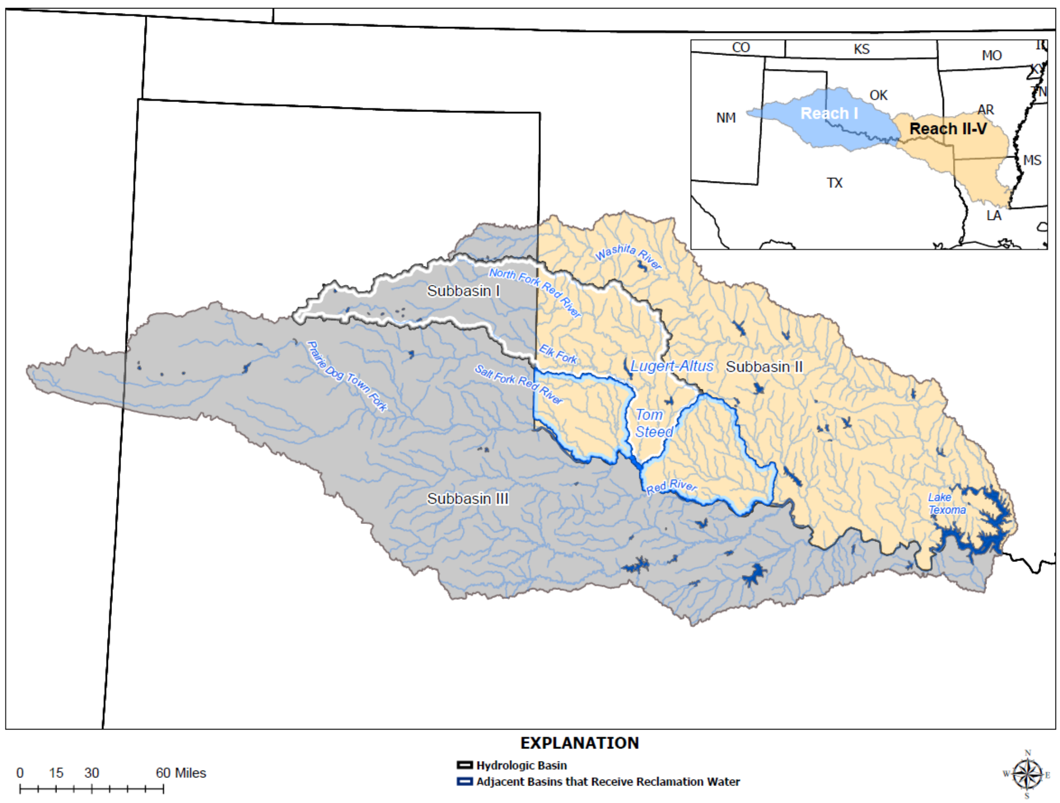

Figure 1-2. Subbasins "I-III" of Reach "I" of the Red River Compact.

Surface Water Resources in Oklahoma

Lugert-Altus Reservoir receives its surface water inflow from the NFRR. Inflow into Tom Steed Reservoir comes naturally from West Otter Creek and Glen Creek, as well as from diversions from Elk Creek (Figure 1-3). Groundwater discharge from underlying aquifers contribute base flows to these streams (discussed more below). Releases from Tom Steed Reservoir into West Otter Creek then merge with Otter Creek and drain into the NFRR downstream of both reservoirs; eventually, the NFRR drains into the Red River along the Oklahoma-Texas border. The Elm Fork Red River also lies within the NFRR hydrologic basin, although it does not contribute inflows to either reservoir.

For reference purposes, the study area is located within eleven designated "Basin" boundaries of the Southwest Watershed Planning Region Oklahoma Comprehensive Water Plan (OCWP) 2012 Update (OWRB, 2012). Lugert-Altus Reservoir's hydrologic basin coincides with Basins 36 and 37; Tom Steed's hydrologic basin coincides with Basins 34 and 35 (Figure 1-3). The contributions of these watersheds to reservoir inflow are discussed in Chapter 5.3.2: Existing Surface Water Supplies.

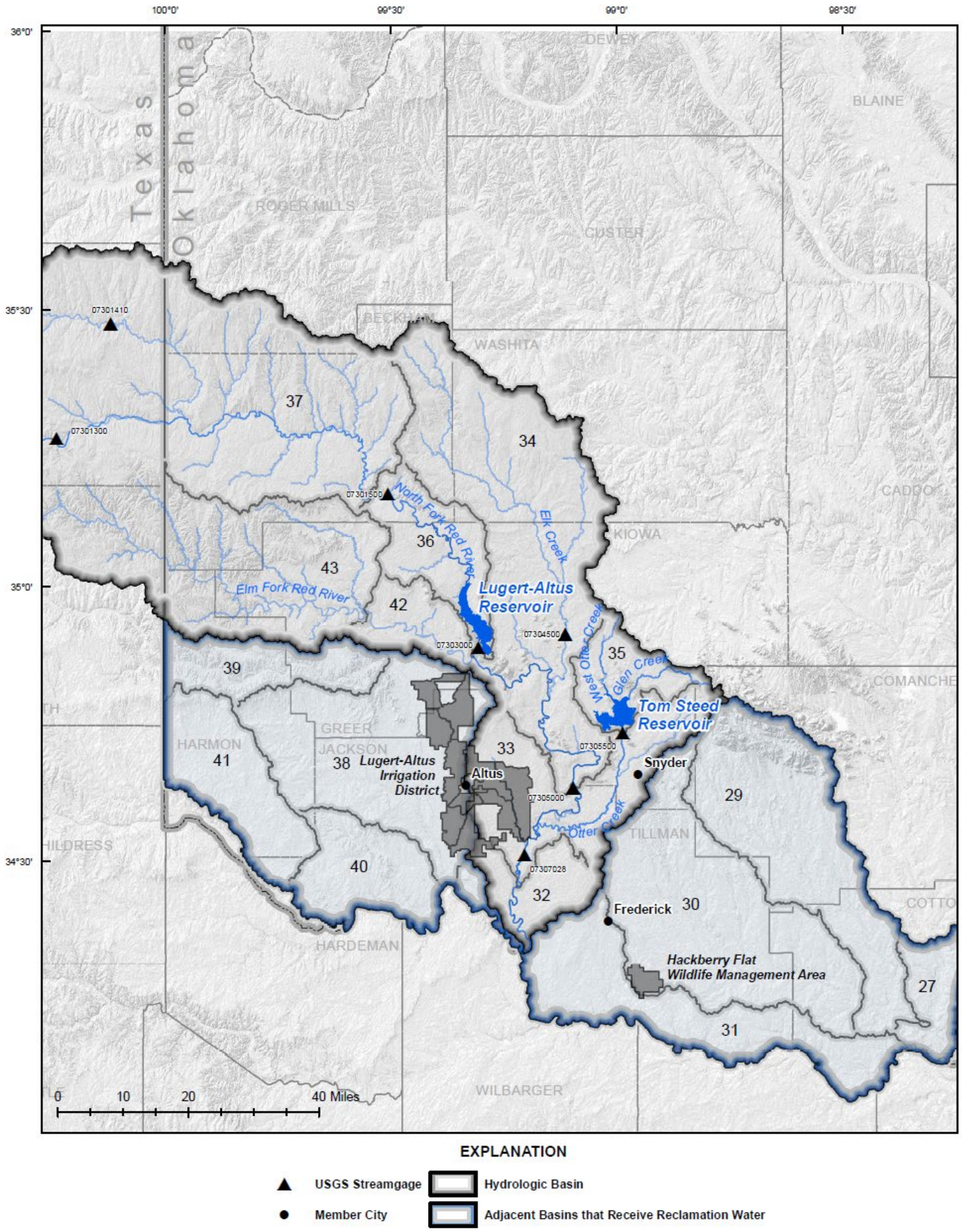

Figure 1-3. Prominent surface water resources within the NFRR hydrologic basin, as well as the designated OCWP 2012 Update Southwest Watershed Planning Region "basins" within the URRBS study area.

Groundwater Resources in Oklahoma

The URRBS study area (within Oklahoma) overlays two major aquifers: Elk City aquifer and the NFRR alluvial aquifer (Figure 1-4). Of these, the most significant groundwater feature affecting Lugert-Altus Reservoir and Tom Steed Reservoir is the NFRR alluvial aquifer. The NFRR aquifer is located in Beckham, Greer, Jackson, Kiowa, and Roger Mills counties and is composed of about 777 square miles of alluvium and terrace deposits along the NFRR and tributaries, including Sweetwater Creek, Elk Creek, Otter Creek, and Elm Fork Red River. Groundwater discharge from the NFRR alluvial aquifer sustains streamflow to the NFRR during most of the year (Smith and Wahl, 2003), which flows into Lugert-Altus Reservoir; however, some gaged reaches of the NFRR and tributaries commonly have no flow (defined as streamflow less than 1 cubic foot per second [cfs]) in the late summer when water demands for irrigation, public supply, and evapotranspiration (ET) are greatest (Smith et al., 2017). The NFRR aquifer was the subject of significant analysis in this study and will be discussed in detail in later chapters.

Unlike Lugert-Altus Reservoir, which is dependent on base flows from the NFRR aquifer for replenishment, Tom Steed Reservoir is near the edge of the NFRR aquifer and is primarily replenished by surface-water runoff from areas outside of the NFRR aquifer (i.e., from Elk Creek, Otter Creek, and West Otter Creek). Base flows in Elk Creek originate from several sources including the NFRR aquifer, Elk City aquifer, and following periods of runoff, from numerous floodwater-retarding structures in the Elk Creek hydrologic basin (Smith et al., 2017). Base flows in West Otter Creek and Glen Creek are assumed to originate from the Southwest Oklahoma minor aquifer, although no studies have been conducted to quantify base flows; this aquifer is considered to be too thinly saturated to support irrigation uses beyond short-term domestic uses (OWRB, 1998).

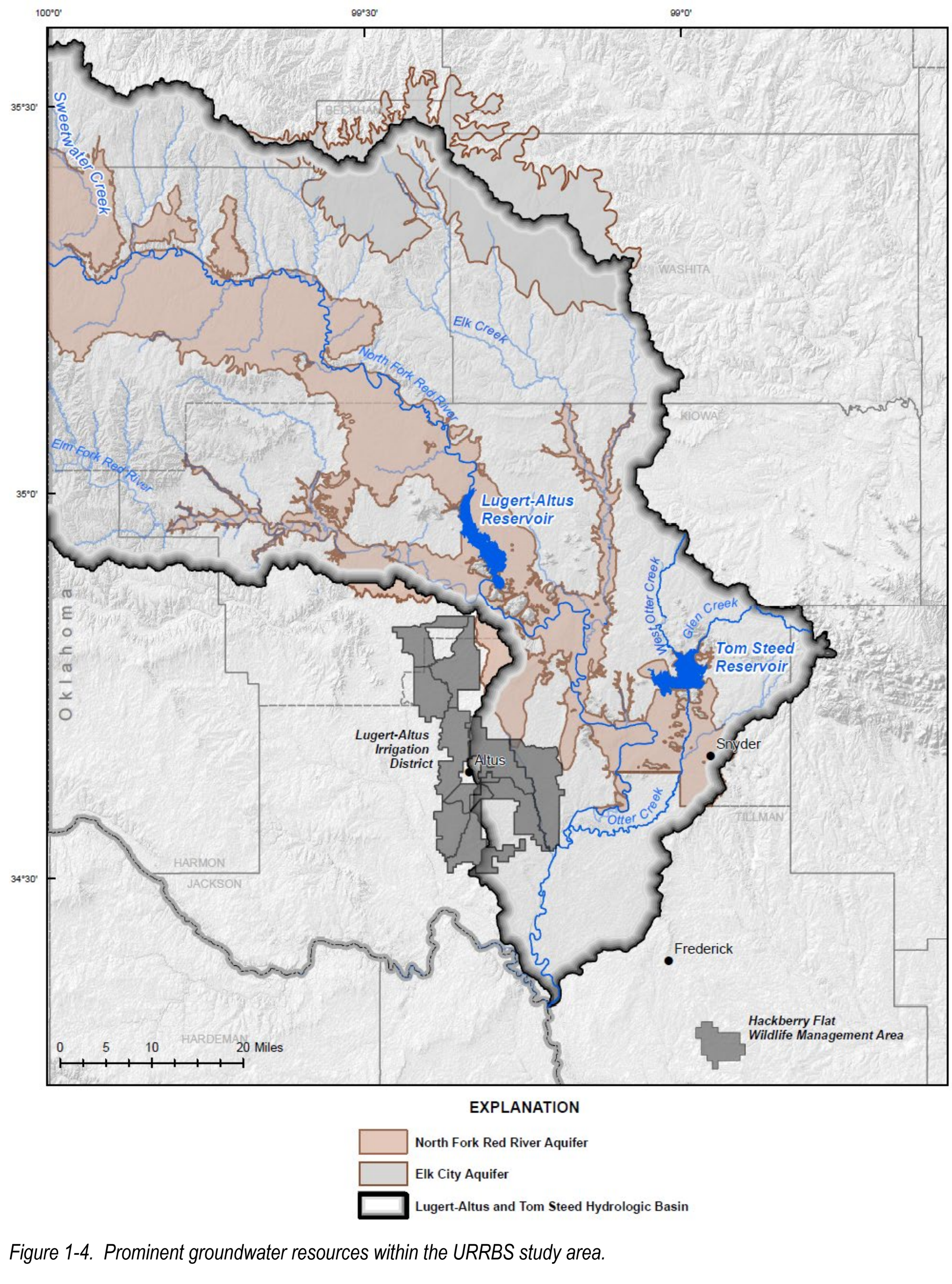

Figure 1-4. Prominent groundwater resources within the URRBS study area.

1.2.2. Federal Projects and Features

Lugert-Altus Reservoir, W.C. Austin Project

The W.C. Austin Project is a water supply project constructed by Reclamation in Greer, Kiowa, and Jackson counties, Oklahoma. The main project feature, Altus Dam, is located about 18 miles north of the city of Altus (Figure 1-5). The dam, along with a series of five dikes, impound the natural flows from the NFRR. Lugert-Altus Reservoir provides irrigation water to 48,000 acres of privately-owned land located within the Lugert-Altus ID. The reservoir also provides supplemental M&I water to the city of Altus, as well as flood control, recreation, and fish and wildlife benefits.

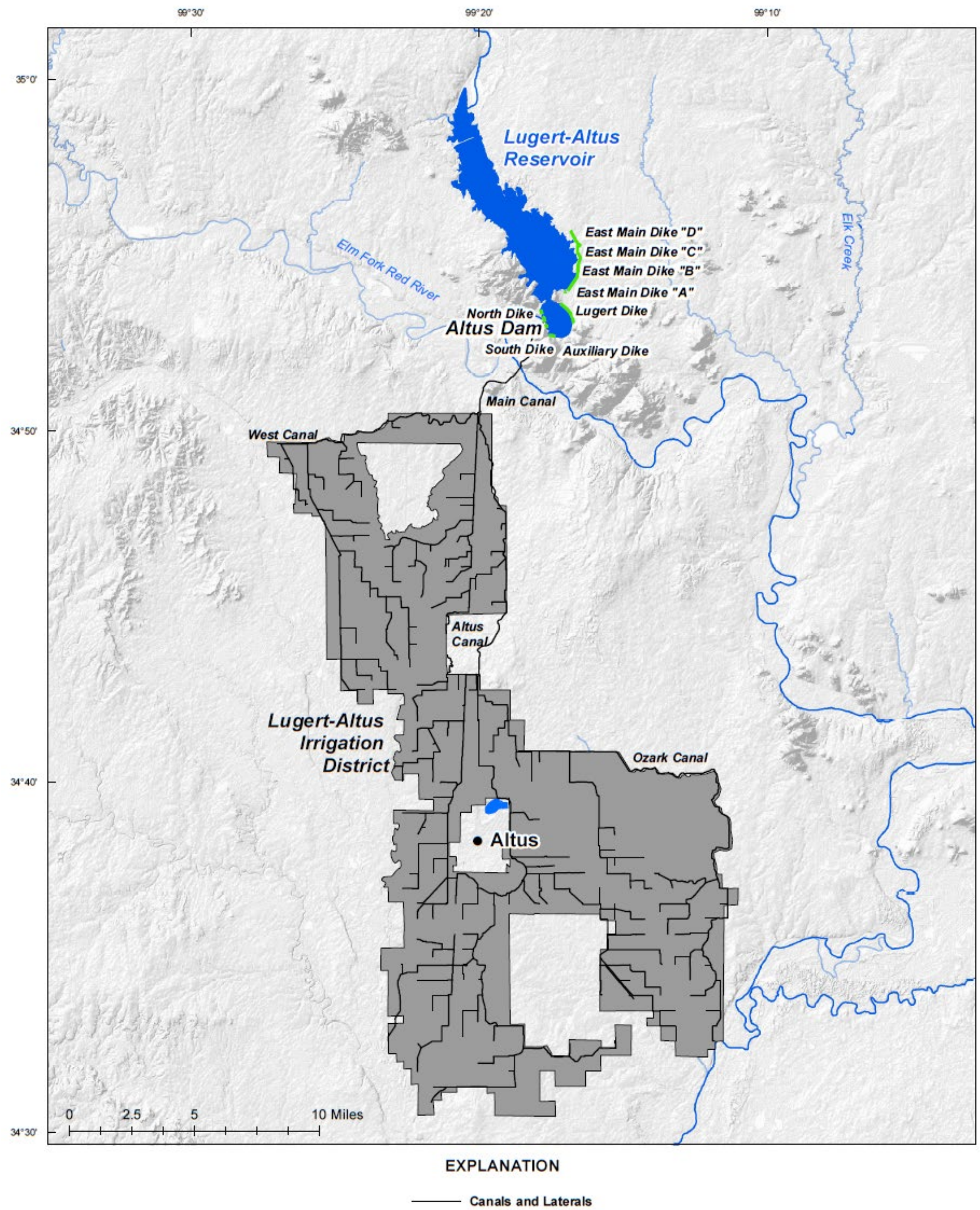

Figure 1-5. Features of the W.C. Austin Project, Oklahoma.

The W.C. Austin Project was authorized by Public Law 75-761 on June 28, 1938, for the purposes of flood control and irrigation. Reclamation initiated construction in 1941, but activities were interrupted by World War II. Construction resumed in 1944, and Altus Dam was completed in 1946. Irrigation water was first furnished to a small acreage in 1945, but it was not until 1949 that the remaining distribution system was completed to serve the entire project. The first full season of irrigation deliveries occurred in 1951.

Figure 1-6. Altus Dam, W.C. Austin Project.

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). Reclamation reimburses Lugert-Altus ID on an annual basis for the portion of O&M costs that are attributable to flood control benefits. Costs to support single purpose irrigation and municipal water are paid for solely by the Lugert-Altus ID and by the city of Altus, and the city pays the Lugert-Altus ID its share of O&M costs.

In 1987 and 1990, the city of Altus and Lugert-Altus ID fulfilled their repayment obligations, respectively, to the U.S. for the portion of project construction costs attributable to M&I and irrigation supply in accordance with the provisions of their repayment contract. The Lugert-Altus ID and city of Altus have since entered into new contracts with the U.S. (in April and May 2016, respectively) for repayment of costs associated with dam safety modifications that are currently underway.

Altus Dam

Altus Dam is a concrete-gravity type, partially curved structure rising 110 feet (ft) above the streambed and has a crest length of 1,104 ft (Figure 1-6). The dam is faced with granite masonry, except on the downstream side of the overflow section.

Incorporated within the dam section are both controlled and uncontrolled overflow-type spillways and an outlet works that delivers water to the canal system. The controlled spillway has a design capacity of 52,200 cfs and is regulated by nine radial gates. Appurtenant reservoir structures constructed along with the dam include five dikes located at depressions along the reservoir perimeter, including the Auxiliary, Lugert, East, North, and South Dikes. The largest, Lugert Dike, is approximately 4,200 ft long and has a maximum height of approximately 45 ft. The crest elevation of these dikes has been raised pursuant to dam safety modifications previously mentioned in order to reduce risks of failure and protect public safety.

Lugert-Altus Reservoir is divided into three operational pools, each having a specific purpose (Figure 1-7). These pools include the active conservation pool, flood control pool, and surcharge pool. The active conservation pool is the largest pool and is used to store water for irrigation and municipal purposes. The flood control and surcharge pools are smaller and temporarily store water from large rainfall events to reduce downstream impacts from flooding. There is also one small, nonoperational pool referred to as the dead pool that is located below the conservation pool. The elevation and volume capacities of each individual pool are presented in Figure 1-7. The pool elevations are depicted through aerial imagery in Figure 1-8. Corresponding surface acreages are included.

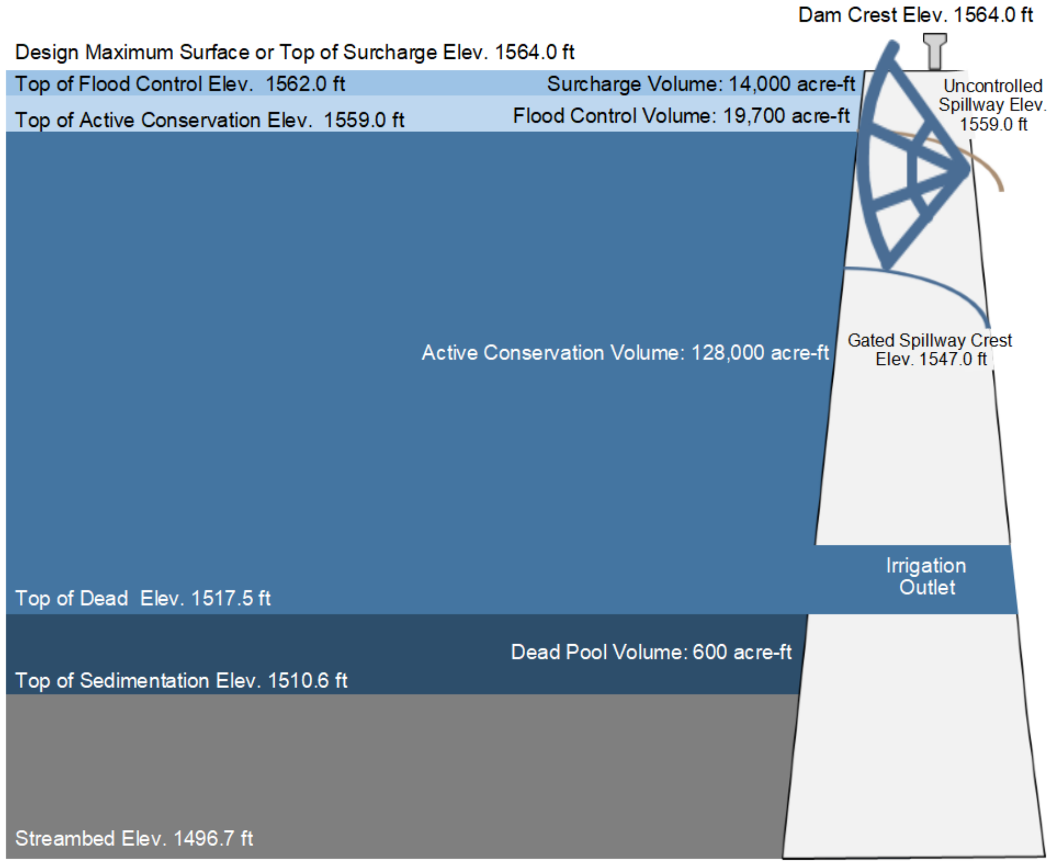

Figure 1-7. Conceptual figure of Altus Dam and Lugert-Altus Reservoir's designated pool volumes and elevations as of 2007 based on the 2007 sediment survey. Note: although elevation designations are fixed, volumes will change over time based on changing sediment conditions.

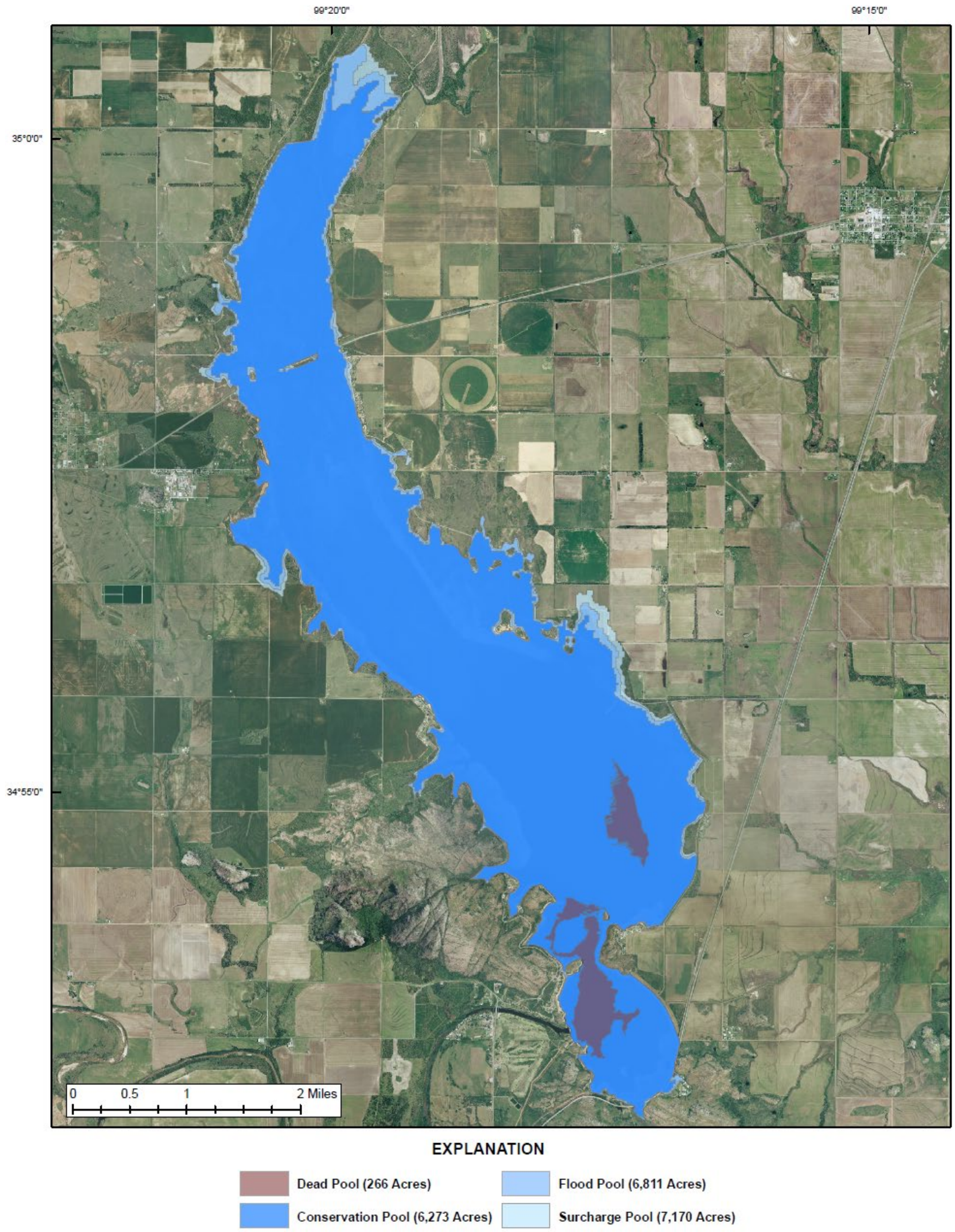

Figure 1-8. Surface acreage of the four designated pools within Lugert-Altus Reservoir, W.C. Austin Project.

Project Benefits, W.C. Austin Project

The W.C. Austin Project provides flood control of the NFRR and water for irrigation of approximately 48,000 acres of privately-owned land south of Lugert-Altus Reservoir. In addition to these two original project purposes, the W.C. Austin Project provides a supplemental M&I water supply for the city of Altus, and about 11,000 surface acres for public recreation and fish and wildlife conservation.

Irrigation Benefits and Features

Irrigation benefits are provided through an irrigation water right that was granted to the Lugert-Altus ID by the State of Oklahoma in 1939 (Oklahoma 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, where it is used to support a diverse array of crops. Cotton is the primary crop, although winter wheat, alfalfa, peanuts, grain sorghums, and potatoes also are prevalent.

Water deliveries for irrigation are made from Altus Dam through the Main Canal. The Main Canal has a design capacity of 1,000 cfs and transports water 4.2 miles to the northern boundary of the irrigation district. At this point, deliveries are separated into the West Canal and the Altus Canal. The West Canal, which has a design capacity of 290 cfs, continues from the end of the Main Canal west about 6 miles, then south for another 5.1 miles. The Altus Canal, which is designed to carry the remaining 710 cfs, continues from the end of the Main Canal south for about 21.7 miles through the city of Altus. About 3.5 miles north of the city, the Ozark Canal (design capacity of 180 cfs) separates from the Altus Canal and continues generally south and east for 14.8 miles. The entire irrigation district includes a total of about 52 miles of canals, 218 miles of laterals, and 26 miles of drains. Figure 1-9 and Figure 1-10 depict the canal system and Lugert-Altus ID features. Within the Lugert-Altus ID lies Altus Lake, a regulating reservoir constructed by the city of Altus in 1916 and 1937, which is used to store and regulate M&I water delivered by the Lugert-Altus ID through the canal system. The city of Altus also receives water from Tom Steed Reservoir via deliveries through the Altus Aqueduct directly to the city's water treatment plant.

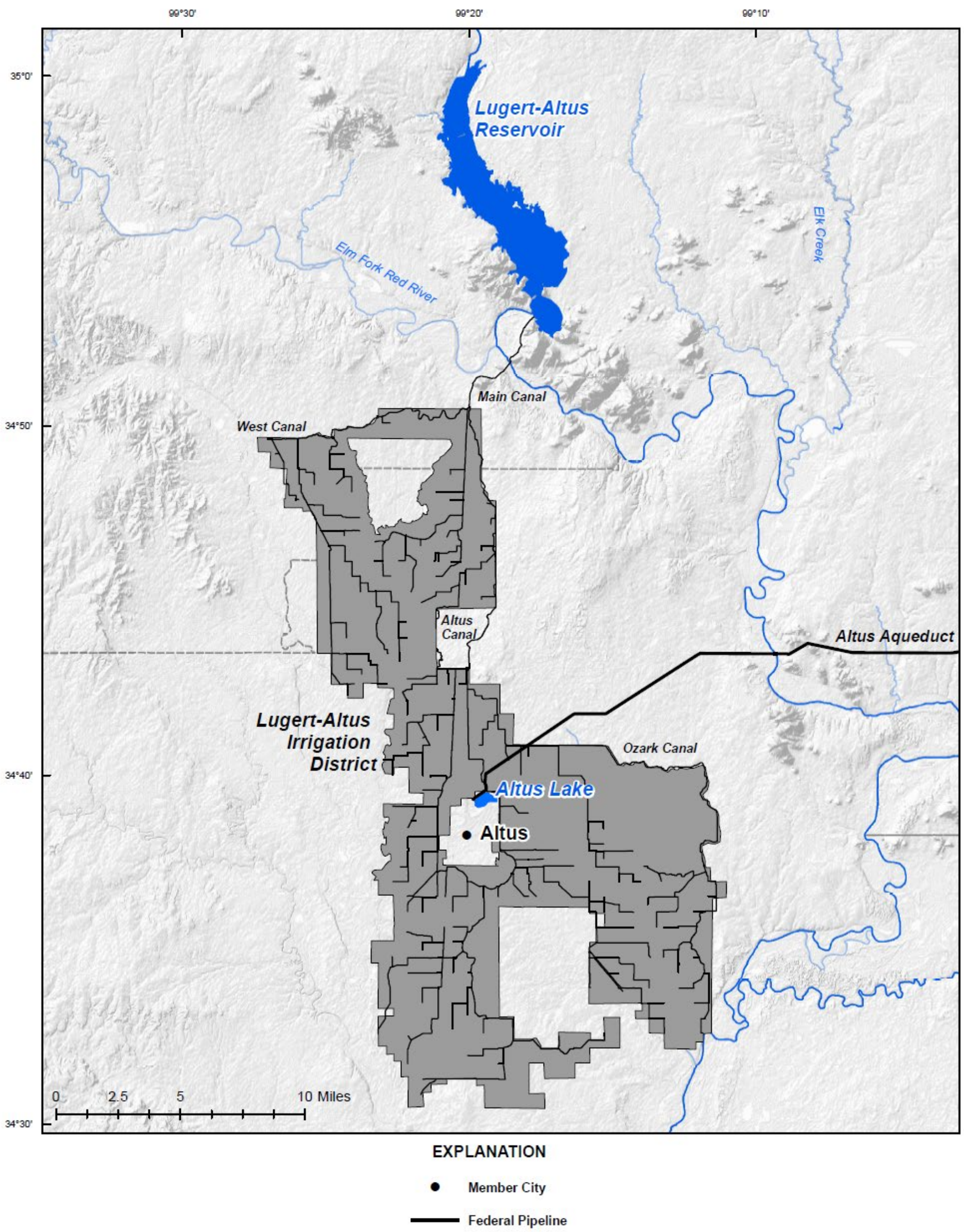

Figure 1-9. Canal system and features of the Lugert-Altus ID, W.C. Austin Project.

Figure 1-10. Canals within the Lugert-Altus ID, W.C. Austin Project.

Municipal Benefits and Features, W.C. Austin Project

Municipal 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[6]. 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)[7]. The city of Altus originally impounded the river in the 1920s and conveyed water to the city for municipal use, but large amounts of sedimentation rendered the impoundment inoperable over time. 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 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 which requires the Lugert-Altus ID to manage withdrawals such that Altus Lake's active conservation storage does not drop below 10,000 acre-feet (acre-ft) at the end of the irrigation season. 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.

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[6] Contract between the United States and the city of Altus for a Municipal Water Supply, Clauses 3 and 5 (May 2, 1941).
[7] OWRB set forth the city of Altus and the LAID water rights in OWRB Final Order No. 4 (July 14, 1964).

Recreation/Fish and Wildlife Benefits and Features

Lugert-Altus Reservoir is located within the scenic Wichita Mountains and is surrounded by approximately 11,000 acres of federally-owned land that attracts tourism and abundant wildlife. Quartz Mountain State Park, managed by the Oklahoma Tourism and Recreation Department (OTRD), is situated on the western side of Lugert-Altus Reservoir (Figure 1-11). The park provides opportunities for camping, swimming, boating, fishing, hiking, picnicking, etc. One of the prominent features within the park is the Quartz Mountain Resort Arts and Conference Center, which contains a lodge-style hotel, an Arts Institute, swimming beaches, cabins, camping, and numerous other amenities that support corporate retreats, conferences, workshops, and weddings (Figure 1-12).

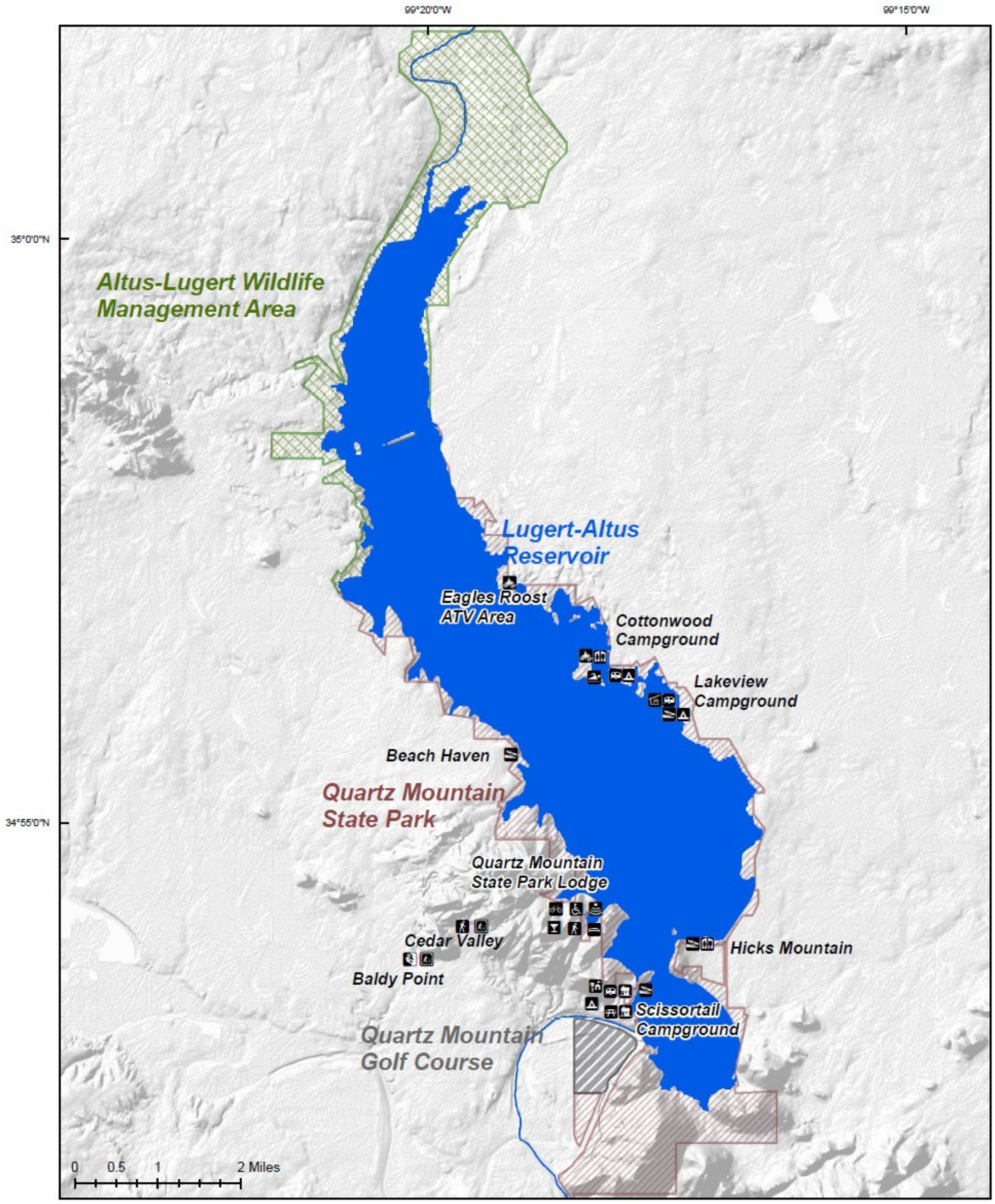

Figure 1-11. Prominent recreation and fish and wildlife features around Lugert-Altus Reservoir, W.C. Austin Project.

On the north end of Lugert-Altus Reservoir lies the Altus-Lugert WMA (Figure 1-13). The WMA is managed by the Oklahoma Department of Wildlife Conservation (ODWC) and is comprised of 3,600 acres of habitat that supports hunting and wildlife viewing. The WMA consists mainly of river bottom and slough areas with dense vegetation, cattail and other aquatic species. Bottomland areas are heavily wooded with cottonwood, American elm, and willow. A limited amount of mixed/tallgrass prairie interspersed with sandplum lies in the northeast portion of the area. Because the NFRR flows through the area, occasional high lake levels back water into the WMA and create areas of flooded timber, resulting in excellent wetland habitat for waterfowl. Common game includes bobcat, coyote, deer, rabbit, turkey, dove, and quail. The WMA supports diverse nongame species, including bald eagles during the winter.

Figure 1-12. Quartz Mountain Resort, Lugert-Altus Reservoir.

Figure 1-13. Altus-Lugert Wildlife Management Area courtesy from ODWC website: https://www.wildlifedepartment.com/wildlife-management-areas/altus-lugert.

These features, including visitation and benefits to the economy, are discussed more in the Economics Analysis provided in Chapter 6.6.

Tom Steed Reservoir, Mountain Park Project

The Mountain Park Project is a water supply project constructed by Reclamation in Jackson, Kiowa, and Tillman counties, Oklahoma. Mountain Park Dam, located six miles north of Snyder, regulates the natural flows of West Otter Creek and Glen Creek creating Tom Steed Reservoir (Figure 1-14). Water from the adjacent Elk Creek hydrologic basin is diverted into Tom Steed Reservoir using the Bretch Diversion Dam and Canal. Tom Steed Reservoir provides M&I water to the member cities of Altus, Snyder, and Frederick, as well as water to support environmental quality benefits at the Hackberry Flat WMA, through the Altus, Snyder, and Frederick aqueducts, respectively (Figure 1-14). Customers of these cities include more than two dozen public water providers and rural water systems, as well as Altus Air Force Base (AFB), a large Air Force training facility (Figure 1-15).

Congress provided construction authority for the Mountain Park Project 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 activities" to the authorized project purposes and allowed for reallocation of project costs to include environmental quality (EQ) activities.

Reclamation initiated construction of the Mountain Park Project in 1971. Mountain Park Dam was completed in 1975, and construction of the Altus Aqueduct and Pumping Plant were completed in 1976; the Bretch Diversion Dam and Canal were completed in 1977. The Frederick Pumping Plant and Aqueduct were completed in the early 1980s.

The Mountain Park Project is owned by the U.S. and administered by Reclamation. 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). Reclamation reimburses the MPMCD on an annual basis for the portion of O&M costs that are attributable to flood control, recreation, and fish and wildlife conservation benefits. The original repayment contract was signed in 1971; however, it was amended in 1996 to reflect the reallocation of project costs following the authorization of EQ benefits at the project.

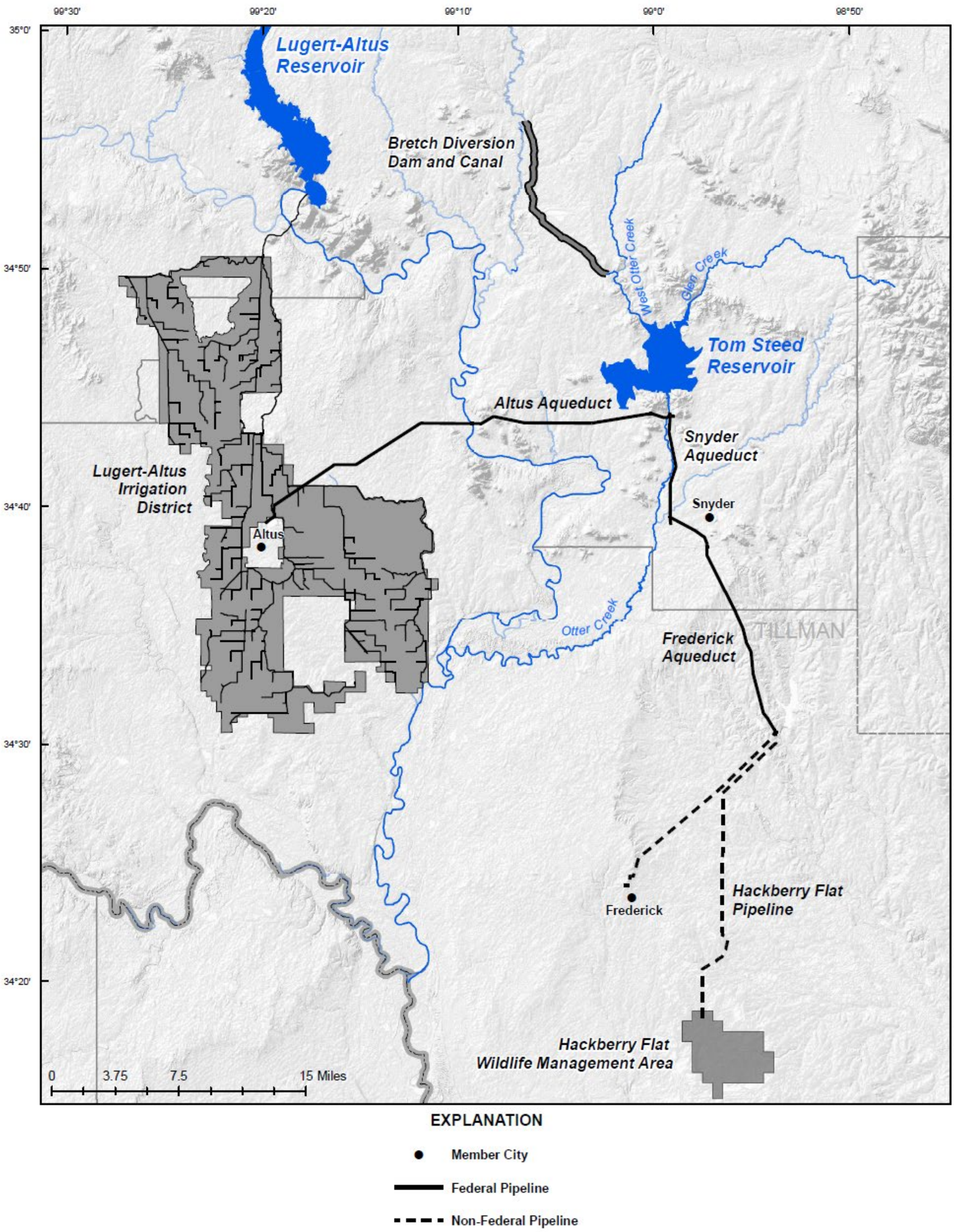

Figure 1-14. Features and member cities of the Mountain Park Project that receive M&I water, as well as the Hackberry Flat WMA which receives water for EQ benefits.

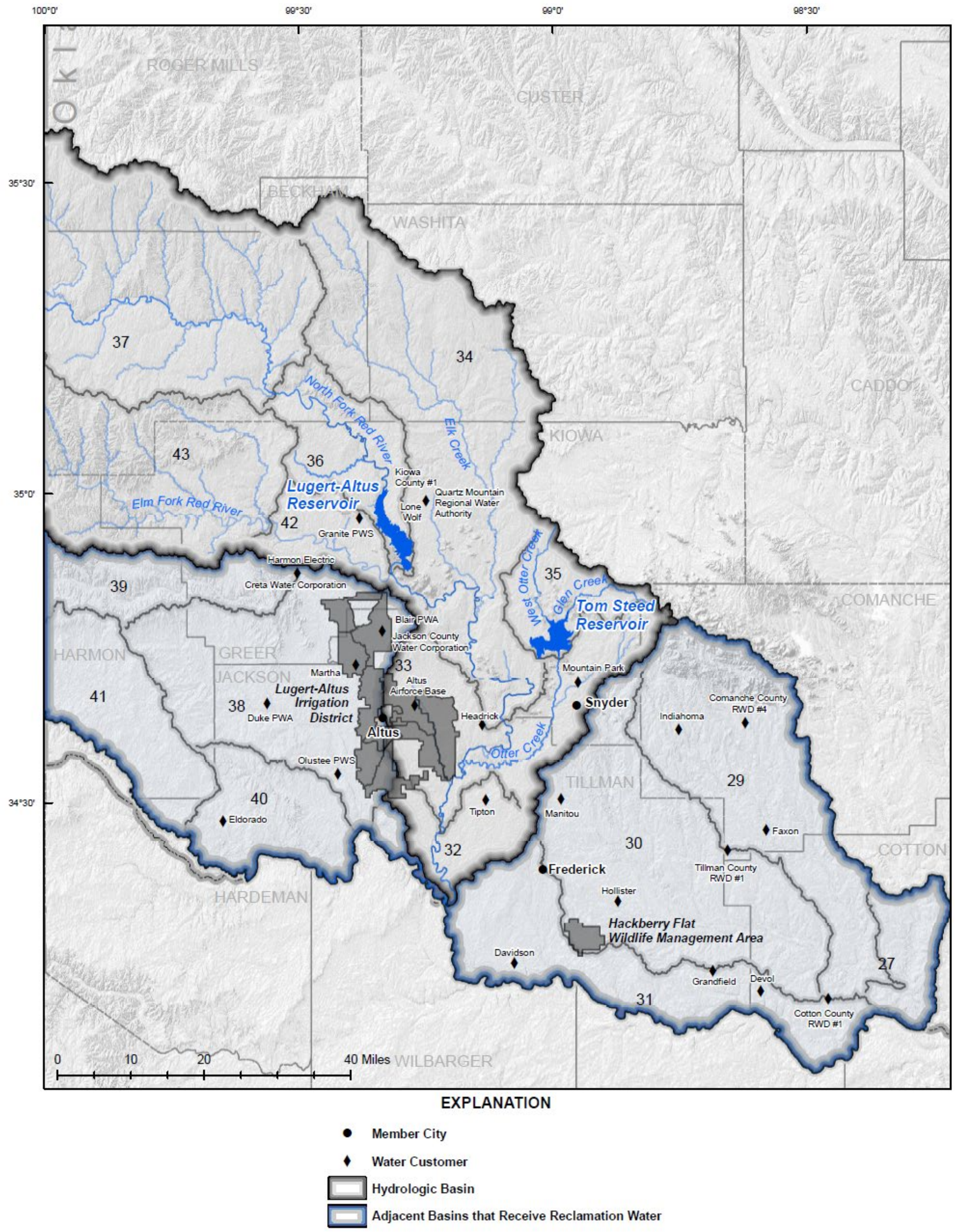

Figure 1-15. Member cities and customers as of 2018 that receive water from Tom Steed Reservoir, Mountain Park Project.

Mountain Park Dam

Mountain Park Dam is a double-curvature concrete arch dam flanked by concrete thrust blocks (Figure 1-16). The dam is 535 ft long with a maximum structural height of 133 ft. This dam and the rolled earth East and West Dike embankments, which extend 10,311 ft and 13,235 ft, respectively, form Tom Steed Reservoir. The concrete arch portion of Mountain Park Dam functions as an uncontrolled, overflow spillway. The crest is at the top of the exclusive flood control pool at elevation 1414.0 ft and is 320 ft long measured along the axis of the dam. Concrete piers and training walls at each end of the spillway direct floodwater into and over the crest. The spillway is designed for a maximum discharge of 38,300 cfs with the reservoir at elevation 1423.6 ft.

Figure 1-16. Mountain Park Dam.

The outlet works for Mountain Park Dam include three outlet pipes, a 42-inch-diameter, joint-use outlet pipe is provided to release water into the aqueduct system: an 84-inch-diameter flood outlet pipe, and a 15-inch-diameter river outlet pipe for floodwater and small streamflows.

Similar to Lugert-Altus Reservoir, Tom Steed Reservoir is divided into three operational pools: conservation pool, flood control pool, and surcharge pool. The conservation pool is the largest pool and is used to store water for M&I purposes. The flood control and surcharge pools are smaller and temporarily store water from large rainfall events to reduce downstream impacts from flooding. There are also two small, nonoperational pools referred to as the dead pool and inactive pool that are located below the conservation pool. The elevation and volume capacities of each individual pool are presented in Figure 1-17. The pool elevations are depicted through aerial imagery in Figure 1-18.

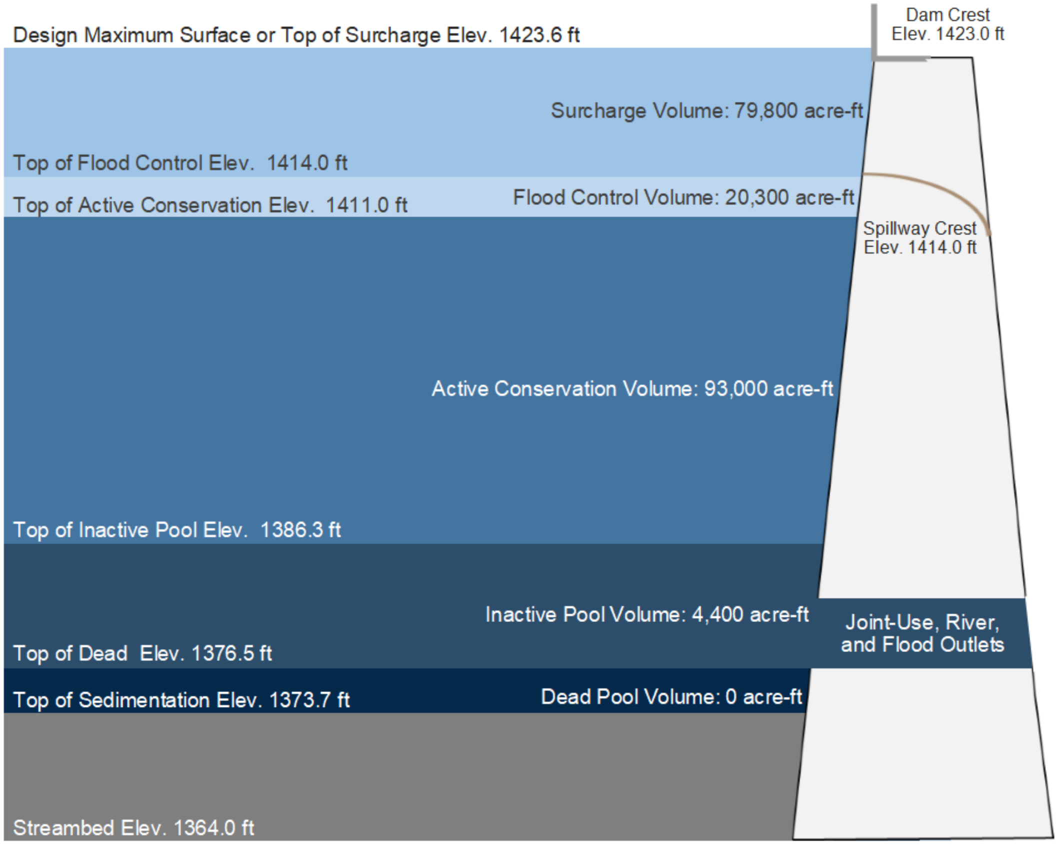

Figure 1-17. Conceptual figure of Mountain Park Dam and Tom Steed Reservoir's designated pool volumes and elevations based on the 2009 sediment survey. Note: although elevation designations are fixed, volumes will change over time based on changing sediment conditions.

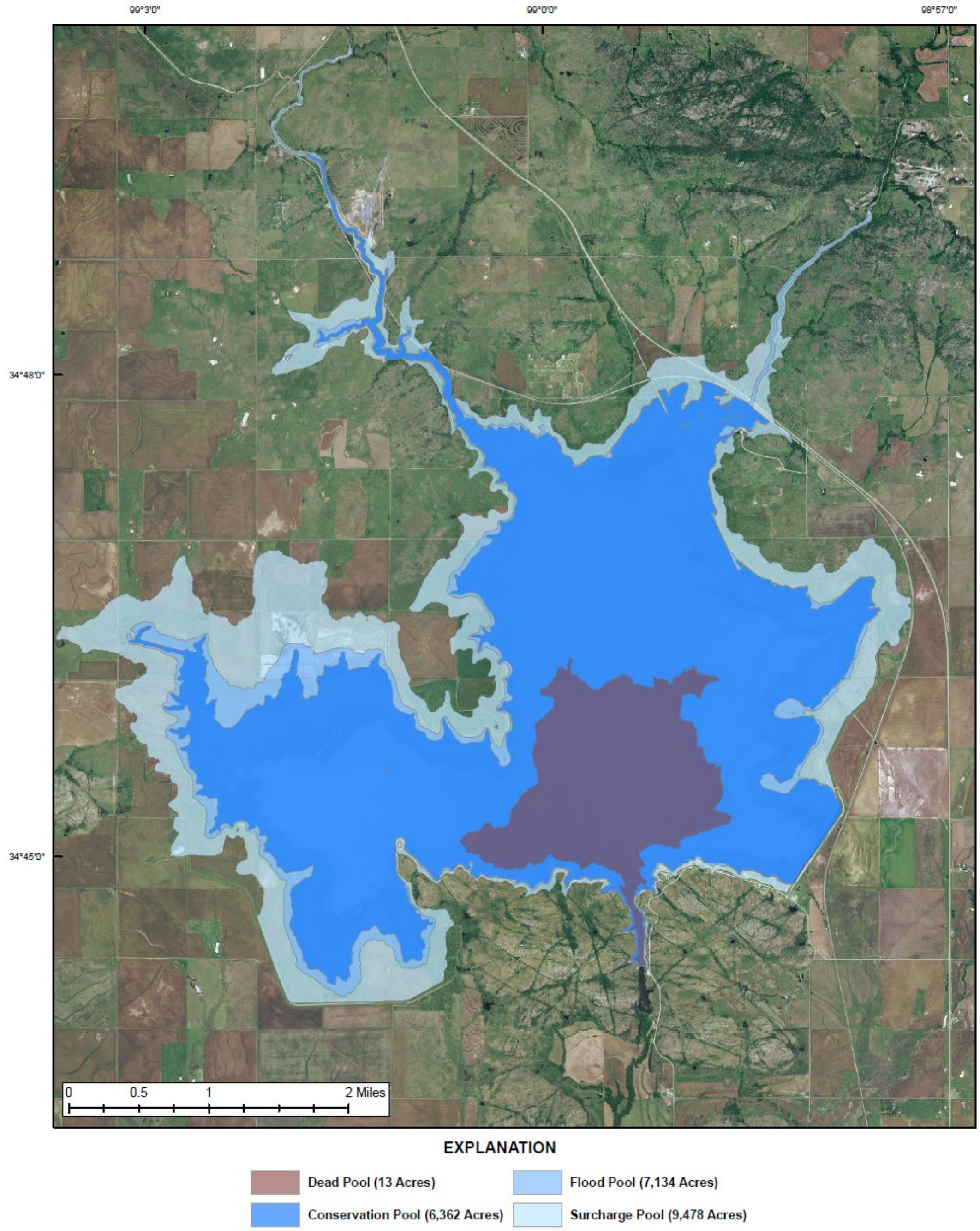

Figure 1-18. Surface acreage of the four designated pools within Tom Steed Reservoir, Mountain Park Project.

Bretch Diversion Dam and Canal

The Bretch Diversion Dam is located on Elk Creek in Kiowa County about 24 miles northeast of the city of Altus and about 15 miles northwest of Mountain Park Dam (Figure 1-14). The dam diverts flows from Elk Creek into Bretch Canal for conveyance into Tom Steed Reservoir through West Otter Creek. This concrete diversion structure has canal headworks and a concrete wing wall on the left abutment, stream control gates in the center section, and a rolled earthfill dike extending from the concrete structure across the flood plain 5,200 ft to the right abutment. The canal headworks contains an 18-foot-square radial gate for controlling flows into Bretch Canal, which is designed for a flow of 1,000 cfs. The stream control gates include two 27- by 21-foot spillway radial gates, one 10- by 21-foot sluiceway radial gate, and one 24-inch-diameter bypass gate. The rolled earthfill dike across the flood plain to the right abutment contains a low grass-covered section which provides an overflow spillway with a crest length of 3,620 ft. Figure 1-19 shows a photograph of the Bretch Diversion and Canal.

Figure 1-19. Bretch Diversion and Canal, Mountain Park Project.

The Bretch Diversion Canal begins at Bretch Diversion Dam and runs generally south and southeast to West Otter Creek (Figure 1-14). The concrete-lined canal is 9.5 miles long and has a capacity of 1,000 cubic feet per second.

Project Benefits, Mountain Park Project

The Mountain Park Project is authorized to store, regulate, and furnish water for municipal, domestic, and industrial purposes; conserving and developing fish and wildlife resources; provide outdoor recreation; and control floods. In addition to these original project purposes, the project provides environmental quality water benefits to 3,750 acres of wetland habitat.

M&I Benefits and Features

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 MPMCD's 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 1-20). The total population served is around 43,000 people (Basin-Wide Demands). An additional 2,352 acre-ft/yr allocated to Hackberry Flat WMA (discussed below) for environmental quality benefits.

Figure 1-20. Altus Aqueduct, Mountain Park Project.

Water for the city of Altus flows from a joint-use forebay tank that is half a mile downstream of the reservoir to the adjacent Altus Pumping Plant, where it is lifted and conveyed though a 20.6-mile concrete pipe to the city of Altus water treatment plant (Figure 1-14; Figure 1-20). The design capacity of the Altus Aqueduct is 24.3 cfs. Water to Snyder and Frederick flows via gravity from the joint-use forebay tank through a 5.5-mile pipe (9.8 cfs capacity) to the Snyder-Frederick Regulating Tank, where the capacity is reduced to 1.7 cfs before being conveyed to Snyder. The Frederick Aqueduct receives 8.1 cfs from the regulating tank at this point and conveys the flow another 12 miles to the Frederick pumping plant northeast of the city of Frederick.

Environmental Quality Benefits and Features

Figure 1-21. Hackberry Flat WMA, along with a photograph of a King Rail by John Kennington.

Environmental quality (EQ) benefits were added to the Mountain Park Project benefits through Public Law 103-434 (Mountain Park Project Act of 1994). In the 1980s, the city of Frederick recognized they would have difficulty servicing their future share of the Project repayment obligation. In addition, the city had never taken any Project water because their existing water supply, Lake Frederick, was meeting their needs. At the same time, the ODWC was developing and restoring Hackberry Flat, a remnant 3,750-acre playa basin located in southwestern Oklahoma (Figure 1-21). ODWC was looking for a source of water to enhance the historic wetland, which had been drained for farming in the early 1900s. At the time, it was the largest natural wetland in Oklahoma and an important staging area for migratory waterfowl and shorebirds. Based on these conditions, the MPMCD, Frederick, and ODWC worked to affect legislation which would allow for use of Project water at the Hackberry Flat WMA.

Pursuant to the legislation, Reclamation, the MPMCD, ODWC, and the city of Frederick developed an Environmental Quality Plan (EQ Plan) which was signed in April 1995. 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 their 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.

The ODWC installed a 15.9-mile aqueduct beginning near the terminus of Reclamation's Frederick Aqueduct and extending to a small storage reservoir at the Hackberry Flat WMA. Construction of the pipeline was completed in 1999, and MPMCD began delivering water to ODWC for use at Hackberry Flat WMA that same year. Today, the Hackberry Flat WMA encompasses 7,120 acres of upland and wetland habitat that support diverse species wildlife including shorebirds, waterfowl, and migrating federally-listed threatened and endangered species such as the Whooping Crane, Interior Least Tern, and Piping Plover. The Hackberry Flat Center offers various developmental programs and workshops that support wetland education and hunter education.

Recreation/Fish and Wildlife Benefits and Features

Tom Steed Reservoir is located within the scenic Wichita Mountains and is surrounded by approximately 12,000 acres of federally-owned land that attracts tourism and abundant wildlife. Great Plains State Park, managed by the OTRD, is situated on the southern and eastern shores of Tom Steed Reservoir (Figure 1-22). The park provides opportunities for camping, swimming, boating, fishing, hiking, picnicking, etc. On the western and northern shores is the Mountain Park WMA, which is managed by ODWC. The Mountain Park WMA is comprised of 5,400 acres of mixed grassland, scrub mesquite, and agricultural fields of winter wheat and milo. The area supports numerous upland game species, including deer, rabbit, bobcat, coyote, turkey, dove, and quail, as well as diverse nongame species, including migrating bald eagles during the winter. A 320-acre wetland unit is managed for waterfowl through agriculture plantings and native wetland plant enhancement. Trees are planted to provide wildlife cover and nesting habitat.

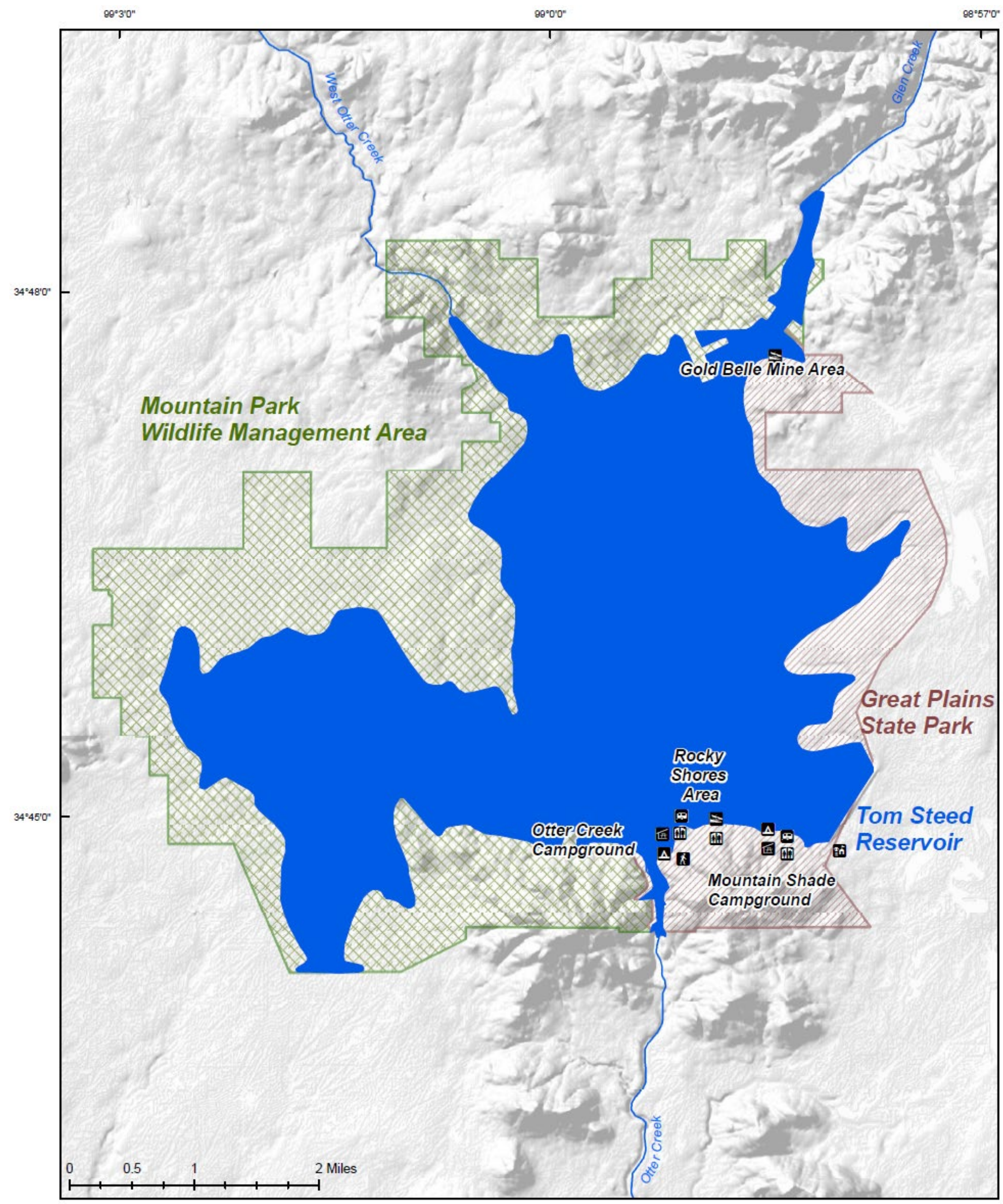

Figure 1-22. Prominent recreation and fish and wildlife features of the Mountain Park Project.

Chapter 2. Problems and Needs

Chapter 1 provided a brief history of how and why the URRBS was initiated, an overview of the study area and prominent groundwater and surface water resources, and an introduction on the features and benefits of Lugert-Altus and Tom Steed reservoirs. This chapter discusses the numerous challenges facing the study area. These challenges are primarily rooted in the overarching need to prepare and respond to drought. Lugert-Altus and Tom Steed reservoirs have demonstrated their vulnerabilities to drought-related reductions in rainfall and runoff, both of which are necessary to maintain reservoir storage. Losses from evaporation deplete reservoir storage even further. This reduced reservoir storage has been exacerbated by increases in upstream demands that reduce the flow in tributaries which contribute to reservoir storage. Furthermore, no two droughts are the same; each varies in intensity, duration, and severity. This causes vulnerabilities in reservoir supplies to manifest differently for every event.

The managers of Lugert-Altus and Tom Steed reservoirs are charged with trying to take into account these and other variables as they make decisions that could determine whether a city runs out of water – or whether water is available to irrigate high value crops, for tourism and recreation, or for important fish and wildlife habitat.

This is wrought with many challenges. It entails managing risk, both from a supply standpoint and from a demand standpoint – because understanding how much water is coming into a reservoir is equally as important as understanding how much is leaving the reservoir. In addition to "how much" water is involved, it entails understanding the "whys" – i.e., which of those risks are induced by "mother nature" (e.g., drought severity) versus those which are induced by humans (e.g., upstream demands). Yet other challenges, such as those involved with aging infrastructure, affect the overall integrity of the system. Indeed, addressing other risks would be meaningless if there is a lack the infrastructure to store and deliver water to customers. Out of a seemingly endless array of factors involved, it is important to recognize which risk factors can be controlled versus the risk factors that cannot be controlled, and then taking action accordingly.

But identifying, evaluating, and ultimately responding to the risks affecting Lugert-Altus and Tom Steed reservoirs requires a better understanding of where these risks lie within the legal and institutional framework of Oklahoma, and to what extent options exist to either improve flexibility within the existing framework and/or change the legal and institutional status quo. It also requires an understanding of the state of the science, the applicability and limitations of available data and tools, and the extent to which options exist to fill in the gaps and/or address these limitations. It also requires building upon previous and ongoing studies in southwest Oklahoma and beyond.

This chapter highlights the multi-layered challenges facing the study area by highlighting the impacts of the record-breaking 2010-2015 drought in southwest Oklahoma. The impacts and the lessons learned help bring into focus the real-world challenges facing Lugert-Altus and Tom Steed reservoirs. Next, this chapter details the ongoing efforts to overcome these challenges at all levels of government, as well as the opportunities to address remaining challenges. These opportunities provide the foundation for the multiple objectives of the URRBS.

2.1. 2010-2015: A New Drought of Record

Southwest Oklahoma experienced a catastrophic drought between 2010 and 2015 (Figure 2-1). Unlike droughts in the past, this drought had a quick onset; reduced rainfall and runoff in the fall of 2010 rapidly manifested into a historic hydrologic drought the following year as surface water supplies dwindled. Tom Steed Reservoir storage fell to 17 percent (Figure 2-2), a record low; M&I demands were curtailed by 40 percent to prevent Tom Steed Reservoir from going dry. Lugert-Altus Reservoir's storage fell even further than Tom Steed's, and at only nine percent full (Figure 2-2), also a record low, agricultural irrigation was shut off for the first time since reservoir construction in the 1940s. The tourism industry also was hit hard, as were fish and wildlife resources. An aerial photograph of Lugert-Altus Reservoir both before and during the drought illustrates the severity of the drought (Figure 2-3). The local and regional economy suffered losses in the hundreds of millions of dollars. As the crisis unfolded, officials turned to alternative supplies, but in some cases, those supplies either were nonexistent or had dried up. Although water uses were restricted, it was difficult to assess what level of curtailment could be considered reasonable or how reservoir supplies could be preserved because of the unknown severity and longevity of the drought. Unbeknownst at the time, they were experiencing a new, record-breaking drought of record (a.k.a., the 2010s Drought of Record).

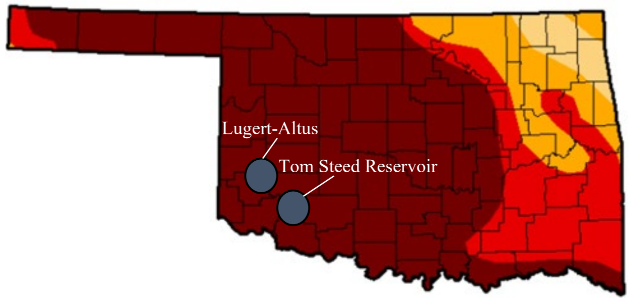

Figure 2-1. Oklahoma, U.S. Drought Monitor 2014.

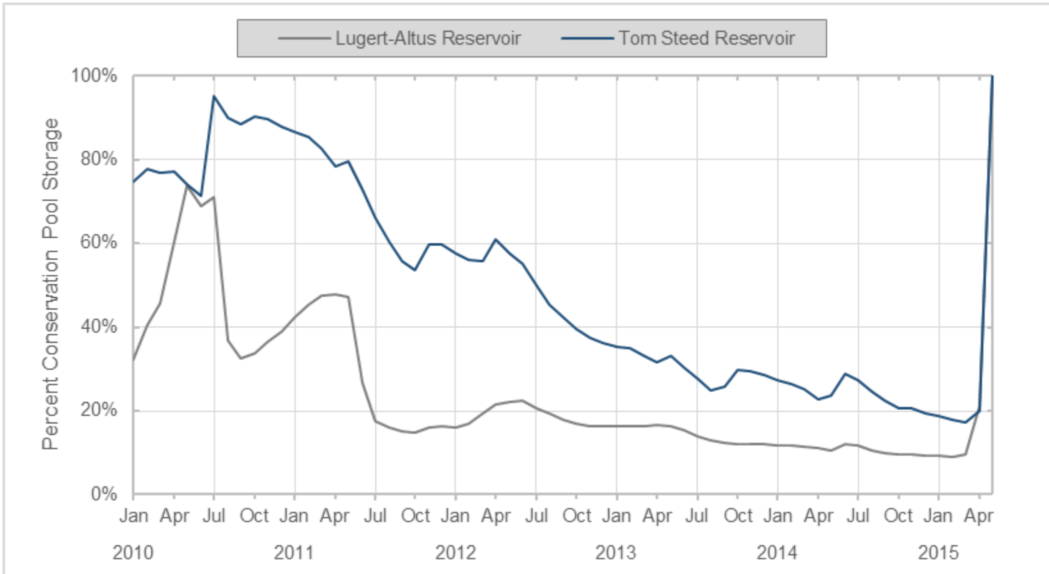

Figure 2-2. Percentage of conservation pool volume available from Lugert-Altus and Tom Steed reservoirs during the 2010s Drought of Record.

Figure 2-3. 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.

2.1.1. Agricultural Deliveries

In 2011, for the first time in over 60 years since Lugert-Altus Reservoir was constructed, irrigation deliveries were discontinued to the 300 landowners that depend on Lugert-Altus Reservoir. The irrigation shutoff extended for another three full years including 2014. In a typical year, the cotton production within the Lugert-Altus ID totals approximately 150,000 to 200,000 bales of cotton, roughly 75 percent of the total cotton production in Oklahoma[8]. The cessation of cotton production reduced local payrolls and expenditures, as well as the production and costs of agriculture-related items including fertilizer, fuel, equipment, repairs, etc. Cumulative impacts were subsequently felt by almost all local retailers in the area. Figure 2-4 and Figure 2-5 illustrate the reservoir and impacts on cotton during the drought.

Figure 2-4. Shane Osborne, assistant Extension specialist, farmer Clint Abernathy and Randy Boman, Extension program leader at the Oklahoma State University Southwest Research and Extension Center in Altus, look at a cotton plot on the station.

Figure 2-5. Lugert-Altus Reservoir during the 2010s Drought of Record.

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[8] Personal communication, Tom Buchanan Lugert-Altus ID Manager on Feb 22, 2018. Represents about 300,000 tons of cotton (one bale of cotton weighs about 500 pounds).

2.1.2. Municipal and Industrial Deliveries

Figure 2-6. Tom Steed Reservoir during the 2010s Drought of Record.

Not only did Tom Steed Reservoir drop to a record-breaking low during the drought (Figure 2-6), it did so at record-breaking speed. As conditions continued to get worse, Reclamation and the MPMCD coordinated to run "what if" scenarios to determine how Tom Steed Reservoir would respond under different demand scenarios. This prompted officials to institute across-the-board water use restrictions on the 43,000 people served by the 29 public and private water providers that depend on Tom Steed Reservoir (Figure 2-7). While Altus and Frederick curtailed demands by 40 percent, Snyder's demands were reduced by almost 60 percent[9]. This included curtailments by the Altus AFB, the primary water recipient from the city of Altus and employer of 60 percent of Altus' workforce (Carollo et al., 2014). The AFB is home to the prominent 97th Air Mobility Wing which trains airlift and aerial refueling crews. The base currently supports 7,100 people, including military, cadets, civilians, and retirees. The Altus AFB contributes over $361 million annually to the local economy[10].

An evaluation of reservoir storage under observed conservation measures versus without conservation measures illustrates how the proactive conservation measures helped sustain the reservoir through the drought (Figure 2-8). In fact, the measures improved storage by about 10 percent, likely resulting in about a 12-month extension of reservoir supplies had drought conditions continued.

[9] Additional details of existing surface water demands are described in Chapter 5.2.2.
[10] https://www.altus.af.mil/Portals/46/Economic%20Impact%20Statement%202018.pdf.

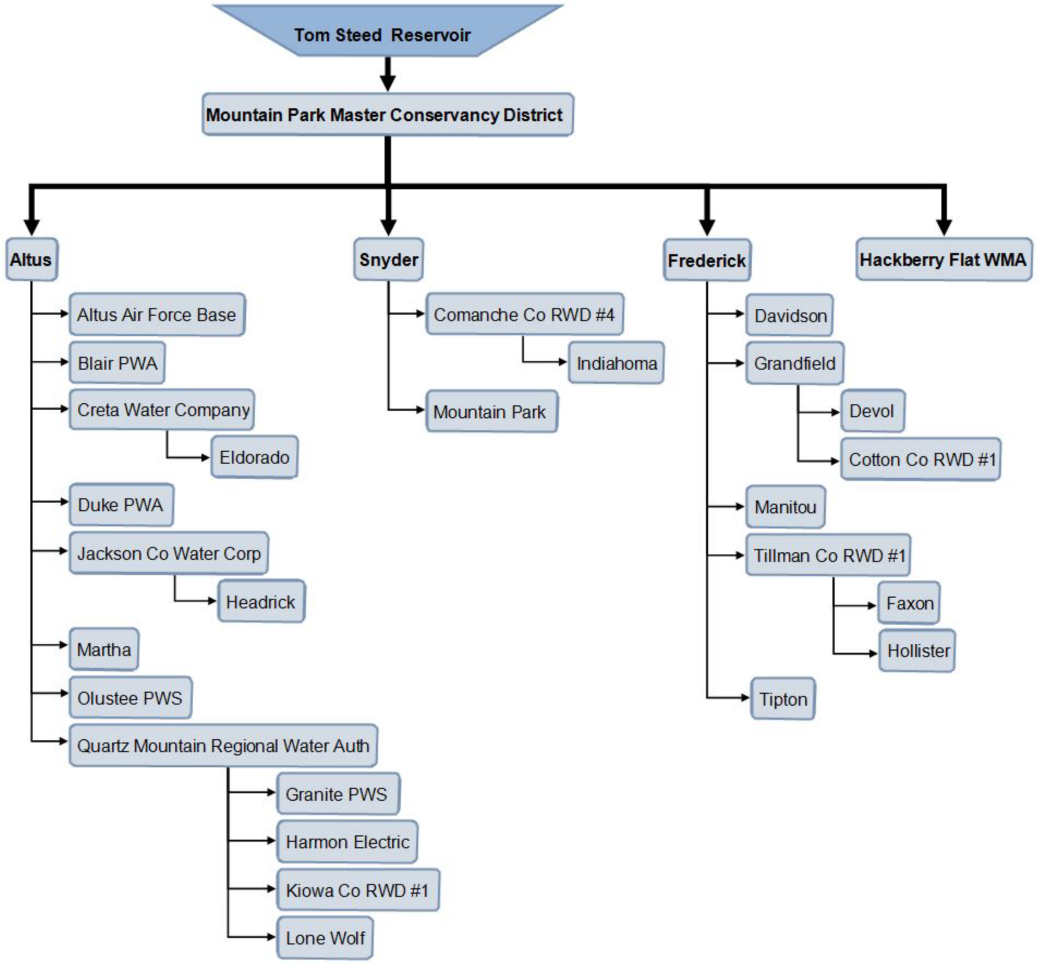

Figure 2-7. M&I customers that receive water from Altus, Snyder, and Frederick, the three member cities which make up the MPMCD. Hackberry Flat WMA also receives water for EQ purposes.

At the same time cities were struggling with water supplies, water quality conditions worsened as levels of trihalomethanes (THMs) in the city of Altus' drinking water supplies became more elevated. Regulated by the Environmental Protection Agency, THMs are potentially harmful disinfection by-products that occur when chlorine and other disinfectants that are used to control microbial contaminants react with naturally occurring organic and inorganic matter. The THM issue has since been resolved by city officials after rehabilitating their water treatment plant and developing additional groundwater supplies that can be used for blending as needed.

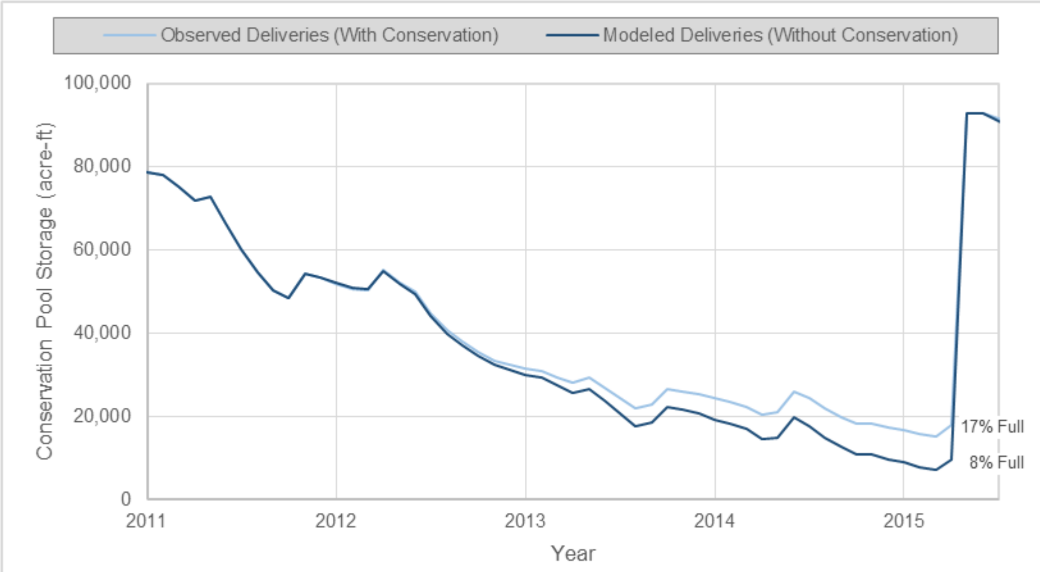

Figure 2-8. Tom Steed Reservoir storage under two demand scenarios, one without conservation; one with conservation.

2.1.3. Recreation/Fish and Wildlife Resources

The 2010s Drought of Record also had severe impacts on tourism and recreation. Figure 2-9 shows an exposed board walk over Lugert-Altus Reservoir. The board walk is a popular destination for visitors of the Quartz Mountain Resort Arts and Conference Center within Quartz Mountain State Park. Many of the reservoirs' docks also were exposed, severely restricting access to boating, fishing, and recreation sports (Figure 2-10). Around this time, the entire fishery at Lugert-Altus Reservoir, an estimated 350,000 fish[11], were killed by toxic Golden Algae, which had bloomed after the reservoir's low storage volume increased the concentration of salts in the reservoir. Furthermore, deliveries from Tom Steed Reservoir to Hackberry Flat WMA were discontinued. Combined with little to no rainfall, the 7,120 acre wetland complex went significantly dry. In addition to the detrimental impacts on nongame species, waterfowl abandoned the wetland as a migratory stopover location, which subsequently reduced hunting opportunities.

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

Figure 2-9. 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 ODWC).

Figure 2-10. A boat ramp and courtesy dock at Tom Steed Reservoir during the 2010s; compliments of State Impact, NPR, Logan Layden Feb 24, 2015.

2.1.4. Lessons Learned and Future Challenges

Due to record rainfall in the late summer of 2015, the drought in Oklahoma ended as quickly and intensely as it had begun. With it came a transformation of lessons learned into a renewed interest by federal, state, and local officials to make sure they were better prepared for the next drought. Local stakeholders have since approved a regional water action plan and began leveraging partnerships and investing millions of dollars on measures to improve water-use efficiency, rehabilitate existing infrastructure, and on the development of new water supplies (discussed more below). Although progress has been made, more opportunities lie ahead, particularly regarding Lugert-Altus and Tom Steed reservoirs. In so far as these reservoirs are and continue to be the cornerstone of the region's water supply portfolio, the drought resilience of Lugert-Altus and Tom Steed reservoirs continues to be an important issue that needs to be addressed.

To address this need, a better understanding is needed of: (1) the factors and associated risks that affect the supplies of Lugert-Altus and Tom Steed reservoirs; (2) which of those factors can be controlled or influenced; and (3) the path by which to mitigate risks and improve water supply reliability. In the next sections, five key challenge areas are discussed, along with the state of the science of strategies to the challenges in each of these areas, and opportunities for additional study.

2.2. Reservoir Supply Challenges

The rapid decline of reservoir levels during the 2010s Drought of Record prompted many questions from local officials about the vulnerabilities of Lugert-Altus and Tom Steed reservoirs. Chief among them was trying to understand how to best stretch available supplies through demand management, delivery efficiency improvements, and improved operations. But at the same time, there was great concern over what caused such a rapid decline of inflows into the reservoirs. It was clear that hot and dry climate conditions (i.e., "Mother Nature") were a driving factor; after all, anytime rainfall and run-off are significantly reduced, inflows into a reservoir are reduced; furthermore, once inflows are stored, they are subjected to losses from heat-induced evaporation. Sedimentation is yet another issue that slowly reduces reservoir storage capacity over time.

Human-induced factors come into play as well. Many users of Lugert-Altus and Tom Steed Reservoir questioned the extent to which reservoir storage was being further diminished by water withdrawals occurring upstream from tributaries that contribute inflow to the reservoirs. This included surface water diversions, as well as the pumping of groundwater stored in aquifers that connect to streams which contribute inflows to Lugert-Altus and Tom Steed reservoirs. It was understood at the time that for upstream agricultural demands in particular, a reduction in rainfall meant that more pressure was being placed on groundwater to meet irrigation demands. The question was, how much were reservoir inflows affected by groundwater pumping? And what was the additive effect of upstream surface water diversions? In the end, stakeholders were interested in understanding the role that upstream water users were playing in causing Lugert-Altus and Tom Steed reservoirs to drop to the lowest storage ever recorded. One of the key challenges was quantifying the impacts on reservoir supplies.

It was recognized that quantifying impacts requires the development of one or more mathematical models, a subject that is discussed in detail below in the section "Challenges with Available Data and Models". Here however, this subject is briefly touched upon in the following topics. These topics must be addressed in a model for them to have meaning from a management standpoint. Reclamation's OTAO currently uses what is called its "Reclamation Reservoir Yield (RRY) Model" to perform calculations on storage and water supply availability (i.e., yield) of its reservoirs. The RRY Model is comprised of an excel-based mass balance equation that performs an accounting of inputs and outputs under a given set of assumptions, over a given period of time. The RRY Model does not directly quantify upstream losses, attribute causes of gains or losses in the stream, or otherwise distribute or quantify impacts in time and space within the watershed. This type of a model, often called a "network stream model", did not exist for the NFRR Basin at the time this URRBS was initiated, but it was recognized that such a model was needed in order to address the complex water management challenges on a watershed scale. Development of a network stream model was a core component of the URRBS.

With this in mind, the discussion turns to some of the key variables that drive calculations made using the RRY Model. A more in-depth discussion of the RRY Model itself is provided in the section below on "Challenges with Available Data and Models".

2.2.1. Climate and Hydrology

To understand the factors driving reservoir supply, one must first begin with an understanding of the natural conditions under which the reservoir resides. The southern Great Plains region, including southwest Oklahoma, is particularly vulnerable to drought because, aside from climatic patterns, many areas lack the topography and climate needed to generate snowmelt that can feed streams that flow into reservoirs where it is stored for beneficial use. Rather, the reservoirs depend almost entirely on rainfall, as well as runoff and base flows generated by connecting aquifers. Once water is in storage, temperature becomes a significant factor because it contributes to evaporation which reduces the amount of water in storage. Thus, the combined impact of temperature and precipitation provides a good indication in southwest Oklahoma not only of the severity of a drought, but how that impacts reservoir supplies. One method of measuring the combined effect of these variables on the relative dryness of an area is through the Palmer Drought Severity Index (PDSI). The PDSI uses temperature and precipitation data to estimate relative dryness on a ten-point scale {-10 (dry) to +10 (wet)}, and it has been reasonably successful at quantifying long-term drought[12]. In Figure 2-11 below, measurements of temperature, precipitation, and PDSI show that west-central Oklahoma has experienced four major droughts on record: mid-1930s, mid-1950s, late-1960s/early-1970s, and 2010-2015.

Figure 2-11. Annual and 5-year running averages for temperature, precipitation, and PDSI (Southwest Oklahoma Climate Division 07, http://charts.srcc.lsu.edu/trends, (Vose et al., 2014)), 1895-2018. Orange boxes illustrate major droughts on record.

[12] National Center for Atmospheric Research.

The U.S. Geological Survey (USGS) recently performed a comparison of a portion of the 2010s drought with previous drought periods which is useful for identifying the extent and severity of the 2010s Drought of Record into context (Shivers and Andrews, 2013). The drought of the 1930s, known as the "Dust Bowl" in the Great Plains, was particularly severe in western Oklahoma, which led to development of nationwide soil conservation measures. Despite the widely known effects of the "Dust Bowl" of the 1930s, the lesser-known 1950s drought was actually more widespread and severe. And while the late 1960s/early 1970s drought lasted even longer than the 1950s drought, it was not as severe. The 2010s Drought of Record lasted only a relatively short period of time, but it was more severe than any of the three previously recorded droughts.

If one compares the observed PDSI presented in Figure 2-12 alongside PDSI calculated over a 600-yr period using tree ring data, it becomes evident that the droughts observed over the relatively short 90-yr period in southwest Oklahoma are far less severe than the so called "paleo droughts" that have occurred throughout the last millennium. In fact, Reclamation recently developed a methodology that uses tree ring data to calculate the impacts of potential future "paleo droughts" on reservoir yield (Reclamation, 2018a). Although it is beyond the scope of this URRBS to apply the methodology to Lugert-Altus and Tom Steed reservoirs, this analysis will likely be performed in the future.

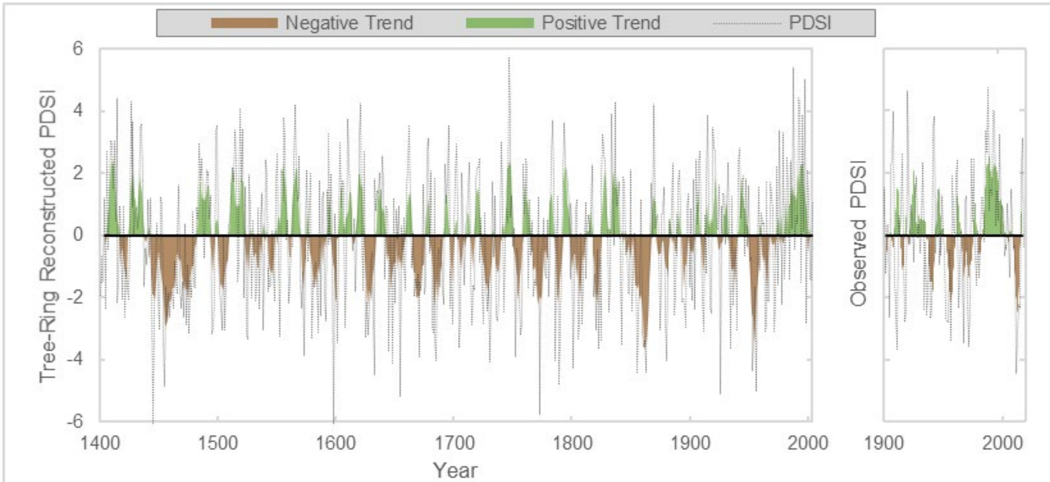

Figure 2-12. Reconstructed (left side) versus observed[13] (right side) PDSI data over a 600-yr period for the Southwest Oklahoma Climate Division 7 (Cook et al., 2004), which includes a majority of the URRBS study area.

In light of what is understood about tree ring data, a key area of interest is to better understand the current data and tools that can provide better information on risk and help make predictions about future droughts in southwest Oklahoma.

Over the past decade, there has been an increased interest in making projections of future climate and subsequent impacts on water supplies. Projections of future climate are developed using the scientific communities' best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections are based upon numerous assumptions about initial conditions, future greenhouse gases in the atmosphere, and other factors such as solar radiation and volcanic activity, to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary.

Observed climatic data and GCM simulations show warming trends over recent decades. However, the degree to which the magnitude of GCM simulated warming agrees with historic observations varies based on the data, methods, and time periods used for making such comparisons

[13] Observed PDSI in this graphic does not capture the entire 2010s Drought of Record.

(Santer et al., 2017ab, Lin et al., 2016, Richardson et al., 2016). The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations, and how measurement errors, internal variability, and other factors can be improved to enhance future performance.

Further, it is important to recognize that these climate prediction models perform better at global rather than regional or watershed level scales. Accordingly, techniques must be employed to localize or "downscale" GCM output for applications to local basins such as the Upper Red River Basin in southwest Oklahoma. Standard practice has been to use the downscaled climate projections as inputs into hydrologic models which produce projected streamflows that can then be used to predict future impacts on reservoir yield (for instance). Both steps contain many uncertainties.

Ultimately, future conditions at any particular time or place cannot be known with certainty. Likewise, it is important to recognize that the risks and impacts are the result of collective changes at a given location. While warming and increased carbon dioxide may increase plant water use efficiency, it may reduce water availability. But this does not mean that efforts should be abandoned to address these challenges. Rather, the complex interactions underscore the importance of using a planning approach that identifies future risks to water resources systems based on a range of plausible future conditions and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

2.2.2. Sedimentation

Rivers and streams carry sediments that accumulate within the reservoirs. In fact, a portion of the reservoir, referred to as the "dead storage zone" or "dead pool", is reserved specifically for the purpose of capturing accumulated sediment. The dead pool contains water that cannot be drained by gravity through the dam's outlet works, which means that it is only accessible with a pump. Above the dead pool, sometimes an “inactive pool” or “minimum pool” may be designated. The inactive pool may be allocated specifically for fish and wildlife purposes or hydraulic head of hydropower generation purposes, but otherwise is not part of the multi-purpose benefits. Above the dead pool (and inactive pool, if applicable) lies the much larger “active conservation pool”. This pool stores water for multi-purpose benefits including agricultural irrigation, M&I, recreation, and fish and wildlife propagation. The remaining storage capacity above the active conservation pool is reserved for “flood control” and “surcharge” purposes, which are used to regulate, control, and store flood waters either below or above the dam spillway, respectively. These pool designations for Lugert-Altus and Tom Steed reservoirs were illustrated earlier in Figure 1-7 and Figure 1-17, respectively.

Perhaps the greatest challenge is that sediment accumulation in a reservoir displaces and reduces the amount of water that is available to achieve project benefits within the active conservation pool. Consequently, there is less water available for M&I or agricultural purposes, as well as recreation and fish and wildlife. Sediment also lessens the volume of water that could be retained during flood events.

As such, understanding the amount and rate of sedimentation into a reservoir is very important, not only for planning the long-term viability of reservoir supplies, but also because of the real-world impacts it can have in the near-term. For example, it is known that the city of Altus’ municipal dam on the NFRR was quickly diminished by sediment accumulation. In fact, it was estimated that the storage capacity of Altus Dam was reduced from approximately 13,100 acre-ft in 1927 to 4,930 acre-ft in 1937, or at a rate of approximately 911 acre-ft/yr during this nine-yr period (Reclamation, 1937). Figure 2-13 depicts accumulated sediment behind Altus Dam in 1942. By

Figure 2-13. View of accumulated sediment in Lake Altus Dam prior to the construction of the W.C. Austin Project, 1942.

1944, only about 700 acre-ft of storage capacity remained prior to abandonment of Altus Dam (Altus Chamber of Commerce, 1947). The importance of sedimentation in water resource planning related to Lugert-Altus and Tom Steed reservoirs is discussed below. It is important to keep in mind, however, that sedimentation calculations should be taken with caution because they are difficult to assess and complicated by numerous factors.

Lugert-Altus Reservoir

Since its construction in 1946, Lugert-Altus Reservoir has continued to capture inflowing sediments from the NFRR. In 1947, after the original contour survey was conducted and W.C. Austin Project was constructed, Reclamation calculated that there was about 157,000 acre-ft of total storage capacity below the top of the conservation pool at elevation 1,559.0 ft. Of this, 152,000 acre-ft was designated as active conservation storage, with the remaining 5,000 acre-ft reserved as dead storage. Contour and range-line surveys of Lugert-Altus Reservoir have since been conducted in 1948, 1953, 1967, and in 2007. According to the most recent sediment survey completed in 2007, the total storage capacity below elevation 1559.0 ft had been reduced by about 28,000 acre-ft in capacity (18 percent of the storage capacity). Although approximately 4,400 acre-ft of sediment had accumulated in the dead pool[14], the majority of sediment (i.e., 23,600 acre-ft) appeared to have accumulated within the active conservation pool[15]. This has effectively reduced Lugert-Altus Reservoir's active conservation pool from 152,000 acre-ft to 128,000 acre-ft as of the year 2007. The annual loss equated to an average sedimentation rate of 417 acre-ft/yr between 1940 and 2007 (Ferrari, 2008).

The sedimentation rate calculated by Ferrari (2008) was notably lower than previous rates calculated by Reclamation[16]. This may be attributable to

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[14] Recall that the dead pool capacity of Lugert-Altus Reservoir is 5,000 acre-ft. As of 2007, the dead pool is almost full.
[15] Sediment does not distribute evenly in a reservoir.
[16] Ferrari (2008) noted previous sedimentation rates based on prior sedimentation surveys. The rate also is much less than the rate cited by Reclamation in its 2005 appraisal assessment of supply augmentation alternatives at the W.C. Austin Project (Reclamation, 2005).

differing approaches in surveying and analyzing sediment and/or from changes over time in watershed management, land use, hydrology, etc. Regardless, the current projected sedimentation rate of 417 acre-ft/yr should be used with caution, whether it is for the purposes of assessing current supply availability or for planning long-term reliability of Lugert-Altus Reservoir. Figure 2-14 illustrates the impacts of sediment accumulation on the active conservation pool volume of Lugert-Altus Reservoir. As of the year 2018, the active conservation pool volume of Lugert-Altus Reservoir was projected to have been reduced to 124,000 acre-ft. Looking forward, the active pool would be reduced even further to 107,000 acre-ft by the year 2060. Figure 2-15 also illustrates how this may affect agricultural and M&I benefits of Lugert-Altus Reservoir. Assuming a sedimentation rate of 417 acre-ft/yr, the active storage capacity of the conservation pool would be insufficient to deliver the combined water rights held by the Lugert-Altus ID and city of Altus by the year 2045[17]. By the year 2060, the active conservation pool capacity would be reduced to a point where maximum allowable irrigation deliveries would fall from 85,630 acre-ft/yr to 77,550 acre-ft/yr[18].

[17] The storage volume needed to deliver both water rights was assumed to by 115,000 acre-ft; the details of this assumption are discussed below in Chapter 2.3.1.
[18] This would occur only in dry years when inflow is exceeded by evaporative losses.

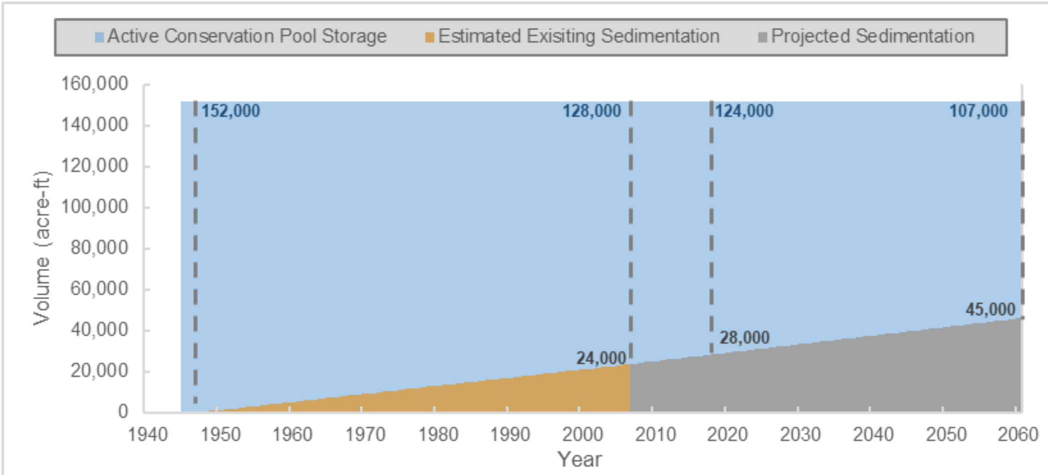

Figure 2-14. Impact of estimated existing sedimentation and projected sedimentation rates on the conservation pool storage volume of Lugert-Altus Reservoir. Assumes a sedimentation rate of 417 acre-ft/yr based on Ferrari (2008).

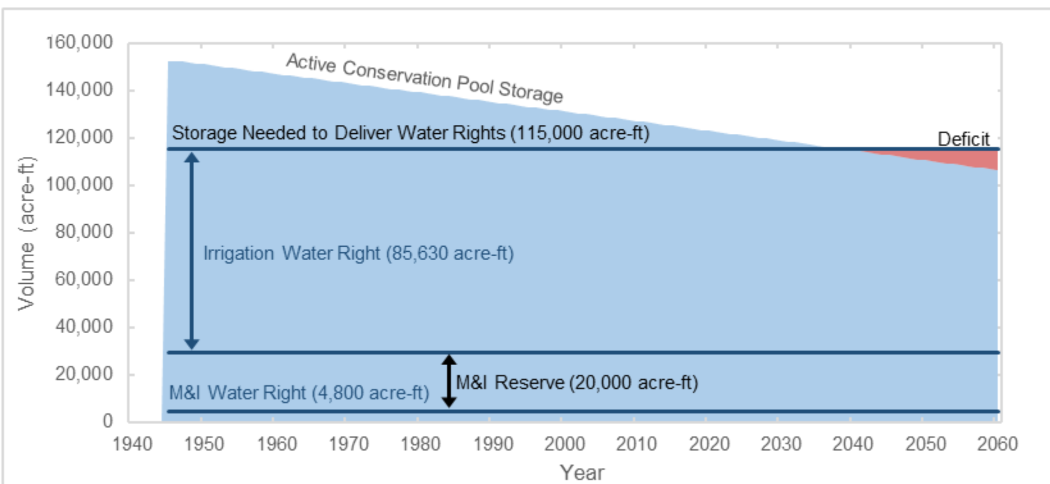

Figure 2-15. Comparison of existing and projected conservation pool storage of Lugert-Altus Reservoir relative to the volume of storage needed to deliver the water rights held by the Lugert-Altus ID and the city of Altus. A deficit is projected to occur in 2040, but only during dry years when inflow is exceeded by evaporative losses. Assumes a sedimentation rate of 417 acre-ft/yr based on Ferrari (2008).

Tom Steed Reservoir

Like Lugert-Altus Reservoir, Tom Steed Reservoir also has continued to capture inflowing sediments since its construction in 1975. Upon its final design, the original storage capacity of Tom Steed Reservoir below the top of conservation pool at elevation 1,411.0 ft was estimated to be 96,200 acre-ft. Of this, 88,400 acre-ft was designated as active conservation storage, with the remaining 5,000 acre-ft and 2,800 acre-ft reserved as inactive and dead storage, respectively. At the time, it was estimated that Elk Creek and the West Otter-Glen Creek watersheds would cumulatively contribute an average sedimentation rate of 165 acre-ft/yr. Applying this rate over a 50-yr planning horizon[19], Tom Steed Reservoir's projected active conservation pool was estimated to be 87,400 acre-ft in the year 2025, effectively yielding a firm supply of 16,100 acre-ft/yr during a repeat of the 1960s drought of record.

A new sediment survey was conducted by Reclamation in 2009, but investigators were unable to compute the volume of conservation pool lost since 1975 or a corresponding sedimentation rate (Ferrari, 2010). As such, the original sedimentation rate of 165 acre-ft/yr has continued to be the accepted rate that supports firm yield calculations on Tom Steed Reservoir.

Following the new drought of record between 2010 and 2015, Reclamation updated Tom Steed Reservoir's firm yield estimate and found that the firm yield had effectively been reduced from 16,100 acre-ft/yr to 14,400 acre-ft/yr[20]. If one applies an 85-yr sedimentation rate and projects forward even further to the year 2060, the active conservation storage capacity of Tom Steed Reservoir would be reduced further to about 87,000 acre-ft, which would effectively yield a firm supply of 13,400 acre-ft/yr during a repeat of the 2010s Drought of Record.

Another complicating factor pertaining to Tom Steed Reservoir discussed later in this study relates to operation of the Bretch Diversion Dam and Canal

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[19] Employing a 50-yr planning horizon was (and still is) common for firm yield calculations.

[20] The updated firm yield estimate applied the same assumptions as the original firm yield estimate, namely a 165 acre-ft/yr sedimentation rate applied across a 50-yr planning horizon from 1975 to 2025.

system. Up until recently, this system had not been optimized to maximize diversions from Elk Creek into Tom Steed Reservoir[21]. Because the majority of sediment would be expected to emanate from Elk Creek, it is reasonable to assume that sediment accumulation has been historically lower than it otherwise would have been under optimized system operations – again making the current firm yield estimates relatively conservative.

[21] Operation of the Bretch Diversion and Canal system are discussed in more detail under Chapter 2.4.2.

2.2.3. The Reduction of Stream Flow by Human Development

Another important factor affecting the supply of Lugert-Altus and Tom Steed reservoirs is the withdrawal of streamflow caused by human development. Upstream withdrawals directly reduce inflow into the reservoirs, while downstream withdrawals can indirectly affect reservoir supply through downstream discharge requirements, if applicable, from the dam. Withdrawals may come from surface water diversions and/or come from groundwater pumping in aquifers that have a hydrologic connection with surface water. Some withdrawals are permitted, while other withdrawals for domestic and household uses do not require a permit.

Prior to the 2010s Drought of Record, southwest Oklahoma experienced almost 30 years of above-average rainfall (Figure 2-11). During this wet period, populations increased, and with it came increasing demands for water. The OWRB issued many groundwater and surface water permits during this time. While these growing demands were met by an abundance of water supplies, the situation changed upon the onset of the drought.

Figure 2-16 illustrates permitted groundwater and surface water use, and Figure 2-17 illustrates non-permitted (groundwater)[22] domestic use within the Lugert-Altus and Tom Steed Reservoir hydrologic basins[23].

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[22] Source: OWRB's well drilling program (https://www.owrb.ok.gov/welldrilling/index.php).

[23] Accounting for domestic surface water use is more difficult than domestic groundwater. Farm ponds must be registered in OWRB's dam safety program (http://www.owrb.ok.gov/damsafety/index.php), some of these are permitted while others are not.

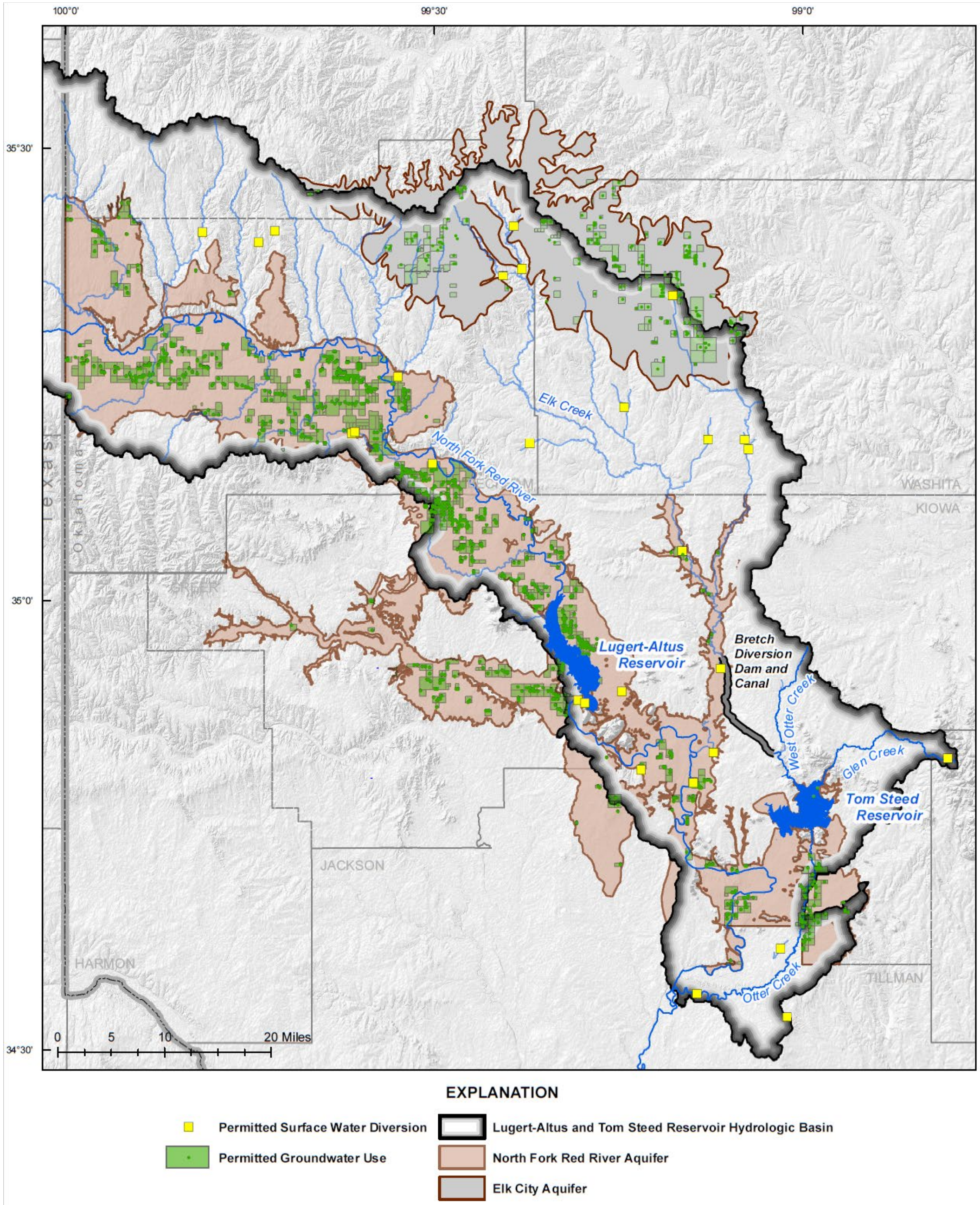

Figure 2-16. Distribution of permitted surface water diversions within the Lugert-Altus and Tom Steed hydrologic basins, as well as permitted groundwater use within the NFRR and Elk City aquifers.

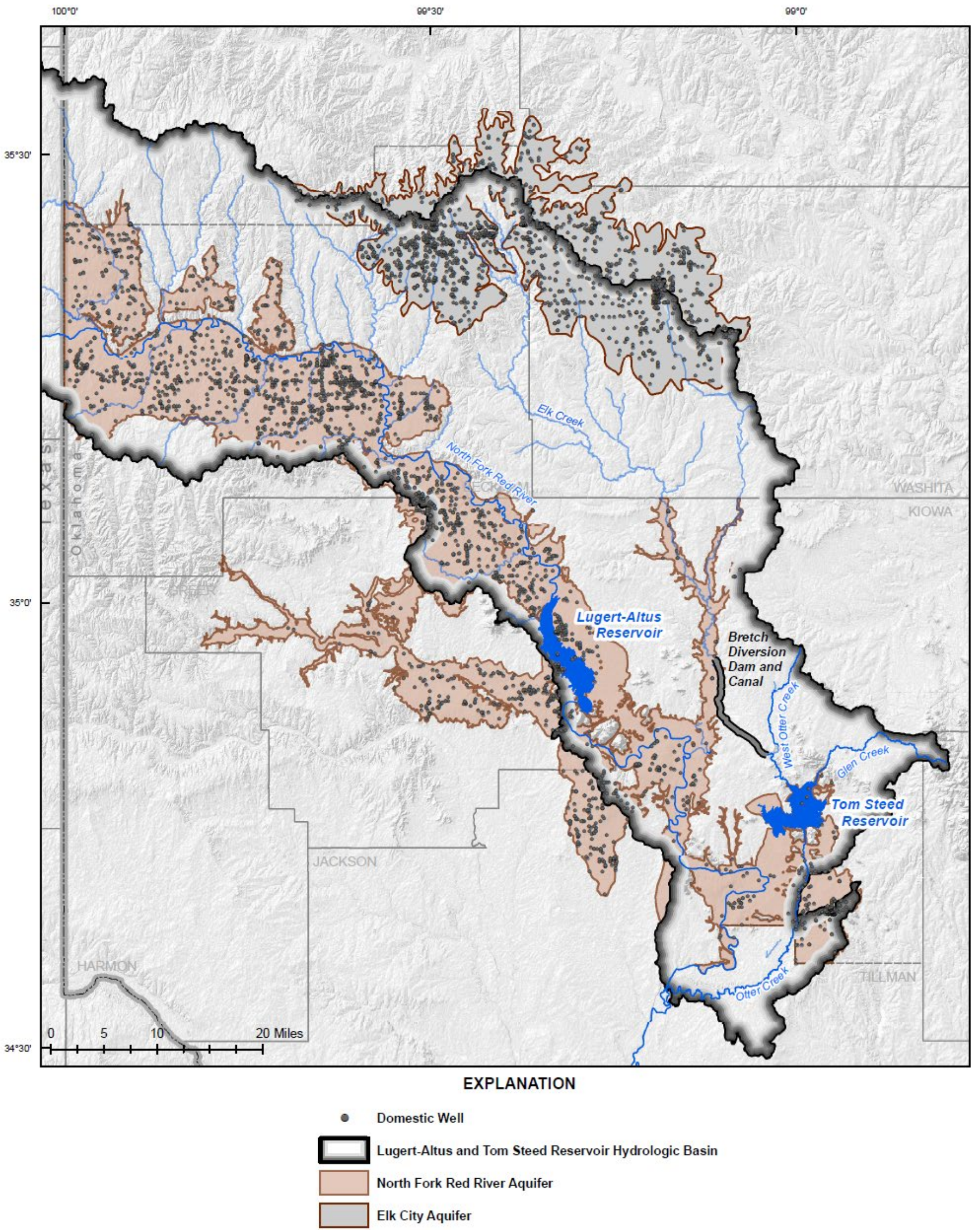

Figure 2-17. Distribution of domestic groundwater wells within the NFRR and Elk City aquifers.

Considering the large amount of use within the hydrologic basins containing Lugert-Altus and Tom Steed reservoirs, some key challenges are worth pointing out:

- Domestic uses that are exempt from permitting remain largely unquantifiable, although some information on groundwater use can be indirectly acquired through data collected from commercial well drillers.
- Metering actual water use is authorized, but not required under Oklahoma law, so withdrawal data are generally dependent upon either "use" reports that are submitted annually to the OWRB; crop census data collected by U.S. Department of Agriculture (USDA); measurements of stream gages; and/or other methods such as satellite imagery.
- A physical accounting of withdrawals requires an understanding of the physical and hydrological characteristics of the stream and groundwater systems from which water is being withdrawn. This requires a significant amount of data, along with the development of models that can incorporate those data to simulate the past and make predictions about the future.
- The accounting of withdrawals also depends on the various legal, regulatory, and policy frameworks of Oklahoma. Some frameworks are rather straightforward while others may be interpreted differently by different people; and some frameworks may appear rigid while others are flexible.
- Once withdrawals can be measured and predicted by models, challenges also arise in identifying and evaluating strategies to address impacts. And while some strategies may be suitable within existing legal, regulatory, and policy frameworks, others may require modification of such frameworks.

Later in this chapter, the discussion turns to challenges associated with collecting data and on the development of models related to accounting for withdrawals related to human development. A summary of legal and policy challenges also is presented. A detailed characterization of Oklahoma's legal and regulatory framework, including background water law and regulations related to water rights, permitting, and water management is provided in Appendix A. Next, a brief overview of Oklahoma water law is described to provide context to the challenges related to withdrawals from human development. The discussion then turns to existing water use in the hydrologic basins, including stream and groundwater permits that could be affecting withdrawals from streamflow entering Lugert-Altus and Tom Steed reservoirs.

Oklahoma Water Law Basics

- 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 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 (yr) 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.

- Surface water is managed under a joint Prior Appropriation/Riparian system. The term "Riparian" refers to the right of smaller users to withdraw surface water for domestic and household uses without a permit. Similar to groundwater, 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. 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[24] from average annual streamflow to determine unappropriated water availability, in part because regulations state that water

[24] The permit volume is approximately equal to the reservoir's 98 percent dependable yield for reservoirs that deliver water for M&I use (i.e., Tom Steed Reservoir), 80 percent dependable yield for reservoirs that deliver water for irrigation use (i.e., Lugert-Altus Reservoir), or as calculated by the agency that owns the reservoir, which is Reclamation in this case.

in reservoir storage above the permitted amount is considered public water and subject to appropriation by the OWRB.

- In this regard, one of the key concerns expressed by Lugert-Altus ID and MPMCD is that by only subtracting the reservoir's permitted amount from average annual flows, the stream system was being over appropriated, thereby increasing the risk of junior permit holders interfering with the District's senior water rights. The concern is based on the fact that the reservoir dependable yield values developed by Reclamation assume that reservoir storage would be full (at the top of conservation pool) at the onset of a critical drought. In other words, the entire conservation pool storage is required for the reservoir to deliver its dependable yield throughout the critical drought (assuming base flow remains constant). To potentially address this concern, the Districts have argued that one option could be for the reservoir's conservation pool, not the permit amount, to be subtracted from the average annual flows to determine unappropriated water availability. Alternatively, instead of basing unappropriated water availability (upstream of the reservoirs) on average annual streamflow, permit availability could be based on the streamflow occurring during the drought of record, and/or conditioning permits such that diversions from junior users are curtailed in a timely manner to protect reservoir dependable yield; after all, the drought of record formed the basis of the reservoir dependable yield calculations. The latter is included as a recommendation by the OWRB in Oklahoma's most recent update to its comprehensive water supply plan, which is discussed later. Other options are available and are the subject of this URRBS Report.

- The Districts have an established priority date for their water rights, which are considered senior to many if not all existing stream-water rights in the hydrologic basins containing the two reservoirs. Regulations allow for water right holders to complain to the OWRB to seek the OWRB action to protect their water right, and/or the holders can bring individual lawsuits to protect their water right from interference. However, what is lacking in Oklahoma's regulations or case law is any definition of interference or any identification of triggers that can be invoked to protect the water rights of senior holders. This issue will be discussed extensively in this report.

Surface Water Permitting and Use

Four types of surface water permits can be issued by the OWRB: regular[25], seasonal, term, and provisional temporary (PT) permits. With the exception of one "term" permit issued within the Tom Steed Reservoir hydrologic basin, only "regular" and "PT" permits have been issued within the Lugert-Altus and Tom Steed Reservoir hydrologic basins. A "regular permit" authorizes the permit holder to divert water on a year-round basis; a "seasonal permit" authorizes the diversion of water for specified time periods during the calendar year; a "term permit" authorizes the diversion of water for a term of years which expires upon expiration of the term permit; a "PT" permit authorizes temporary use for up to 90 days. In circumstances where there is less water actually available than that calculated for purposes of considering a regular permit application, regular permit holders have a better right over all other classes of permits. Seasonal, term, and PT permits may be issued even if the OWRB finds no unappropriated water available (the method the OWRB uses to appropriate surface water is discussed later in this chapter); and PTs can be granted directly by the OWRB's Executive Director without the requirement of a hearing or notification to downstream users. For these reasons, the issuance of PTs, on top of the regular permits issued in the hydrologic basins containing Reclamation's reservoirs, has caused significant concern among the Districts. Other concerns center on how the OWRB determines the amount of surface water available for appropriation, the extent to which the OWRB's approach may increase the risk of interference with the Districts' senior water rights, and how interference may be avoided and/or enforced during dry periods.

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[25] "Regular" permits issued before 1963 were considered "vested" permits. For this report, we refer to all long-term year-round permits as "regular" permits.

Surface Water Use within the Lugert-Altus Reservoir Hydrologic Basin

Lugert-Altus Reservoir depends almost exclusively on inflows from the NFRR. Thirteen regular surface water permits totaling 1,422 acre-ft/yr have been issued within the NFRR hydrologic basin that have the potential to impact Lugert-Altus Reservoir (Figure 2-18). Most of the permits are upstream of the reservoir. All of these permits are considered junior[26] to the water rights held by the Lugert-Altus ID and the city of Altus (dated 1939 and 1926, respectively). While reported permit use fluctuates from year to year, the volume of reported use has generally been less than the permitted volume (Figure 2-18)[27].

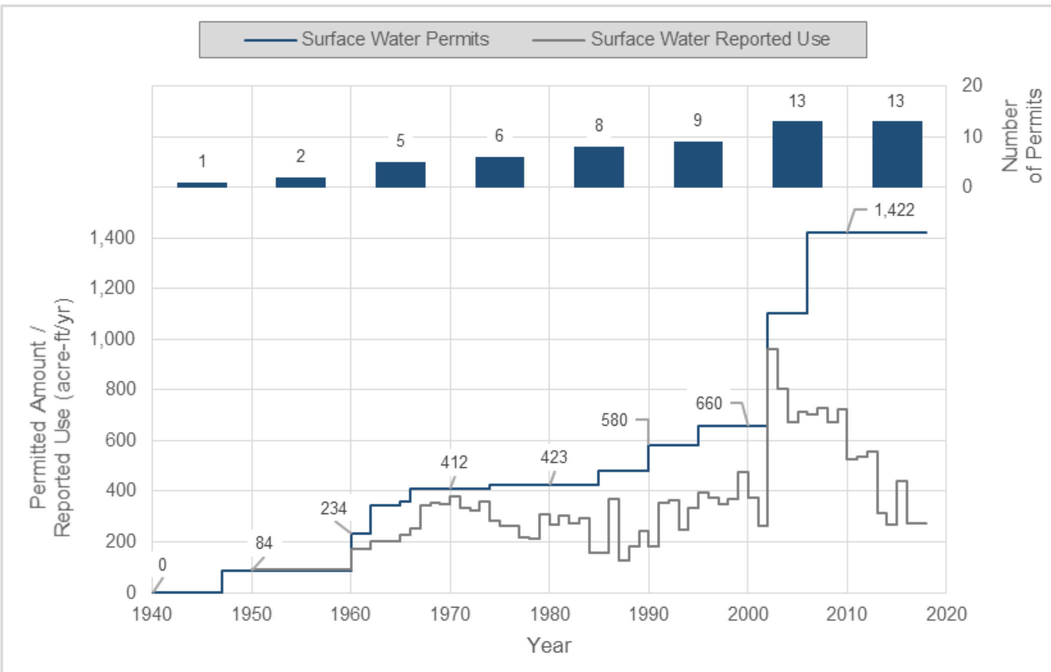

Figure 2-18. "Regular" surface water permits issued in the Lugert-Altus Reservoir hydrologic basin, including number of permits, cumulative permitted volumes and reported use.

[26] The terms "junior" and "senior" are based solely on the water right application date listed on OWRB's water rights database. The surface water basins have not been officially adjudicated by the state of Oklahoma.
[27] Reported use volumes prior to 1967 are estimates only. Reported use after 1967 may not reflect actual water use; this is discussed in more detail later in this report.

Surface Water Use within the Tom Steed Reservoir Hydrologic Basin

Tom Steed Reservoir depends on out-of-basin flows from Elk Creek and natural flows from the West Otter Creek/Glen Creek watershed. Sixteen regular surface water permits and one term surface water permit totaling 6,649 acre-ft/yr have been issued within the two watersheds that have the potential to impact Tom Steed Reservoir (Figure 2-19). Ten of the 17 permits are considered junior[28] to the water rights held by the MPMCD. Similar to the NFRR hydrologic basin, reported use in the watersheds fluctuates from year to year, the volume of reported use has generally been less than the permitted volume (Figure 2-19)[29].

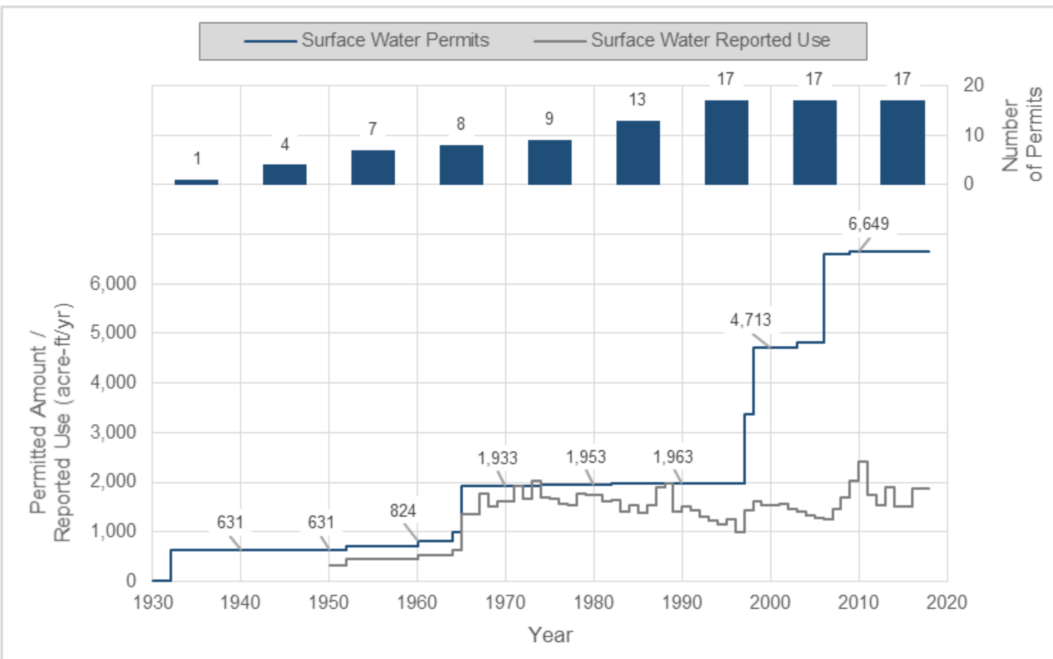

Figure 2-19. "Regular" and "Term" surface water permits issued in the Tom Steed Reservoir hydrologic basin, broken down by number of permits, cumulative permitted volumes and reported use.

[28] The terms "junior" and "senior" are based solely on the water right application date listed on OWRB's water rights database. The surface water basins have not been officially adjudicated by the state of Oklahoma since 1964. This issue is discussed extensively Chapter 8.2.1, Chapter 8.3.1, and Appendix H.

[29] Reported use volumes prior to 1967 are estimates only. Reported use after 1967 may not reflect actual water use; this is discussed in more detail later in this report.

Groundwater Permitting and Use

When the total outputs of an aquifer (e.g., groundwater pumping) exceed the total inputs into that aquifer (e.g., aquifer recharge), then the amount of water stored in the aquifer will decline over time; and as an aquifer's storage decreases, so too does an aquifer's saturated thickness (a.k.a., water table); and when the saturated thickness decreases, groundwater wells can go dry because they are no longer deep enough to reach the water table. If that aquifer hydrologically connects to an adjacent stream, the declining saturated thickness of an aquifer can reduce the base flow of the adjoining stream, and subsequently reduce the yield of downstream reservoirs that depend on base flow to sustain their storage during extended periods of drought when precipitation run-off is unavailable.

Similar to surface water, there are different types of groundwater permits. It was stated earlier in this section that 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, both of which must be updated by the OWRB through a legally-mandated review at least every 20 years. If a landowner has a "prior" groundwater right or a "regular" groundwater use permit, the landowner's right is considered vested and the EPS cannot be reduced, even if the OWRB's updated review shows that an aquifer's MAY is lower than previously thought. For aquifers where the OWRB has not performed an official hydrologic investigation and no MAY has been determined, the OWRB issues "temporary" permits to landowners allowing a default withdrawal of two acre-ft/yr or one acre-ft/yr depending on whether the aquifer is bedrock or alluvial, respectively. Similar to surface water, the OWRB also has discretion to issue "PT" permits allowing use for up to 90 days.

Groundwater Use within the Lugert-Altus Reservoir Hydrologic Basin

Base flows of the NFRR are driven by groundwater discharges from the adjacent and underlying NFRR aquifer. Within the NFRR aquifer, 480 groundwater permits totaling about 96,330 acre-ft/yr have been issued over the last several decades (Figure 2-20). Of these, 229 permits are prior rights; 220 permits are regular permits; and 31 permits are temporary permits. The spatial distribution of these groundwater wells is illustrated in Figure 2-16.

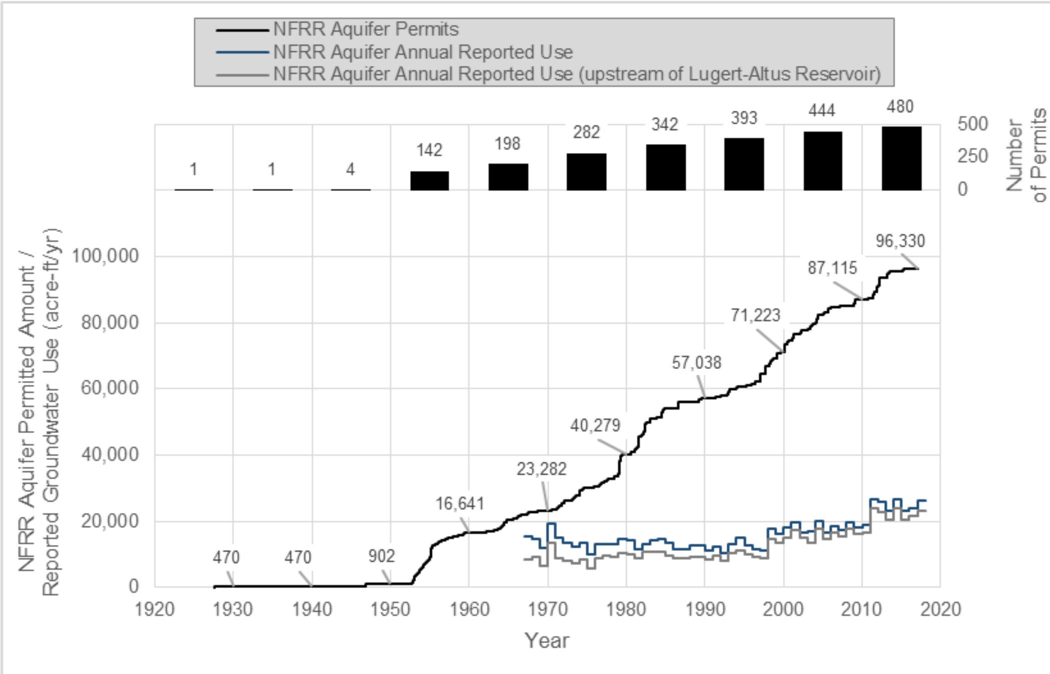

Figure 2-20. Groundwater permits issued in the NFRR aquifer, including number of permits, cumulative permitted volumes and reported use.

Importantly, the NFRR aquifer has been the subject of a complex hydrogeological investigation by the OWRB in support of efforts to identify the aquifer's MAY and corresponding EPS (these terms were described earlier under "Oklahoma Water Law Basics"). The investigation was a major component of this URRBS with significant implications on the management of the NFRR aquifer and on Lugert-Altus and Tom Steed reservoirs. This is discussed briefly in the next section.

Groundwater Use within the Tom Steed Reservoir Hydrologic Basin

Tom Steed Reservoir depends on inflows from Elk Creek and West Otter Creek/Glen Creek. Base flows in Elk Creek (and its tributaries) originate partly from the NFRR aquifer around the proximity of the Bretch Diversion Dam, but primarily from the Elk City aquifer further upstream in Washita and Beckham counties (Figure 2-16) (Wagner et al., 2021). As such, groundwater pumping from both aquifers has the potential to affect flows in Elk Creek, and subsequently, the yield of Tom Steed Reservoir; however, the extent to which pumping out of either the NFRR or Elk City aquifer affects the base flow of Elk Creek remains a significant challenge and is one of the subjects of this URRBS report. Regarding West Otter and Glen Creek, base flows were assumed to originate from the Southwest Oklahoma minor aquifer, which is considered to be too thinly saturated to support irrigation uses beyond short-term domestic uses (OWRB, 1998).

In addition to the wells permitted in the NFRR aquifer discussed above, 106 groundwater permits totaling almost 24,100 acre-ft/yr have been issued in the Elk City aquifer[30]. The temporal distribution of these groundwater wells is illustrated in Figure 2-21. Of these, 37 permits are prior rights; 64 permits are regular permits; and five permits are temporary permits.

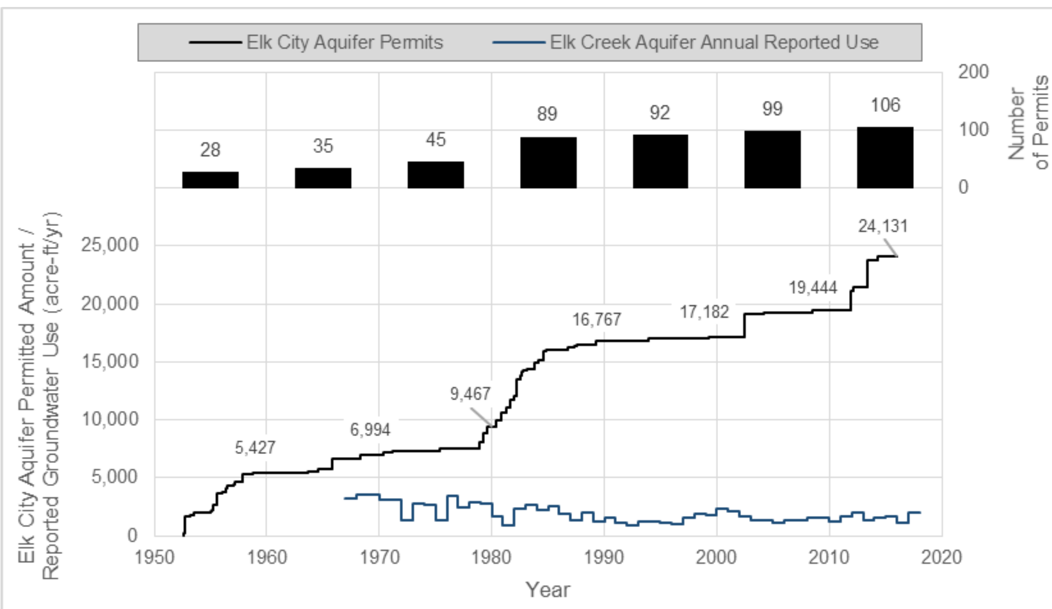

Figure 2-21. Groundwater permits issued in the Elk City aquifer, including number of permits, cumulative permitted volumes and reported use.

[30] The geographic boundary of the Elk City aquifer presented in this URRBS report, along with the corresponding number and volume of permits, reflects the best available data prior to publication of the new Elk City aquifer hydrologic investigations report (Wagner et al., 2021). Therefore, the data presented here for the Elk City aquifer are different than the data presented in Wagner et al. (2021).

2.3. Reservoir Demand Challenges

In the previous section, several of the challenges were presented associated with understanding and predicting reservoir supplies. Challenges were presented in the context of Reclamation's RRY Model, a mass balance model used to predict reservoir supply. In defining "supplies", the discussion focused on "inputs" to the model, namely on the challenges of measuring and predicting how the streamflow entering Lugert-Altus and Tom Steed reservoirs may be affected by (1) hydrology, temperature, and precipitation; versus (2) demands from water users upstream of the reservoirs. Another important variable, evaporation, is discussed later in this Chapter.

In this section, the focus is on another key input into the RRY model: reservoir demands. To be clear, unlike the upstream demands which affect reservoir inflow (i.e., supply) discussed previously, the focus is on the agricultural and M&I customers served by the Lugert- Altus ID and MPMCD, both of which have repayment/O&M contracts with Reclamation, and which draw water directly from the reservoirs.

2.3.1. Demands on Lugert-Altus Reservoir

Water demands on Lugert-Altus Reservoir are primarily derived from agricultural irrigation of 48,000 acres of land within the Lugert-Altus ID. The principal crop is cotton. Next, the discussion turns to challenges cotton farmers face in managing cotton production, the role of improved delivery and on-farm irrigation efficiency, and the overarching challenges and importance of maintaining a consistent and reliable water supply in Lugert-Altus Reservoir. Ultimately, supply reliability is the most significant factor which drives how farmers plan and manage their land and investments.

Crop Irrigation Requirements

The original 1937 planning report on the W.C. Austin Project (1937 Report) recognized the challenges of supporting irrigated agriculture in southwest Oklahoma, an arid, drought-prone region which often experiences high intensity rainfall events and flash flooding. Prior to construction of the W.C. Austin Project, about 200,000 acres of land in Jackson and Greer counties had been under cultivation over a 40-yr period, where principal crops of cotton, wheat, and grain sorghums were grown, as these crops were known to withstand the hot, dry weather of mid-summer. When efforts began to develop the W.C. Austin Project, a newly constructed reservoir was expected to be capable of irrigating an area between 20,000 and 70,000 acres with an average of 47,000 acres (Reclamation, 1937). At the time, a soil- moisture-holding-capacity study had not been conducted, so Reclamation's near-by Carlsbad Project in New Mexico was used as a surrogate in estimating an irrigation requirement of 39 inches for the W.C. Austin Project. Experiments by the Texas Agricultural Experiment Station at the time indicated that 30 inches of water was needed to obtain maximum yields of cotton[31]; however, Reclamation planned for a 39-inch total application requirement, excluding conveyance losses, to account for higher demands from crops such as alfalfa and for additional needs during the non-growing season.

Today, data collected from the Oklahoma mesonet, a network of environmental/weather monitoring stations, can be used to provide further insights into crop demands[32]. Long-term mesonet data from the city of Altus suggests that healthy cotton requires a total of about 30 inches of water in southwest Oklahoma (Boman and Warren, 2017). Accounting for average total rainfall during irrigation months of May through September in the area (15.72 inches; Figure 2-22), cotton farmers typically need a net of about 15 inches

[31] Irrigation Requirements of Cotton and Grain Sorghum in the Wichita Valley of Texas. Bulletin No. 543, Texas Agricultural Experiment Station, August, 1937. College Station, Texas.
[32] https://www.mesonet.org/.

of irrigation water[33]. Figure 2-23 illustrates typical seasonal water-use pattern for cotton produced in the Texas High Plains region, which is similar to southwest Oklahoma, and which is supported by 10-yr average cotton evapotranspiration data collected by the Oklahoma mesonet for Altus (Boman and Warren, 2017).

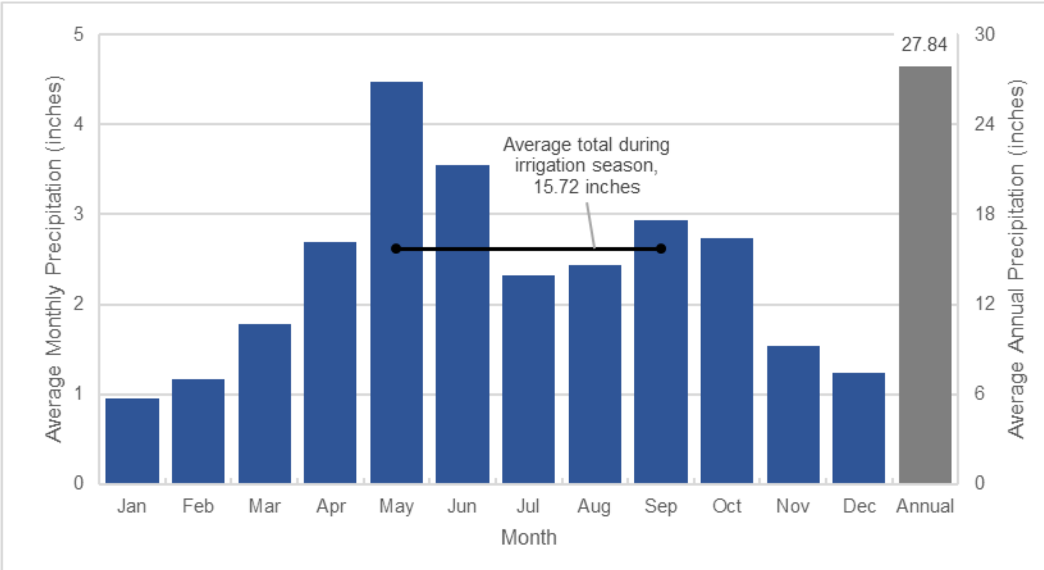

Figure 2-22. Distribution of monthly mean precipitation and average annual precipitation, 1895-2018 (Southwest Oklahoma Climate Division 07). The cumulative total mean precipitation between irrigation months (May through September) is 15.72 inches.

[33] Randy Boman, Research Director and Extension cotton program leader at the Oklahoma State University Research Center in Altus, in Sept 10, 2014 Southwest Farm Press.

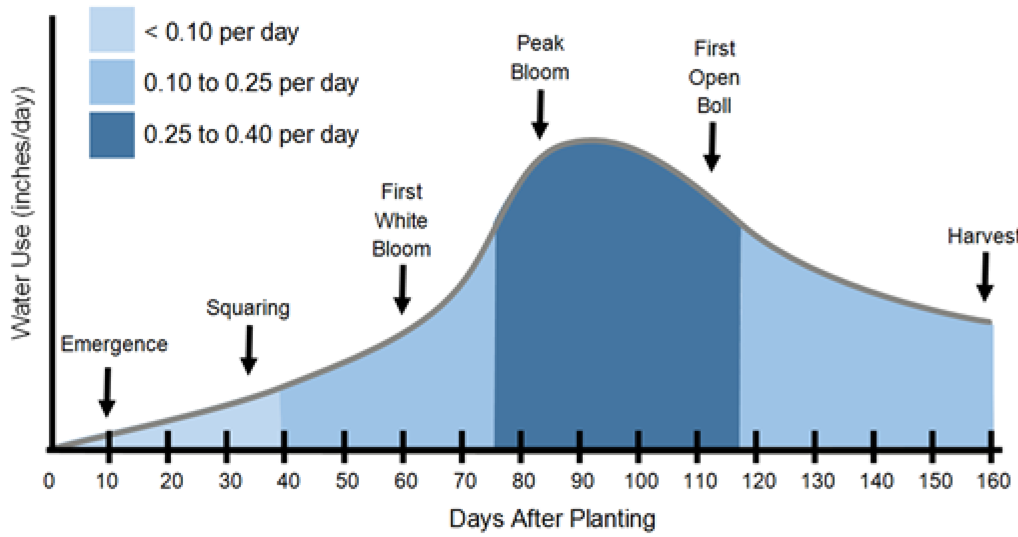

Figure 2-23. Typical seasonal water-use pattern for cotton produced in the Texas High Plains region (Boman and Warren, 2017).

Today, the Lugert-Altus ID holds a water right of 85,630 acre-ft/yr and irrigates approximately 48,000 acres of land, principally cotton. Assuming a delivery efficiency of 68 percent[34] (32 percent loss), 58,200 acre-ft/yr of supply is available for irrigation, which equates to an allocation of 1.2 acre-ft/acre (15 inches). Interestingly, but perhaps not coincidentally, this net requirement is consistent with studies cited previously. The allocation fluctuates slightly depending on the number of acres irrigated in a given year.

Balancing Irrigation Demands with M&I Demands

The city of Altus has a right to use 4,800 acre-ft/yr of M&I water from Lugert-Altus Reservoir. In addition, a 1954 Settlement Agreement with the Lugert-Altus ID requires the District to manage irrigation operations such that 10,000 acre-ft of water remains in storage at the end of the irrigation season to ensure that the 4,800 acre-ft can be delivered to Altus the following year, if needed. This is discussed in more detail in the following section under Lugert-Altus ID operations. Overall, deliveries to the city of Altus average

[34] Meeting Minutes, Board of Directors of the Lugert-Altus ID, October 25, 2017.

2,716 acre-ft/yr (Figure 2-24), but most of Altus' demands concentrated between the late 1960s and 1970s prior to the construction of Tom Steed Reservoir. Over the past 30 years, Tom Steed Reservoir has served as Altus' primary M&I water supply (Figure 2-25). However, during the peak of the 2010s Drought of Record, 824 acre-ft, 674 acre-ft, and 1,002 acre-ft were delivered in 2011, 2012, and 2013, respectively, for a total of 2,500 acre-ft. During this time period, zero deliveries were made for agricultural irrigation. Although M&I demands were very small relative to irrigation demands, it is an important operational constraint that affects reservoir supply management during drought periods.

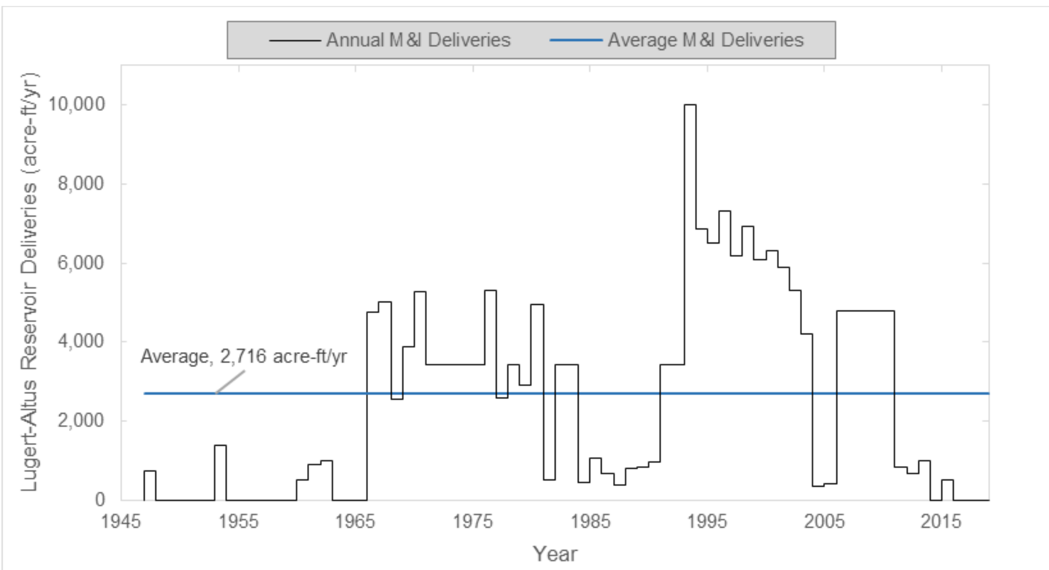

Figure 2-24. Annual deliveries from Lugert-Altus Reservoir to the city of Altus for M&I purposes, 1947-2018.

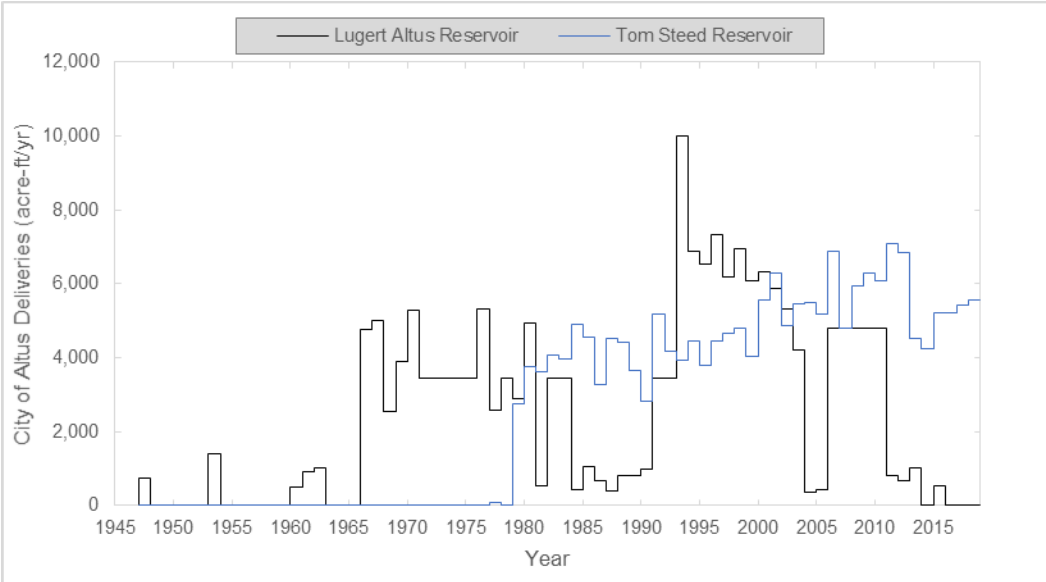

Figure 2-25. Annual deliveries from Lugert-Altus and Tom Steed reservoirs to the city of Altus for M&I purposes, 1947-2018.

Irrigation Operations: Timing and Reliability of Deliveries

One of the biggest challenges facing farmers is planning and adjusting to supply uncertainty. The Lugert-Altus ID's goal, therefore, is to operate its system in a way that maximizes agricultural deliveries, while also optimizing the reliability of existing and future storage at Lugert-Altus Reservoir - both during wet and dry cycles, as well as throughout extended periods of drought. Not unlike managing a bank account, irrigation deliveries serve as expenditures on necessary goods while the amount of water left in storage acts as a "savings account" that can supplement future year(s) if a drought occurs.

In managing its storage savings account, the Lugert-Altus ID must monitor and account for various factors. First, the Lugert-Altus ID must adhere to its obligation to "neither make nor order irrigation withdrawals from storage…which will reduce the active storage below 10,000 acre-ft"[35]. The 10,000 acre-ft storage mandate accounts for 5,200 acre-ft/yr in "push" water that is needed to deliver the 4,800 acre-ft/yr-water right held by the city of Altus[36]. On top of this 10,000 acre-ft, the Lugert-Altus ID sets aside an additional 10,000 acre-ft of storage to meet minimum pool requirements and an estimate of approximately 5,000 to 9,450 acre-ft to account for evaporation, bringing the total "reserve" to approximately 29,450 acre-ft. The additional reserve accounts for anticipated storage losses caused by evaporation; these losses are adjusted throughout the season to reflect real-world climate conditions and storage volumes. Furthermore, the Lugert-Altus ID must account for the timing and location of irrigation calls and the corresponding efficiency of delivering water to those locations. The irrigation season typically lasts from May through September. At the onset and throughout the irrigation season, the amount of water available for irrigation is calculated as follows:

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[35] 1954 settlement agreement, Lugert-Altus ID and city of Altus.

[36] "Push" water creates the necessary hydraulic head/pressure to convey the city of Altus' allotted water through the canal system.

Step 1: (S – R) – (E x D) = B

Step 2: (B x %) / A = Irrigation Allocation (acre-ft per acre)

Where:

S = End-of-Month Storage at Lugert-Altus Reservoir

R = 20,000 acre-ft reserve[37]

E = Evaporation Rate per Day

D = Number of Days Left of Irrigation Season

B = Total Storage Balance (acre-ft) that can be Delivered

% = Delivery Efficiency

A = Acreage Irrigated

A real-world example that occurred in May 2011 at the onset of the drought is as follows[38]:

S = 64,806 acre-ft

R = 20,000 acre-ft

E = 100 acre-ft

D = 60

B = 38,806 acre-ft

% = 60[39]

A = 45,941 acres

Irrigation Allocation = 0.51 acre-ft per acre

---

[37] Comprised of 10,000 acre-ft needed the current season deliveries and 10,000 acre-ft to ensure that a minimum storage in compliance with the settlement agreement.

[38] Meeting Minutes, Board of Directors of the Lugert-Altus ID, May 19, 2011.

[39] The delivery efficiency fluctuates based on the volume and location of water delivered, as well on implementation of delivery efficiency improvements made by the Lugert-Altus ID.

As the drought progressed and conditions worsened, reservoir storage rapidly declined to 37,000 acre-ft, and evaporation was increasing. As such, irrigation deliveries were discontinued for the first time in over 60 years on July 22, 2011 at 8:00 am[40].

Figure 2-26 illustrates irrigation deliveries from Lugert-Altus Reservoir. Over the 68-yr record, the max delivery was 106,542 acre-ft/yr in the year 2000; and the average delivery is 49,600 acre-ft/yr. The Lugert-Altus ID delivered the full volume of its 85,630 acre-ft/yr water right on three occasions (1963, 1998, and 2000). The delivery volumes observed are a reflection of the Lugert-Altus ID's operational goal of maximizing supply certainty over variable conditions that may exist over extended periods of time. The fact that 85,630 acre-ft/yr has only been delivered on a few occasions is not a reflection on the demands for irrigation supplies; rather, it is a reflection on the reliability of available supplies and the corresponding operation of the Lugert-Altus ID. From a farmer's perspective, it is often preferred to have less water on a consistent basis rather than more water on an inconsistent basis. It is a delicate balance that the Lugert-Altus ID must weigh throughout the irrigation season, and it highlights the importance of supply reliability.

[40] Meeting Minutes, Board of Directors of the Lugert-Altus ID, July 6, 2011.

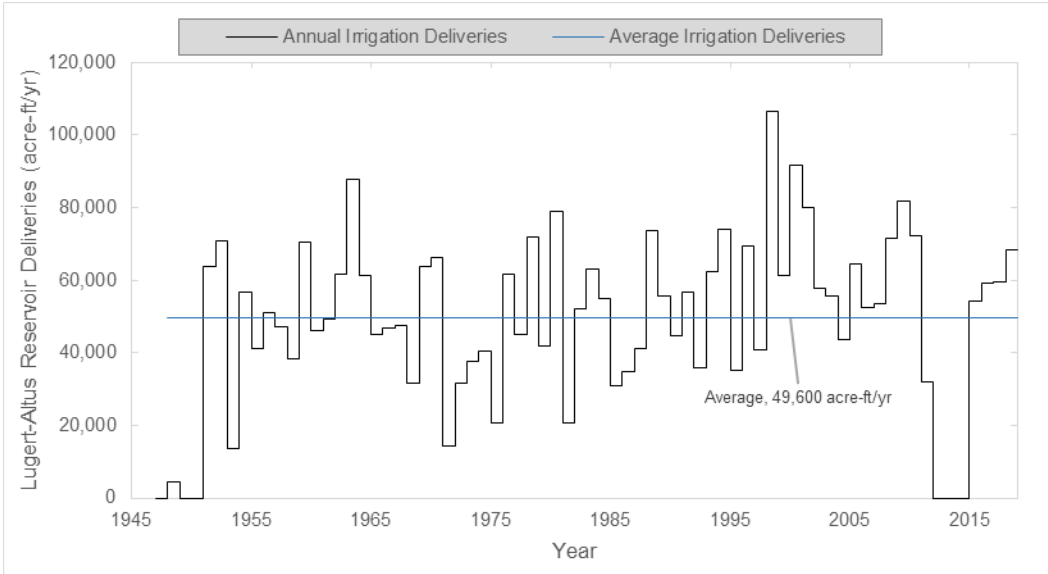

Figure 2-26. Annual deliveries from Lugert-Altus Reservoir for irrigation purposes, 1947- 2018.

Reservoir Supply Availability

In the previous section, the discussion focused on how irrigation demands are driven by the volume and reliability of water supplies. An important issue that also needs to be addressed is the volume of storage in Lugert-Altus Reservoir needed to deliver the Lugert-Altus ID's full irrigation right of 85,630 acre-ft/yr, combined with the M&I right of 4,800 acre-ft/yr.

Based on Reclamation's analysis, the volume of storage needed to deliver the combined irrigation and M&I water rights appears to be 115,000 acre-ft/yr. This storage volume was based on two assumptions: First, the Lugert-Altus ID would continue to operate with 20,000 acre-ft/yr set aside in storage to ensure that water is available for the city of Altus for M&I use. Second, "net" [41] evaporative losses through the irrigation season were assumed to total 9,450 acre-ft/yr. Reclamation performed an analysis of observed evaporative losses over the 66-yr period of record and found that average net evaporative loss at Lugert-Altus Reservoir was 3,350 acre-ft/yr, with a maximum of 9,450 acre-ft/yr. For planning purposes, a conservative approach towards accounting for evaporation was to use the 9,450 acre-ft/yr maximum[42].

Based on an analysis of observed conservation pool storage volumes over time, 115,000 acre-ft has historically been available between 15 and 43 percent of the time at the beginning of the irrigation season (Figure 2-27). Looking towards the future, this percentage would only decrease under assumed sedimentation conditions (Figure 2-28). Beginning in the year 2040, the storage capacity of Lugert-Altus Reservoir's conservation pool was projected to be insufficient to deliver the combined water rights held by Lugert-Altus ID and the city of Altus[43].

Importantly, this analysis focused solely on the impact of sedimentation and thus excluded reductions in inflow caused by potential changes in climate conditions and upstream uses. Nevertheless, it stresses the importance of

[41] The term "net" evaporation refers to net losses after accounting for inflows into the reservoir.
[42] Equates to about 60 acre-ft/day on average, assuming a 150-day irrigation season from May 1 to October 1.
[43] This deficit would occur only during dry years when inflow is exceeded by evaporative losses.

identifying the factors that impact supply reliability and then taking the necessary actions within its power to address adapt and mitigate accordingly.

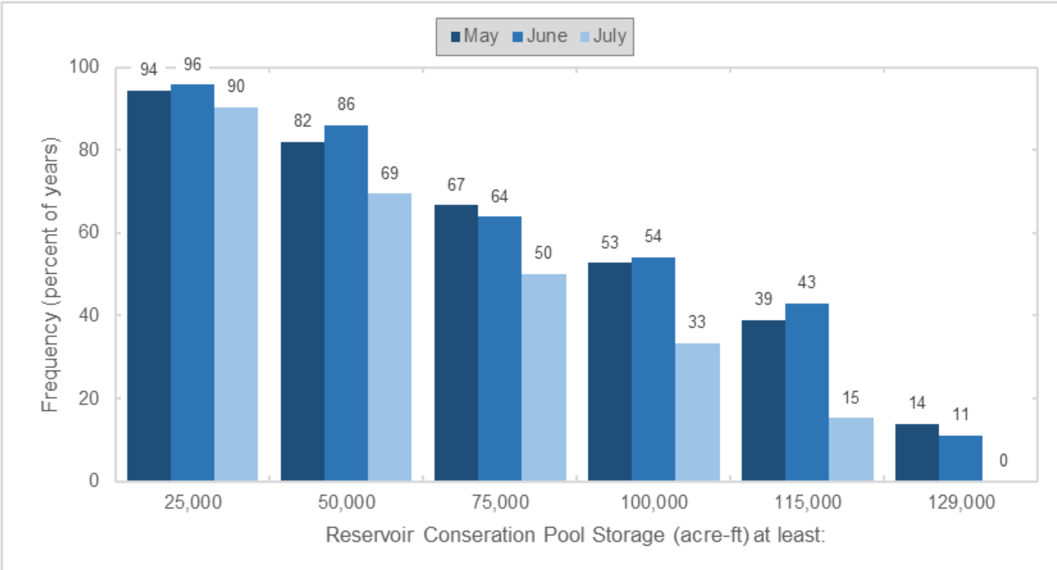

Figure 2-27. Frequency of a range of observed available conservation pool storage volumes at the beginning of the irrigation season (May thru July) at Lugert-Altus Reservoir, 1947-2018.

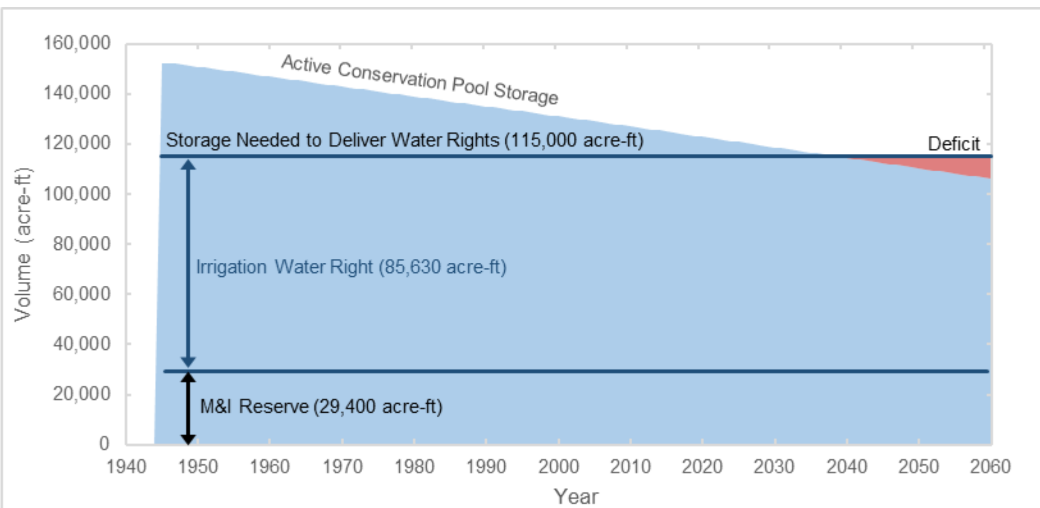

Figure 2-28. Comparison of existing and projected conservation pool storage of Lugert-Altus Reservoir relative to the volume of storage needed to deliver the water rights held by the Lugert-Altus ID and the city of Altus. A deficit is projected to occur in 2040, but only during dry years when inflow is exceeded by evaporative losses.

Irrigation District and On-Farm Irrigation Efficiency and Conservation

Another important factor affecting irrigation demands is the efficiency by which water is delivered, applied, and used by the crop that is not lost to evaporation, transpiration, seepage, percolation, or run-off. The more efficient a system is, the less water it takes to achieve a desired result, which means more water is available to optimize production, assuming a given amount of irrigated acreage. The key challenge is balancing the benefits of improved efficiencies which can create higher yields and allow the production of higher value crops with the potential increased costs of installation and maintenance, especially for farmers. Indeed, the uncertainty about future water availability and the risk of reduced crop yields are among the most important barriers to investments in efficiency improvements.

At the District level, types of efficiency losses include losses from over irrigation and resulting tailwaters that are "lost" to other uses, meter inaccuracies, unrecorded usage, leakage, seepage, and evaporation. Common solutions include infrastructure improvements such as canal lining, piping of smaller laterals, and flow control, regulation, and measurement. Solutions also involve improvements in crop selection, farmer operations, and the distance, location, and timing of conveyance. The Lugert-Altus ID began undertaking steps to modernize its infrastructure and improve operations more than a decade ago. This includes a system optimization assessment (Styles, 2005), improvements in gate rehabilitation, flow measurement/control, and telemetry[44].

As part of the Lugert-Altus ID five-yr update to its Water Conservation Plan, Reclamation performed a technical analysis to identify opportunities to reduce water losses caused by seepage from laterals and canals throughout the District delivery system. The focus also was on identifying funding opportunities within Reclamation's WaterSMART program that could be used to design and install improvements that address seepage and evaporative losses. Specifically,

[44] Improvements were funded through Reclamation grants awarded in 2005 and 2011.

the project identified the types of soils present in the District in terms of low-, moderate-, and highly permeable soils; estimated seepage losses based on length of soil permeability and the average wetter perimeter for each stretch of laterals and canals within different zones [(i.e., DRDs] of the District; and identified which laterals, canals, and DRDs would benefit most from infrastructure improvements that reduce or eliminate seepage (i.e., canal lining or conversion to pipe). Using Reclamation's findings, the Lugert-Altus ID is currently pursuing state and Federal funds to implement numerous canal-to-pipe conversion projects that would result in significant water savings. A copy of the Lugert-Altus IDs five-yr WCP Update is located in Reclamation OTAO's central files and is available upon request.

At the farm level, measures typically involve optimizing farm designs to improve conveyance, scheduling, and application of irrigation water. Flood irrigation is the most prominent type of irrigation application at the Lugert-Altus ID, but it also is the most wasteful; however, many farmers are converting from flood irrigation to more efficient subsurface (drip) irrigation, which can significantly improve application efficiency. Of the 48,000 acres within the Lugert-Altus ID, approximately 11,500 acres (about 25 percent) currently use drip irrigation; this number is expected to increase by 1,000 acres per year[45]. The conversion from flood to subsurface irrigation presents some logistical challenges to the District in terms of water delivery schedules and rotation among the farms; however, the challenges are steadily being resolved, and the resulting on-field water efficiency gains are welcomed and encouraged by the Lugert-Altus ID.

[45] Email from Don Skiles, District Conservationist, USDA/NRCS Altus, OK. March 7, 2018.

2.3.2. Demands on Tom Steed Reservoir

Unlike Lugert-Altus Reservoir which provides water primarily for agricultural irrigation, water from Tom Steed Reservoir is provided primarily for M&I and EQ benefits. This presents a different set of challenges. M&I demands include but are not limited to needs for domestic/residential purposes (e.g., human consumption/sanitation), hospitals, hotels, and commercial/industrial processes. These uses require a reliable water supply that can only be curtailed so much during critical drought periods without having detrimental impacts on public health, welfare, and sanitation. This highlights the importance of the cities of Altus, Snyder, and Frederick having access to a firm reservoir supply during a critical drought. At the same time, when a portion of Frederick's M&I supply allocation was transferred for EQ purposes to the Hackberry Flat WMA, the U.S. effectively "purchased" (and continues to annually purchase) the EQ water because the MPMCD's Project repayment and annual O&M obligations were proportionally reduced to reflect the volume of water reallocation from M&I to EQ. The U.S. therefore has an interest in ensuring that EQ benefits at the Project also are fulfilled, including during critical drought periods.

Water Delivery Contracts

Of the 16,100 acre-ft/yr water right held by the MPMCD, the original 1971 water delivery contracts allocated 15,970 acre-ft/yr of Project water for M&I purposes to the member cities as follows:

- Altus: 11,200 acre-ft/yr (70.13 percent)
- Frederick: 3,920 acre-ft/yr (24.54 percent)
- Snyder: 850 acre-ft /yr (5.33 percent)

In the 1980s, the city of Frederick recognized they would have difficulty servicing their future share of the Project repayment obligation, combined with the fact that they had never taken any Project water because their existing water supply, Lake Frederick, was meeting their needs. At the same time, the ODWC was developing and restoring Hackberry Flat, a remnant 3,750-acre playa basin located in southwestern Oklahoma. ODWC was looking for a source of water to enhance the historic wetland, which before it was drained for farming in the early 1900s, was the largest natural wetland in Oklahoma and an important staging area for migratory waterfowl and shorebirds. Based on these conditions, the MPMCD, Frederick, and ODWC worked to affect legislation which would allow for use of Project water at the Hackberry Flat WMA.

The Mountain Park Project Act of 1994 defined the term "environmental quality activity" as any activity that "primarily benefits the quality of natural environmental resources." The Act required the Secretary to conduct appropriate investigations to determine EQ activities that could be carried out and to make an appropriate reallocation of the costs of the Mountain Park Project to accommodate the EQ activities implemented. In particular, the Act required investigations of the benefits to natural environmental resources achievable from EQ activities that require reallocating water or using facilities or land of the Project, including (1) developing instream flows; (2) developing wetland habitat; and (3) any other environmental quality activity the Secretary determines to be appropriate to benefit the overall quality of the environment. Pursuant to the legislation, Reclamation, the District, ODWC, and Frederick developed and finalized an EQ Plan in April 1995. The EQ Plan identified reallocation of 60 percent 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. To that end, the four parties signed the EQ Plan and agreed to the following actions:

1. Frederick would relinquish 60 percent of its contractual share of the Project water supply (2,352 acre-ft/year) in exchange for a proportional adjustment to their share of the MPMCD's repayment and O&M obligations.

2. Upon request, the MPMCD would deliver up to 2,352 acre-ft/year of Project water to ODWC for EQ purposes at the Hackberry Flat WMA.

3. The ODWC would install a new pipeline from the existing Frederick Aqueduct to Hackberry Flat WMA and take delivery of the Project water reallocated to EQ purposes.

4. Reclamation would proportionally reallocate Project costs associated with repayment and O&M of the 2,352 acre-ft/yr to non-reimbursable EQ accounts.

5. The MPMCD would renegotiate their water service contract with Frederick to reflect the reapportionment of water and costs.

6. The MPMCD and ODWC would enter into a contract for delivery of water from the Project to the Hackberry Flat WMA.

In 2005, the MPMCD and Frederick executed a revised water delivery contract which reallocated Frederick's water supply and effectively reduced the M&I allocation by 2,352 acre-ft/yr from 15,970 acre-ft/yr to 13,618 acre-ft/yr as follows (Table 2-1):

- Altus: 11,200 acre-ft/yr (70.13 percent)
- Frederick: 1,568 acre-ft/yr (9.81 percent)
- Snyder: 850 acre-ft/yr (5.33 percent)

The total M&I allocation was 85.27 percent. The remaining 14.73 percent (i.e., 2,352 acre-ft/yr) had been "allocated" to Hackberry Flat WMA through the 1995 EQ Plan. Although delivery of water to Hackberry Flat WMA started in 1999, a contract between the MPMCD and ODWC to deliver the EQ water was not executed until 2016. Until 2010, 130 acre-ft/yr of the District's 16,100 acre-ft/yr water right remained unallocated. In 2010, the District allocated the 130 acre-ft/yr among its three member cities in proportion to their existing M&I water supply contract volumes by revising the contracts as follows (Table 2-1):

- Altus: 107 acre-ft/yr (82.25 percent)[46]
- Frederick: 15 acre-ft/yr (11.51 percent)[47]
- Snyder: 8 acre-ft/yr (6.24 percent)[48]

In 2016, subsequent to issues (discussed below) that manifested during the 2010s Drought of Record, the MPMCD and ODWC finally executed a contract to deliver up to 2,352 acre-ft/yr of EQ water to Hackberry Flat WMA.

[46] Equals 70.13% of the M&I subtotal of 85.27%.

[47] Equals 9.81% of the M&I subtotal of 85.27%.

[48] Equals 5.33% of the M&I subtotal of 85.27%.

Table 2-1. M&I and EQ allocation volumes/percentages that are contractually required in accordance with available water supplies, including during times of scarcity.

Contract Provisions	Municipal & Industrial Water Supply								Environmental Quality Water Supply		Total Contracted Water Supply
	Altus		Frederick		Snyder		M&I Subtotal		Hackberry Flat Wildlife Management Area		
	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)
Water supply allocation when 15,970 acre-ft is available	11,200	70.13	1,567	9.81	851	5.33	13,618	85.27	2,352	14.73	15,970
Excess volume of water supply allocation when more than 15,970 acre-ft is available	107	82.24[a]	15	11.50[b]	8	6.25[c]	130	100.0	0	0	130
Maximum water supply allocation (16,100 acre-ft is available)	11,307	70.23	1,582	9.83	859	5.34	13,748	85.39	2,352	14.61	16,100[d]

[a] Equals 82.24% of the M&I Subtotal (i.e., 70.13% of 85.27%).
[b] Equals 11.50% of the M&I Subtotal (i.e., 9.81% of 85.27%).
[c] Equals 6.25% of the M&I Subtotal (i.e., 5.33% of 85.27%).
[d] Equals District Surface Water Permit.

Balancing M&I and EQ Deliveries through Shared Shortages

Figure 2-29 below shows annual deliveries from Tom Steed Reservoir between 1979 and 2018. A noticeable increase was observed when EQ deliveries to Hackberry Flat WMA began in 1999. As previously stated, southwest Oklahoma experienced a relatively wet climate throughout most of this record, up until the 2010s Drought of Record when deliveries were significantly curtailed.

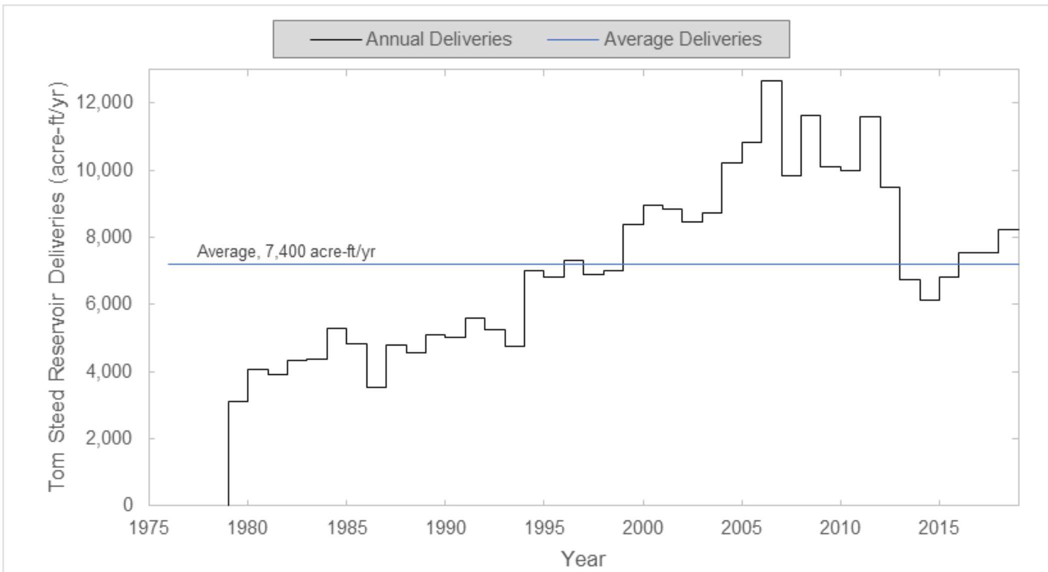

Figure 2-29. Annual deliveries from Tom Steed Reservoir, 1979-2018. EQ deliveries began in 1999, so deliveries between 1979 and 1998 were for M&I only.

The water delivery contracts between the MPMCD; the cities of Altus, Frederick, Snyder; and ODWC recognize the importance of managing available supplies during droughts. A "shared shortage" provision within each contract states that all participating entities shall, "share in the available water supply in the ratio of their contract rights during periods of scarcity when rationing is in the opinion of the MPMCD required". The contracts address shortages further by stating that during such years that the MPMCD "determines" that "available project water supply" shall be less than the total combined amount of contracted water supply, then the amount of water available to the participating entity shall be limited to each entity's percent allocation of available project water supply. A key challenge is that an agreed-upon threshold does not currently exist to support the MPMCD's "opinion" or "determination" on whether the "available project water supply" constitutes a "scarcity". Furthermore, predictive modeling tools would be required to make an informed determination on the "available project water supply" such that a shared shortage could be implemented prior to the reservoir volume falling below the total contracted water supply, at which point a supply deficit has occurred. Table 2-1 above summarizes the M&I and EQ allocation volumes/percentages that would be required according to the availability of contracted water supply, including during times of scarcity.

These challenges became pronounced during the 2010s Drought of Record when at its onset, water deliveries to Altus, Frederick, and Snyder were equivalent to 67 percent, 96 percent, and 129 percent of their respective M&I allocations (Figure 2-30)[49]. The deliveries to all three cities, as well as to miscellaneous customers that were surplus to MPMCD customer's contractual needs, represented 72 percent of the total M&I allocation. In 2014 during the peak of the drought, the combined deliveries of the three cities had been reduced through conservation to only 40 percent of the total M&I allocation. While conservation measures were necessary and beneficial, their effects were disproportionate, with Altus', Frederick's, Snyder's, and Hackberry Flat WMA's deliveries equaling 40 percent, 45 percent, 71 percent, and zero percent of their allocations, respectively. In effect, despite aggressive and well-intended conservation measures, Snyder and Frederick were both using a portion of Altus' and Hackberry Flat WMA's water allocations because Altus and Hackberry Flat WMA were both less than 40 percent of their respective allocations while Frederick and Snyder were each using more than 40 percent of their allocations. Had the MPMCD "declared a shared shortage" in accordance with shared shortage provisions of the contracts, in 2014, each entity would have equally utilized 40 percent of their respective M&I/EQ allocations (Figure 2-31), or the entities with excess water could have

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[49] An additional 300 acre-ft/yr of surplus water also was delivered by MPMCD that was in excess to the contracted water needed by its customers.

transferred/sold some portion of their water allocation to the entities who could not achieve the required level of conservation.

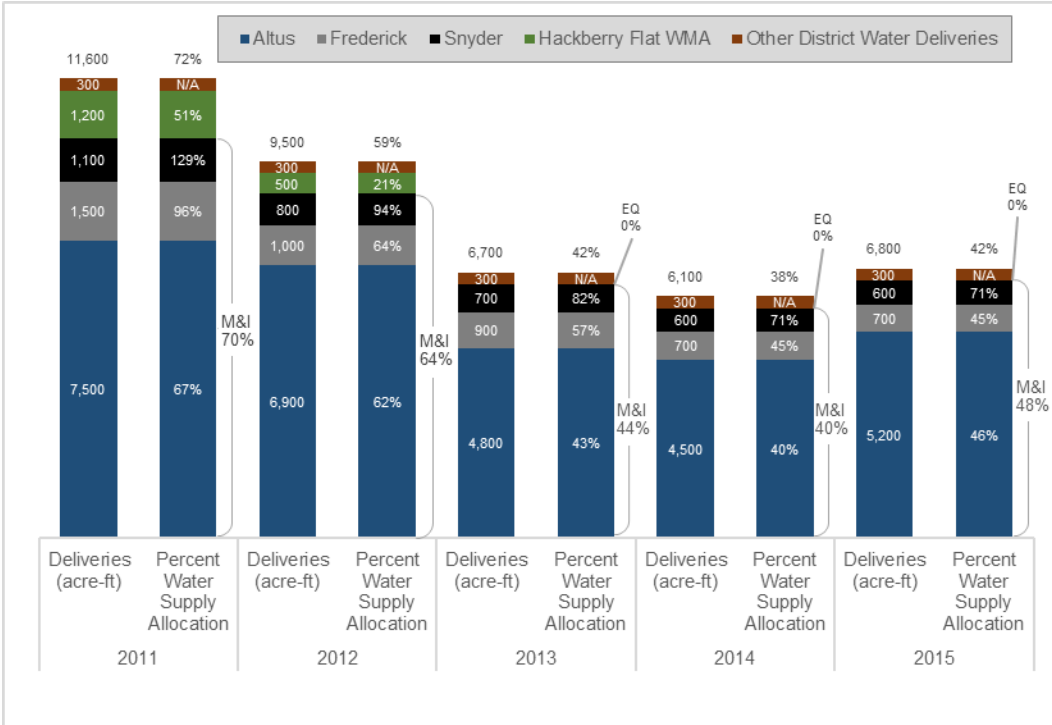

Figure 2-30. Observed water deliveries and corresponding supply allocations of MPMCD customers during the 2010s Drought of Record.

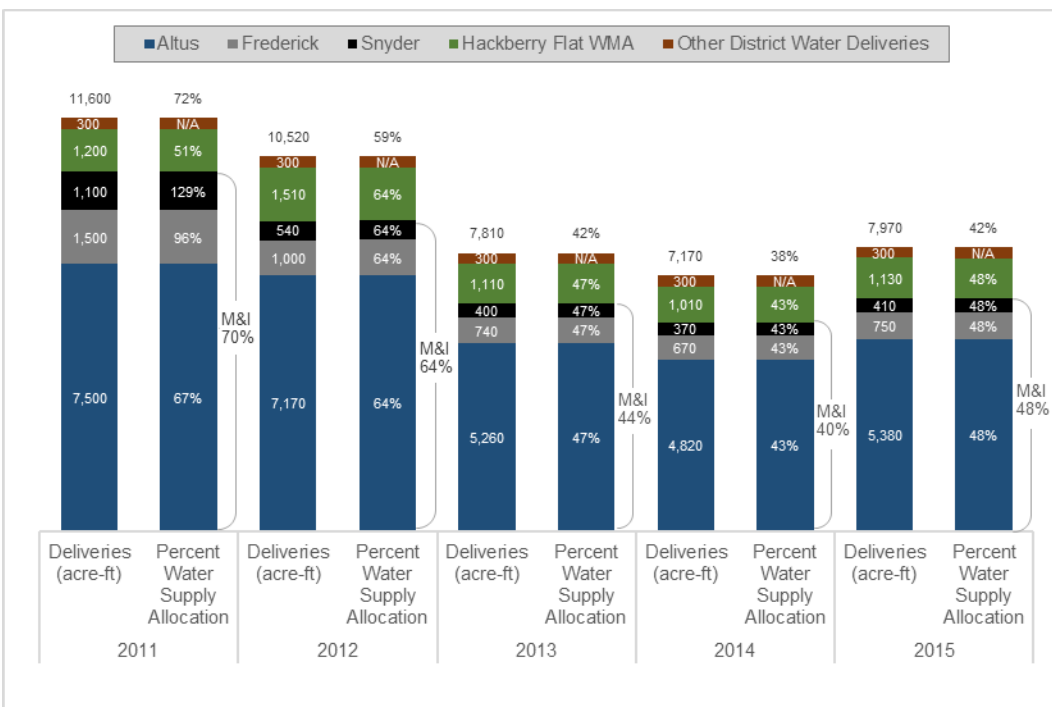

Figure 2-31. Hypothetical water deliveries and corresponding supply allocations of MPMCD customers during the 2010s Drought of Record under a "shared shortage" scenario where each customer reduces usage in equal proportions relative to their respective allocation.

M&I Demand Challenges

M&I Conservation and Efficiency Improvements

The last section discussed the steps taken by Altus, Snyder, Frederick, and Hackberry Flat WMA to restrict water use during the 2010s Drought of Record, but the focus was on the challenge of balancing water use restrictions while conforming to existing water delivery contracts. Here, the focus is on benefits and challenges of water conservation in a broader context, including measures that improve the efficiency of water treatment and delivery infrastructure, as well as planning and implementing drought contingency measures that conserve water or otherwise reduce demands on the system and/or offset pressure on Tom Steed Reservoir. Looking towards the future, the discussion turns to the challenges of making well-informed water demand projections and understanding how those projections affect risks and vulnerabilities of supplies.

At the onset of the drought, peak M&I demands (in 2011) were 9,500 acre-ft/yr (70 percent of the M&I allocation), and Altus, Frederick, and Snyder were using 67 percent, 96 percent, and 129 percent of their allocations, respectively (Figure 2-31). As the drought intensified over the next several months, officials became increasingly worried that Tom Steed Reservoir could go dry. Reclamation coordinated with the MPMCD to model reservoir storage projections under various supply and demand scenarios. Had peak M&I/EQ demands continued along with drought conditions, Tom Steed Reservoir would have gone dry within months. Subsequently, over the course of the next several months, M&I use for all three cities was restricted by 43 percent from 10,100 acre-ft/yr to 5,800 acre-ft/yr; the M&I allocation correspondingly went from 70 percent to 40 percent; and Hackberry Flat WMA deliveries were discontinued altogether. Altus, Frederick, and Snyder instituted Stage 3 emergency drought restrictions, prohibiting outdoor watering to one day per week[50]. Frederick restricted outdoor watering of building foundations, plants, and

[50] Altus City Ordinance, Article III Section 28.

trees to once per week by hand only, and prohibited outdoor lawn watering altogether[51]. Conservation measures had a positive impact on reservoir levels, increasing Tom Steed Reservoir storage by about ten percent over what it otherwise would have been during the drought. This appeared to have prolonged reservoir storage by about 12-18 months relative to a scenario where peak demands continued through 2015 (Figure 2-32).

However, after the drought ended in 2015, officials reflected on the experience and were concerned as to the level and type of water use restrictions that would have been necessary, had it not rained. Out of the total water use, questions emerged as to what usage was considered essential versus nonessential. Other questions emerged related to how reduced water use had impacted water sales and associated revenues that some of the cities depend on to operate and maintain various public services. For instance, Frederick's water sales decreased by about ten percent from 2013 to 2014. This highlights the importance of cities being able to implement water conservation measures while balancing revenue losses by instituting appropriate water rate structures and diversifying their revenue streams.

[51] Frederick City Code Section 17-201-213.

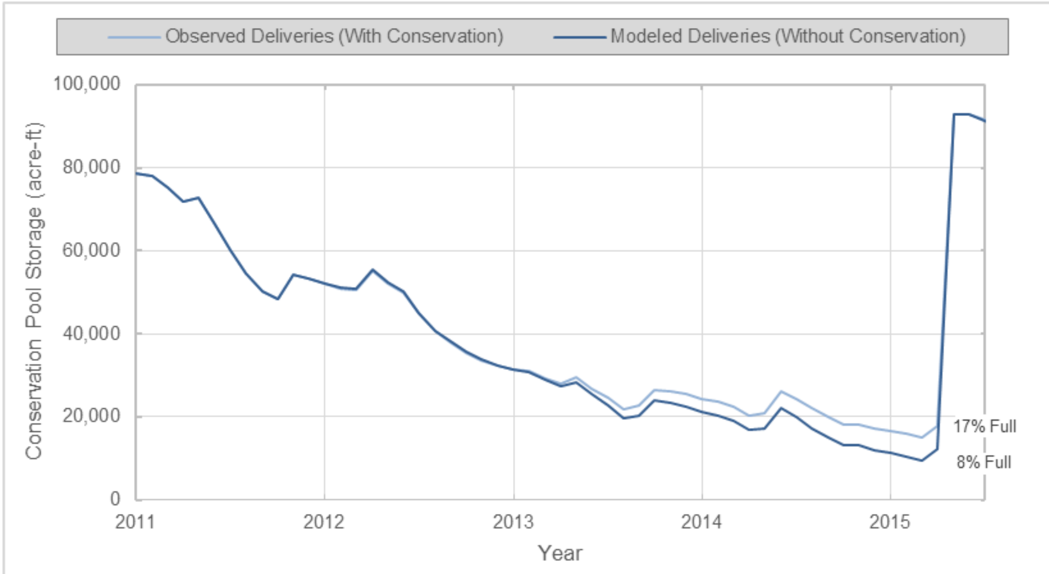

Figure 2-32. A comparison of observed deliveries from Tom Steed Reservoir with conservation measures in place versus model hypothetical deliveries without conservation measures during the 2010s Drought of Record.

M&I Demand Projections

Looking towards the future, another consideration, beyond temporary water use restriction previously discussed, is the extent to which permanent measures could be implemented to reduce water demands in the long-term. This includes improvements in treatment and conveyance systems that reduce losses and improve water delivery efficiency, as well as pursuing supplemental supplies that can offset or reduce pressure on Tom Steed Reservoir. Several measures are being pursued by the MPMCD and its customers, but the extent to which these actions have reduced demands on Tom Steed Reservoir sufficient to withstand a drought worse than the 2010s Drought of Record remains unclear. The timing of the next drought matters. If a drought emerges in 2040 or 2050, population growth could increase water demands and potentially counterbalance advances made through conservation and efficiency improvements. This highlights the importance of making informed projections of future demands. Ultimately, by knowing how much demand pressure could be placed on Tom Steed Reservoir, additional actions and investments can be identified, including the timing thereof, to adapt accordingly. This may entail protecting the existing supply of Tom Steed Reservoir through improvements in water rights administration, optimizing existing infrastructure and improving water use efficiency, and/or pursuing supplemental supplies.

The challenge here is identifying the key factors that influence M&I water demands on Tom Steed Reservoir, and then understanding how those factors may (or may not) change over time. This is typically done by obtaining observed/historical use data, identifying trends over time, and then adjusting those trends accordingly to predict future conditions. Like reservoir supplies, the demands on a reservoir are neither fixed nor absolute, and assumptions have to be made that account for uncertainties. Multiple factors need to be considered, including the number of communities/entities served; population growth; types and sizes of customers and water use; measurement of use; system losses; and the role other supplemental supply sources may play in meeting M&I demands. Figure 2-33 illustrates a conceptual model of factors to consider as part of demand projections. A key challenge is trying to acquire and evaluate these data for all 29 entities that depend on Tom Steed Reservoir.

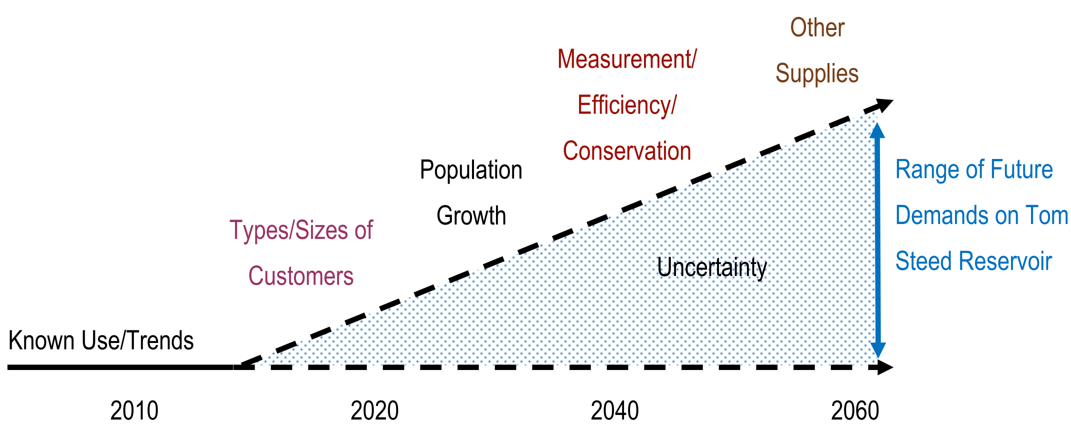

Figure 2-33. Conceptual illustration of factors that affect long-range water demand projections.

EQ Demand Challenges

The previous sections discussed the history of how EQ benefits became authorized as a Mountain Park Project purpose and were assigned to Hackberry Flat WMA. They described the 2010s Drought of Record and how deliveries to Hackberry Flat WMA were discontinued in an effort to conserve water for the M&I users. And they discussed the importance of shared shortage provisions within the MPMCD water delivery contracts and associated challenges of determining water availability thresholds that could trigger future shared shortages. In this section, the discussion turns to the challenges of fulfilling EQ benefits at the Mountain Park Project, including Hackberry Flat WMA.

When a portion of Frederick's M&I supply allocation was transferred for EQ purposes to the Hackberry Flat WMA, the U.S. effectively "purchased" (and continues to annually purchase) the EQ water because the MPMCD's Project repayment and annual O&M obligations were proportionally reduced to reflect the volume of water reallocated from M&I to EQ. In fact, this amounted to a $6.5 million reduction in MPMCD's Project construction repayment costs, and the U.S. has paid an average of $95,000 per year to the MPMCD to reimburse them for O&M costs attributable to EQ[52]. The U.S. therefore has an interest in ensuring Project EQ purposes are achieved, including during critical drought periods. And to the extent that these EQ benefits are not achieved, the U.S. has an interest in exploring other alternatives, such as reallocating all or a portion of the EQ benefits back to its original M&I use.

Water deliveries to Hackberry Flat WMA have fluctuated significantly from year to year (Figure 2-34). Between 1999 and 2011, at the start of the 2010s Drought of Record, a total of 25,024 acre-ft of EQ water was delivered to Hackberry Flat WMA. Over 2,000 acre-ft/yr has been delivered in seven of the 19 years since deliveries to Hackberry Flat WMA began, with a maximum delivery of 2,641 acre-ft/yr occurring in 2005 (Figure 2-34). Monthly deliveries

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[52] O&M costs attributable to EQ benefits that are based on MPMPD's O&M reimbursement requests between 2010 and 2014.

are illustrated in Figure 2-35. Deliveries to Hackberry Flat WMA average 1,250 acre-ft/yr (1,790 acre-ft/yr on average in years that water was delivered). Overall, the EQ has made restoration of the Hackberry Flat WMA a tremendous success both in terms of fish and wildlife propagation, and in terms of public education, wildlife viewing, hunting, and other outdoor opportunities. In addition, the wetland now plays an important role as a stopover location for migratory birds and federally-listed threatened and endangered species such as the Whooping Crane, Interior Least Tern, and Piping Plover.

However, Hackberry Flat WMA may not need that much water during years where the timing and amount of rainfall is sufficient to optimize wetland performance. As well, the lack of a water delivery contract may have affected decision-making and reduced the predictability and certainty of historic deliveries. Other considerations include the viability and optimization of infrastructure needed to regulate, convey, and measure water deliveries, as well as management and operations of the wetland system itself, which is complex and comprised of multiple interconnected units.

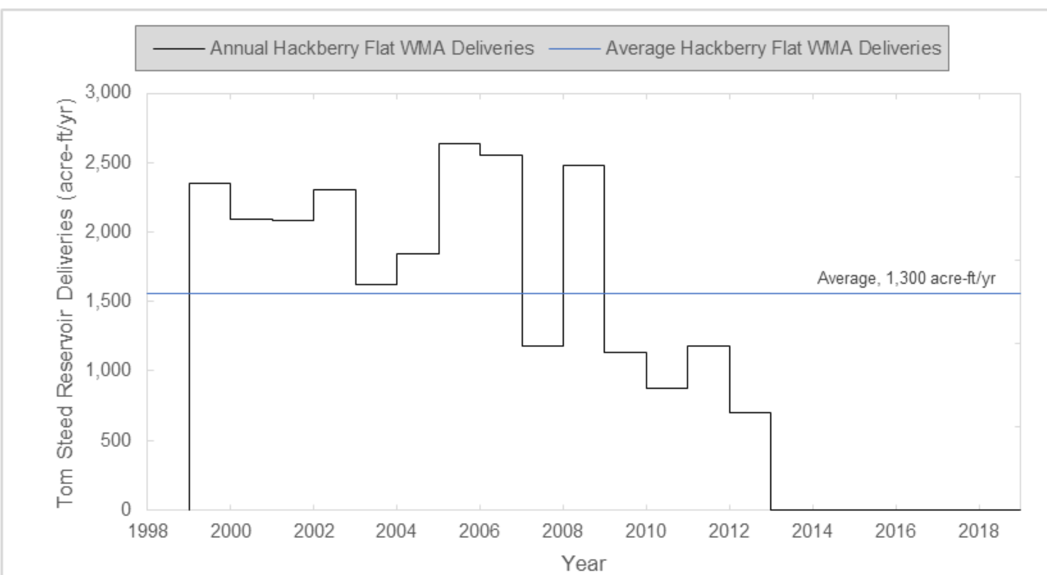

Figure 2-34. Annual and average water deliveries from Tom Steed Reservoir to Hackberry Flat WMA, 1999-2016.

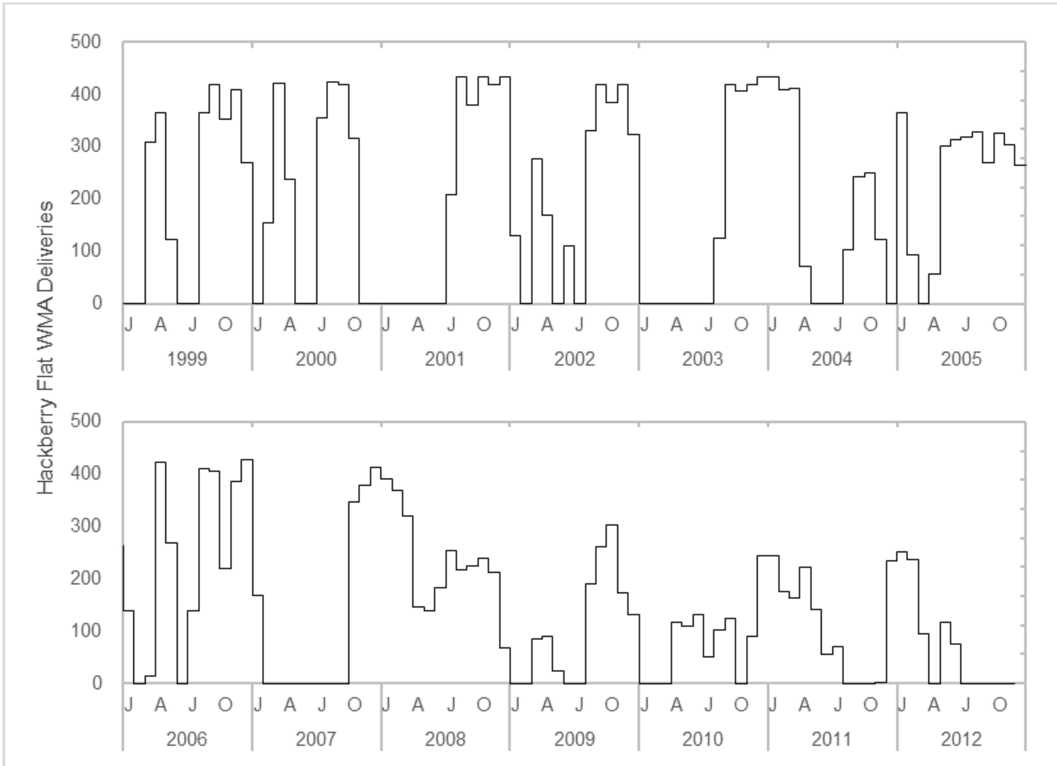

Figure 2-35. Monthly deliveries from Tom Steed Reservoir to Hackberry Flat WMA, 1999-2012. No deliveries have been made since 2012.

Looking towards the future, a key challenge is determining whether EQ benefits can be fulfilled at Hackberry Flat WMA, and if not, whether EQ benefits should be reassigned to another EQ activity and/or reallocated back to M&I purposes. Recall that the Mountain Park Project Act of 1994 defined the term "environmental quality activity" as any activity that "primarily benefits the quality of natural environmental resources." The Act required investigations of the benefits to natural environmental resources achievable from EQ activities that require reallocating water or using facilities or land of the Project, including (1) developing instream flows; (2) developing wetland habitat; and (3) any other environmental quality activity the Secretary determines to be appropriate to benefit the overall quality of the environment. The 1995 EQ Plan assigned EQ benefits to Hackberry Flat WMA, but the 2016 water delivery contract between the MPMCD and ODWC addresses EQ benefits more broadly in the following provision:

> "At times, the Project water allocated for use by the Department for the Hackberry Flat Wildlife Management Area will be in excess of the amount scheduled for use by the Department which will create surplus environmental quality water. The District shall utilize such surplus water for other authorized environmental quality purposes as directed by the United States. Such purposes may include maintaining reservoir levels in Tom Steed Reservoir, maintaining instream flows downstream of Tom Steed Reservoir, or other environmental quality activities that primarily benefit the quality of natural environmental resources as determined by the United States."

This provision provides the U.S. with discretion in determining when and how EQ benefits are assigned to the Mountain Park Project. Again, a challenge moving forward is establishing a framework and/or criteria by which to determine whether "success" has been achieved at Hackberry Flat WMA, and if not, how EQ benefits can be achieved elsewhere or reallocated for another purpose, namely back to its original M&I use.

Balancing Supplies and Demands

The challenges summarized thus far have focused individually on supplies and demands. The goal should be to evaluate supplies and demands together to avoid water supply imbalances. As previously discussed, from a planning standpoint, this entails using the best available data to make informed predictions about future conditions and understanding the associated risks and uncertainties. One of the key overarching goals of this study is to develop the models and tools to better understand these risks. Case in point: Figure 2-36 plots a projection of Tom Steed Reservoir's firm yield through 2060, along with historic water deliveries and a range of projected water demands. Figure 2-36 reveals a few points: (1) By 2060, sedimentation alone is projected to reduce Tom Steed's firm yield by 1,000 acre-ft/yr (seven percent) from 14,800 acre-ft/yr to 13,400 acre-ft/yr; (2) Tom Steed Reservoir's firm yield appears insufficient to deliver the MPMCD's water right of 16,100 acre-ft/yr; and (3) The projected firm yield is likely sufficient to meet future demands through the year 2050, but beyond that, if demands are relatively high, then the firm yield would not meet projected demands.

While these cursory projections are useful, importantly, the projections in Figure 2-36 very likely overestimate the firm supply of Tom Steed Reservoir. This is because existing modeling are incapable of accounting for potential reductions in inflows caused by potential changes in climate factors and/or from upstream groundwater and surface water permits, both of which are the subject of extensive analyses by this URRBS. By developing tools that account for these factors, a more robust range of reservoir yield projections can be produced. This should reduce uncertainty and risk, and ultimately help MPMCD and its customers take the necessary actions to (1) ensure that enough reservoir supplies are available to meet demands and/or deliver the MPMCD water right; and (2) pursue supplemental water supplies, as necessary, to meet demands.

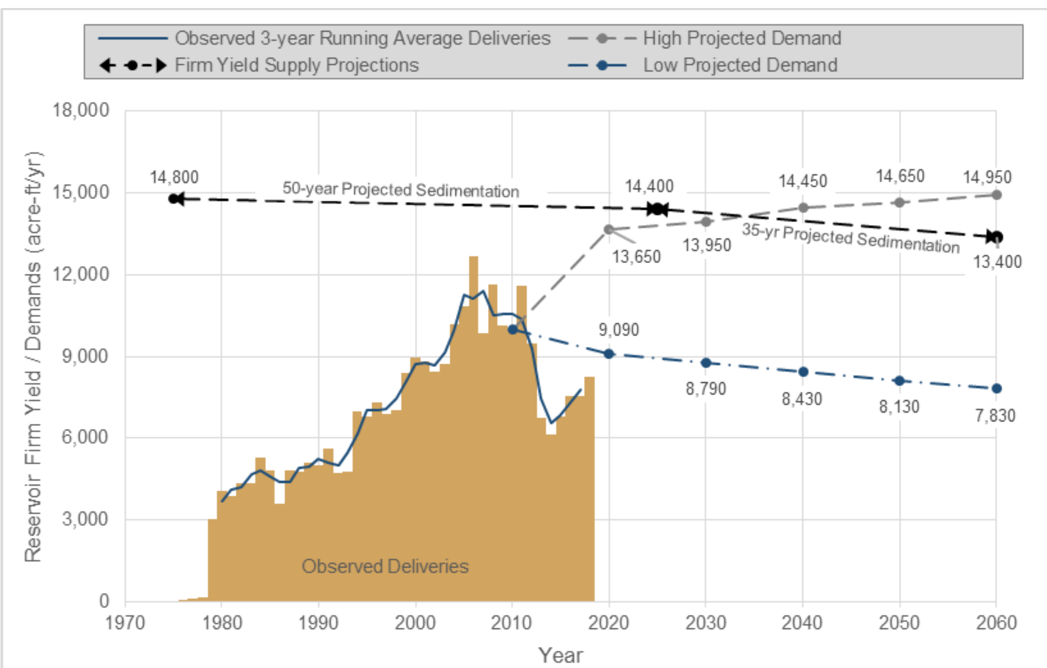

Figure 2-36. Sedimentation projections and firm yield of Tom Steed Reservoir combined with observed and projected water deliveries and demands through 2060.

2.4. Reclamation Infrastructure and Operational Challenges

The previous sections described the challenges facing Lugert-Altus and Tom Steed reservoirs associated with understanding and managing supplies and demands, including the risk of imbalances. Here, the focus is on challenges associated with infrastructure and operations, both of which are key strategies needed to adapt to and mitigate these imbalances, both now and into the future. This includes improvements in existing infrastructure and operations, as well as new infrastructure to advance the development of new supplies that could augment existing reservoir supplies or otherwise provide redundancy and diversification in the overall water supply system.

2.4.1. Lugert-Altus Reservoir

In light of the supply challenges facing the W.C. Austin Project over the years, Reclamation has completed two studies on the needs and opportunities to improve available supplies and develop new supplies to augment the W.C. Austin Project. The first was a preliminary evaluation of over a dozen alternatives to improve delivery efficiencies, add new storage, and augment supplies of Lugert-Altus Reservoir, where alternatives were ranked according to supply, costs, and environmental impacts (Reclamation, 2004). A second, more detailed appraisal investigation was completed on the merits of a select number of these alternatives, including efficiency improvements, water reuse, and the construction of new reservoir storage (Reclamation, 2005). The investigation found that infrastructure and operational efficiency improvements were the most cost-effective and least risky of the alternatives evaluated, followed by water reuse and new reservoir storage. Over the last decade, steps have been taken to improve efficiencies, but more opportunities remain; local stakeholders are poised to study the merits of water reuse on their own, along with a suite of other alternatives developed through locally-led planning efforts (discussed later in this report). Regarding new reservoir storage, stakeholder interest has focused primarily on the construction of one reservoir in particular, “Cable Mountain”; in fact, out of the full range of supply augmentation alternatives that exist, URRBS partners and stakeholders have asked Reclamation to focus its resources under the URRBS on the challenges and opportunities of constructing Cable Mountain Reservoir[53].

Existing Infrastructure and Operations

For the W.C. Austin Project, as previously discussed, one of the overarching goals of the Lugert-Altus ID is to reduce waste by matching on-farm demands with the amount of water delivered through canals. This entails ensuring that the Lugert-Altus ID’s existing network of pumps, canals, gates, meters, etc. is being operated, maintained, and modernized to the extent possible to prevent waste/losses while stretching available supplies. This raises an important question: what conveyance efficiency percentage could be a reasonable target for the Lugert-Altus ID?

Although a detailed site assessment would be required to make an informed conclusion, improving efficiency by 10 to 20 percent (from 65 percent to either 75 or 85 percent) would be consistent with efficiencies achieved by other IDs, such as those in southern Texas (Phipps, 2000). Assuming that the Lugert-Altus ID’s water right of 85,630 acre-ft/yr is available, a 10 to 20 percent efficiency improvement would improve irrigation supply from 55,660 acre-ft/yr to 64,200 acre-ft/yr (75 percent efficiency) or 72,800 acre-ft/yr (85 percent efficiency). This equates to about two to four inches per acre, respectively[54]. Assuming a targeted irrigation rate of 15 inches per acre, these improvements would stretch available supplies by about 8,500 acre-ft/yr to 17,100 acre-ft/yr, respectively. The key challenge for the Lugert-Altus ID is assessing the costs versus benefits of efficiency improvements, prioritizing the timing of

[53] Letter from Jed Winters, Chairman Southwest Action Plan Advisory Committee, Austin Chamber of Commerce. November 23, 2015.
[54] Assumes 15 inches per acre with 48,000 acres irrigated.

implementation, securing the necessary funds, and ultimately taking actions that minimize risk and present the biggest return on investment.

New Infrastructure

As important as efficiency improvements are towards stretching available supplies of Lugert-Altus Reservoir, they do not add more inflow into the reservoir or otherwise create a new supply which could improve reliability of the system or offset supply imbalances. One way to do this is through the development of new supplies. As previously mentioned, study partners and local stakeholders have asked Reclamation to focus on further studying the merits of Cable Mountain Dam and Reservoir. Located below the confluence of Elk Creek and NFRR downstream of Lugert-Altus Reservoir[55] (Figure 2-37), Cable Mountain Reservoir has the potential to provide a significant amount of supplemental water to the region, including the Lugert-Altus ID. However, significant challenges remain, including better understanding the volume and dependability of potential storage, financing and permitting, and undertaking measures to control/treat the high volumes of naturally-occurring saline water that would be impounded in the reservoir.

[55] The NFRR downstream of Lugert-Altus Reservoir also receives flows from the Elm Fork Red River.

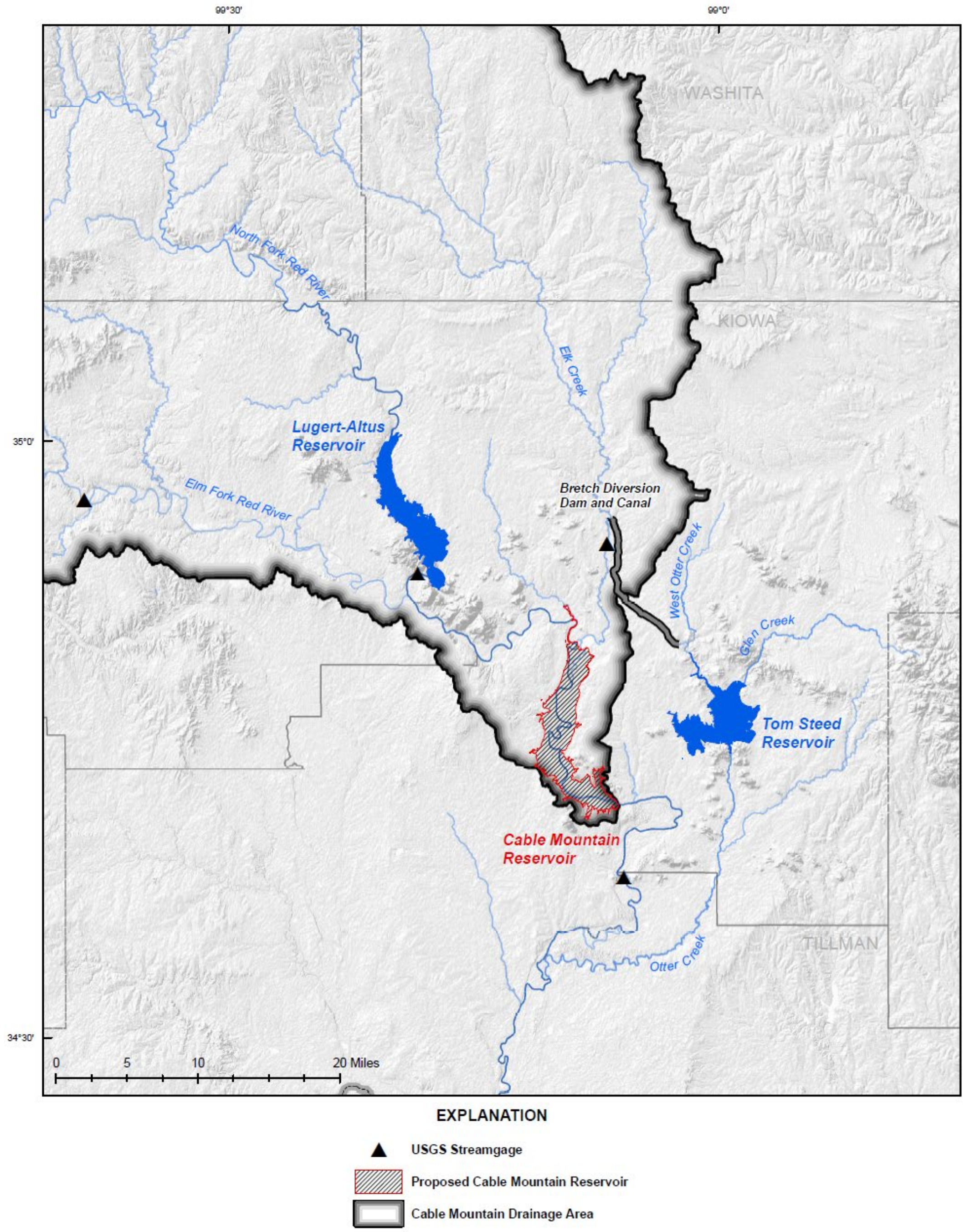

Figure 2-37. Proposed location of Cable Mountain Reservoir.

2.4.2. Tom Steed Reservoir

Existing Infrastructure and Operations

Optimizing and/or Expanding Elk Creek Diversions into Tom Steed Reservoir

The Mountain Park Project was designed such that Tom Steed Reservoir would receive its supply from two sources: (1) natural inflows from West Otter Creek and Glen Creek and (2) out-of-basin diversions from Elk Creek. Of the two tributaries, West Otter Creek is located within a smaller watershed, and while it provides less inflow into Tom Steed Reservoir on average relative to Elk Creek, West Otter Creek's base flows are higher which would help sustain Tom Steed Reservoir during prolonged drought periods. Elk Creek, on the other hand, is located within a much larger watershed, which enables it to capture more run-off from rain events. On average, Elk Creek provides relatively more inflows into Tom Steed Reservoir[56]; however, its base flows are lower, making them less reliable during prolonged drought periods. This highlights the importance of ensuring that flows in Elk Creek are captured from the Bretch Diversion when available. It also has raised the question of whether modifying the existing diversion and canal system to capture and convey additional Elk Creek flows could increase reservoir yield in a cost-effective way.

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[56] This assumes optimized Elk Creek diversions from the Bretch Diversion and Canal system.

Diversions from Elk Creek are made by storing water behind the Bretch Diversion Dam (Figure 2-38) and releasing it into the Bretch Canal for conveyance into Tom Steed Reservoir. The system was designed to convey river flow as needed to supplement Tom Steed storage when the reservoir drops below the top of conservation pool. Over the 30-yr-period that occurred prior to the 2010s Drought of Record, conditions were generally wet and Elk Creek diversions were minimal, in part to offset operation and maintenance costs, but also because Tom Steed Reservoir levels were fairly stable. As the 2010s Drought of Record unfolded and the reservoir elevation dropped, diversions were initially kept to a status-quo minimum. As conditions worsened, operations were eventually modified in the fall of 2013 such that all divertible flows from Elk Creek would be conveyed to Tom Steed Reservoir[57]. At its lowest point, Tom Steed Reservoir dropped to only 17 percent of storage (15,400 acre-ft), a record low, before the drought ended in 2015. Had Elk Creek diversions been initiated in 2010 when the reservoir first dropped below conservation pool rather than waiting until 2013 (a.k.a., "Optimized Bretch Diversions"), simulated storage of Tom Steed Reservoir would have only dropped to 25 percent of storage (23,500 acre-ft), assuming similar water demands (Figure 2-39). If water demands had been at the full permitted amount of 16,100 acre-ft, then optimizing Elk Creek diversions would have prevented Tom Steed Reservoir from going dry compared

Figure 2-38. Bretch Diversion and Canal, Mountain Park Project.

[57] About 10 cfs was allowed to pass for downstream uses.

to delivering the same amount of water under status-quo Elk Creek diversions. (Figure 2-39)[58].

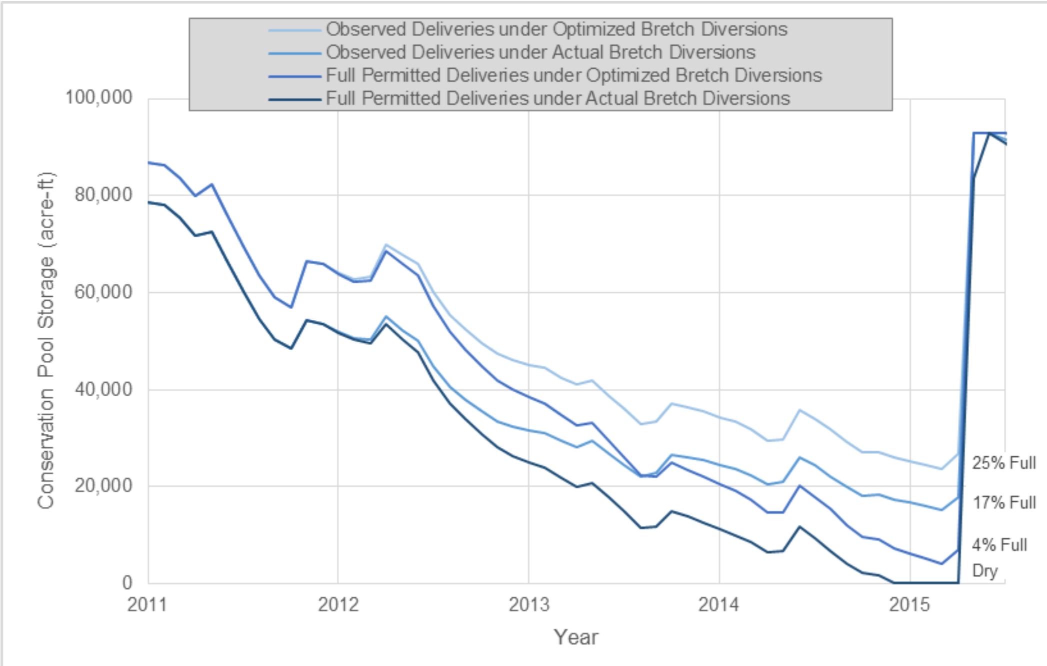

Figure 2-39. Tom Steed Reservoir storage under observed diversions from Elk Creek during the 2010s Drought of Record compared to modeled reservoir storage under optimized diversions, each shown with observed M&I deliveries and full permitted deliveries of 16,100 acre-ft/yr.

Assuming that optimized Elk Creek diversions become the new "status-quo", a key question that has been raised is whether there would be any benefit to Tom Steed's firm yield by expanding the capacity of the diversion system to capture additional flows from Elk Creek (Figure 2-40). Interest in this analysis was expressed in a letter from URRBS partners and stakeholders to Reclamation[59]. The Bretch Diversion Dam and Canal are currently sized with capacities of 970 acre-ft and 1,000 cfs, respectively. Their capacities were determined as the most efficient means of maximizing reservoir firm yield based an analysis included in the original 1962 Plan of Development for the Mountain Park Project. The original analysis used available hydrology data through 1959[60],

[58] Under 2060 sediment conditions, the reservoir would not be able to deliver the full permitted amount even under optimized Bretch diversions.
[59] Letter from Jed Winters, Chairman Southwest Action Plan Advisory Committee, Austin Chamber of Commerce. November 23, 2015.
[60] Monthly data from 1926 to 1959; daily data from 1949 to 1959.

including the 1950s drought of record (at that time). Considering over 50 years has passed since the original analysis, an opportunity exists to reevaluate whether or not Tom Steed Reservoir's firm yield could be enhanced, and at what cost, by increasing the capacities of the system using updated hydrology through 2015 that includes the new 2010s Drought of Record.

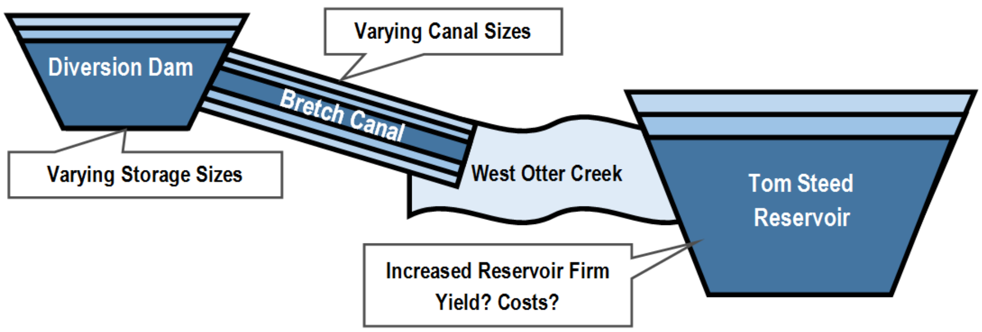

Figure 2-40. Conceptual illustration of the analysis of sizing the Bretch Diversion Dam and Canal System, Mountain Park Project.

Water Supply Contract Compliance

The water demands section above discussed the importance of operating the Mountain Park Project in a manner which balances deliveries through shared shortages during time of drought pursuant to the water supply contracts held between member entities and the MPMCD. This is an operation issue as much as it is a demand management issue. As previously stated, the "shared shortage" provision within each contract states that all participating entities shall, "share in the available water supply in the ratio of their contract rights during periods of scarcity when rationing is in the opinion of the MPMCD is required". The contracts address shortages further by stating that during such years that the MPMCD "determines" that "available project water supply" shall be less than the total combined amount of contracted water supply, then the amount of water available to the participating entity shall be limited to each participating entity's percent allocation of available project water supply. A key challenge is that an agreed-upon threshold does not currently exist to support the MPMCD's "opinion" or "determination" on whether the "available project water supply" constitutes a "scarcity". Predictive modeling tools would be required to make an informed determination on the "available project water supply" such that a shared shortage could be implemented prior to the reservoir volume falling below the total contracted water supply, at which point a supply deficit has occurred.

Hackberry Flat Infrastructure

Even if shared shortages were properly applied to users of Tom Steed Reservoir, challenges remain as it relates to the viability and optimization of infrastructure needed to regulate, convey, and measure water deliveries to Hackberry Flat WMA. While deliveries to Hackberry Flat continued for more than a decade, no deliveries have been made to Hackberry Flat WMA since 2013. The ODWC and MPMCD have indicated to Reclamation that a leading cause of the discontinuance of deliveries is that the 15.9-mile Hackberry Flat Pipeline (Figure 2-41) appears to be leaking a substantial volume of water and is likely no longer in viable condition[61]. The ODWC, which currently owns and operates the pipeline that was initially installed in 1999, has had discussions with MPMCD and Reclamation on the matter, but an initial step of performing a formal condition assessment on the pipeline has not been completed. Thus, the extent to which all or a portion of the pipeline can be repaired and/or replaced remains unknown. Another challenge relates to the storage and regulation of water that is either delivered to Hackberry Flat or otherwise that enters the wetland as natural run-off. First, questions remain as to whether sedimentation into the NRCS impoundment structure may be adversely impacting operations and reducing the efficiency of water deliveries. Second, a preliminary analysis conducted by Reclamation found that local rainfall and run-off may be sufficient to provide Hackberry Flat WMA with all or a portion of the water that could/would be delivered through the pipeline, assuming the pipeline issues cited above are addressed. Finally, challenges exist within the wetland itself in terms of

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[61] The pipeline connecting the Frederick Aqueduct to Hackberry Flat WMA was apparently donated to ODWC by an oil company that had used the pipeline to convey oil.

providing optimal flow regulation and measurement to achieve desired outcomes through the complex array of wetland cells.

Whatever the case may be, a reevaluation of Mountain Park Project benefits is warranted, including an assessment of the EQ water needs at Hackberry Flat WMA. The EQ needs should be evaluated from a new perspective that considers an up-to-date analysis on the management objectives of Hackberry Flat WMA, whether local and natural climatological/hydrological conditions may be sufficient to support those objectives, and whether delivering a lesser volume than 2,352 acre-ft/yr, or no EQ water at all, could impact achievement of the newly-developed management objectives at Hackberry Flat WMA. An optimization assessment also should be performed that identifies opportunities to conserve water through improved water management and instrumentation within the Hackberry Flat WMA complex.

Depending on the continued viability of the Hackberry Pipeline, and depending on the outcome of a reevaluation study on the needs and objectives of Hackberry Flat WMA, if all or a portion of EQ water remains unused, then an incentive may exist for the MPMCD to coordinate with any or all of its member cities, along with ODWC and Reclamation, to identify and implement steps to reallocate any unused EQ water back to M&I purposes.

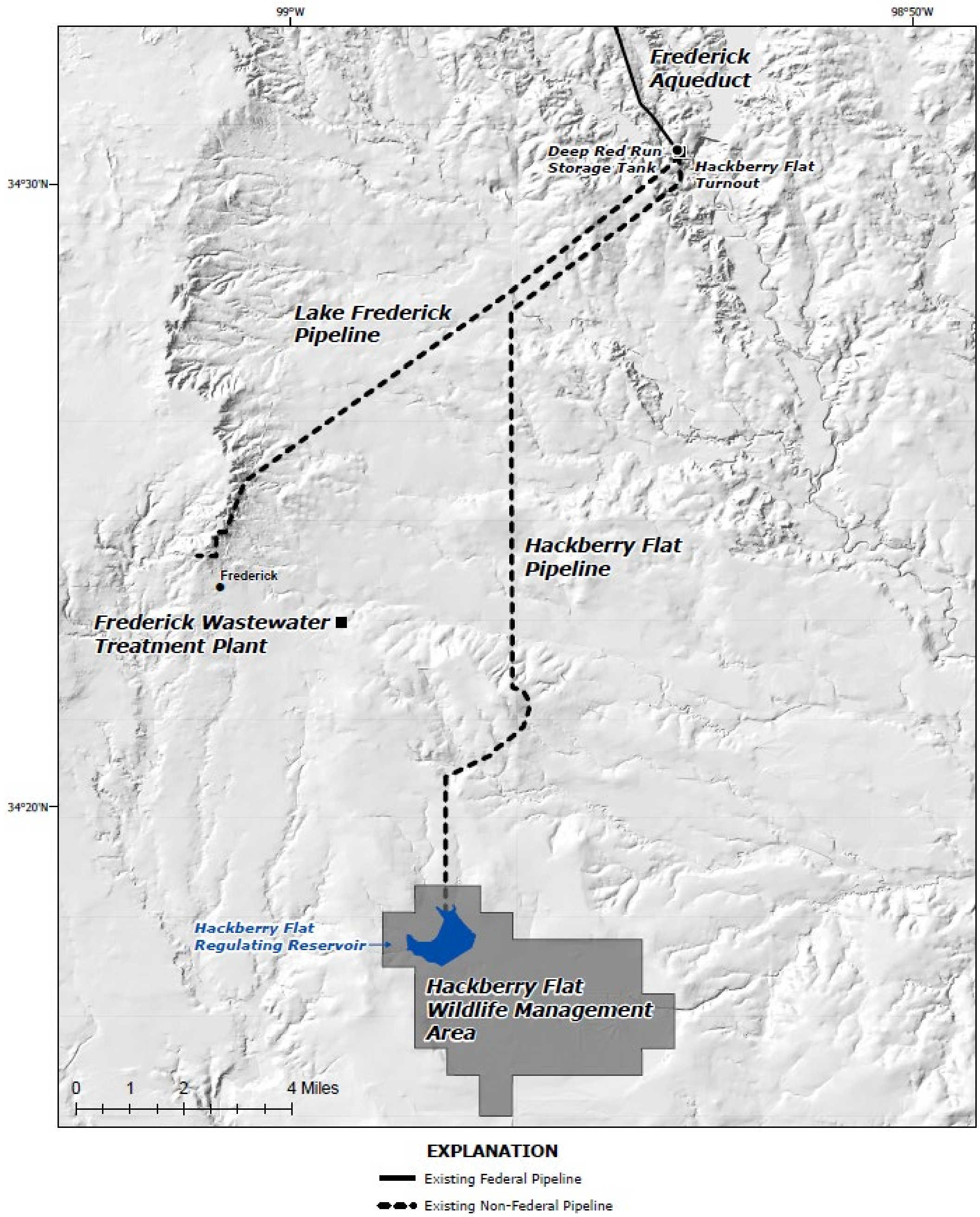

Figure 2-41. Existing infrastructure used to deliver water to Hackberry Flat Wildlife Management Area, Mountain Park Project, Oklahoma.

New Infrastructure

Construction of Groundwater Wells to Supplement Reservoir Yield

Previous sections of this report described the history and context into why the Mountain Park Project was designed to deliver a water quantity equal to the reservoir firm yield of 16,100 acre-ft/yr (based on the 1960s drought of record), and how the MPMCD was subsequently issued a surface water right by the OWRB for 16,100 acre-ft/yr. However, even under optimized Elk Creek diversions (as previously discussed), Tom Steed Reservoir would not have been able to provide enough water to furnish MPMCD's 16,100 acre-ft/yr water right. Modeling shows that Tom Steed Reservoir's new firm yield under a repeat of the 2010s Drought of Record is likely closer to between 14,800 acre-ft/yr and 13,400 acre-ft/yr (Figure 2-36)[62]. If one accounts for future depletions caused by the continued development upstream of the reservoir, then Tom Steed Reservoir's firm yield may be far lower.

Recognizing this newly-discovered vulnerability, the MPMCD has since been developing engineering plans to install new groundwater wells that would supplement Tom Steed Reservoir and fulfill Project purposes by helping ensure that the MPMCD's full water right of 16,100 acre-ft/yr can be delivered during a repeat of the 2010s Drought of Record. The wells would be installed on Project land adjacent to Elk Creek downstream of the reservoir, and groundwater would be conveyed through Project aqueducts that already deliver surface water from the reservoir for M&I purposes. Although the groundwater would be used as a redundant emergency drought supply, depending on the quality of the groundwater, the MPMCD is considering a continuous blending of groundwater with the surface water to help the city of Altus resolve THM issues at their water treatment plant.

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[62] The range in firm yield depends on the assumed sediment condition. The firm yield is 14,800 acre-ft/yr under 2025 sediment conditions and 13,400 acre-ft/yr is the firm yield under 2060 sediment conditions.

As a matter of legal authority, Reclamation has made an official determination that this supplemental groundwater would be considered "Project water"[63] because: (1) the wells would be located on Project land; (2) the MPMCD's contract does not specify whether its water rights are for groundwater or surface water; (3) the Project authorization does not specify the source of the water (i.e., ground or surface) that the Project would store, regulate, and furnish for M&I purposes; and (4) the cumulative groundwater and surface water delivered from the Project would not exceed the MPMCD's existing water right of 16,100 acre-ft/yr.

Key challenges remain on implementation of the project. First, plans need to be developed on how to integrate supplemental groundwater into Project operations, including the development of criteria or thresholds for volume and timing of groundwater supplementation. As well, additional coordination is needed to determine if any contractual changes are required; to formally establish when and how much groundwater will be conveyed; to establish who would be responsible for funding operation and maintenance costs for the groundwater wells; to determine who would hold the groundwater permit from the OWRB; to determine ownership of the wells; and to ensure compliance with the National Environmental Policy Act.

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[63] Federal law prohibits Reclamation from using its infrastructure to convey "non-project water" for M&I purposes. By deeming this groundwater source "Project water", the proposed project would be allowable under Federal law.

2.5. Challenges with Available Data and Models

The discussions thus far have focused on laying out the key elements that directly affect the supply reliability of Lugert-Altus and Tom Steed reservoirs, covering issues related to climate and hydrology, sedimentation, losses from human development within the watersheds; demands on the reservoirs themselves; and on having the infrastructure in place to firm up, augment, and/or deliver those supplies. Addressing the challenges of any one single element does not provide a "silver bullet" solution to reservoir supply reliability. Rather, it requires a broad, systematic approach that accounts for the role each element plays, as well as how that element combines with other elements to create a cumulative effect on reservoir supplies. Models can be a very useful tool to help implement this type of approach.

2.5.1. The Importance of Building Models

A "model" is simply a mathematical tool that provides a representation of assumed conditions that can be used to make predictions about the real world. For the outcome to be meaningful to water resource managers, it must be measurable/quantifiable, and it must be based on sufficient data collected based on sound scientific practices that are replicable and defendable. It also must exist within an existing or reasonably foreseeable legal, institutional, and regulatory framework.

For example, a key ongoing challenge previously discussed that manifested during the 2010s Drought of Record centered on trying to identify the root causes of such record-low reservoir levels, whether it was from natural phenomena triggered by drought conditions or from human development and associated withdrawals upstream of the reservoirs. As this study will demonstrate, models can serve as a powerful tool to help stakeholders better understand these issues, not only in terms of quantifying impacts on Lugert-Altus and Tom Steed reservoirs, but attributing the sources of those impacts, both individually and cumulatively. Furthermore, models can be used to evaluate strategies to respond and adapt to those impacts, including those that may alter how water is managed on the watershed-scale, and ultimately to measure success.

However, prior to building one or more models, one first needs to understand how the hydrologic system works as a whole, identify the variables that affect the system, and evaluate how to collect the best available data for model development. After all, the model is only as good as the variables and data that are input into the model. This stresses the importance of examining the strengths and weaknesses of existing models one might have available and identifying opportunities to either improve these models or build new models altogether.

2.5.2. Reclamation's Reservoir Yield Model

Prior to the construction of Lugert-Altus and Tom Steed reservoirs, O&M/repayment contracts between the U.S. and the local managing water districts were signed, and those districts were issued water rights by the OWRB to put the reservoirs' storage to beneficial use. The contracts, including apportionment of reimbursable project costs shared by the U.S., as well as the water rights, were in part based on an assumed (and expected) yield of the reservoirs. For planning purposes, Reclamation periodically updates these yield calculations when new conditions and/or data warrant consideration of different assumptions that are built into the calculation. Reclamation has done this using its RRY Model[64]. While the specific components of the RRY Model are indeed complex, the RRY Model's purpose has always been rather straightforward: determine how much water a particular reservoir can store and deliver under a

[64] The RRY Model was developed by OTAO staff and has been widely used in performing reservoir storage/yield calculations at OTAO's eleven reservoirs. The RRY Model has not been broadly adopted across Reclamation as a whole. Henceforth, the use of the term "Reclamation" in the context of this model is actually OTAO.

rather broad set of assumptions. As such, the RRY Model was designed such that variables going into the calculation generally occur at one point in space: the reservoir. The RRY Model was not designed to perform a basin-wide accounting of gains and losses or to distribute or quantify impacts in time and space within a watershed. With some modification, the RRY Model has been used by OTAO for cursory basin-scale "what if" analyses, but only by adjusting reservoir inflow to account for broad, lump-sum gains and losses in the watershed. Indeed, the detailed accounting needed to address the numerous challenges previously described requires a more sophisticated "network stream model". Such a model did not exist in the NFRR Basin until this URRBS.

That said, the RRY Model holds tremendous value, not only in its intended uses at a local, site-specific reservoir, but also because it can be used to calibrate and validate reservoir yield predictions that may be performed as part of a basin-wide simulation using a network stream model; details on the latter are discussed in Chapter 6. This stresses the importance of ensuring the RRY Model is adaptive and refined as needed to reflect changing conditions and the best available data. Next, the discussion turns to the challenges and opportunities to improve the data which make up the RRY Model.

For the purposes here, it is sufficient to state that at its core, the amount of water a reservoir can supply generally depends on two key factors: (1) how much water is entering the reservoir (i.e., inputs) and (2) how much water is leaving the reservoir (i.e., outputs). Figure 2-42 illustrates the variables that make up these inputs and outputs in graphic form in the RRY Model. Inputs into the reservoir are assumptions on future streamflow, precipitation, and sedimentation; the outputs are assumptions on future evaporation, flood releases, seepage, and deliveries[65].

[65] In the context here, "inputs" include variables that increase storage while "outputs" describe variables that reduce storage. Sedimentation is an exception: although sedimentation results in reduced storage, we include sedimentation as an input because it included in the starting reservoir storage volume.

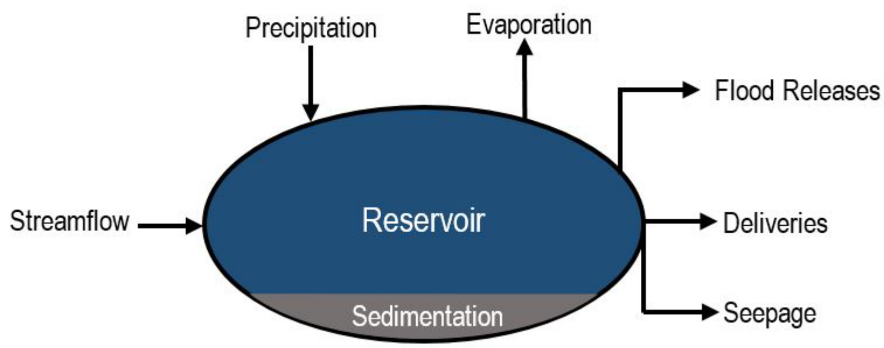

Figure 2-42. Schematic of RRY Model.

Firm Yield Mass Balance Equation

[**Starting Reservoir Volume** (Adjusted for Sedimentation)] + [**Inflow** (Streamflow + Precipitation)] – [**Losses/Uses** (Evaporation + Seepage + Flood Releases + Downstream Releases + M&I Deliveries)] = **Ending Reservoir Volume**

Figure 2-43 illustrates two storage scenarios of Tom Steed Reservoir: the top section features actual historical reservoir storage under 43 years (1975-2018) of observed conditions since construction, including through the 2010s Drought of Record. The bottom section features the RRY Model simulation of future Tom Steed Reservoir's storage that has been adjusted to account for sedimentation. The simulation includes not only the 43 years of observed storage data, but also includes storage based on an additional 50 years of observed streamflow and climate conditions that existed prior to reservoir construction. Under the RRY Model simulation, Tom Steed Reservoir's firm yield is 13,400 acre-ft/yr through the 2010s Drought of Record under assumed 2060 sediment conditions. Considering previous discussions on the challenges associated with understanding reservoir supply, two important questions one should ask are: (1) Which factors previously discussed are the primary drivers of Tom Steed Reservoir's yield? (2) What can be done to protect and enhance Tom Steed Reservoir's firm yield?

The largest contributing input to reservoir yield is streamflow. This is the reason such importance was placed in this study on understanding how streamflow is affected by natural climate/hydrology conditions versus the conditions caused by withdrawals from other users within the watershed.

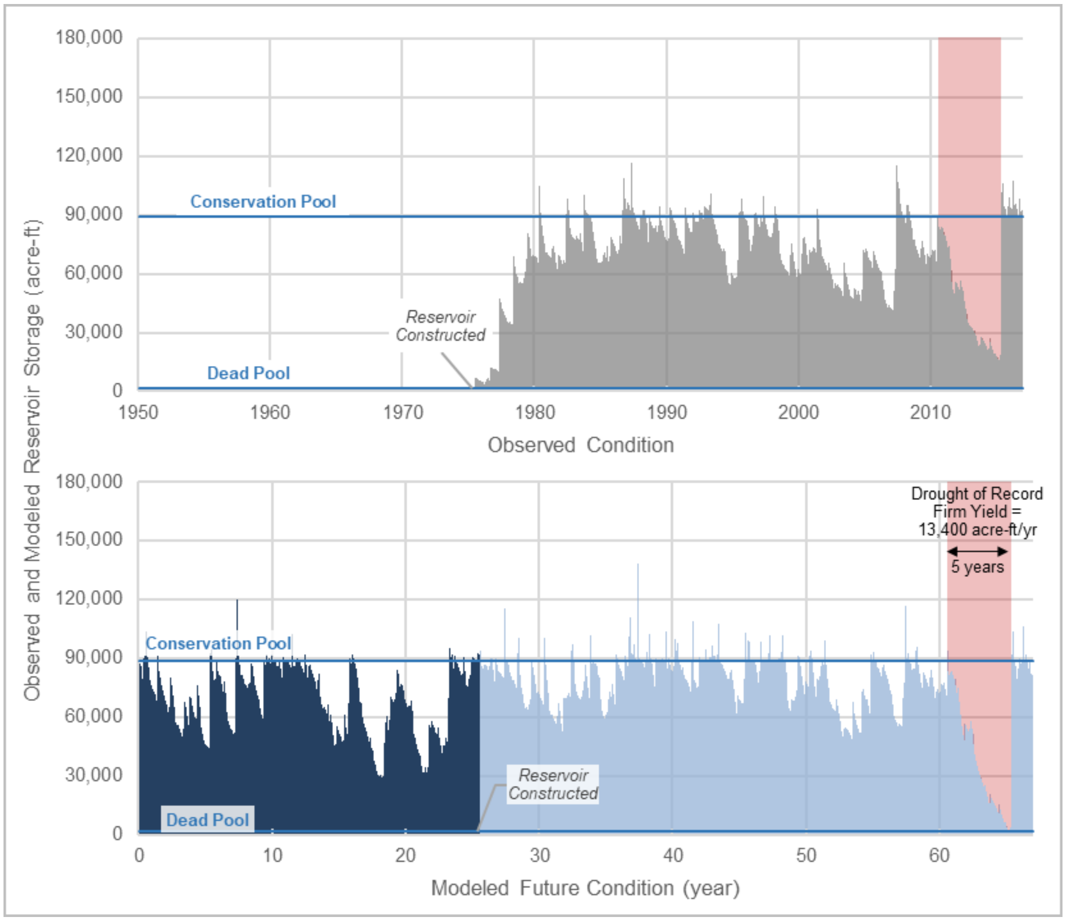

Figure 2-43. Top: Observed storage of Tom Steed Reservoir, 1975- 2018. Bottom: Simulated storage of Tom Steed Reservoir using the RRY Model over 67 years of observed stream flows and climate conditions. Dark blue shading illustrates simulated storage, adjusted based on sedimentation, using streamflow and climate conditions that existed prior to reservoir construction. Light blue shading illustrates simulated storage, adjusted based on sedimentation, based on 43 years of observed storage of Tom Steed Reservoir. The RRY Model shows that the firm yield is 13,400 acre-ft/yr under a repeat of the 2010s Drought of Record under assumed 2060 sediment conditions. Red shading illustrates the 2010s Drought of Record.

Precipitation and Evaporation

Historical

The measurement of historical precipitation onto, along with evaporation out of, the reservoir is relatively straightforward because these variables can be directly measured and/or extrapolated using standard practices (for the most part) regardless of whether one is accounting for pre-reservoir construction conditions or post-reservoir construction conditions; and, unlike streamflow, rainfall and evaporation are not readily subject to the influence of human development. Rainfall and evaporation are taken from the recorded values in Tom Steed Reservoir Water Supply Report, which are available from hydrologic and meteorological monitoring station (HydroMet) records. If data are missing, then extrapolations are made using the nearest weather/monitoring stations. Rainfall is combined with evaporation data to calculate a "net evaporation" rate, which is applied to the reservoir surface area to generate a volume of reservoir evaporation.

Future

The degree to which future precipitation and evaporation may impact reservoir yield is based on the assumptions one makes regarding the extent to which these variables may change over time. A commonly used assumption is that future precipitation and evaporation remain static relative to the past. This assumption is problematic because the observed period of record encompasses a relatively short period of time, creating a limited dataset from which to base assumptions on future conditions. Earlier, it was discussed in general terms how the combined impact of precipitation and temperature are measured through the PDSI, and in turn, how the observed PDSI based on historical data collected over the last 90 years can be compared to a reconstructed PDSI that is based on tree ring data representing conditions extending back hundreds of years. It was beyond the scope of this URRBS to use tree ring-informed PDSI data to make predictions about future climate conditions, including precipitation and evaporation, and subsequent impacts on reservoir supply[66]. Rather, this study focused on making predictions that build on the observed record encompassing 67 years of data from 1950- 2016 but took into account a range of important variables to improve the predictions.

Much effort has been placed on the collection of data and on the development of Global Climate Models (GCMs) that seek to predict future changes in climate, both on a broad scale and local scale. The problem is that GCM projections require numerous assumptions about initial conditions, and factors such as solar radiation, ocean dynamics, greenhouse gases, and volcanic activity to just name a few. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary. To further complicate matters, to assess how GCM outputs ultimately affect reservoir yield, one must then convert the global-scale precipitation and temperature projections to "down scaled" projections at the local level, and then ultimately use these data to make projections of streamflow into Lugert-Altus and Tom Steed reservoirs. Complications notwithstanding, the program under which this URRBS was conducted required an analysis of future climate change scenarios on future available water supplies and overall system reliability.

[66] The goal is to complete this type of analysis after completion of this URRBS.

Sedimentation

Historical

Sedimentation is another factor that affects reservoir yield. The amount of sediment accumulated is typically estimated using field data collected during a sediment survey. As previously discussed, such surveys have been conducted periodically over the years at both Lugert-Altus and Tom Steed reservoirs. These data were used to generate an "area-capacity curve" that is built into the respective reservoir model. However, it is important to point out that sedimentation rates vary depending on the type, location, and timing of sediment survey methods and analytics, as well as spatial and temporal changes in upstream land use, watershed management, and hydrology. These challenges present some level of uncertainty in the sedimentation rates used to calculate reservoir yield.

Future

For the purposes of this URRBS, projections of future sedimentation of Lugert-Altus and Tom Steed reservoirs were based on the most recent sediment surveys that were conducted in 2007 and 2009, respectively, as these were considered the best available data. Addressing the aforementioned challenges associated with collecting reliable sedimentation data were considered beyond the scope of this URRBS and are not further discussed.

Seepage

Historical

Seepage occurs when stored reservoir water is lost through percolation into the ground and/or underneath the dam. Seepage is difficult to quantify, although some measurements can be made at an earthen dam's toe drain outfall (for example). Under post-reservoir construction conditions, any seepage losses are already accounted for in the reservoir elevation data taken from the Water Supply Reports. These losses can then be applied to the pre-construction period.

Future

Future seepage losses were assumed to remain static relative to historical losses and are not discussed further in this report.

Flood Releases

Historical

Regulation of flood control storage at both reservoirs is directed by the U.S. Army Corp of Engineers, Tulsa District in accordance with Flood Control Act of 1944 (Section 7, Public Law 78-534, 58 Stat 890, 33 W.S.C. 709). Water is typically stored throughout the duration of a storm event in the flood control pool and released slowly overtime when downstream conditions are safe. If a storm forces the reservoir to store water into the surcharge pool, Reclamation then directs flood releases to protect the safety of the structure. An established decision framework has been agreed upon by all parties for both reservoirs and is used to guide and protect all parties involved.

Future

Flood releases are made by the RRY Model when simulated net inflow into the reservoir exceeds storage limits within the top of the reservoir's conservation pool. In this case, the "excess" volume above the reservoir's conservation pool is "spilled" (i.e., released) from the reservoir. These losses were calculated directly by the RRY model. In any month when a spill occurs, the end-of-month reservoir content will be equal to the content at the top of the conservation pool. In a month where no spilling occurs, the model showed the spill to be zero.

Deliveries

Historical

Historical water deliveries were accounted for in water delivery reports provided by the Lugert-Altus ID and MPMCD. Collection of these data are straightforward and not further discussed.

Future

The RRY Model reduces reservoir volume by the amount of irrigation and/or M&I water assumed to be delivered over the simulated time period. Earlier in this chapter, challenges associated with responding to irrigation needs were discussed, including maintaining compliance with water supply contracts, quantifying and/or projecting M&I and EQ demands, and the consideration of agriculture and M&I efficiency-use improvements and other conservation measures. To the extent these challenges are addressed, modeling the impacts that demands have on reservoir storage is relatively straightforward and was based on some assumed volume and distribution of demands placed on the reservoir by end users.

Streamflow

Streamflow is the largest input to reservoir supply, and it is more complicated to measure and simulate using a model because (1) when data are missing, extrapolation techniques are needed; and (2) they are influenced by gains and losses that vary in time and space. Gains in streamflow are primarily comprised of runoff from precipitation, as well as from base flows generated from underlying aquifers that connect to the stream. Losses in streamflow are primarily comprised of direct diversions from the stream, from pumping of an aquifer that connects to the stream which either reduces base flows or diminishes the underflow of the stream, and/or from natural seepage into an underlying aquifer.

Both of these factors present different challenges depending on whether one is accounting for historical conditions versus future conditions. In this section, the limitations of the RRY Model are discussed in terms of its ability to account for these complexities, in particular the gains and losses in the stream system.

Historical

For pre-construction periods, streamflow into a reservoir is extrapolated and reported in the project Definite Plan Report (DPR) using USGS gage data within the subject river basin, if available, although the data are adjusted depending on the location of the gage relative to the reservoir. If gage data are not available within the basin, streamflow may be generated using correlations developed based on gage data from an adjacent river basin. For post-construction periods, the RRY Model back calculates streamflows as "computed inflows" using actual observed end-of-month reservoir conditions as reported in Reclamation's monthly Water Supply Reports. These conditions are based on known reservoir levels and on assumed losses from reservoir releases, and assumed evaporation, seepage, etc. which have previously been described. The problem is, the computed inflows do not provide any insight into specific gains and losses upstream of the reservoir, and without information on gains and losses, one cannot simulate what streamflow would look like in a "naturalized" state. By naturalized, the stream is free from impacts caused by human development, including stream diversions and losses attributable to groundwater pumping in adjacent/underlying aquifers that connect with the stream; and without a naturalized state, one cannot discern between impacts on streamflow that may be attributable to humans versus those that are caused by the climatological limitations of the basin. This, in turn, limits the ability to make assumptions about how to account for and manage future streamflow and reservoir supplies. This is one of the key limitations of the RRY Model.

Future

The RRY Model simulates future streamflow by taking the historic "computed inflows" and forward projecting the computed inflows into the future (Figure 2-44). The future streamflow is often assumed to remain static, but adjustments can be made to account for assumed changes in climate factors such as precipitation and evaporation discussed earlier in this section. Those types of changes cannot be calculated or predicted using the RRY model; rather, those adjustments require yet another model, such as the Variable Infiltration Capacity (VIC) model[67]. The VIC model can quantify change factors that can subsequently be applied to streamflow and plugged into the RRY model to calculate reservoir yield. More discussion will focus on the VIC model later.

Assumed changes in streamflow also can be adjusted to account for future losses attributable to groundwater pumping and/or stream diversions, but those adjustments are rather arbitrary.

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[67] https://vic.readthedocs.io/en/master/.

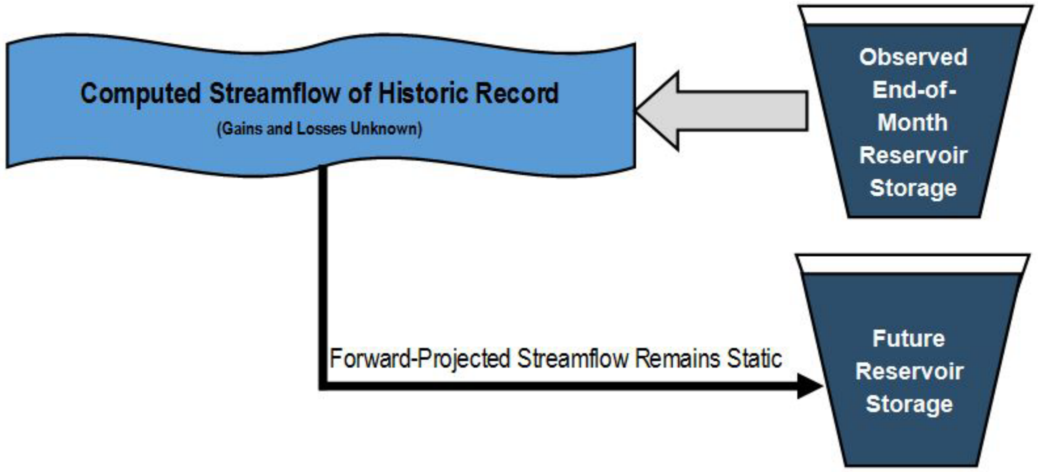

Figure 2-44. Schematic of the RRY Model's general approach towards calculating future reservoir storage.

The problem is, neither the computed inflows of the past, nor the forward-projected streamflows of the future used in the RRY Model account for the location, volume, and timing of gains and losses in streamflow that have occurred, are occurring, or could be occurring in the future. Without a measurement of gains and losses in the system, one cannot meaningfully attribute reductions in reservoir yield to any particular source, whether it is naturally occurring climatic and hydrologic events and/or upstream withdrawals from surface diversions and groundwater pumping. Subsequently, if the status quo continues, the managers of Lugert-Altus and Tom Steed Reservoir could be left without any recourse to protect the yield of their reservoirs or otherwise mitigate and adapt accordingly. This is a fundamental limitation of the RRY Model; while the RRY Model is good at measuring reservoir yield, it is not useful at evaluating the stream system as a whole.

Therefore, a key challenge is to collect the necessary data and develop a model or set of models that can use those data to quantify the gains and losses in the system, including reasonable measurements on the location, volume, and timing thereof (Figure 2-45). Furthermore, the calculations must be done under the existing (and reasonably foreseeable) legal and regulatory framework of Oklahoma that determines how surface and groundwater are permitted and managed.

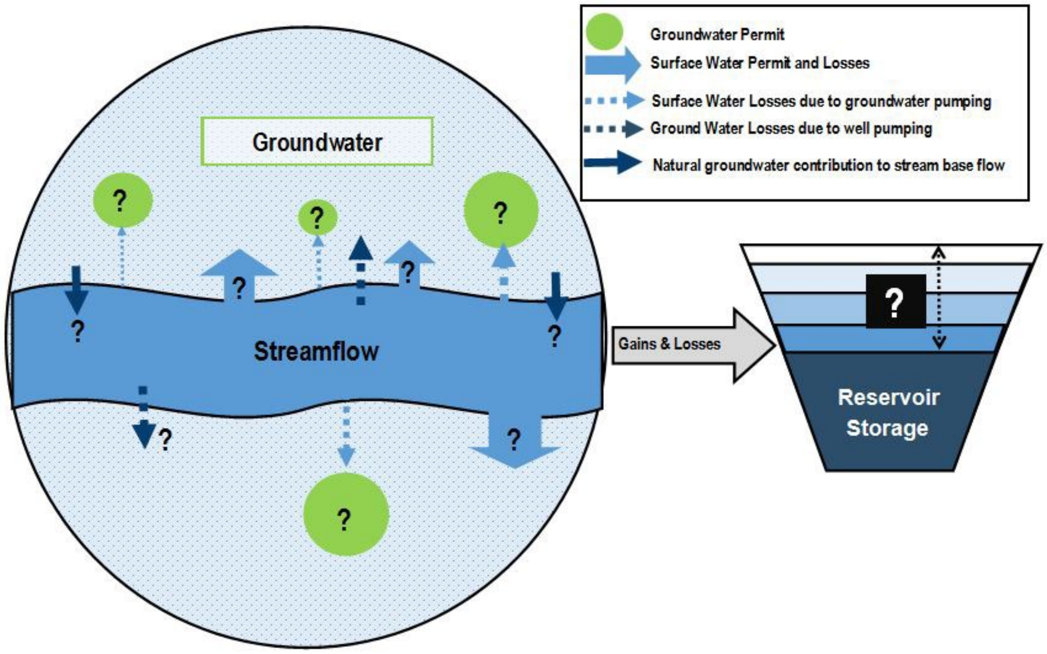

Figure 2-45. Schematic of the gains and losses associated with groundwater and surface water and associated impacts on reservoir storage.

2.5.3. Measuring Impacts of Surface Water Diversions

Historical Surface Water Diversions

Surface water diversions include non-permitted domestic uses, as well as permitted uses. It is difficult to measure the direct impacts of domestic or permitted use in the NFRR basin because Oklahoma law does not require users to meter or otherwise measure the volume of water diverted from an authorized diversion point. That said, permit holders are required to report their use to the OWRB on an annual basis which is maintained by the OWRB in their water rights database[68]. Because it is self-reported and not verified, some claim that reported-use statistics are inflated, while others claim the opposite; whatever the case may be, reported use is currently considered the best available data when accounting for withdrawals associated with a specific surface water permit.

In addition to reported use, withdrawals can be measured or interpolated using other methods, such as calculating the difference in flow occurring at two locations where the flow can be directly measured (i.e., by a USGS gaging station). But again, without metered data, the source of diversions remains unknown, including whether or not they are the result of permitted users or domestic users. Reported use can be evaluated in combination with USGS gage data, but uncertainty still remains. Other important factors including precipitation run-off, evaporation, and groundwater-surface water interaction need to be taken into account. Such an accounting requires a network stream model of the watershed - and to the extent that interactions are occurring with an aquifer, it also requires a groundwater model that considers the aquifer's hydrogeology and can account for the aquifer's inputs and outputs, including groundwater pumping (discussed in the next section). Neither of these models exist in the NFRR Basin.

[68] Under Oklahoma law, domestic users are not required to report their water use to OWRB.

Future Surface Water Diversions

The same set of challenges confront attempts to quantify future surface water diversions. Further complicating the matter is another layer of questions that need to be answered when one considers future growth and development. In the end, assumptions have to be made on items such as:

1. Of the existing permit holders in the watershed, how much of their permitted amount might be put to beneficial use in the future? What would be the impacts if all permit holders were withdrawing their full permitted amounts?
2. How much additional growth may be expected, and where?
3. What are the expected types of use (agricultural use, M&I, oil and gas, etc.)?
4. To what extent would future water supplies be available to meet these needs?
5. How much of this use would be permitted versus for domestic purposes?
6. How might future permits be regulated under Oklahoma water law?
7. What role could changing climate conditions affect supplies and demands, and subsequently the amount of surface water available to meet those demands?

As previously stated, Reclamation's "default" approach over the years has been to simulate future streamflow using the RRY Model by taking computed inflows and forward projecting the computed inflows into the future. While future streamflow is often assumed to remain static, "what if" scenarios can be made to run by the RRY Model that incorporate lump-sum changes in reservoir inflow due to an assumed withdrawal from upstream development. But again, these types of scenarios are somewhat arbitrary relative to more-informed scenarios based on actual data and outputs from a combined groundwater/network surface water modeling approach.

The approach employed by the OWRB to appropriate surface water permits faces some of the same limitations as those faced by the RRY Model. For example, when evaluating an application for a new surface water permit, the OWRB's default approach (discussed more in Chapter 2.5.6) assumes that future average annual streamflow is based on historic precipitation run-off conditions that repeat into the future; the OWRB then assumes a certain amount of future withdrawals are occurring from domestic use, and that existing permit holders are withdrawing their full permitted amounts. In the case of reservoir permits, the same holds true; but importantly (as previously stated in Chapter 2.2.3 under Oklahoma Water Law Basics), the withdrawal is premised on the OWRB's assumption that the volume of reservoir storage needed to deliver the permitted amount is equal only to the permitted amount (i.e., if MPMCD's permits equals 16,100 acre-ft/yr, then 16,100 acre-ft/yr is needed in reservoir storage). The fact is, because of evaporation, transpiration, seepage, etc., the amount of water needed in storage will always exceed a like amount of water needed for delivery. The "storage to delivery" ratio increases rapidly during a drought as precipitation decreases and evaporation increases, with the ratio maximizing during a repeat of the drought of record, where the RRY Model shows that to deliver the reservoir's permitted amount, the entire active conservation pool storage is needed at the onset of the drought.

2.5.4. Measuring Impacts of Groundwater Pumping

Groundwater pumping presents a different set of challenges, particularly when it is alluvial groundwater that is hydrologically connected with streamflow. Reductions in streamflow can reduce reservoir yield, which can affect the management of appropriated stream-water rights, which in turn, could affect the management of permitted groundwater (Figure 2-46).

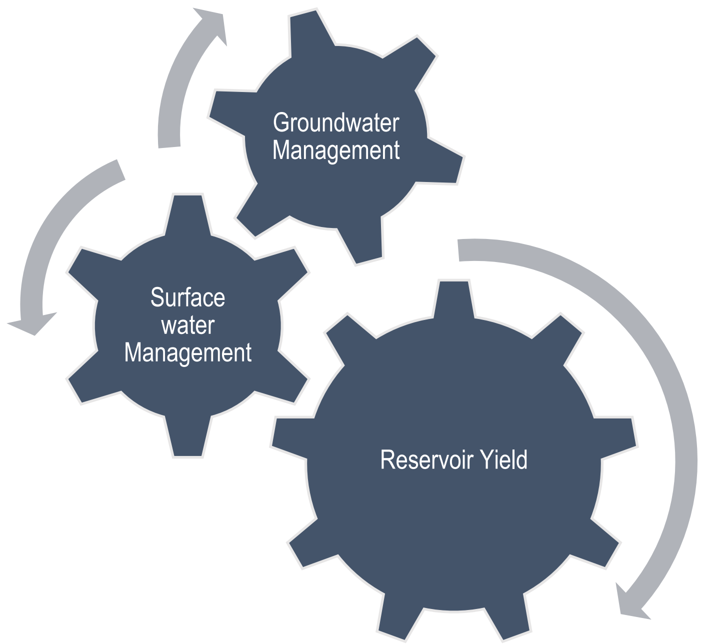

Figure 2-46. Conceptual illustration of the interrelationship between groundwater management, surface water management, and reservoir yield.

Measuring the impacts of groundwater pumping on streamflow is more complex than measuring the impact of a surface water diversion alone. This is because the withdrawal from a groundwater well is further removed from the stream, both in time and space, and is subject to complex hydraulic features that affect the location, rate, and direction of groundwater flow. Before discussing the challenges associated with understanding and measuring impacts of historical and future groundwater pumping on streamflow in the context of this URRBS, an overview of key terminology and characteristics of aquifers is provided. These discussions were taken from USGS Circular 1376, "Streamwater Depletion by Wells – Understanding and Managing the Effects of Groundwater Pumping on Streamflow" (Barlow and Leake, 2012). Interested readers should refer to this publication for details.

Groundwater 101: Aquifer Terminology, Characteristics, and Processes

The term aquifer refers to subsurface deposits and geologic formations that are capable of yielding usable quantities of water to a well or spring. In most locations, an unsaturated zone, in which both water and air fill the voids, exists immediately beneath the land surface (Figure 2-47). At greater depths, the voids become fully saturated with water. The top of the saturated zone is referred to as the water table, and the water within the saturated zone is groundwater.

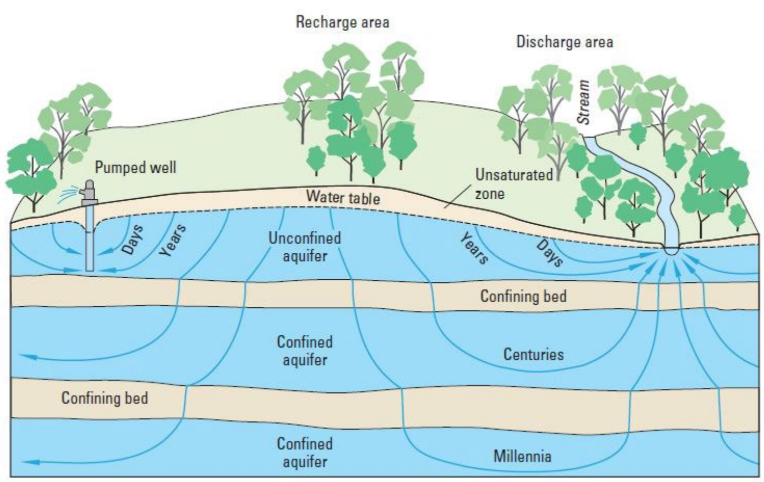

Figure 2-47. Groundwater flow paths in a multi-layer aquifer groundwater system. Groundwater flows from recharge areas at the water table to discharge locations at the stream and well. The movement of groundwater can range from days to millennia. Modified from Barlow and Leake (2012).

Most aquifers are classified as either confined or unconfined. A confined aquifer is one that lies between two confining layers, whereas an unconfined aquifer is one in which the uppermost boundary is the water table (Figure 2-47). Because of their proximity to land surface and associated surface waters, unconfined aquifers are often of interest when one is concerned about streamflow depletion by wells; however, pumping from confined aquifers also can cause depletions. The NFRR and Elk City aquifers are considered unconfined aquifers (Kent, 1980; Kent and Lyons, 1982, respectively).

Groundwater moves through aquifers from areas of groundwater recharge to areas of groundwater discharge (Figure 2-47). The upper, unconfined aquifer shown in Figure 2-47 is recharged by water that infiltrates across the land surface and then moves downward through the unsaturated zone to the water table to become groundwater. The source of groundwater recharge typically is precipitation (rain or melted snow) but can also originate from human sources such as infiltration of irrigation return flow and septic-system wastewater. The collection of water at the top of the saturated zone causes the water table to rise, and as a result, the saturated thickness of the unconfined aquifer increases. As recharge diminishes, the water table will decline, and the saturated thickness will decrease. Groundwater commonly discharges to streams and wells, as illustrated in Figure 2-47, but it can also discharge to springs, lakes, and ponds; and by evaporation and plant transpiration in low-lying areas where the water table lies close to land surface, such as in wetlands or near streams. The residence time of water in a groundwater system can range from days to a few years for water recharged close to discharge boundaries, to millennia for water that travels along deep flow paths through low-permeability materials.

The direction of groundwater flow is determined from measurements of the altitude of groundwater levels made in wells. Groundwater levels are equivalent to hydraulic heads and reflect the total potential energy of the groundwater system at the point of measurement. In a manner similar to flow in other potential fields (such as in electrical or thermal systems), groundwater flows from locations of higher potential energy to locations of lower potential energy and, therefore, in the direction of decreasing hydraulic head (Figure 2-48).

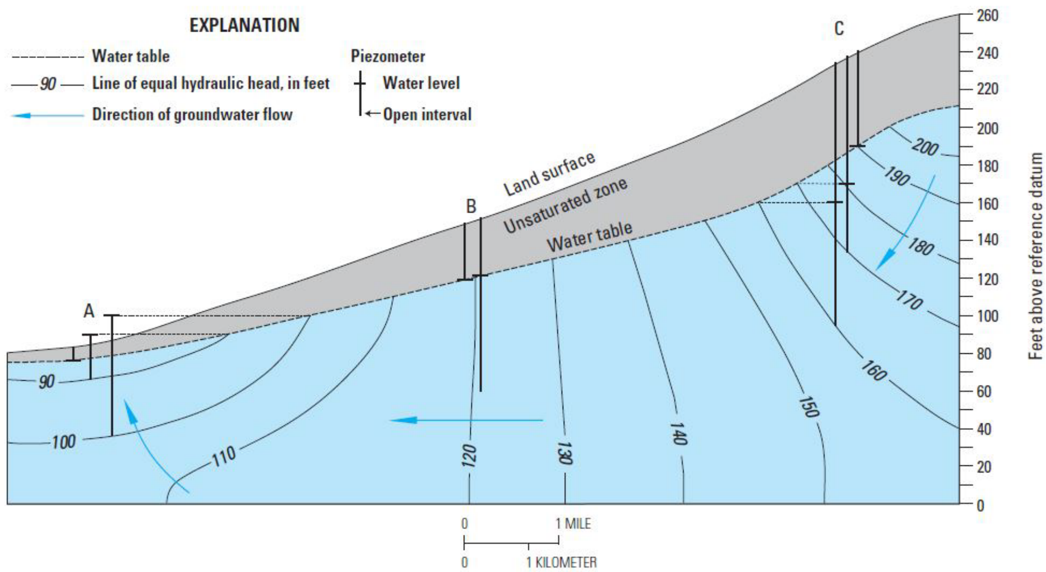

Figure 2-48. Distribution of hydraulic-head contours (groundwater levels) showing groundwater-flow directions in a vertical section of a hypothetical unconfined aquifer. Groundwater levels are measured in piezometers, which are a type of observation well. Measurements at location C indicate downward groundwater flow at that location, whereas measurements at locations B and A indicate lateral and upward flow at those locations, respectively. Modified from Barlow and Leake (2012).

The rate of groundwater flow in a particular direction is dependent on the hydraulic conductivity of the aquifer and the gradient of the hydraulic head in the direction of interest. For groundwater systems dominated by horizontal flow, the transmissivity at each location in the aquifer is a product of the hydraulic conductivity and the saturated thickness at that location. The hydraulic gradient, which is equal to the change in head over a unit distance, can be determined from pairs of water-level measurements or from water-level contours drawn for a horizontal or vertical section of an aquifer. The hydraulic gradient between the 130- and 120- ft contours shown in Figure 2-48, for example, is approximately 10 ft per mile, as determined by the change in hydraulic head between the two contours divided by the approximate distance between the contours along the flow line.

Groundwater systems are referred to as being in either a steady-state or a transient condition. A steady-state system is one in which groundwater levels and flow rates within and along the boundaries of the system are constant with time, and the rate of storage change within the flow system is zero. A transient system is one in which groundwater levels and flow rates change with time and are accompanied by changes in groundwater storage. Transient conditions occur in response to changes in flow rates along the boundaries of a groundwater system, such as short-term and long-term fluctuations in recharge rates, or changes in flow rates at points within a groundwater system, such as fluctuations in pumping rates. Although steady-state flow conditions rarely occur for real-world hydrologic conditions, it is often acceptable to assume that steady-state conditions exist if the fluctuations in water levels and storage changes are relatively small or if there is an interest in an evaluation of the long-term average condition of the flow system. Many studies of regional aquifer systems, for example, are conducted with the assumption that steady-state conditions occurred prior to large-scale groundwater development. During the predevelopment period, average rates of natural recharge and discharge to the aquifers are assumed to have been in long-term balance.

Groundwater and Streamflow Interaction

The sources of water flowing in streams are generally recognized to result from four processes (Linsley et al., 1982): precipitation that falls directly onto a stream, which is a relatively small component of total streamflow; surface runoff (or overland flow) that travels over the land surface to a stream channel; interflow (or subsurface storm flow) that moves through the upper soil layers to a stream channel; and groundwater discharge, which is commonly referred to as base flow. Surface runoff and interflow are important during storm events, and their contributions typically are combined into a single term called the direct-runoff component of streamflow. Groundwater on the other hand is most important for sustaining the flow of a stream (i.e., base flow) during periods between storms and during dry times of the year.

That said, streams and rivers are commonly the primary locations of groundwater discharge, and groundwater discharge is often the primary component of streamflow. Groundwater is discharged to the stream where the altitude of the water table is greater than the altitude of the stream surface (Figure 2-49A). Conversely, streamflow seeps into the underlying groundwater system where the altitude of the stream surface is greater than the altitude of the adjoining water table (Figure 2-49B). Stream reaches that receive groundwater discharge are called gaining reaches, and those that lose water to the underlying aquifer are called losing reaches. The rate at which water flows between a stream and adjoining aquifer depends on the hydraulic gradient between the two water bodies and also on the hydraulic conductivity of geologic materials that may be located at the groundwater/surface-water interface.

Figure 2-49C illustrates the effects of gaining and losing conditions on streamflow during a period of no direct surface-water runoff to the river. The figure shows that the rate of streamflow increases along gaining reaches and decreases along losing reaches. The figure also demonstrates that a stream can have both gaining and losing reaches simultaneously. Moreover, because precipitation rates, pumping rates, and other hydrologic stresses vary with time, it is possible for a particular stream reach to switch from a gaining to a losing condition or from a losing to a gaining condition from one period of time to the next.

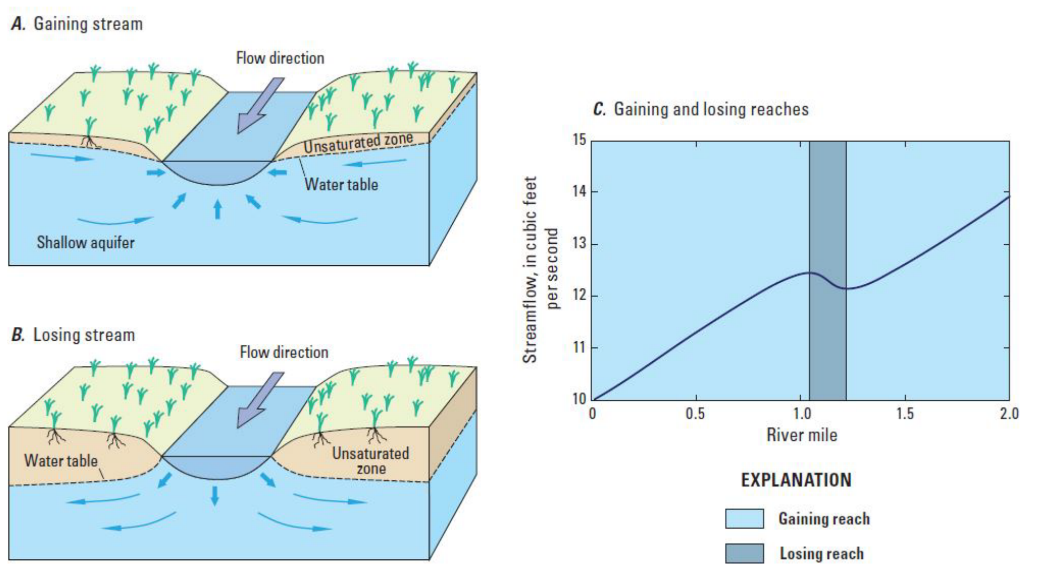

Figure 2-49. Schematic A depicts a “gaining” reach of a stream that receives water (discharge) from an aquifer whereas schematic B depicts a “losing” reach of stream that loses water to the aquifer. Schematic C depicts a hypothetical stream comprised of two gaining reaches separated by a losing reach.

Measuring Streamflow Response to Groundwater Pumping

One of the key challenges in measuring streamflow response to groundwater pumping is understanding the influence of various factors over a period of time. When a groundwater well begins to pump water from an aquifer, groundwater levels around the well decline, creating what is called a “cone of depression” in the water levels around the well (Figure 2-50A). The hydraulic gradient that is established within the cone of depression forces water to move from the aquifer into the well. Initially, all of the water pumped by the well comes from water stored in the aquifer (Figure 2-50B). But as the cone of depression deepens and expands with increased pumping time, it may alter the groundwater gradients and lead to reductions in streamflow (Figure 2-50 C and D). As one might assume, the volume of streamflow reduction will vary depending on the number of wells, location, and pumping rates along the stream.

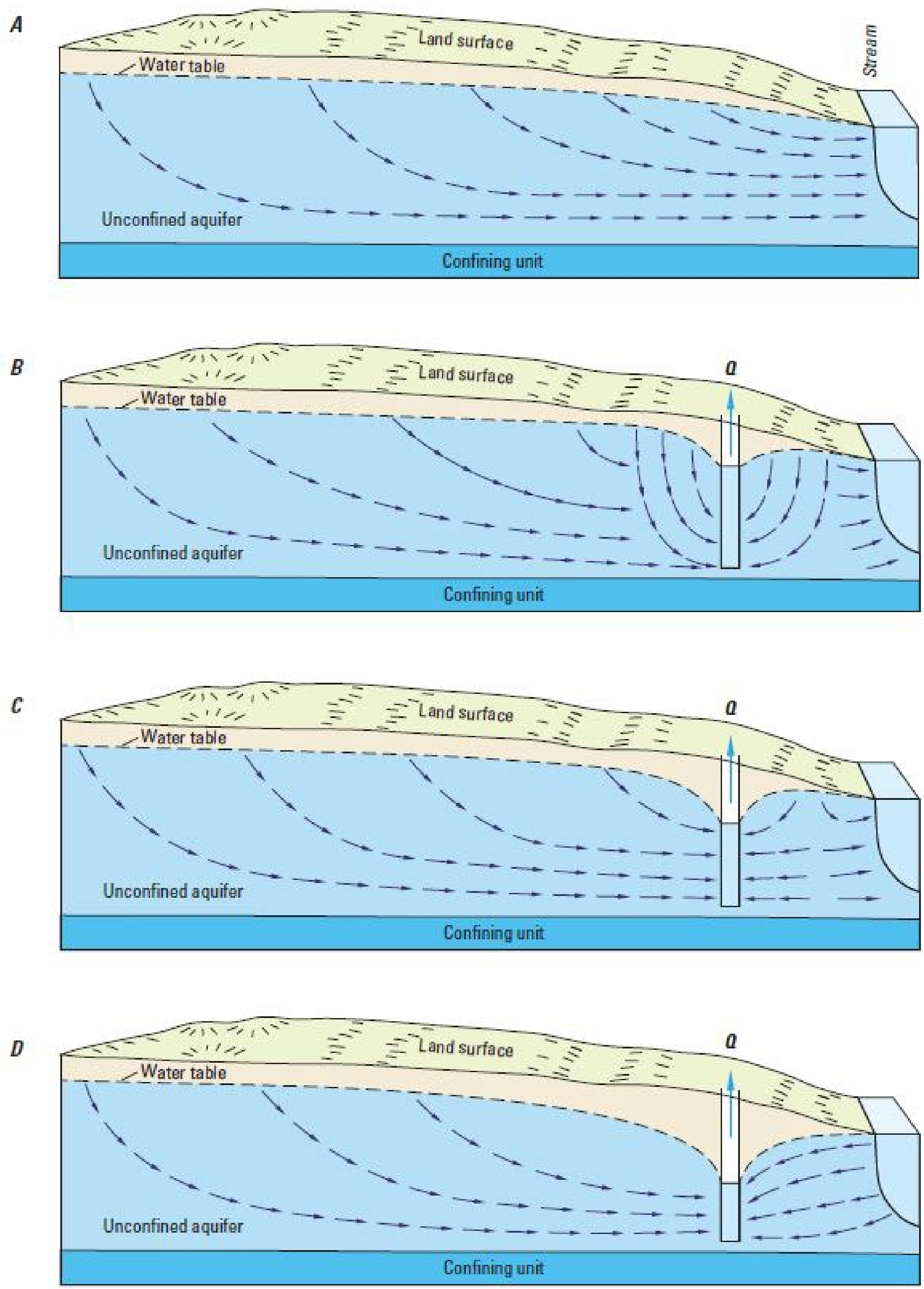

Figure 2-50. Effects of pumping from a hypothetical water-table aquifer that discharges to a stream. Under natural conditions, A, recharge at the water table is equal to the discharge at the stream. In B, soon after pumping, a "cone of depression" is created around the well and all of the water pumped by the well is derived from water released from groundwater storage. In C, *as the cone of depression expands outward from the well, the well begins to capture groundwater that would otherwise have discharged to the stream. In D, groundwater pumping has sufficiently increased enough to prevent any groundwater from discharging into the stream.*

This is illustrated through a hydrograph of a stream following 180 days of pumping from a hypothetical well in proximity to a stream (Figure 2-51). The lower curve illustrates that streamflow continues to rise and fall in response to precipitation events, but the rates of streamflow are lower than those that would occur in the absence of pumping. Another way of viewing reductions in streamflow that can result from pumping at a hypothetical well are illustrated in Figure 2-52, which shows how the source of well water changes over time with continued groundwater pumping.

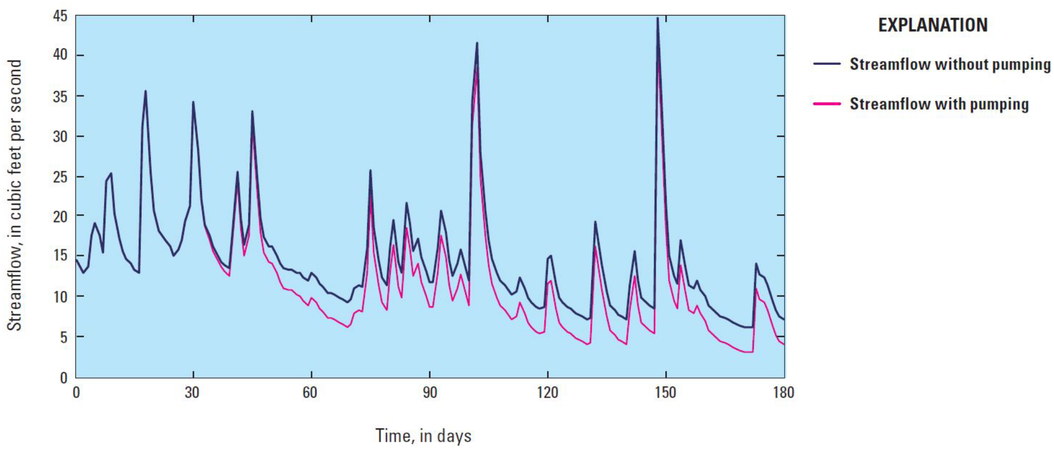

Figure 2-51. Effects of groundwater pumping on a hypothetical streamflow hydrograph. Top curve shows daily streamflow without pumping at a nearby well. Lower curve shows daily streamflow with pumping from a well located near the stream at a rate of 2.0 million gallons per day (about 3.1 cubic feet per second) beginning at day 30. After about day 60, the total decrease in streamflow each day is equal to the pumping rate of the well.

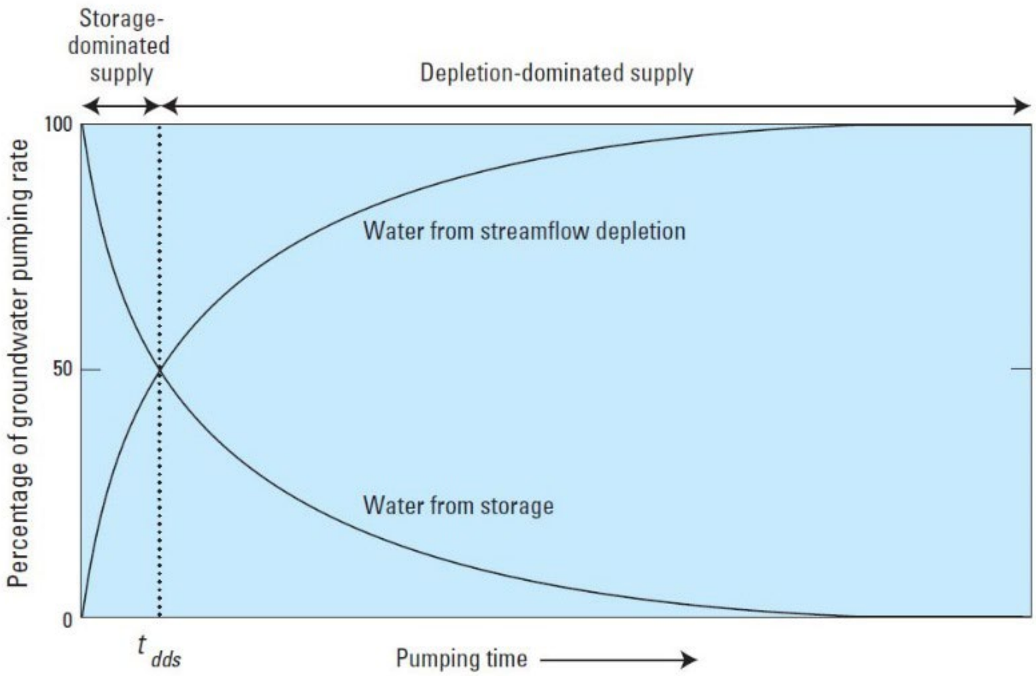

Figure 2-52. Relation of storage change and streamflow depletion as sources of pumped groundwater through time for a hypothetical well. Initially, the source of water (or supply) to the well is dominated by reductions in aquifer storage. At later times, streamflow depletion is the dominant source of supply. The condition of more than half of the pumping rate coming from streamflow depletion is designated as depletion-dominated supply, and variable t_{dds} is the time to reach the condition of depletion-dominated supply for a particular pumping location.

With the basic concepts of groundwater and stream water interaction having been introduced, the next major question to ask is: What are the factors that influence how quickly groundwater pumping can affect streamflow? In addition to the hydraulic properties of the groundwater system previously discussed, other important factors come into play. This includes (a) the locations and hydrologic conditions along the boundaries of the groundwater system, including the streams; and (b) horizontal and vertical distances of wells from the streams.

The discussion begins with well distances. Figure 2-53 illustrates streamflow depletion for two hypothetical wells pumping from the same aquifer. Because well "A" is located much farther from the stream than well "B", the time necessary for the cone of depression formed by pumping at well A to reach the stream is much longer than that for well "B", and as a result, groundwater-storage depletion is a source of water to the well for a longer period of time. In contrast, the cone of depression formed by pumping at well "B" reaches the stream much sooner than that for well "A", and streamflow depletion becomes the primary source of water to the well much sooner than for well "A". The point is, if one is going to attribute streamflow depletion to a specific well, it must take into account the well's distance from the stream.

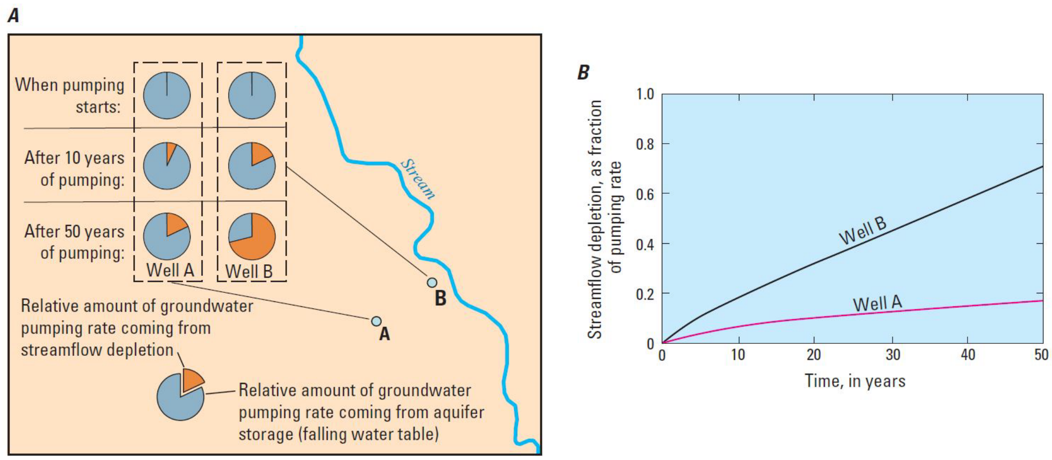

Figure 2-53. A, Sources of pumped groundwater at two hypothetical well locations for pumping times of 10 and 50 years. B, Streamflow depletion is a much larger source of water to well B than to well A during the 50-yr pumping period because well B is much closer to the stream (modified from Leake and Haney, 2010).

The other important factor to consider in evaluating streamflow depletion is the extent to which streambed and streambank sediments may impede the flow of water at the stream-aquifer interface (Figure 2-54). Streambed sediments often consist of fine-grained deposits and organic materials that have a lower hydraulic conductivity (permeability) than the surrounding aquifer materials. This may reduce the amount of streamflow depletion that occurs at any given time relative to a condition in which the low-permeability sediments are absent.

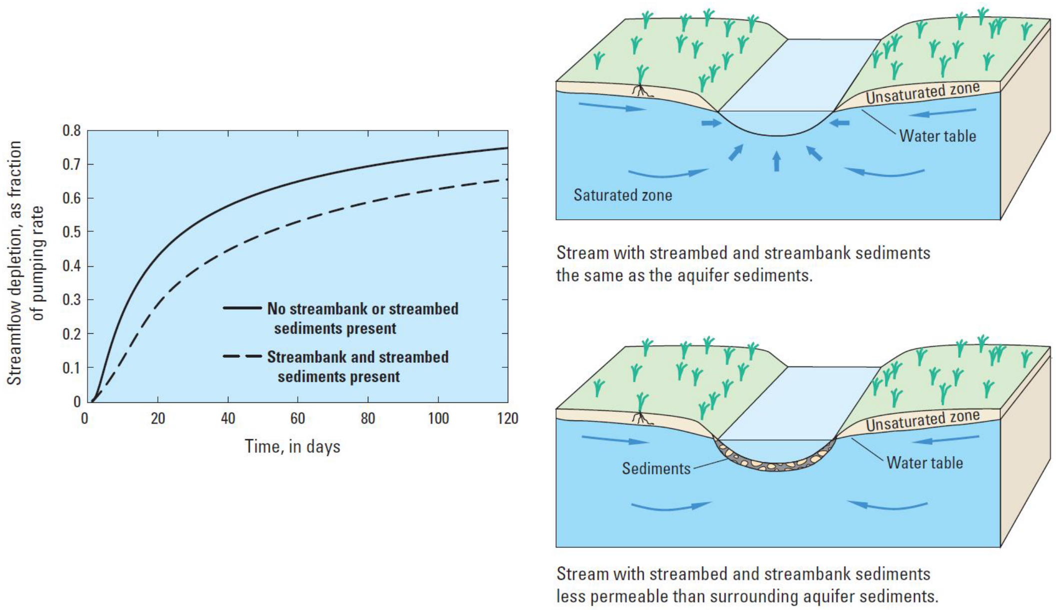

Figure 2-54. Streamflow depletion resulting from a well pumping 500 ft from a stream at a rate of 250 gallons per minute. The presence of streambed and streambank materials with lower permeability than the surrounding aquifer reduces the amount of streamflow depletion during the 120 days of pumping.

Groundwater Data Collection and Modeling

Given the complexity of the characteristics and processes associated with interacting groundwater and surface water systems, it comes as no surprise that collecting data and developing a model to simulate the features described above present key challenges. As discussed in Barlow and Leake (2012), one of the biggest challenges is collecting the necessary field data to measure changes in the aquifer and changes in streamflow, and then trying to separate pumping-induced changes in streamflow from changes in flow caused by other factors such as climate-driven variations in recharge and stream stage. This may include direct measurement of streamflow (e.g., through a USGS gage), and/or measuring water levels at observation wells, piezometers, streambed seepage meters, etc.

With the necessary field data in hand, the next step is to develop the aquifer's hydrogeological framework, which is a three-dimensional representation of the aquifer, its boundaries, and its geologic and hydraulic properties. The hydrogeological framework, in turn, forms the basis of a corresponding conceptual model of the aquifer. The conceptual groundwater-flow model is essentially a water budget – or a simplified model description of the hydrologic boundaries, including major inflow and outflow sources of a groundwater-flow system for a specified period of time. The conceptual model is then used as the basis of developing a numerical groundwater-flow model that is calibrated with "real-world" data to represent the groundwater-flow system and simulate impacts of different pumping scenarios. Figure 2-55 illustrates how these steps interrelate with each other to help inform decision-making and policy related to aquifers.

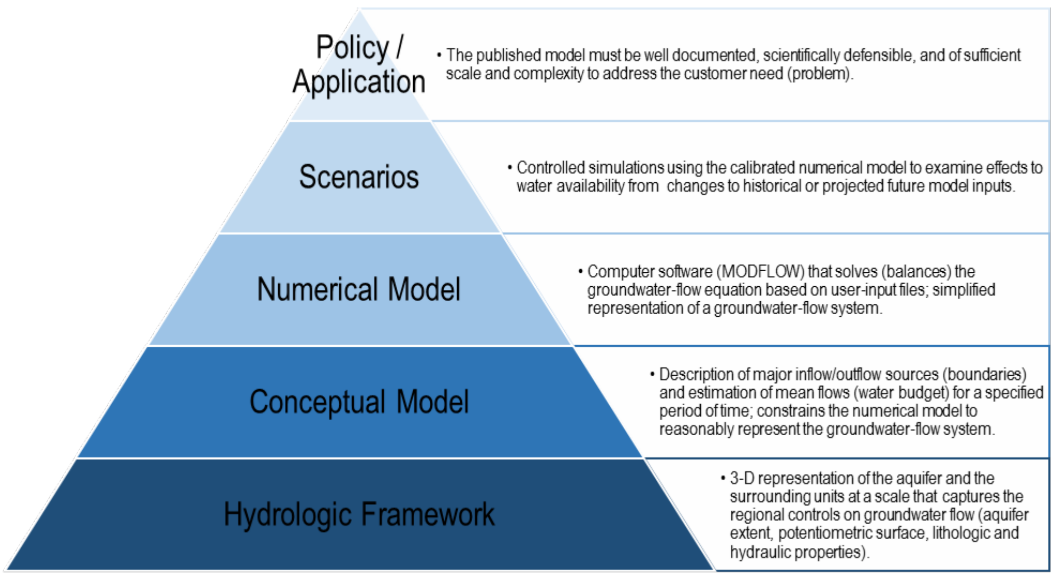

Figure 2-55. Conceptual illustration of interrelated steps involved in simulating an aquifer properties and impacts from groundwater pumping scenarios. Adapted from a USGS (2018).

Historical Groundwater Pumping

Next, the discussion turns back to groundwater pumping in the context of Oklahoma water law. The measurement of historical groundwater pumping faces some similar challenges as those facing surface water. For example, it is difficult to measure the direct impacts of domestic or permitted groundwater use because Oklahoma law does not require users to meter or otherwise measure the volume of water pumped from an aquifer - and similar to surface water, groundwater use permit holders are required to report their use to the OWRB on an annual basis[69]. However, because groundwater use is self-reported and not verified, the same arguments apply regarding the accuracy of use statistics maintained on OWRB's water rights database.

Yet, some challenges are unique to estimating irrigation water use, and in particular the impacts on the source aquifer. Because groundwater is the primary source of irrigation water in the URRBS area aside from Lugert-Altus Reservoir, the focus here is on challenges related to estimating groundwater use in lieu of relying on reported-use statistics provided to the OWRB. Regardless of whether the supply source is surface or groundwater, the same challenges apply when it comes to estimating crop water demands. Generally speaking, these challenges center on estimating the type and acreage of crops being grown, and then estimating the total net irrigation water requirement (NIWR) over a given area. The NIWR is equal to the total crop demand minus the amount of demand that is met by precipitation, where crop demand is a function of evapotranspiration (ET) (Figure 2-56). The ET is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Jensen et al., 1990). In addition to the use volumes reported to the OWRB, the type and volume of crops can be estimated using agricultural census data collected by the USDA and/or by remote sensing. Estimates of ET can be made using different modeling techniques that account for plant transpiration and soil moisture evaporation.

[69] Domestic groundwater users are not required to report their use to OWRB.

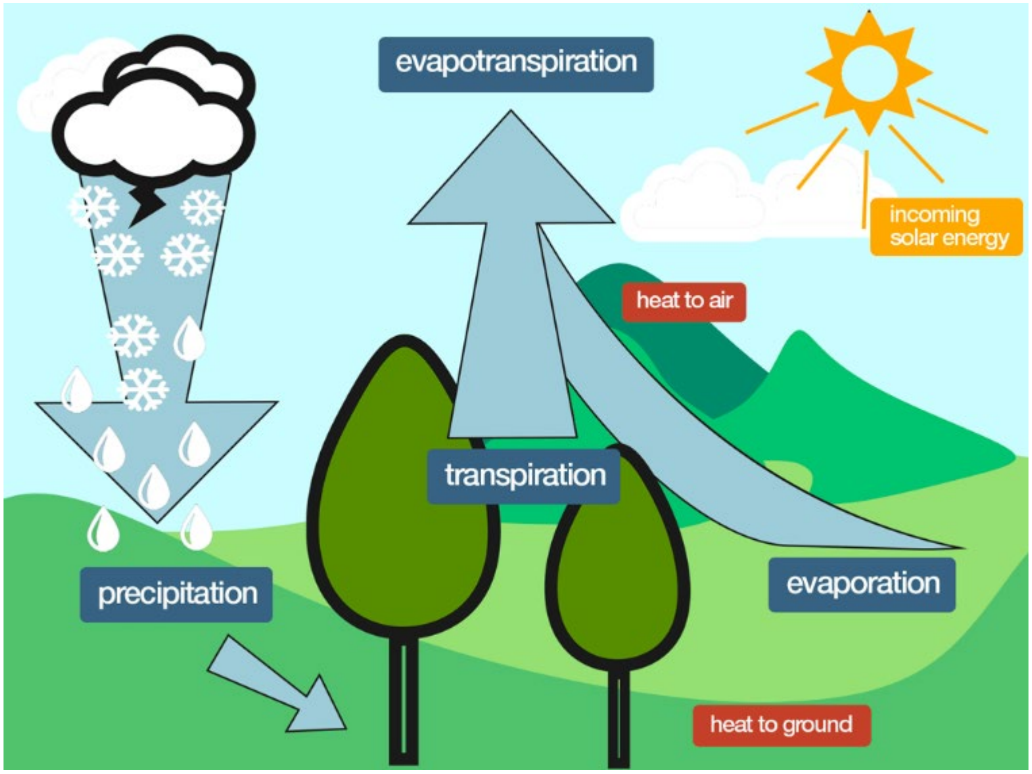

Figure 2-56. Schematic of variables that affect crop evapotranspiration, a key component used to calculate net irrigation water demand (Oberly, 2015).

Future Groundwater Pumping

Similar to surface water, accounting for future groundwater pumping raises many questions, such as:

1. Of the existing groundwater use permit holders in the hydrologic basin, how much of their permitted amount might be put to beneficial use in the future?
2. How much additional growth may be expected, and where?
3. What are the expected types of use (agricultural use, M&I, oil and gas, etc.)?
4. To what extent would future groundwater water supplies be available to meet these needs?

5. How much of this use would be permitted versus set aside for domestic purposes?
6. How might future groundwater permits be regulated under Oklahoma water law?
7. What role could changing climate conditions affect supplies and demands, and subsequently on the need for groundwater pumping to meet those demands?

Similar to surface water, in large part due to the lack of data and tools, and to avoid making arbitrary assumptions, Reclamation's "default" approach over the years has been to apply "what if" scenarios using the RRY Model that entail a range of assumed withdrawals from upstream groundwater pumping. Again, this approach is somewhat arbitrary relative to more-informed scenarios based on actual data and outputs from a combined groundwater/network surface water modeling approach.

It also is worth restating again how groundwater is managed under existing Oklahoma law. As discussed in Chapter 2.2.3, like most major aquifers in Oklahoma, permits to pump water from the aquifer are issued based on the amount of land owned by an applicant, 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 on 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-yr period, the aquifer would be almost fully depleted, with a 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.

The questions are: if this type of pumping occurred, how long would it take for NFRR and Elk City aquifers to be depleted? How would a fully developed NFRR and Elk City aquifer impact base flows of the NFRR, and the corresponding yield of Lugert-Altus and Tom Steed reservoirs? Again, this reinforces the need for a combined groundwater/network surface water modeling approach that currently does not exist.

2.5.5. Measuring Impacts of Climate and Hydrology

Historical

A key factor to measuring the impacts to climate and hydrology is having a standard of comparison. This means being able to simulate the system in its naturalized state without human impacts. As previously discussed, the status-quo approach has been to extrapolate or back-calculate historical conditions using USGS gage data and observed end-of-month reservoir conditions that are based on known reservoir levels, assumed losses from reservoir releases, and assumed evaporation, seepage, etc. The problem is, the computed inflows do not provide insight into specific gains and losses upstream of the reservoir; and without information on gains and losses, one cannot simulate streamflow in its "naturalized" state. By naturalized, the stream is free from impacts caused by human development, including stream diversions and losses attributable to groundwater pumping in adjacent/underlying aquifers that connect with the stream. Without a naturalized state, one cannot distinguish between impacts on streamflow that may be attributable to anthropogenic factors (humans) versus those that are caused by natural changes in climate and hydrology. This limits one's ability to make assumptions about how to account for and manage future streamflow and reservoir supplies.

An important challenge is that naturalized flows have not been developed in the Lugert-Altus and Tom Steed Reservoir hydrologic basins. The limitations of the RRY Model in terms of being able to mimic a naturalized system have already been discussed. In Chapter 2.5.6 below, the discussion turns briefly to the OWRB's Arc GIS-Based Water Rights (Arc-GIS) Model. The OWRB currently uses this model to quantify unappropriated water availability for surface water permits. Notably, the OWRB's Arc-GIS Model does not use naturalized streamflow as a baseline to simulate gains and losses and to quantify water availability; rather, it uses USGS-calculated average annual run-off estimates from 1951-1980.

Future

An important factor that should be addressed when accounting for future stream and groundwater development is the impacts that changing future climate conditions could have on future water supplies and demands. In the URRBS study area, taking into account future climate change presents many challenges. The RRY Model has traditionally calculated future streamflow by taking the "computed inflows" (based on reservoir storage levels) and forward projecting the computed inflows into the future, and future streamflow has often been assumed to remain static. That said, adjustments in inflow can be made to account for assumed changes in factors such as precipitation, evaporation, run-off, etc. that result from a changing climate. For the purposes of this study, primarily because of the requirements and guidance provided under the URRBS program related to climate change, the focus was on using GCM projections. Tree rings also can be used to make predictions about future climate and hydrology. Specifically, one can reconstruct future drought conditions based on severe droughts that are known to have occurred in the distant past (more than 600 years). Whether using climate change or tree rings, one or both of these techniques could be employed, but both are complicated and require good data and sophisticated models.

Returning to the OWRB's Arc-GIS Model, when an applicant applies for a new surface water permit, the OWRB calculates unappropriated surface water available based, in part, on average annual rainfall run-off estimates from 1951-1980. In other words, the OWRB assumes that future run-off will be similar to that of the past, and in doing so, makes assumptions about whether or not a new permit may interfere with domestic users and senior water right holders.

2.5.6. Measuring Water Availability for Permitting

Thus far in this section, the discussion focused on the importance of data and models, highlighting status-quo approaches and challenges associated with accounting for human- and naturally-induced hydrologic impacts. Next, the discussion turns to challenges associated with current modeling approaches employed to measure the amount of water available for permitting. In doing so, this section briefly touches on Oklahoma water law. A lengthier discussion of legal and policy challenges for Chapter 2.6, and a full and detailed assessment of Oklahoma's legal framework is provided in Appendix A.

Groundwater Permit Availability

The appropriation of groundwater is covered under OAC 785:30-9-2, which states that after completing a hydrologic survey of an aquifer, the OWRB shall make a tentative determination of the MAY of groundwater to be produced from each major groundwater basin or subbasin therein – and that this determination shall be based upon the following:

1. The total land area overlying the basin or subbasin;
2. The amount of water in storage in the basin or subbasin at the time of the survey or investigation;
3. The rate of recharge to the basin or subbasin and total discharge from the basin or subbasin the time of the survey or investigation;
4. Transmissibility or transmissivity[70] of the basin or subbasin; and
5. The possibility of pollution of the basin or subbasin from natural sources.

The Rule goes on to state that the MAY of each groundwater basin or subbasin shall be based upon a minimum basin or subbasin life of twenty (20)

[70] As described in Section 2.5.4, transmissivity measures the rate of groundwater flow.

years from the order establishing the final determination of the maximum annual yield. The MAY is then divided up equally across all land acres overlying the aquifer on an acre-ft per acre basis. Thus, each acre has its own EPS of the MAY. In other words, if each and every acre overlying the aquifer was to experience a withdrawal of a 20-yr EPS, then the aquifer would be fully depleted, albeit with a portion of the aquifer's saturated thickness reserved for domestic use.
Figure 2-57 provides a conceptual illustration of the EPS.

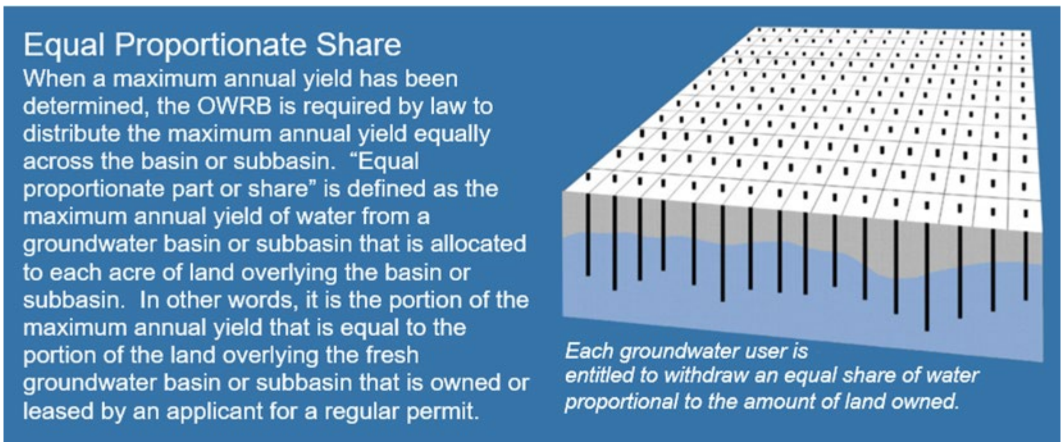

Figure 2-57. Conceptual illustration of an aquifer EPS (https://www.owrb.ok.gov/about/about_pdf/Fact-MAY.pdf).

To arrive at a basin's MAY, investigators map the total land overlying the aquifer and estimate the amount of water in storage. Next, they determine the rate of natural recharge, total discharge, and transmissivity. The balance of the available water is then allocated proportionately to each acre of land overlying the basin. As discussed in Chapter 2.5.4, the EPS calculation entails a three-step process, each with their own set of challenges - beginning with the development of a hydrogeological framework of the aquifer, which in turn forms the basis of a corresponding conceptual model of the aquifer (i.e., water budget), which is subsequently used to develop a numerical groundwater-flow model that is calibrated with "real-world" data to represent the groundwater-flow system and simulate impacts of different EPS pumping scenarios. The details of this process can be found among the multiple hydrologic investigation reports that are available on the OWRB's website[71].

Surface Water Permit Availability

The appropriation of surface water is covered under OAC 785:20-5-5, which states that for direct diversions from a stream, the determination of water available for appropriation shall take into consideration:

1. Mean annual precipitation run-off in the hydrologic basin above the point(s) of diversion;
2. Mean annual flow;
3. Stream gage measurements;
4. Domestic uses; and
5. All existing appropriations and other designated purposes in the stream system.

The Rule also states that the OWRB may consider other evidence or laws relating to streamflow or elevation when considering water available for appropriation. This provision gives the OWRB broad discretion in performing these calculations. Next, the discussion turns to the model and approach that the OWRB uses to appropriate surface water[72].

OWRB's ArcGIS-Based Water Rights Model

The maximum amount of water that can be recommended for "regular" surface water permit approval is limited by the unappropriated water available at a specific diversion location, use(s) identified on the permit application with present or future need, and type of permit requested. A regular permit authorizes the permit holder to use water year-round. This is applied in the OWRB-

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[71]. http://www.owrb.ok.gov/studies/groundwater/groundwater.php.

[72] The methodology is provided in an OWRB "Note to File" "Standard Determination of Available Surface water", Elise Sherrod 2018. This document is available by OWRB upon request.

administered stream systems for the purpose of preventing over-appropriation. The calculations are performed by a model based in ArcGIS and used to perform a unique analysis, specific to the requested diversion location(s), for each regular permit application. This process involves an analysis of appropriated use upstream (Step I) and downstream (Step II) of the proposed diversion point[73].

In **Step I**, the amount of upstream use (U) is subtracted from the amount of available water (A) at the proposed diversion point, where:

A = **Water Available** = Average Annual Run-Off between 1951-1980 (Gebert et al., 1986)

U = **Upstream Use** is defined as the sum of:

- Volume of Existing Permits
- Volume of Pending Permit Applications
- Volume of NRCS storage impoundments (greater than or equal to 25 ft in height and/or 50 acre-ft in impoundment)
- Volume of Dependable Yield of Reservoirs Less Permits
- Volume for Navigation
- Volume of Domestic Use

In **Step II**, a point is selected using ArcGIS to mark the extent of the downstream analysis. Selection of this point, which is up to the discretion of the OWRB staff, must cover a minimum downstream distance to reach one of the following:

- The stream meeting a major confluence
- The outlet of the OWRB stream system
- The dam of a reservoir with a dependable yield

For the selected downstream segment, the amount of downstream use (D) is subtracted from the proposed use by the permit applicant (P), where:

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[73] Additional considerations (Step III) are applied when the proposed use requires transportation of water outside the stream system of diversion. For the sake of brevity, we only discuss Steps I and II.

P = **Proposed Permit Volume** = volume of proposed permit at the point of diversion

D = **Downstream Use** is defined as the sum of:

- Volume of Existing Permits
- Volume of Pending Permit Applications
- Volume of Dependable Yield of Reservoirs Less Permits
- Volume of Domestic Use

The following equation summarizes the OWRB's calculation and determination of water available for appropriation:

If [(**A** - **U**) - (**P** - **D**)] > 0, then there is no over-appropriation and no interference would be anticipated; thus, a regular permit may be recommended by the OWRB.

If [(**A** - **U**) - (**P** - **D**)] ≤ 0, then the stream may be over-appropriated and interference would be anticipated.

If the potential over-appropriation is due to the protection of a reservoir yield, Step I would be repeated at the reservoir dam to include all streams flowing into the reservoir. If unappropriated water is still less than or equal to zero, then another evaluation would be performed to determine if any water, previously unaccounted for, is available to the uses downstream. This is done by repeating Step I with the downstream evaluation point, selected in Step II, acting as the diversion point with Proposed Use by the Applicant included in the equation. If unappropriated water is still less than zero, then a lesser permit amount would be recommended to the applicant. If unappropriated water available is not found for the proposed use, then the applicant may choose to have their application held with a pending status to be revaluated in the event water becomes available at a later date and/or the applicant may choose to apply for a different type of permit, such as a term, seasonal, or provisional temporary permit.

A few notable challenges arise from the approach currently employed by the OWRB in calculating surface water available for permitting. First, a certain amount of flexibility and discretion is allowed by the OWRB in terms of how it employs this approach. This can create uncertainty among water users in terms of how much water is available and how water would be managed during dry conditions when shortages arise. While these challenges primarily fall within the legal and institutional framework described later in this chapter, they are briefly described here in so far as they relate to the type of data and the OWRB's use of the ArcGIS model to measure permit water availability.

First, as previously stated, the OWRB has the authority under the existing surface water appropriation Rule to exercise discretion in determining the amount water available for appropriation to a regular permit. For example, instead of using average annual run-off between 1951 and 1980, the OWRB could use any number of alternative flow regimes, such as a run-off flow record that extends through present day; or a "naturalized" flow regime could be used. Many options exist, with each one potentially yielding a different amount of permit water availability within the system. Another challenge relates to how the OWRB calculates permit water availability in cases where a proposed applicant is located upstream of a reservoir. In this case, only the "dependable yield" of the downstream reservoir is "set aside" for use. For Lugert-Altus and Tom Steed reservoirs, the OWRB considers (for permit appropriation purposes) dependable yields of 85,630 acre-ft/yr and 16,100 acre-ft/yr, respectively[74]. These dependable yields correspond to the reservoir permit volumes. However, the entire conservation pool volume of the reservoir is needed to deliver the dependable yield during the drought of record. Therefore, by subtracting only the dependable yield (among other variables) from the average annual run-off, some have argued that the OWRB may be substantially over-estimating the amount of water upstream of the reservoir that is available for appropriation of a regular permit, and thus are increasing the likelihood that inference may occur during a repeat of the drought of record.

[74] Personal communications with OWRB; OWRB "Note to File" "Standard Determination of Available Surface water", Elise Sherrod 2018. This document is available by OWRB upon request.

In the OCWP 2012 Update[75], the OWRB performed an analysis on water availability upstream of Lugert-Altus and Tom Steed reservoirs. In Basins 36 and 37, which include Lugert-Altus Reservoir, the OCWP 2012 Update showed that water was not available for new regular permits; in fact, Basins 36 and 37 had a gap (deficit) of 133,300 acre-ft/yr and 67,400 acre-ft/yr, respectively - totaling 200,700 acre-ft/yr, indicating that the hydrologic basin was over allocated by a substantial amount. The OCWP 2012 Update projected that this gap would increase to 206,700 acre-ft/yr in 2060. For Tom Steed Reservoir, the OCWP also found that water was not available for new regular surface water permits. Similar to upstream of Lugert-Altus Reservoir, in Basins 34 and 35 which include Tom Steed Reservoir, a permit gap of 40,400 acre-ft/yr and 16,100 acre-ft/yr was found to exist, respectively – totaling 56,500 acre-ft/yr. The OCWP projected that these gaps would increase by 2060 to 48,100 acre-ft/yr and 19,600 acre-ft/yr, respectively, in Basins 34 and 35. A more recent analysis in 2018 was conducted by the OWRB staff, which also showed what appears to be an over-appropriated stream system containing both Lugert-Altus and Tom Steed reservoirs, but the values were different than those presented in the OCWP 2012 Update and may be the result of a different calculation[76].

Further complicating the matter is that in over-appropriated streams, where the risk of interference increases during dry periods, the current approach using the ArcGIS model does not allow one to quantify or otherwise attribute potential interference associated with any specific permit. Rather, the ArcGIS model output merely provides an indication on whether interference may occur within the system as a whole.

Aside from the calculation of availability for regular permits, another challenge relates to the discretion provided to the OWRB to issue other types of surface water permits even when water for a regular permit is deemed unavailable. As stated in 785:20-7-3, "*in addition to regular permits, the Board is authorized to issue seasonal, temporary, term or provisional temporary permits at*

[75] OCWP 2012 Update - Water Supply Permit Availability Report 2011, Table 2-2.
[76] Email from Elise Sherrod April 9, 2018. Document available upon request.

any time it finds such issuance will not impair or interfere with domestic uses or existing rights of prior appropriators and may do so even where it finds no unappropriated water is available for a regular permit." Unlike regular permits, PT permits may be granted by the Executive Director of the OWRB for a period of 90 days without the requirement of holding a hearing, publishing data, or notifying adjacent landowners[77]. During the 2011 drought of record, 43 groundwater PTs were issued in the NFRR aquifer within the hydrologic basins of Lugert-Altus and Tom Steed Reservoir, totaling 2,253 acre-ft (i.e., average of 451 acre-ft annually). A total of 51 surface water PTs was issued upstream of Lugert-Altus Reservoir totaling 345 acre-ft (i.e., average of 69 acre-ft annually), and seven PTs were issued above Tom Steed Reservoir totaling 43.5 acre-ft (i.e., average of nine acre-ft annually). While these volumes are relatively small compared to the volume of regular permits and to the overall aquifer storage and/or streamflow in the system, their presence no less caused significant concern among the users of Lugert-Altus and Tom Steed Reservoir.

[77] https://www.owrb.ok.gov/about/about_pdf/Fact-PTPermits.pdf.

2.6. Legal and Policy Challenges

This chapter concludes with a discussion on legal and policy challenges. 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. Not surprisingly, 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) – for each of these three sources provide policies, statutes, regulations, and judicial opinions that influence our understanding of the 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[78] as the outside party to conduct the

[78] Dr. Kershen is an Earl Sneed Centennial Professor of Law Emeritus at the University of Oklahoma, College of Law.

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 would be comprised of a "Background Law" chapter that provides 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 would include detailed legal 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. This section briefly draws from Dr. Kershen's "Background Law" chapter and provides an overview of the legal and policy challenges related to managing water in the URRBS study area. The challenges are henceforth presented as a list of questions that warrant careful attention moving forward:

1. The fundamental law that guides Reclamation is the Reclamation Act of 1902 and its various amendments. Water rights are discussed in Section 8 of the Act. What is the intent of Section 8 in terms of creating and defining water rights related to a Reclamation project (i.e., Lugert-Altus and Tom Steed reservoirs)? Who owns the water or the water rights in a Reclamation project? Who owns the storage rights versus the beneficial use rights?
2. Oklahoma law allows the U.S. to withdraw stream water for Reclamation projects pursuant to various procedural obligations. What is the meaning and implication of Oklahoma's statutes governing Reclamation withdrawals of waters associated with Reclamation's projects? More specifically, who has water rights to the withdrawn waters, and how does this affect the priority date for project water?
3. Lugert-Altus and Tom Steed reservoirs are considered "transferred works", meaning (among other things) day-to-day operations and maintenance of the projects have been transferred to the Lugert-Altus ID and MPMCD, respectively, while ownership of the land and facilities

remains with the U.S. What is the meaning and implication of Oklahoma's statutes governing the creation, role, and rights of the Districts relative to Reclamation and end users of project water?

4. Procedural requirements in water supply contracts for water stored in Reclamation's reservoirs contain provisions related to "surplus" water and "excess" water. Oklahoma law also recognizes "excess waters" within Reclamation's reservoirs. To what extent are federal and state definitions of excess or surplus water compatible, and what is the meaning and impact on the water rights held by the Lugert-Altus ID and MPMCD, and/or on the appropriation of water rights by the OWRB?
5. Beneficial use, along with priority of water rights based on first-in-time is first-in-right, is a foundational principle of the prior appropriation system of water law in Oklahoma. The OWRB regulations define "beneficial use" as the basis, the measure, and the limit of the right to use stream water in Oklahoma, with beneficial uses including but not limited to municipal, industrial, irrigation, recreation, fish and wildlife, etc. A definition of beneficial use does not exist in Oklahoma law. What do these definitions, or lack thereof, mean for the management of water within and upstream of Lugert-Altus and Tom Steed reservoirs?
6. The Lugert-Altus ID and MPMCD have an established priority date for their water rights. These holders can seek the OWRB action to protect the holder's water right, and these holders can bring individual lawsuits to protect their water right from interference. What is lacking in the statutes, the regulations, and the case law is any definition of interference or any identification of triggers that can be invoked to protect the water rights of senior holders. With that said, what administrative procedures could the OWRB set up, either under existing law or new law, to stop or prevent interference with senior priority rights or to prevent out-of-priority use of water rights within the hydrologic basins of Lugert-Altus and Tom Steed reservoirs, while at the same time maximizing the beneficial use of stream

water throughout the system? What would need to be the basis for such procedures?

7. It was stated previously that Oklahoma manages streams under a dual prior appropriation/riparian water rights system. How might this dual system, in particular non-permitted domestic use reserves, affect the strength and priority of water rights in the hydrologic basins of Lugert-Altus and Tom Steed reservoirs?
8. In the prior appropriation system, a phrase commonly used is that the person with a water right must "use the water or lose it". Oklahoma law expresses this "use it or lose it" philosophy by explicitly stating that if a permit holder does not use the full amount authorized, the unused amount is forfeited and reverts to the public as unappropriated water. What is the meaning and implication of Oklahoma's statutes governing "use it or lose it" associated rights to water within Lugert-Altus and Tom Steed reservoirs?
9. In Oklahoma, stream water is public water accessed by the public for beneficial use through prior appropriation. Groundwater, on the other hand, is owned by the overlying landowners and accessed through separate groundwater law. What is the meaning and implication of Oklahoma law and legislative actions in defining the terms "definite stream" and "groundwater" with regard to distinguishing groundwater from stream water? To be more precise, the issue is whether waters in alluvial aquifers are groundwater or stream waters. The Supreme Court of Oklahoma has twice decided cases that clearly presented facts and the legal issue as to classifying the water in dispute as groundwater or stream water; yet are there viable arguments to be made that alluvial aquifers are indeed stream water? What would this mean for the management of water in the hydrologic basins of Lugert-Altus and Tom Steed reservoirs?
10. In accordance with Oklahoma groundwater law, groundwater permits are issued by the OWRB based on land owned or leased by applicants such that each acre of land overlying an aquifer is allocated an EPS of the

aquifer's MAY. The MAY is the amount of water the aquifer can provide for beneficial use on 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-yr period, the aquifer would be almost fully depleted, with a portion of the aquifer's saturated thickness reserved for domestic use. The MAY and corresponding EPS must be reviewed and updated based on hydrological surveys at least every 20 years. Does Oklahoma law allow the OWRB to reduce a landowner's existing EPS, either directly or indirectly, if new data result in a lower MAY?

11. In 2012, Oklahoma passed the Water for 2060 Act which made it the policy of this state to establish and work toward a goal of consuming no more fresh water in the year 2060 than is consumed statewide in the year 2012, while continuing to grow the population and economy. This would be achieved by utilizing existing water supplies more efficiently and expanding the use of alternatives provided those alternatives are not construed as amending provisions of existing law pertaining to rights or permits to use water. What discretion does the OWRB have in advancing policy mandated by the Water for 2060 Act, by means of alternative strategies to manage water within the Lugert-Altus and Tom Steed Reservoir hydrologic basins?
12. The OCWP 2012 Update recommended consideration of conjunctive management as an option to improve water supply reliability. "Conjunctive water management" was defined by the OWRB as the management of hydraulically connected surface water and groundwater resources such that the total benefits of integrated management exceed the sum of the benefits that would result from an independent management of each water resource. Aside from the Arbuckle Simpson aquifer in eastern Oklahoma, the OWRB manages the Oklahoma stream water law and the Oklahoma groundwater law as separate, independent water law systems pursuant to existing law. However, could these laws provide the OWRB

with an (unrecognized) authority to indirectly consider the hydrological interconnection between a groundwater aquifer and streamflows when it appropriates groundwater or stream water?

13. The OCWP 2012 Update also recommended investigations into the establishment of an instream flow program to recognize non-consumptive water needs and in support of recreational and local economic interests. Although Oklahoma water law presently does not recognize instream flow as a water right, could the OWRB grant an applicant's petition to acquire a stream water permit for recreation or fish and wildlife? By recognizing a non-consumptive use for recreation and fish and wildlife, the OWRB indirectly would be creating an instream flow right that could protect the yield of a Reclamation reservoir.
14. Although water law exists and is important in every state of the United States, water law is a more prominent area of law and legal practice in the 17 most western states of the United States, including Oklahoma. To what extent can the laws of these western states provide a source of ideas for implementation of new groundwater and stream water management solutions in Oklahoma?

2.7. Conclusions

The five categories of water supply reliability challenges/vulnerabilities presented in this chapter are a testament to complex and multi-layered needs facing the URRBS study area (Figure 2-58). Having begun this study amidst the worst drought in recorded history, with much of its analyses occurring both during and after the 2010s Drought of Record, this URRBS was afforded a unique benefit at the time of its authorship. The goal was to chart a long-term course for future action to improve water supply reliability in the URRBS study area.

Some adaptation strategies have already been completed, while others are in the planning stages or underway. Some strategies are being led locally, while others are uniquely suited for implementation by the state and Federal government – or by academia. These important efforts are discussed in the next chapter. Also discussed are the important gaps in information and tools that remain, including the role that Reclamation and URRBS partners have played in addressing these gaps.

Figure 2-58. Five categories of drought and water supply reliability challenges/vulnerabilities facing Lugert-Altus and Tom Steed reservoirs. An opportunity exists to address these needs through further study.

Chapter 3. Related Activities and Opportunities

Chapter 2 presented the numerous and multi-layered water-related challenges facing western Oklahoma, including the basins containing Lugert-Altus and Tom Steed reservoirs. To provide context for the collaborative state, local, and Federal partnership that spearheaded this URRBS, this chapter discusses previous and ongoing efforts that have either been recently completed or are underway to address these challenges.

3.1. 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 3-1). 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 which are manifested in an Executive Report, 13 Watershed Planning Region Reports, and many other supporting technical publications[79]. Since its

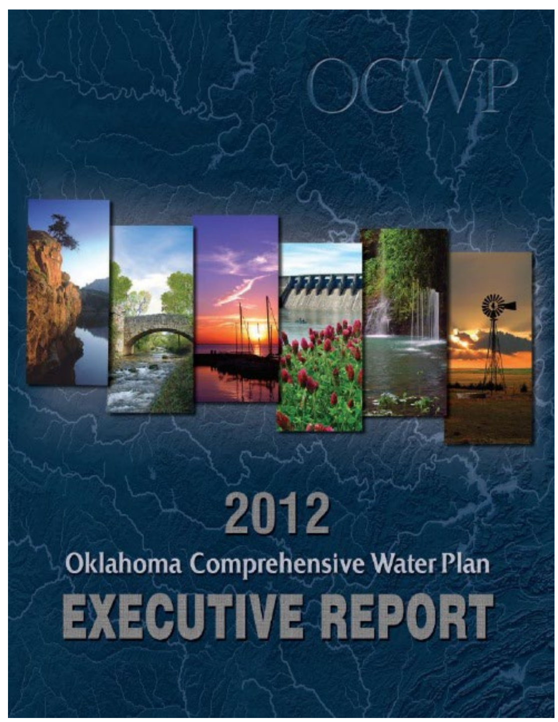

Figure 3-1. Cover page, OCWP 2012 Update Executive Report.

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

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.

With regards to the needs set forth in Chapter 2, it is worth pointing out some notable quotes from the OCWP's Executive Report:

- 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 statutes 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-yr 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:*
    a. *Consideration of a seasonal (rather than annual) stream water allocation program to address seasonal surface water shortages and water rights interference.*
    b. *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.*
    c. *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.

d. *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."*

3.2. Stakeholder-Led Efforts

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 3-2; Figure 3-3). 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 (Figure 3-4).

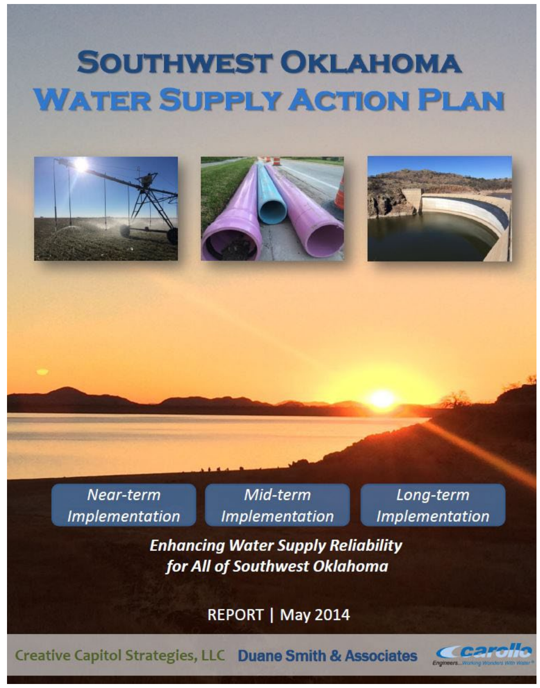

Figure 3-2. The Southwest Oklahoma Water Supply Action Plan was completed in 2014 and identified a variety of strategies to address water supply vulnerabilities.

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. These strategies are discussed in detail within the 2014 SWAP (Carollo et al., 2014). During the development of this URRBS, the SWAP has since been updated (Duane Smith and Associates, 2018). The 2018 SWAP provides an update on the completion status of strategies recommended in the 2014 SWAP and identifies this URRBS as a yet-to-be-completed future strategy (Figure 3-4).

Figure 3-3. SWAP Advisory Group comprised of MPMCD (representing Tom Steed interests for Altus, Snyder, Frederick and Hackberry Flats), the city of Altus, Altus Air Force Base, Lugert Altus ID, and various rural water users. Reclamation met with the SWAP in September 2015 to get feedback on regional priorities of the SWAP and areas of interest where Reclamation should provide assistance under this URRBS.

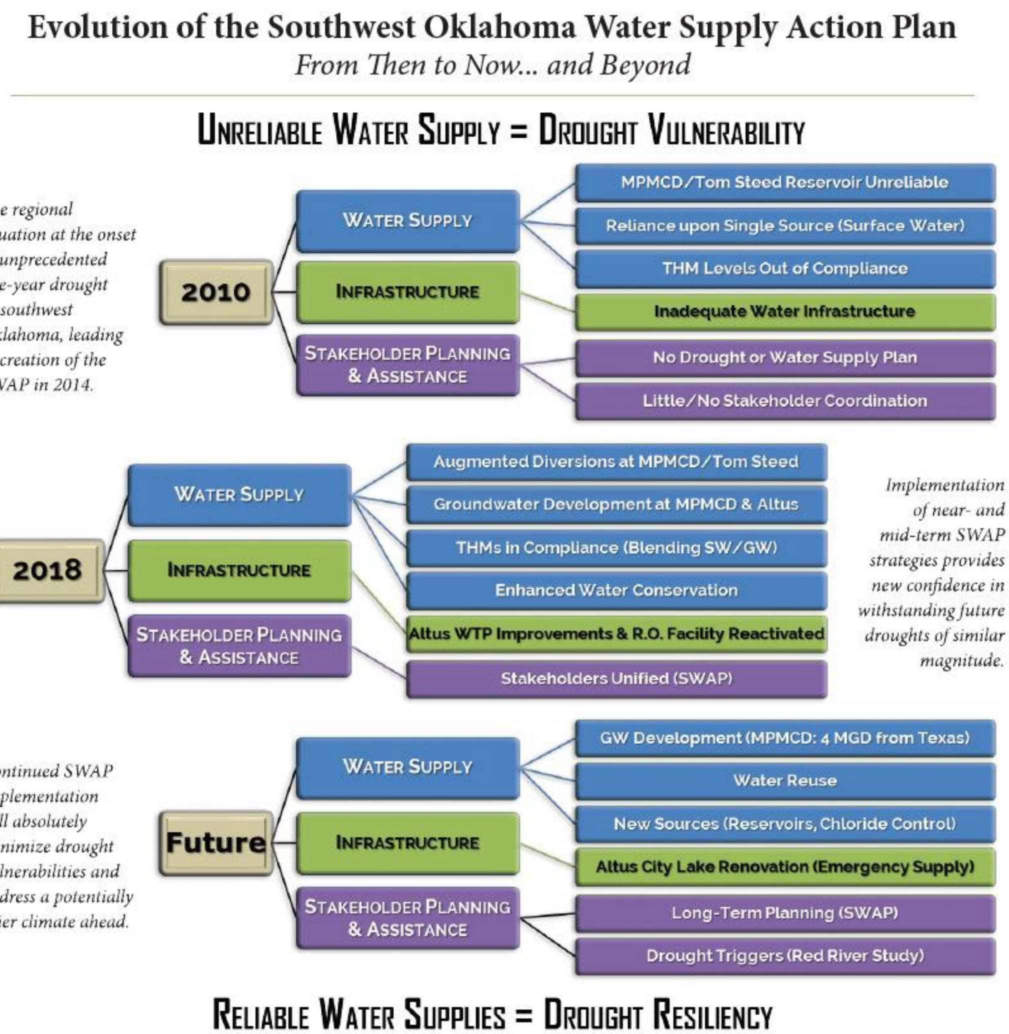

Figure 3-4. An update on strategies originally identified in the 2014 SWAP. This URRBS, identified here as the "Red River Study", is identified as a future strategy to assist stakeholder planning and assistance.

3.3. 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 so that when the next drought arrives, the region is more resilient. Importantly, within these road maps also emerged the potential role of the Federal government to help address needs of the area.

3.3.1. National Drought Resiliency Partnership

A consortium of Federal agencies making up the National Drought Resilience Partnership (NDRP) came together on the heels of the 2010s Drought of Record under an organized effort to bring Federal resources to bare in southwest Oklahoma. At a meeting in Washington D.C., the OWRB asked the NDRP to provide assistance to address water needs in southwest Oklahoma. The NDRP was developed to combine Federal resources in support of locally driven, long-term planning efforts. The NDRP was comprised of the Western Federal Agency Support Team (WestFAST), a group established long ago to support the Western States Water Council (WSWC) and Western Governors Association. WestFAST, and by extension the NDRP, is a collaboration among one dozen Federal agencies to coordinate and maximize Federal water-related efforts on the state and local level in the western U.S. (Figure 3-5). Having been recently established, the NDRP was looking for a case study to model how the Federal government could work regionally/locally across the nation, ideally under a common framework, to improve drought resilience. The NDRP agreed to use Oklahoma as a national case study. The next step was to identify roles and responsibilities of the NDRP partnership that build upon the state and locally-led OCWP and SWAP. As the owner of Lugert-Altus and Tom Steed reservoirs, Reclamation was recognized as a prominent member of the NDRP case study.

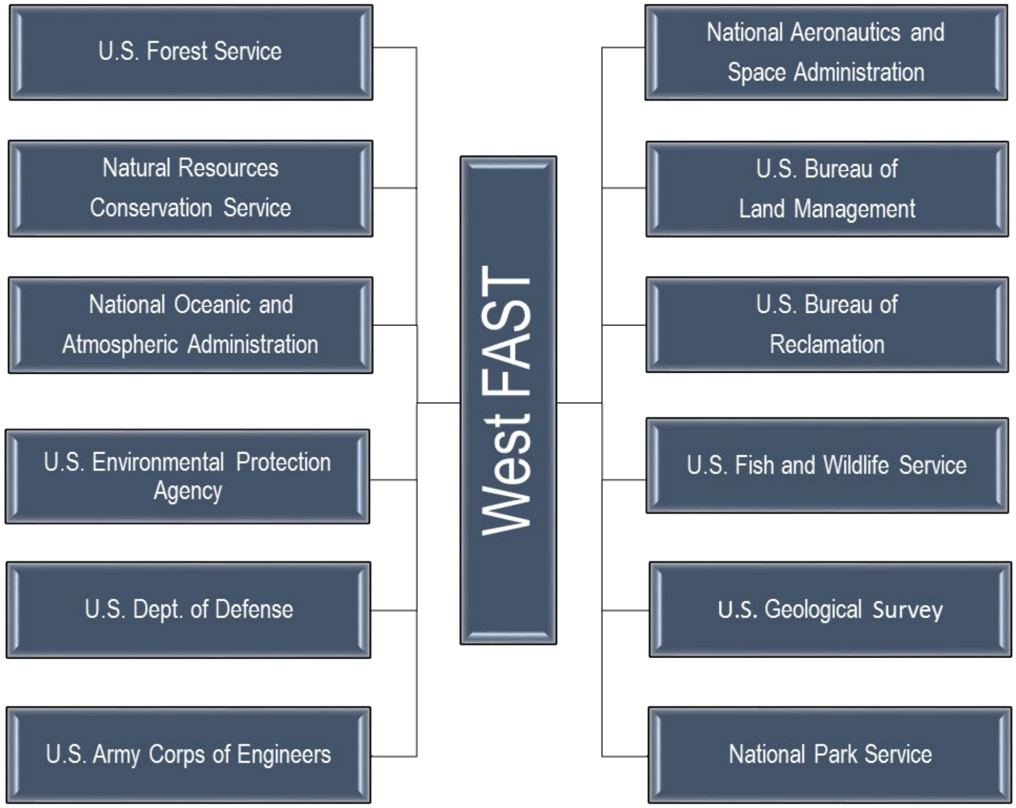

Figure 3-5. Federal agencies that make up WestFAST, and by extension, the NDRP.

In 2017, a summit was held in Altus, Oklahoma, where the NDRP, OWRB and other state agencies, alongside local leadership from businesses, municipal and rural water districts, held discussions on the implementation of SWAP initiatives. Several NDRP action areas were identified, and which were included in the 2018 update to the SWAP (Figure 3-6). A draft NDRP Action Plan was subsequently prepared that identified several opportunities for Federal involvement:

- Department of Defense and Altus AFB: conducting investigations into supplemental groundwater.
- EPA: permitting and funding for infrastructure such as water recycling and reuse, as well as municipal water system enhancements (e.g., water loss auditing, monitoring, and control).
- NOAA/NIDIS: technical assistance on drought forecasting and drought contingency planning.

- USGS: brackish groundwater mapping, as well as modeling in support of the URRBS.
- NRCS: technical and financial assistance on irrigation efficiency improvements, as well as management to reduce sedimentation into Lugert-Altus Reservoir.
- Reclamation: continue efforts in support of the URRBS; also take advantage of grants available under the WaterSMART program.

National Drought Resilience Partnership

The NDRP Framework emphasizes improvements in federal agency collaboration to ensure more efficient use of program dollars and agency expertise in building national capabilities for long-term drought resilience.

Strategies:

- Strengthening coordination of federal drought policies and programs in support of state, tribal, and community efforts;
- Serving as a single federal point of contact on drought resilience;
- Leveraging the work of existing federal investments such as the National Integrated Drought Information System (NIDIS), the development of a National Soil Moisture Network, and the Bureau of Reclamation-Natural Resource Conservation Service partnership to improve agricultural water use efficiencies; and
- Linking information, such as monitoring, forecasts, outlooks, and early warnings, with long-term drought resilience strategies in critical sectors, such as agriculture, municipal water systems, energy, recreation and manufacturing.

Partnerships:

- Data Integration and Collection... support Federal, state, and local data collection and distribution efforts;
- Preparedness, Mitigation, and Risk Management... supporting regional state, local, and tribal preparedness and planning;
- Actionable, Science-Based Information and Tools... converting data into knowledge for timely and informed decision-making;
- Sustainable Water Infrastructure... managing resources for a more secure water future;
- Managing Lands & Waters... resilient farms, ranches, and forests that support healthy watersheds and ecosystems; and
- Programs, Incentives, Outreach, and Education... 21st century approaches to drought preparedness and water security.

Figure 3-6. Excerpt from the SWAP 2018 Update, which includes a road map of potential roles and strategies of the NDRP, as identified from a water summit held in Altus, Oklahoma in 2017.

3.3.2. USGS Focus Area Study on the Red River

During the development of this URRBS, the USGS began a multi-year Focus Area Study (FAS) of the entire Red River basin as part of its National Water Census[80]. The National Water Census evaluates water availability using a water-budget approach to better quantify the inflows and outflows of water at a regional (basin) scale. The FAS was initiated, in part, to help address concerns about increasing water needs in the rapidly expanding Dallas-Fort Worth, Texas area, increases in water use for consumption and power generation, changes in water quality (e.g., salinity), and maintenance of ecological flows.

A portion of the FAS being conducted by USGS overlaps with the study area of this URRBS, but a few key items are worth noting that help provide context for the range of vulnerabilities and challenges that remain unexplored in the FAS. First, the FAS encompasses the entire multi-state Red River Basin, and was thus not meant to evaluate needs on a local or even sub-basin scale; rather, the FAS's goal was to estimate an overall "wet" water balance on a very large basin scale. Also, the FAS did not seek to address legal and institutional issues including vulnerabilities and management associated with groundwater and surface water rights. And finally, the FAS evaluated how changes in the use *and quality* of water within the entire basin may affect ecological needs, including fish communities. The FAS was completed in 2021.

3.3.3. South-Central Climate Adaptation Science Center

Oklahoma is home to the Department of the Interior's South Central Climate Adaptation Science Center (CASC), which was established in 2012 as part of a federal network of eight centers across the U.S. that are managed by the

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[80] https://webapps.usgs.gov/watercensus/redriver_fas/index.html.

USGS. Comprised of a consortium of Federal, tribal, and academic partners, the CASC covers all or parts of New Mexico, Oklahoma, and Texas. The main goal of the CASC is to generate data, decision-support tools, and other products that are practical and relevant to monitoring and adapting to variable and changing climate conditions. Since its formation, the CASC has led and/or funded a large number of investigations addressing how climate-related issues affect ecological communities, water resources, and socioeconomics, to name a few. A full list of publications is available on the CASC website[81].

One study is worth noting here because it addressed climate-related vulnerabilities in the entire Red River Basin, and thus included an evaluation on the upper reaches that contain Lugert-Altus and Tom Steed reservoirs. Sponsored by the Chickasaw and Choctaw Nations and completed in 2016, the study applied a range of possible climate change scenarios to assess future water availability in the Red River Basin (McPherson, 2016). While noting that considerable uncertainty exists in predicting future climate change impacts, the study indicated that the basin overall would experience more extreme climate events, including more intense droughts and flooding; the study also predicted lower flows and reservoir storage in the western (drier) parts of the basin that contain Lugert-Altus and Tom Steed reservoirs. With that said, the study cautioned against "generalizing these results for any particular reservoir" and against "using any single simulation for water management decisions".

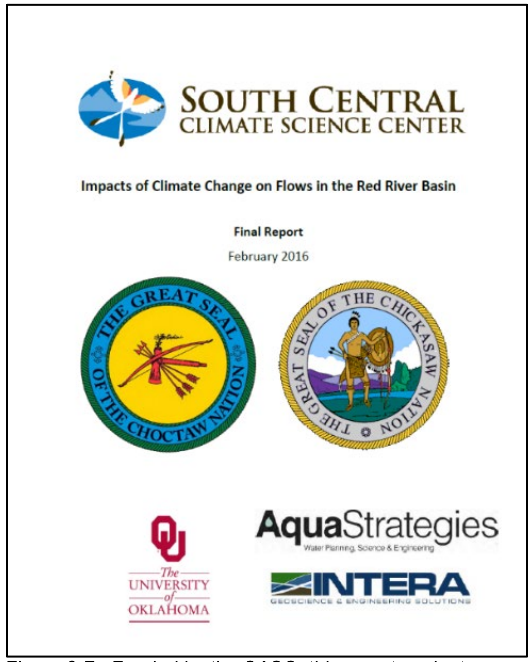

Figure 3-7. Funded by the CASC, this report evaluates potential streamflow vulnerabilities caused by climate change in the Red River Basin.

81 https://southcentralclimate.org/about-us/.

3.4. Academia-Led Efforts

Chapter 2 discussed how the 2010s Drought of Record revealed a fundamental challenge facing the managers and users of Lugert-Altus and Tom Steed reservoirs, namely trying to understand the role that "Mother Nature" played versus the role that human factors played in the drastic reduction of inflows into (and storage of) Lugert-Altus and Tom Steed reservoirs. Addressing this question was a key objective of Krueger et al. (2017), who sought to describe the relationships of climate and human variables with streamflow in the watershed upstream of Lugert-Altus Reservoir. Rather than simulating impacts of groundwater withdrawals on streamflow through the development and use of a numerical groundwater model of the NFRR aquifer, they used statistical methods to correlate historical groundwater use with observed streamflow. Their study found that human factors through NFRR aquifer alluvial groundwater withdrawals (for irrigation purposes) accounted for a little over half (51 to 56 percent) of the observed changes in streamflow between 1970 and 2014. Combined with precipitation, alluvial groundwater withdrawals accounted for 81 percent of annual streamflow variability between 1970 and 2014. Their study suggested that the interaction between groundwater and surface water plays an important role in affecting how alluvial groundwater withdrawals out of the NFRR aquifer can reduce inflow into Lugert-Altus Reservoir. As a solution to help address these impacts, Krueger et al. (2017) suggested that conjunctive management of groundwater and surface water may be necessary to sustain irrigated agriculture in the watershed upstream of Lugert-Altus Reservoir. The following conclusions by Krueger et al. (2017) are worth quoting in full:

> *"Currently, surface and groundwater are treated and permitted as separate and unrelated resources in Oklahoma water law and policy, with the exception of one isolated aquifer where conjunctive management is required (OWRB, 2012). This artificial separation*

does not provide a suitable management framework in areas where surface and groundwater interact. For example, in the permitting process for wells in the North Fork alluvial aquifer, current policy does not consider the potential impact of the proposed wells on streamflow. If groundwater pumping is impacting flows in Oklahoma rivers, as our results and others suggest, then there is a need for increased conjunctive management of surface and groundwater within the state. One possible approach to implementing conjunctive water management would be the creation of a water conservation district (Blomquist et al., 2001) charged with developing conjunctive use strategies for the North Fork watershed. Our work has shown that people, as much as climate, dictate changes in water availability in the region. Concentrating decision making ability within the people dependent upon the watershed could empower them to develop strategies to sustain it. The effort would require tremendous cooperation among stakeholders, decisions would unlikely be unanimous, and winners and losers would be almost unavoidable. Still, by banding together and using information from studies like ours, stakeholders would then have the opportunity to cooperatively make conjunctive water management decisions and could avoid having external decisions imposed upon them."

3.5. Opportunities for New Investigations

Despite the many efforts to address the water supply needs facing the area, gaps remain. An illustration of the categories of challenges presented in Chapter 2 is provided below (Figure 3-8).

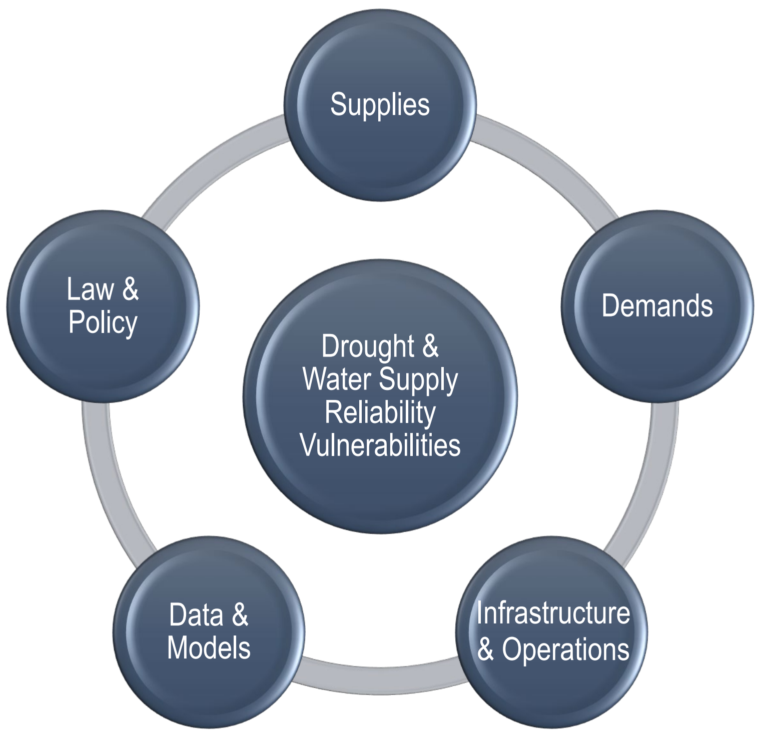

Figure 3-8. Five categories of drought and water supply reliability challenges/vulnerabilities facing Lugert-Altus and Tom Steed reservoirs. An opportunity exists to address these needs through further study.

The beginning of this chapter outlined how different agencies and entities have set out to address some of these challenges with the purpose of not only helping formulate the objectives of this study, but to provide a foundation for the collaborative state, local, and Federal partnerships that are needed to accomplish these objectives. The chapter began by recognizing the prominent role of the state-led OCWP. In the OCWP, a suite of high priority water-related planning and infrastructure recommendations and initiatives were advanced – including (among other things) the need for stakeholder-driven processes to vet and recommend courses of action that address water supply needs on a regional and local, case-by-case basis. One such plan is the SWAP. Like the state-led OCWP, the SWAP charted a course of action to secure reliable water supplies, but it did so with the specific needs and resources of local stakeholders in mind – entities like the cities of Altus, Snyder, and Frederick – and the Altus AFB – and the Lugert-Altus ID. Federal-led efforts also were discussed. While Reclamation undoubtedly holds a unique Federal authority and interest in helping address water-related needs of Lugert-Altus and Tom Steed reservoirs, the Federal presence in the region has and continues to extend beyond Reclamation. Finally, the chapter focused on studies led by Academia; while countless academic-led studies have been done in the NFRR basin, this study noted one investigation in particular that is relevant to many of the issues at hand.

Recognizing the relevant efforts that have been completed or are currently underway, this study now formulates study objectives that aim to fill in the gaps that remain.

Chapter 4. Purpose, Goals, and Objectives

The goal of this URRBS was to address many of the challenges outlined in Chapter 2 for 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 interest of the public.
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 replicable, credible, 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 is not to make recommendations, nor is 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 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 United States Geological Survey (USGS). A detailed accounting of the NFRR aquifer model and the impacts of groundwater pumping on base flows of the NFRR and water availability in the hydrologic basins is provided in Chapter 6 of the URRBS Report.

3. **Develop a basin-wide surface water allocation model for the NFRR, 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 reservoirs' 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 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 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 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 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 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*.

Chapter 5. Basin-Wide Demands and Supplies

This chapter provides an inventory of existing water supplies and existing and future demands in the URRBS study area. Future supplies are discussed in Chapter 6 for reasons described below. Because water supply availability is dependent in large part upon the local climate, as well as on the demands placed on those supplies, this discussion begins with climate characteristics and water demands. For demands, current (i.e., existing) demands on both groundwater and surface water are presented next, 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 arise not only from direct withdrawals, but also indirectly by groundwater withdrawals from adjoining aquifers.

Projecting into the future, various future demand scenarios are presented that may be placed on future groundwater and surface water supplies, including both permitted demands and non-permitted domestic uses. The scenarios were developed by study partners based on assumptions of what "status-quo" conditions may be in the future if current water management practices by the OWRB continue in the future (i.e., no changes in Oklahoma water law) or if reasonably foreseeable changes in current practices occur within existing Oklahoma water law. As noted later in this chapter, quantifying future supplies is more complicated than that of demands because it requires the development and use of both groundwater and surface water models that can simulate the system as a whole, including physical and hydrological variables, gains and losses, and what the system would look like in its naturalized state. Furthermore, quantifying future supplies is dependent upon how reliable those supplies are in terms of meeting future demands. Because future water supplies and system reliability are so intertwined, a detailed evaluation of future supplies under a range of future demand scenarios is presented in the next chapter, Chapter 6: Future Supplies, System Reliability, and Status-Quo Impact Assessment.

5.1. Climate Characteristics

The URRBS lies within Climate Divisions (CD) 4 and 7 (Figure 5-1 and Figure 5-2; Oklahoma Climatological Survey, 2014), with the upper basin lying with in CD 4 and the reservoir and service area lying within CD 7. According to NOAA's National Climate Data Center, CD 7 has generally trended towards a slightly hotter and wetter climate than CD 4. In CD 4, annual temperatures range from 59 to 65 degrees (°) F, averaging 61°F; annual precipitation ranges from 15 to 45 inches, averaging 28 inches (Figure 5-3). In CD 7, annual temperatures range from 56 to 62°F, averaging 59°F; annual precipitation ranges from 14 to 42 inches, averaging 26 inches (Figure 5-3). Similar to annual data, monthly temperature and precipitation are generally higher throughout the year in CD 7 compared to CD 4 (Figure 5-4). Across both CDs, mean monthly temperatures range from 39°F (January) to 84°F (June), and mean precipitation ranges from 0.9 inches (January) to 4.6 inches (June). A list of mean monthly temperature and precipitation data across each climate station within each of the two CDs is provided in Table 5-1.

While long-term temperature and precipitation averages reveal important context about conditions within the URRBS study area, like many hydrologic basins across the western U.S., water supply availability in the URRBS study area is often driven by variable weather patterns and extreme events. For example, the total amount of annual precipitation occurs only over a fraction of days throughout the year (about 25 percent), often (but not always) during June and July (Figure 5-5). This causes flashy variations in run-off and streamflow, which highlights the important role that Lugert-Altus and Tom Steed reservoirs play in storing and regulating flows to enhance water supply and mitigate flood risk.

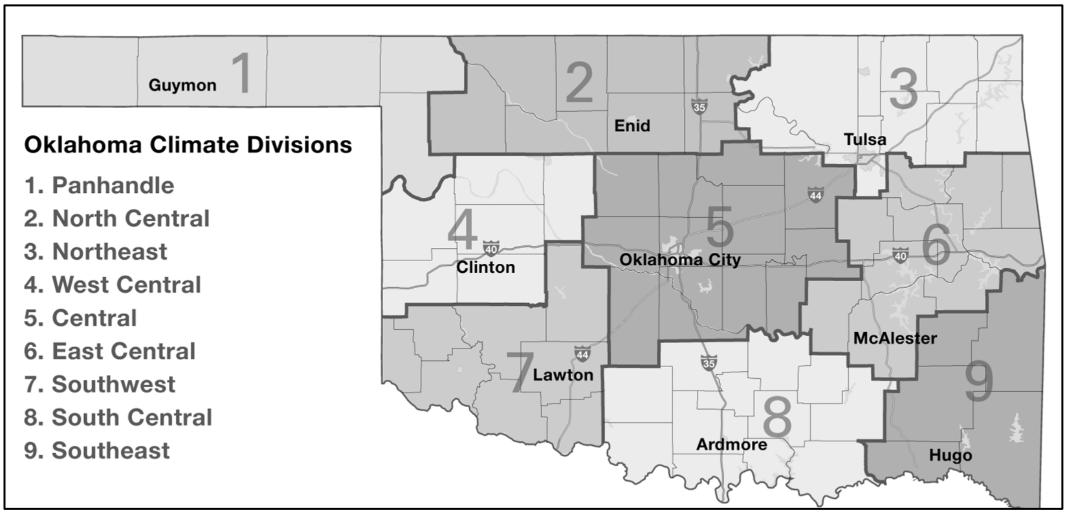

Figure 5-1. Oklahoma Climate Divisions according to NOAA's National Climate Data Center (OCS, 2014).

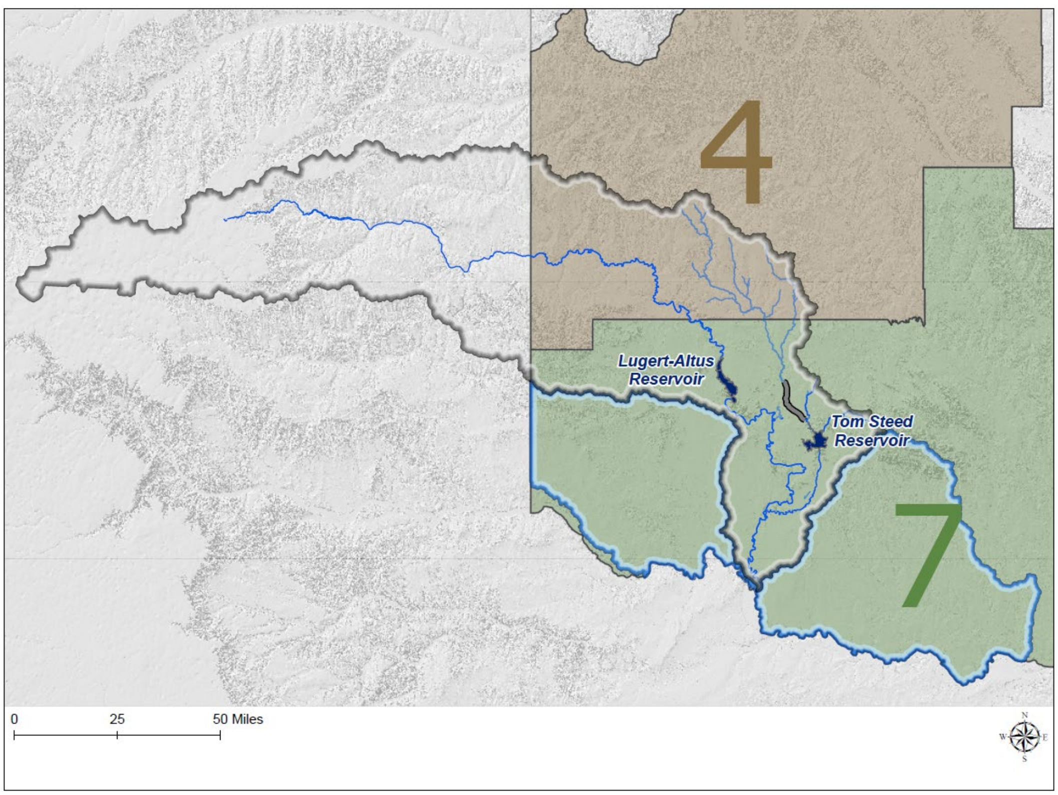

Figure 5-2. Location of the URRBS study area relative to Oklahoma's Climate Divisions 4 and 7 (NOAA's National Climate Data Center).

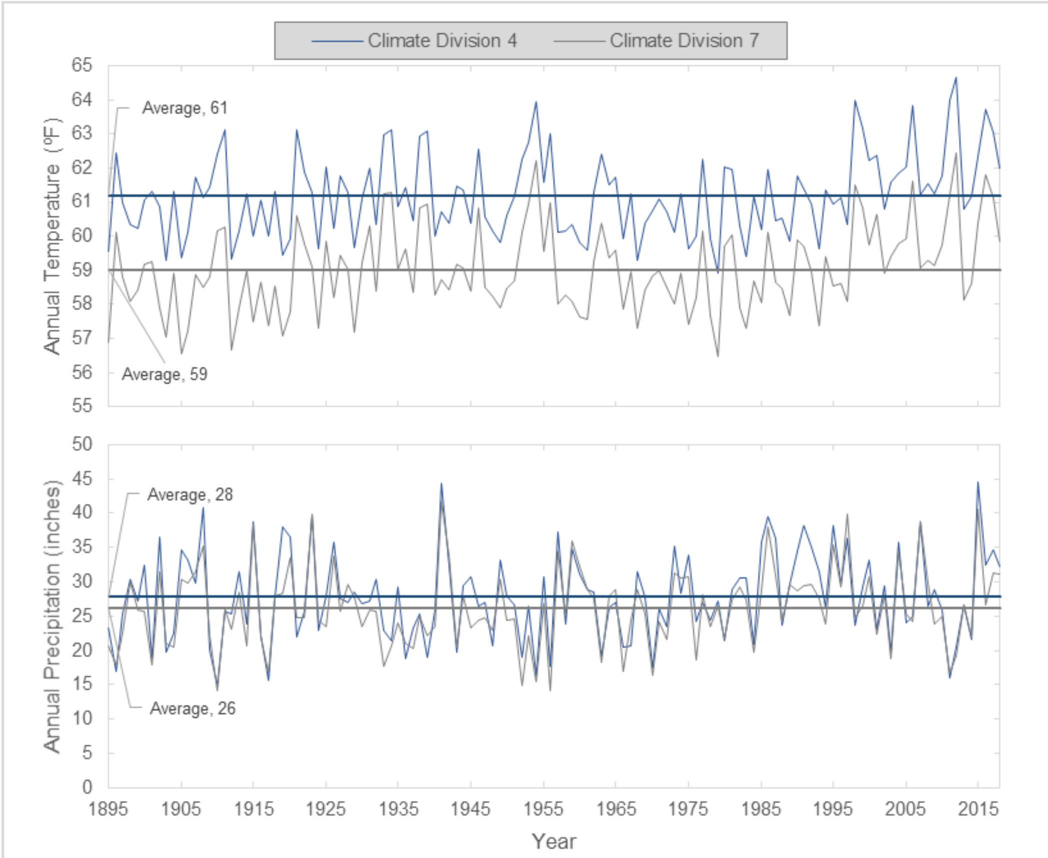

Figure 5-3. Annual temperature and precipitation, 1950-2018 (Oklahoma's Climate Divisions 4 and 7).

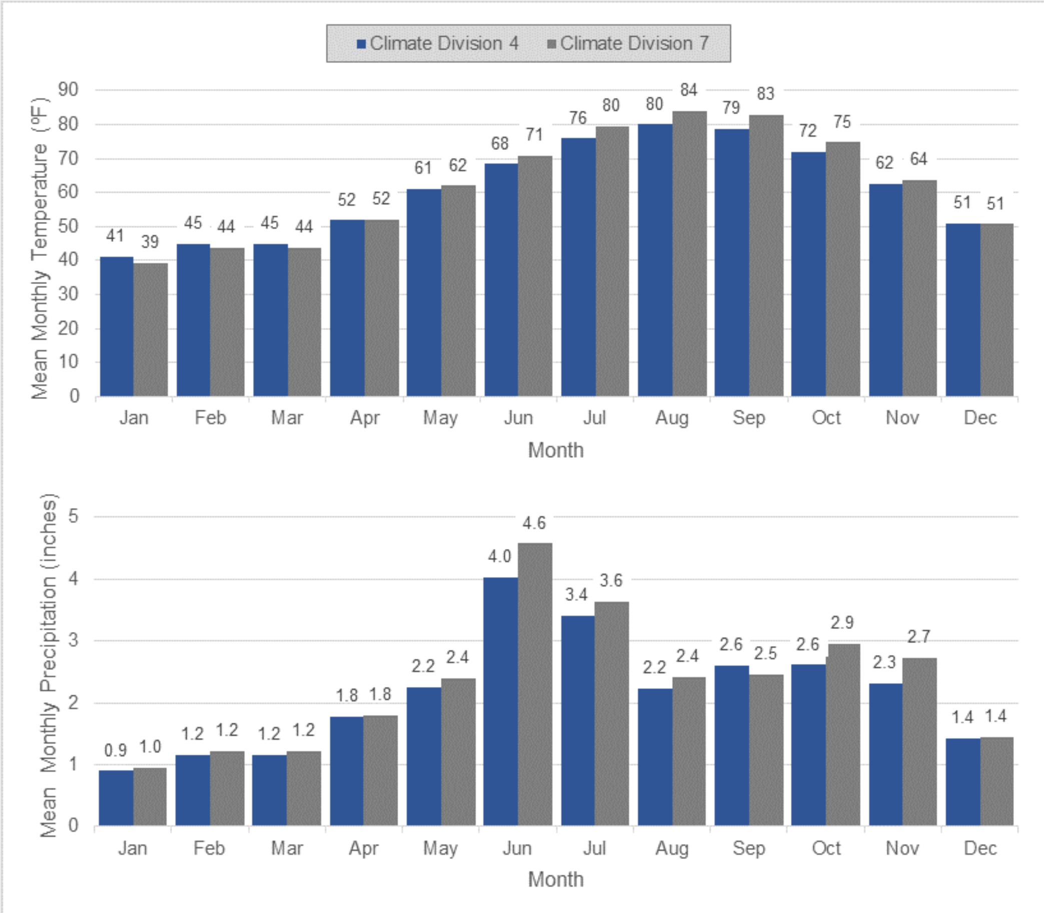

Figure 5-4. Monthly mean temperature and precipitation, 1950-2018 (Climate Divisions 4 and 7).

Table 5-1. Mean monthly precipitation and temperature data by climate station within Climate Divisions 4 and 7.

Station Number	Station Name	Period of Record[a]		Mean Monthly Temperature (ºF)	Mean Monthly Precipitation (inches/month)
		Temperature	Precipitation	Period of Record	Period of Record
Beckham County, West Central Climate Division (CD 4)					
342849	Elk City	1904-2019	1904-2019	60.12	26.00
342944	Erick	1904-2016	1904-2019	60.21	24.94
346035	Moravia	-	1941-2019	-	26.13
347952	Sayre	1936-2016	1936-2019	60.45	23.98
Comanche County, Southwest Climate Division (CD 7)					
341706	Chattanooga[b]	1905-2016	1905-2019	62.52	28.34
345063	Lawton[b]	1912-2016	1912-2019	62.67	31.13
349629	Wichita Mountain Wildlife Refuge[b]	1906-2016	1906-2019	60.87	31.07
Greer County, Southwest Climate Division (CD 7)					
345509	Mangum	1920-2016	1920-2019	62.08	25.70
Harmon County, Southwest Climate Division (CD 7)					
343871	Hollis[b]	1922-2011	1922-2013	62.48	23.63
349212	Vinson[b]	-	1940-2017	-	25.12
Jackson County, Southwest Climate Division (CD 7)					
340179	Altus Irrigation Research Station	1903-2011	1903-2013	62.87	25.69
Kiowa County, Southwest Climate Division (CD 7)					
340184	Altus Dam	1945-2019	1945-2019	62.16	27.78
344204	Hobart	1910-2019	1910-2019	61.24	26.14
347727	Roosevelt	-	1943-2019	-	28.25
348299	Snyder	1906-1920	1906-2013	63.11	27.57
Tillman County, Southwest Climate Division (CD 7)					
343353	Frederick[b]	1904-2010	1904-2011	63.80	26.91
343709	Grandfield[b]	-	1941-1994	-	36.65
348879	Tipton	1938-2019	1938-2019	62.68	25.34
Roger Mills County, West Central Climate Division (CD 4)					
341738	Cheyenne[b]	-	1923-1994	-	17.88
343871	Hammon[b]	1920-2005	1920-2005	57.64	21.82
347579	Reydon[b]	1941-2007	1941-2007	58.98	23.01
Washita County, West Central Climate Division (CD 4)					
341927	Cloud Chief[b]	1893-1975	1893-1975	67.02	36.87
342125	Cordell[b]	1936-2008	1936-2008	60.91	27.96

[a] Period of Record may not be continuous.
[b] Adjacent to hydrologic basins.

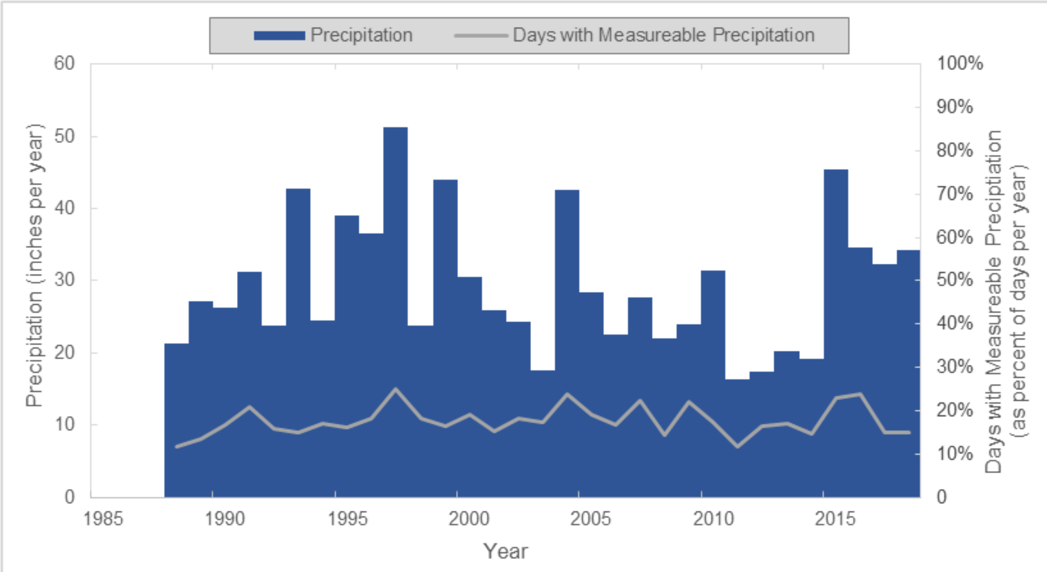

Figure 5-5. Annual precipitation and the percent of days each year with measurable precipitation at Altus Dam, 1988-2018.

5.2. Existing Basin-Wide Demands

Because groundwater serves as a key source of available surface water supplies in the URRBS study area, this section begins with a discussion on demand pressures on the NFRR and Elk City aquifers before moving on to present surface water demands on the hydrologic basins containing Lugert-Altus and Tom Steed reservoirs (i.e., NFRR; Elk and Otter Creeks), along with the reservoirs themselves.

5.2.1. Existing Groundwater Demands

The most significant groundwater features in the URRBS study area are the NFRR and Elk City aquifers (Figure 5-6)[82]. The NFRR aquifer contributes base flow to the NFRR which provides inflow into Lugert-Altus Reservoir; a small portion of the NFRR aquifer extends below Elk Creek, and thus contributes some base flow to Elk Creek above the Bretch Diversion and Canal which feeds into Tom Steed Reservoir. Most of Elk Creek's base flow is derived from the Elk City aquifer.

Well Permits and Reported Use

The OWRB permits and regulates groundwater use in Oklahoma, with the exception of domestic use[83]. Within the NFRR aquifer, as of the year 2017, 480 groundwater permits totaling 96,330 acre-ft/yr have been issued; the associated land area "dedicated" to these permits total 145,940 acres, or about 30 percent of the total land area overlying the NFRR aquifer[84]. Of the 480 permits,

[82] The geographic boundary of the Elk City aquifer presented in this URRBS report, along with the corresponding number and volume of permits, reflects the best available data prior to publication of the new Elk City aquifer hydrologic investigations report (Wagner et al., 2021). Therefore, the data presented in the URRBS for the Elk City aquifer are different than the data presented in Wagner et al. (2021).
[83] Domestic groundwater use is defined as use less than five acre-ft/yr for domestic and agricultural purposes and use for irrigation of less than three acres of land.
[84] The surface area overlying the NFRR aquifer is 497,582 acres or 777 square miles (Smith et al., 2017).

229 are prior rights, 220 are regular permits, and 31 are temporary[85]. The spatial distribution of the 480 well permits, dedicated land area, and use-type is illustrated in Figure 5-7[86]. Most of the permitted amount of 96,330 acre-ft/yr is allocated for irrigation and public supply (Figure 5-8; Figure 5-9); while the annual number and permit amounts have experienced growth since the 1950s, irrigation growth has out-paced growth in public water supply (Figure 5-8). Reported use in the NFRR aquifer has been much lower than the total permitted volume, averaging 16,215 acre-ft/yr between 1967 and 2018. Over the last decade (2009 – 2018), reported use has averaged 23,861 acre-ft/yr, or a little less than one-quarter the total permitted volume, and with two-thirds of the reported use going towards irrigation (Figure 5-9). The vast majority (79 percent) of reported use of the NFRR aquifer are located upstream of Lugert-Altus Reservoir (Figure 5-9). Reported use peaked at 26,714 acre-ft/yr in 2011.

Within the Elk City aquifer, 106 groundwater permits have been issued totaling almost 24,130 acre-ft/yr (Figure 5-10); the associated land area "dedicated" to these permits totals 36,105 acres, or about 19 percent of the total land area overlying the Elk City aquifer[87]. Of these, 37 are prior rights, 64 are regular permits, and five are temporary. The spatial distribution of the 106 groundwater permits, including by use-type, is illustrated in Figure 5-7. Most of the 24,100 acre-ft/yr is allocated for irrigation and public supply (Figure 5-10; Figure 5-11). Similar to the NFRR aquifer, while the annual number and permit amounts have experienced growth since the 1950s, irrigation growth has out-paced growth in public water supply (Figure 5-10). Reported use in the Elk City aquifer has been much lower than the total permitted volume, with annual use averaging 1,905 acre-ft/yr; over the last decade (2009-2018), reported use has gone down slightly, averaging 1,627 acre-ft/yr, or about one-fifteenth the total permitted volume, and with one-third of the reported use going towards irrigation (Figure 5-11). Reported use peaked at 3,597 acre-ft/yr in 1968.

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[85] Only temporary permits are subject to a reduction in an EPS; this implications of this will be discussed in Chapter 7.
[86] Each permit may include multiple wells that share the allocated groundwater use.
[87] The surface area overlying the Elk City aquifer is 193,137 acres or 301.78 square miles (Becker et al., 1997).

Non-permitted domestic wells also constitute demand withdrawals from the NFRR and Elk City aquifers. Non-permitted domestic wells are illustrated in Figure 5-12. Domestic uses are not only exempted from permitting, they also are exempt from having to report their use to the OWRB; therefore, their demand on the aquifers remain largely unquantifiable, although some information on groundwater use can be indirectly acquired through data collected from commercial well drillers. These data show that the NFRR aquifer contains a total of 750 domestic wells, while the Elk City aquifer contains a total of 618 wells[88]. Assuming a productivity from all of these wells with a maximum withdrawal of five acre-ft/yr allowable for domestic purposes[89], the total annual volume pumped for domestic purposes out of the two aquifers could be up to 3,750 acre-ft/yr and 3,090 acre-ft/yr, respectively.

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[88] Source: OWRB's well drilling program (https://www.owrb.ok.gov/welldrilling/index.php).
[89] Oklahoma Administrative Code 785:35.

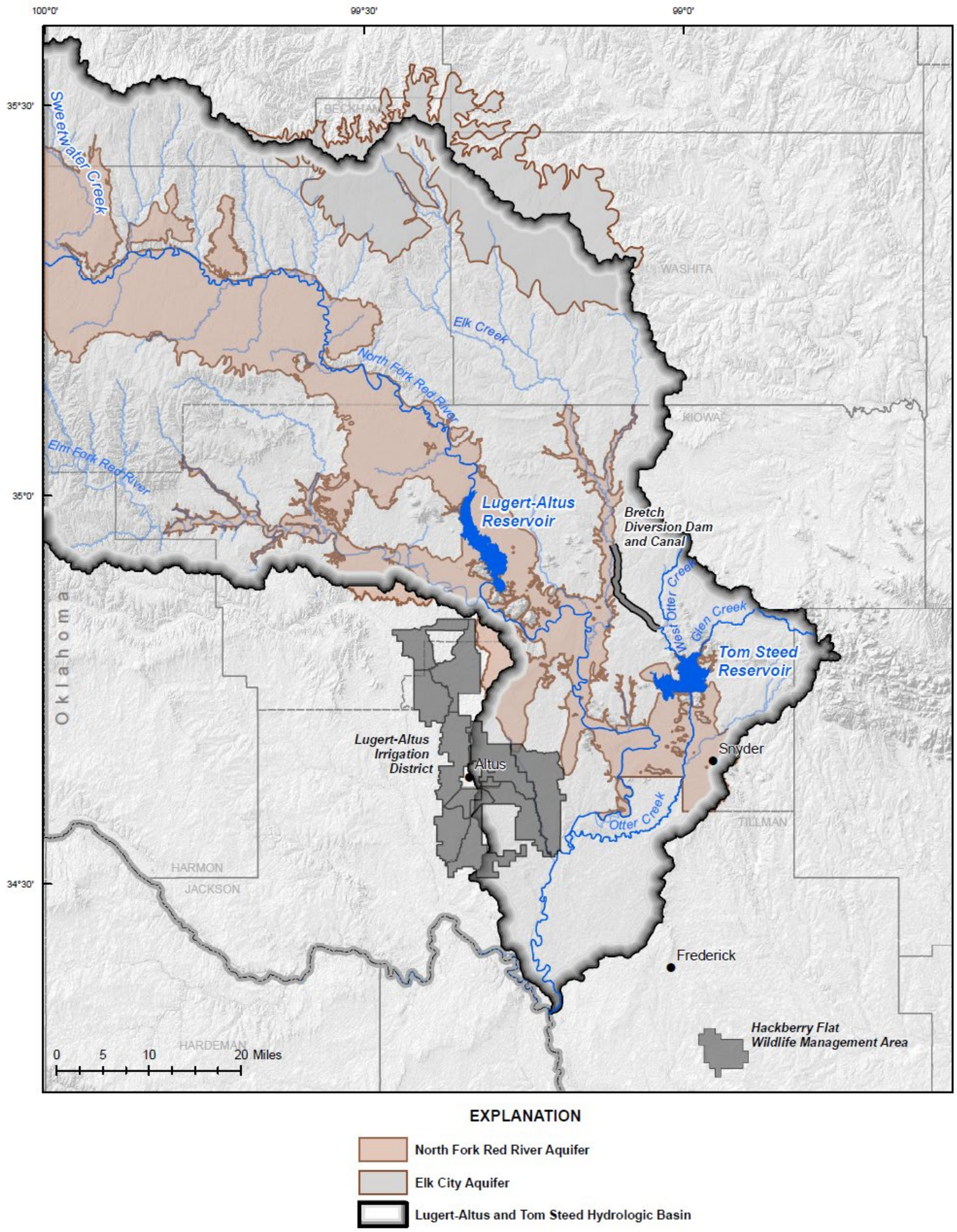

Figure 5-6. NFRR and Elk City aquifers, southwest Oklahoma.

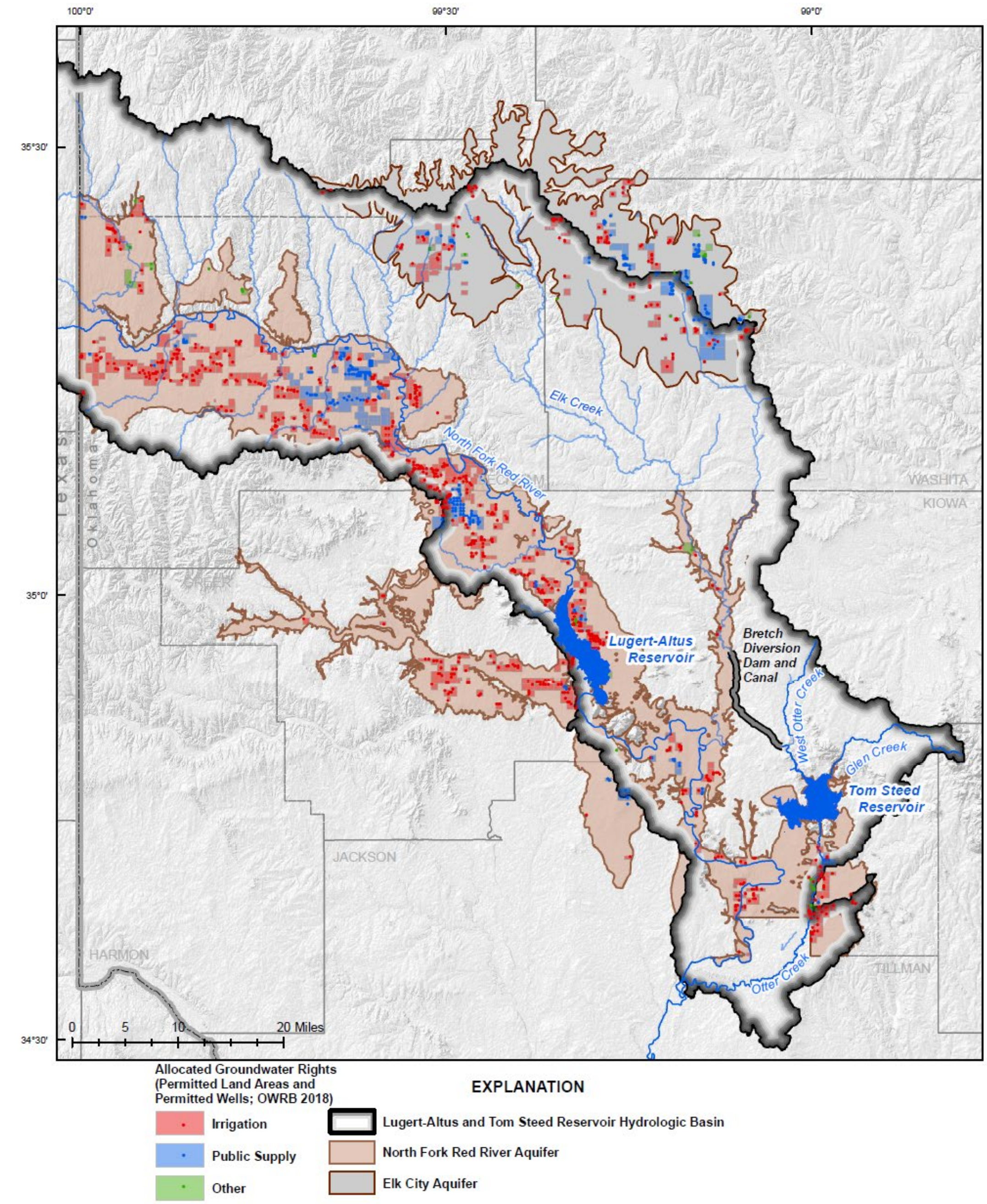

Figure 5-7. Land areas (i.e., dedicated lands) and wells permitted for groundwater use, including use-type, in the NFRR and Elk City aquifers.

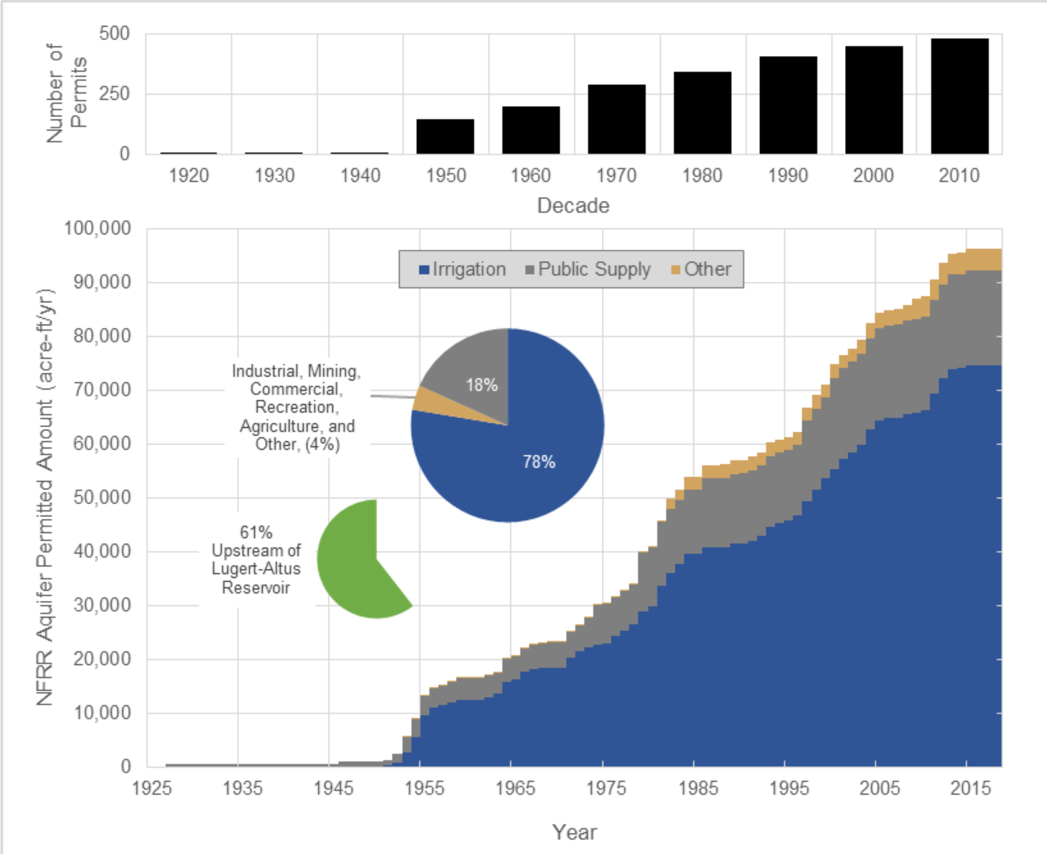

Figure 5-8. Annual amount of permitted groundwater use by use type in the NFRR aquifer, 1927-2018.

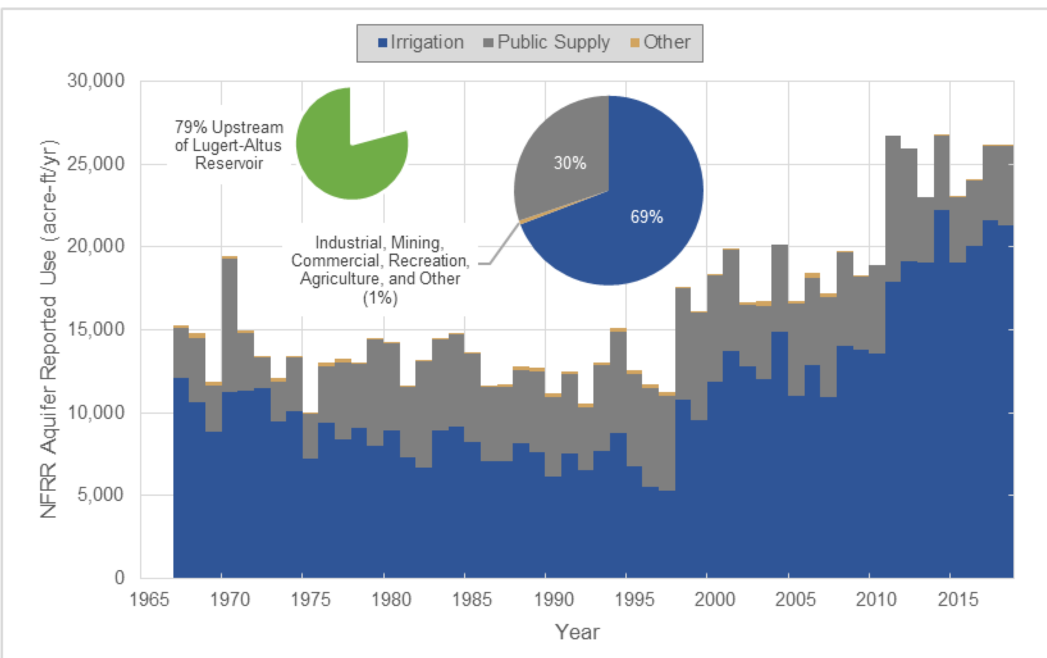

Figure 5-9. Annual reported use of permitted wells by use-type in the NFRR aquifer, 1967-2018.

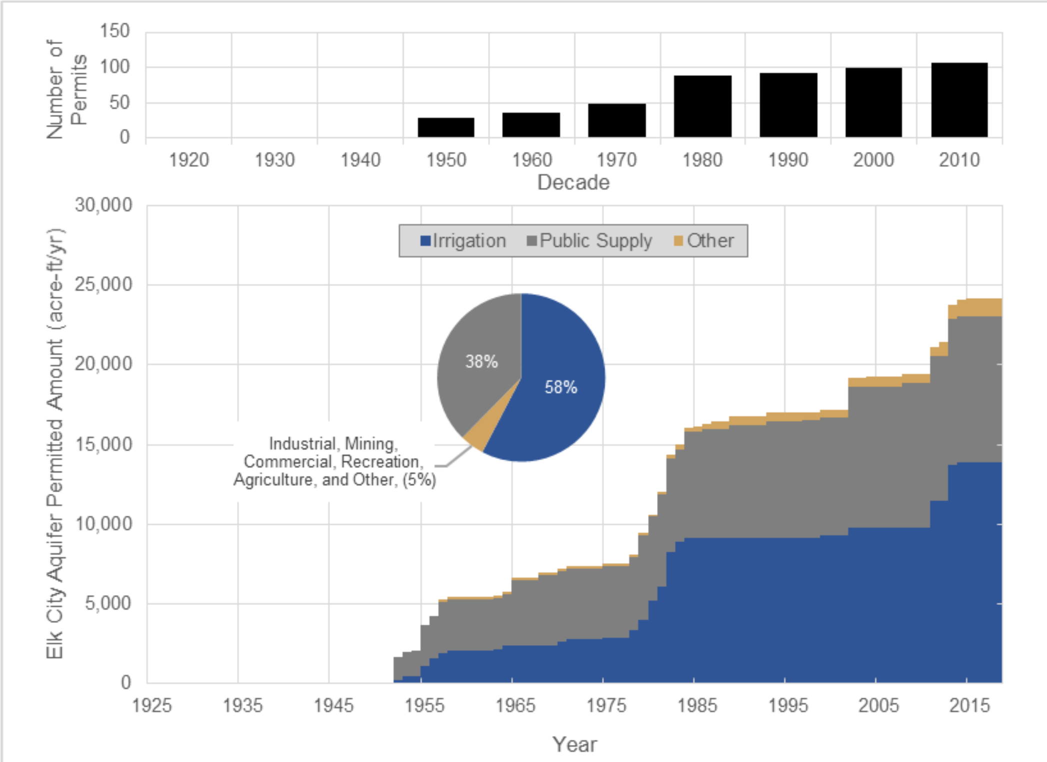

Figure 5-10. Annual amount of permitted groundwater use by use type in the Elk City aquifer, 1952-2018.

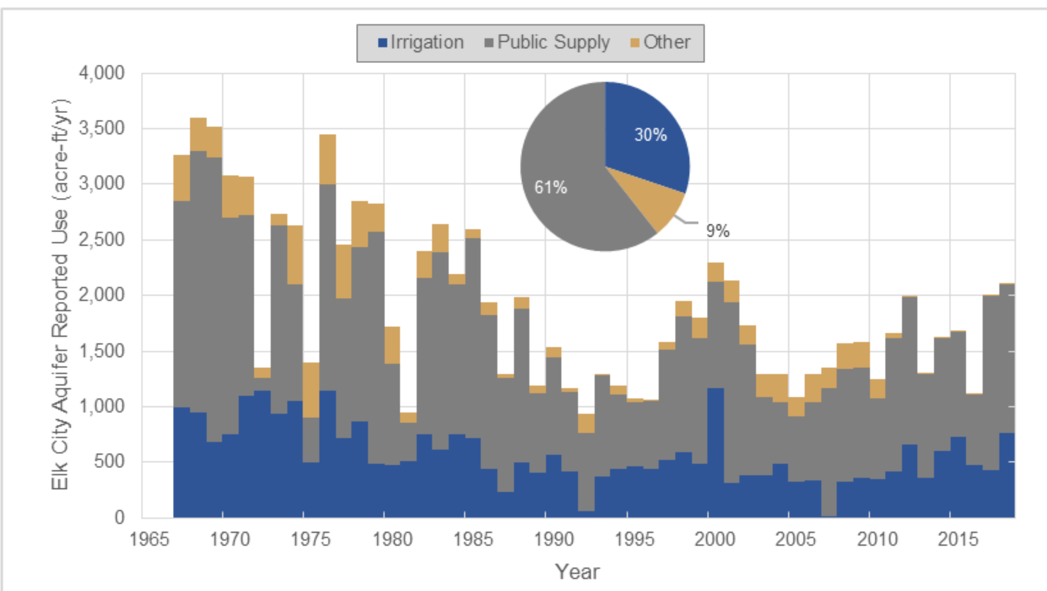

Figure 5-11. Annual reported use of permitted wells by use-type in the Elk City aquifer, 1967-2017.

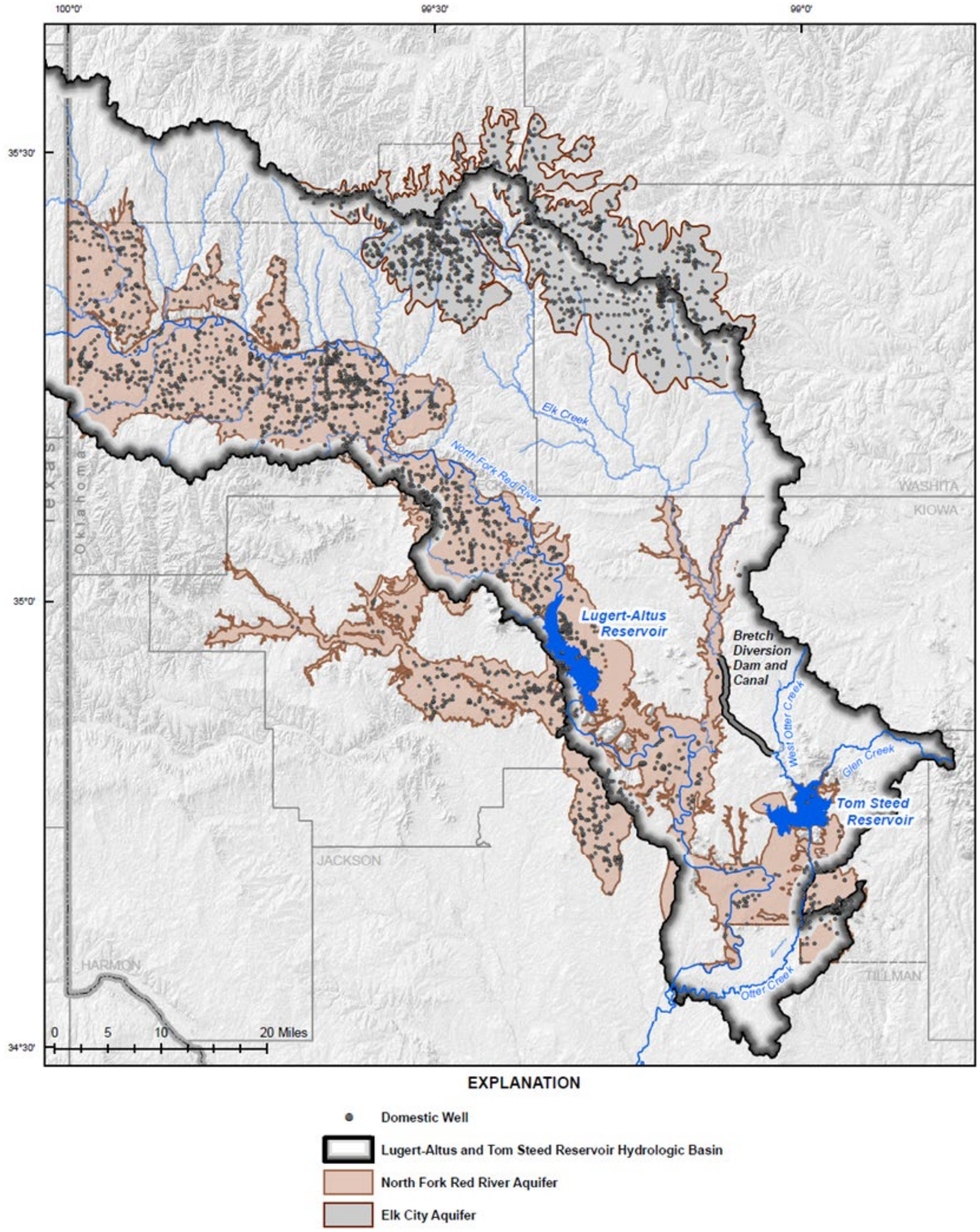

Figure 5-12. Non-permitted domestic groundwater wells within the NFRR and Elk City aquifers.

Uncertainties

Existing demands on groundwater centered on both permit amounts and on the volume of reported use. However, some findings indicate that reported use for irrigation purposes may represent a lower bound of irrigation demands on groundwater. For example, the use volume voluntarily reported by groundwater permit holders to the OWRB out of the NFRR aquifer in the year 2013 totaled 22,998 acre-ft/yr. Over 80 percent of this amount (19,045 acre-ft) was for agricultural irrigation. At the request of Lugert-Altus ID, Reclamation evaluated USDA crop census/Cropland Data Layers and modeled the potential crop irrigation requirements of agricultural land within the Lugert-Altus Reservoir hydrologic basin during the year 2013 (Reclamation, 2017) (Appendix G). The evaluation found that net crop irrigation demands were far higher than what is reported by permit holders in 2013[90]. Like reported use, these findings depend in part on the accuracy of reported crop census data submitted by permit holders to USDA; and because it was a preliminary analysis, numerous assumptions had to be made on inputs into the ET Model (Reclamation, 2019) (Appendix H). Short of metering well pumping, the best approach may entail the use of a model(s) that combines state-of-the-art remote sensing with regional, local, and ground-based hydro-climate data, while also accounting for variable soil conditions overlying the NFRR aquifer. Considering these data are currently unavailable, the combination of permit amounts with reported volume were considered the best available data and represent a reasonable range of assumed groundwater demands. This rationale also applies to future groundwater demands and is discussed again in Chapter 5.4.1.

[90] Net irrigation demands were estimated to be 86,000 acre-ft in 2013 for irrigated lands over the NFRR Aquifer within the Lugert-Altus Reservoir hydrologic basin.

5.2.2. Existing Surface Water Demands

This section details (1) streamflow demands, which include run-of-the-river permitted and non-permitted domestic uses out of the Lugert-Altus and Tom Steed Reservoir hydrologic basins; and (2) demands from the direct users of Lugert-Altus and Tom Steed reservoirs.

Existing Streamflow Demands

Lugert-Altus Reservoir Hydrologic Basin

The Lugert-Altus Reservoir hydrologic basin is formed by the NFRR. Thirteen regular surface water permits totaling 91,853 acre-ft/yr exist in the basin, 90,430 acre-ft/yr is permitted to Lugert-Altus ID (85,630 acre-ft/yr) and the city of Altus (4,800 acre-ft/yr). The spatial distribution of these permits is provided in Figure 5-13. Excluding the two permits held by the Luger-Altus ID and the city of Altus, the remaining 11 regular surface water permits total 1,422 acre-ft/yr (Figure 5-14). Most of these permits are for irrigation (89 percent), with the remaining 11 percent for recreation, fish and wildlife; and most permits are located upstream of the reservoir (65 percent) (Figure 5-14). All are considered junior[91] to the water rights held by the Lugert-Altus ID and the city of Altus (dated 1939 and 1926, respectively).

While reported permit use fluctuates from year to year, the volume of reported use has generally been less than the permitted amount (Figure 5-14; Figure 5-15)[92]. As expected, most reported use (79 percent) is for irrigation purposes and is located upstream of Lugert-Altus Reservoir (83 percent) (Figure 5-15). In addition to reported use, withdrawals can be measured or interpolated using other methods, such as calculating the difference in flow occurring at two locations where the flow can be directly measured (i.e., by a

[91] The terms "junior" and "senior" are based solely on the water right application date listed on OWRB's water rights database. The surface water basins have not been officially adjudicated by the state of Oklahoma.
[92] Reported use volumes prior to 1967 are estimates only. Reported use after 1967 may not reflect actual water use; this is discussed in more detail later in this report.

USGS gaging station). But without metered data, or data collected from remote sensing with regional, local, and ground-based hydro-climate data, the source of diversions remains unknown, including whether or not they are the result of permitted users or domestic users.

PT permits (PTs) also make up a portion of demands withdrawn from the NFRR. As discussed in Chapter 2, PTs authorize temporary use for up to 90 days and can be granted directly by the OWRB's Executive Director without the requirement of a hearing or notification to downstream users. For this reason, the issuance of PTs upstream of the reservoirs, on top of the regular permits issued in the hydrologic basins containing Lugert-Altus and Tom Steed reservoirs, has caused concern among the Districts, particularly during critical drought periods. For reference purposes, during the 2010s Drought of Record, 51 stream water 90-day PTs were issued in the NFRR upstream of Lugert-Altus Reservoir totaling 345 acre-ft (i.e., average of 69 acre-ft annually). Figure 5-16 presents a comparison of the volume of PTs relative to regular surface water permits between 2011-2015.

Similar to groundwater, domestic users also place demand pressures on surface water. Like groundwater, domestic surface water is exempt from permitting and reporting, so domestic demands on surface water also remain largely unquantifiable. Further complicating the matter is the fact that, unlike groundwater wells which require drill licensing that can be catalogued, official records that catalogue domestic surface water use are limited to only when farm ponds require registration/permitting with the OWRB's dam safety program.[93]

[93] http://www.owrb.ok.gov/damsafety/index.php.

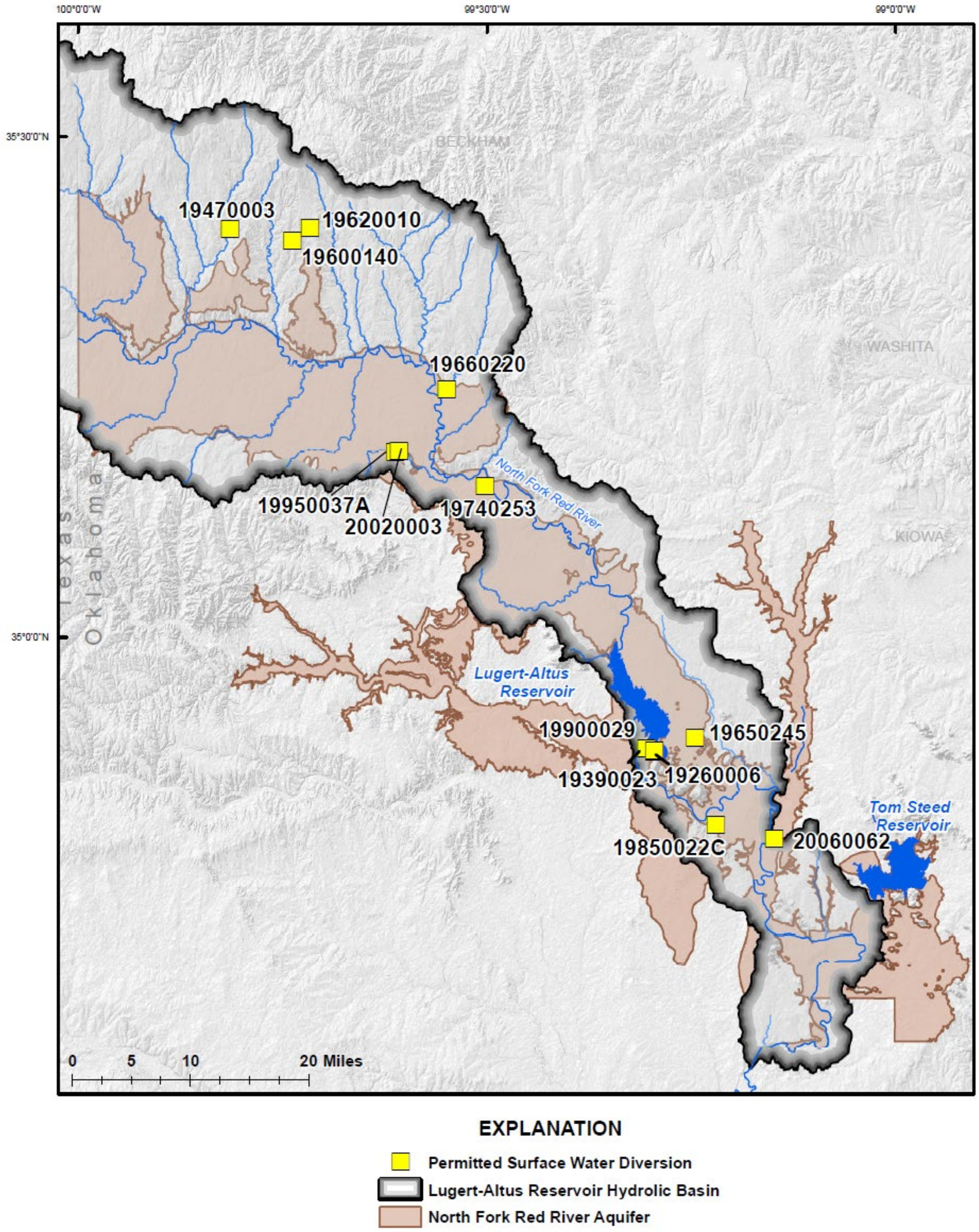

Figure 5-13. Distribution of regular surface water permits issued in the Lugert-Altus Reservoir hydrologic basin.

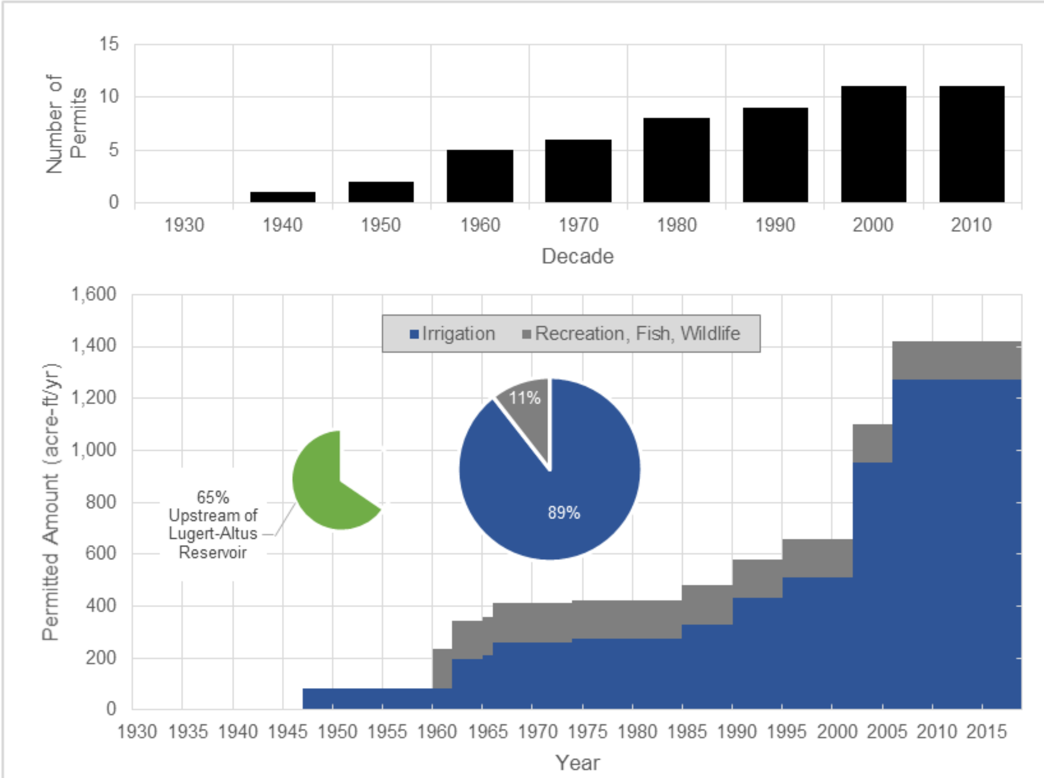

Figure 5-14. Regular surface water permits within the Lugert-Altus Reservoir hydrologic basin, including number of permits, cumulative permitted volumes and percent, excluding permits held by the city of Altus and Lugert-Altus ID, 1947-2018.

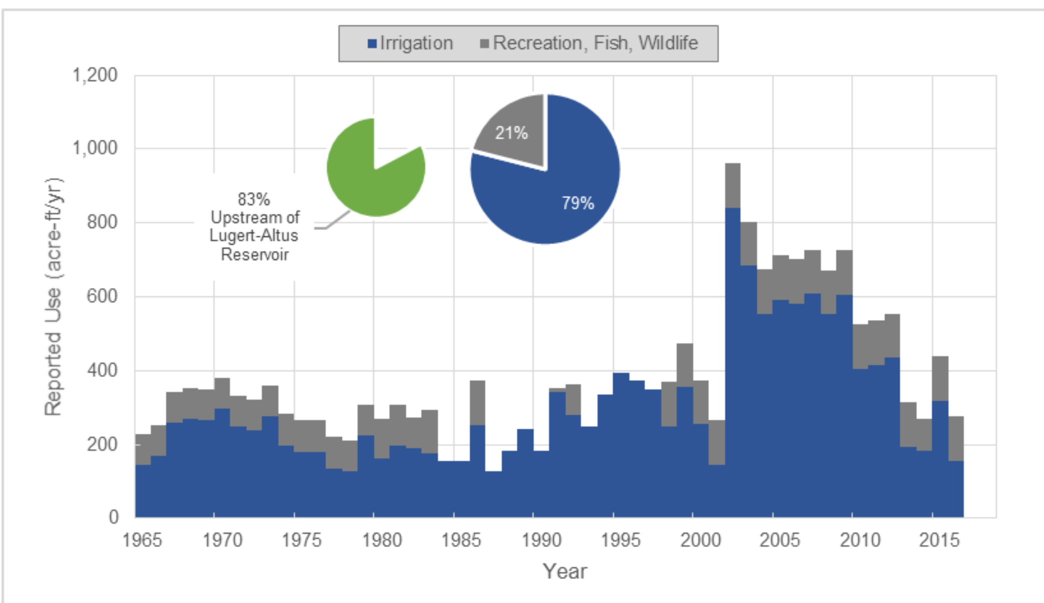

Figure 5-15. Annual reported use by use-type for regular surface water permits within the Lugert-Altus Reservoir hydrological basin, excluding permits held by the city of Altus and Lugert-Altus ID, 1965-2016.

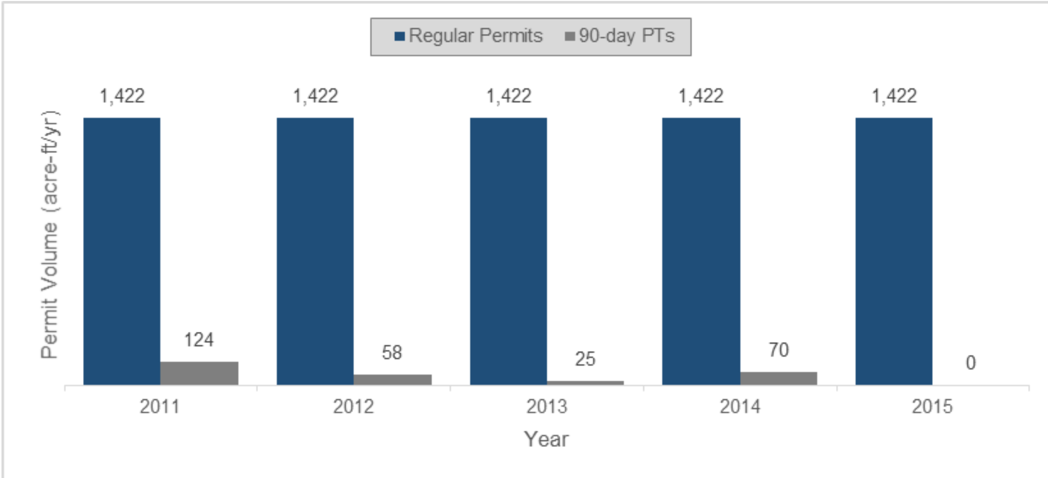

Figure 5-16. Volume of regular surface water permits versus 90-day stream water PT permits in Lugert-Altus Reservoir's hydrologic basin upstream of the reservoir during the 2010s Drought of Record, 2011-2015.

Tom Steed Reservoir Hydrologic Basin

Tom Steed Reservoir's hydrologic basin includes out-of-basin flows from Elk Creek and natural, in-basin flows from the West Otter Creek/Glen Creek watershed. Eighteen surface water permits, comprised of 17 regular permits and one term permit, exist in the basin totaling 22,749 acre-ft/yr. The spatial distribution of these permits is illustrated in Figure 5-17. Of the 22,749 acre-ft/yr permitted, 16,100 acre-ft/yr is permitted to the MPMCD; the remaining 17 surface water permits total 6,649 acre-ft/yr (Figure 5-18). These permits are allocated for irrigation (62 percent), public water supply (26 percent), and recreation, fish, and wildlife (12 percent); most permits are upstream of the reservoir (69 percent) (Figure 5-18). Unlike the Lugert-Altus Reservoir hydrologic basin, not all permits are junior to the water rights held by the MPMCD[94]. Of the 17 permits totaling 6,649 acre-ft/yr permitted in the basin, seven of those are senior to the MPMCD's permit, totaling 1,933 acre-ft/yr or 29 percent of the total permit volume (excluding MPMCD's permit). Six of the seven senior permits are located upstream of Tom Steed Reservoir (Figure 5-17), totaling 1,856 acre-ft/yr or 96 percent of the total volume of senior permits.

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[94] The terms "junior" and "senior" are based solely on the water right application date listed on OWRB's water rights database. The surface water basins have not been officially adjudicated by the state of Oklahoma.

While reported permit use fluctuates from year to year, the volume of reported use has generally been less than the permitted amount (Figure 5-18; Figure 5-19)[95]. Reported use is roughly distributed evenly by irrigation (39 percent), public water supply (25 percent); and recreation, fish, and wildlife (36 percent); most reported use is located upstream of Tom Steed Reservoir (86 percent) (Figure 5-19). Ten of the 17 permits are considered junior[96] to the water rights held by the MPMCD. Similar arguments exist regarding the validity of reported use estimates, but in the absence of metering, reported use is considered the best available data.

In addition to regular and term surface water permits, PTs also constitute a demand withdrawal from Tom Steed Reservoir's hydrologic basin. Similar to Lugert-Altus Reservoir, concerns have focused on the issuance of PTs during critical dry periods. During the 2010s Drought of Record, seven PTs were issued in the Elk Creek hydrologic basin upstream of Tom Steed Reservoir totaling 43.5 acre-ft (i.e., average of nine acre-ft annually). Figure 5-20 presents a comparison of the volume of PTs relative to regular/term permits over that time.

Finally, similar to Lugert-Altus Reservoir's hydrologic basin, domestic use of surface water in Tom Steed Reservoir's hydrologic basin is exempt from permitting and use reporting, so domestic demands remain largely unquantifiable, with the exception of some farm ponds.

[95] Reported use volumes prior to 1967 are estimates only. Reported use after 1967 may not reflect actual water use; this is discussed in more detail later in this report.
[96] The terms "junior" and "senior" are based solely on the water right application date listed on OWRB's water rights database. The surface water basins have not been officially adjudicated by the state of Oklahoma.

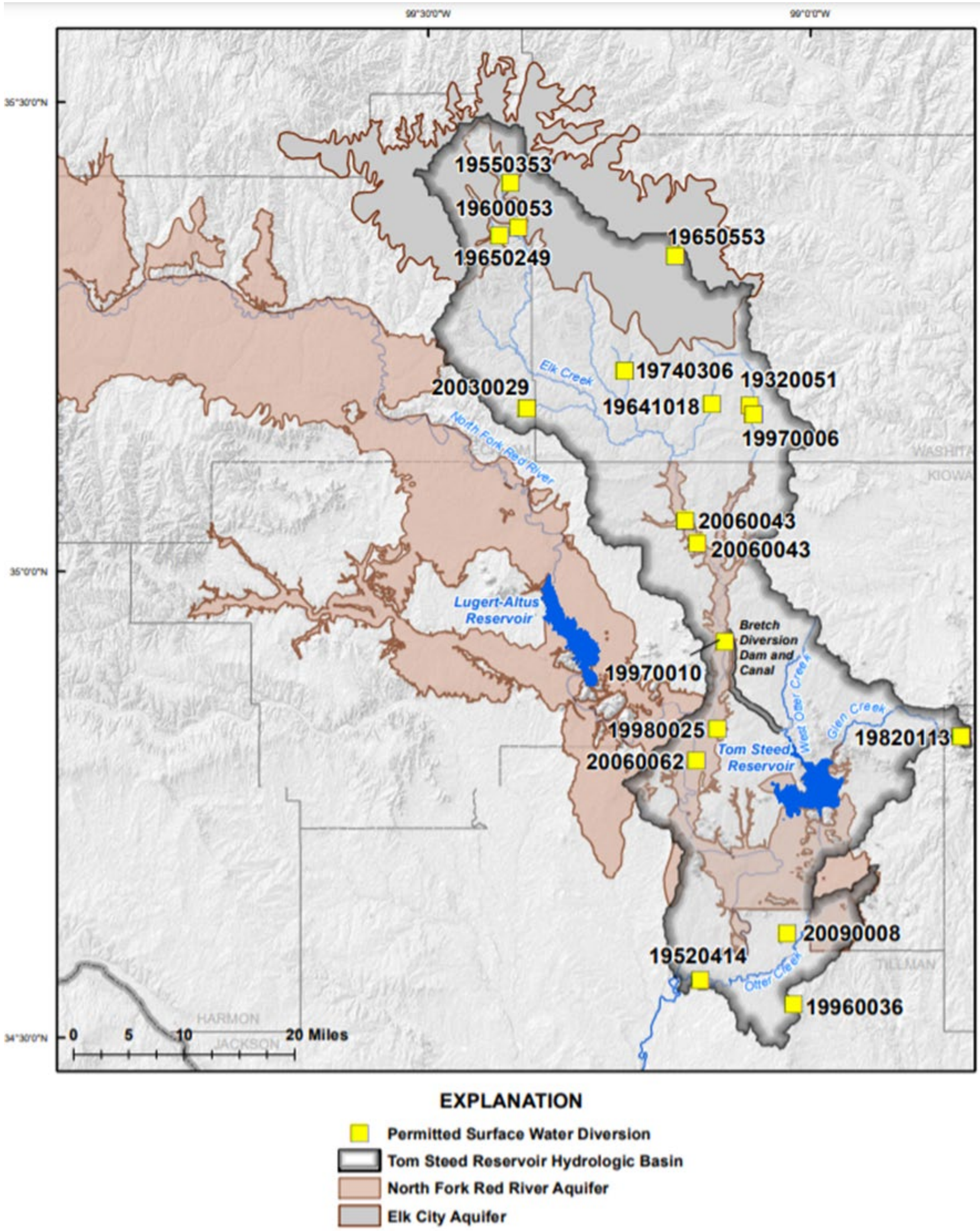

Figure 5-17. Distribution of regular and term surface water permits issued in the Tom Steed Reservoir hydrologic basin.

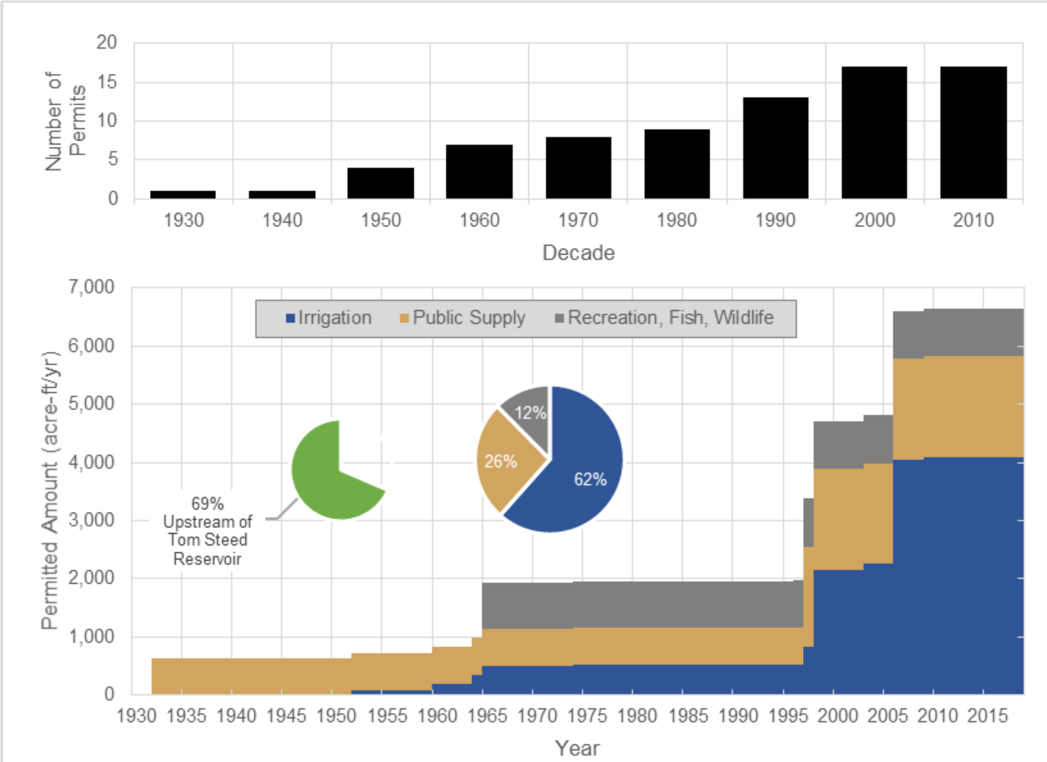

Figure 5-18. Regular and Term surface water permits within in the Tom Steed Reservoir hydrologic basin, broken down by number of permits, cumulative permitted volumes and percent, excluding the permit held by MPMCD, 1932-2018.

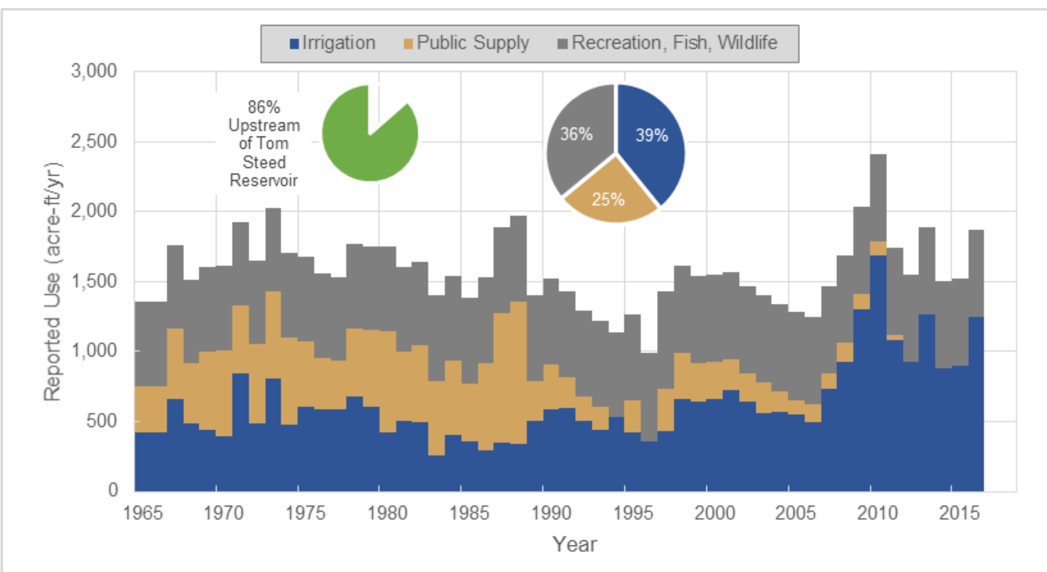

Figure 5-19. Annual reported use by use-type for regular and term surface water permits within the Tom Steed Reservoir hydrological basin, excluding the permit held by MPMCD, 1965-2016.

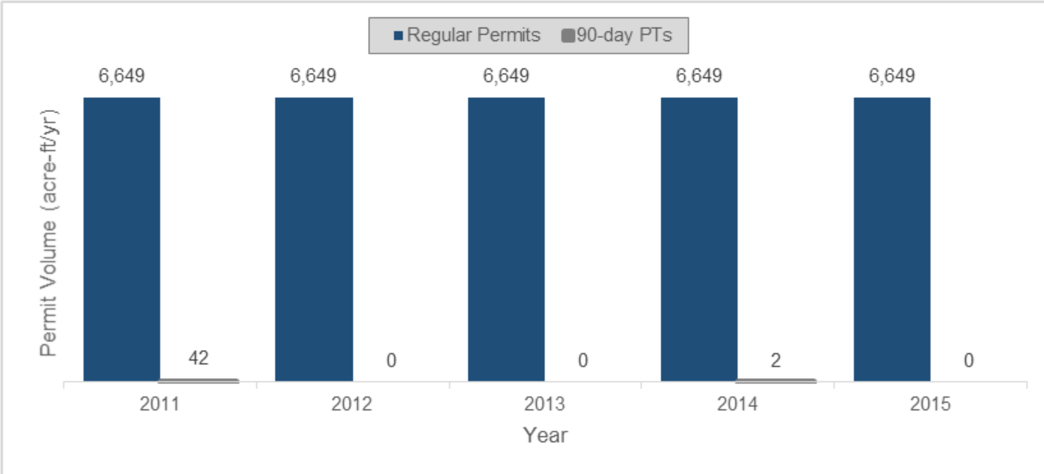

Figure 5-20. Volume of regular stream water permits versus 90-day stream water PT permits in Tom Steed Reservoir's hydrologic basin upstream of the reservoir during the 2010s Drought of Record.

Uncertainties

Similar to groundwater demands, existing demands on streamflow were derived based on permit amounts and voluntary reported use. Again, it should be noted that a more accurate approximation of stream-water use would entail the direct measurement at the point of diversion. Considering the unavailability of metered data, permit amounts and reported use are considered the best available data.

Existing Reservoir Demands

The existing demands on Lugert-Altus and Tom Steed reservoirs are primarily characterized in terms of observed, historic deliveries. While deliveries to the cities served by these reservoirs are a good indicator of M&I demands on the reservoirs[97], deliveries from Lugert-Altus Reservoir for agricultural irrigation within the Lugert-Altus ID reveal only a portion of the water actually required (i.e., demanded) for consistent, productive crop yields. This was first discussed in Chapter 2.3.1 and is summarized again below. The same can be said for EQ

[97] This analysis focuses on reservoir demands and does not quantify historic demands/deliveries on other supplemental sources such as groundwater.

deliveries to Hackberry Flat WMA, which serve only as a partial indicator of water demands of the EQ benefit in general; this, too, is discussed below.

Lugert-Altus Reservoir

Water demands on Lugert-Altus Reservoir are primarily derived from the Lugert-Altus ID's 85,630 acre-ft water right to irrigate 48,000 acres of land within the Lugert-Altus ID for agricultural use (primarily cotton), but also from a requirement to ensure the city of Altus' 4,800 acre-ft/yr senior M&I water right is protected. In Chapter 2.3.1, we derived 115,000 acre-ft/yr as the volume of storage needed in Lugert-Altus Reservoir to meet these demands; this volume includes a legally-mandated storage reserve to ensure water is available to the city of Altus and also accounts for evaporation. Chapter 2 also detailed operational challenges related to balancing these dual demands on the reservoir to maintain a consistent and reliable water supply in Lugert-Altus Reservoir. For the purposes here, we present again a few key pieces of information contained in Chapter 2.3.1 to support our demand analysis on Lugert-Altus Reservoir.

Crop Irrigation Demands

The Lugert-Altus ID holds a water right of 85,630 acre-ft/yr and irrigates approximately 48,000 acres of land, principally cotton, although winter wheat, alfalfa, peanuts, grain sorghums, and potatoes also are prevalent (Figure 5-21). Long-term mesonet data from the city of Altus suggests that healthy cotton requires a total of about 30 inches of water in southwest Oklahoma (Boman and Warren, 2017). Accounting for average total rainfall during irrigation months of May through September in the area (15.72 inches; Figure 5-22), cotton farmers typically need a net of about 15 inches of irrigation water[98]. Figure 5-23 illustrates typical seasonal water-use pattern for cotton produced in the Texas High Plains region, which is similar to southwest Oklahoma, and which is

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[98] Randy Boman, Research Director and Extension cotton program leader at the Oklahoma State University Research Center in Altus, in Sept 10, 2014 Southwest Farm Press.

supported by 10-yr average cotton evapotranspiration data collected by the Oklahoma mesonet for Altus (Boman and Warren, 2017).

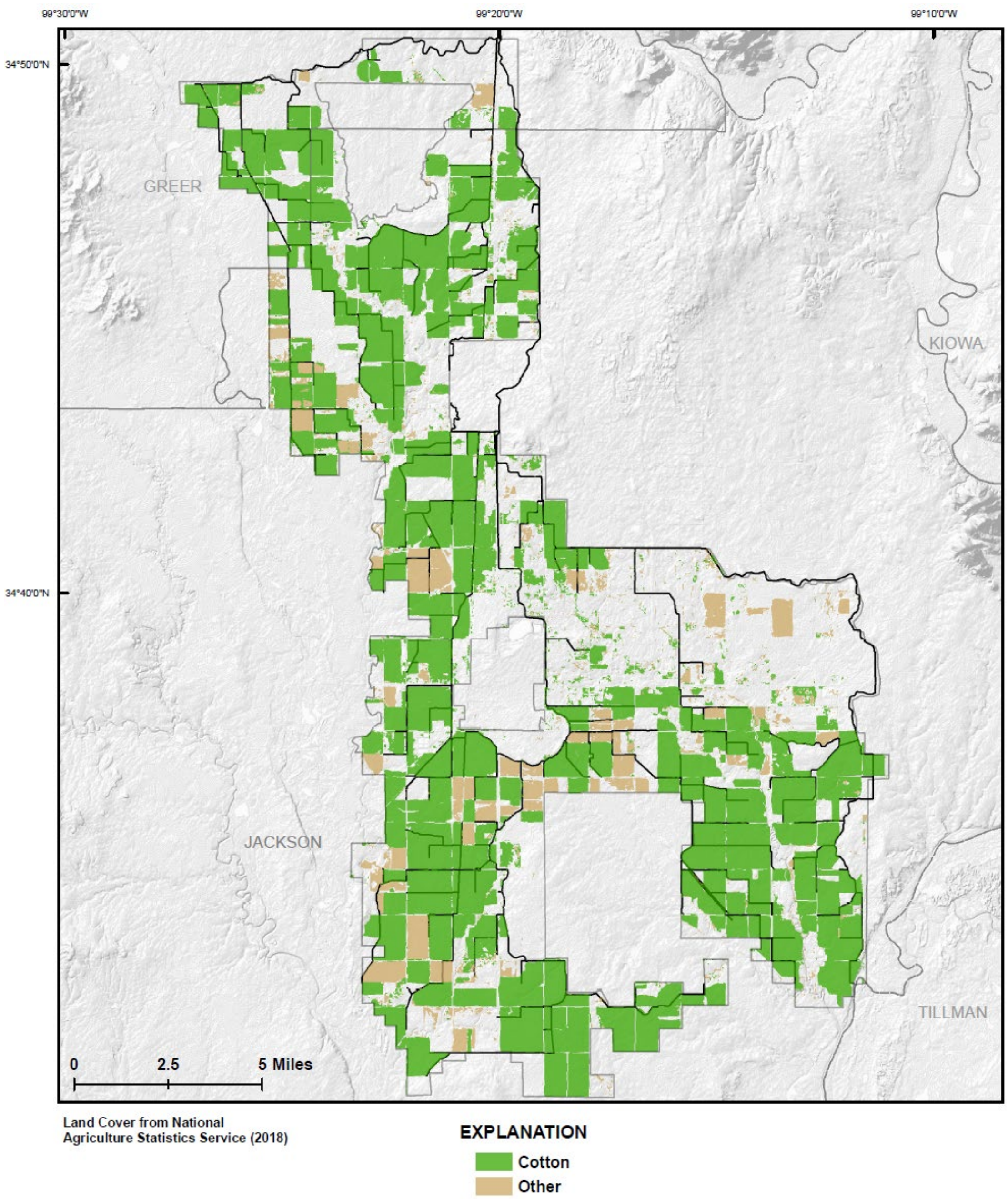

Figure 5-21. Lugert-Altus ID land cover data from the National Agriculture Research Service in 2018.

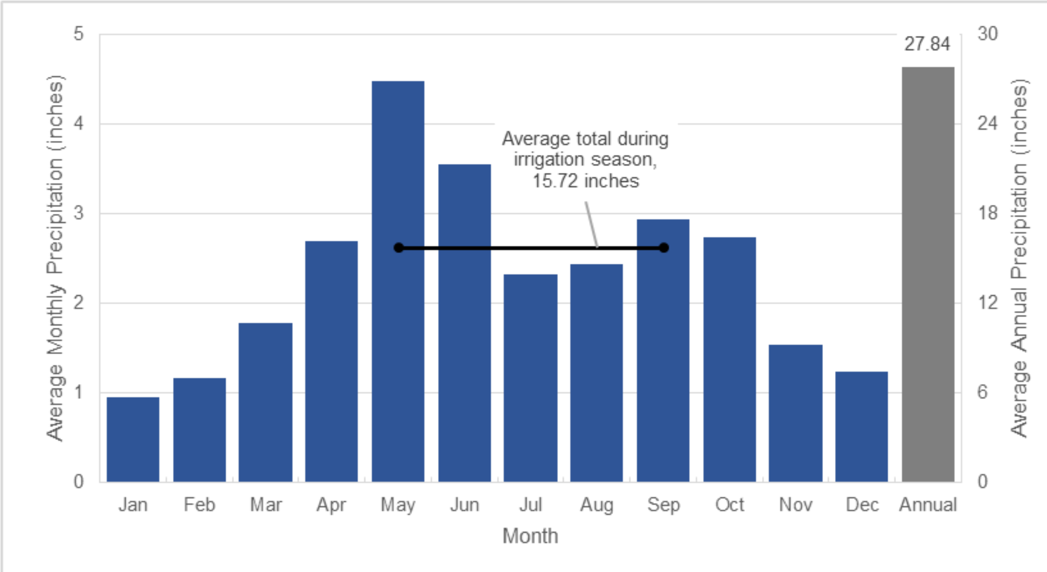

Figure 5-22. Distribution of monthly mean precipitation and average annual precipitation, 1895-2018 (Southwest Oklahoma Climate Division 07). The cumulative total mean precipitation between irrigation months (May through September) is 15.72 inches.

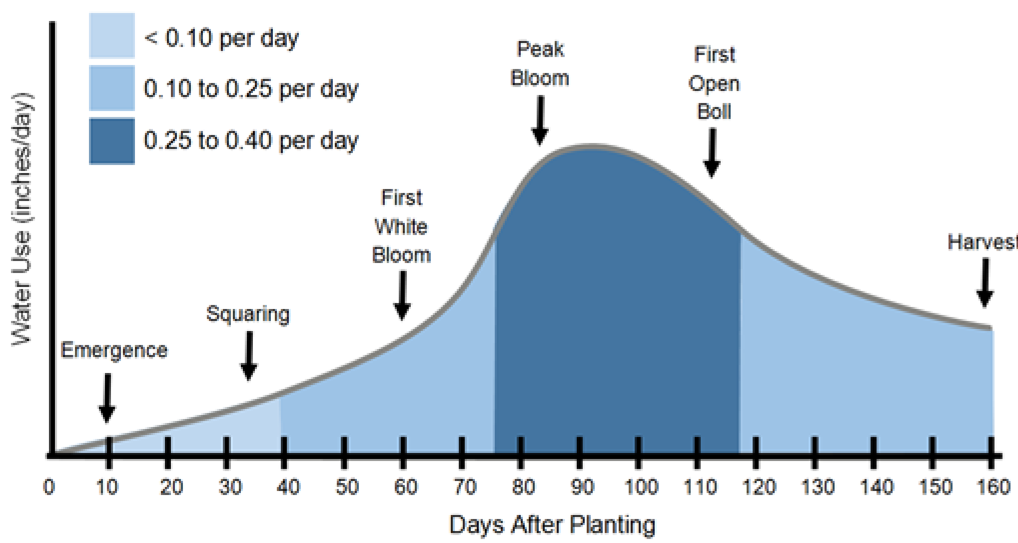

Figure 5-23. Typical seasonal water-use pattern for cotton produced in the Texas High Plains region (Boman and Warren, 2017).

Balancing Irrigation Demands with M&I Demands

The city of Altus has a contracted right with the U.S. to use 4,800 acre-ft/yr of M&I water from Lugert-Altus Reservoir, as well as a 1954 settlement agreement with the Lugert-Altus ID that requires the Lugert-Altus ID to manage irrigation operations such that 10,000 acre-ft in storage be reserved to ensure that the 4,800 acre-ft can be delivered to Altus, if needed. Overall, deliveries average 2,716 acre-ft/yr (Figure 5-24), but most of Altus' demands concentrated between the late 1960's and 1970's prior to the construction of Tom Steed Reservoir. Over the past 30 years, Tom Steed Reservoir has served as the city of Altus' primary M&I water supply (Figure 5-25)[99]. However, during the peak of the 2010s Drought of Record, 918 acre-ft, 724 acre-ft, and 467 acre-ft were delivered in 2012, 2013, and 2014, respectively, for a total of 2,109 acre-ft. During this time period, zero deliveries were made for agricultural irrigation. Although M&I demands are very small relative to irrigation demands, it is an important operational constraint that affects reservoir supply management during drought periods.

Figure 5-26 illustrates irrigation deliveries from Lugert-Altus Reservoir. Over the 68-yr record, the max delivery was 106,542 acre-ft/yr in the year 2000; the average delivery is 49,600 acre-ft/yr. Lugert-Altus ID delivered the full volume of its 85,630 acre-ft/yr water right on three occasions (1963, 1998, and 2000). The delivery volumes observed are a reflection of Lugert-Altus ID's operational goal of maximizing supply certainty over variable conditions that may exist over extended periods of time. The fact that 85,630 acre-ft/yr has only been delivered on a few occasions is not a reflection on the demands for irrigation supplies; rather, it is a reflection on the reliability of available supplies and the corresponding operation of the Lugert-Altus ID. From a farmer's perspective, it is often preferred to have less water on a consistent basis rather than more water on an inconsistent basis. It is a delicate balance that the Lugert-Altus ID must weigh throughout the irrigation season, and it highlights the importance of supply reliability.

[99] City of Altus demands on Tom Steed Reservoir are discussed more in the next section.

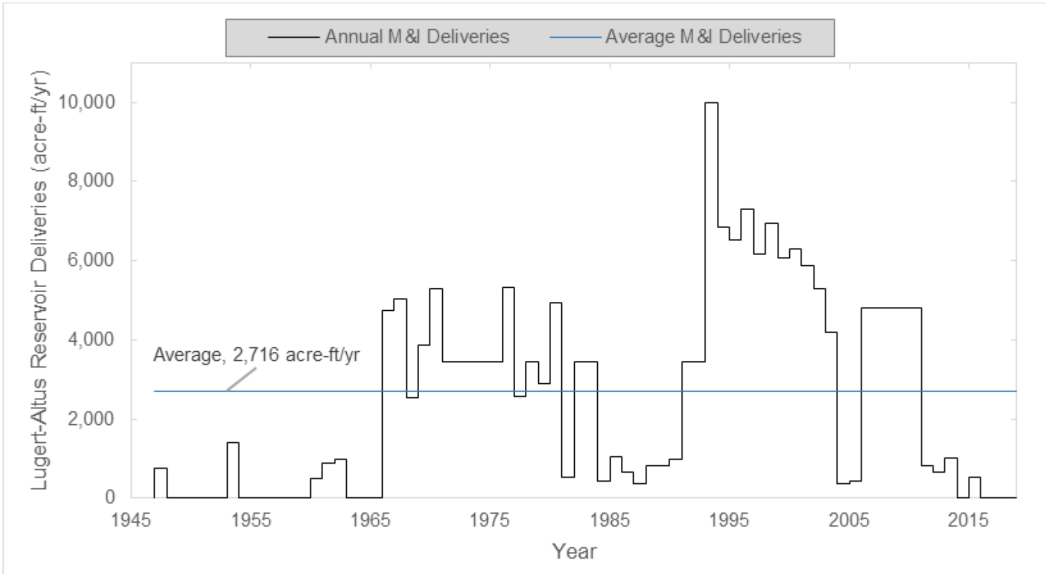

Figure 5-24. Annual deliveries from Lugert-Altus Reservoir to the city of Altus for M&I purposes, 1947-2018.

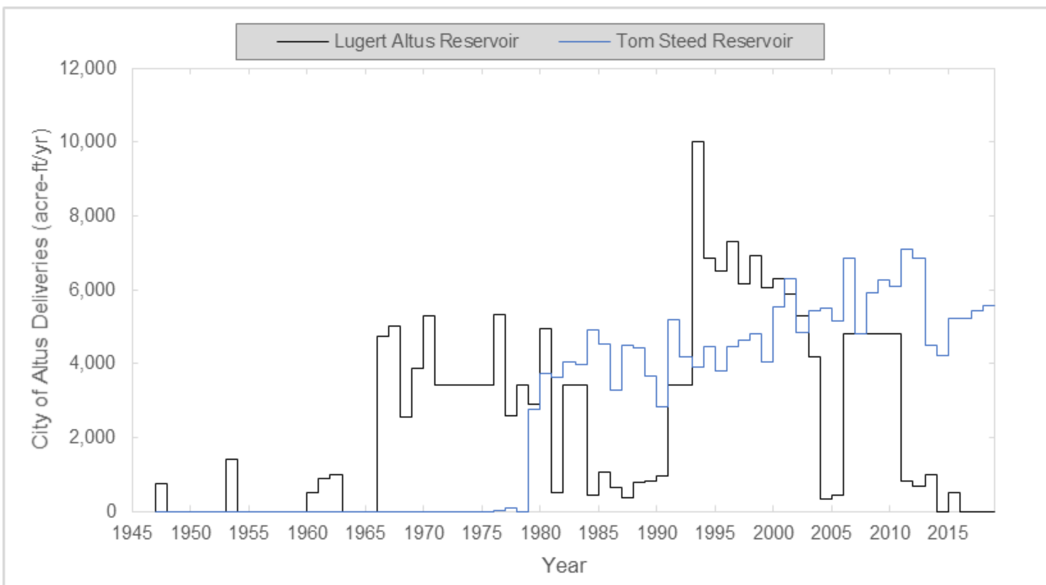

Figure 5-25. Annual deliveries from Lugert-Altus and Tom Steed reservoirs to the city of Altus for M&I purposes, 1947-2018.

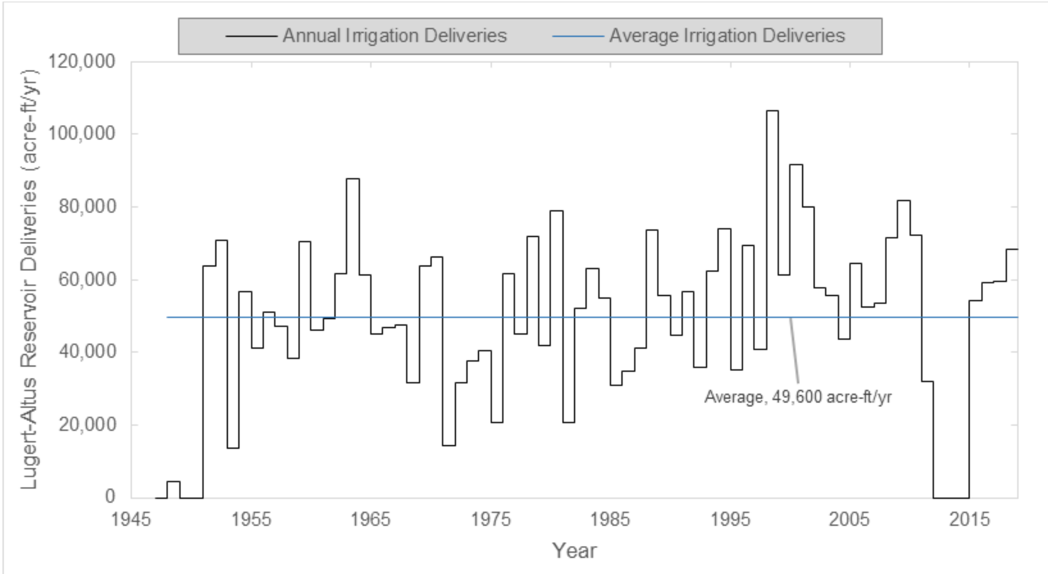

Figure 5-26. Annual irrigation deliveries from Lugert-Altus Reservoir, 1947-2018.

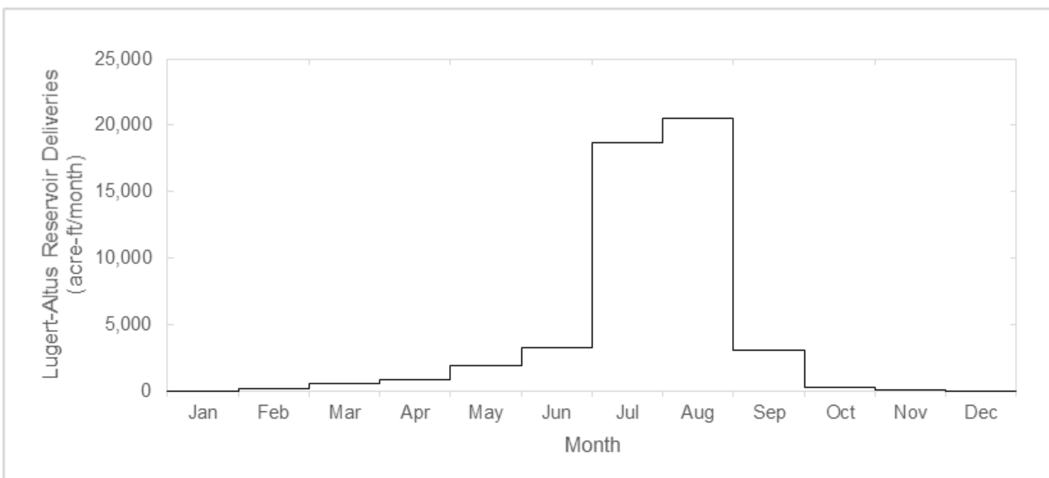

Figure 5-27. Average monthly distribution of irrigation deliveries from Lugert-Altus Reservoir, 1980-2016.

Tom Steed Reservoir

Water Delivery Contracts

Water demands on Tom Steed Reservoir are derived from the cumulative M&I demands of the MPMCD's three member cities: city of Altus, Frederick, and Snyder – as well as EQ demands from Hackberry Flat WMA. The MPMCD's water right for these beneficial uses is 16,100 acre-ft/yr, of which 13,748 acre-ft/yr (85.39 percent) is allocated to M&I and 2,352 acre-ft/yr (14.61 percent) is allocated to EQ benefits[100]. Chapter 2.3.2 detailed the history and challenges related to the development of EQ benefits, as well as balancing EQ and M&I demands that need not be repeated here. That said, we present again only contract allocations to support our current demand analysis on Tom Steed Reservoir (Table 5-2).

[100] Assumes 16,100 acre-ft/yr is available; Table 5-2 details allocations based on reservoir supply availability.

Table 5-2. M&I and EQ allocation volumes/percentages that are contractually required in accordance with available water supplies, including during times of scarcity.

Contract Provisions	Municipal & Industrial Water Supply								Environmental Quality Water Supply		Total Contracted Water Supply
	Altus		Frederick		Snyder		M&I Subtotal		Hackberry Flat Wildlife Management Area		
	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)	(percent)	(acre-ft/yr)
Water supply allocation when 15,970 acre-ft is available	11,200	70.13	1,567	9.81	851	5.33	13,618	85.27	2,352	14.73	15,970
Excess volume of water supply allocation when more than 15,970 acre-ft is available	107	82.24[a]	15	11.50[b]	8	6.25[c]	130	100.0	0	0	130
Maximum water supply allocation (16,100 acre-ft is available)	11,307	70.23	1,582	9.83	859	5.34	13,748	85.39	2,352	14.61	16,100[d]

[a] Equals 82.24% of the M&I Subtotal (i.e., 70.13% of 85.27%).
[b] Equals 11.50% of the M&I Subtotal (i.e., 9.81% of 85.27%).
[c] Equals 6.25% of the M&I Subtotal (i.e., 5.33% of 85.27%).
[d] Equals District Surface Water Permit.

M&I Demands

Figure 5-28 below shows observed annual deliveries from Tom Steed Reservoir between 1979 and 2018. Total deliveries averaged 7,400 acre-ft/yr, with a maximum delivery of 12,700 acre-ft/yr in 2006 (Figure 5-28). This maximum delivery accounted for 79 percent of the 16,100 acre-ft/yr water right. A noticeable increase is observed when EQ deliveries to Hackberry Flat WMA began in 1999. The effect of the 2010s Drought of Record also can be observed through the significant reduction in deliveries between 2011 and 2015.
Figure 5-29 illustrates the relative annual deliveries from Tom Steed Reservoir to each M&I member entity, as well as to Hackberry Flat WMA and other District Water Deliveries. M&I deliveries averaged 6,700 acre-ft/yr, with a maximum M&I delivery of 10,300 acre-ft/yr in 2011 (Figure 5-30). This represented 75 percent of the total M&I allocation of 13,748 acre-ft/yr. Deliveries to the city of Altus averaged 5,200 acre-ft/yr, with a maximum delivery of 7,500 acre-ft/yr that accounted for 66 percent of Altus' M&I allocation. Deliveries to the city of Frederick averaged 700 acre-ft/yr, with a maximum of 2,000 acre-ft/yr that accounted for 51 percent of Frederick's M&I allocation at the time (Figure 5-32). Deliveries to the city of Snyder have averaged 600 acre-ft/yr, with a maximum delivery of 1,100 acre-ft/yr that exceeded their 859 acre-ft/yr allocation by 25 percent (Figure 5-33).

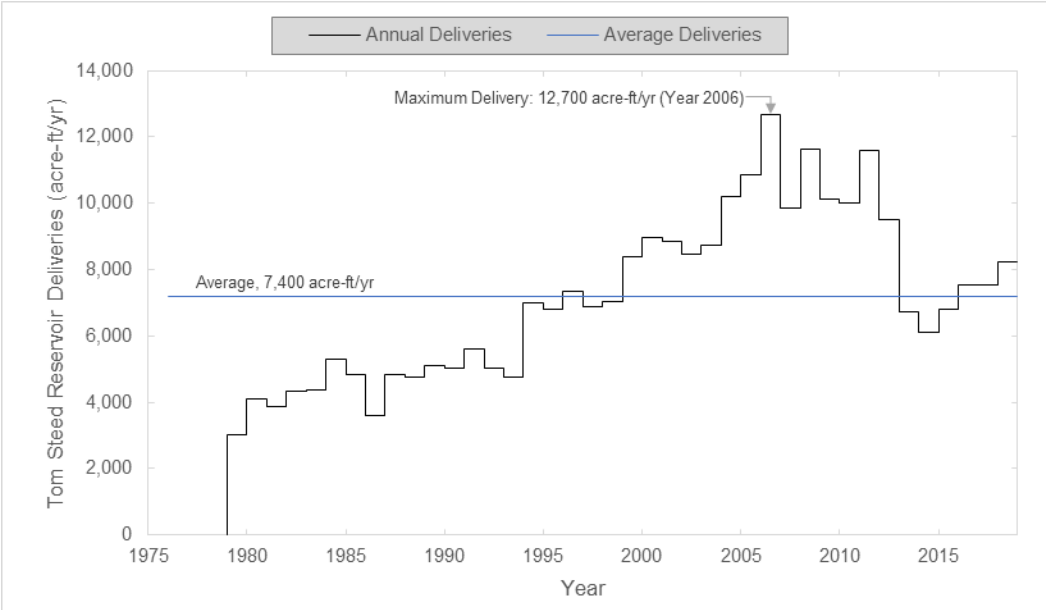

Figure 5-28. Annual deliveries from Tom Steed Reservoir, 1979-2018. EQ deliveries began in 1999, so deliveries between 1979 and 1998 were for M&I only.

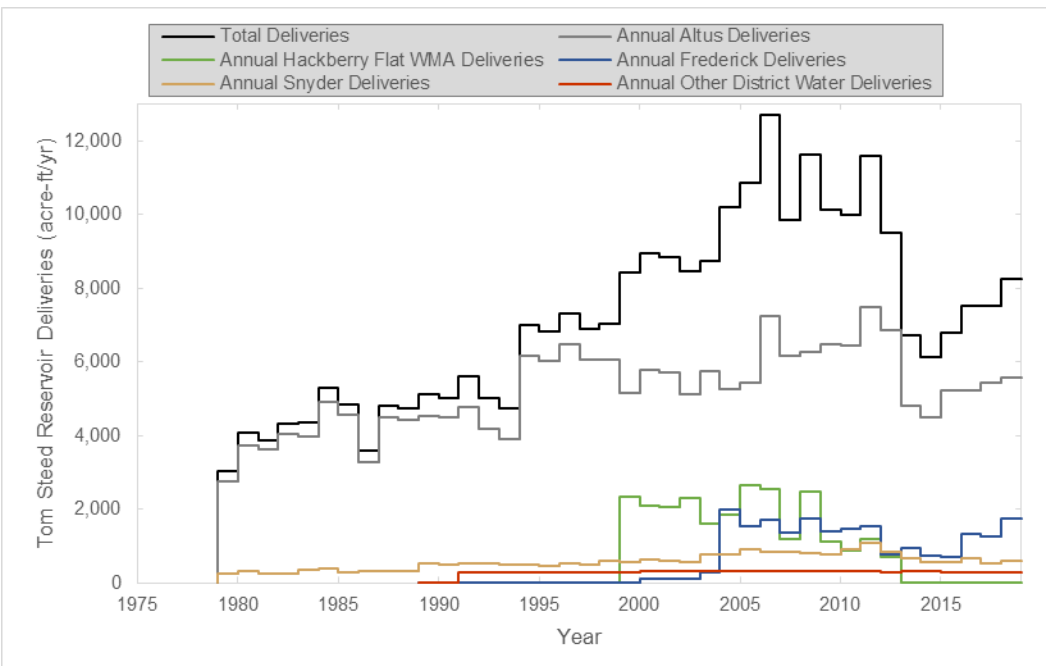

Figure 5-29. Annual deliveries from Tom Steed Reservoir, including deliveries overall, for each member city, and for Hackberry Flat WMA and Other District Water Deliveries, 1979-2018.

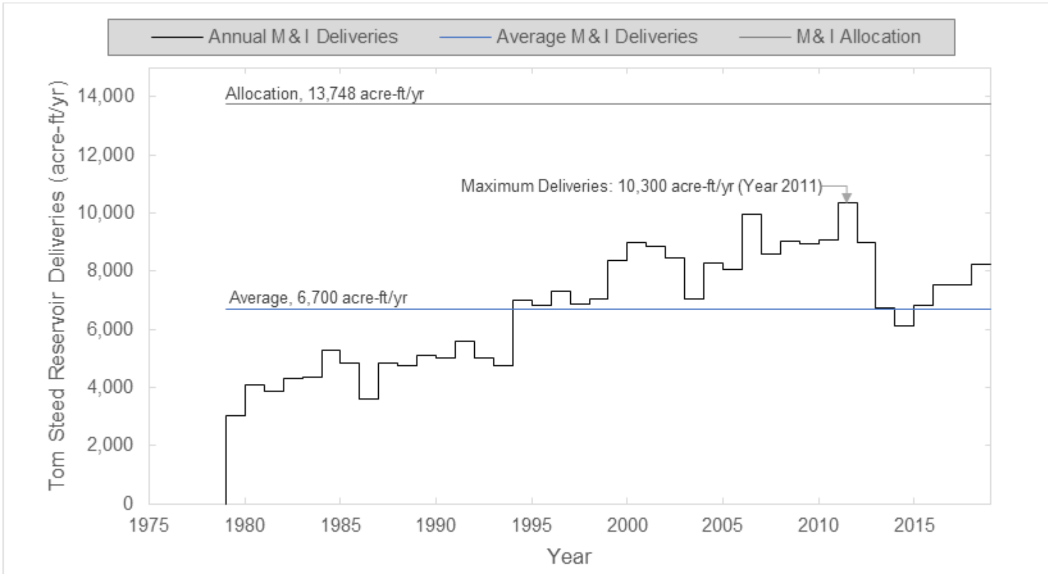

Figure 5-30. Annual M&I deliveries from Tom Steed Reservoir, 1979-2018.

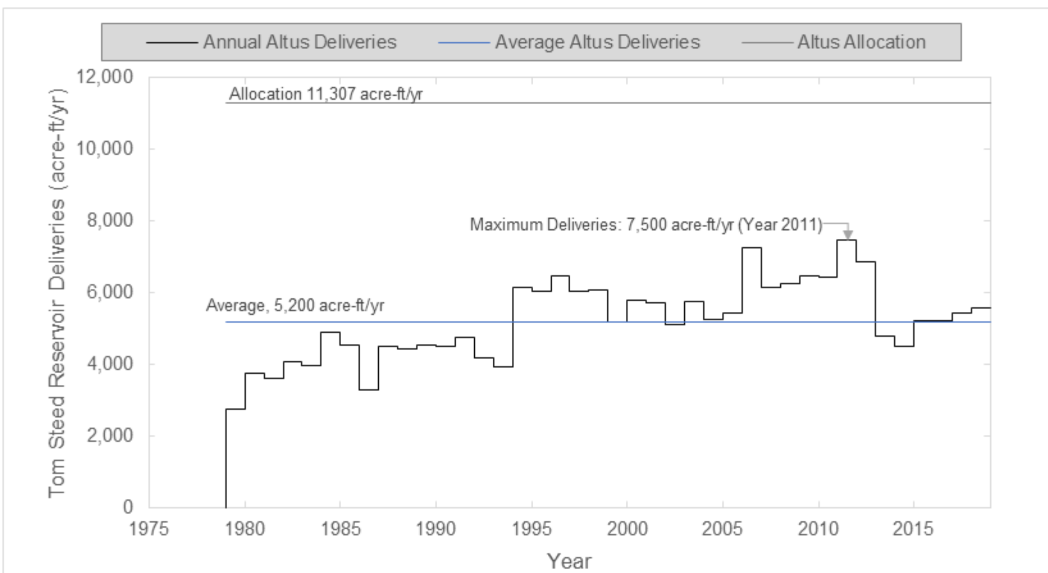

Figure 5-31. Annual M&I deliveries from Tom Steed Reservoir to the city of Altus, 1979-2018.

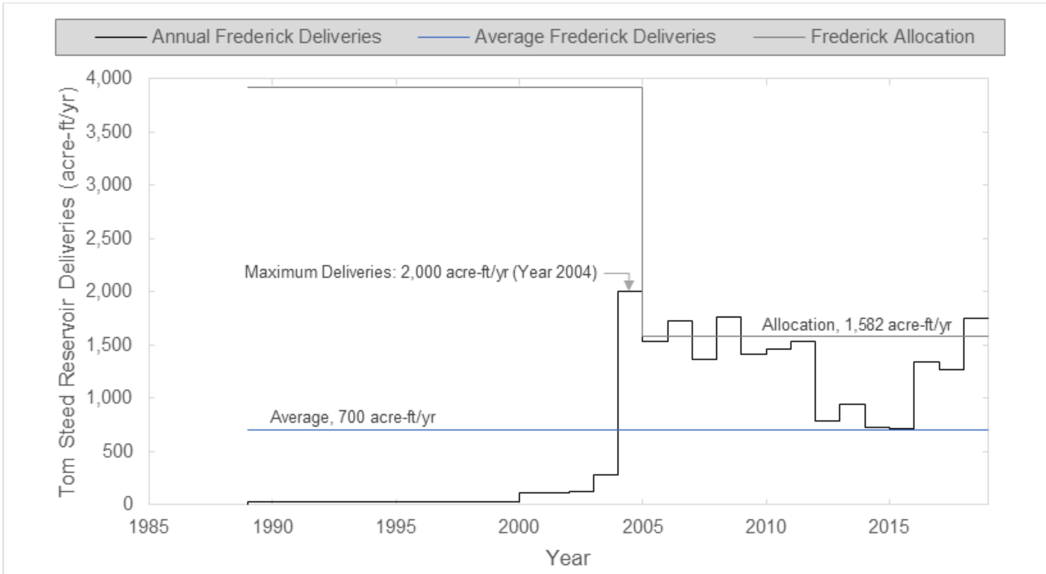

Figure 5-32. Annual M&I deliveries from Tom Steed Reservoir to the city of Frederick, 2003-2018. Frederick did not receive deliveries before 2003.

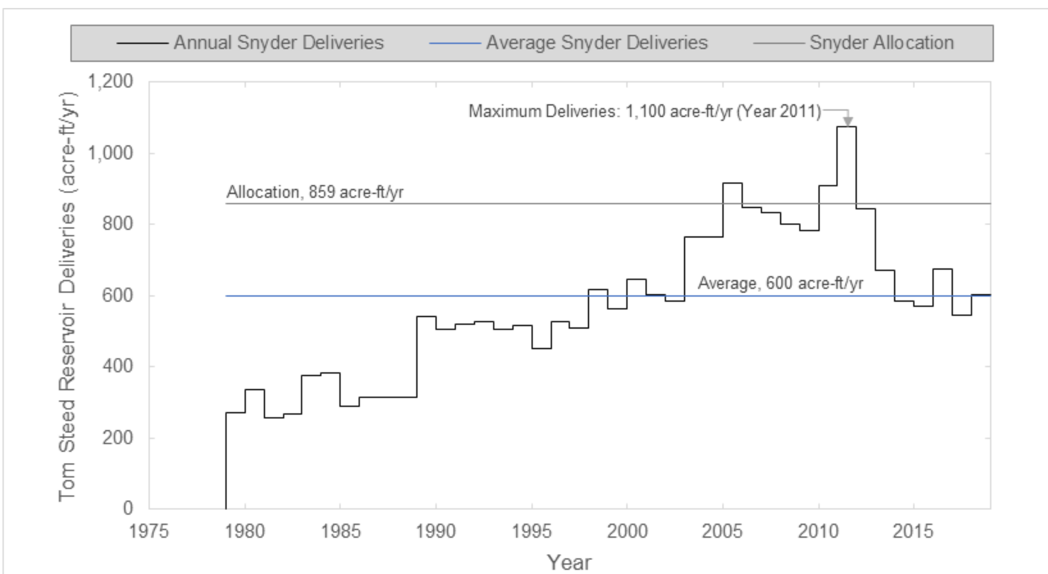

Figure 5-33. Annual M&I deliveries from Tom Steed Reservoir to the city of Snyder, 1979-2018.

EQ Demands

We began this section acknowledging that observed deliveries to Hackberry Flat WMA serve only as a partial indicator of EQ water demands. Arguably, the EQ demand is equal to its EQ allocation of 2,352 acre-ft/yr, whether this benefit is realized through the delivery of water to the Hackberry Flat WMA or by other means allowed in the EQ authorizing legislation. But even focusing on Hackberry Flat WMA as an indicator of EQ demands, challenges arise in determining just how much water the wetland may actually "demand"; for example, Hackberry Flat WMA may not need that much water during years where the timing and amount of rainfall is sufficient to optimize wetland performance. Other considerations include the viability and optimization of infrastructure needed to regulate, convey, and measure water deliveries, as well as management and operations of the wetland system itself, which is complex and comprised of multiple interconnected units.

That said, we focus our attention on Hackberry Flat WMA. Although we present historic water delivery data below, caution should be used in interpreting these data as actual EQ demands. An analysis of EQ demands, including those from Hackberry Flat WMA and alternative options to realize all or a portion of EQ benefits, is the subject of ongoing analyses with the ODWC and is beyond the scope of this URRBS. Water deliveries to Hackberry Flat WMA fluctuate significantly from year to year (Figure 5-34). Between 1999 and 2011, at the start of the 2010s Drought of Record a total of 25,024 acre-ft of EQ water was delivered to Hackberry Flat WMA. Over 2,000 acre-ft/yr has been delivered in seven of the 19 years since deliveries to Hackberry Flat WMA began, with a maximum delivery of 2,641 acre-ft/yr that occurred in 2005, which exceed the 2,352 acre-ft/yr allocation (Figure 5-34). Deliveries to Hackberry Flat WMA have averaged 1,300 acre-ft/yr across all years (Figure 5-34); on years that water was delivered, deliveries averaged 1,790 acre-ft/yr. Monthly deliveries are illustrated in Figure 5-35. Deliveries are fairly sporadic, but generally occur through the late summer, fall, and winter.

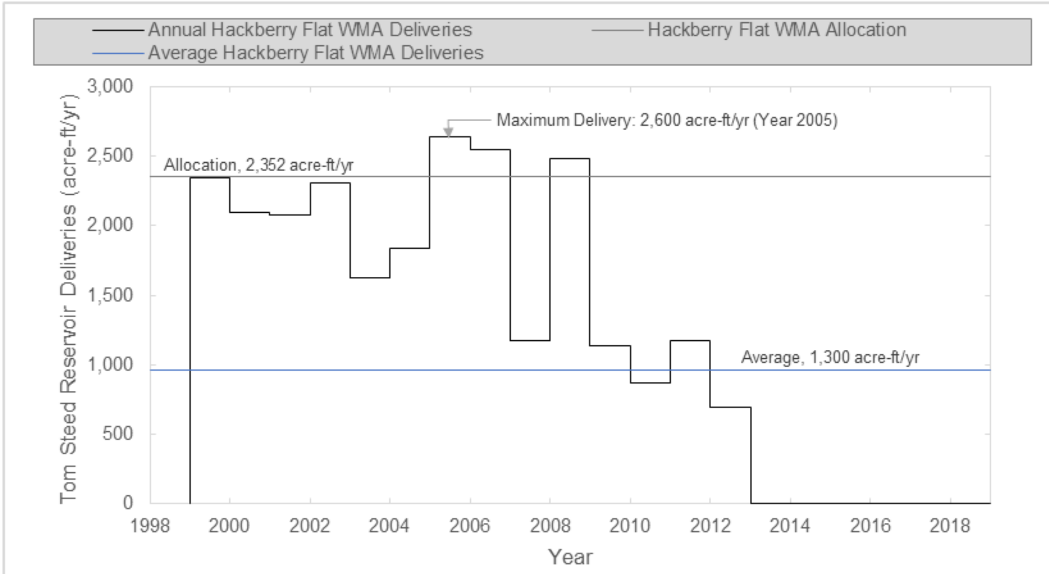

Figure 5-34. Annual water deliveries from Tom Steed Reservoir to Hackberry Flat WMA, 1999-2018.

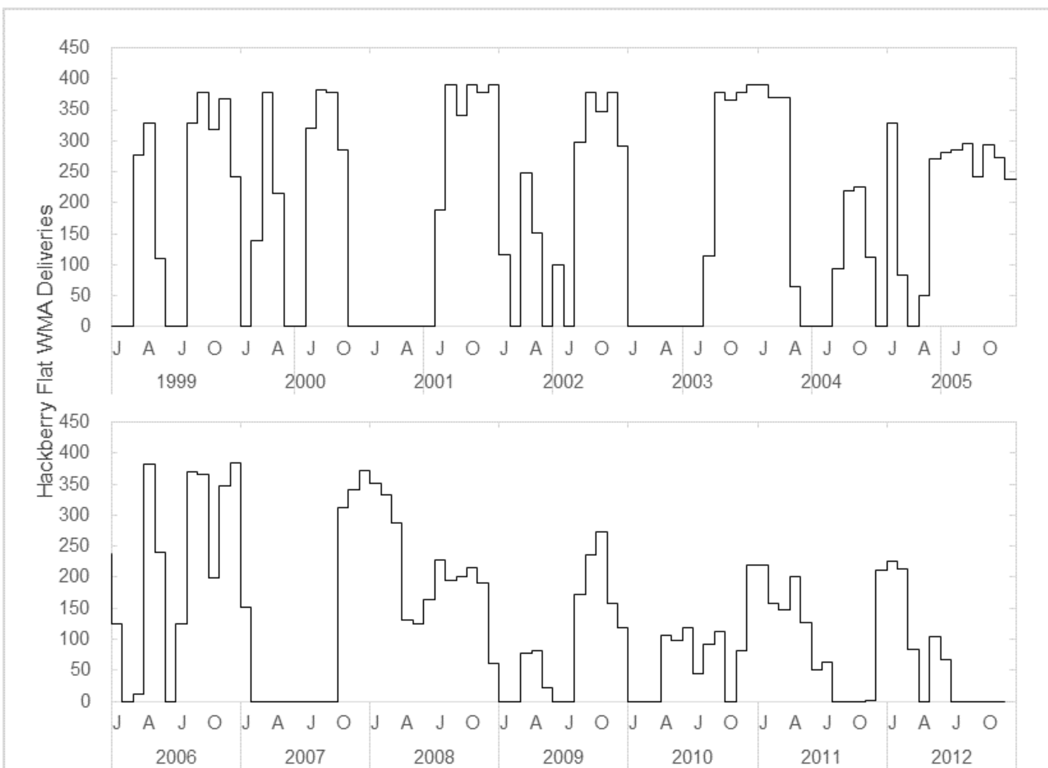

Figure 5-35. Monthly deliveries from Tom Steed Reservoir to Hackberry Flat WMA, 1999-2012. No deliveries have been made since 2012.

5.3. Existing Basin-Wide Supplies

Similar to Chapter 5.2, this section begins with a discussion on groundwater, recognizing that groundwater supplies and surface water supplies are interconnected and that the latter is driven by the former. The focus again is on the NFRR and Elk City aquifers before moving on to present a supply inventory of the hydrologic basins containing Lugert-Altus and Tom Steed reservoirs, as well as the reservoirs themselves.

5.3.1. Existing Groundwater Supplies

NFRR Aquifer

This section presents a summary of groundwater supplies provided by the NFRR aquifer, as described by USGS (Smith et al., 2017). The NFRR aquifer contributes base flow to the NFRR which provides inflow into Lugert-Altus Reservoir; a small portion of the NFRR aquifer extends below Elk Creek, and thus contributes some base flow to Elk Creek above the Bretch Diversion and Canal which feeds into Tom Steed Reservoir.

Well Yields

As presented in USGS (Smith et al., 2017), well yields in the NFRR aquifer vary with location and depth. Well yields reported for irrigation, public-supply, and domestic plus non-irrigation agricultural use were mostly 100-450, 150-250, and 10-25 gallons per minute, respectively (OWRB, 2015b; USGS, 2015a; Table 5-3). Irrigation and public-supply wells with the greatest reported yields (greater than or equal to 800 gal/min) generally were located in west-central Beckham County north of Erick, Okla., and near Lake Altus east of Granite, Okla.; wells with the greatest reported yields generally were greater than 150 ft in depth (Smith et al., 2017).

Table 5-3. Statistical summary of reported yields of wells completed in the North Fork Red River aquifer, 1936–2015.

Water-use type	Number of wells with reported yield values	Statistics for reported well-yield values (gallons per minute)[a]					
		Minimum	25th percentile	Median	75th percentile	Maximum	Mean
Irrigation	500	15	100	250	450	1,500	333
Public Supply	126	15	150	198	250	900	215
Industrial and mining	55	5	35	60	70	1,200	94
Domestic and agriculture (non-irrigation)	682	1	10	15	25	300	25

[a] Well-yield values less than 1 gallon per minute were excluded.

NFRR Aquifer Hydrogeologic Framework

A hydrogeologic framework for the NFRR aquifer was developed by USGS in collaboration with the OWRB and described in USGS (Smith et al., 2017). The framework is a three-dimensional representation of the NFRR aquifer and the surrounding geologic units at a scale that captures the regional controls on groundwater flow. For reference, Chapter 2.5.4 provides an overview of aquifer terminology and the steps involved from the development of a hydrogeologic framework to the construction of a numerical groundwater-flow model. Details on the NFRR aquifer's hydrogeologic framework, including potentiometric surface, textural and hydraulic properties, etc. are described in USGS (Smith et al., 2017).

NFRR Aquifer Budget

A numerical groundwater-flow model (hereafter referred to as the numerical model) on the NFRR aquifer was developed by USGS to represent the groundwater-flow system. An aquifer water budget (Table 5-4) estimated mean annual inflows to and outflows from the NFRR aquifer for the period 1980–2013 and included a sub-accounting of mean annual inflows and outflows for the portions of the aquifer that were upgradient and downgradient from Lugert-Altus Reservoir. Details on the development of the conceptual model, data collection, calibration, and other methods and findings are provided in USGS (Smith et al., 2017).

According to USGS (Smith et al., 2017), simulated recharge (79 percent of inflows) was the largest inflow for the calibrated numerical model (about 122,000 acre-ft/yr or 2.94 in/yr over the aquifer area of 497,582 acres). Most recharge occurs upgradient of Lugert-Altus Reservoir in Beckham County (Smith et al., 2017). Seepage from streams was about 14 percent, lakebed seepage was about 4 percent, and lateral groundwater inflow was about 3 percent of inflows. Seepage to streams (56 percent of outflows) was the largest outflow for the calibrated numerical model; saturated-zone ET was about 23 percent, lateral groundwater outflow (with springs and seeps) was about 10 percent, well withdrawals were about 8 percent, and lakebed seepage was about 2 percent of outflows. Table 5-4 summarizes these inputs and outputs.

Table 5-4. Mean annual water budget for the numerical groundwater-flow model of the NFRR aquifer, 1980–2013. All units in acre-ft/yr; net budget total is calculated as inflow minus outfall; therefore, positive values indicate net inflow, and negative numbers indicate net outflow; components may not sum to totals because of rounding.

Water-budget category	Upgradient from Lugert-Altus Reservoir	Downgradient from Lugert-Altus Reservoir	Total	Percentage of water budget
		Inflow		
Recharge	68,054	54,247	122,301[a]	79%
Streambed seepage from streams	9,597	12,082	21,679	14%
Lakebed seepage inflow	5,009	1,320	6,328	4%
Lateral groundwater inflow	4,701	0	4,701	3%
Total inflow	87,360	67,648	155,009	100%
		Outflow		
Streambed seepage from streams	43,879	46,530	90,409	56%
Saturated-zone evapotranspiration	21,868	15,591	37,459	23%
Lateral groundwater outflow, springs, and seeps	7,529	9,223	16,752	10%
Well withdrawals	11,472	1,899	13,371	8%
Lakebed seepage outflow	2,630	667	3,297	2%
Total outflow	87,377	73,910	161,288	100%
		Net water-budget totals		
Net streambed seepage	-34,282	-34,448	-68,730	
Net lateral flow, springs, and seeps	-2,878	-9,223	-12,051	
Net lakebed seepage	2,379	652	3,031	
Net change in groundwater storage[b]	4,165	2,117	6,282	

[a] Equals 2.94 inches per year over the aquifer area of 497,582 acres.

[b] Positive net change in groundwater storage indicates loss of groundwater storage from the aquifer; loss of groundwater storage is reported as an aquifer inflow in the numerical groundwater-flow model mass balance.

Simulated groundwater storage generally correlates to changes in precipitation, which is not surprising considering recharge accounts for nearly 80 percent of NFRR aquifer inflow (Table 5-4). A correlated water-level response to these precipitation trends is demonstrated in the hydrographs of water-table-altitude observation wells (Smith et al., 2017). At the end of the study period, mean simulated outflows exceeded inflows by about 6,300 acre-ft/yr (Table 5-4). This difference is equivalent to a cumulative net change in groundwater storage of about 214,000 acre-ft for 1980 – 2013 (34 years), or a cumulative net water-level decline of about 3.6 ft. A mean monthly distribution of storage changes is provided in USGS (Smith et al., 2017).

Elk City Aquifer

This section presents a summary of hydraulic properties of the Elk City aquifer. The summary is taken from a hydrologic investigation completed by the OWRB as part of a state-mandated MAY/EPS update on the Elk City aquifer (Wagner et al., 2021). The last MAY was completed by the OWRB in 1982[101], and the resulting EPS was determined to be 1.0 acre-ft/acre. The summary here focuses solely on content as it relates to Elk Creek, the headwaters and tributaries of which form within the Elk City aquifer, and which flows into Tom Steed Reservoir via the Bretch Diversion and Canal system. Groundwater in the Elk City aquifer is under unconfined conditions throughout the study area. Regional groundwater flow is split between the upper third of the aquifer, which flows north towards the Washita River, and the bottom two thirds of the aquifer, which flows south/southeast towards the NFRR and which forms Elk Creek. The thickest areas of saturated thickness in the Elk City aquifer are located in the central and eastern portions of the aquifer with the saturated thickness ranging from 150-199 ft, and the thinnest portions are located along the edges and near streams, including Elk Creek. Mean saturated thickness for the Elk City aquifer is 56 ft. The water table of the aquifer lies below the stream bed of Elk Creek in some areas and above in others, suggesting that the contribution to base flow of Elk Creek is variable. Saturated thickness and aquifer thickness appear to be greatest in the southeastern part of the aquifer from Elk Creek to the aquifer boundary. Mean annual recharge is estimated to be 0.64 inches, ranging from a maximum of 3.16 inches (year 1948) to 0.01 inches (year 2011). Mean monthly recharge was highest in May and the lowest in July. Compared with other portions of the Elk City aquifer, recharge is relatively high in the east-central portion of the aquifer containing the Elk Creek drainage basin. Other hydraulic properties, including hydraulic conductivity, transmissivity, and aquifer storage can be found in Wagner et al. (2021).

[101] Kent, D.C., Lyons, T., and Witz, F.E., 1982, Evaluation of aquifer performance and water supply capabilities of the Elk City aquifer in Washita, Beckham, Custer, and Roger Mills counties, Oklahoma: Oklahoma State University, 96 p.

5.3.2. Existing Surface Water Supplies

Streamflow serves as the key source of available surface water supplies in the URRBS study area, both in terms of supplying water for permitted and non-permitted surface water diversions, as well as providing inflow for reservoir storage. Aside from providing valuable benefits for recreation and fish/wildlife, reservoirs serve as vital regulators of streamflow, which is highly variable. In addition to controlling and mitigating flood risks, reservoirs store streamflow when rainfall is abundant for later use during drier periods when rainfall is scarce, and in doing so, help provide dependable water supplies. The regulation of streamflow by a reservoir may occur within any given year in response to seasonal fluctuations in precipitation, it can occur across multiple years in response to annual rainfall fluctuations, and/or it can occur over extended time periods with relative wetness and dryness. As demonstrated in Chapter 2, these characteristics are shared by Lugert-Altus and Tom Steed reservoirs, which regulate streamflow of the NFRR and Elk Creek/Otter Creek, respectively, and which serve as the primary surface water supply sources in the URRBS study area.

Unlike streams from many parts of the western U.S. which primarily derive their flow from snow-driven spring run-off, streamflow within the URRBS study area is derived exclusively from precipitation run-off and from base flow generated by adjoining aquifers. Losses in streamflow and reservoir storage occur from direct withdrawals/diversions, reductions in base flow induced by groundwater pumping, evaporation, and from seepage into the ground and/or underlying aquifers.

Streamflow

The Lugert-Altus and Tom Steed reservoirs' hydrologic basins encompass over 2,700 square miles of combined drainage areas into the NFRR within Oklahoma and Texas, as well as Elk, West Otter, and Glen Creeks in Oklahoma. Streamflow is measured directly and/or extrapolated from data collected at nine streamgages within the two basins (Figure 5-36).

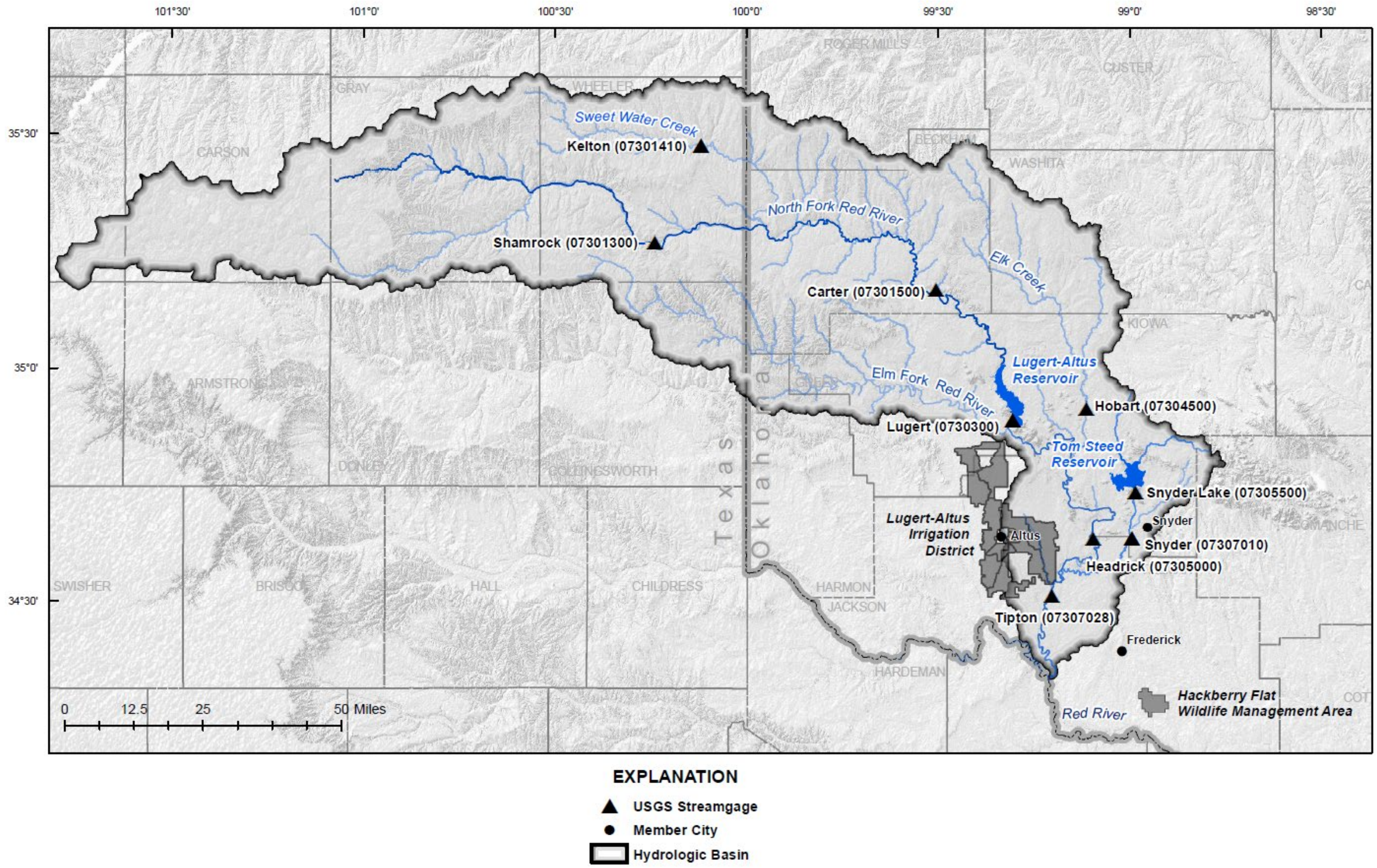

Figure 5-36. USGS streamgage locations within the Lugert-Altus and Tom Steed hydrologic basins.

Lugert-Altus Reservoir Hydrologic Basin

The Lugert-Altus hydrologic basin encompasses about 2,100 square miles of drainage area into the NFRR within Oklahoma and Texas. Streamflow of the NFRR is measured at four USGS streamgage stations (Figure 5-36). Streamflow trends, expressed as annual departures from the mean, are presented below as follows: Shamrock streamgage (No. 07301300; Figure 5-37), Kelton streamgage (No. 07301410; Figure 5-38), and Carter streamgage (No. 07301500; Figure 5-39). The Carter streamgage is the nearest USGS streamgage upstream from Lugert-Altus Reservoir. Three additional streamgages are located downstream of Altus dam, and thus are regulated by releases from Lugert-Altus Reservoir: Lugert streamgage (No. 07303000; Figure 5-40), Headrick streamgage (07305000; Figure 5-41), and Tipton streamgage (No. 07307028; Figure 5-42).

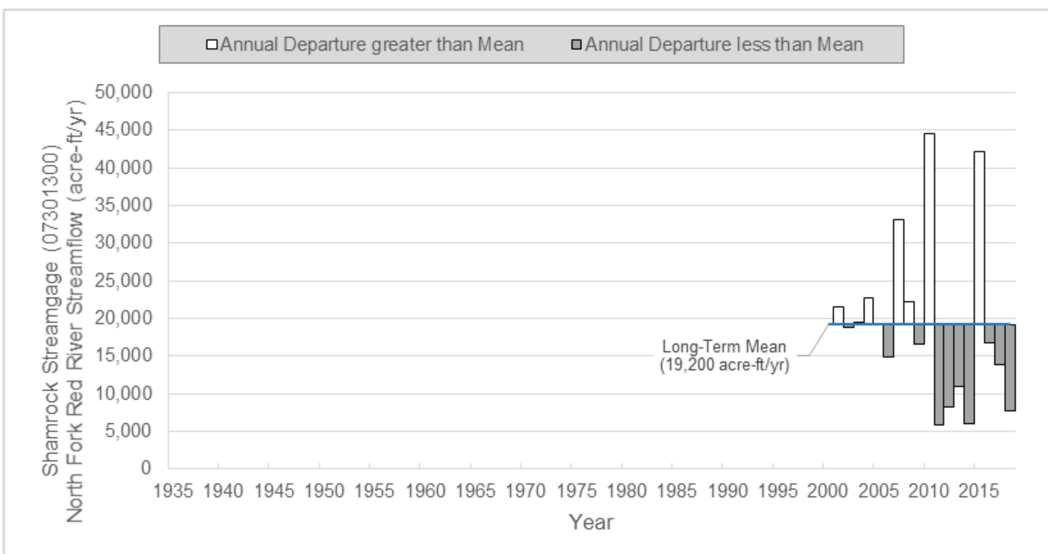

Figure 5-37. Streamflow trends (annual departure from the mean) derived from flow data collected at the Shamrock streamgage; data available 2001-2018 from gage website.

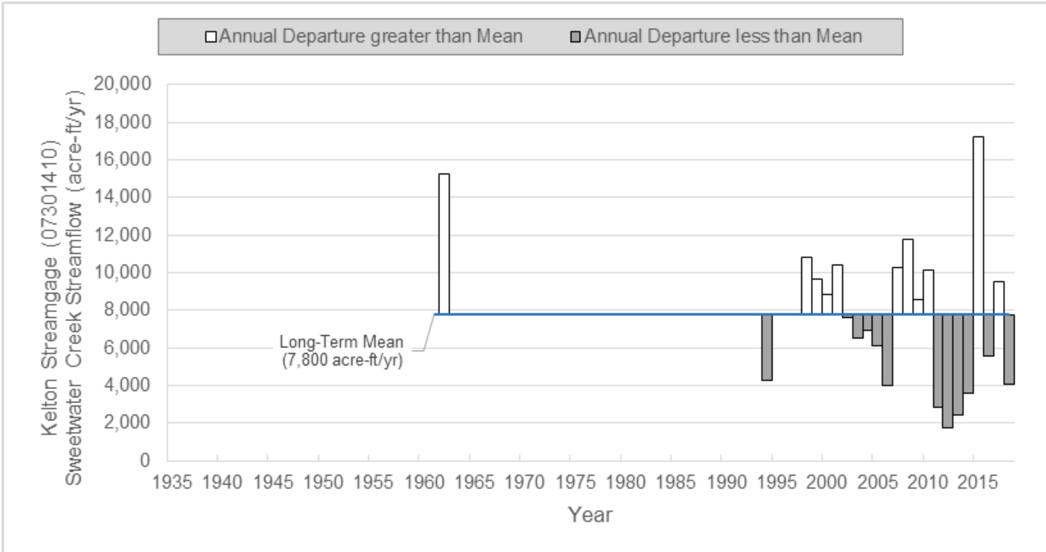

Figure 5-38. Streamflow trends (annual departure from the mean) derived from flow data collected at the Kelton streamgage; data available for 1962, 1994, 1998-2018 from gage website.

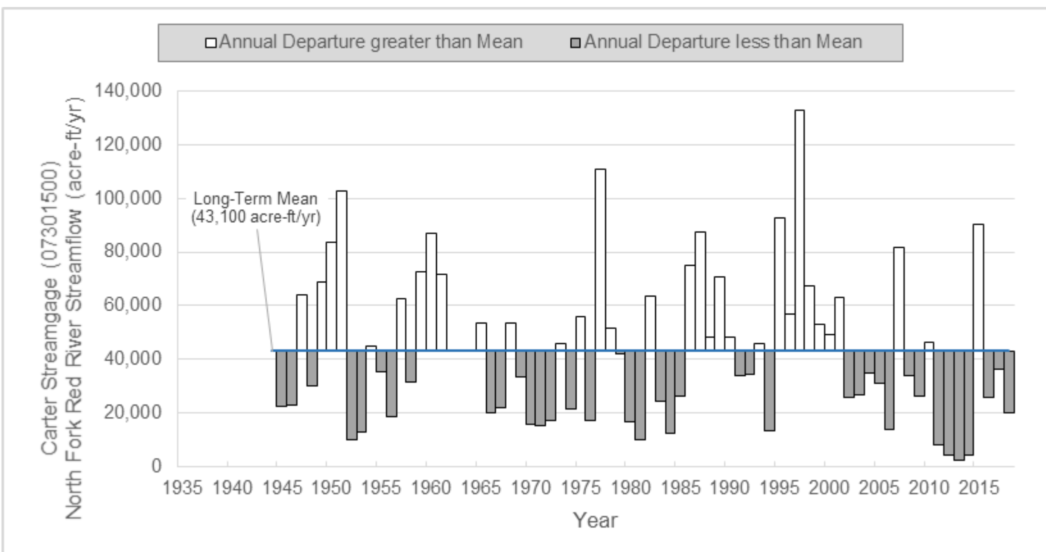

Figure 5-39. Streamflow trends (annual departure from the mean) derived from flow data collected at the Carter streamgage; data available for 1945-1961 and 1965-present from gage website.

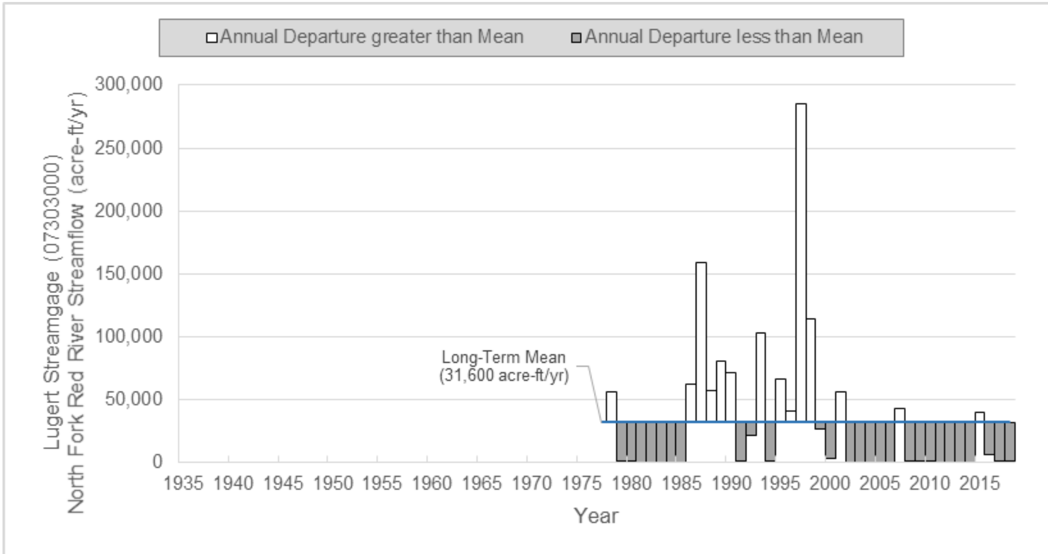

Figure 5-40. Streamflow trends (annual departure from the mean) derived from flow data collected at the Lugert streamgage; data available for 1978-2018 from gage website.

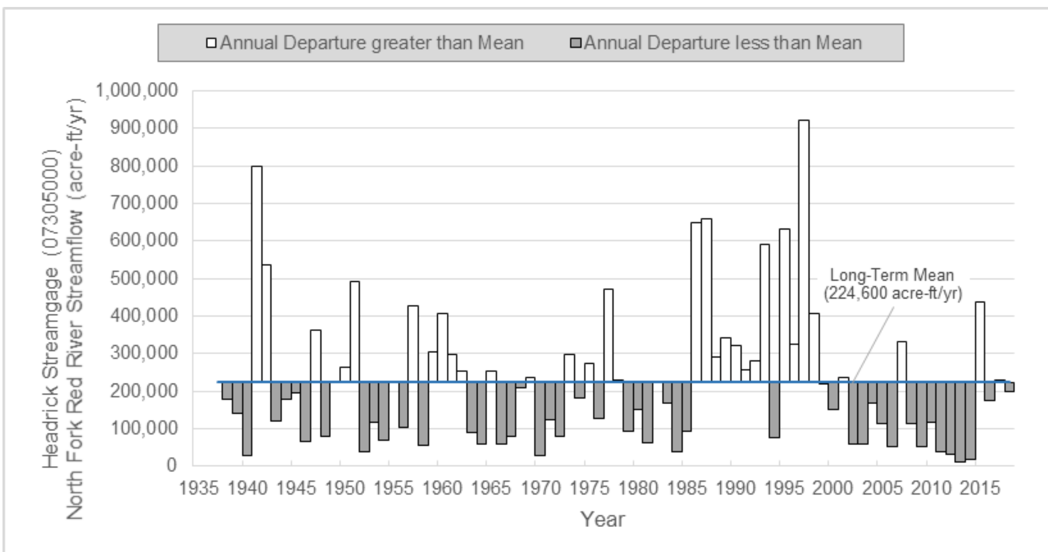

Figure 5-41. Streamflow trends (annual departure from the mean) derived from flow data collected at the Headrick streamgage; data available for 1938-2018 from gage website.

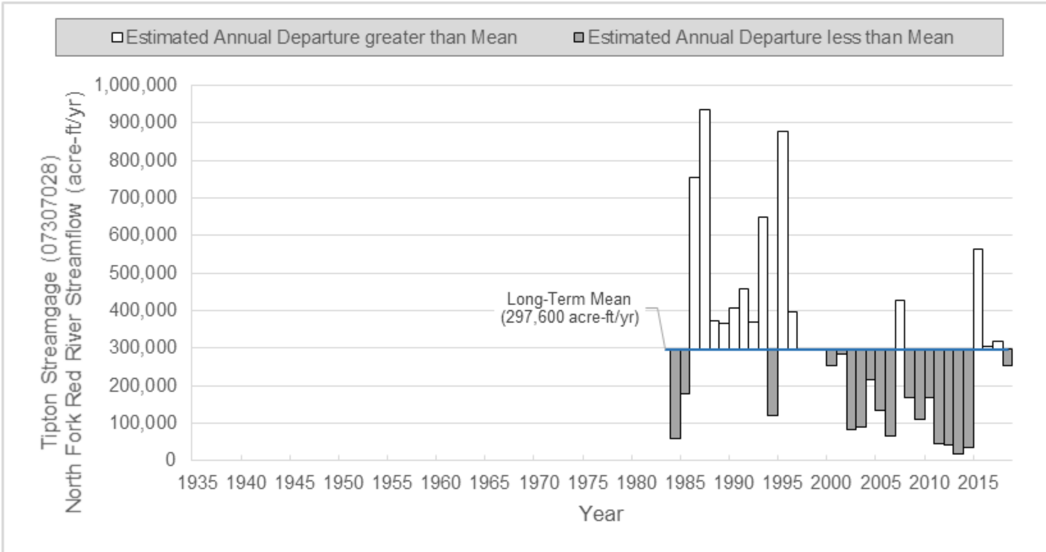

Figure 5-42. Streamflow trends (annual departure from the mean) derived from flow data collected at the Tipton streamgage; data available for 1984-1996 and 1999-2018 from gage website.

According to USGS (Smith et al., 2017), at the Carter streamgage (07301500) immediately upstream of Lugert-Altus Reservoir, nearly half of the annual surface-water inflow to Lugert-Altus Reservoir was supplied by base flow (study period 1980–2013). Since the 1960s, the total annual base flow and the base-flow index (the ratio of total annual base flow to total annual streamflow) generally have been increasing (Figure 5-43). The reasons for these increasing trends in base flow and base-flow index are not clear but could include increases in the number of impoundments, such as floodwater-retarding structures (Figure 5-44) or changes in agricultural practices that reduce runoff and promote artificial recharge to the aquifer (Smith et al., 2017; Smith and Wahl, 2003). In recent years (between 2000 and 2013) at the Carter streamgage (07301500), the base-flow index exceeded 60 percent in four out of 14 years with a maximum base-flow index of 81.1 percent in 2011 (Smith et al., 2017).

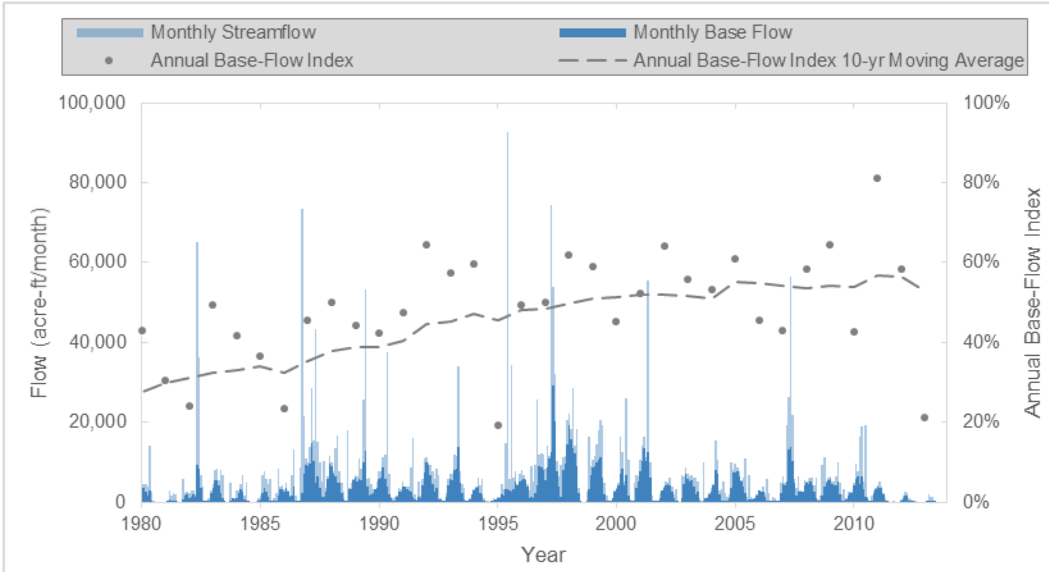

Figure 5-43. Monthly streamflow, base flow, and annual base-flow index, Carter streamgage (07301500).

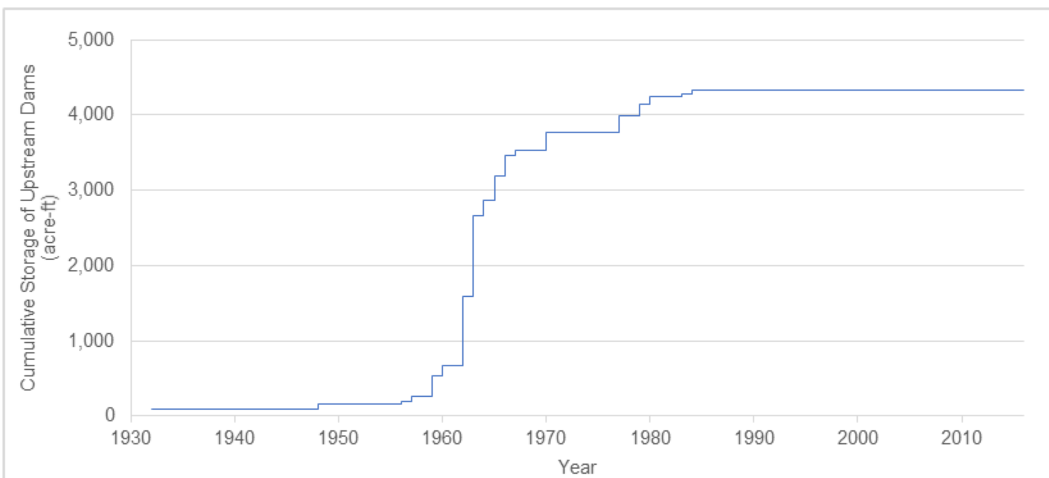

Figure 5-44. Cumulative storage of dams completed upstream of Lugert-Altus Reservoir. OWRB's Dam Safety online database (http://www.owrb.ok.gov/damsafety/index.php).

Synoptic streamflow measurements (also known as seepage-run measurements) within the NFRR in March 2013 were taken by USGS to capture tributary-inflow and base-flow conditions across the NFRR aquifer at one point in time. The measurements were used to calculate net streambed seepage and classify stream reaches as "gaining" (having a downstream increase in base flow) or "losing" (having a downstream decrease in base flow). According to USGS (Smith et al., 2017), these data (Figure 5-45) show that: (1) most small tributaries that originate away from the aquifer carried negligible base flows to the NFRR;

(2) stream reaches upstream from the Texas border generally were gaining; (3) stream reaches between the Texas border and Lugert-Altus Reservoir generally were losing; and (4) stream reaches downstream from Lugert-Altus Reservoir generally were gaining. It should be noted that the streambed-seepage data were collected during a severe drought period and therefore may be more representative of less-frequent drought conditions than typical late-winter base-flow conditions. A set of synoptic streamflow measurements from July 2003 (Smith et al., 2003; Stephens, 2003), another dry year, reinforced that reaches of the NFRR upstream from Lugert-Altus Reservoir can be losing or dry in the summer months when ET, irrigation, and public-supply water demands are greatest.

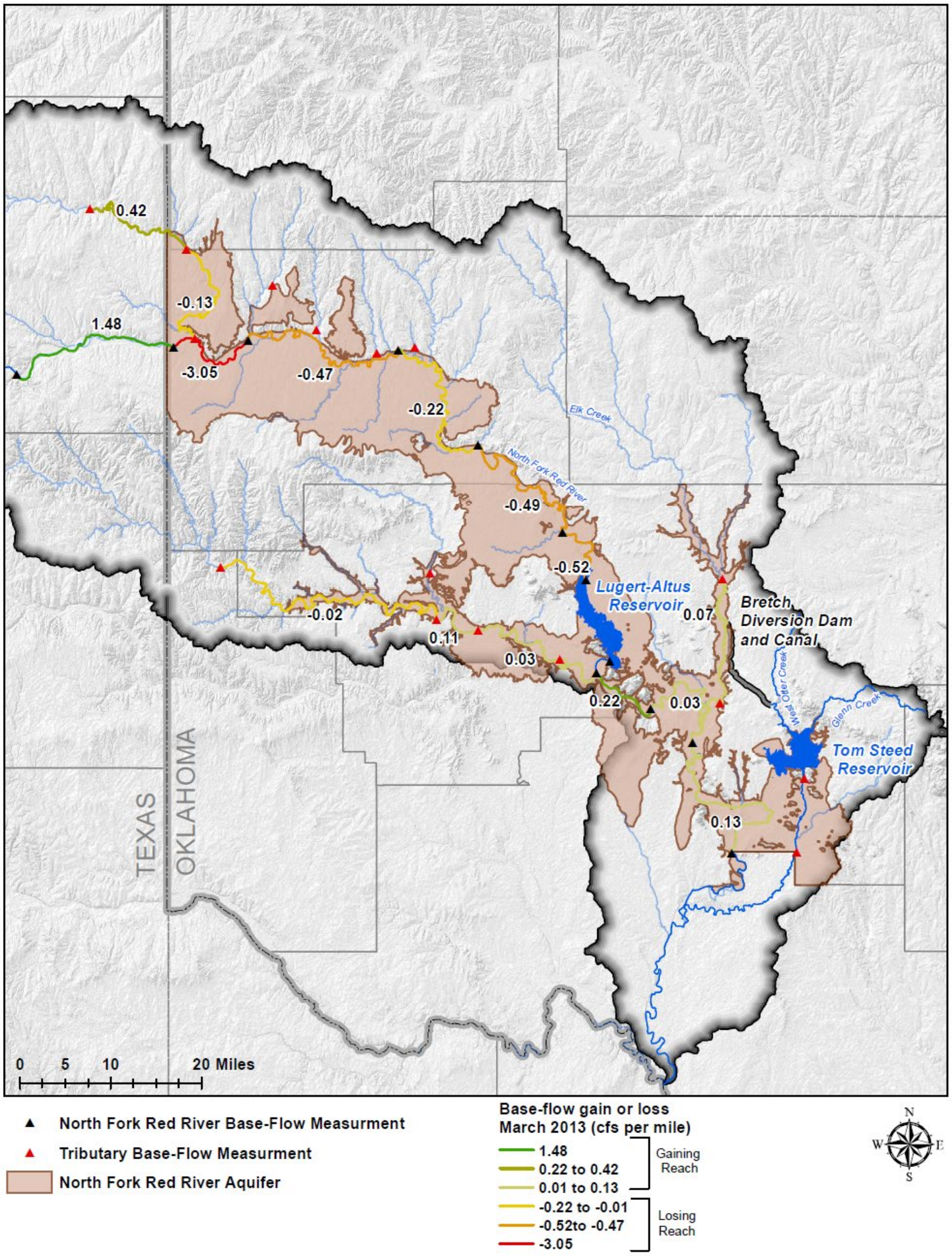

Figure 5-45. Base-flow measurements with gaining and losing reaches of the NFRR and tributaries, March 2013. Adapted from USGS (Smith et al., 2017).

Tom Steed Reservoir Hydrologic Basin

The Tom Steed Reservoir hydrologic basin encompasses about 670 square miles within Oklahoma, 531 square miles of which encompasses the Elk Creek drainage area upstream of the Bretch Diversion Dam and Canal, and the remaining portion encompasses the West Otter and Glen Creek drainage areas. Streamflow measurements in the drainage area were historically made by two gages (Figure 5-36), but both have been discontinued and no longer record flows. The Hobart streamgage (07304500), located above the Bretch Diversion on Elk Creek, recorded flows from 1949 to 1993. The Snyder Lake streamgage (07305500), located on West Otter Creek downstream of Mountain Park Dam, recorded flows from 1952 to 2003.

The lack of up-to-date streamflow data presents a challenge in fully assessing existing surface water supplies in the hydrologic basin, including Tom Steed Reservoir. Both interpolation (estimating between two points) and extrapolation (estimation by extending a known sequence) techniques must be used to estimate streamflow and fill in the gaps for recent years where data were not available. For Elk Creek, the nearby Headrick streamgage on the NFRR (Figure 5-36) is used to estimate streamflow at the Hobart streamgage location on Elk Creek beyond 1993. This is done by comparing daily recorded flows of both gages during overlapping time periods prior to 1993, making adjustments to the Hobart streamgage recordings based on the NFRR flows and the unique physical and hydrologic attributes of each of the two watersheds, and then extending the streamflow record on Elk Creek to the year 2016. Streamflow is estimated at the Hobart streamgage location, as well as upstream at the Bretch Diversion, the latter of which is used to estimate daily divertible flows from Elk Creek that contribute to the yield of Tom Steed Reservoir. Figure 5-46 displays recorded (1949 – 1993) and estimated (1993 – 2016) flows, expressed as annual departure from the mean, at the Hobart streamgage on Elk Creek.

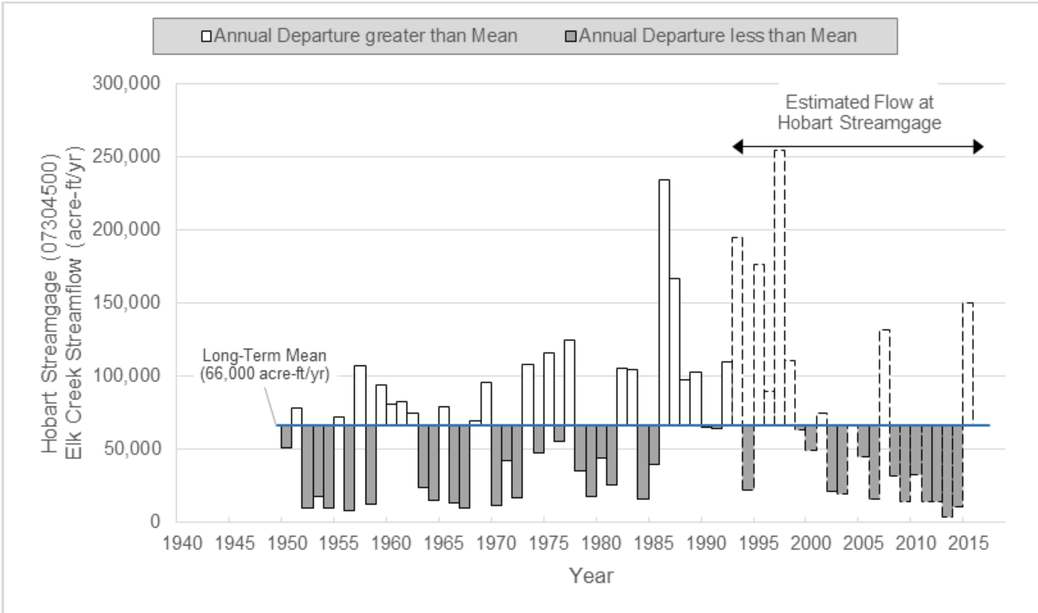

Figure 5-46. Streamflow trends (annual departure from the mean) derived from flow data collected at the Hobart streamgage; data available for 1950-1992 from gage website; streamflow between 1993 and 2016 are extrapolated using flows from the Headrick streamgage.

Like Elk Creek, the flow of West Otter Creek was recorded from 1952 to 2003 and is therefore incomplete. The streamgage's namesake is derived from Snyder Lake, which captured and regulated flows on West Otter Creek from 1952 until 1975 when Mountain Park Dam/Tom Steed Reservoir was constructed. Between project construction and the year 2003 when the Snyder Lake streamgage was discontinued, flows recorded on West Otter Creek were comprised almost solely of releases/spills from Mountain Park Dam. The same can be said for flows since 2003, which is why recorded releases/spills at Mountain Park Dam have since been used as a replacement for streamgage data. Figure 5-47 displays recorded streamflow (1952 – 2003) and Tom Steed Reservoir releases (2003 – 2016) expressed as annual departures from the mean. It is important to mention that a new streamgage (Snyder streamgage) was installed in 2016 on Otter Creek below the confluence of West Otter and East Otter Creeks (Figure 5-48). Although streamflow recordings are too recent to be included in the modeling period included within this Basin Study, they likely will play an important role in future water management within the basin. Flows downstream of the confluence of Otter Creek and NFRR are measured at the Tipton streamgage (Figure 5-49).

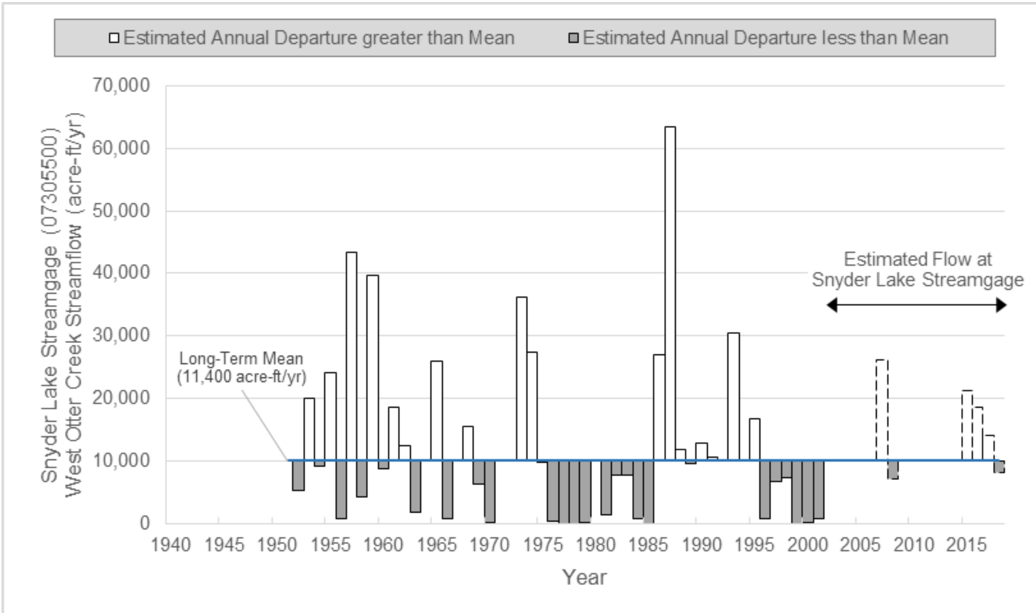

Figure 5-47. Streamflow trends (annual departure from the mean) derived from flow data collected at the Snyder Lake streamgage; data available for 1952-1970, 1973-2002 from gage website; streamflow between 2003-2018 estimated using Tom Steed Reservoir releases.

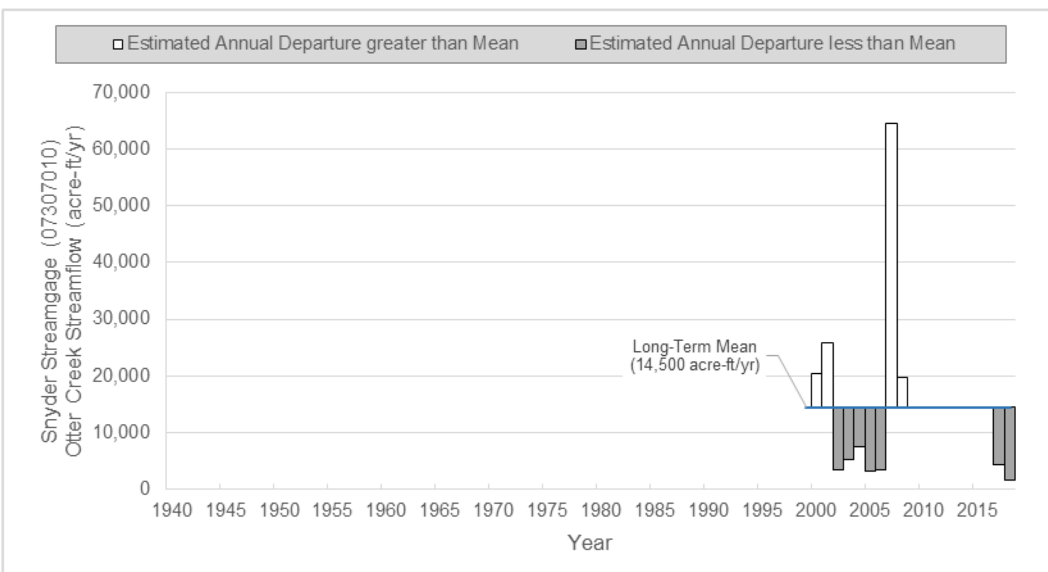

Figure 5-48. Streamflow trends (annual departure from the mean) derived from flow data collected at the Snyder streamgage; data available for 2001-2008 from USGS (Smith et al, 2017) and 2017-2018 from gage website.

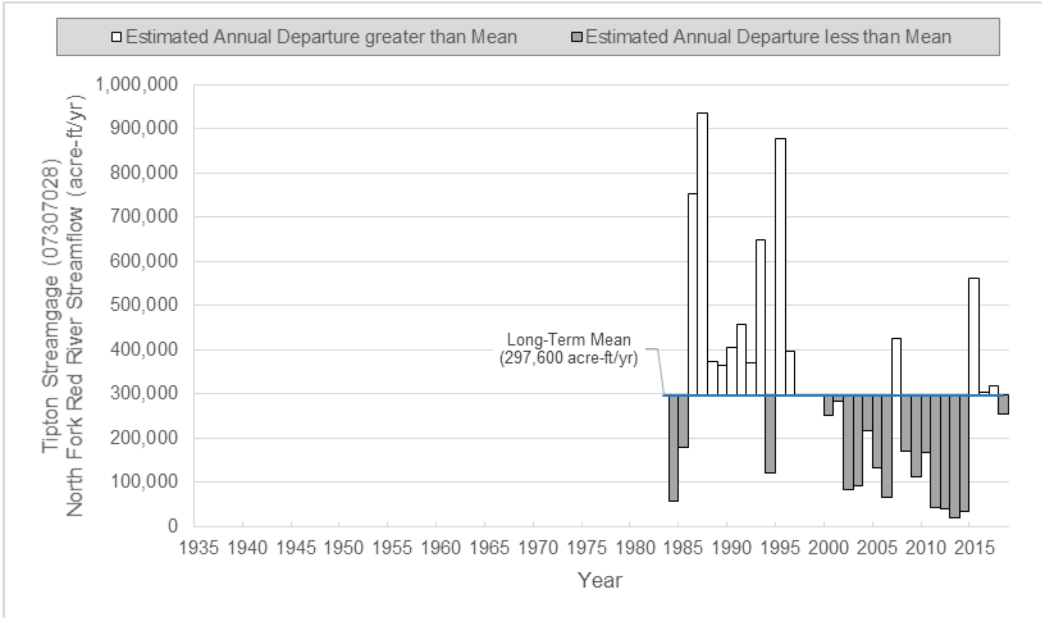

Figure 5-49. Streamflow trends (annual departure from the mean) derived from flow data collected at the Tipton streamgage; data available for 1984-1996 and 1999-2018 from gage website.

Unlike Lugert-Altus Reservoir, which is dependent on base flows from the NFRR aquifer for replenishment, Tom Steed Reservoir is near the edge of the aquifer and primarily is replenished by surface-water runoff from areas outside of the NFRR aquifer (Smith et al., 2017). Base flows in Elk Creek originate from several sources including the Elk City aquifer, the NFRR aquifer, and, following periods of runoff, numerous floodwater-retarding structures (Figure 5-50) in the Elk Creek hydrologic basin (Smith et al., 2017). Figure 5-51 illustrates streamflow, annual baseflow, and the annual base flow index at the Hobart streamgage on Elk Creek. Between 1980 and 1992, BFI appears to show a slight increasing trend, with the exception of the year 1984 when BFI rose to 51.7 percent.

Based on the previously-discussed synoptic streamflow measurements within the NFRR conducted by USGS in March 2013, Elk Creek above the Bretch Diversion is classified as a "gaining" stream reach (Figure 5-45), meaning that NFRR aquifer discharge increases Elk Creek's base flow from upstream to downstream (Smith et al., 2017).

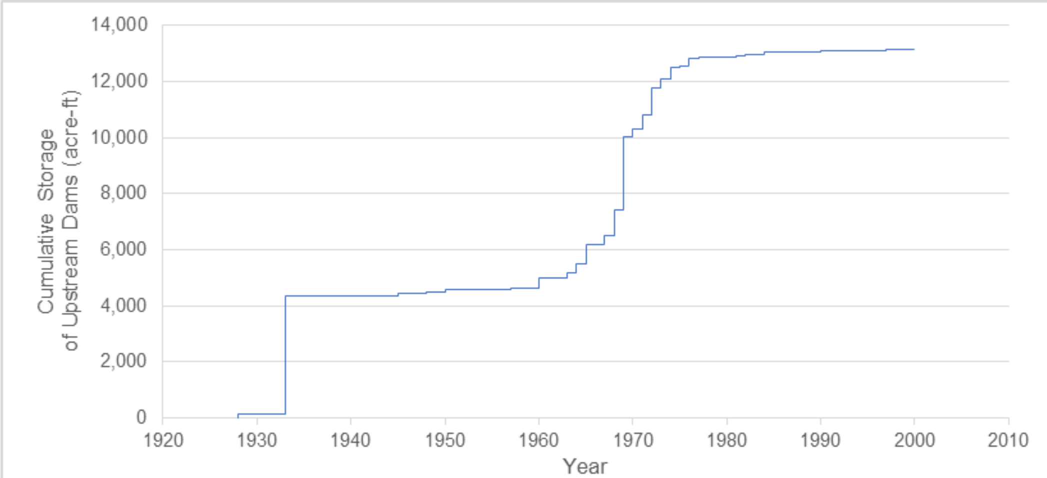

Figure 5-50. Cumulative storage of dams completed upstream of the Bretch Diversion on Elk Creek. OWRB's Dam Safety online database (http://www.owrb.ok.gov/damsafety/index.php).

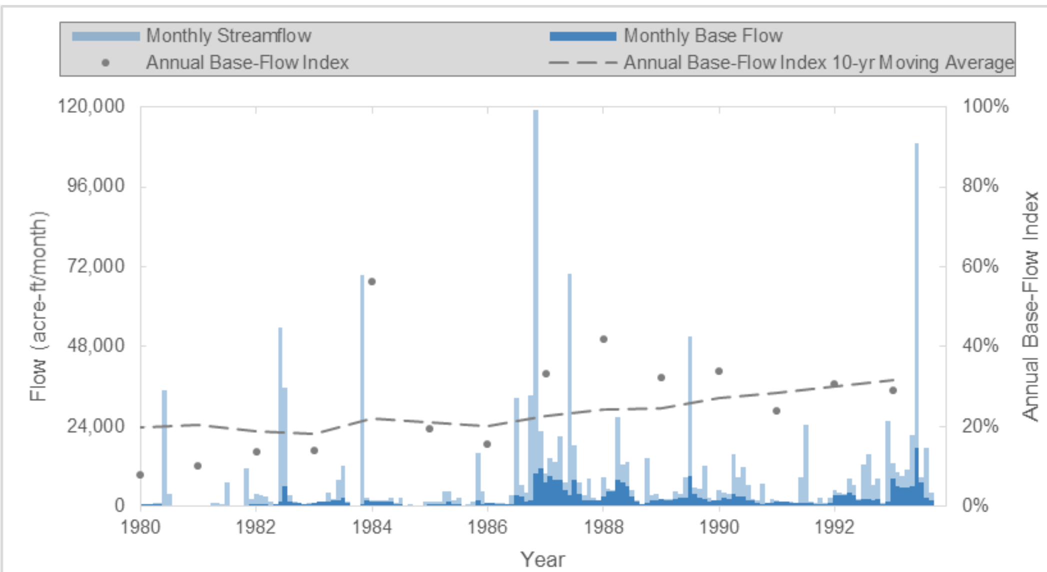

Figure 5-51. Monthly streamflow, base flow, and annual base-flow index, Hobart streamgage (07304500); data available for 1980-1993. Derived using data provided by USGS.

Reservoir Supply

Together, Lugert-Altus and Tom Steed reservoirs provide storage for 99 percent of the surface water supplies within the Oklahoma study area. As previously discussed, the climate and hydrology experience extreme fluctuations, with periods of drought periodically interrupted by large amounts of precipitation. In addition to controlling and mitigating flood risks, Lugert-Altus and Tom Steed reservoirs store streamflow when rainfall is abundant for later use during drier periods when rainfall is scarce, and in doing so, help provide dependable water supplies to the region. That said, as discussed in Chapter 2.2 and Chapter 2.5, assessing reservoir dependability is complicated by many factors, including assumptions that must be made on the duration, frequency, and magnitude of these natural fluctuations, which are often accompanied by changes in human-induced pressures – either via direct withdrawals or indirectly through upstream development. In Chapters 6 and 7, these factors are assessed in detail with the goal of refining the calculations of reservoir supply dependability under a fairly broad range of scenarios and assumptions. For the purposes here, an inventory of reservoir supply is provided as it has been observed over the period of record; a focus also is made on providing an inventory of key drivers that make up the supply. Recall that at its core (Figure 2-42), the amount of water a reservoir can supply boils down to two things: (1) how much water is entering the reservoir (i.e., inputs) versus (2) how much water is leaving the reservoir (i.e., outputs). Inputs into the reservoir are streamflow, precipitation, and sedimentation; the outputs are evaporation, flood releases, seepage, and water deliveries[102]. Because the focus here is on observations, it does not include sedimentation and seepage as part of this inventory; these (in particular sedimentation) are discussed in Chapters 6 and 7 where future supplies are considered.

[102] In the context here, "inputs" include variables that increase storage while "outputs" describe variables that reduce storage. Sedimentation is an exception: although sedimentation results in reduced storage, sedimentation was included as an input because it included in the starting reservoir storage volume.

Lugert-Altus Reservoir Supply

The Lugert-Altus ID holds a water right of 85,630 acre-ft/yr and irrigates approximately 48,000 acres of land, principally cotton, although winter wheat, alfalfa, peanuts, grain sorghums, and potatoes also are prevalent. Assuming a delivery efficiency of 68 percent[103] (32 percent loss), 58,200 acre-ft/yr of supply is available for irrigation, which equates to an allocation of 1.2 acre-ft/acre (15 inches). Interestingly, but perhaps not coincidentally, this net requirement is consistent with studies cited in Chapter 2.3.1 which describes the net irrigation requirement for cotton in western Oklahoma.

Lugert-Altus Reservoir is unique because it provides water for both agricultural irrigation and M&I use. As detailed in Chapter 2, one of the biggest challenges is operating the system in a way as to protect the city of Altus' senior M&I water right while maximizing agricultural deliveries, both during wet and dry cycles. Not unlike managing a bank account, irrigation deliveries serve as expenditures on necessary goods while the amount of water left in storage acts as a "savings account" that not only protects the M&I water right and non-consumptive recreation and fish and wildlife uses, but also can supplement irrigation demands and manage farmer expectations and uncertainty. The point here is not to reconstruct the intricacies of Lugert-Altus ID's operations discussed in Chapter 2; rather, it is to stress that caution should be used when thinking of the term "supply" – because in the case of Lugert-Altus Reservoir, it is a complex issue. Nevertheless, we will set operations aside, and focus here on supply from the standpoint of "wet" water conditions in the Lugert-Altus hydrologic basin and the impacts those have on observed deliveries over time.

The variation in annual deliveries reflects changes in available storage in Lugert-Altus Reservoir prior to and during the irrigation season (Figure 5-52). Over the period of record, annual deliveries have ranged from zero (years 2011-2014), when storage was relatively low across multiple years, to 106,542 acre-ft/yr (year 2000), when storage was relatively higher for multiple

[103] Meeting Minutes, Board of Directors of the Lugert-Altus ID, October 25, 2017.

years (Figure 5-52). Available storage (and by extension deliveries) is driven primarily by gains from inflow and losses from evaporation (Figure 5-53). Figure 5-53 illustrates net changes in reservoir storage relative to annual changes in inflow, evaporation, deliveries, and flood releases between 1947 and 2018. As previously stated, inflow is the primary source of storage of Lugert-Altus Reservoir. The largest amount of inflow occurs during the months of May and June, with the largest net increase in reservoir storage occurring in May (Figure 5-54). Inflow fluctuates tremendously, ranging from 6,650 acre-ft/yr to 399,100 acre-ft/yr over the period of record, with an average annual inflow of 104,800 acre-ft/yr (Figure 5-55). This variable rate of inflow is reflected in the sporadic flood releases observed over the same period (Figure 5-56) and reflects the flashiness of run-off from precipitation events in the relatively large hydrologic basin draining into Lugert-Altus Reservoir. Evaporative losses fluctuate based on reservoir storage, with larger annual losses corresponding to higher storage volumes (Figure 5-53) and to higher temperatures that occur during the summer months (Figure 5-54). Annual evaporation rates ranged from 9,700 to 29,100 acre-ft/yr, averaging 20,300 acre-ft/yr (Figure 5-57).

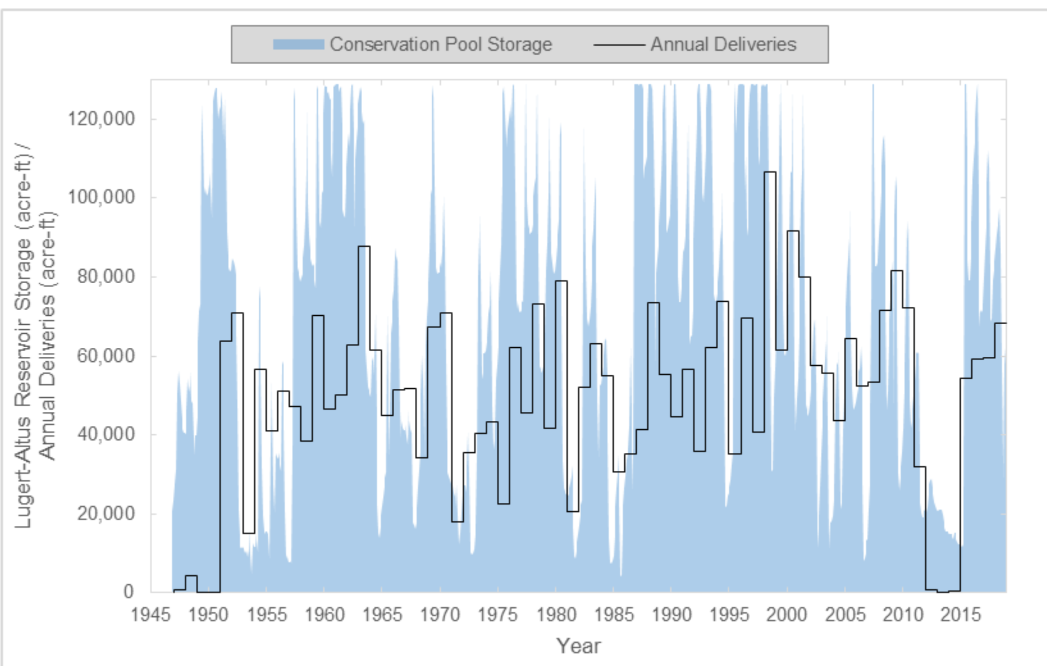

Figure 5-52. Annual conservation pool storage of Luger-Altus Reservoir and annual deliveries, 1947-2018.

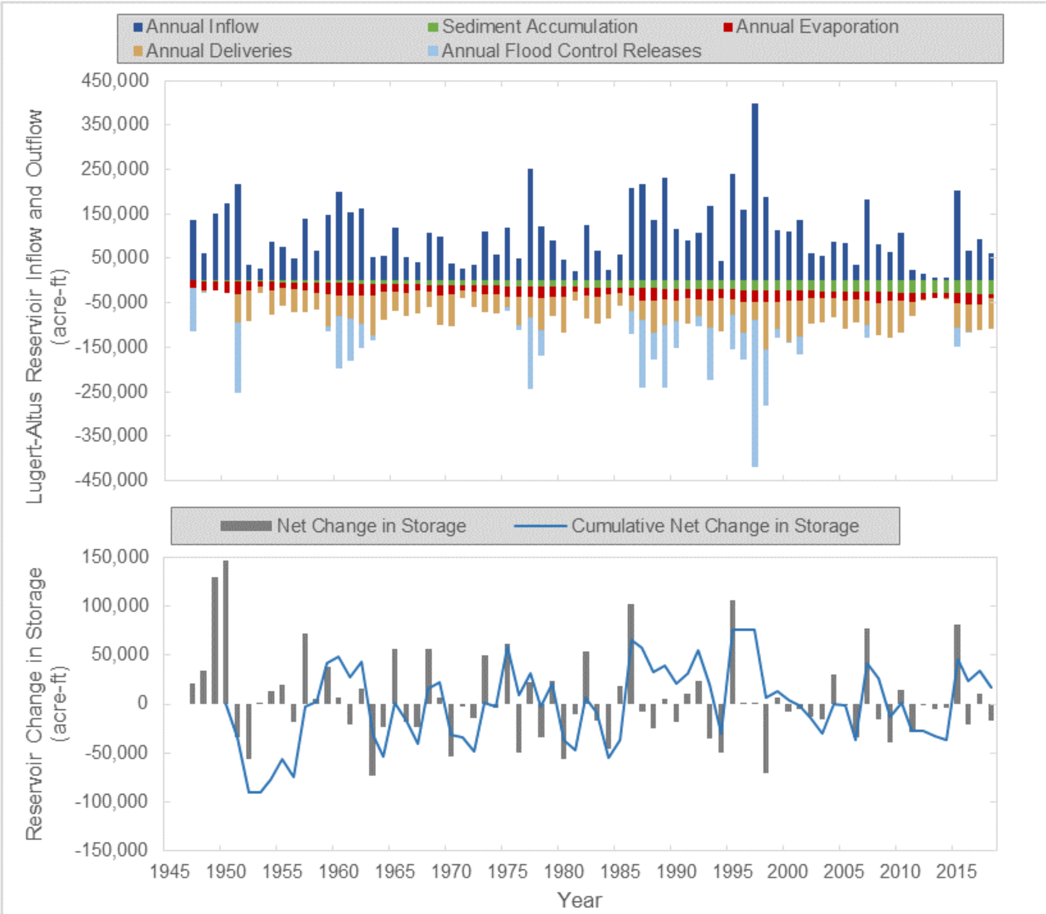

Figure 5-53. Observed annual balance of inputs and outputs (top) and net reservoir storage (bottom) of Lugert-Altus Reservoir, 1947-2018.

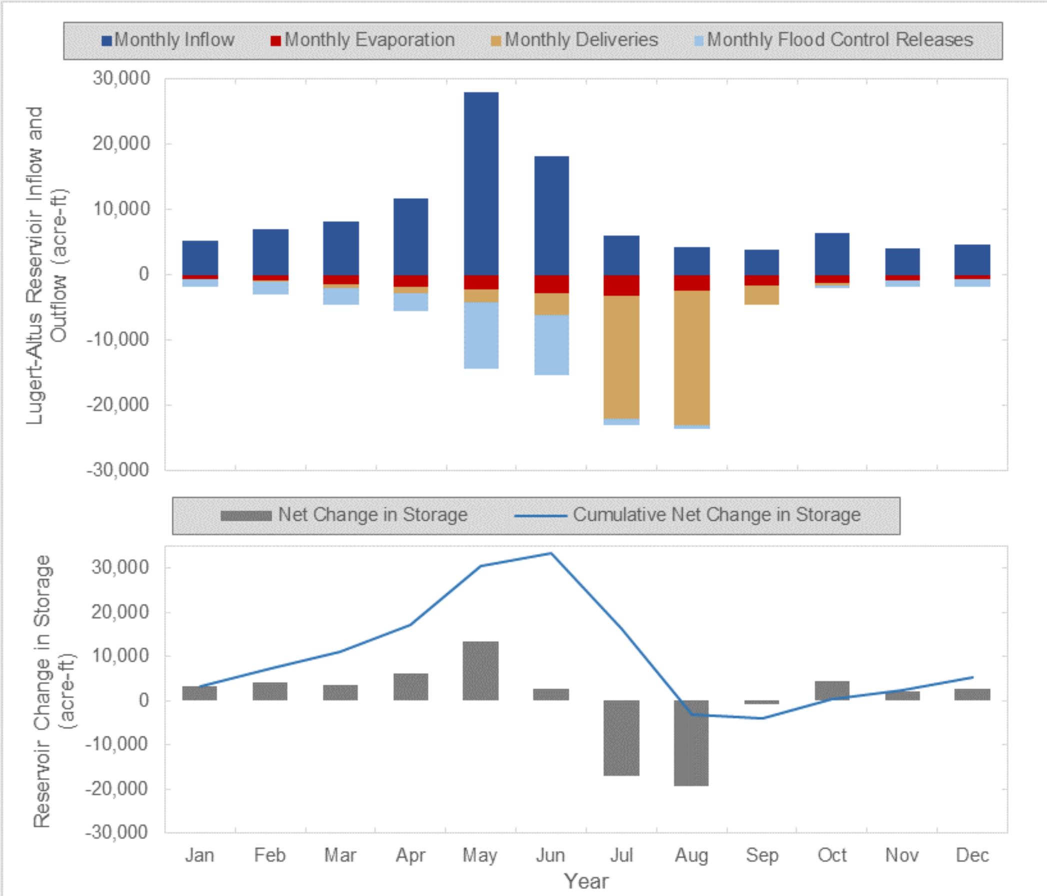

Figure 5-54. Observed monthly balance of inputs and outputs (top) and net reservoir storage (bottom) of Lugert-Altus Reservoir, 1947-2018.

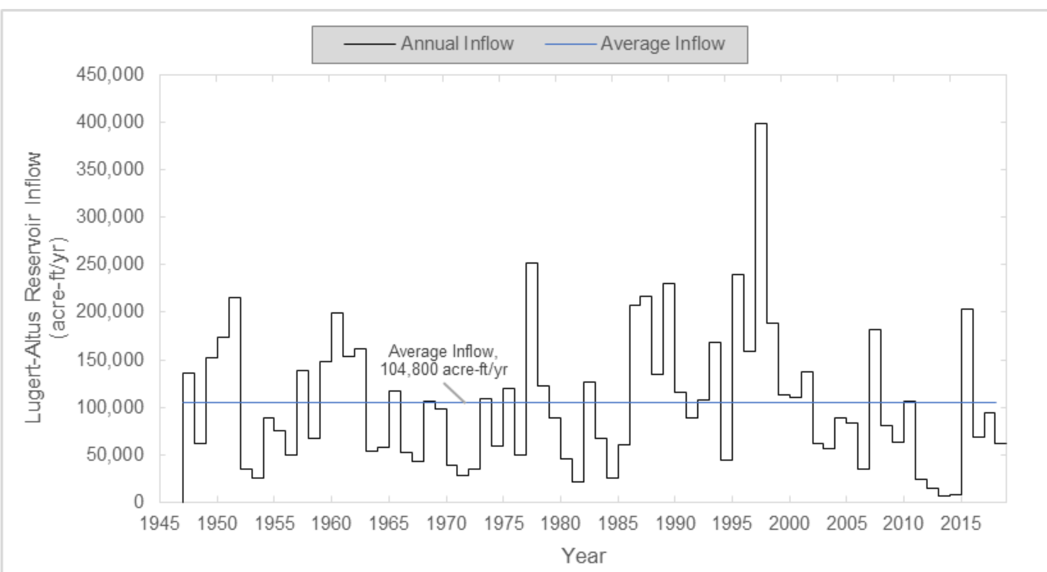

Figure 5-55. Annual inflow into Lugert-Altus Reservoir, 1947-2018.

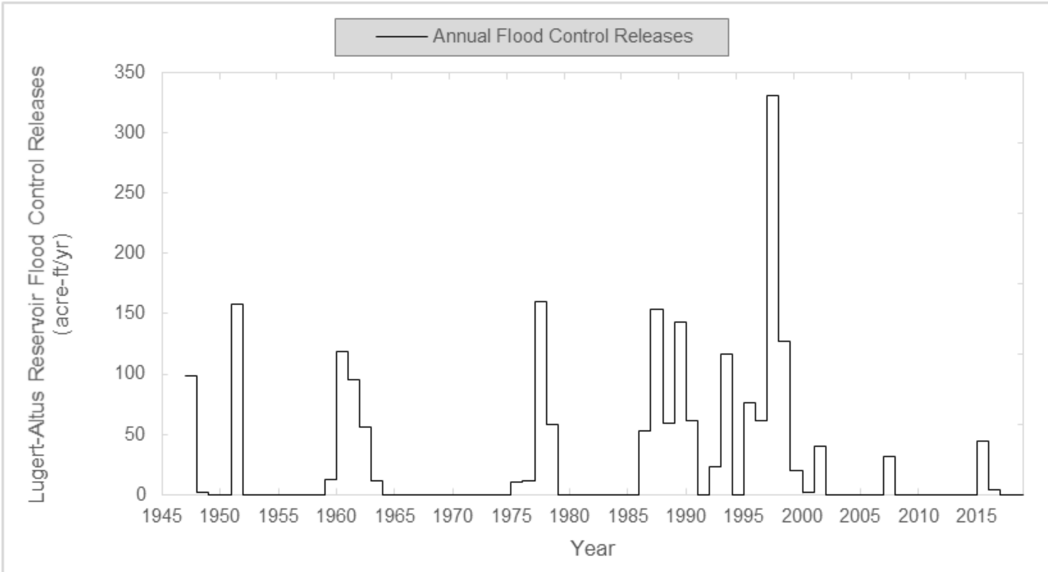

Figure 5-56. Annual flood releases out of Lugert-Altus Reservoir, 1947-2018.

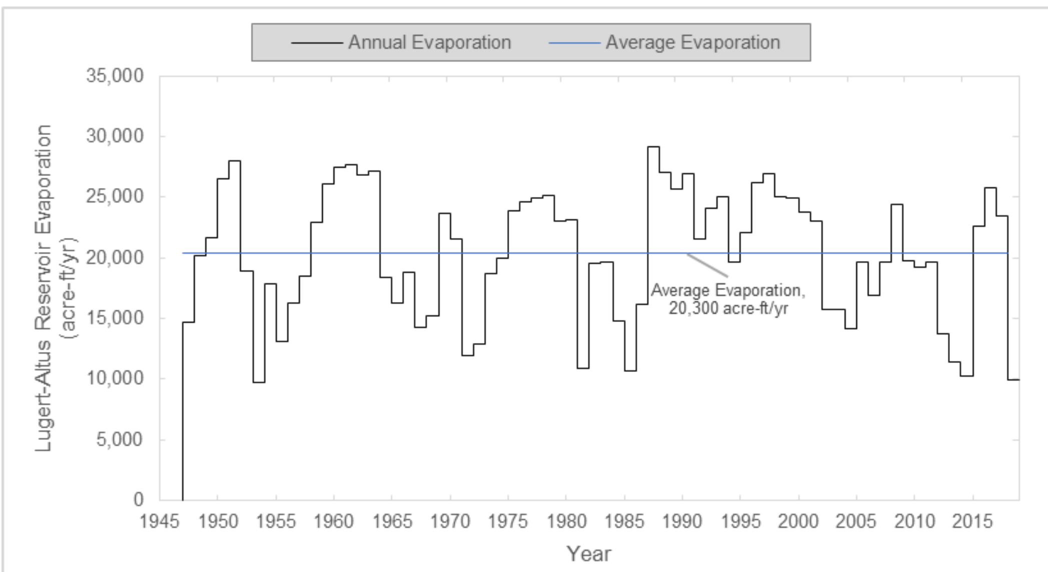

Figure 5-57. Annual evaporative losses out of Lugert-Altus Reservoir, 1947-2018.

Tom Steed Reservoir Supply

While the supply of Lugert-Altus Reservoir could be derived in part by accounting for observed deliveries almost exclusively for irrigation which maximizes use of available storage during relatively dry periods, the supply of Tom Steed Reservoir is better derived by accounting for observed reservoir storage. This is because the majority of demand on Tom Steed Reservoir is for M&I purposes, meaning demands are largely constrained less by climate and hydrology than they are by factors such as population size and the distribution of demands across residential, commercial, and industrial sectors. These sectors vary not only in the volumes of water they consume, but also in their resiliency to fluctuating climate patterns, including their vulnerability to curtailment during extended drought periods. For example, the impacts of curtailing water use for hospitals, residential sanitation, or for the Altus AFB are likely greater than those of curtailing irrigation of residential lawns. For these reasons, reservoirs such as Tom Steed Reservoir that primarily supply water for M&I purposes are designed to store enough water to dependably supply the needs of M&I customers during an extended, critical drought. When the MPMCD applied for and received its water right in 1967, a volume of 16,100 acre-ft/yr was determined at the time to be the amount of water required to meet the M&I needs to be met by Tom Steed Reservoir, and an amount of 45,000 acre-ft/yr was determined as the average annual inflow required to produce 16,100 acre-ft/yr during a repeat of what was considered the drought of record at the time. In effect, 16,100 acre-ft/yr was identified as Tom Steed Reservoir's dependable yield (i.e., "firm yield")[104]. Given the new 2010s Drought of Record, it is now known that the firm yield is lower than 16,100 acre-ft/yr, the details of which will be discussed in Chapter 6.

Similar to Lugert-Altus Reservoir, available storage in Tom Steed Reservoir has been driven primarily by gains from inflow and losses from

[104] The original water right permit issued in 1967 by the OWRB to MPMCD was for 45,000 acre-ft/yr. The permit was amended in 1991 and reduced to 16,100 acre-ft/yr. The history and context of this modification is discussed in detail in the "Legal Review of Adaptation Strategies: Constraints and Options for Tom Steed Reservoir (Kershen, 2020)".

evaporation (Figure 5-58). Figure 5-58 illustrates net changes in reservoir storage relative to annual changes in inflow, evaporation, deliveries, and flood releases between 1976 and 2018. As expected, inflow is the primary source of storage of Tom Steed Reservoir, yet inflow fluctuations are relatively smaller than those at Lugert-Altus Reservoir because the cumulatively smaller-sized watersheds of Elk and West Otter Creeks. Also similar to Lugert-Altus Reservoir, the most amount of inflow into Tom Steed Reservoir occurs during the months of May and June, with the greatest net storage increase occurring in May (Figure 5-59). Inflow ranges from 9,800 acre-ft/yr to 133,800 acre-ft/yr over the period of record, with an average of annual inflow of 41,600 acre-ft/yr (Figure 5-60). Flood releases (Figure 5-61) are less flashy than those of Lugert-Altus Reservoir, again due to the relatively smaller hydrologic basins draining into Tom Steed Reservoir. The proportion of evaporative losses relative to inflow at Tom Steed Reservoir is substantially higher than that at Lugert-Altus Reservoir (Figure 5-58); in fact, evaporative losses far exceed deliveries throughout the year, contributing to the greatest net loss in reservoir storage in July and August (Figure 5-59). Annual evaporation rates range from 7,500 acre-ft/yr to 34,600 acre-ft/yr, averaging 25,900 acre-ft/yr (Figure 5-62).

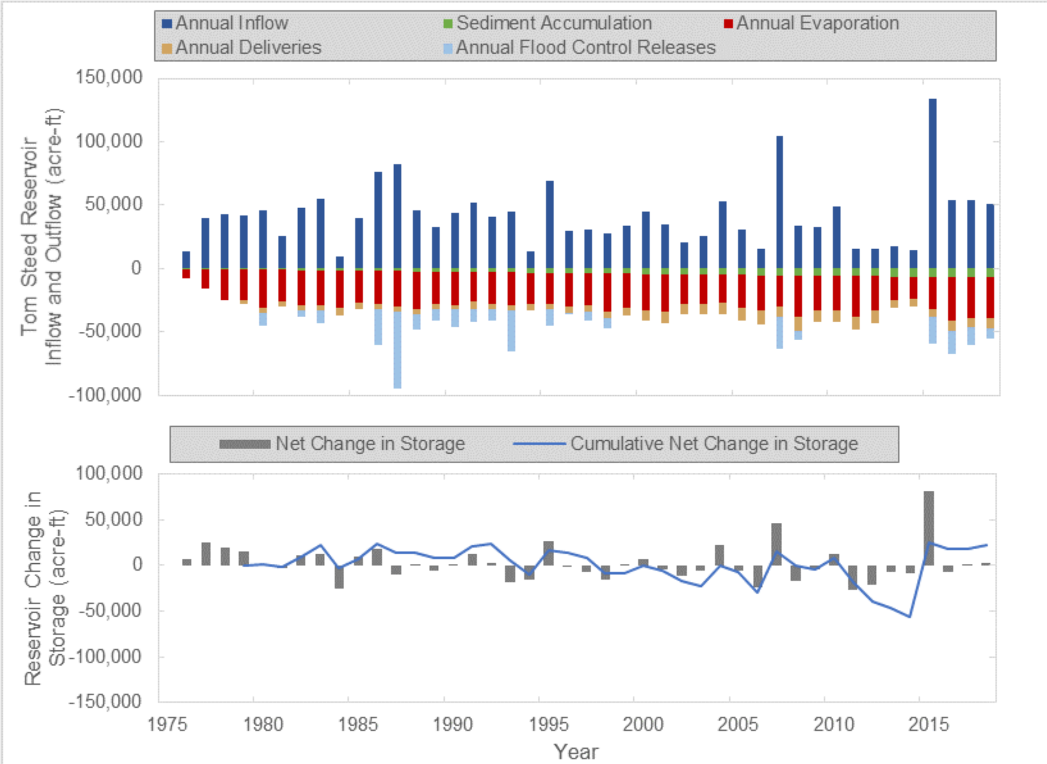

Figure 5-58. Observed annual balance of inputs and outputs (top) and net reservoir storage (bottom) of Tom Steed Reservoir, 1976-2018.

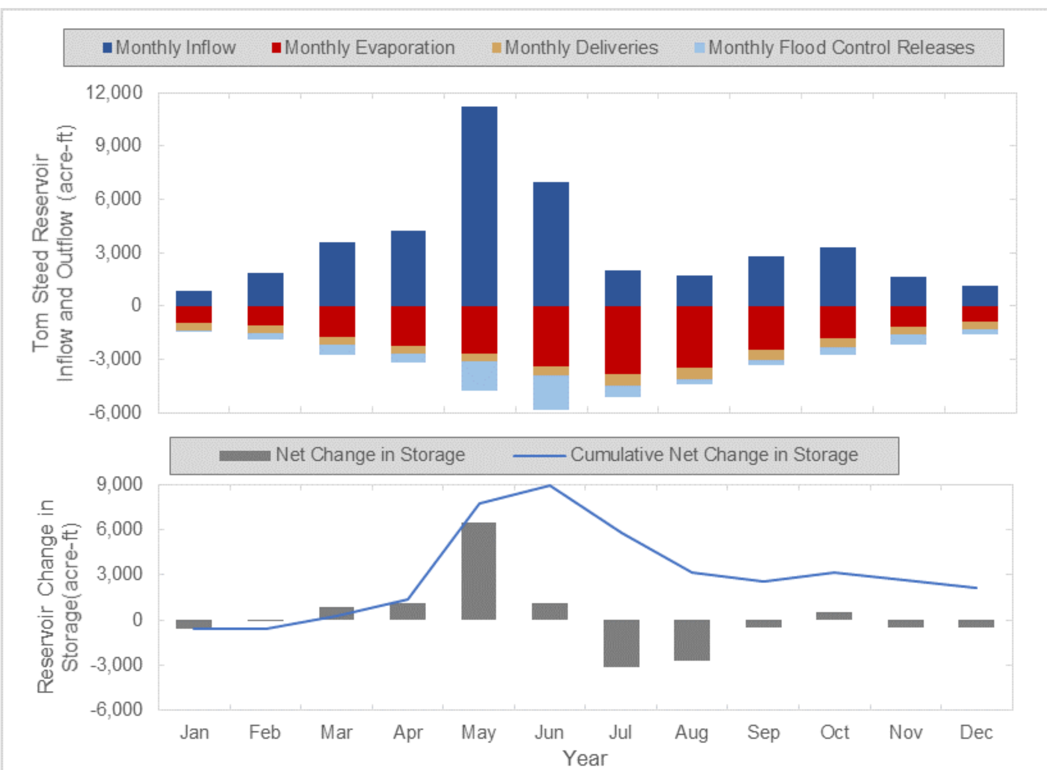

Figure 5-59. Observed monthly balance of inputs and outputs (top) and net reservoir storage (bottom) of Tom Steed Reservoir, 1976-2018.

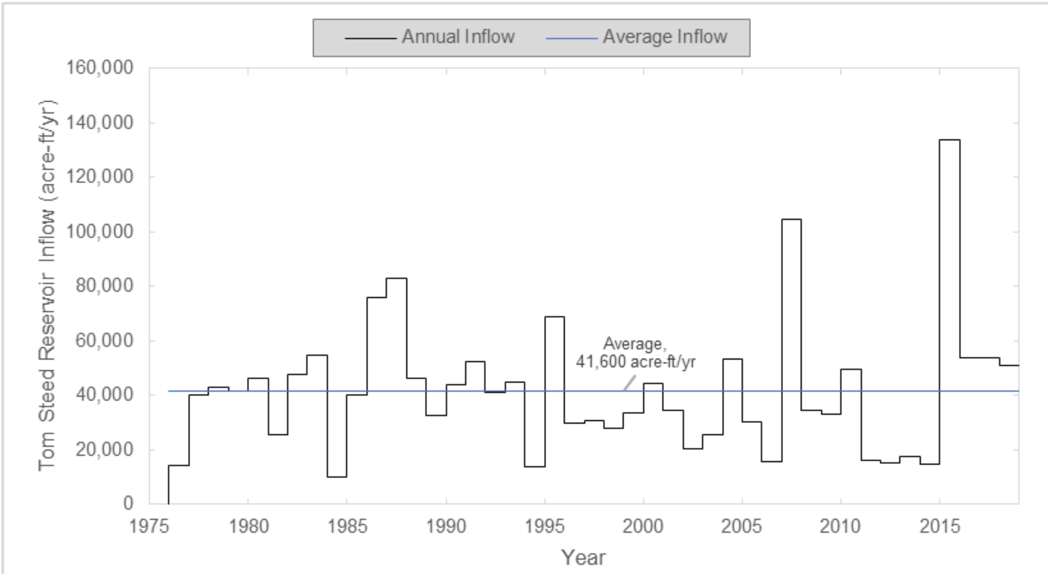

Figure 5-60. Annual inflow into Tom Steed Reservoir, 1977-2018.

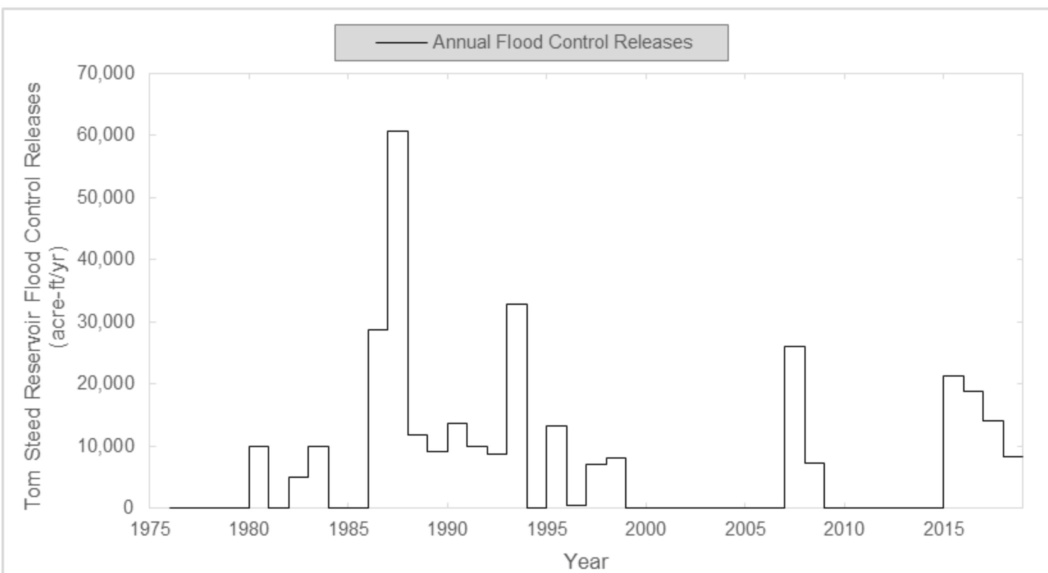

Figure 5-61. Annual flood releases out of Tom Steed Reservoir, 1977-2018.

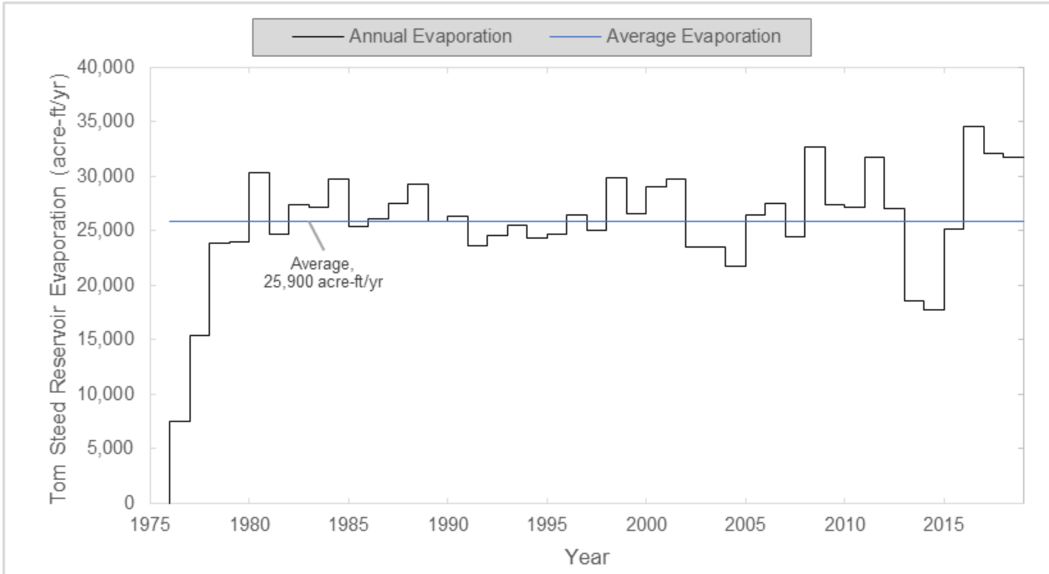

Figure 5-62. Annual evaporative losses out of Tom Steed Reservoir, 1977-2018.

5.4. Future Basin-Wide Demands

Chapters 5.2 and 5.3 provided an inventory of existing water demands and supplies within the URRBS area. This section projects towards the future, presenting various scenarios that reasonably represent a range of increasing, incremental future demand pressures that may be placed on available groundwater and surface water supplies in the basin. Recognizing that the future cannot be predicted with any degree of certainty, consideration of future conditions must be based on a fundamental set of assumptions. The fundamental assumption underlying the development of demand scenarios for this study was that the future would be constrained by existing Oklahoma water law (i.e., no changes in Oklahoma water law). Henceforth, these conditions are referred to as “status-quo”. Status-quo conditions are discussed in more detail in Chapter 6.1 Status-Quo Conditions. This is not to say that the future status quo implies no changes in water policy. Because water policy is often developed and may be changed at the discretion of the OWRB, it is reasonable to assume that changes in water policy may occur in the status-quo future. This is particularly relevant for policy decisions related to water rights permitting and management, which serve as the primary drivers that constrain demands on water. This will be discussed in more detail later in this section.

Another important consideration in the development of status-quo demand scenarios was the availability of data and predictive models. Without these, one cannot make reasonable predictions about future conditions. In the case of groundwater, status quo was defined based on four future pumping scenarios that were identified and evaluated in great detail as part of the MAY investigation on the NFRR aquifer (Smith et al., 2017). The groundwater model is summarized in Chapter 6.2.1. These pumping scenarios, in turn, provided the basis for formulating future demand scenarios on surface water. And like groundwater, demand scenarios on surface water were made possible by the development of a model – in this case a predictive network stream model developed as part of this

Basin Study, namely the OWRB's NFRR Surface Water Allocation Model (SWAM). The NFRR SWAM will be discussed in Chapter 6.2.2.

5.4.1. Future Groundwater Demands

Chapter 2.5.4 discussed how the lack of data and tools have limited the ability to make informed predictions about future groundwater use, and that Reclamation's "default" approach over the years has been to apply "what if" scenarios using the RRY Model that entail a range of assumed withdrawals from upstream groundwater pumping. As part of this basin study, this approach has been improved through the collection of better data, and through the development of a hydrogeological framework, conceptual model, and numerical model on the NFRR aquifer (this terminology was first introduced in Chapter 2.5.4) that allows one to predict future conditions of the groundwater system under different future pumping scenarios[105]. At the time of this URRBS, a numerical groundwater model on the Elk City aquifer had not been developed, so impacts of groundwater pumping out of the Elk City aquifer were not quantified. Given the relatively low volume of reported uses out of the aquifer (Chapter 5.2), impacts from existing and future groundwater pumping out of the Elk City aquifer are likely minor.

Modeled Groundwater Demand Scenarios

For the purposes of this basin study, 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 were assumed: (a) Permits were considered "regular" permits; (b) Pumping lasts for 50 years, beginning in 2013 and ending in 2062; and (c) hydrogeology was simulated under "baseline" (observed, historic) climate conditions[106]. The scenarios differed in

[105] Because a detailed hydrogeological investigation has not yet been performed on the Elk City Aquifer, we are limited in the assumptions that can be made about future groundwater demands on the Elk City Aquifer.
[106] The impact of potential changing climate conditions on supplies are addressed in Chapter 6.5.

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.
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 peak of 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 represented 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-yr EPS[107].

To bring further clarity to the range of assumed future groundwater use conditions, it is worth returning to and answering the questions raised in Chapter 2.5.4, which were posed as key challenges with predicting and accounting for future groundwater pumping[108]:

1. Of the existing groundwater use permit holders in the hydrologic basin, how much of their permitted amount might be put to beneficial use in the future? *The volume of pumping reported to the OWRB is assumed to be put to beneficial use. Under the "Existing" use scenario, 24 percent of the total permitted volume was reported as pumped[109]. This same percentage is assumed as being put to beneficial use under the future "New" use scenario. Under the "Full" use scenario, all 294,000 acre-*

[107] The EPS and MAY results are provided in Chapter 6.
[108] These questions do not apply to the naturalized (no) groundwater use scenario.
[109] The cumulative permitted volume in 2013 totaled 95,511 acre-ft/yr. Reported use totaled 22,988 acre-ft/yr.

ft/yr of groundwater pumped from the NFRR aquifer is assumed to be put to beneficial use.

2. How much additional growth may we expect, and where? *The three groundwater use scenarios define growth as such: "Existing" (growth is relatively static and future groundwater use continues at peak pumping rates observed during the 2010s Drought of Record); "New" (growth increases and future groundwater use is 20.4 percent higher than use observed in the year 2013); "Full" (growth is maximized and future groundwater use utilizes the full NFRR aquifer MAY).*

3. What are the expected types of use (agricultural use, M&I, oil and gas, etc.)? *As cited above, existing groundwater demands have primarily been for agricultural irrigation. This is likely to continue into the future.*

4. To what extent would future groundwater water supplies be available to meet these needs? *All three future groundwater use scenarios assumed that groundwater supplies were available by both the NFRR and Elk City aquifers.*

5. How much of this use would be permitted versus set aside for domestic purposes? *In allowing no more than 50 percent of the NFRR and Elk City aquifers' saturated thickness to be depleted to greater than 5 ft or 15 ft, respectively, Oklahoma law attempts to ensure that enough groundwater storage is set aside for domestic use and that domestic uses are not interfered with by groundwater permits.*

6. How might future groundwater permits be regulated under Oklahoma water law? *All three future groundwater use scenarios assume no changes in groundwater regulations.*

7. What role could changing climate conditions affect supplies and demands, and subsequently on the need for groundwater pumping to meet those demands? *The impact of potential changing climate conditions on*

demands are discussed next. Impacts of changing climate conditions on supplies is addressed in Chapter 6.5.

Uncertainties

It is important to acknowledge that the demand scenarios presented above represent an assumed range of pressures that could be placed on supplies in the basin through the year 2060. Although these assumptions are considered reasonable in-so-far as they are based on the best available data, they are by no means certain. For example, the "Existing" groundwater pumping scenario assumes 50 years of pumping out of the NFRR aquifer at a rate of 22,998 acre-ft/yr. As discussed in Chapter 5.2.1, using USDA crop census/Cropland Data Layers to model the potential crop irrigation requirements of agricultural land over the NFRR aquifer, Reclamation found that net crop irrigation demands were far higher than what is reported by permit holders in 2013 (Reclamation, 2017)[110] (Appendix G). Therefore, reported use for irrigation purposes may represent a lower bound of irrigation demands on groundwater in the Lugert-Altus Reservoir hydrologic basin. In other words, the "Existing" groundwater modeled demand scenario evaluated by USGS (Smith et al., 2017), which assumed a 50-yr pumping rate of 22,998 acre-ft/yr, may underestimate future pumping out of the NFRR aquifer; and by extension, the "New" scenario, which applies a 20.4 percent growth rate on top of the "Existing" scenario, also may underestimate future pumping. Short of metering actual irrigation use, the best approach may entail the use of a model(s) that combines state-of-the-art remote sensing with regional, local, and ground-based hydro-climate data, while also accounting for variable soil conditions overlying the NFRR aquifer. Whatever the case may be, reported use is considered the best available data when accounting for withdrawals associated with a specific groundwater permit.

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[110] Net irrigation demands were estimated to be 86,000 acre-ft in 2013 for irrigated lands over the NFRR Aquifer within the Lugert-Altus Reservoir hydrologic basin.

Another consideration is uncertainty related to the growth projections assumed in the 50-yr pumping rate of the “New” use scenario out of the NFRR aquifer, as well as the uncertainty related to ever fully developing the NFRR. The 20.4 percent growth rate was based on population/growth projections cited in the OCWP 2012 Update. Although it was not known the extent to which 20.4 percent either over- or underestimates future growth and development of the NFRR aquifer, it was considered reasonable and based on best available data. Regarding full development of the NFRR aquifer, although it certainly represented a worst-case scenario, study partners wanted to assess the full range of potential impacts of future development on water availability in accordance with Oklahoma law. This required the evaluation of a fully developed aquifer.

Another source of uncertainty relates to development of the Elk City aquifer. As previously stated, a numerical model on the Elk City aquifer did not yet exist at the time of this URRBS and was not considered within the scope of the URRBS study; therefore, network stream modeling did not quantify/simulate the impacts of pumping out of the Elk City aquifer. Therefore, the groundwater pumping scenarios may underestimate future demands on the Elk City aquifer, and subsequently on Elk Creek, which in turn, may underestimate impacts on Tom Steed Reservoir. However, given the relatively low reported pumping volumes out of the Elk City aquifer, potential impacts on base flow and reservoir yield, if any, would be expected to be minor.

5.4.2. Future Surface Water Demands

Future Streamflow Demands

Given the known connection of groundwater and stream-water in the study area as detailed in Chapter 5.3, future stream water conditions and use were informed by and incorporate the four 50-yr groundwater use scenarios described in the previous section. In addition to integrating the cumulative impacts of groundwater pumping scenarios, assumptions on incremental increases in future stream water conditions were made. This included incremental increases in the volume of existing stream-water permits put to beneficial use, the volume of domestic stream use, and the volume of additional stream water potentially available for future permitting (if applicable). All projections were through the year 2060[111]. These assumptions are summarized below and detailed in within the modeling approach described in Chapter 6.2.

Regarding existing stream-water permits, with the exception of the "naturalized" use scenario, all future surface water demands assumed full use of existing regular stream-water permits in the NFRR (for Lugert-Altus Reservoir) and Elk Creek/Otter Creek (Tom Steed Reservoir). All stream water demand scenarios included existing, historical domestic use. Importantly, existing domestic use could not be quantified, although it was already accounted for in the USGS streamgage data that were used to derive all streamflow calculations.

Regarding future domestic stream use, two future domestic use scenarios were identified: a "low" and a "high" future domestic use. The "high" domestic use scenario assumed OWRB's permitting practice of allocating six acre-ft per acre to each of four assumed users within each square mile within the upstream watershed. The "low" domestic use estimate was selected as a mid-point volume between existing domestic use (which is unknown) and high domestic use.

[111] The 50-yr groundwater use scenarios are actually through the year 2062, but for simplicity, throughout this report, all future demands are assumed through year 2060.

Regarding new future stream permits, different assumptions were made between the Lugert-Altus and Tom Steed Reservoir hydrologic basins. For Lugert-Altus Reservoir hydrologic basin, a “Full” permit scenario was selected, such that all average annual naturalized flows (1950 to 2016), minus existing permits and assumed domestic uses, would be available for new stream permits. For Tom Steed Reservoir hydrologic basin, three future stream permitting scenarios were selected: “Low”, “High”, and “Full”. Similar to the Lugert-Altus basin, a “full” permit scenario was selected, such that all average annual naturalized flows (1950 to 2016), minus existing permits and assumed domestic uses, would be available for new stream permits. In addition, both “low” and “high” stream permit scenarios were selected to represent two different mid-point permitting volumes between the existing permitted volume and the “full” stream permit volume (i.e., “low” = 2,500 acre-ft/yr and “high” = 5,000 acre-ft/yr). The methods and assumptions related to the calculation of future domestic and permitted stream use are described in Chapter 6.2.2. Next, the discussion turns to the future stream-water demand scenarios assumed specifically for the Lugert-Altus and Tom Steed Reservoir hydrologic basins.

Lugert-Altus Reservoir Hydrologic Basin

Pursuant to the brief introduction above, the following future stream-water demand scenarios were considered:

1. **“*Naturalized*”**: Assumed no diversions from existing or future stream-water permits[112] 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.

[112] 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-yr EPS[113]; 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-yr EPS; full use of existing stream-water permits of 1,422 acre-ft/yr; and an assumed new future domestic stream use totaling 5,000 acre-ft/yr[114]. 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-yr EPS; full use of existing stream water permits of 1,422 acre-ft/yr; an assumed new future 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, if available[115].

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-yr EPS; full use of existing stream water permits of 1,422

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113 EPS and MAY results are provided in Chapter 6.
114 The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.2.
115 Results regarding availability of new stream-water permits are provided in Chapter 6.4.3. 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.

acre-ft/yr; and an assumed new future domestic stream use totaling 20,000 acre-ft/yr[111]. Assumed no new stream permits would be issued.

8. ***"Full GW Permits, 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-yr 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, if available.

Tom Steed Reservoir Hydrologic Basin

Pursuant to the brief introduction above, the following future stream-water demand scenarios were considered:

1. **"*Naturalized*"**: Assumes no diversions from existing or future stream-water permits[116] 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.
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. **"*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

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

the NFRR aquifer. Assumed 2,500 acre-ft/yr would be issued in new stream permits.

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.

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.

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 27,678 acre-ft/yr over the NFRR aquifer. Assumed 5,000 acre-ft/yr would be issued in new stream permits.

8. ***"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-yr EPS[117]; 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 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-yr 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[118]. Assumed no new stream permits would be issued.

[117] EPS and MAY results are provided in Chapter 6.
[118] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3

10. ***"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-yr 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, if available[119].

11. **"*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-yr 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[120]. Assumed no new stream permits would be issued.

12. ***"Full GW Permits, 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-yr 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, if available.

Similar to the discussion on groundwater demands, to bring further clarity to the range of assumed future stream-water demand scenarios, it is worth returning to and answering the questions raised in Chapter 2.5.3, which were posed as key challenges with predicting and accounting for future surface water demands[121]:

1. Of the existing permit holders in the watershed, how much of their permitted amount might be put to beneficial use in the future? What would

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[119] Results regarding availability of new stream-water permits are provided in Chapter 6.4.4. 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.
[120] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3.
[121] These questions do not apply to the naturalized stream-water demand scenario.

be the impacts if all permit holders were withdrawing their full permitted amounts?

Under the prior appropriation system, a phrase commonly used is that the person with a water right must "use the water or lose it". Oklahoma law expresses this "use it or lose it" philosophy by explicitly stating that if a permit holder does not use the full amount authorized, the unused amount is forfeited and reverts to the public as unappropriated water. The OWRB has consistently worked with permit holders to reduce their permitted amount if unused or to setup a reasonable use schedule to determine when the full use of their permit will come to fruition. Based on Oklahoma Law and OWRB policies, we can only assume that existing permits will continue to be put to beneficial use or will be reduced for the issuance of new permits until full appropriation of the stream water system. The impacts of all permit holders withdrawing their full permitted amount is evaluated as part of the future stream water use scenarios and will be detailed presented in Chapter 6.

2. How much additional growth may we expect, and where? *Growth in stream-water use largely depends on the extent to which use is for domestic purposes or if a permit is required. The stream-water use scenarios described above consider static, low, and high domestic use growth rates. The volume of new stream water permits available is based, in part, on naturalized stream flows generated by the OWRB's SWAM using USGS gage data from 1950 to 2016 as opposed to the OWRB's current practice of determining unappropriated water availability using (among other considerations) average annual run-off from 1951 to 1980.*

3. What are the expected types of use (agricultural use, M&I, oil and gas, etc.)? *As cited above, existing stream-water demands have primarily been for agricultural irrigation. This is likely to continue into the future.*

4. To what extent would future water supplies be available to meet these needs? *The future stream water use scenarios will be used to determine*

the extent to which water supplies are available to meet these needs. Chapter 6 will present the full range of availability utilizing the best available data and tools.

5. How much of this use would be permitted versus for domestic purposes? *Some scenarios assumed that domestic use would remain unchanged from current conditions and that all growth in stream water use would occur through the permitting process. Other demand scenarios assumed that growth would occur in both domestic and permitted uses. Regarding future domestic stream use, a "low" and a "high" estimate were assumed. Regarding the availability of stream water for future permitting, the volume of new stream water permits was based, in part, on naturalized stream flows generated by the OWRB's SWAM using USGS gage data from 1950 to 2016 as opposed to the OWRB's current practice of determining unappropriated water availability using (among other considerations) average annual run-off from 1951 to 1980.*
6. How might future permits be regulated under Oklahoma water law? *All future stream water use scenarios assumed no changes in stream water regulations.*
7. What role could changing climate conditions affect supplies and demands, and subsequently the amount of surface water available to meet those demands? *The impact of potential changing climate conditions on demands are discussed next. The impacts of changing climate conditions on supplies are addressed in Chapter 6.5 Impacts under Climate Change.*

Uncertainties

Because future stream-water demand scenarios incorporated groundwater use, the same uncertainties discussed above for groundwater apply here, namely related to the accuracy of reported use, inability to simulate pumping out of the Elk City aquifer, and future growth projections. In addition to these, other uncertainties should be noted. For example, unlike the "Existing" and "New" groundwater use scenarios which are based on reported use, the “Existing” and “New” stream-water use scenarios assumed full use of existing and new stream-water permits. An analysis of reported use from streams would not provide much value considering the small volume of stream-water permits (and even lower volume of reported use) relative to the very large volume of streamflows within the Lugert-Altus and Tom Steed Reservoir hydrologic basins.

Similar to groundwater, in formulating the stream-water demand scenarios, the goal was to capture the wide range of potential increases in incremental demand pressures that could be placed on future streamflow. This included a best-case scenario (“Naturalized”), middle-case scenarios (“Existing SW”; “New”), and worst-case scenarios (“Full GW and SW”). Included within the middle- and worst-case scenarios were low and high estimates of domestic use, and in the case of Tom Steed Reservoir, the addition of new future stream permits with volumes that fall between the existing and full stream permit volumes. As previously stated, historical domestic use could not be quantified. This is because metered data on stream diversions do not exist. This complicated any projections on future domestic use assumed within the demand scenarios. Absent these data, a range of use was assumed such that “High” domestic use was calculated based on the OWRB’s practice of allocating six acre-ft per acre to each of four assumed users within each square mile within the upstream watershed. This volume is reserved by the OWRB for domestic use and subtracted from the average annual run-off volumes that form the basis of determining stream-water permit availability. A demand of 5,000 acre-ft/yr was assumed for the “New” future domestic use “Low” scenario, a volume that could be viewed as arbitrary, but study partners believed it is reasonable as a conservative, low-end estimate of new domestic growth within 50 years.

A final source of uncertainty lies within the stream water appropriation volumes assumed within the “Full SW” use scenarios. The assumed permit availability values were for planning purposes only and may not represent the actual quantity of stream water available for new permits, nor do they represent a position by the OWRB regarding how determinations of stream water availability for appropriation are made. In the context of this basin study, future worse-case scenarios on groundwater and stream water development were established with the intent of fully utilizing groundwater and stream water resources for beneficial use as authorized by current Oklahoma law. For the purposes of this basin study, the volume of new "regular" stream water permits would be based on naturalized stream flows generated by a new SWAM using USGS gage data from 1950 to 2016, as well as outputs from a new groundwater model that simulates full development of groundwater from an adjacent aquifer. This is discussed more in Chapter 6. It should be noted that the OWRB's existing practice does not employ this approach; rather, the OWRB currently determines unappropriated water availability in streams using a model based in ArcGIS that is specific to the requested diversion location(s) for each new regular permit application, and which uses average annual run-off from 1951 to 1980 as one of many variables when considering unappropriated stream water available[122]. However, as discussed in Section 2.5.6, Oklahoma's OAC 785:20-5-5 provides the OWRB with discretion in how it determines water available for appropriation. It states that for direct diversions from a stream, the determination of water available for appropriation shall take into consideration: mean annual precipitation run-off in the hydrologic basin above the point(s) of diversion; mean annual flow; stream gage measurements; domestic uses; and all existing appropriations and other designated purposes in the stream system. The Rule also states that the OWRB may consider other evidence or laws relating to streamflow or elevation when considering water available for appropriation. While one can estimate what one believes may be the amount of water available for appropriation, the discretion provided to the OWRB by Oklahoma water code introduced uncertainty into these calculations.

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[122] OWRB Memorandum to File by E. Sherrod, dated October 2018.

Future Reservoir Demands

Lugert-Altus Reservoir

As previously discussed, water demands on Lugert-Altus Reservoir were primarily derived from the Lugert-Altus ID's 85,630 acre-ft water right to irrigate 48,000 acres of land within the Lugert-Altus ID for agricultural use (primarily cotton), but also from a requirement to ensure the city of Altus' 4,800 acre-ft/yr senior right to water was protected. Although the city of Altus' contracted water right remains protected within Lugert-Altus Reservoir, its water supply has primarily been delivered from Tom Steed Reservoir over the years, with the exception of the 2010s Drought of Record. For the purposes of projecting 2060 reservoir demands, this analysis assumed that the city of Altus may receive its water from either of the two reservoirs; for the sake of brevity, a discussion on the city of Altus' projected 2060 demands is discussed in the next section on Tom Steed Reservoir. Next, the analysis turns to Lugert-Altus ID.

Crop Irrigation and M&I Demands

In Chapter 2.3.1, this analysis derived 115,000 acre-ft/yr as the volume of storage needed in Lugert-Altus Reservoir to meet both the irrigation and M&I demands; this volume includes a legally-mandated storage reserve to ensure water is available to the city of Altus while also accounting for evaporation. Furthermore, assuming a delivery efficiency of 68 percent (32 percent loss), 58,200 acre-ft/yr of supply is available for the irrigation of Lugert-Altus ID's 48,000 acres – this equates to an allocation of 1.2 acre-ft/acre (15 inches). This net requirement is consistent with studies cited in Chapter 2.3.1 which describes the net irrigation requirement for cotton in western Oklahoma. However, if the net irrigation water requirement was to increase in the future, the amount of water supply demanded by a similar acreage of crops within the Lugert-Altus ID would increase. Just how much water could be needed is complicated and must be assessed under a set of various assumptions about future changes/variations in crop evapotranspiration, which are primarily driven by climate. An assessment on how a range of potential future climate conditions may affect irrigation demands is provided in Chapter 6.5.6: "Impacts on Future Irrigation Demands". For the purposes here, this analysis concludes that future (2060) demands on Lugert-Altus Reservoir would remain at 115,000 acre-ft/yr, which is the effective storage needed to deliver enough water to fulfill the combined M&I and irrigation water rights of 90,430 acre-ft/yr.

Uncertainties

Two key uncertainties should be noted again about future demands on Lugert-Altus Reservoir. First, any potential changes in the Lugert-Altus ID operating rules currently in place that protect the senior water right for city of Altus would have a corresponding impact on the reservoir storage needed to deliver the irrigation and/or M&I water rights. Second, the net irrigation demand of 15 inches cited above was only an approximation, and actual net irrigation demand varies across the 48,000 acres of irrigable land based on soil moisture, crop type/yield, evapotranspiration, etc. Considering cropping patterns are driven by water availability, it is reasonable to assume that increases in water availability may prompt an increase in net irrigation demands as farmers switch to more productive, thirsty crops. Another factor that could increase future net irrigation demand is climate change; indeed, a warming climate will increase irrigation demands. That said, increases in net irrigation demand would, in turn, require more reservoir storage to deliver the irrigation water rights. And as discussed in Chapter 2.2.2, sedimentation may exacerbate the situation by reducing storage capacity of Lugert-Altus Reservoir. Considering all of these factors, it would be reasonable to assume that future demands on Lugert-Altus Reservoir may require more than 115,000 acre-ft, potentially requiring the entire 128,000 acre-ft conservation pool storage capacity to deliver the irrigation and M&I water rights.

Tom Steed Reservoir

Future water demands on Tom Steed Reservoir were projected through 2060 using the cumulative M&I demand estimates of the MPMCD's three member cities: city of Altus, Frederick, and Snyder – as well as EQ demands from Hackberry Flat WMA. The goal was to identify the key factors that influence M&I water demands on Tom Steed Reservoir, and then make a prediction on how those factors may (or may not) change over time. The first step was to gather observed/historical water use data, identify trends over time, and then to adjust those trends accordingly to predict future water use conditions. However, like reservoir supplies, the demands on a reservoir are neither fixed nor absolute, and assumptions have to be made that account for uncertainties.

M&I Water Use Projections

The first step was to quantify how much M&I water has historically been consumed and then to use these data to project future water consumption through 2060. The M&I water is made up of the combined water consumption for domestic and residential indoor and outdoor uses, as well as uses for commercial businesses, hospitals, industry, manufacturing, etc. Water consumption is typically calculated on a per capita (per person) basis [(a.k.a. Gallons Per Capita Day (GPCD)]. The GPCD of a given entity can be calculated by simply dividing the total amount of water consumed per day (depending on available data) by the total population of the entity. Water consumption by MPMCD M&I customers was based on metered readings that measure monthly deliveries between 2010 and 2018 from Tom Steed Reservoir to the member cities of Altus, Fredrick and Snyder, including total deliveries from MPMCD (Figure 5-63 to Figure 5-66). Next, the water use for each member city was divided by the total combined population of each member city and its respective customers. Recall that a total of 29 customers receive water from Tom Steed Reservoir, including the three member cities. Populations between 2010 to 2018 were obtained using estimates provided by the U.S. Census Bureau[123]. Table 5-5 shows the estimated population for each member city between 2010 and 2018, the respective water deliveries, and both peak and average usage in GPCD.

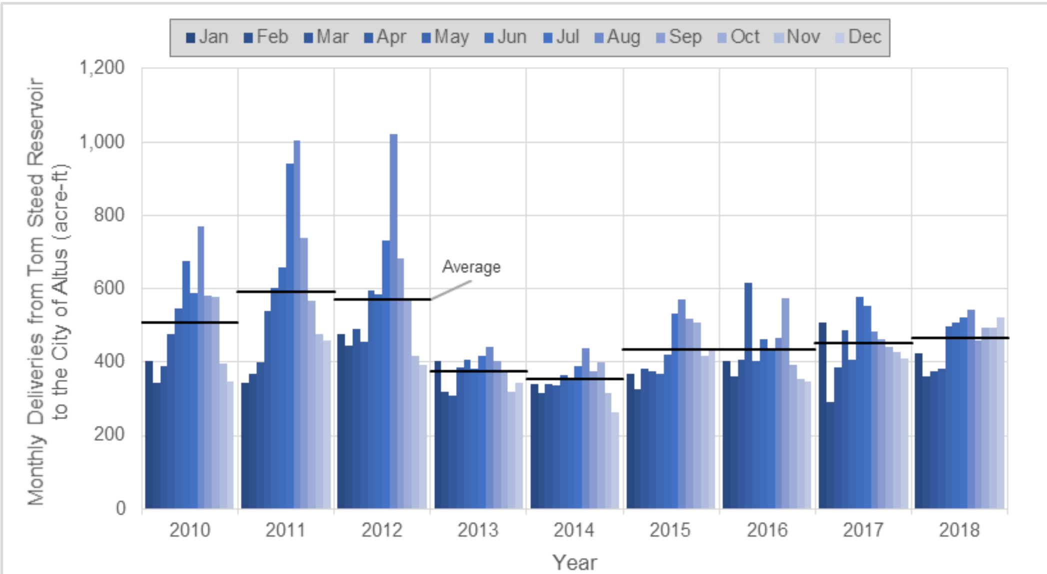

Figure 5-63. Monthly MPMCD deliveries from Tom Steed Reservoir to the city of Altus, 2010-2018.

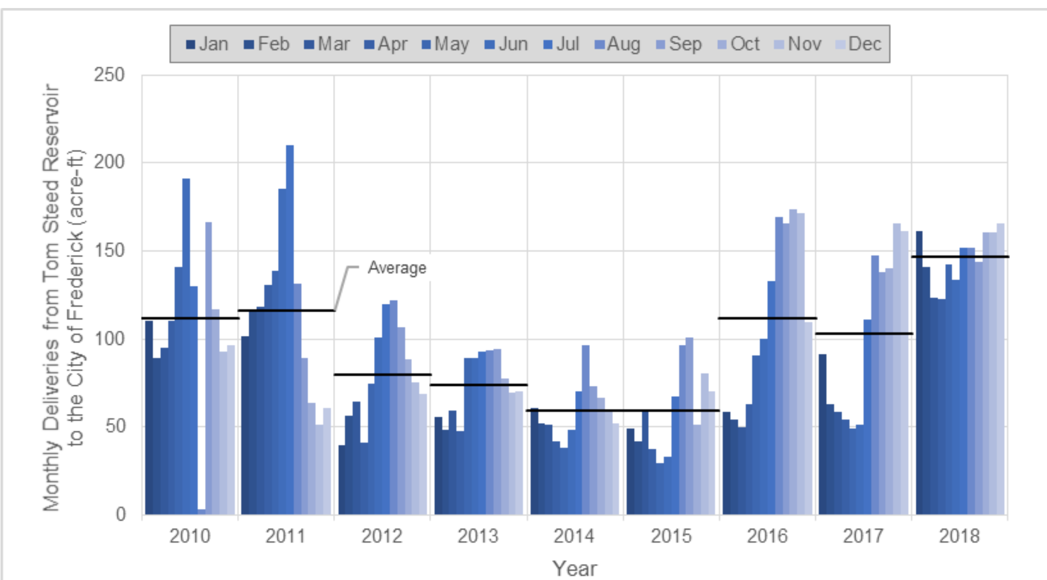

Figure 5-64. Monthly MPMCD deliveries from Tom Steed Reservoir to the city of Frederick, 2010-2018.

[123] https://www.census.gov/data/tables/time-series/demo/popest/2010s-total-cities-and-towns.html.

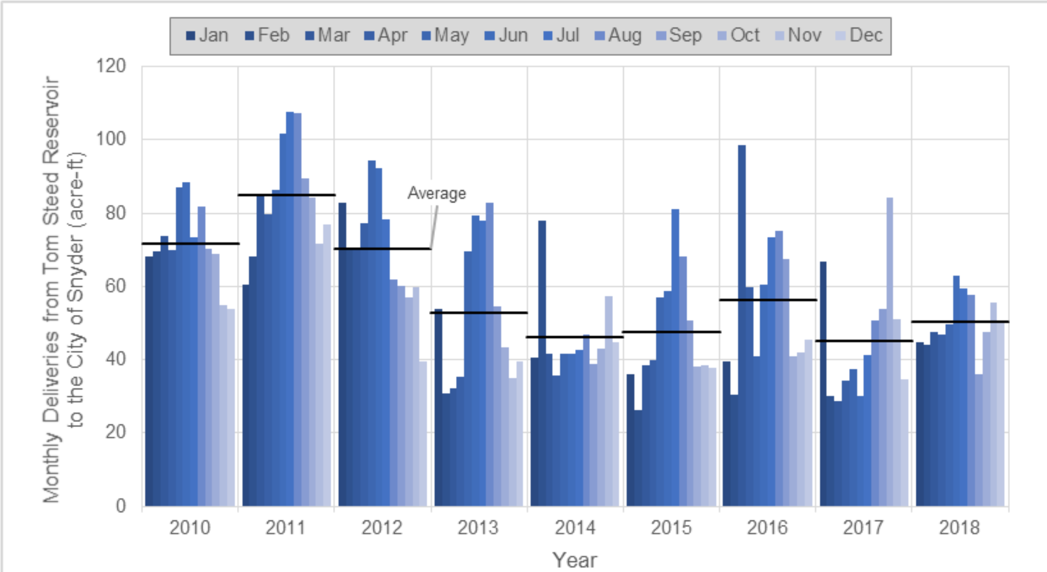

Figure 5-65. Monthly MPMCD deliveries from Tom Steed Reservoir to the city of Snyder, 2010-2018.

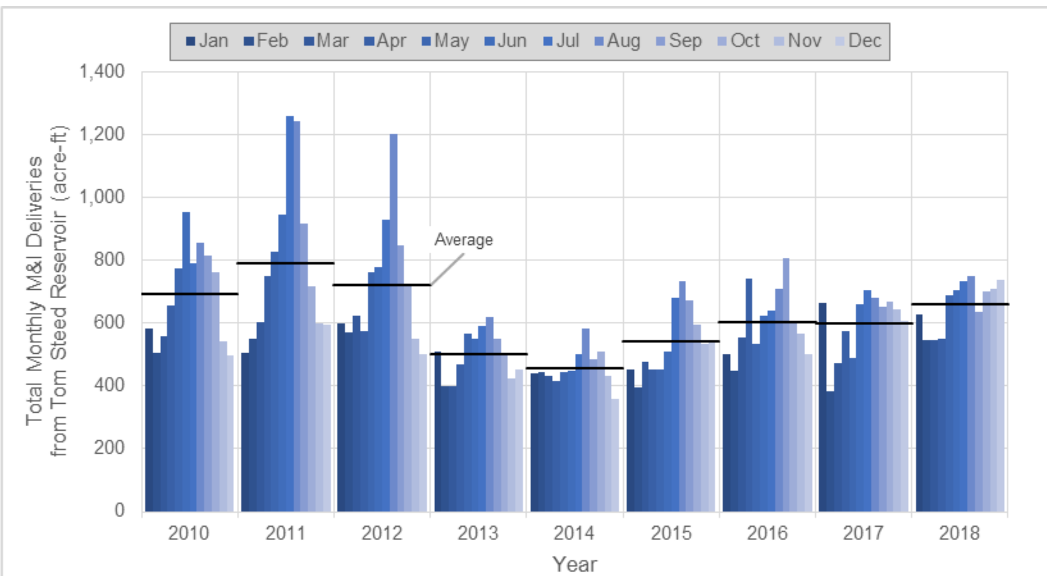

Figure 5-66. Total combined monthly MPMCD deliveries from Tom Steed Reservoir to the cities of Altus, Frederick, and Snyder, 2010-2018.

Table 5-5. Water usage (GPCD) for the cities of Altus, Frederick, and Snyder between 2010 and 2018.

Year	Altus			Frederick			Snyder		
	Population	Deliveries	GPCD	Population	Deliveries	GPCD	Population	Deliveries	GPCD
2010	29,116	6,094	187	8,664	1,343	138	5,054	860	152
2011	29,055	7,091	218	8,667	1,396	144	5,046	1,019	180
2012	28,860	6,861	212	8,513	959	101	5,022	845	150
2013	28,764	4,505	140	8,415	889	94	5,003	634	113
2014	28,507	4,233	133	8,361	710	76	4,981	553	99
2015	28,167	5,215	165	8,262	716	77	4,935	571	103
2016	28,127	5,222	166	8,204	1,339	146	4,902	674	123
2017	27,864	5,428	174	8,101	1,232	136	4,862	543	100
2018	27,618	5,573	180	8,020	1,759	196	4,826	603	111
Average GPCD (2010 – 2018)			175			123			126
Peak GPCD (2010 – 2018)			218			196			180

Population Projections

Population projections were obtained from the OWRB's OCWP 2012 Update[124], as well as through calculations performed by Reclamation using linear regression of U.S. census data collected/estimates between 1970 and 2015 (Table 5-6). The range of future population growth varied substantially between the two forecasting methods, with the OCWP forecast generating higher population estimates relative to Reclamation's regression forecasts (Figure 5-67).

[124] The OCWP 2012 Update incorporated population projections calculated by the Oklahoma Department of Commerce: https://www.okcommerce.gov/wp-content/uploads/Population-Projections-Report-2012.pdf.

Table 5-6. Populations of the three member entities of the Mountain Park Master Conservancy District, as well as their respective service areas (based on U.S. Census data).

	Census Data					
Entity	**1970**	**1980**	**1990**	**2000**	**2010**	**2015**
Altus	23,302	23,101	21,940	21,479	19,813	19,549
Blair	1,114	1,092	922	894	818	778
Creta	-	-	-	221	221	221
Department of Corrections	-	-	-	1,050	1,050	1,050
Duke	486	484	360	445	424	407
Eldorado	737	688	581	533	446	428
Granite	1,808	1,617	1,844	1,844	2,065	2,015
Harmon Electric	-	-	-	181	181	181
Headrick	139	223	179	129	94	126
Jackson County Water Corp[a]	-	-	-	2,662	2,561	2,510
Kiowa County RWD #1[a]	-	-	-	176	176	173
Lone Wolf	584	613	576	498	438	450
Martha	268	219	216	196	164	157
Olustee	819	721	702	679	608	583
Quartz Mountain Regional Water Authority	7	7	7	7	7	7
Quartz Mtn Lodge & Center	-	-	-	50	50	50
Total Population Served by Altus	**29,264**	**28,765**	**27,327**	**31,044**	**29,116**	**28,685**
Frederick	6,132	6,153	5,313	4,692	3,940	3,693
Cotton County RWD #1	-	-	-	600	588	577
Davidson	515	501	461	381	315	298
Devol	-	-	165	151	151	160
Faxon	121	128	135	134	136	134
Grandfield	1,524	1,445	1,228	1,125	1,038	972
Hollister	105	82	59	60	50	47
Manituo	308	322	240	282	181	171
Tillman County RWD #1	-	-	-	1,500	1,418	1,379
Tipton	1,206	1,475	1,043	921	847	794
Total Population Served by Frederick	**9,911**	**10,106**	**8,644**	**9,846**	**8,664**	**8,225**
Snyder	1,671	1,848	1,592	1,511	1,394	1,345
Comanche County RWD#4a	-	-	-	3,000	2,907	2,861
Indiahoma	434	364	337	374	344	341
Mountain Park	458	557	467	389	409	396
Total Population Served by Snyder	**2,563**	**2,769**	**2,396**	**5,274**	**5,054**	**4,943**
Total Population Served by Tom Steed Reservoir	**41,738**	**41,640**	**38,367**	**46,164**	**42,834**	**41,853**

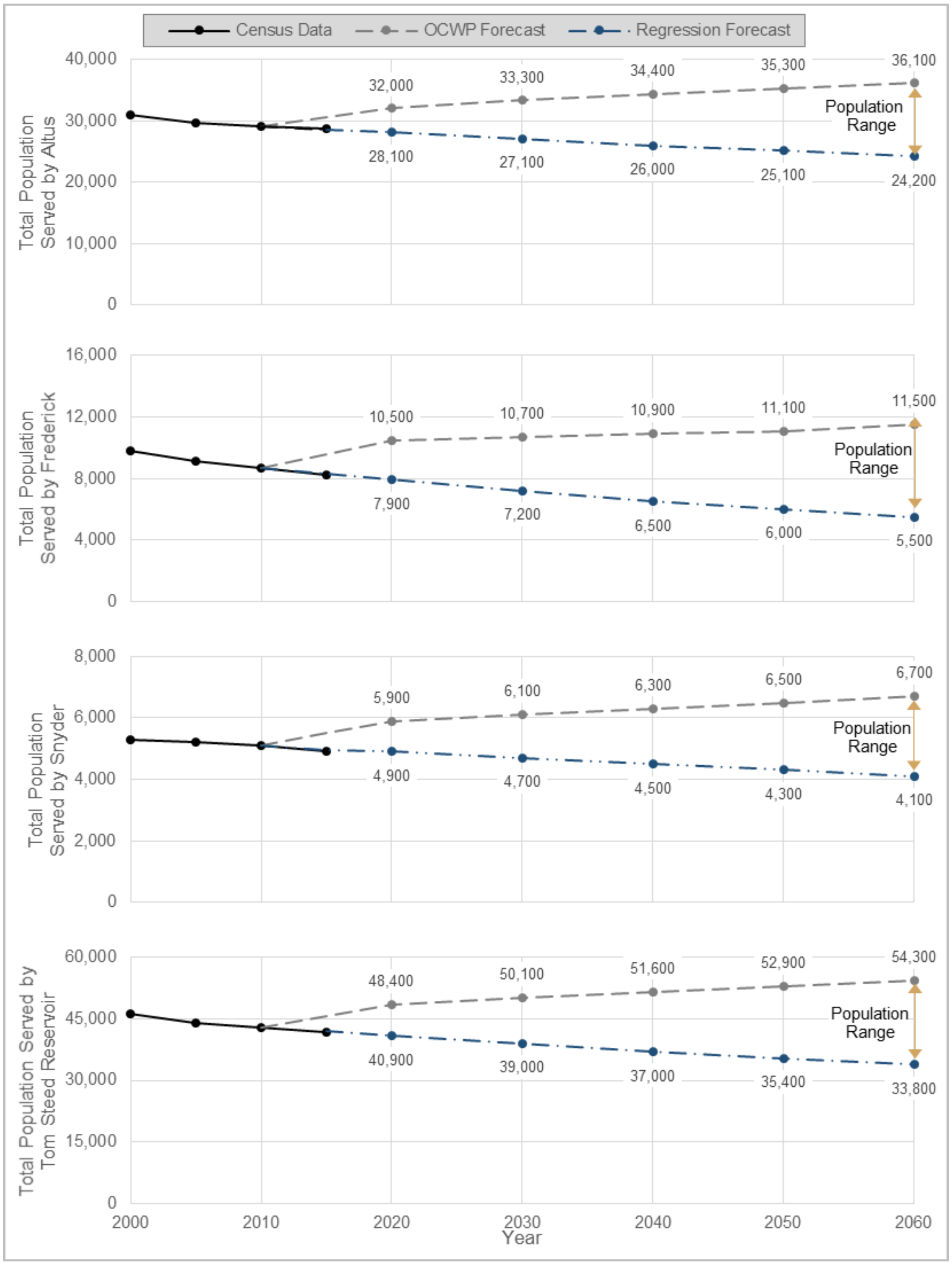

Figure 5-67. Population census data (2000 to 2015) and range of population (2020 to 2060) based on two forecasts for the service areas of Altus, Frederick, and Snyder, as well as total population served by Tom Steed Reservoir.

Water Demand Projections

The final step was to multiply the GPCD estimates by the forecasted population size of the member city service areas. Recall that the average GPCD (2010 to 2018) was 175, 123, and 126 for the service areas of Altus, Frederick, and Snyder, respectively; peak GPCD was 218, 196, and 180, respectively. To calculate a range of future M&I demands, the population projections obtained by the OCWP 2012 Update were multiplied by the peak GPCD use estimates (i.e., "higher projected demand"), whereas population projections derived using the linear regression approach were multiplied by the average GPCD use estimates (i.e., "lower projected demand") (Figure 5-68). Total projected M&I demands on Tom Steed Reservoir ranged from 6,000 acre-ft/yr to 12,600 acre-ft/yr. Next, EQ demands from Hackberry Flat WMA were taken into account. To calculate the range of total demands (both M&I and EQ) on Tom Steed Reservoir, a maximum use of the total EQ volume of 2,352 acre-ft/yr was assumed for the "higher projected demand", and an average Hackberry Flat WMA delivery of 1,800 acre-ft/yr was assumed for the "lower projected demand". As such, the total future (year 2060) water demand on Tom Steed Reservoir ranged from 7,830 acre-ft/yr to 14,950 acre-ft/yr (Figure 5-68). The higher projected demand of 14,950 acre-ft/yr was selected as one of three demand scenarios on Tom Steed Reservoir for water availability modeling purposes. Modeling scenarios are described in detail in Chapter 6.2.2.

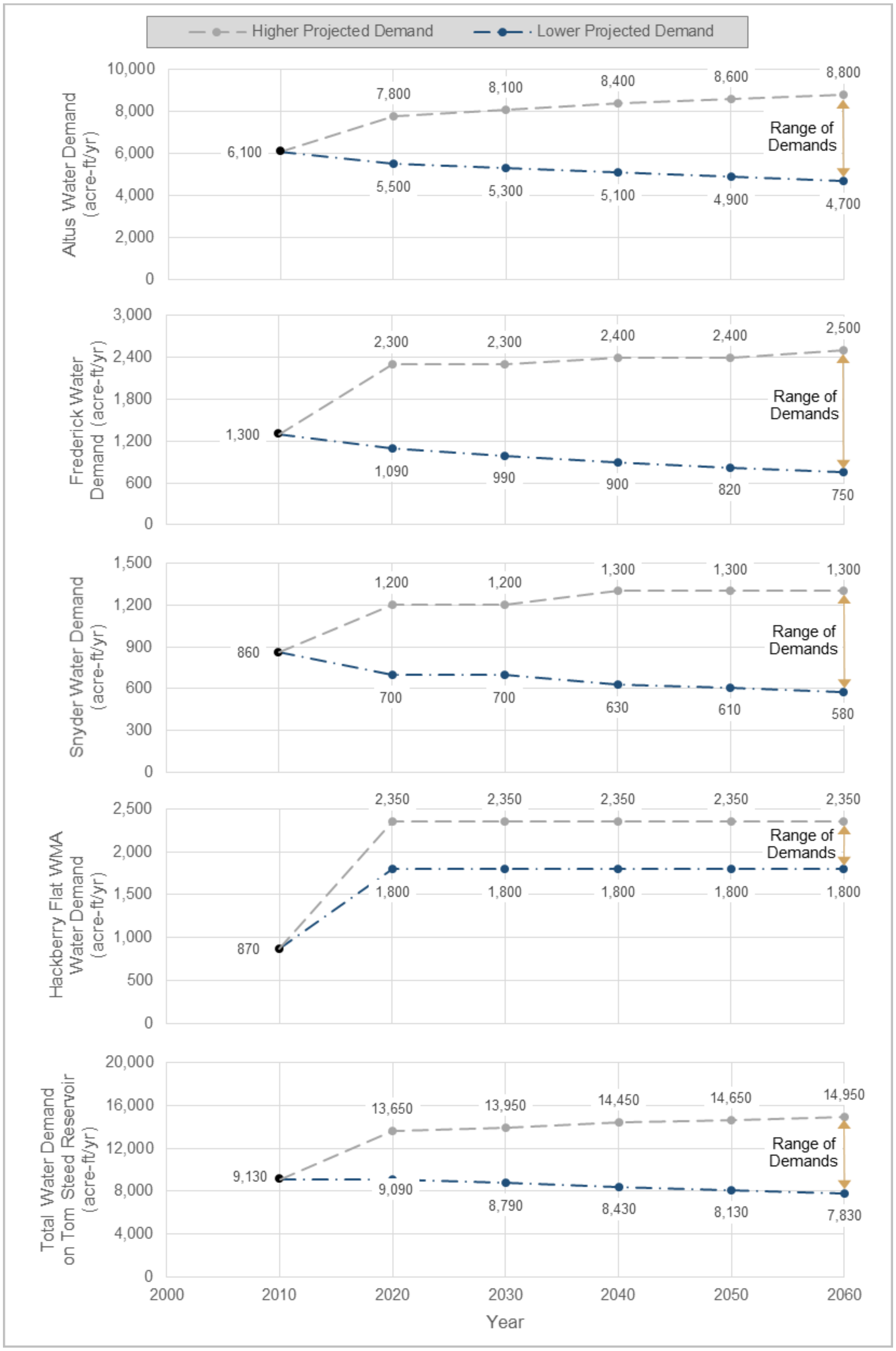

Figure 5-68. Range of projected water demands on Tom Steed Reservoir, including both M&I demands from the service areas of Altus, Frederick, and Snyder, as well as EQ demands from Hackberry Flat WMA.

M&I Demand Uncertainties

It is important to acknowledge the uncertainty and assumptions that are built into the water demand projections cited above. We calculated a range of future demands, such that higher demands assumed peak GPCD use estimates (by a greater population size) and lower demands assumed average GPCD use estimates (by a lower population size). What we did not take into account when making assumptions on future water use were other factors, including but not limited to: (1) the level of drought contingency planning and potential staging of water use restrictions; (2) the extent to which water losses occur and/or could be reduced through improved technologies and infrastructure that better account for water use and leak detection and improve the efficiency of treatment, conveyance, and storage of water; (3) the extent to which mandates or incentives are put in place involving the installation of high water efficiency fixtures in residential or commercial developments; (4) whether or not volumetric pricing (i.e., conservation-based rate structure) has been put in place that increases water rates based on volume used; and (5) the level of public education about water use and conservation. The rationale for not taking these factors into account is that they are largely influenced at the local level; and considering the large number of local entities that depend on Tom Steed Reservoir, it was beyond the scope of this Basin Study to make assumptions and assess the extent to which these factors may affect future water demands on the reservoir. The point here is to acknowledge the fact that these and other factors build uncertainty into the water use estimates that form the basis of the 2060 demand projections on Tom Steed Reservoir.

Regarding the role of water conservation, it should be acknowledged that the average water use projections for 2010-2018 cited above encompass the 2010s Drought of Record, meaning that the water use estimates included in the future GPCD use projections already account for reductions that could be implemented during future critical drought periods. Recall that the MPMCD’s water right is 16,100 acre-ft/yr, of which 13,748 acre-ft/yr (85.39 percent) is allocated to M&I and 2,352 acre-ft/yr (14.61 percent) is allocated to EQ benefits. During the 2010s

Drought of Record, outdoor watering restrictions alone by the three member cities reduced M&I use by 42 percent from 9,500 acre-ft/yr to 5,500 acre-ft/yr. Given these reductions, the previously-calculated average GPCD rate of 175, 123, and 126 for the cities of Altus, Frederick, and Snyder, respectively, likely provides a reasonable estimate on the impact of potential future outdoor watering restrictions on water use.

In forecasting M&I demands on Tom Steed Reservoir, consideration also must be given towards the availability of alternative, supplemental supplies. Although Tom Steed Reservoir provides most of the surface water to area customers, other sources are available – such as through existing interconnects among customers; the city of Frederick's 3,400 acre-ft right to water stored in Frederick Lake; and groundwater from minor aquifers. These alternative sources may not be considered reliable, drought-proof supplies but the extent to which they could impact demands on Tom Steed Reservoir cannot be quantified.

EQ Demand and Uncertainties

The demand projections on Tom Steed Reservoir that are cited above also include two key assumptions: (1) 2,352 acre-ft/yr remains fully allocated for EQ benefits pursuant to the Mountain Park Project Act of 1994; and (2) the EQ benefit is achieved[125]. Recall the discussion on EQ demands described in Chapter 2.3.2. While EQ water has made restoration of the Hackberry Flat WMA a tremendous success both in terms of fish and wildlife propagation, public education, and wildlife viewing, hunting, and other outdoor opportunities, some have argued that Hackberry Flat WMA may not need 2,352 acre-ft/yr of water during years where the timing and amount of rainfall is sufficient to optimize wetland performance. Moreover, the infrastructure to deliver water to Hackberry Flat WMA has recently come into question, prompting ongoing investigations to assess the viability and optimization of infrastructure needed to regulate, convey,

[125] This also assumes sufficient water availability to achieve the EQ benefits. Recall the "shared shortage" discussion in Chapter 2.3.2 citing the contract provision stating that all participating entities shall, "share in the available water supply in the ratio of their contract rights during periods of scarcity when rationing is in the opinion of the MPMCD required".

and measure water deliveries to Hackberry Flat WMA. A key challenge remains in determining whether a threshold, and timing thereof, should exist by which to determine whether the EQ purpose has been met at Hackberry Flat WMA. If Hackberry Flat WMA cannot provide the full EQ benefit, then consideration should be given towards reallocating all or a portion of the EQ benefit for M&I purposes. This is discussed in more detail in Chapter 7.3.6 and Chapter 8.3.6.

5.5. Future Basin-Wide Supplies

Chapter 5.4, presented scenarios representing a range of future demand pressures that may be placed on future groundwater and surface water supplies in the URRBS area. The impacts those demand scenarios have on future basin-wide water supplies is discussed next. It is worth noting again that one of the key underlying assumptions used to develop demand scenarios was that the future is constrained by existing Oklahoma water law (i.e., no changes in Oklahoma water law). Quantifying future supplies is complicated because it requires the development of models that can account for multiple physical and hydrological variables, quantify gains and losses, and simulate supplies in their naturalized state. One can then test how reliable future supplies are in meeting future demands. As well, one can attribute the extent to which natural and/or human-induced factors influence water supply reliability. Because future water supplies and system reliability are so intertwined, the discussion of future supplies is included the next chapter, Chapter 6: Future Supplies, System Reliability, and Status-Quo Impact Assessment.

Chapter 6. Future Supplies, System Reliability, and Status-Quo Impact Assessment

In this chapter, the impacts of groundwater and surface water demand scenarios on future basin-wide water supplies were evaluated under future "status-quo" conditions. Status-quo development assumed that current the OWRB water management practices would continue into the future or that reasonably foreseeable changes in the OWRB practices could occur within existing Oklahoma water law. First, the assumptions that underly how status quo was defined are discussed in detail. Next, the groundwater and surface water models used to simulate the demand-supply system are discussed, as well as the performance metrics selected to evaluate the reliability of water supplies in meeting future demands. In doing so, one can attribute the extent to which natural and/or human-induced factors influence supply reliability; and in turn, this informs the formulation of adaptation strategies that aim to address potential imbalances under status quo. 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.

6.1. Status-Quo Conditions

The fundamental assumption underlying the development of demand scenarios for this study was that the future is constrained by existing Oklahoma water law and current the OWRB regulations and water policy, except as specifically noted in the following sections. In Chapter 5.4, a range of future permitting and development scenarios were discussed; these range from no development under a "naturalized system" to full development of both groundwater and surface water. Below is a description of the key assumptions and relevant the OWRB statutory rules used to guide development of status quo.

6.1.1. Groundwater Status Quo

The appropriation of groundwater is covered under OAC 785:30-9-2, Appropriation of Groundwater. Under status quo, the assumption was that the OWRB continues to permit groundwater under current practice, which is to issue permits out of the NFRR and Elk City aquifers in accordance with the aquifer's MAY and corresponding EPS pumping rates. In other words, status quo assumed Oklahoma law would not allow the OWRB to reduce a landowner's existing EPS if new data result in a lower aquifer MAY or demonstrate adverse impacts on a connecting stream. As discussed in Chapter 2.5.6, this rule states that after completing a hydrologic survey of an aquifer, the OWRB must make a determination of each major aquifer's MAY based on, among other things, the overlying land area, aquifer storage, aquifer recharge, and aquifer transmissivity. The rule goes on to state that the MAY of each groundwater basin or subbasin shall be based upon a minimum basin or subbasin life of 20 years from the order establishing the final determination of the maximum annual yield. Status quo assumed the current OWRB practice, which is to consider a 20-yr, 40-yr, and a 50-yr life of the aquifer. The MAY was then divided up equally across all land acres overlying the aquifer on an acre-ft per acre basis. Thus, each acre had its own EPS of the MAY of the aquifer. In other words, if each and every acre overlying the aquifer was to experience a withdrawal of a 20-, 40-, or 50-yr EPS, then the aquifer would be fully depleted, albeit with a portion of the aquifer's saturated thickness reserved for domestic use. The only difference is how long it takes for the aquifer to be depleted. Figure 2-57 in Chapter 2.5.6 provides a conceptual illustration of the EPS.

Another condition defining status quo relates to the connectedness of groundwater with stream water. Under Oklahoma law, the OWRB must take into account certain factors in making the MAY determination. One factor is "the rate of recharge to the basin or subbasin and *total discharge from the basis or subbasin*." Given the hydrological interconnectedness between the NFRR aquifer and the NFRR, the OWRB may have (unrecognized) authority to conjunctively manage the two systems (Kershen, 2021)[126]. This is reflected in the modeling approach, which takes into account the impacts of groundwater pumping on stream water. This is the only groundwater status-quo assumption which deviates from current the OWRB practice, and it was necessary in this technical study because the groundwater and surface water are in fact hydraulically connected and cannot be accurately modeled if that hydraulic connection is ignored. As discussed in Chapter 6.2, 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.

It is important to note that although status quo assumed the OWRB would continue to permit groundwater out of the NFRR and Elk City aquifers in accordance with its MAY and EPS, this does not mean that these aquifers would be fully permitted (developed) within the year 2060 planning horizon covered by the URRBS. For this reason, in addition to the fully developed aquifer scenario, status quo assumed two other groundwater development scenarios for the NFRR aquifer. The first assumed aquifer pumping rates were limited to only historic reported use from existing permits, whereas the second assumed aquifer pumping rates increased by an amount proportionate to projected population growth through the year 2060. These scenarios were discussed in Chapter 5.4 and are discussed again in this chapter below.

[126] To be clear, OWRB does not have a legal mandate or statutory authority to manage groundwater and stream-water conjunctively, and as such, stream-water law and groundwater law in Oklahoma are viewed and managed accordingly as separate, independent water law systems (Kershen, 2021).

6.1.2. Surface Water Status Quo

The appropriation of stream water is covered by OAC 785:20-5-4, Appropriation of Stream Water, and 785:20-5-5, Board Determination and Approval of Application. OAC 785:20-5-4 states, among other things, that the OWRB can approve a new permit for stream water if: (1) unappropriated water is available…as set forth in 785:20-5-5; and (2) the proposed use does not interfere with domestic or existing appropriative uses. As discussed in Chapter 2.5.6, the OWRB uses an ArcGIS-based model to calculate water availability for permitting. In its calculation, current OWRB practice is to use average annual run-off between 1951-1980 as the baseline flow regime from which it calculates permit water availability. From this baseline flow regime, the OWRB subtracts the proposed regular permit volume from upstream and downstream uses (e.g., volume of existing and pending permits; dependable yield of upstream reservoirs less permits; and domestic uses) to determine if water is available for the new permit. Importantly, under status quo, if water is found to be available by the OWRB, then according to OAC 785:20-5-5, interference against senior permit holders would *not* be anticipated. In this case, a regular permit may be recommended by the OWRB. If water is not found to be available, then interference would be anticipated, and the stream permit may not be issued by the OWRB. The reason this is important is because under status-quo management, junior permit holders could continue to divert stream water as it is available regardless of whether stream-water permit shortages existed or how low downstream reservoir levels dropped during a drought[127].

Another important consideration in OAC 785:20-5-5 that is relevant to status quo is the provision which states that the OWRB may consider "*other evidence"* or laws relating to stream flow or elevation when performing a calculation on water availability for appropriation. In effect, this provision provides the OWRB with the authority to exercise discretion in determining the

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[127] This assumption has important implications on modeling withdrawals of existing stream-water permits under status quo, which is discussed in Chapter 6.2.2.

amount water available for appropriation to a regular permit. The OWRB currently uses average annual run-off between 1951 and 1980 when determining the amount of water available for appropriation, but could use any number of alternative flow regimes such as an updated run-off flow record that extends through present day. Because this URRBS has made available a naturalized flow regime through the year 2016, the study team selected this extended (i.e., 1951-2016) naturalized flow regime as the best available data from which to base the water availability calculations and the status-quo modeling. This is reflected in the stream-water development scenarios described in Chapter 6.2.2.

Another defining characteristic of status-quo stream-water conditions relates to domestic use. Under Oklahoma law, the OWRB is required to protect riparian domestic uses of stream water. In doing so, the OWRB assumes a domestic riparian diversion on every quarter section of land downstream from the applicant's point of diversion to the confluence with the next larger stream. As the domestic riparian right is six acre-ft/yr, the OWRB already recognizes a significant protection of instream flow on many streams, including the NFRR, Elk Creek, and West Otter and Glen Creeks, in its calculation of stream water availability for appropriation. This is reflected in the fact that four of the eight stream-water use scenarios considered future domestic use. These scenarios were discussed in Chapter 5.4 and are discussed again in this chapter below.

6.2. Modeling Objectives and Methods

A "model" is simply a mathematical tool that provides a representation of hydrology and water use that can be used to make predictions about the real world. For the outcome to be meaningful to water resource managers, it must be measurable/quantifiable, and it must be based on sufficient data collected based on sound scientific practices that are replicable and defensible. As well, it must exist within an existing or reasonably foreseeable legal, institutional, and regulatory framework.

Modeling Objectives

The modeling objectives of the URRBS were as follows:

- Understand the major physical and hydrological characteristics of the NFRR aquifer, the NFRR stream water system, and Lugert-Altus and Tom Steed reservoirs, including the associated water budgets (gains and losses).
- Understand how the groundwater and stream water systems interact and function together in a "naturalized" state without the influence of reservoir construction and human development. This includes determining the contributions of groundwater from the NFRR aquifer towards base flows of the NFRR.
- Determine impacts from status-quo groundwater pumping scenarios (i.e., constrained by existing Oklahoma law, regulations, and/or policy) on groundwater storage in the NFRR aquifer and aquifer saturated thickness, including the calculation of an EPS pumping rate and corresponding MAY in accordance with Oklahoma law. It is important to note that the MAY is defined as the amount of groundwater that can be withdrawn annually while ensuring a minimum 20-yr life of the groundwater basin. When a MAY has been established, the amount of land owned or leased by a permit applicant determines the annual volume of water allocated to that permit applicant. The annual volume of water allocated per acre of land is known as the EPS pumping rate. For alluvium and terrace aquifers such as the NFRR aquifer, the groundwater-basin-life requirement is satisfied if, after 20 years of MAY withdrawals, 50 percent of the groundwater basin retains a saturated thickness of at least 5 ft.
- Quantify how changes in NFRR aquifer storage and saturated thickness under various groundwater pumping scenarios impact base flows of the NFRR.
- Quantify how existing and future stream-water permits within the NFRR under status-quo management by the OWRB, combined with changes in base

flow under various status-quo groundwater pumping scenarios, impact the yield and dependability of Lugert-Altus and Tom Steed reservoirs, as well as the dependability of stream-water permits in the NFRR, Elk Creek, and West Otter and Glen Creek drainage basins.

Modeling Approach

Groundwater and surface water models that were developed as part of the URRBS were used to evaluate impacts of demand scenarios under status-quo management. Each model played an important role in the analysis, with each model's outputs contributing to subsequent model inputs. As discussed in more detail below, 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 6-1).

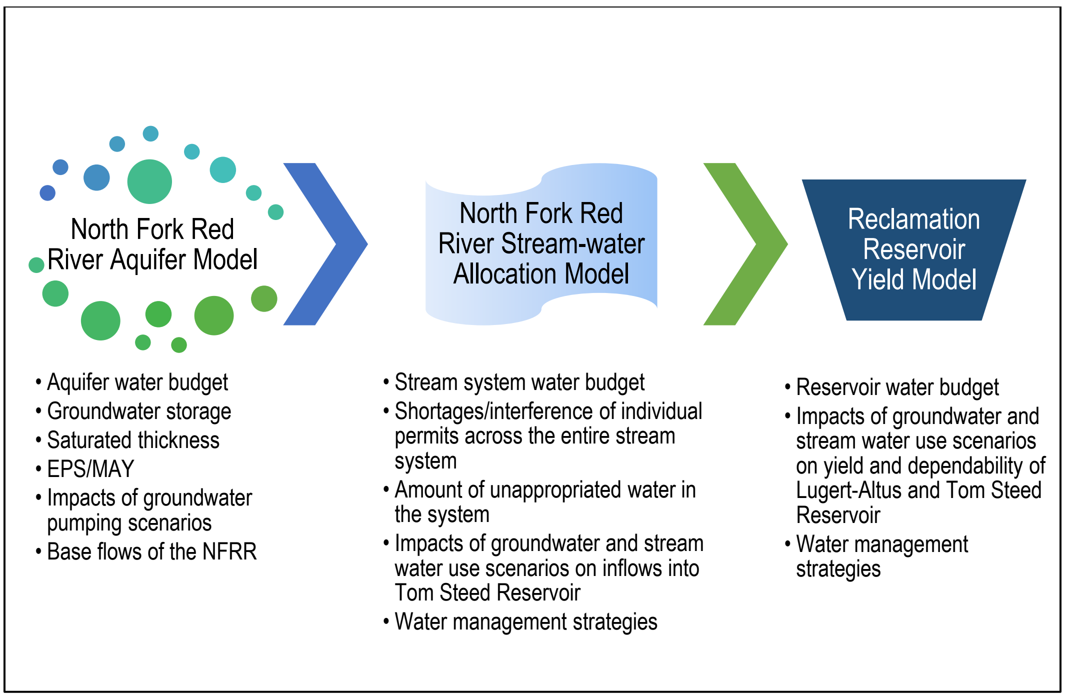

Figure 6-1. Key components of and relationship between the North Fork Red River aquifer model, North Fork Red River Stream-water Allocation Model, and the Reclamation Reservoir Yield Models.

6.2.1. Groundwater Modeling Methods

NFRR Aquifer Model Overview

Details on the NFRR aquifer model can be found in USGS SIR 2017-5098 [(Smith et al., 2017) (Appendix B)]. Development of the model entailed multiple steps, beginning with a hydrogeologic framework of the aquifer extent and potentiometric surface, as well as a description of the textural and hydraulic properties of aquifer materials. Next, a conceptual model budget was developed to constrain the construction and calibration of a numerical groundwater-flow model (numerical model). The numerical model of the NFRR aquifer was constructed by USGS using MODFLOW-2005 (Harbaugh, 2005). The model water budget was comprised of inputs to and outputs from the NFRR aquifer for the period 1980–2013, and included variables such as recharge, streambed seepage, groundwater storage, saturated thickness, well withdrawals, groundwater flow, etc. The model was calibrated based on real-world observations of water table levels, base flow, and reservoir storage elevations. For the URRBS, the primary objectives of the NFRR aquifer model were as follows:

1. Develop a hydrogeological framework based on physical and hydrogeological characteristics of the aquifer.
2. Develop an aquifer water budget, including inputs (e.g., aquifer recharge) and outputs (e.g., base flows into the NFRR).
3. Estimate aquifer storage and saturated thickness (a.k.a, thickness of the water table).
4. Calculate the EPS pumping rates and corresponding MAYs that guarantee a minimum 20-, 40-, and 50-yr life of the aquifer in accordance with Oklahoma law.
5. Simulate changes in aquifer storage and saturated thickness, as well as changes in NFRR base flows following 50 years of groundwater withdrawals under various groundwater management scenarios.

As previously stated, development of a numerical model on the Elk City aquifer was considered beyond the scope of the URRBS; therefore, unlike the

NFRR aquifer, a comprehensive analysis of groundwater pumping scenarios on the Elk City aquifer was not performed.

Groundwater Demand Scenarios and Modeling Assumptions

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[128]. 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-yr EPS[129].

Provisional Temporary Groundwater Permits

The groundwater withdrawal scenarios described above focused on "regular" groundwater permits. Concern has been raised by some stakeholders about the impacts of PT permits, namely related to the flexibility and discretion

[128] The impact of potential changing climate conditions on supplies are addressed in Chapter 9.1.
[129] The MAY and EPS results are provided in Chapter 6.

afforded to the OWRB in issuing PT permits without consideration of the aquifer's MAY and EPS. It is important to note that the observed hydrologic record used in the NFRR aquifer model included losses associated with historic domestic uses, as well as losses associated with previously-issued groundwater PT permits. Therefore, all three use scenarios that were modeled, by default, already accounted for potential base flow reductions that may have been caused in part by groundwater PT permits and domestic use; however, the actual base flow reductions attributable to these uses could not be quantified. For reference purposes, during the drought of record, 43 groundwater 90-day PTs were issued in the NFRR aquifer totaling 2,253 acre-ft (i.e., average of 451 acre-ft annually). Figure 6-2 below presents a comparison of the volume of PTs relative to regular permits under the "Existing" scenario.

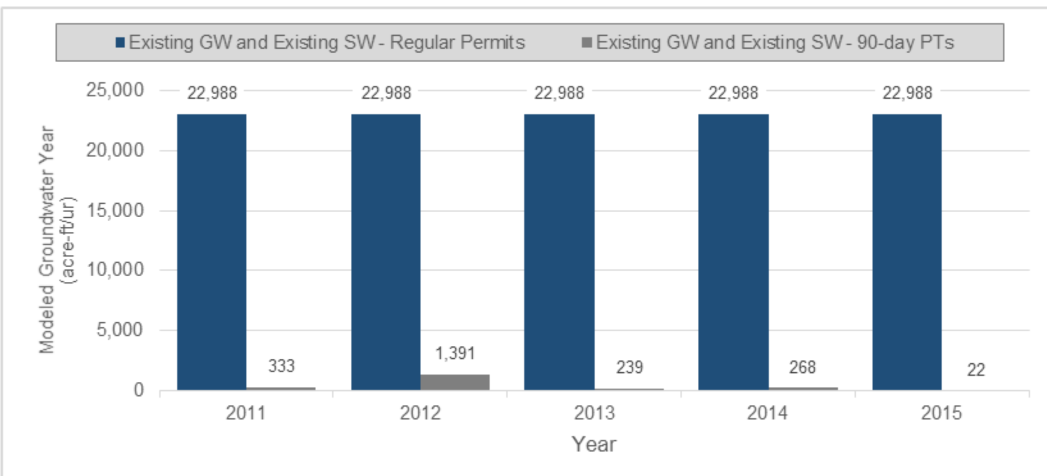

Figure 6-2. A comparison of regular groundwater permits versus 90-day groundwater PTs in the NFRR aquifer during the drought of record under the "Existing" use scenario.

6.2.2. Surface Water Modeling Methods

NFRR Stream Water Allocation Model (SWAM) Overview

Details on the NFRR SWAM can be found in the NFRR System Model Summary Report [(North Fork of the Red River System, Model Naturalization Update as prepared by Lynker Technologies, 2022; Appendix C)], which was prepared for and contracted by the OWRB. This report describes development of the NFRR water budget, including the naturalization process, using a period of record from Jan 1950 to Dec 2016. Also included are descriptions of data sources, spatial domains, development of the model network, inputs, operating rules, modeling scenarios, and model verification. For the URRBS, the primary objectives of the NFRR SWAM were as follows:

1. Develop a NFRR water budget using naturalized flows that are developed by adding evaporative losses, stream withdrawals (i.e., reported water use), changes in reservoir storage, and other losses back into the observed streamflow record.
2. Simulate the NFRR in its naturalized state and evaluate how changes in base flows (as calculated by the NFRR aquifer model) affect streamflow under a range of groundwater withdrawal scenarios.
3. Evaluate water availability based on historical, existing, and future stream-water use conditions and operating rules.
4. Evaluate impacts of groundwater and stream-water use scenarios on inflows into Lugert-Altus and Tom Steed reservoirs, as well as storage and reservoir permit availability under different physical and operational conditions.
5. Evaluate the extent to which water rights are satisfied under various groundwater and stream-water development scenarios, including a range of potential future domestic use of stream water.
6. Evaluate the impact of water management strategies on stream flow, availability of existing and future stream-water permits, and reservoir storage and permit availability in the Lugert-Altus and Tom Steed Reservoir hydrologic basins.

Stream-water demand Scenarios and Modeling Assumptions

Stream-water demand scenarios were first introduced in Chapter 5.4.2 and are discussed here in more detail. In the Lugert-Altus Reservoir hydrologic basin, eight development scenarios were evaluated, and in the Tom Steed Reservoir hydrologic basin, twenty-four scenarios were evaluated. Additional demand scenarios were developed in the Tom Steed Reservoir hydrologic basin for two reasons.

First, the full permitted water to Tom Steed Reservoir is not currently being utilized by MPMCD. Therefore, three reservoir demand (use) scenarios were developed for Tom Steed Reservoir: (1) an "Existing" reservoir use scenario that assumed that MPMCD would utilize 12,700 acre-ft/yr, which was the maximum volume of water that has ever been reported by MPMCD to the OWRB as being used out of Tom Steed Reservoir in a given year[130]; (2) a "Mid" projected use scenario that assumed that MPMCD would utilize 14,400 acre-ft/yr, which is the mid-point between "Existing" and "Full"; and (3) a "Full" permitted use scenario that assumed that MPMCD would utilize 16,100 acre-ft/yr, which is the full volume permitted to Tom Steed Reservoir.

Second, when using the naturalized flow record to calculate the potential for new future stream permits, results in Chapter 6.4.3 will show in that zero water is available for the appropriation of new stream permits in the Lugert-Altus Reservoir hydrologic basin; whereas, in the Tom Steed Reservoir hydrologic basin, results in Chapter 6.4.4 will show that there is plenty of potential water available to appropriate new future stream permits. Given the potential availability of water for new stream permits in the Tom Steed Reservoir hydrologic basin, three new stream permitting scenarios were evaluated in that basin: "Low", "High", and "Full". The "Full" permit scenario assumed that all average annual naturalized flows (1950 to 2016), minus existing permits and assumed domestic uses, would be permitted and diverted from the NFRR. The "Low" and "High" stream permit scenarios assumed two different mid-point

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[130] According to OWRB records, the year of maximum reported use by MPMCD was 2006.

volumes between the existing permitted volume and the "Full" stream permit volume would be permitted and diverted from the NFRR. The "Low" scenario assumed an additional 2,500 acre-ft/yr of new stream permits would be issued, and the "High" scenario assumed an additional 5,000 acre-ft/yr of new stream permits would be issued.

With the exception of existing domestic uses which cannot be quantified, all future demands were removed from the naturalized streamflows calculated using the NFRR SWAM. Four key points are noted here in terms of methods and assumptions that went into the NFRR SWAM.

First, groundwater pumping was considered senior to stream-water diversions, so base flow reductions to the stream resulting from modeled groundwater pumping were removed from the stream as a demand prior to the modeled withdrawal of stream-water demands.

Second, modeled stream-water demands were not prioritized based on permit seniority (i.e., first in time, first in right); rather, they were removed from the stream going from upstream to downstream on a first-come, first-serve basis.

Third, except for the naturalized condition, all stream-water demand scenarios assumed full use of existing regular stream-water permits. In the Lugert-Altus Reservoir hydrologic basin, existing permits totaled 1,422 acre-ft/yr, all of which were junior to Lugert-Altus Irrigation District and the city of Altus (Table 6-1). In the Tom Steed Reservoir hydrologic basin, existing permits totaled 6,649 acre-ft/yr, 1,933 acre-ft/yr of which were considered senior to the MPMCD's permit[131], and 4,716 acre-ft/yr are junior to the MPMCD's permit (Table 6-2). Existing permits were modeled by the NFRR SWAM such that only consumptive demands, based on annual reported use volumes submitted by permit holders to the OWRB, were removed from the stream, and non-consumptive demands remain in the system as return flows. These volumes are presented in

[131] A formal adjudication and final order of vested stream-water rights has not been performed in the Tom Steed Reservoir hydrologic basin since 1964. The volume of permits that are senior to MPMCD's permit may be subject to change. This is discussed more in Chapter 8.3.1.

Table 6-1 and Table 6-2, along with the corresponding permit date, location, and type within both hydrologic basins.

Table 6-1. Regular stream-water permits within the Lugert-Altus Reservoir hydrologic basin, including modeled consumptive demand volume of junior and senior stream-water permit holders.

Location	Permit Number	Permit Owner	Permit Type	Permits Junior to the city of Altus and the Lugert-Altus ID[a]		Permits Senior to the City of Altus and the Lugert-Altus ID[b]	
				Permitted Volume (acre-ft/yr)	Modeled Consumptive Demand (acre-ft/yr)	Permitted Volume (acre-ft/yr)	Modeled Consumptive Demand (acre-ft/yr)
Upstream of Reservoir	19470003	Private	Irrigation	84	61	-	-
	19600140	Private	Recreation, Fish, and Wildlife	150	120	-	-
	19620010	Private	Irrigation	110	78	-	-
	19660220	Private	Irrigation	53	39	-	-
	20020003	Private	Irrigation	442.5	313	-	-
	19950037A	Private	Irrigation	80	58	-	-
	19740253	Private	Irrigation	11	9	-	-
			Total	***930.5***	***678***	***0***	***0***
Reservoir	19260006	City of Altus	M&I	4,800	4,800	4,800	4,800
	19390023	Lugert-Altus ID	Irrigation	85,630	85,630	85,630	85,630
Downstream of Reservoir	19900029	Private	Irrigation	100	73	-	-
	19850022C	Private	Irrigation	56.5	42	-	-
	19650245	Private	Irrigation	15	13	-	-
	20060062	Private	Irrigation	320	226	-	-
			Total	***491.5***	***354***	***0***	***0***

[a] "Junior" is defined as having an application date later than both the City of Altus and Lugert-Altus Irrigation District.
[b] "Senior" is defined as having an application date earlier than both the City of Altus and Lugert-Altus Irrigation District.

Table 6-2. Regular stream-water permits within the Tom Steed Reservoir hydrologic basin, including modeled consumptive demand volume of junior and senior stream-water permit holders.

Location	Permit Number	Permit Owner	Permit Type	Permits Junior to MPMCD[a] Permitted Volume (acre-ft/yr)	Permits Junior to MPMCD[a] Modeled Consumptive Demand (acre-ft/yr)	Permits Senior to MPMCD[b] Permitted Volume (acre-ft/yr)	Permits Senior to MPMCD[b] Modeled Consumptive Demand (acre-ft/yr)
Upstream of Reservoir	19650249	Private	Recreation, Fish, and Wildlife	-	-	800	600
	19550353	Private	Irrigation	-	-	7.5	7
	19600053	Private	Irrigation	-	-	108	77
	20030029	Private	Irrigation	100	73	-	-
	19740306	Private	Irrigation	20	16	-	-
	19641018	Private	Irrigation	-	-	160	113
	20060043	Private	Irrigation	1,470	1,031	-	-
	19320051	Public	M&I	-	-	631	321
	19650553	Private	Irrigation	-	-	149	106
	19970006	Public	M&I	1,100	558	-	-
	19820113	Public	Recreation, Fish, and Wildlife	10	10	-	-
			Total	***2,700***	***1,688***	***1,856***	***1,224***
Reservoir	19670671	MPMCD	M&I	16,100	16,100	16,100	16,100
Downstream of Reservoir	19970010	Private	Irrigation	297	210	-	-
	19980025	Private	Irrigation	1,338	939	-	-
	20060062	Private	Irrigation	320	226	-	-
	19520414	Private	Irrigation	-	-	77	55
	19960036	Private	Recreation, Fish, and Wildlife	15	12	-	-
	20090008	Private	Irrigation	46	34	-	-
			Total	***2,016***	***1,421***	***77***	***55***

[a] "Junior" is defined as having an application date later than the Mountain Park Master Conservancy District.
[b] "Senior" is defined as having an application date earlier than the Mountain Park Master Conservancy District.

Fourth, stream-water development scenarios considered historical/existing domestic stream-water use and a range of future new domestic stream-water use, as well as the appropriation of new regular stream-water permits. Future New domestic uses were considered senior to both existing and new stream-water permits. New stream-water permits, if applicable, were considered junior to existing stream-water permits. In summary, water demands were removed from the naturalized flow regime in order of priority as follows: (1) permitted groundwater use; (2) new domestic stream-water use, if applicable; (3) existing permitted stream-water use; and (4) future permitted stream-water use, if applicable.

The methods for calculating future domestic and stream-water use are discussed below. The legal and regulatory basis for these assumptions is described in 6.1.2. Assumptions and uncertainties are described in Chapter 5.4.2. For the purposes here, it is worth stating again that the assumed domestic and permit availability values that were calculated were for planning purposes only and do not represent the actual quantity of water available for domestic and/or permitted use, nor do they represent a position by the OWRB regarding how determinations of stream water availability for appropriation are made.

Calculating New Domestic Use

Recall that all seven stream-water use scenarios (excluding the naturalized condition) include historical/existing domestic use, and although this historical domestic use could not be quantified due to lack of metered data, it is already accounted for in the USGS streamgage data that were used to derive all streamflow calculations. Four of the eight stream-water use scenarios also considered estimates for new domestic use beyond what might have been observed historically. In these scenarios, new domestic uses were considered by the NFRR SWAM to be senior to all permitted stream-water diversions, both existing and new (if applicable), and thus were subtracted from naturalized flows prior to subtraction of permitted diversions.

Both a "high" and "low" domestic reserve assumption was identified to account for variations in potential new domestic use. The "high" domestic reserve estimate was based on the calculation the OWRB currently employs when determining water availability for appropriation of new stream-water permits. Specifically, when making that determination, the OWRB typically reserves six acre-ft per acre per year to each of four assumed domestic users within each square mile of the hydrologic basin watershed area upstream of a proposed stream permit. For the Lugert-Altus Reservoir hydrologic basin, the NFRR watershed area (in Oklahoma) upstream of the two permits for Lugert-Altus Reservoir totals about 860 square miles. Based on this area, the volume of future stream water reserved for domestic use under the OWRB current practice was calculated to be about 20,000 acre-ft/yr for "high" use. For the Tom Steed Reservoir hydrologic basin, the area of the Elk Creek and West Otter-Glen Creek watersheds totals about 670 square miles, which under the OWRB current practice would bring the volume of future stream water reserved for domestic use to about 16,000 acre-ft/yr for "high" domestic use, although this was rounded to 15,000 acre-ft/yr for the sake of simplicity. Finally, given the relative size of the two watersheds contributing to Tom Steed Reservoir, about 80 percent of the 15,000 acre-ft/yr domestic reserve was distributed to Elk Creek, and 20 percent was distributed to West Otter and Glen Creeks. The "low" domestic reserve estimate assumed future new domestic use would be less pronounced relative to that which has already occurred over the historical period. For both the Lugert-Altus and Tom Steed Reservoir hydrologic basins, the low estimate of future new domestic use was assumed to be 5,000 acre-ft/yr. Although there is no mathematical methodology supporting this estimate, study partners believed it to be a reasonable and conservative lower-end estimate of domestic growth through the year 2060.

Calculating New Future Stream-water permit Availability

Recall the formula described in Chapter 2.5.6 that the OWRB has typically employed to calculate stream-water permit availability. For the NFRR

SWAM, naturalized average annual flows between 1950-2016 were used as a baseline hydrology to determine future new stream-water permit availability in lieu of observed, average annual run-off between 1951-1980. The new formula also considered impacts on future base flow. Overall, water was considered available for future new stream-water permits if average annual naturalized flows exceeded the cumulative reductions in base flow, domestic use, and existing permits, including those for water stored in Lugert-Altus and Tom Steed reservoirs. In other words, the volume of naturalized flows that remained after all these existing and future uses have been removed was considered available for new stream-water permits. If future new stream-water permits were found to be available, then those 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 Lugert-Altus on the NFRR or above Tom Steed Reservoir, both above the Bretch Diversion on Elk Creek and on West-Otter and Glen Creeks[132].

Stream-water demand Scenarios

For clarity, the demand scenarios are listed again here as follows and are shown in Table 6-3 and Table 6-4 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[133] and no groundwater pumping.

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[132] Seventy-five percent of the new permits were distributed on Elk Creek above the Bretch Diversion and 25 percent were distributed to West Otter-Glen Creeks, which is the approximate proportionate distribution of inflows into Tom Steed Reservoir.

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

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.

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-yr EPS[134]; 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-yr 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[135]. 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-yr 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[136].

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[134] EPS and MAY results are provided in Chapter 6.

[135] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.2

[136] Results regarding availability of new stream-water permits are provided in Chapter 6.2.2. 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.

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-yr 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[111]. 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-yr 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.

Table 6-3. 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
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)

Tom Steed Reservoir Hydrologic Basin

1. "***Naturalized***": Assumes no diversions from existing or future stream-water permits[137] 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

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

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 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-yr EPS[138]; 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-yr 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[139]. Assumed no new stream permits would be issued.

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[138] EPS and MAY results are provided in Chapter 6.
[139] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3

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-yr 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[140].

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-yr 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[141]. 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-yr 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.

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[140] 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.

[141] The methods and assumptions supporting future domestic use estimates are provided in Chapter 6.2.3

Table 6-4. Summary of groundwater and stream-water modeling conditions for the Tom Steed Reservoir hydrologic basin.

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)

Provisional Temporary Stream-Water Permits

The observed hydrologic record used in the model includes losses associated with historic domestic uses, as well as losses associated with previously-issued stream-water PTs. Therefore, all three use scenarios, by default, already account for potential base flow reductions that may have been caused in part by stream-water PTs and domestic use; however, the actual base flow reductions attributable to these uses were not quantified. For reference purposes, during the drought of record, 51 stream-water 90-day PTs were issued in the NFRR upstream of Lugert-Altus Reservoir totaling 345 acre-ft (i.e., average of 69 acre-ft annually). Figure 6-3 below presents a comparison of the volume of the 51 PTs relative to regular permits under the "Existing Water Use" scenario. In the Elk Creek drainage area upstream of Tom Steed Reservoir, during the drought of record, seven stream-water 90-day PTs were issued totaling 43.5 acre-ft (i.e., average of nine acre-ft annually). Figure 6-4 below presents a comparison of the volume of the seven PTs relative to regular permits under the "Existing" scenario.

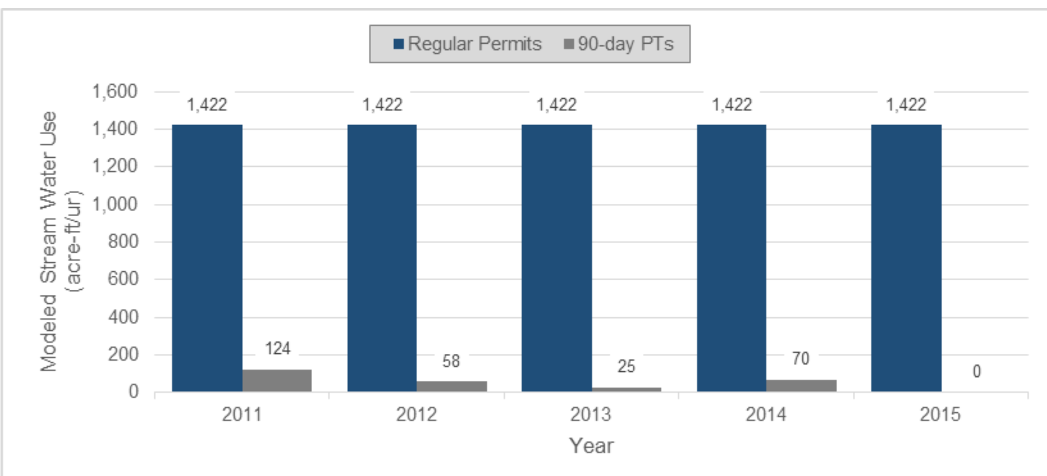

Figure 6-3. A comparison of the volume of regular stream-water permits versus 90-day stream-water PTs in the NFRR upstream of Lugert-Altus Reservoir during the drought of record.

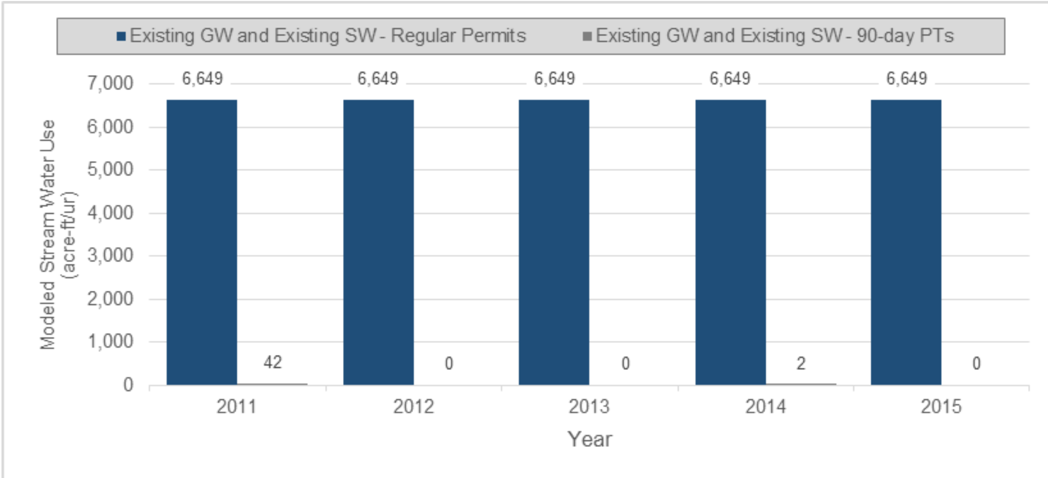

Figure 6-4. A comparison of the volume of regular stream-water permits versus 90-day stream-water PTs in the Elk Creek drainage area upstream of Tom Steed Reservoir during the drought of record.

Reclamation's Reservoir Yield (RRY) Model Overview

Details on the RRY model can be found in two technical memorandums (TMs) published by Reclamation in 2021 (Reclamation, 2021a and 2021b). One TM focuses on the RRY Model for Lugert-Altus Reservoir (Appendix D), and the other focuses on Tom Steed Reservoir (Appendix E). The RRY models develop a water budget for Lugert-Altus and Tom Steed reservoirs, including inputs (e.g., inflow, precipitation), outputs (e.g., evaporation and deliveries), and changes in storage due to sedimentation on a monthly time step between Jan 1926 and Dec 2016. For the URRBS, the primary objectives of the RRY models were as follows:

1. Simulate yield and dependability of Lugert-Altus and Tom Steed reservoirs under various inflow sequences (derived from the NFRR SWAM) and determine the extent to which water rights for Lugert-Altus and Tom Steed reservoirs are satisfied under various development scenarios.
2. Compliment the NFRR SWAM by evaluating the impact of water management strategies on the yield and dependability of Lugert-Altus and Tom Steed reservoirs, including the extent to which water rights for those reservoirs are satisfied under various development scenarios.

RRY Modeling Scenarios and Reservoir Operations

Stream-water permit conditions and use scenarios input into the two RRY models were the same as those previously described for the NFRR SWAM. One item that is particularly important and worth discussion here relates to operations of Lugert-Altus Reservoir. Lugert-Altus Reservoir operations are different than Tom Steed Reservoir. Unlike Tom Steed Reservoir, two rights for water are held for water stored in Lugert-Altus Reservoir, one for irrigation use that is held by Lugert-Altus ID and one for M&I use that is held by the city of Altus. The Lugert-Altus ID's irrigation water right is far greater than the M&I water right for the city of Altus, making irrigation a primary benefit of Lugert-Altus Reservoir; but the M&I water right is senior to Lugert-Altus ID's irrigation water right. The implications of this are two-fold. First, it has a significant impact on reservoir operations because the Lugert-Altus ID operates its system in a way that does not interfere with the senior M&I water right for the city of Altus. Second, the District must avoid interference while also trying to maximize supply reliability of agricultural irrigation deliveries. Given the importance of water supply reliability to farmers, having an understanding of the frequency distribution of water supply availability over the period of record becomes more important than focusing on the supply which is "firm" during a critical drought, such as in the case of M&I demands which encompass critical needs for public health and sanitation, health care, industry, manufacturing, etc. The analysis and results included in the URRBS reflect this reality.

As previously discussed throughout this report, the Lugert-Altus ID and city of Altus signed a settlement agreement in 1954 that requires the District to manage irrigation operations such that 10,000 acre-ft of water remains in storage at the end of the irrigation season to ensure that the 4,800 acre-ft can be delivered to the city of Altus the following year, if needed. This end-of-season provision aims to ensure that sufficient water in storage is available to deliver M&I water in the case that conditions are dry or become dry the following year. Specifically, the settlement agreement states that "…upon completion of any irrigation run and filling of the city reservoirs (lakes), there shall remain in the Altus Dam and Reservoir a minimum of 10,000 acre-ft of active storage"[142]. To "fill the city reservoirs (lakes)" with 4,800 acre-ft of M&I water, a total of 10,000 acre-ft in storage is needed. This is because 5,200 acre-ft/yr in "push" water is needed to create the necessary hydraulic head/pressure to convey the city of Altus' allotted water through the canal system[143]. In effect, Lugert-Altus ID operates to maintain 20,000 acre-ft in storage to ensure compliance with the settlement agreement, 10,000 acre-ft of which is allocated for the current irrigation year, with the other 10,000 acre-ft allocated for the following year. Furthermore, Lugert-Altus ID's current practice is to set aside an additional 9,450 acre-ft to account for

[142] 1954 Settlement Agreement, Lugert-Altus ID and city of Altus.
[143] The 5,200 acre-ft in push water is an assumption and calculated based on best professional management practices.

evaporative losses, bringing the total storage reserve to up to 29,450 acre-ft for each irrigation season. These losses are adjusted throughout the irrigation season (typically May to September) to reflect real-world climate conditions and storage volumes.

For the purposes of the reservoir yield analysis on Lugert-Altus Reservoir, when reservoir storage fell below the 29,450 acre-ft threshold, irrigation was discontinued. It should be noted that this threshold was used by Lugert-Altus ID under real-world conditions during the drought of record when inflow was low and evaporation rates were high. Therefore, this modeling assumption was considered to be conservative, yet defensible; however, it should be noted that the storage threshold needed to comply with the settlement agreement changes from year to year and within the irrigation season depending on real-world conditions.

With this operational reality in mind, an important step was evaluating when sufficient water is available for irrigation, and then evaluating historical deliveries to make assumptions on how to distribute irrigation deliveries over the model period. Based on the operational considerations cited above, water was considered available for irrigation only when modeled reservoir storage was above 29,450 acre-ft (the storage needed to protect the city of Altus' senior M&I water right). For the model simulation, when sufficient water was available for irrigation over the model period, irrigation deliveries were distributed monthly based on observed, average monthly irrigation deliveries during the irrigation season (May through September) between 1950 and 2016.

Another important operation rule built into the yield model centered on the 85,630 acre-ft/yr irrigation water right. The yield model simulated reservoir storage under the assumption that the Lugert-Altus ID would always deliver its full water right when supplies (i.e., storage and inflow) were available to do so. In years when sufficient supply was not available to deliver the full permitted volume of 85,630 acre-ft, the model solved for the maximum volume of water that could be delivered for irrigation while at the same time attempting to maintain the 29,450 acre-ft storage reserve at the end of the irrigation season (Figure 6-5). As illustrated in Figure 6-5, over the model period, during relatively drier periods, the reservoir did drop below 29,450 acre-ft, in which case irrigation deliveries ceased.

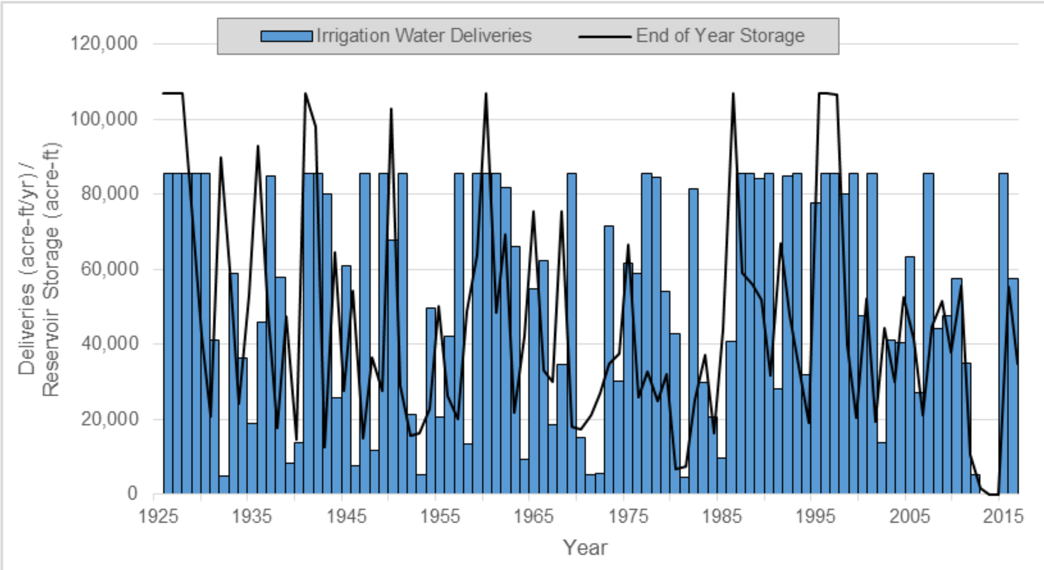

Figure 6-5. Modeled Lugert-Altus Reservoir storage and irrigation water deliveries up to the full permitted amount of 85,630 acre-ft/yr when available, 2060 sediment condition.

For Tom Steed Reservoir, two operation scenarios were evaluated: "firm yield" and "permit availability". Under the firm yield scenario, the model solved for maximum annual deliveries that could be made 100 percent of the time, including during the drought of record, without Tom Steed Reservoir going into the inactive pool. The maximum annual delivery volume is known as the "firm yield". Once this volume was known, it was delivered from the reservoir each and every year over the model period. In effect, this scenario assumed that the 1950s drought of record was imminent every time Tom Steed Reservoir drops below the top of conservation pool, and thus eliminates the potential for the reservoir to drop into the inactive pool. In the permit availability scenario, the availability of MPMCD's permit volume of 16,100 acre-ft/yr was evaluated. In this scenario, the model simulated the delivery of 16,100 acre-ft/yr or the maximum volume of water available if less than 16,100 acre-ft/yr. When 16,100 acre-ft/yr was not available (e.g., during the drought of record), the model solved for the lowest volume of permit water that was available during that time.

Two additional operational assumptions were included for Tom Steed Reservoir. First, it was assumed that during times of water scarcity MPMCD would comply with the "shared shortage" contract provision stipulating equitable reductions among each member city and Hackberry Flat WMA proportionate to each of their water contract allocations. Second, it was assumed that the operation of the Bretch Diversion would be optimized such that flows from Elk Creek would be diverted when available. The justification for making these assumptions can be found by recalling the operational challenges cited in Chapter 2.4.2.

NFRR SWAM and RRY Model Calibration

The purpose of the NFRR SWAM was to help the OWRB simulate allocation of water rights and to assess the impacts of new permits on water availability under a range of future hydrologic conditions, operations, and development scenarios. Water availability was calculated by the SWAM in terms of the magnitude and frequency of stream-water permit availability for the entire hydrologic basin, including the reservoir permit; however, the SWAM does not calculate reservoir firm yield. Reclamation's firm yield model, on the other hand, can calculate both permit availability and firm yield, but only at the reservoir. Given these differences in purpose and scope, the SWAM must account for multiple diversion/depletion points along the stream, and thus generally calculates reservoir storage and permit availability using streamgage data; however, the firm yield model must only account for one point in space (i.e., the reservoir), and thus calculates reservoir storage, permit availability, and firm yield using reservoir elevation levels and computed inflow.

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 items. Regarding Lugert-Altus Reservoir, consensus was made to utilize Lugert-Altus ID's operating rules that ensure compliance with the 1954 settlement agreement in the OWRB's SWAM modeling[144]. Consensus also was made on use of Reclamation's estimates of reservoir area capacity, net evaporation, seepage, and reservoir releases[145]. Regarding Tom Steed Reservoir, the Reclamation and OWRB came to a consensus to utilize both of the Elk Creek and West Otter Creek-Glen Creek inflow records derived by Reclamation as a baseline flow record into the NFRR SWAM's larger basin-wide water budget. For Elk Creek, similar to the RRY model, the NFRR SWAM calculated monthly inflow into Tom Steed Reservoir based on daily divertible flows at the Bretch Diversion. Reclamation and OWRB also came to consensus on incorporating Reclamation's assumptions related to Tom Steed Reservoir's area capacity curve, net evaporation, seepage, and releases to ensure that the NFRR SWAM simulated reservoir storage and permit availability under a similar set of assumptions as the Reclamation RRY models[146]. These assumptions were important in demonstrating the validity and consistency of reservoir storage and yield estimates calculated by the OWRB's SWAM as part of the URRBS. What is particularly relevant is that the baseline inflow dataset used by the NFRR SWAM to quantify inflow depletions was the same inflow dataset used by Reclamation in its own yield calculations performed by the RRY models. This means that depleted inflows can be simulated and compared to non-depleted inflows on an "apples to apples" basis using the RRY models. Furthermore, given that the OWRB and Reclamation models included the same set of assumptions for calculating permit availability, the NFRR SWAM's estimate of reservoir yield should be similar if not identical to the estimate made by Reclamation, although small deviations exist for some results between the two models. These estimates were validated during the calibration process.

[144] These operating rules are discussed extensively in the TM on Lugert-Altus Reservoir yield (Appendix C).
[145] The SWAM can adjust these variables as needed to accommodate conditions and scenarios deemed appropriate by the OWRB for its own planning purposes that may be beyond the scope of the URRBS.
[146] The SWAM can adjust these variables as needed to accommodate conditions and scenarios deemed appropriate by the OWRB for its own planning purposes that may be beyond the scope of the URRBS.

6.2.3. Summary of Model Integration to Evaluate Development Scenarios

The information discussed above is summarized into two tables that illustrate the integration of the models used to evaluate the naturalized condition along with seven groundwater and surface water development scenarios. Table 6-5 summarizes integration of the NFRR aquifer, NFRR SWAM, and RRY models to simulate inflow and water availability in the Lugert-Altus Reservoir hydrologic basin. Table 6-6 summarizes integration of the NFRR aquifer, NFRR SWAM, and RRY models to simulate inflow and water availability in the Tom Steed Reservoir hydrologic basin. Model outputs are illustrated in blue shading.

Table 6-5. Multiple scenarios, defined by groundwater and stream-water permit/use conditions, that were evaluated using the NFRR aquifer model, NFRR SWAM, and RRY model to simulate inflows and water availability in the Lugert-Altus Reservoir hydrologic basin.

Model (Use) Scenario	NFRR Aquifer Model		NFRR SWAM						Reservoir Yield Model		
	Groundwater Pumping Condition	Groundwater Permit Use (acre-ft/yr)	Base Flow Reduction Relative to Naturalized Condition (acre-ft/yr / Percent)	Existing Senior SW Permit Use[a] (acre-ft/yr)	Existing Junior SW Permit Use[b] (acre-ft/yr)	Modeled Future Domestic Use Upstream of Reservoir (acre-ft/yr)	Modeled New "Regular" Stream Water Permits (acre-ft/yr)	Water Availability (Amount and Frequency of Permit Shortages)	Inflow Sequence at the Reservoir	Average Annual Inflow (acre-ft/yr)	Lugert-Altus Reservoir Yield and Dependability
Naturalized	Naturalized	0	0 / 0%	Naturalized	Naturalized	0	0	-	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Existing GW Permits, Existing Domestic SW, Existing SW Permits	Existing	22,988	NFRR Aquifer Model Output	N/A (None Exist)	Existing (1,422)	0	0	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
New GW Permits, Existing Domestic SW, Existing SW Permits	New	27,678	NFRR Aquifer Model Output	N/A (None Exist)	Existing (1,422)	0	0	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	NFRR Aquifer Model Output	NFRR Aquifer Model Output	N/A (None Exist)	Existing (1,422)	0	0	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	NFRR Aquifer Model Output	NFRR Aquifer Model Output	N/A (None Exist)	Existing (1,422)	Low 5,000	0	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	NFRR Aquifer Model Output	NFRR Aquifer Model Output	N/A (None Exist)	Full (1,422)	Low 5,000	SWAM Output	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	NFRR Aquifer Model Output	NFRR Aquifer Model Output	N/A (None Exist)	Existing (1,422)	High 20,000	0	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (High), Full SW Permits	Full	NFRR Aquifer Model Output	NFRR Aquifer Model Output	N/A (None Exist)	Full (1,422)	High 20,000	SWAM Output	SWAM Output	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output

[a] "Senior" is defined as having an application date earlier than both the City of Altus and Lugert-Altus Irrigation District.
[b] "Junior" is defined as having an application date later than both the City of Altus and Lugert-Altus Irrigation District.

Table 6-6. Multiple scenarios, defined by groundwater and stream-water permit/use conditions, that were evaluated using the NFRR aquifer Model, NFRR SWAM, and RRY model to simulate inflows and water availability in the Tom Steed Reservoir hydrologic basin.

Model (Use) Scenario	NFRR Aquifer Model			NFRR SWAM									Reservoir Yield Model		
	Groundwater Pumping Condition	Groundwater Permit Use (acre-ft/yr)		Base Flow Reduction Relative to Naturalized Condition (acre-ft/yr / Percent)	Existing Senior SW Permit Use[a] (acre-ft/yr)	Reservoir Use (acre-ft/yr)	Existing Junior SW Permit Use[b] (acre-ft/yr)	Modeled Future Domestic Use Upstream of Reservoir (acre-ft/yr)	Modeled New "Regular" Stream Water Permits (acre-ft/yr): Elk Creek	Modeled New "Regular" Stream Water Permits (acre-ft/yr): Otter Creek	Water Availability (Amount and Frequency of Permit Shortages)		Inflow Sequence at the Reservoir	Average Annual Inflow (acre-ft/yr)	Reservoir Firm Yield (acre-ft/yr)
Naturalized	Naturalized	0	▶	0 / 0%	Naturalized	Naturalized	Naturalized	0	0	0	-	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Existing GW Permits, Existing Domestic SW, Existing/New SW Permits	Existing	22,988	▶	NFRR Aquifer Model Output	Existing (1,933)	Existing (12,700) / Mid (14,400) / Full (16,100)	Existing (4,716)	0	0 / Low (625) / High (1,250)	0 / Low (625) / High (1,250)	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
New GW Permits, Existing Domestic SW, Existing/New SW Permits	New	27,678	▶	NFRR Aquifer Model Output	Existing (1,933)	Existing (12,700) / Mid (14,400) / Full (16,100)	Existing (4,716)	0	0 / Low (625) / High (1,250)	0 / Low (625) / High (1,250)	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	NFRR Aquifer Model Output	▶	NFRR Aquifer Model Output	Existing (1,933)	Full (16,100)	Existing (4,716)	0	0	0	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	NFRR Aquifer Model Output	▶	NFRR Aquifer Model Output	Existing (1,933)	Full (16,100)	Existing (4,716)	Low 5,000	0	0	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	NFRR Aquifer Model Output	▶	NFRR Aquifer Model Output	Full (1,933)	Full (16,100)	Full (4,716)	Low 5,000	SWAM Output	SWAM Output	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	NFRR Aquifer Model Output	▶	NFRR Aquifer Model Output	Existing (1,933)	Full (16,100)	Existing (4,716)	High 15,000	0	0	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output
Full GW Permits, New Domestic SW (High), Full SW Permits	Full	NFRR Aquifer Model Output	▶	NFRR Aquifer Model Output	Full (1,933)	Full (16,100)	Full (4,716)	High 15,000	SWAM Output	SWAM Output	SWAM Output	▶	SWAM Output	Reservoir Yield Model Output	Reservoir Yield Model Output

[a] "Senior" is defined as having an application date earlier than the Mountain Park Master Conservancy District.
[b] "Junior" is defined as having an application date later than the Mountain Park Master Conservancy District.

6.3. Performance Metrics

In this section, performance metrics are defined that were selected 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, which are discussed in Chapter 7. 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 6-6).

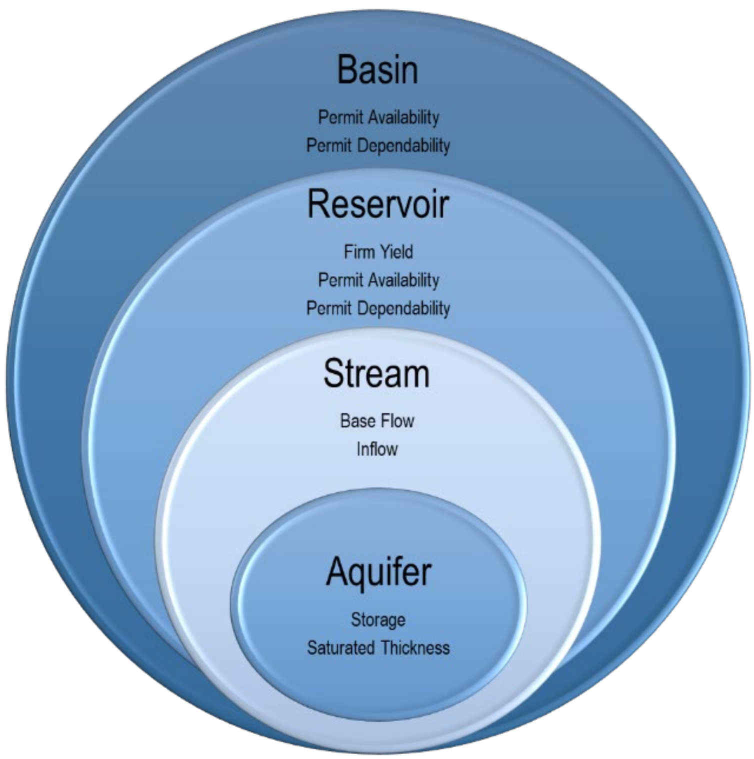

Figure 6-6. Conceptual illustration and relation of performance metrics evaluated under status quo water system reliability analysis.

6.3.1. Aquifer Metrics

In this section, we return to the concepts introduced in Chapter 2.5.4, including terminology related to aquifer management, and their importance in measuring the impacts of groundwater pumping and its interrelation with streamflow and reservoir yield. The aquifer performance metrics selected for analysis apply only to the NFRR aquifer because as previously stated, development of a numerical model on the Elk City aquifer was not included in the scope of the URRBS. For the purposes of this section, only general, qualitative definitions are provided. The computational basis of these metrics can be found in Smith et al. (2017), with more comprehensive definitions provided in Barlow and Leake (2012). Impacts of groundwater demands on the NFRR aquifer were evaluated using the following metrics:

Aquifer EPS and MAY

The annual EPS and MAY were calculated using the NFRR aquifer model. The EPS and MAY are not performance metrics, per se, but the calculation of each represent a critical component of the URRBS. The EPS and MAY are necessary for the evaluation of aquifer performance metrics under the "full" groundwater demand scenario. This is because the EPS and MAY determine the amount of groundwater that could be pumped to maintain the life of the aquifer for a specified period of time. By aquifer life, this means groundwater storage and saturated thickness, both of which are inextricably linked. In accordance with OAC 785:30, the MAY is defined as the amount of fresh groundwater that can be withdrawn annually while ensuring a minimum 20-yr life of the groundwater basin. For alluvium and terrace aquifers (such as the NFRR aquifer), the groundwater-basin-life requirement is satisfied if, after 20 years of MAY withdrawals, 50 percent of the groundwater basin retains a saturated thickness of at least five ft. When a MAY has been established, the amount of land owned or leased by a permit applicant determines the annual volume of water allocated to that permit applicant. The annual volume of water allocated per acre of land is known as the EPS pumping rate.

Using the NFRR aquifer model, EPS scenarios for the NFRR aquifer were run for periods of 20-, 40-, and 50-yrs using methods described in Smith et al. (2017). The 2013 simulated water table from the calibrated numerical model was used as the starting water table in each EPS scenario. To determine the EPS pumping rate, hypothetical wells were placed in each layer's active cell (covering 18 acres) and pumped at the same rate for the duration of the scenario. If at the end of the scenario more than 50 percent of the active cells had a saturated thickness of at least five ft, the pumping rate was increased by about 35 cubic ft per day (1 cubic meter per day). The scenario was repeated until 50 percent of the cells had a saturated thickness of less than five ft. The resulting pumping rate was identified as the EPS for 20-, 40-, and 50-yr aquifer life scenarios. The EPS rates were then multiplied by the 497,582-acre aquifer area, to derive the 20-, 40-, and 50-yr MAY values.

Aquifer Storage

Changes in total aquifer storage over a 50-yr pumping period were calculated using the NFRR aquifer model. Only changes in annual aquifer storage were presented in this study. Aquifer storage can be defined generally as the total volume of water located or held within the saturated zone of the aquifer that could be accessible by pumping[147]. The top of the saturated zone also is referred to as the water table, and the bottom of the saturated zone is considered bedrock or the base of the aquifer.

[147] Some amount of water stored in the aquifer remains locked in isolated or unconnected pore spaces, meaning that even if one depleted the aquifer by well pumping, there will always be some storage remaining that freely drains from connected pores but cannot be extracted by wells (Smith, Personal Communications, 03/31/2021).

Aquifer Saturated Thickness

Changes in aquifer-wide mean saturated thickness after a 50-yr pumping period were calculated using the NFRR aquifer model. Saturated thickness can be defined as the distance between the top of the saturated zone (i.e., water table) and the bottom of the saturated zone (bedrock or aquifer base) (Smith et al., 2017). Saturated thickness generally correlates with stream base flow, which is defined below as a performance metric for the stream system.

6.3.2. Surface Water Metrics

Three performance metrics were used to evaluate status-quo impacts on surface water: base flow, streamflow, and reservoir inflow. Base flow was quantified using the NFRR aquifer model, and then input into the NFRR SWAM to quantify changes in streamflow and reservoir inflow over the model period (Jan 1950-Dec 2016). These metrics are defined as follows:

Base Flow

Annual changes in total NFRR and Elk Creek base flow over a 50-yr pumping period were calculated using the NFRR aquifer model in terms of both total volume and as a percent change relative to the naturalized condition. Base flow can be defined as the component of streamflow that is supplied by the discharge of groundwater to a stream[148], the other components being precipitation that falls directly onto a stream, surface runoff that travels over the land surface to the stream channel, and interflow (subsurface storm flow) that moves through the upper soil layers to a stream (Linsley et al., 1982). Base flow was calculated by USGS along various reaches of the NFRR and Elk Creek. Details, including the computational basis for calculation of base flow, can be found in Smith et al. (2017).

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[148] For the purposes of this study, base flow is classified as a surface water metric, but it also could be considered as an aquifer performance metric.

As previously stated, although development of a numerical model on the Elk City aquifer was not included in the scope of the URRBS, assumptions could still be made regarding impacts on base flow.

As previously stated, base flows in West Otter Creek and Glen Creek were assumed to originate from the Southwest Oklahoma minor aquifer. Although no studies have been conducted to quantify base flows, this aquifer is considered to be too thinly saturated to support irrigation uses beyond short-term domestic uses (OWRB, 1998).

Streamflow

Streamflow in the NFRR SWAM was calculated at each model “node”, which was defined by USGS streamgage locations within the Lugert-Altus and Tom Steed Reservoir hydrologic basins, and by the point of diversion of each regular stream-water permit. This enabled simulations to be performed by the NFRR SWAM on the magnitude and frequency of stream-water permit availability. For the sake of brevity, streamflow results at each model node are not presented in this report; rather, study results focus on stream-water permit availability (discussed below under basin-wide performance metrics). Streamflow also was calculated at the location(s) immediately above Lugert-Altus and Tom Steed reservoirs (discussed below under reservoir inflow). The computational basis for the calculation of streamflow, along with a full accounting of streamflow results, can be found in Lynker (2021) (Appendix C).

Reservoir Inflow

For each of the model scenarios listed in Table 6-3, the monthly inflow data calculated using the NFRR SWAM were summarized and presented as annual inflows into Lugert-Altus Reservoir. The average annual inflow into Lugert-Altus Reservoir over the entire period of record (1950-2016) and during the drought of record (2011-2014) also was calculated, both in terms of volume and as percent change relative to the naturalized condition

Tom Steed Reservoir

Similar to Lugert-Altus Reservoir, for each of the model scenarios listed in Table 6-4, the monthly inflow data calculated using the NFRR SWAM were summarized and presented as annual inflows into Tom Steed Reservoir. The inflows from Elk Creek and from West Otter-Glen Creeks were evaluated separately and as a cumulative total. The average annual inflow into Tom Steed Reservoir over the entire period of record (1950-2016) and during the drought of record (2011-2014) also was calculated, both in terms of volume and as percent change relative to the naturalized condition.

6.3.3. Reservoir Metrics

Performance metrics at Lugert-Altus and Tom Steed reservoirs were calculated under status-quo management using the RRY model based on inflows provided by the NFRR SWAM. Metrics were simulated over the period of record (1950-2016), and in some cases, over the 2011-2015 drought of record. All reservoir simulations assumed year 2060 reservoir sediment conditions.

Lugert-Altus Reservoir

Average Annual Yield

Reservoir average annual yield was calculated for each of the model scenarios listed in Table 6-3 using the RRY model for Lugert-Altus Reservoir.

Irrigation and M&I Permit Dependability

Frequency of full irrigation permit availability was calculated for each of the Table 6-3 model scenarios using the NFRR SWAM and RRY model, along with the frequency (percent of years) of full M&I permit availability. In addition, the volume of irrigation water available that is 20-, 30-, 40-, 50-, 60-, 70-, 80-, 90-, and 100- percent dependable was calculated using the RRY model. Permit dependability is defined as the percent of years that 85,630 acre-ft/yr was available for irrigation purposes and percent of years that 4,800 acre-ft/yr was available for M&I purposes.

Tom Steed Reservoir

Firm Yield

Unlike Lugert-Altus Reservoir, which is operated primarily to deliver agricultural irrigation, Tom Steed Reservoir delivers water for both M&I and EQ purposes. As such, it was important to understand Tom Steed Reservoir's firm yield. Reservoir firm yield was calculated for each of the model scenarios presented in Table 6-4 using the RRY model. Firm yield is defined as the annual volume of M&I water than can reliably be delivered during the drought of record without allowing the reservoir to drop below dead pool (see 2.5.2 and Appendix E). Recall that under the firm yield operations scenario, the model solved for maximum annual deliveries that can be made 100 percent of the time, including during the drought of record, without the reservoir going into the inactive pool. That maximum annual delivery volume is known as the "firm yield". Once this volume is known, it was delivered from the reservoir each and every year over the model period. In effect, this scenario assumed that the drought of record is imminent every time Tom Steed Reservoir drops below the top of conservation pool, and thus eliminates the potential for the reservoir to drop into the inactive pool.

Reservoir Supply Dependability

To evaluate *Tom Steed Reservoir supply dependability*, the model simulated the delivery of three different reservoir demand (use) scenarios out of Tom Steed Reservoir under the range of development scenarios defined in Table 6-4: (1) "Existing" reservoir use, which assumed that MPMCD would utilize 12,700 acre-ft/yr, the maximum volume of water that has ever been reported by MPMCD to the OWRB as being used out of Tom Steed Reservoir in a given year; (2) "Mid" reservoir use, which assumed that MPMCD would utilize 14,400 acre-ft/yr, the mid-point between "Existing" and "Full"; and (3) "Full" reservoir use, which assumed that MPMCD would utilize 16,100 acre-ft/yr, the full volume permitted to MPMCD. For each demand scenario, if the assigned reservoir use was not available (e.g., during the drought of record), the model solved for the volume of permit water that was available during that time, and if a gap existed between the volume demanded out of the reservoir and the volume in reservoir storage that was available, the gap in storage was called a "shortage".

6.3.4. Basin-Wide Metrics

Existing and Future Stream-Water Permit Availability

The availability of existing regular stream-water permits, as well as the availability of stream water for new permits, were calculated under each of the modeling scenarios presented in Tables 6-3 and 6-4 for the Lugert-Altus and Tom Steed Reservoir hydrologic basins, respectively, using the NFRR SWAM. The water availability for new stream-water permits was calculated in accordance with the methods described in Chapter 6.2.2. Existing stream-water permits are listed in Table 6-1 and Table 6-2 for the respective basins. If stream water was found to be available for new permits, then permit availability was evaluated in terms of the percent of years that any permit water was available, as well as the percent of years when full permit water was available. As previously discussed, because this evaluation related to impacts of status-quo management, permit water availability was calculated going from upstream to downstream on a first-come, first-serve basis without regards to seniority.

6.4. Impacts of Status Quo under Baseline Climate (Observed Hydrology)

6.4.1. Aquifer EPS and MAY

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. The 40-yr EPS pumping rate and corresponding impacts on groundwater storage, saturated thickness, and base flows were the same as under the 50-yr EPS rate. This is because for the 40-yr and 50-yr EPS scenarios, most (90 percent) aquifer depletions occurred during the first 20 years of pumping. During that time, annual EPS pumping decreased as the thinner parts of the aquifer went dry. Annual aquifer storage changes decreased as annual EPS pumping decreased, and approximate steady-state conditions were reached after about 30 years. These approximate steady-state conditions explain why the 40- and 50-yr EPS pumping rates are the same. Details can be found in Smith et al. (2017). For this reason, impacts of the 40-yr EPS pumping rate are not discussed in this report.

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

Results are illustrated in Figure 6-7 and tabulated in Table 6-7. According to Smith et al. (2017), at the end of the "Naturalized" (i.e., no pumping) scenario, groundwater storage in the NFRR aquifer after 50 years of no pumping was 2,606,000 acre-ft. Under the "Existing" and "New" groundwater pumping rates, groundwater storage in the NFRR aquifer was 2,398,000 acre-ft and 2,361,00 acre-ft, respectively. After groundwater withdrawals at the 50-yr and 20-yr EPS pumping rates, groundwater storage in the NFRR aquifer was 948,000 acre-ft and 951,000 acre-ft, respectively. Under the "Naturalized" scenario, saturated thickness was 43.6 ft. After the "Existing" and "New" groundwater pumping rates, average saturated thickness was 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 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 (Figure 6-8). 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). This finding was confirmed by the base flow modeling results discussed below, as well as by investigations performed by the OWRB on the Elk City aquifer during the time that this URRBS report was being published (Wagner et al., 2019).

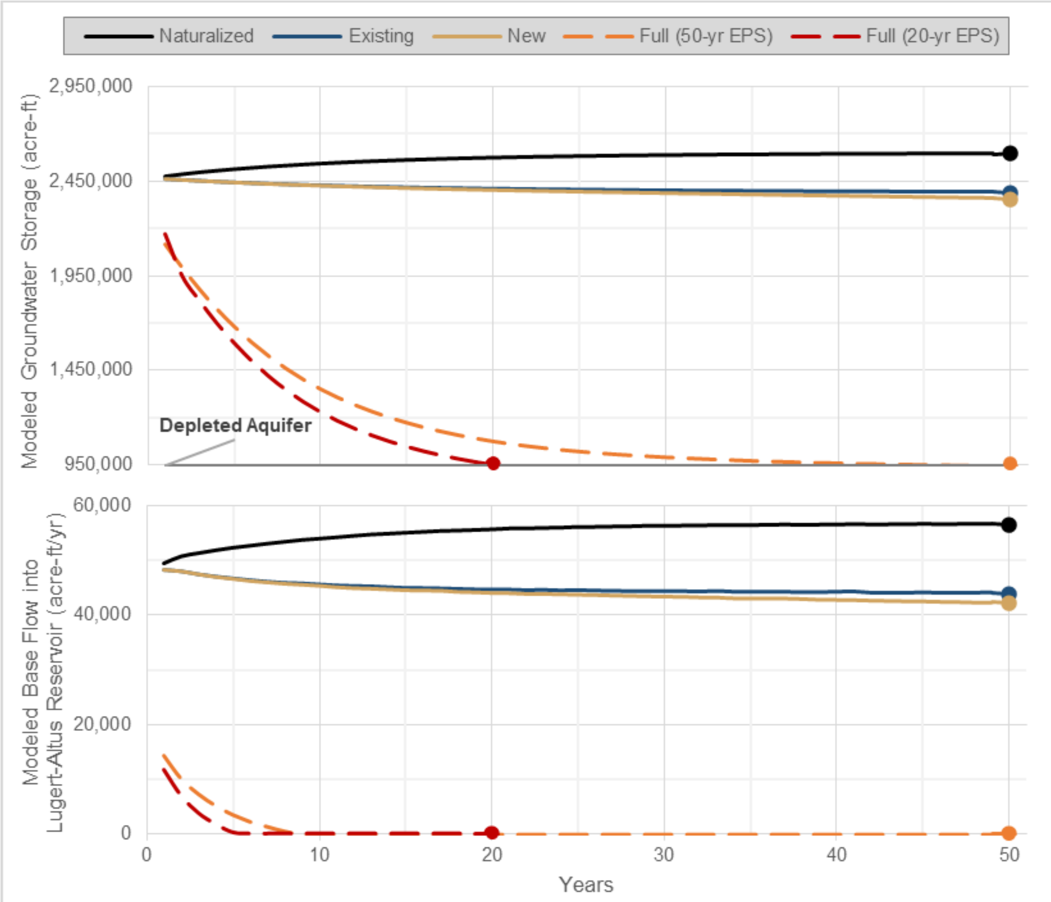


Figure 6-7. Simulated changes in groundwater storage of the NFRR aquifer and base flows of the NFRR over 50 years of withdrawals under five pumping scenarios.

Table 6-7. Simulated changes in groundwater storage and saturated thickness of the NFRR aquifer, along with corresponding changes in base flows of the NFRR 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.

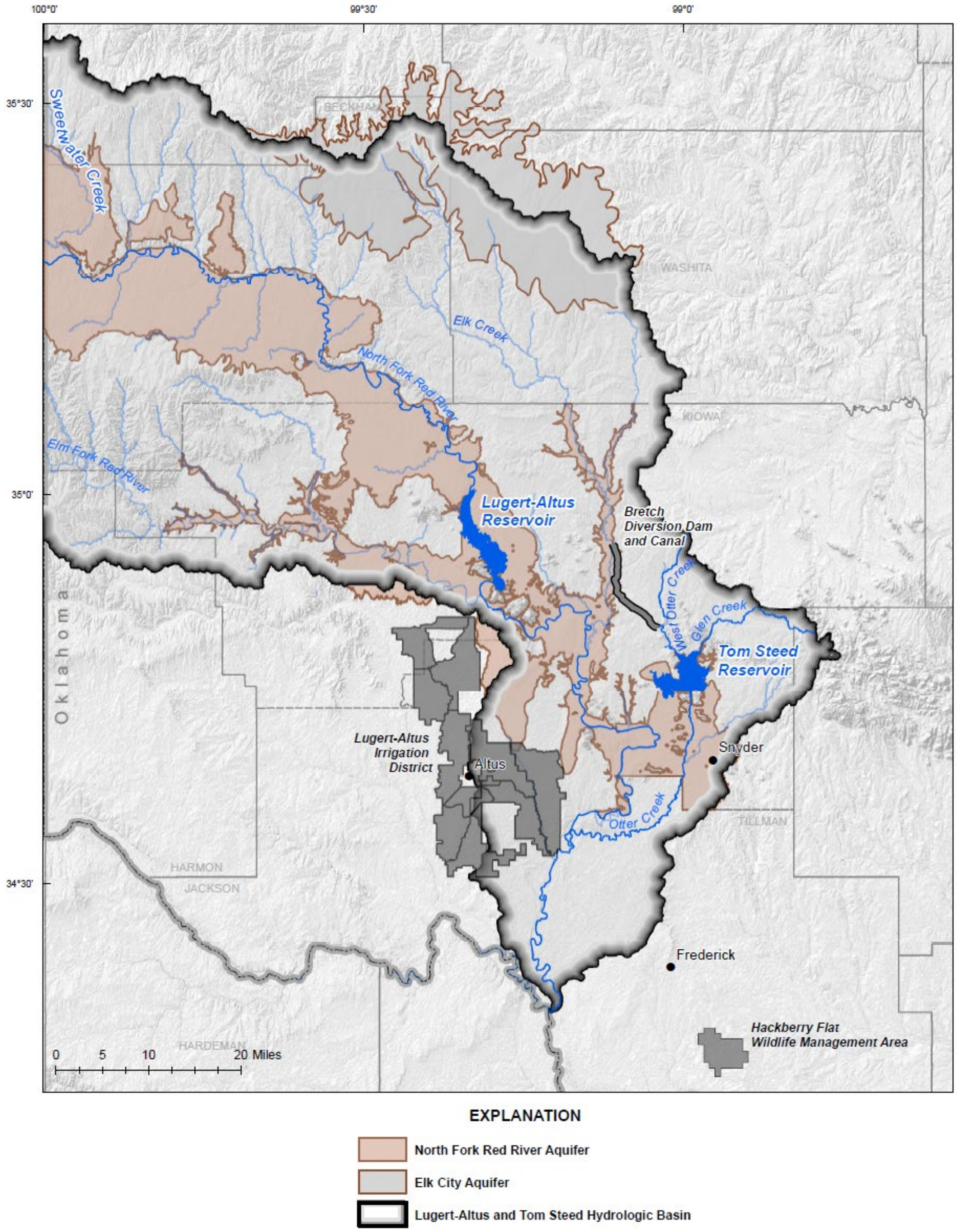


Figure 6-8. Geographic extent of the North Fork Red River (NFRR) aquifer delineated by Smith et al. (2017), as well as the geographic extent of the Elk City aquifer delineated by the OWRB. The hashed red square outlines the portion of the NFRR aquifer that extends underneath Elk Creek above the Bretch Diversion.

Impacts on Base Flow of the NFRR

Under the "Naturalized" scenario, base flow in the NFRR above Lugert-Altus Reservoir 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. 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). 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. Results are presented in Figure 6-7 and Table 6-7.

Impacts on Base Flow of Elk Creek

Under the "Naturalized" (i.e., no pumping) scenario, base flow of Elk Creek at the Hobart streamgage above the Bretch Diversion was 22,300 acre-ft/yr (Smith et al., 2017). Under the "Existing" and "New" groundwater pumping rates, base flow remained unchanged. 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. Results are presented below in Figure 6-9 and Table 6-8.

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 the OWRB's existing EPS pumping rate of 1.0 acre-ft/acre/yr, it could be assumed that Elk Creek's base flows also could be fully depleted to zero. This assumption would be 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).

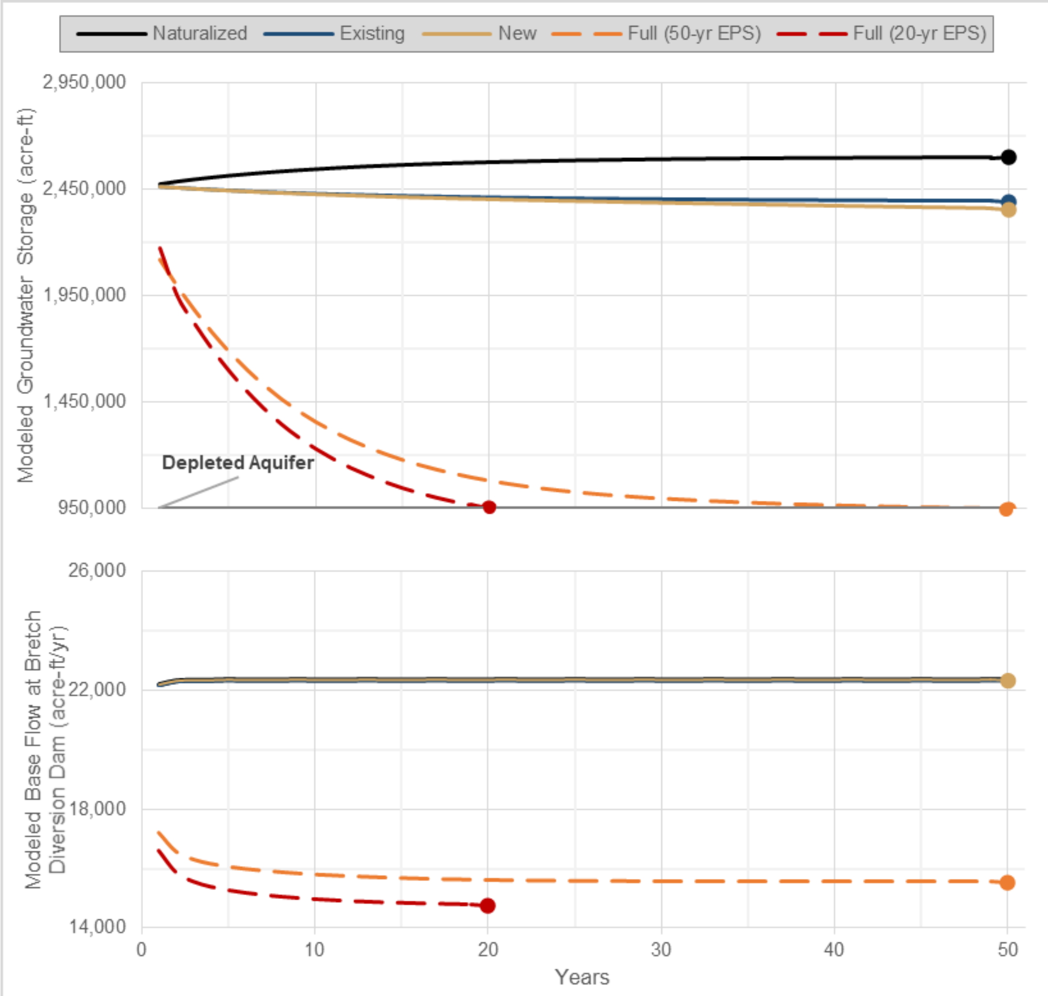


Figure 6-9. Simulated changes in groundwater storage of the NFRR aquifer and base flows of Elk Creek over 50 years of withdrawals under five groundwater pumping scenarios.

Table 6-8. 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.

6.4.3. Impacts in the Lugert-Altus Reservoir Hydrologic Basin

Next, the base flow results for all four groundwater use scenarios presented in the previous section were combined with the four surface 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 6.3.2, 6.3.3 and 6.3.4, respectively.

Regarding surface water and reservoir water metrics, the reader should recall Table 6-5 presented in Chapter 6.2.3, which summarized integration of the NFRR aquifer, NFRR SWAM, and RRY models to simulate inflow and water availability in the Lugert-Altus Reservoir hydrologic basin. In Table 6-5, expected model outputs were denoted by blue shading. The purpose of the shading was to facilitate an understanding of which results are derived from which models. In this section, the model outputs (results) were incorporated into the same table, referenced here as Table 6-9. Results are again denoted by blue shading, some of which include cross references to other tables and figures to facilitate easier understanding of such a comprehensive set of results. A discussion of results follows.

Table 6-9. Multiple scenarios, defined by groundwater and stream-water permit/use conditions, and their impacts on groundwater and stream-water performance metrics (results designated as blue cells).

Model (Use) Scenario	NFRR Aquifer Model			NFRR SWAM							Reservoir Yield Model		
	Groundwater Pumping Condition	Groundwater Permit Use (acre-ft/yr)		Base Flow (acre-ft/yr) / Percent Relative to Naturalized Condition	Existing Senior SW Permit Use[a] (acre-ft/yr)	Existing Junior SW Permit Use[b] (acre-ft/yr)	Modeled Future Domestic Use Upstream of Reservoir (acre-ft/yr)	Modeled New "Regular" Stream Water Permits (acre-ft/yr)	Water Availability (Amount and Frequency of Permit Shortages)		Inflow Sequence at the Reservoir	Average Annual Inflow (acre-ft/yr)	Lugert-Altus Reservoir Full Irrigation Permit Dependability[c] (Percent of Years)
Naturalized	Naturalized	0	►	56,683 / 100%	Naturalized	Naturalized	0	0	-	►	Figure 6-10	116,000	31
Existing GW Permits, Existing Domestic SW, Existing SW Permits	Existing	22,988	►	43,983 / 78%	N/A (None Exist)	Existing (1,422)	0	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	92,000	21
New GW Permits, Existing Domestic SW, Existing SW Permits	New	27,678	►	42,272 / 75%	N/A (None Exist)	Existing (1,422)	0	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	91,000	21
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	294,000	►	0 / 0%	N/A (None Exist)	Existing (1,422)	0	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	80,000	19
Full GW Permits, Future Domestic SW (Low), Existing SW Permits	Full	294,000	►	0 / 0%	N/A (None Exist)	Existing (1,422)	Low 5,000	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	77,000	19
Full GW Permits, Future Domestic SW (High), Existing SW Permits	Full	294,000	►	0 / 0%	N/A (None Exist)	Existing (1,422)	High 20,000	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	71,000	19
Full GW Permits, Future Domestic SW (Low), Full SW Permits	Full	294,000	►	0 / 0%	N/A (None Exist)	Full (1,422)	Low 5,000	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	77,000	19
Full GW Permits, Future Domestic SW (High), Full SW Permits	Full	294,000	►	0 / 0%	N/A (None Exist)	Full (1,422)	High 20,000	0	Table 6-12 Table 6-13 Table 6-14	►	Figure 6-10	71,000	19

[a] "Senior" is defined as having an application date earlier than both the City of Altus and Lugert-Altus Irrigation District.
[b] "Junior" is defined as having an application date later than both the City of Altus and Lugert-Altus Irrigation District.
[c] Based on a 2060 sediment condition.

Reservoir Inflow and Average Annual Water Availability

Overall, impacts on Lugert-Altus Reservoir varied greatly depending on the scenario considered. An illustration of reservoir inflow sequences generated by the SWAM under all eight scenarios is provided in Figure 6-10. Over the entire period of record, average annual inflow into Lugert-Altus Reservoir was 116,000 acre-ft/yr under the "Naturalized" (no use) scenario (Figure 6-10; Figure 6-11). 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 6-10; Figure 6-11).

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. Recall the calculation used to determine the availability of water for future new stream-water permits discussed in Chapter 6.2.2. These 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 drought of record, average annual inflow into Lugert-Altus Reservoir was 38,000 acre-ft/yr under the "Naturalized" scenario (Figure 6-10; Figure 6-11). 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 6-10; Figure 6-11). 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 6-12).

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 6-10). 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 6-10)]. 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 6-10)]. 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 6-10.

As expected, inflows were the highest under the "Naturalized" scenario because there is no upstream use, and 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. A more thorough discussion of these impacts is included under Planning Objectives in Chapter 7.2.

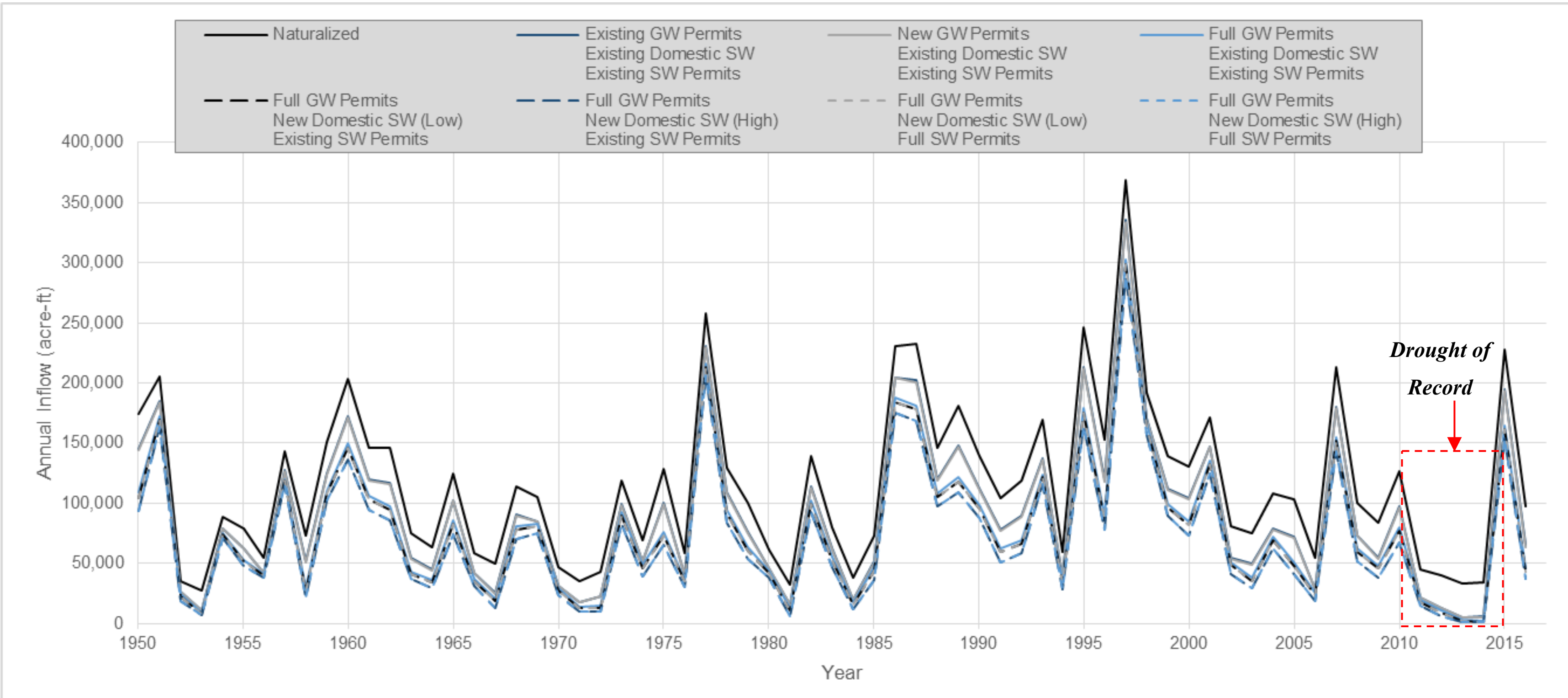
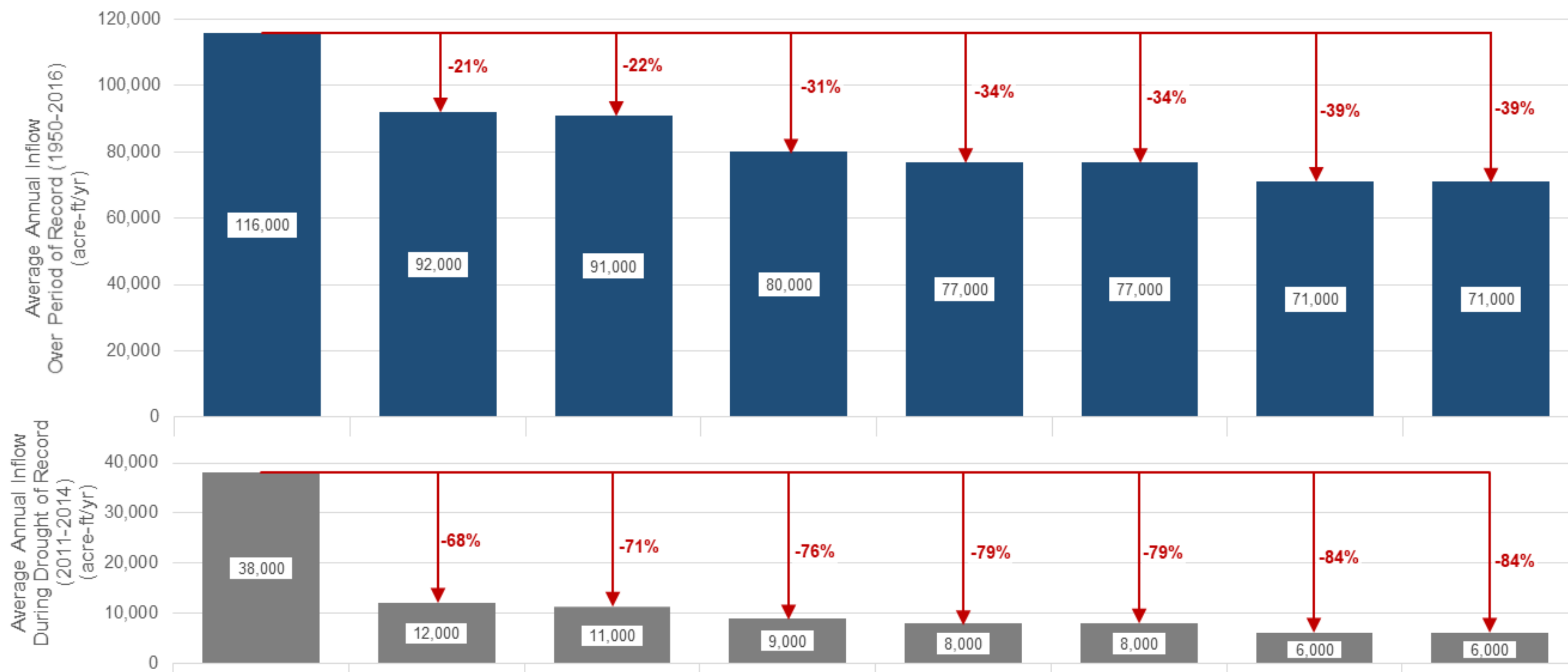


Figure 6-10. Annual inflows into Lugert-Altus Reservoir under a range of groundwater and stream-water use scenarios, 1950-2016.



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

Figure 6-11. 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 6-10. 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%

Reservoir Irrigation and M&I Permit Dependability

Under the "Naturalized" (no use) scenario, the full permitted irrigation volume of 85,630 acre-ft/yr was available 31 percent of the time, and the full permitted M&I volume of 4,800 acre-ft/yr from the reservoir was available 100 percent of the time (Figure 6-13). 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 96 percent of the time under all development scenarios (Figure 6-13).

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 6-14). 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 6-14.

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 6-11). 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 6-11)]. The incremental reductions associated with each variable making up the range of development scenarios is provided in Table 6-11. 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 6-11)]

These results showed that reservoir dependability has been impacted more by existing groundwater permits (the “Existing GW” scenario) than by future 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. A more thorough discussion of these impacts is included under Planning Objectives in Chapter 7.2.

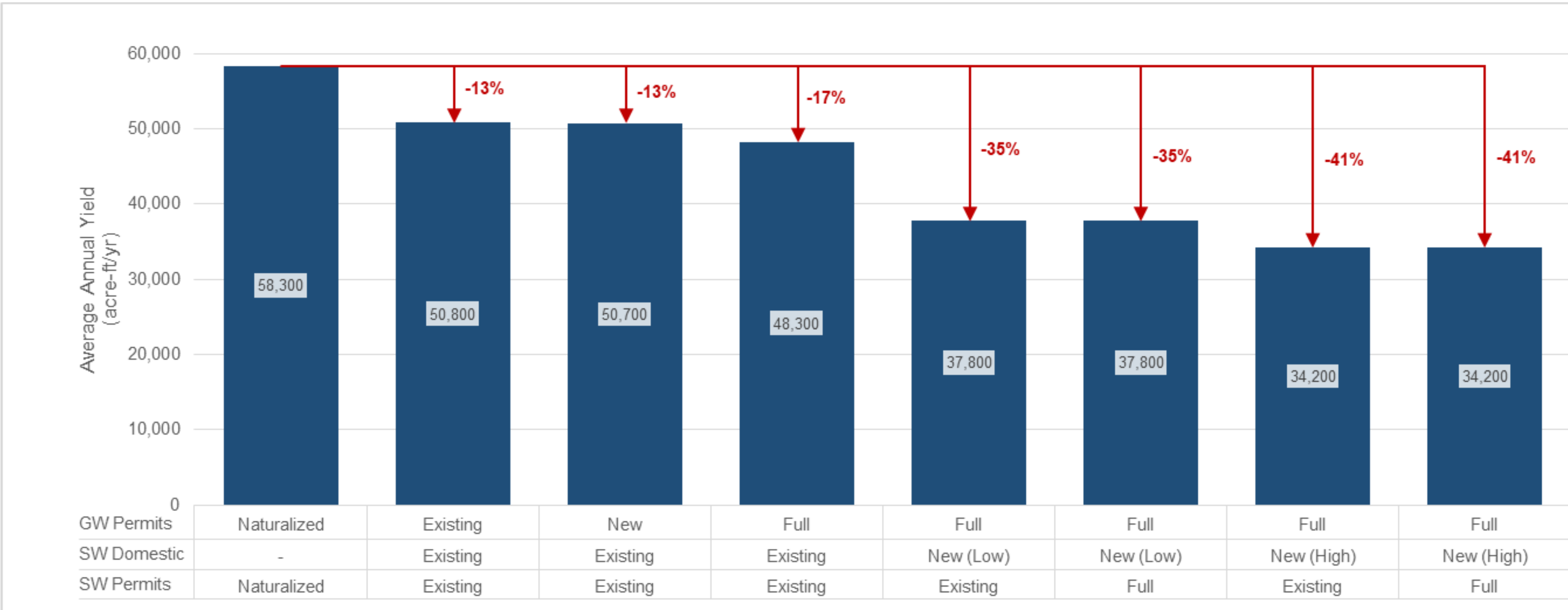


Figure 6-12. Average annual yield of Lugert-Altus Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016), 2060 sediment condition.

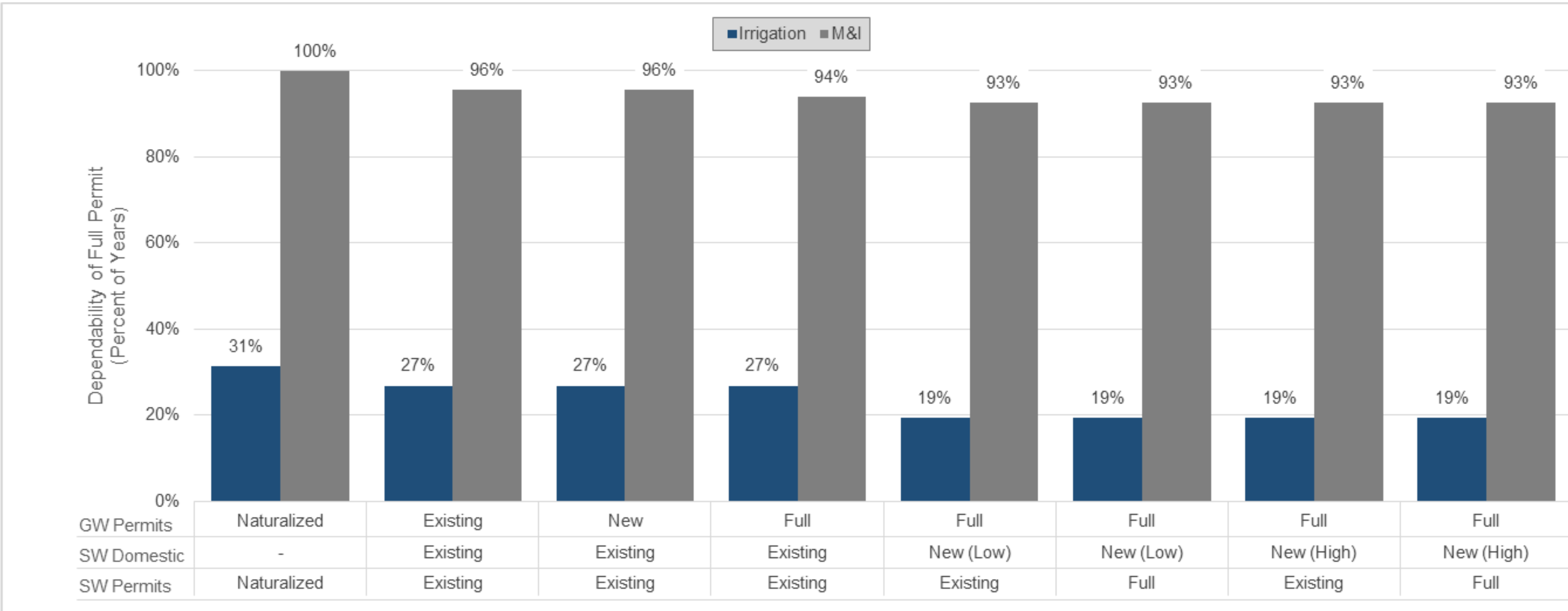
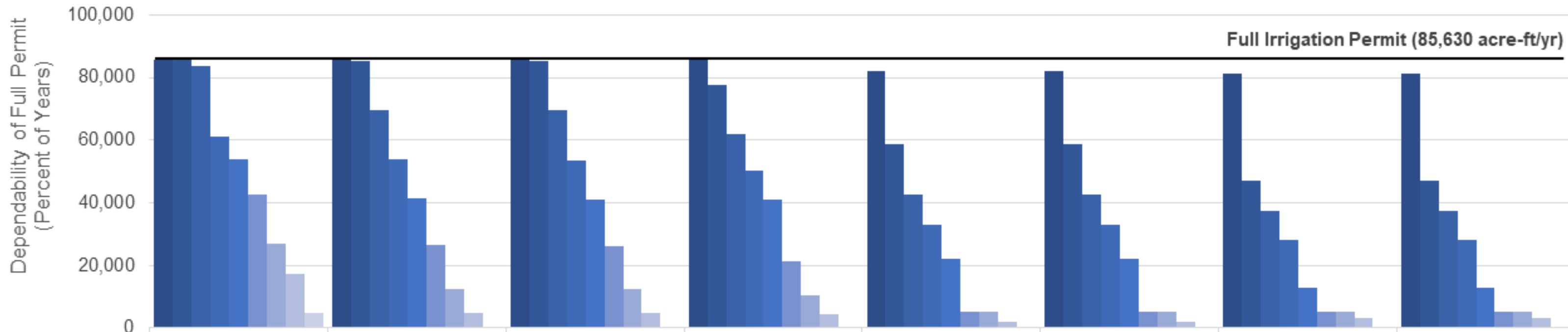


Figure 6-13. Dependability of the full volume of irrigation water permitted to Lugert-Altus ID (85,630 acre-ft/yr) and the 4,800-acre ft/yr of M&I water permitted to the United States for use by the city of Altus based on modeled storage of Lugert-Altus Reservoir under a range of groundwater and surface-water development scenarios, 2060 sediment condition.



GW Permits	Naturalized	Existing	New	Full	Full	Full	Full	Full
SW Domestuc	-	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 6-14. 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, 2060 sediment condition.

Table 6-11. 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.

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%

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, recall again that stream-water permits are listed in Table 6-1, including permit seniority date, type, volume, and consumptive demand, and the location of these permits within the basin are illustrated in Figure 5-13. 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 6-15) and for existing individual permits (Table 6-12); the percent of years when at least some portion of each individual permit volume was available (Table 6-13); and the percent of years when the full volume of each individual permit was available (Table 6-14).

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 6-15). Similar trends were observed for the average annual yield of each individual stream permit (Table 6-12), 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 6-15). For example, the largest reductions in average permit availability of existing junior permits were caused by the “New Domestic SW (Low)” and New Domestic SW (High) scenarios, which both caused a two 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 6-15)]. 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.

Regarding the frequency of individual permit availability, even though impacts from future development were negligible on most permits, there was some decrease in water availability of permits upstream of Lugert-Altus Reservoir. Upstream of the reservoir, while a portion of each individual permit volume was available 99 percent and 100 percent of the time (Table 6-13), the full volume of each individual permit was available between 12 percent and 96 percent of the time (Table 6-14). Downstream of Lugert-Altus Reservoir, a portion of individual permit volume was available 100 percent of the time (Table 6-13); and the full volume of each individual permit was available between 93 percent and 97 percent of the time (Table 6-14). The reason full permit availability was higher downstream of the reservoir is likely because downstream permits have access to increased run-off in tributaries downstream of the reservoir.

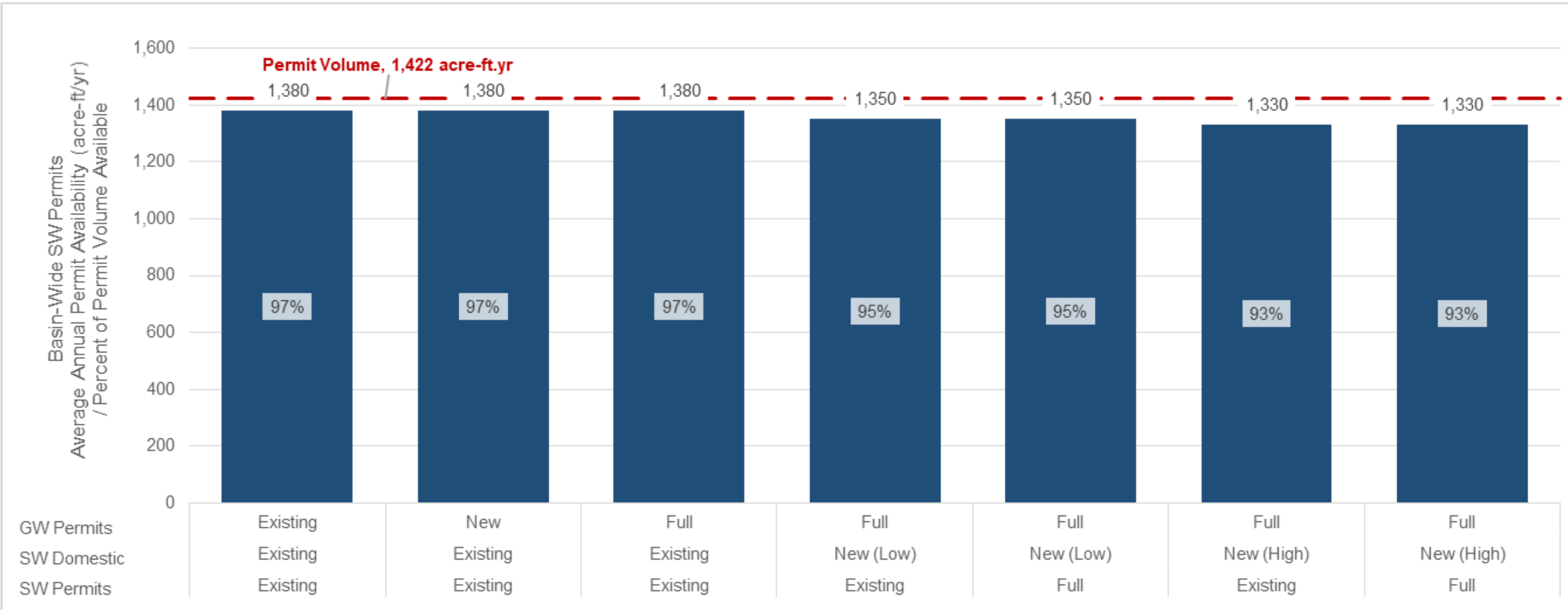


Figure 6-15. Basin-wide SW Permits average annual permit availability (excluding LAID and City of Altus) within the Lugert-Altus Reservoir hydrologic basin.

Table 6-12. 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.

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
		19950037 A	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	19850022 C	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 6-13. Frequency that a portion of permit water is available for existing regular stream water permits in the Lugert-Altus Reservoir hydrologic basin under seven groundwater and stream-water use scenarios.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Percent of Years with Any Permit Water Available***						
				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	100	100	100	100	100	100	100
		19600140	150	100	100	100	100	100	100	100
		19620010	110	99	99	99	99	99	99	99
	30204	19660220	53	100	100	100	100	100	100	100
		20020003	442.5	100	100	100	100	100	100	100
		19950037A	80	100	100	100	100	100	100	100
		19740253	11	100	100	100	100	100	100	100
Lugert-Altus Reservoir		19260006	4,800	100	100	100	99	94	97	97
		19390023	85,630	96	96	96	94	93	93	93
Downstream of Reservoir	30204	19900029	100	100	100	100	100	100	100	100
	30304	19850022C	56.5	100	100	100	100	100	100	100
		19650245	15	100	100	100	100	100	100	100
		20060062	320	100	100	100	100	100	100	100

Table 6-14. Frequency that the full permitted volume is available for existing regular stream water permits in the Lugert-Altus Reservoir hydrologic basin under seven groundwater and stream-water use scenarios.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Percent of Years with Full Permit Water Available***						
				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	96	96	91	42	42	10	10
		19600140	150	61	61	61	61	61	61	61
		19620010	110	51	51	51	40	40	12	12
	30204	19660220	53	78	78	78	78	78	78	78
		20020003	442.5	94	94	94	91	91	91	91
		19950037A	80	94	94	93	88	88	88	88
		19740253	11	96	96	91	87	87	87	87
Lugert-Altus Reservoir		19260006	4,800	96	96	94	93	93	93	93
		19390023	85,630	27	27	27	19	19	19	19
Downstream of Reservoir	30204	19900029	100	93	93	93	76	76	75	75
	30304	19850022C	56.5	97	97	97	97	97	97	97
		19650245	15	93	93	93	93	93	93	93
		20060062	320	96	96	96	96	96	96	96

Table 6-15. Incremental impacts of development-scenario variables on the average annual availability of existing upstream junior stream-water permits.

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%

6.4.4. 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 6.3.2, 6.3.3 and 6.3.4, respectively.

Regarding surface and reservoir water metrics, recall that reservoir performance metrics cited in Chapter 6.3.3 were average annual inflow, reservoir firm yield, and the dependability of the full volume of the M&I permit. The reader also should recall Table 6-6 presented in Chapter 6.2.4, which summarized integration of the NFRR aquifer, NFRR SWAM, and RRY models to simulate inflow and water availability in the Tom Steed Reservoir hydrologic basin. In Table 6-6, expected model outputs were denoted by blue shading. The purpose of the shading was to facilitate an understanding of which results are derived from which models. In this section, the model outputs (results) are incorporated into the same table, referenced here as Table 6-16. Results are again denoted by blue shading, some of which include cross references to other tables and figures to facilitate easier understanding of such a comprehensive set of results. A discussion of results follows.

Table 6-16. Multiple scenarios, defined by groundwater and stream-water permit/use conditions, and their impacts on groundwater and stream-water performance metrics (results designated as blue cells).

Model (Use) Scenario	NFRR Aquifer Model			NFRR SWAM									Reservoir Yield Model		
	Groundwater Pumping Condition	Groundwater Permit Use (acre-ft/yr)		Base Flow Reduction Relative to Naturalized Condition (acre-ft/yr / Percent)	Existing Senior SW Permit Use[a] (acre-ft/yr)	Reservoir Use (acre-ft/yr)	Existing Junior SW Permit Use[b] (acre-ft/yr)	Modeled Future Domestic Use Upstream of Reservoir (acre-ft/yr)	Modeled New "Regular" Stream Water Permits (acre-ft/yr): Elk Creek	Modeled New "Regular" Stream Water Permits (acre-ft/yr): Otter Creek	Water Availability (Amount and Frequency of Permit Shortages)		Inflow Sequence at the Reservoir	Average Annual Inflow (acre-ft/yr)	Reservoir Firm Yield (acre-ft/yr)
Naturalized	Naturalized	0	►	0 / 0%	Naturalized	Naturalized	Naturalized	0	0	0	-	►	Figure 6-17	80,000	16,100
Existing GW Permits, Existing Domestic SW, Existing/New SW Permits	Existing	22,988	►	22,200 / 0%	Existing (1,933)	Existing (12,700) / Mid (14,400) / Full (16,100)	Existing (4,716)	0	0 / Low (625) / High (1,250)	0 / Low (1,875) / High (3,750)	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	52,000 – 53,000	11,300 – 13,400
New GW Permits, Existing Domestic SW, Existing/New SW Permits	New	27,678	►	22,300 / 0%	Existing (1,933)	Existing (12,700) / Mid (14,400) / Full (16,100)	Existing (4,716)	0	0 / Low (625) / High (1,250)	0 / Low (1,875) / High (3,750)	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	52,000 – 53,000	11,300 – 13,400
Full GW Permits, Existing Domestic SW, Existing SW Permits	Full	294,000	►	14,800 / 34%	Existing (1,933)	Full (16,100)	Existing (4,716)	0	0	0	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	52,000	13,200
Full GW Permits, New Domestic SW (Low), Existing SW Permits	Full	294,000	►	14,800 / 34%	Existing (1,933)	Full (16,100)	Existing (4,716)	Low 5,000	0	0	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	52,000	12,100
Full GW Permits, New Domestic SW (Low), Full SW Permits	Full	294,000	►	14,800 / 34%	Full (1,933)	Full (16,100)	Full (4,716)	Low 5,000	Full 9,000	Full 26,900	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	45,000	5,800
Full GW Permits, New Domestic SW (High), Existing SW Permits	Full	294,000	►	14,800 / 34%	Existing (1,933)	Full (16,100)	Existing (4,716)	High 15,000	0	0	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	50,000	9,900
Full GW Permits, New Domestic SW (High), Full SW Permits	Full	294,000	►	14,800 / 34%	Full (1,933)	Full (16,100)	Full (4,716)	High 15,000	Full 8,500	Full 25,400	Table 6-21 Table 6-22 Table 6-23	►	Figure 6-17	44,000	5,000

[a] "Senior" is defined as having an application date earlier than the Mountain Park Master Conservancy District.
[b] "Junior" is defined as having an application date later than the Mountain Park Master Conservancy District.

Reservoir Inflow

Impacts on Tom Steed Reservoir varied greatly depending on the scenario considered. An illustration of inflow sequences generated by the SWAM under all development scenarios is provided in Figure 6-16. 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 (Table 6-16; Figure 6-17). 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 (Table 6-16; Figure 6-17 and Figure 6-18). 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 (Table 6-16; Figure 6-17 and Figure 6-18). 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 (recall again the calculation used to determine the availability of water for future new stream-water permits that was discussed in Chapter 6.2.2.)[149]. 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 6-17).

[149] 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.

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 6-17). 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 6-17)]. 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 6-17)]. 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 6-17.

As expected, 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 7.3.

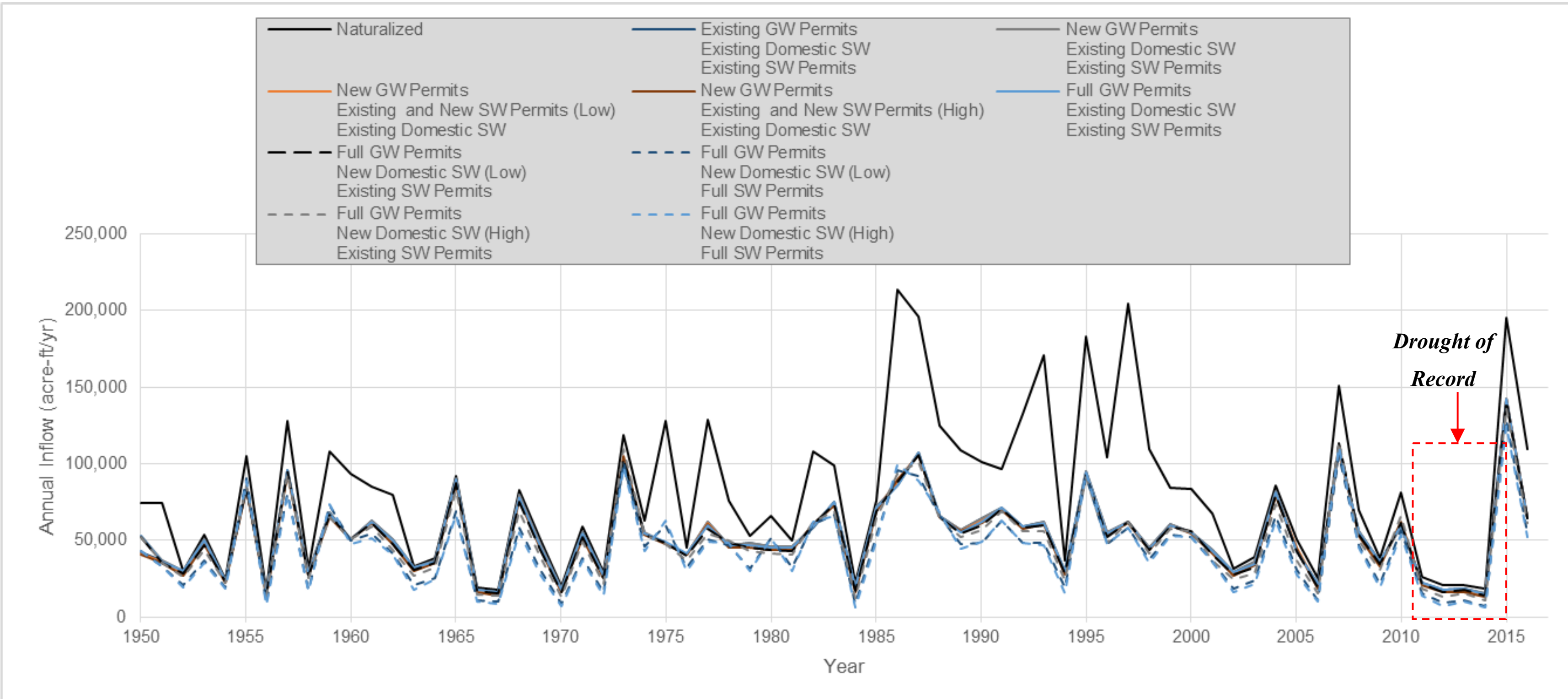


Figure 6-16. Annual inflows into Tom Steed Reservoir under a range of groundwater and stream-water use scenarios, 1950-2016.

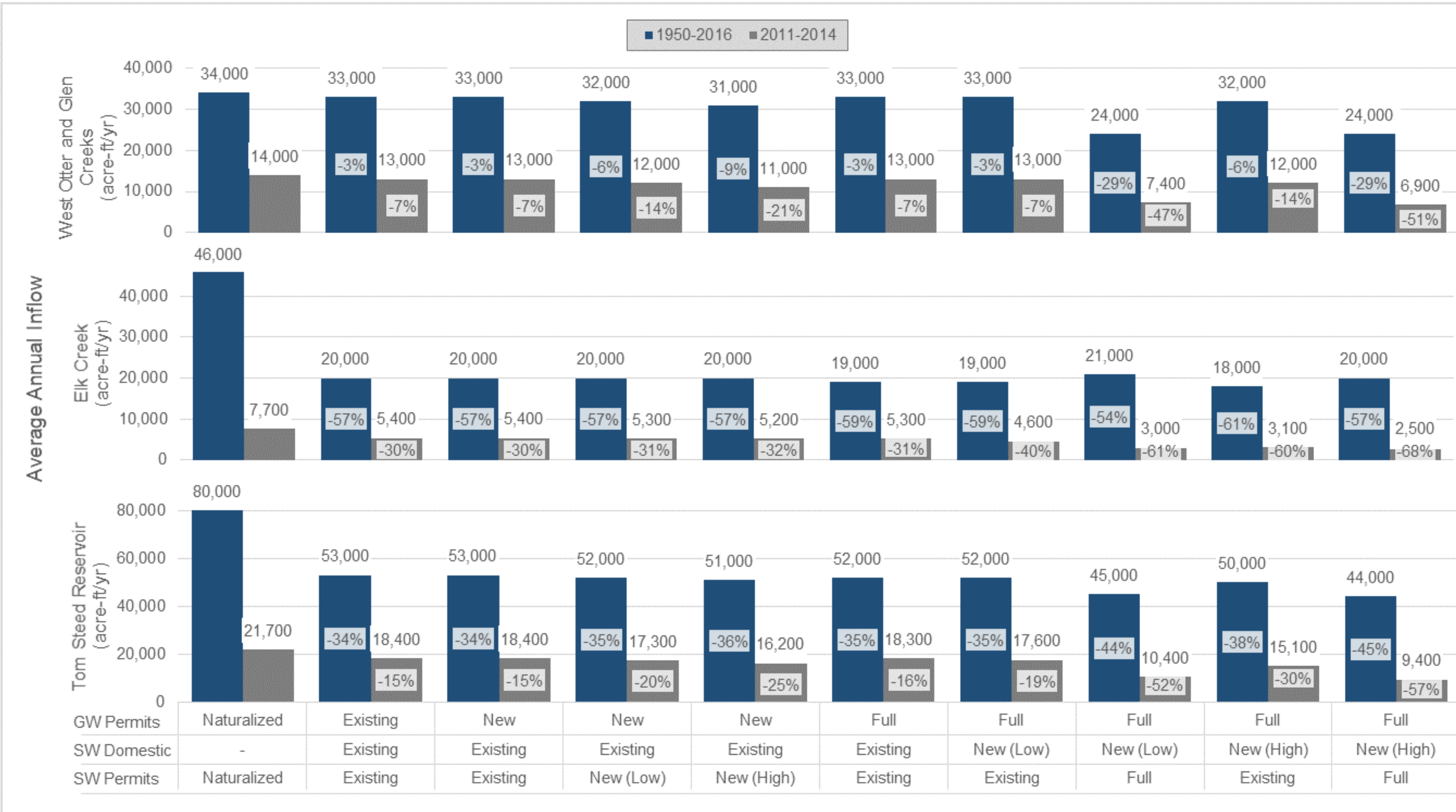
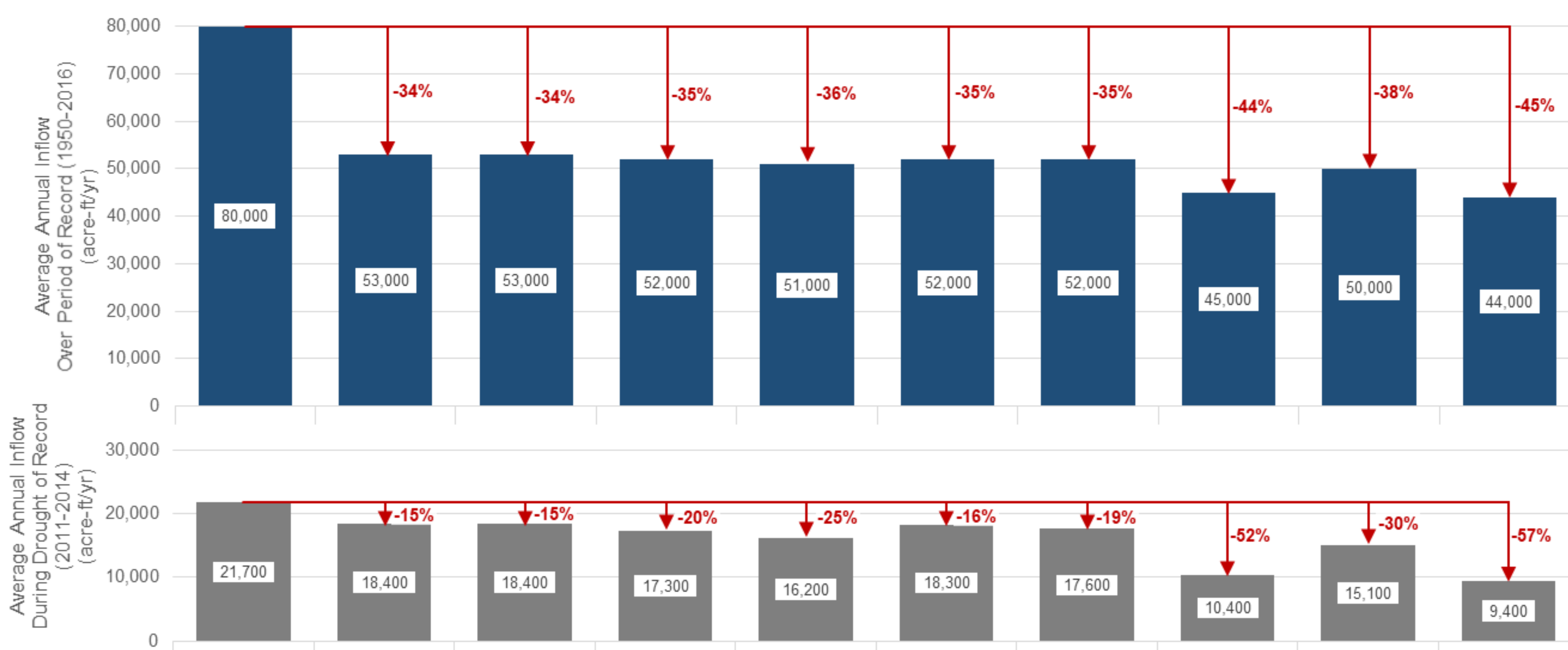


Figure 6-17. Average annual inflows into Tom Steed Reservoir under a range of groundwater and stream-water use scenarios over the period of record (1950-2016) and during the drought of record (2011-2014).



GW Permits	Naturalized	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	Naturalized	Existing	Existing	New (Low)	New (High)	Existing	Existing	Full	Existing	Full

Figure 6-18. 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 6-17. Incremental impacts of development-scenario variables on average annual inflow into Tom Steed 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[a]	0%	0%
New GW Permits	0%	0%
Full GW Permits	1%	1%
New Domestic SW (Low)	0%	3%
New SW Permits (Low)	1%	5%
New SW Permits (High)	2%	10%
New Domestic SW (High)	3%	14%
Existing SW Permits	34%	15%
Full SW Permits with New Domestic SW (High)	7%	27%
Full SW Permits with New Domestic SW (Low)	9%	33%

[a] Results for "Existing GW Permits" were identified in Section 6.4.2.

Reservoir Firm Yield

Tom Steed Reservoir firm yield varied greatly depending on the scenario considered. 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 6-19)[150].

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 6-18). For example, the largest reduction in firm yield was caused by the “Full SW Permits (Low)” scenario (33 percent reduction), while the smallest reduction in firm yield was caused by the “Existing GW Permits” and “New GW Permits” scenarios [(zero percent) (Table 6-18)]. The incremental reductions associated with each variable making up the range of development scenarios is provided in Table 6-18.

As expected, reservoir firm yield was the highest 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 7.3.

[150] For reasons previously discussed, firm yield results excluded an analysis of pumping from the Elk City aquifer. If one assumes zero base flow from Elk Creek (which would be a reasonable assumption if both the NFRR and Elk City aquifers were fully developed), then firm yield under the “Full GW” scenario would be reduced by another 16 percent. This cursory analysis was performed using the RRY model.

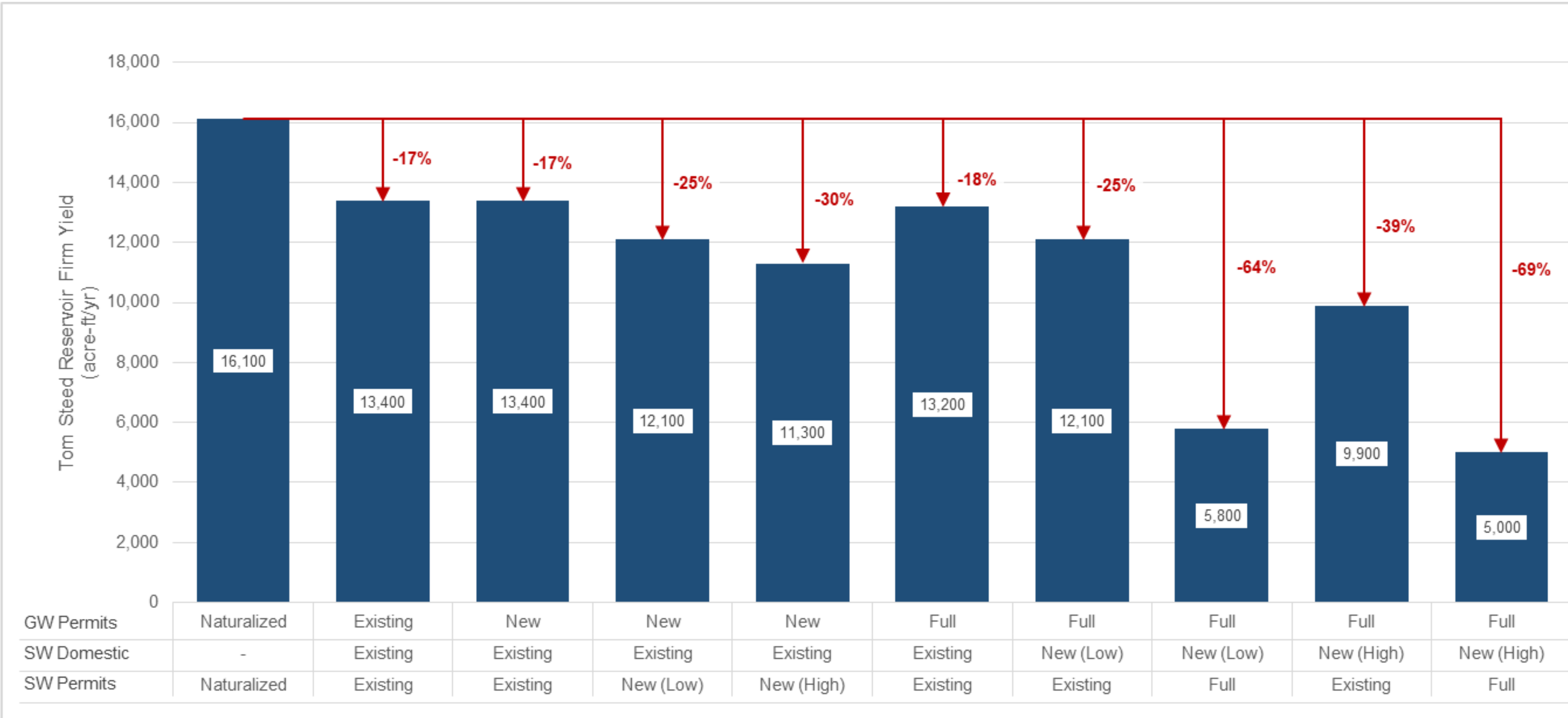


Figure 6-19. Tom Steed Reservoir firm yield under a range of groundwater and surface-water development scenarios, 2060 sediment condition.

Table 6-18. Incremental impacts of development-scenario variables on Tom Steed Reservoir firm yield, 2060 sediment condition.

Development Variable	Incremental Impact on Tom Steed Reservoir Firm Yield
Existing GW Permits[a]	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%

[a] Results for "Existing GW Permits" were identified in Section 6.4.2.

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 "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 6-19).

Reservoir supply shortages ranged from zero acre-ft/yr to 11,600 acre-ft/yr depending on the reservoir use and development scenario (Table 6-19). 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 6-19).

A visual representation of reservoir supply shortages across the range of development scenarios assuming "Full" reservoir use is provided in Figure 6-20. 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 Figure 6-21, Figure 6-22, and Figure 6-23, respectively.

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 (Figure 2-11)[151]. This highlights the severity of the 2010s Drought of Record; and although single-calendar-year permit shortages were noted in Figure 6-20, 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.

[151] A cursory discussion on observed, historical droughts was provided in Chapter 2.2.1. A more extensive discussion is provided in Chapter 8.3.2.

Table 6-19. 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, 2060 sediment condition.

Modeling Scenarios for the MPMCD	Tom Steed Reservoir Use	Tom Steed Reservoir Supply Dependability (Percent of Calendar Years)	Tom Steed Reservoir Supply Dependability (Percent of Months)	Maximum Calendar-Year Permit Shortage (acre-ft/yr)	Maximum Calendar-Year Permit Shortage (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.

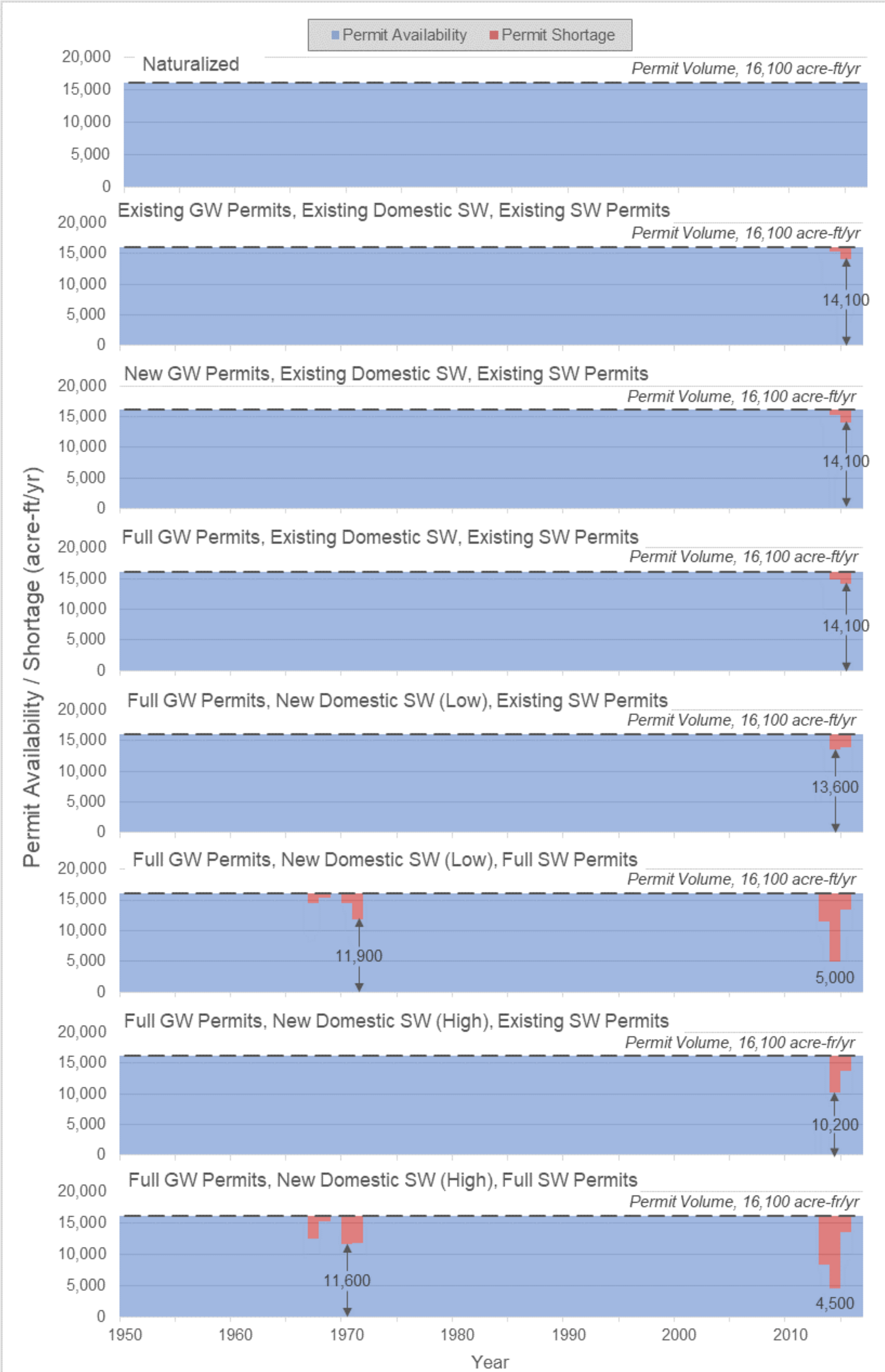


Figure 6-20. The dependability of Tom Steed Reservoir supply in delivering the "Full" permit demands on the reservoir for each calendar year under a range of groundwater and surface-water development scenarios, 2060 sediment condition.

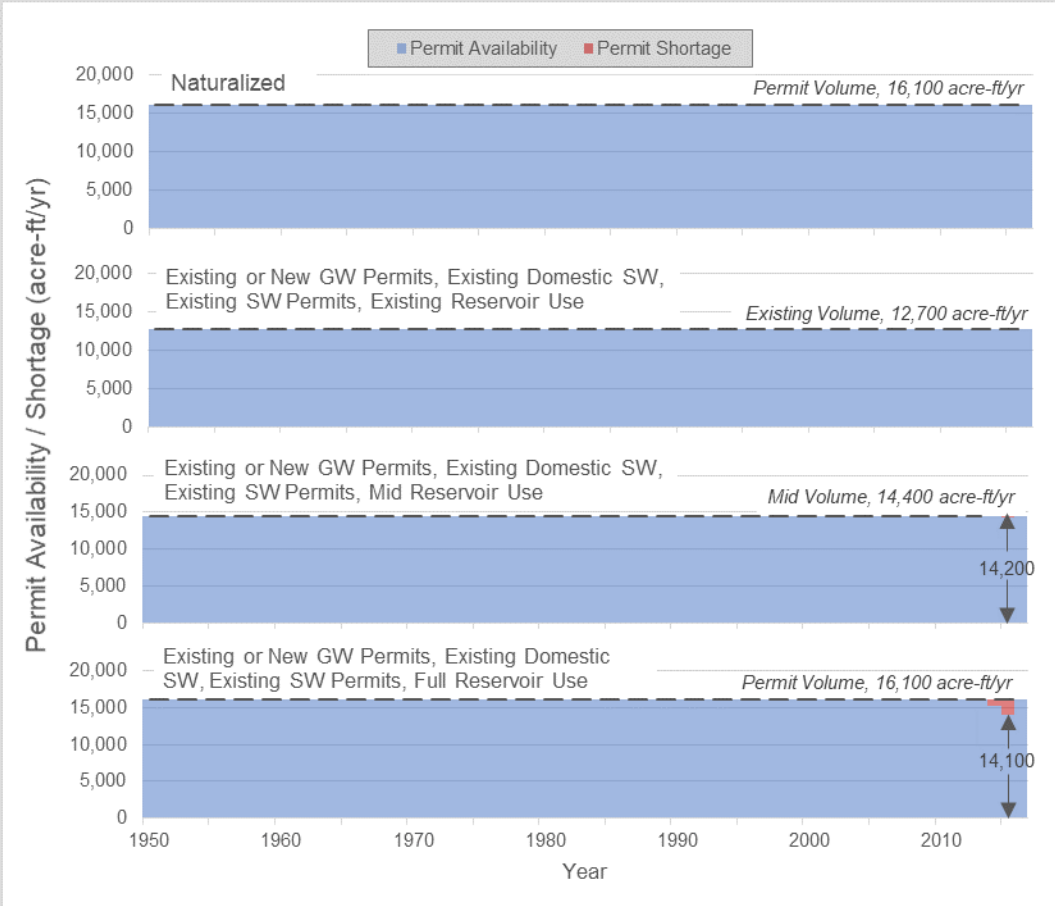


Figure 6-21. The dependability of Tom Steed Reservoir supply in delivering three different reservoir demand scenarios for each calendar year under a range of groundwater and surface-water development scenarios, 2060 sediment condition. Assumes development is limited to Existing or New GW Permits, Existing SW Permits, and Existing Domestic SW.

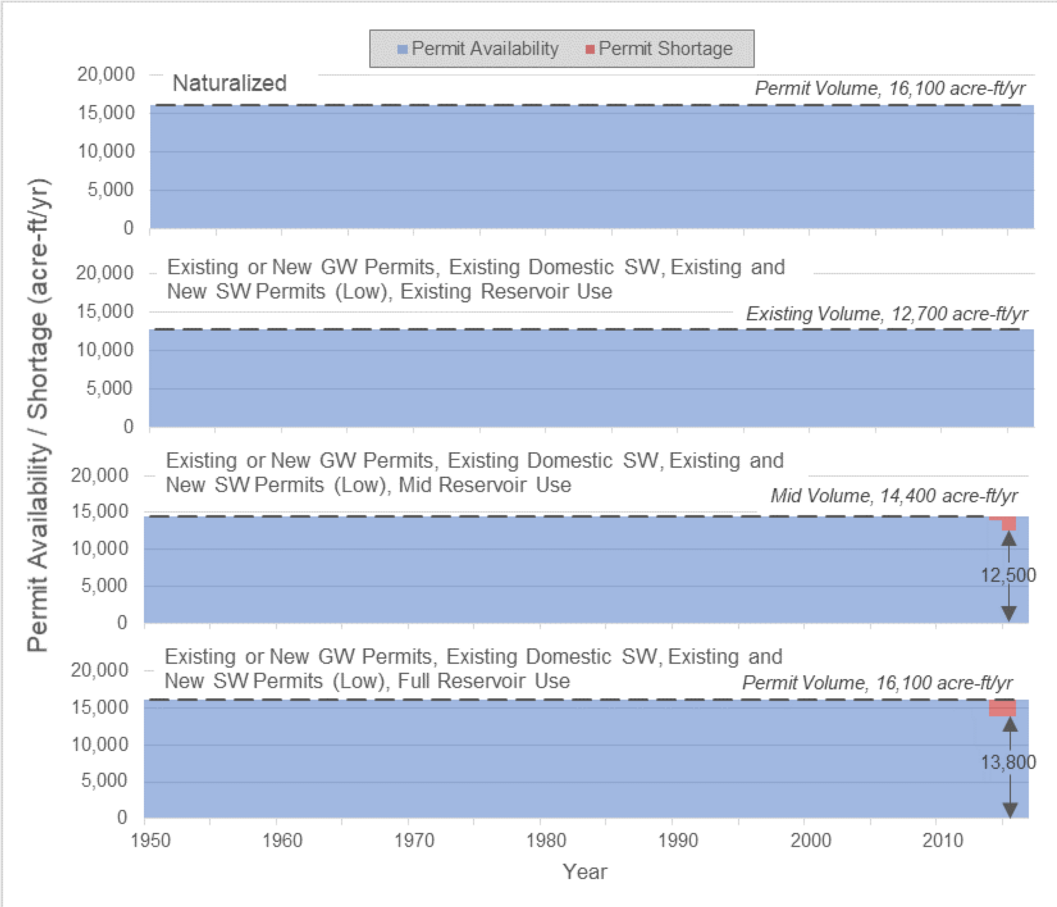


Figure 6-22. The dependability of Tom Steed Reservoir supply in delivering three different reservoir demand scenarios for each calendar year under a range of groundwater and surface-water development scenarios, 2060 sediment condition. Assumes development is limited to Existing or New GW Permits, Existing or New SW Permits (Low), and Existing Domestic SW.

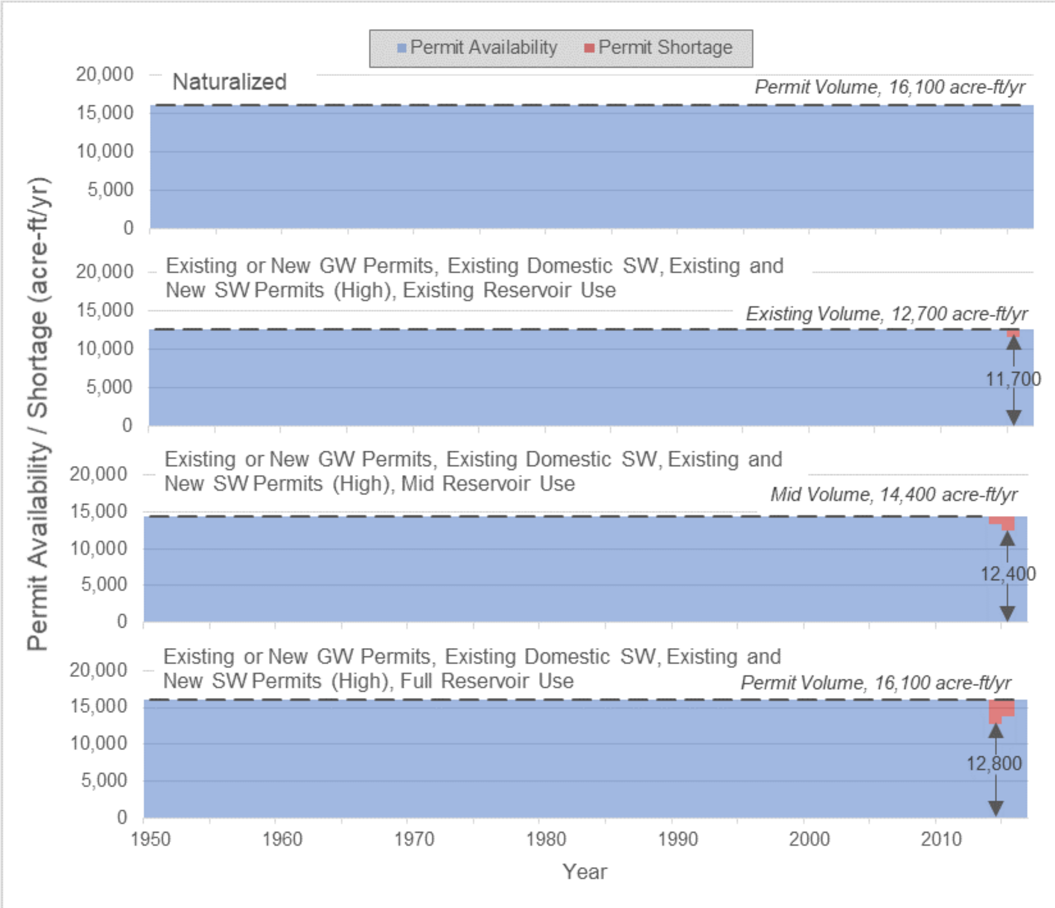


Figure 6-23. The dependability of Tom Steed Reservoir supply in delivering three different reservoir demand scenarios for each calendar year under a range of groundwater and surface-water development scenarios, 2060 sediment condition. Assumes development is limited to Existing or New GW Permits, Existing or New SW Permits (Hight), and Existing Domestic SW.

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, recall again that stream-water permits are listed in Table 6-2, including permit seniority date, type, volume, and consumptive demand, and the location of these permits within the basin are illustrated in Figure 5-17. 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 6-24); basin-wide average annual permit availability for individual permits (Table 6-21); the percent of years when at least some portion of each individual permit volume was available (Table 6-22); and the percent of years when the full volume of each individual permit was available (Table 6-23). Because modeled stream-water demands and permit availability were removed from the stream going from upstream to downstream on a first-come, first-serve basis, the "existing" and "mid" reservoir use scenarios were not applicable to this analysis and are therefore not presented.

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 6-24).

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 6-20). 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 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 6-20)]. It is important to note that modeling assumed all New SW Permit scenarios were downstream of existing upstream junior SW permits and therefore resulted in zero incremental impacts, so additional modeling would be needed to assess other locations and associated impacts on 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 6-20.

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.

The availability of existing individual stream permits varied depending on the development scenario. Downstream of the reservoir, a portion of individual permit volume was available between 75 percent of the time and 100 percent of the time depending on the development scenario (Table 6-22); and the full volume of individual permits was available between seven and 100 percent of the time (Table 6-23). Upstream of the reservoir, a portion of individual permit volume was available between 85 percent and 100 percent of the time (Table 6-22); and the full volume of individual permits was available between zero percent and 93 percent of the time (Table 6-23).

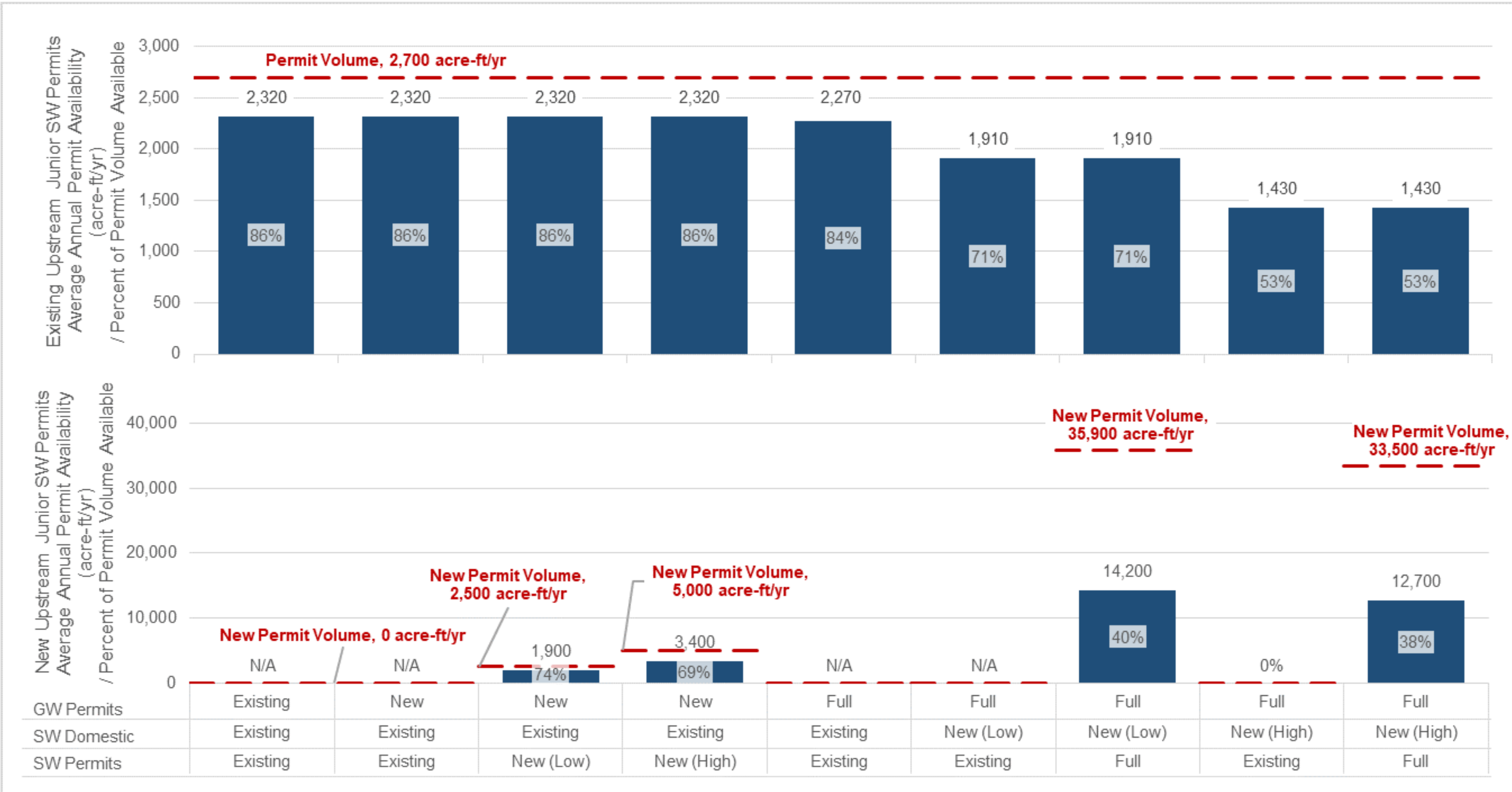


Figure 6-24. Average annual permit availability of upstream junior permits within the Tom Steed Reservoir hydrologic basin under a range of groundwater and stream-water development scenarios.

Table 6-20. Incremental impacts of development-scenario variables on the average annual availability of existing upstream junior stream-water permits.

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.

Table 6-21. 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.

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 6-22. Frequency that a portion of permit water is available for existing regular and new stream water permits in the Tom Steed Reservoir hydrologic basin under a range of groundwater and stream-water development scenarios.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Percent of Years with a Portion of Permit Water Available***							
				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	99	99	99	99	97	97	90	90
		19600053	108	100	100	100	100	99	99	94	94
		19650249	800	100	100	100	100	100	100	100	100
		20030029	100	100	100	100	100	99	99	93	93
		19740306	20	100	100	100	100	99	99	94	94
		19641018	160	99	99	99	99	97	97	97	97
		20060043	1,470	99	99	99	99	97	97	90	90
	30302	19650553	149	97	97	97	97	93	93	85	85
		19970006	1,100	100	100	100	100	100	100	100	100
		19320051	631	100	100	100	100	100	100	100	100
		New Permits	Varies[a]	N/A[b]	100	100	N/A	N/A	100	N/A	100
	30303	19820113	10	100	100	100	100	100	100	100	100
		New Permits	Varies[c]	N/A	100	100	N/A	N/A	100	N/A	100
Tom Steed Reservoir		19670671L	16,100	100	100	100	100	100	100	100	100
Downstream of Reservoir	30302	19970010	297	93	93	88	87	85	79	82	75
		19980025	1,338	100	100	100	100	100	100	100	100
	30304	20060062	320	100	100	100	100	100	100	100	100
	30303	20090008	46	100	100	100	100	100	100	100	100
		19960036	15	100	100	100	100	100	100	100	100
		19520414	77	100	100	100	100	100	100	100	100

[a] New Permit 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 stands for Not Applicable.
[c] New Permit 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).

Table 6-23. Frequency that the full permitted volume is available for existing regular and new stream water permits in the Tom Steed Reservoir hydrologic basin under a range of groundwater and stream-water development scenarios.

Location	HUC Ten Number (1112-0)	Permit Number	Permitted Volume (acre-ft/yr)	***Percent of Years with Full Permit Water Available***							
				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	84	84	84	84	55	55	25	25
		19600053	108	87	87	87	87	55	55	25	25
		19650249	800	21	21	21	9	7	7	1	1
		20030029	100	79	79	79	79	51	51	24	24
		19740306	20	93	93	93	93	64	64	28	28
		19641018	160	90	90	90	78	58	58	48	48
		20060043	1,470	55	55	55	46	28	28	19	19
	30302	19650553	149	40	40	40	40	28	28	18	18
		19970006	1,100	37	37	37	37	24	24	10	10
		19320051	631	75	75	75	73	42	42	16	16
		New Permits	Varies[a]	N/A[b]	45	40	N/A	N/A	3	N/A	1
	30303	19820113	10	63	63	63	63	12	12	4	4
		New Permits	Varies[c]	N/A	1	0	N/A	N/A	0	N/A	0
Tom Steed Reservoir		19670671L	16,100	97	97	97	97	97	90	97	90
Downstream of Reservoir	30302	19970010	297	27	25	24	24	19	12	13	7
		19980025	1,338	43	42	42	42	30	28	21	16
	30304	20060062	320	96	96	96	96	96	96	96	96
	30303	20090008	46	100	100	100	100	100	100	100	100
		19960036	15	97	97	97	97	97	97	97	97
		19520414	77	99	99	99	99	99	99	99	99

[a] New Permit 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 stands for Not Applicable.
[c] New Permit 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).

6.5. Impacts under Climate Change

Recall in Chapter 1.1 that 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 risk factors, including future changes in climate and hydrology, on water supply and demands.

6.5.1. Disclaimer and Uncertainties Related to Climate Change

As with any long-range projection about future water demand or supply conditions, it is important to recognize the uncertainties and assumptions that go into those projections. Projections of future climate are developed using the scientific communities' best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections include numerous assumptions about initial conditions, future greenhouse gases in the atmosphere, and other factors such as solar radiation and volcanic activity to name just a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of ET, temperature, and precipitation changes, may vary. Observed climatic data and GCM simulations show warming trends over recent decades. However, the degree to which the magnitude of GCM simulated warming agrees with historic observations varies based on the data, methods, and time periods used for making such comparisons (Santer et al., 2017ab, Lin et al., 2016, Richardson et al., 2016). The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations, and how measurement errors, internal variability, and other factors can be improved to enhance future performance.

Further, it is important to recognize that these climate prediction models perform better at global rather than regional or watershed level scales. Accordingly, techniques must be employed to localize or "downscale" GCM output for applications to local basins such as the Upper Red River Basin in southwest Oklahoma. Standard practice has been to use the downscaled climate projections as inputs into either demand or supply models which produce projected conditions. Both steps contain many uncertainties. That said, this does not mean that efforts should be abandoned to address these challenges. Rather, the complex interactions underscore the importance of using a planning approach that identifies future risks to water resources systems based on a range of potential future conditions and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

6.5.2. Future Climate Projections

Climate projections of air temperature and precipitation[152] for the URRBS study area were obtained from an archive of downscaled projections developed by Reclamation in partnership with the USGS, U.S. Army Corps of Engineers, Lawrence Livermore National Laboratory, Santa Clara University, Climate Central, and Scripps Institution of Oceanography[153]. The downscaled dataset was originally derived based on GCM simulations compiled by the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP), specifically Phase 5 (CMIP5). The GCM resolutions are 100 to 250 km whereas the downscaled data are closer to 10 km resolution (1/8° latitude by 1/8° longitude) which is more appropriate to assess regional conditions, namely the four eight-digit Hydrologic Unit Code (HUC8) sub-basins making up the URRBS study area (Figure 6-25). A total of 231 projections of average annual temperature and

[152] Precipitation and air temperature are considered primary drivers that affect supply and demand.
[153] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

precipitation encompassing the years 2045 to 2074 were compared to average annual historical ("baseline") temperature and precipitation conditions encompassing the years 1950 to 1999[154]. Details on the CMIP5 projections and how those projections were downscaled to the URRBS study area are found in Reclamation (2016) (Appendix F).

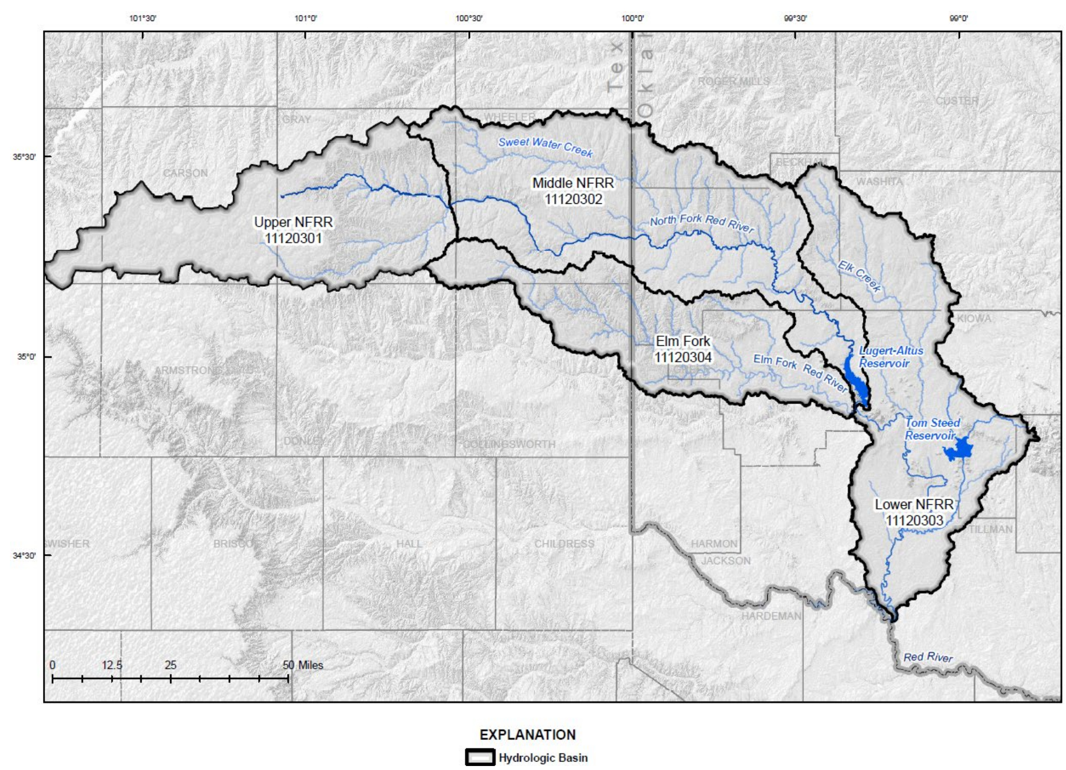


Figure 6-25. Hydrologic Unit Code (HUC8) sub-basins making up the URRBS.

Under baseline conditions for the URRBS study area, average annual temperature was 60°F and average annual rainfall was 24 inches across all four sub-basin HUCs. The relative percent change in baseline versus future projected climate conditions is illustrated in Figure 6-26. All projections showed future warming, ranging from a one to 15 percent increase in average annual temperature from baseline conditions across all four sub-basin HUCs (Figure 6-26). Future precipitation was projected to be more variable, ranging

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[154] Downscaled baseline conditions for the URRBS study area were derived using a dataset developed by Maurer et al. (2002).

from a 24 percent decrease (drier) to a 22 percent increase (wetter) in average annual precipitation relative to baseline conditions (Figure 6-26).

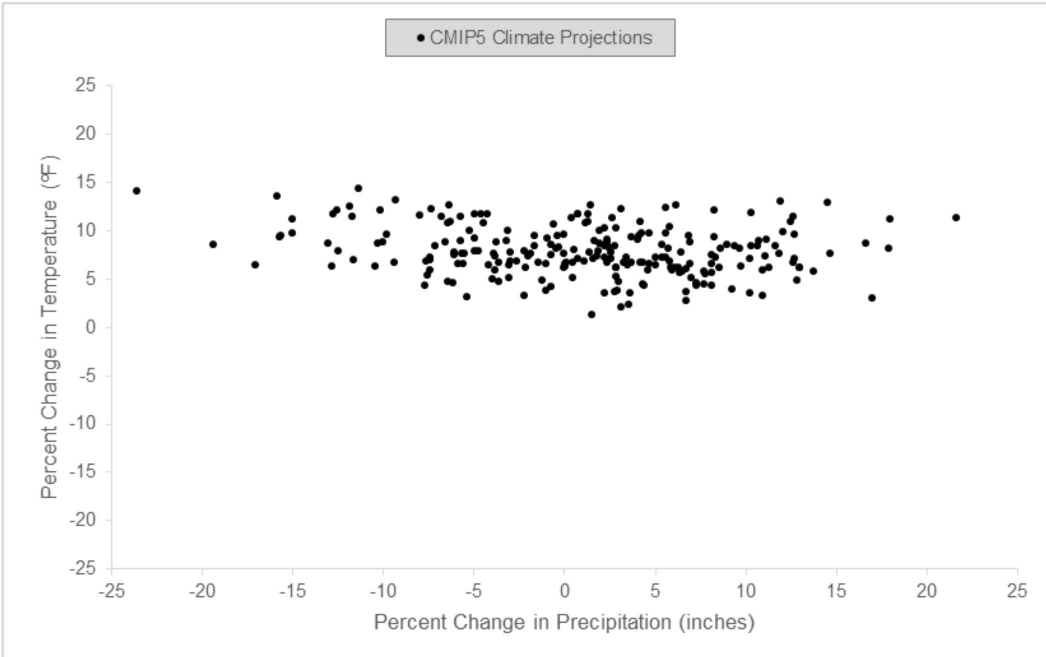


Figure 6-26. Percent change in future (2045-2074) temperature and precipitation relative to historical baseline conditions (1950-1999) where average annual temperature and precipitation are 60°F and 24 inches, respectively, across four sub-basin HUCs making up the URRBS study area. Changes are based on 231 downscaled CMIP5 projections.

6.5.3. Future Climate Change Scenarios

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 10th, 50th, and 90th percentiles of change relative to the baseline (Figure 6-27). This approach not only smoothed out the projections by removing extreme outliers but reduced the number of model runs (three versus 231), while still ensuring that the full range of future conditions were considered. Using Figure 6-27, three climate change scenarios were selected as follows: (1) *warm-wet* (blue diamonds); (2) *median* (yellow diamonds); and (3) *hot-dry* (red diamonds). Table 6-24 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. All three climate scenarios showed future warming, ranging from a five to 16 percent increase in average annual temperature from baseline conditions across all four sub-basin HUCs (Figure 6-26). The basin-wide mean temperature, weighted by surface area, for the warm-wet, median, and hot-dry scenarios was projected to increase by six, nine, and 13 percent relative to the baseline (Table 6-24). Future precipitation was projected to be more variable, ranging from a five percent decrease (drier) to a 11 percent increase (wetter) in average annual precipitation relative to baseline conditions (Table 6-24). The basin-wide mean precipitation, weighted by surface area, for the warm-wet, median, and hot-dry scenarios was projected to increase by 11 percent, increase by six percent, and decrease by five percent relative to the baseline (Table 6-24).

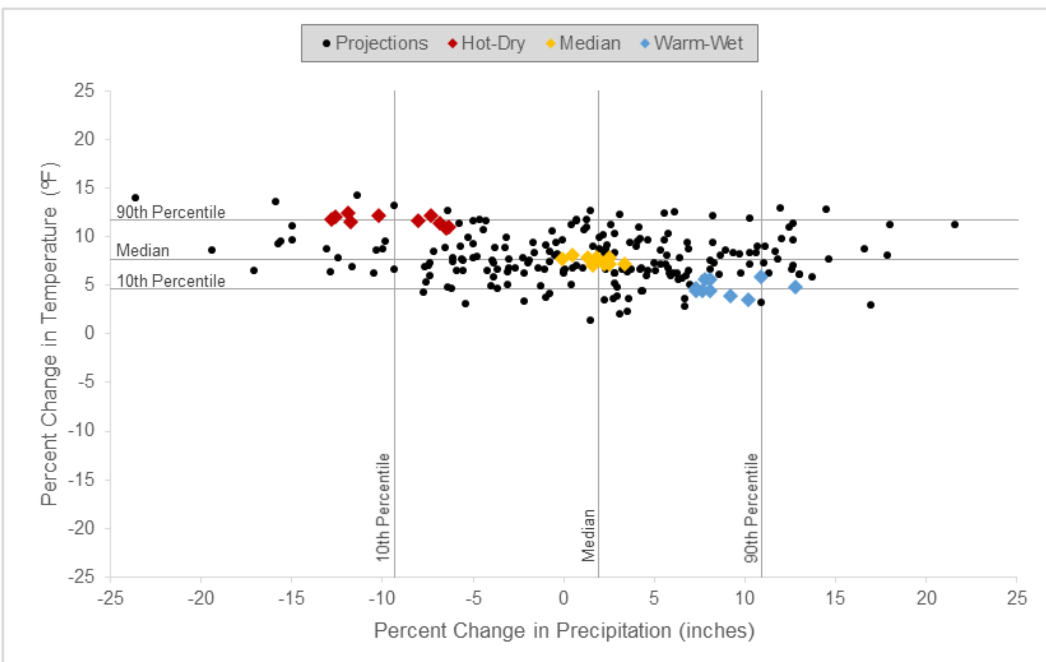


Figure 6-27. Three subgroups (hot-dry; median; and warm-wet), each comprised of ten temperature and precipitation projections (2045-2074) that fall closest to the intersections of the 10th, 50th, and 90th percentiles of change relative to the baseline (1950-1999).

Table 6-24. 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.

	Baseline	Warm-Wet	Median	Hot-Dry
Sub-basin (HUC)	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%*

6.5.4. 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, both at the reservoir and within the basin, under all eight status-quo groundwater and stream-water development scenarios evaluated in Chapter 6.4, including the naturalized flow record based on reported water use between 1950 and 2016. However, this option would have effectively added 30 additional modeling scenarios to an already complicated status-quo analysis[155], and study partners were concerned that such a large number of modeling scenarios could create confusion among stakeholders and subsequently reduce the probability of

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

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.

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 (the RRY model is discussed in Chapter 6.2.2), and the weighted basin mean percent change factors for each of the three climate change scenarios identified in Table 6-24 were applied to the observed period of record between Jan 1926 to Dec 2016. Simulated reservoir yield and supply dependability estimates assumed year 2060 sediment conditions.

6.5.5. Impacts on Lugert-Altus Reservoir Supply

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. An illustration comparing annual inflow based on the observed record versus the three future climate change scenarios is provided in Figure 6-28. Using the observed period of record, average annual inflow into Lugert-Altus Reservoir was 108,000 acre-ft/yr (Figure 6-29). 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 6-29). 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 6-30). Similar trends resulted when evaluating the impacts of future climate change on dependability of both the irrigation and M&I permits (Figure 6-31), as well as a range of available irrigation supplies (Figure 6-32).

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.

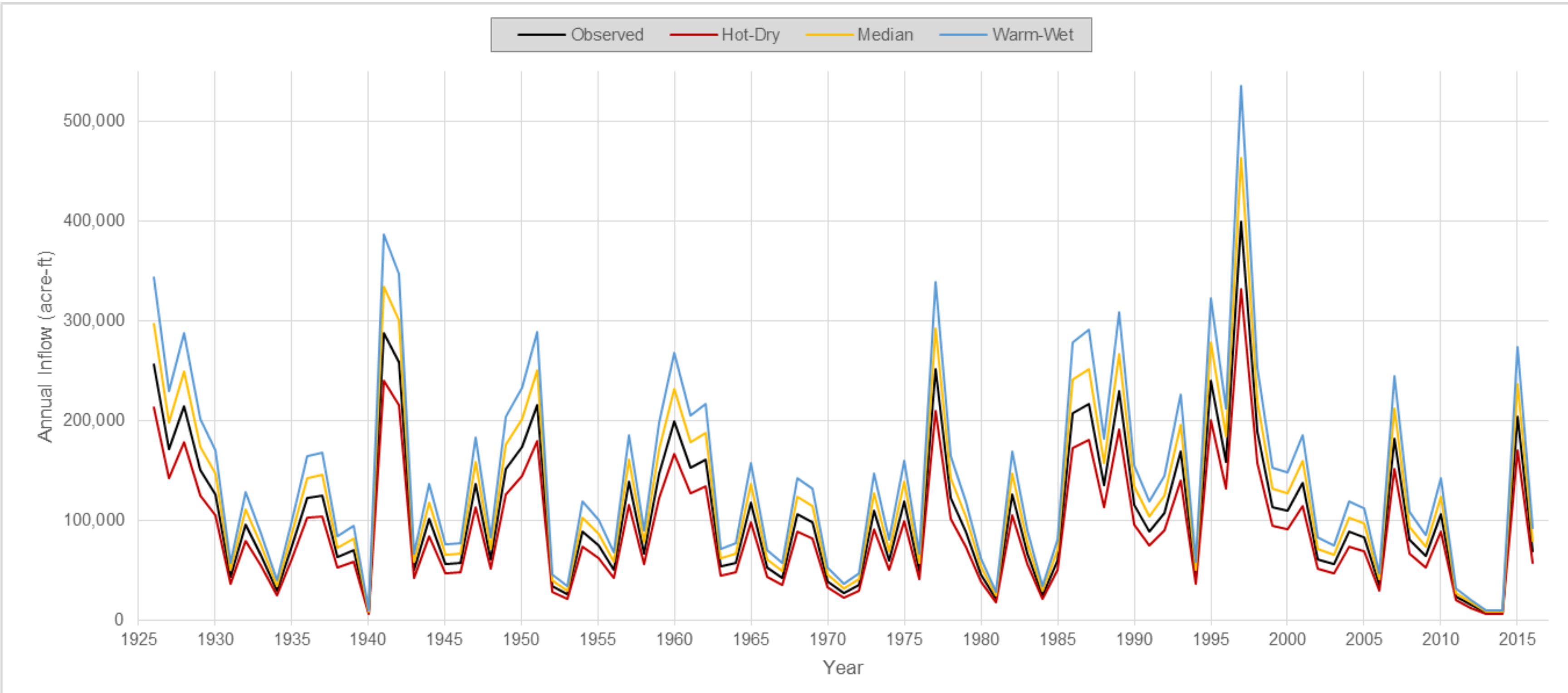


Figure 6-28. A comparison of annual inflows into Lugert-Altus Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

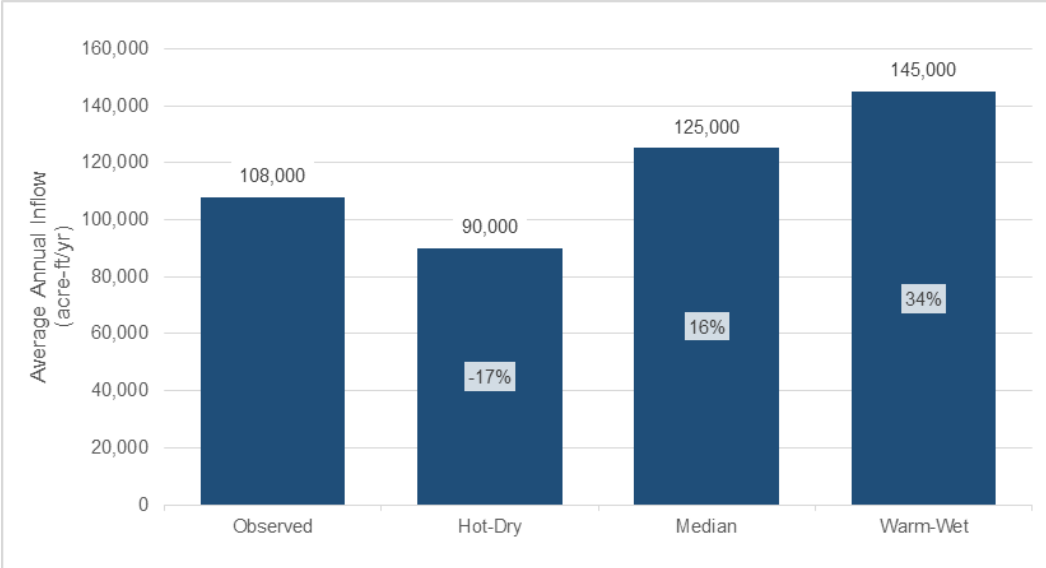


Figure 6-29. A comparison of average annual inflow into Lugert-Altus Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

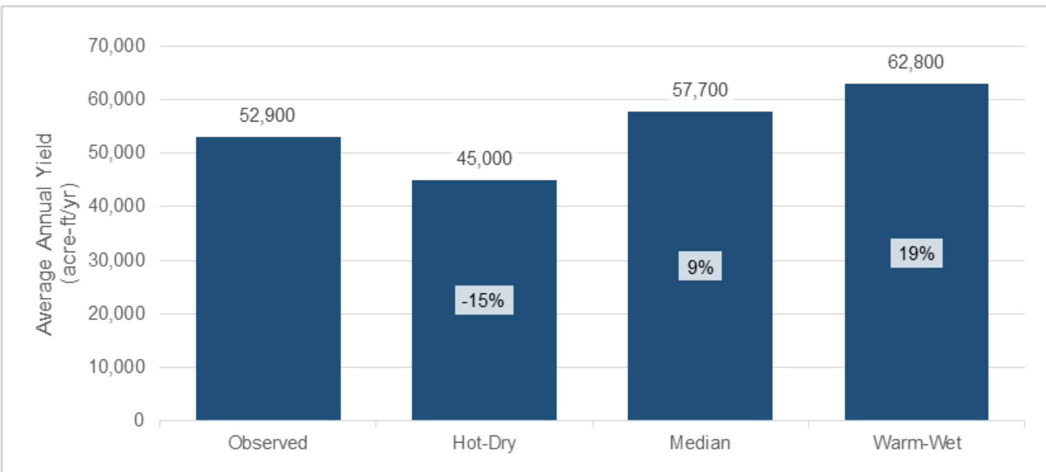


Figure 6-30. A comparison of average annual yield of Lugert-Altus Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

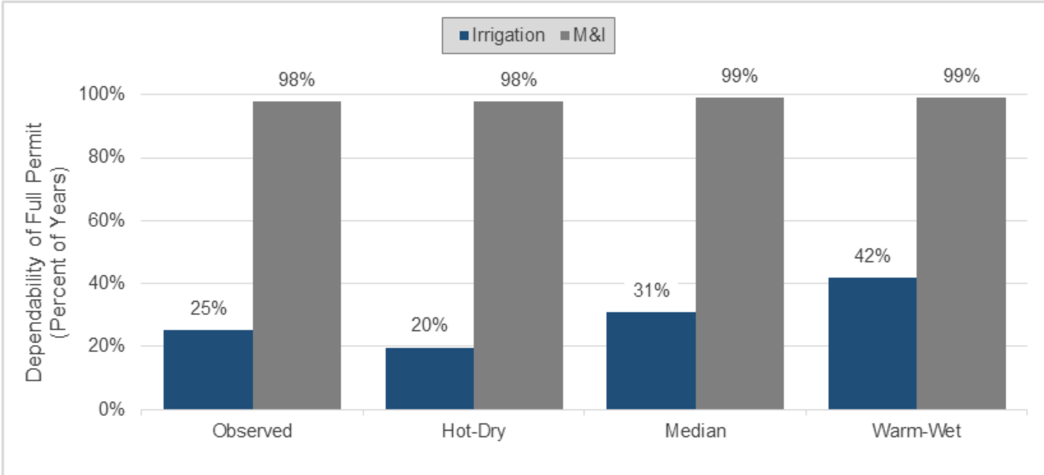
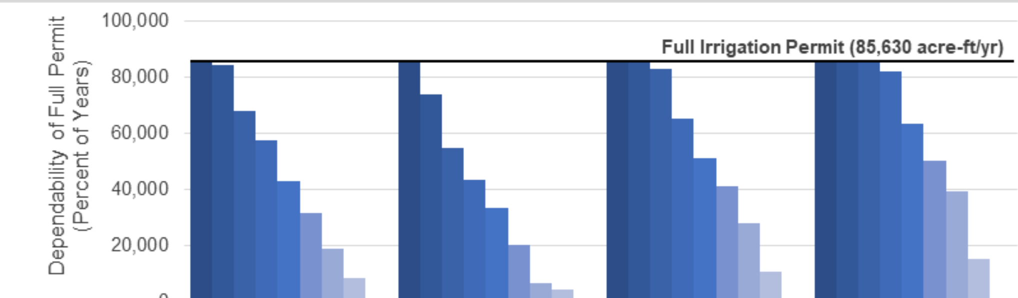


Figure 6-31. A comparison of the dependability of the full volume of irrigation water permitted to Lugert-Altus ID (85,630 acre-ft/yr) and the 4,800 acre -ft/yr of M&I water permitted to the United States for use by the city of Altus based on the observed record (1926-2016) versus three future (2045-2074) 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 6-32. 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).

6.5.6. Impacts on Lugert-Altus Reservoir Demands

This section summarizes a risk analysis completed by Reclamation on the impacts of climate change 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 most of the discussion below centers on agricultural irrigation demands with a brief discussion on M&I demands. Details on the approach and findings can be found in two documents. Reclamation (2017) described: (1) the methods used to develop historical and future estimates of agricultural lands and cropping patterns in the hydrologic basin; (2) how meteorological data and global climate model projections were used; (3) the methodology for calculating evapotranspiration demands; and (4) results on the net irrigation water requirements of future agriculture in the basin. Using these methods, Reclamation (2019) provided updated results when new information became available.

Impacts on Future Irrigation Demands

Demands were evaluated by calculating the Net Irrigation Water Requirement (NIWR) for agricultural lands overlying the NFRR aquifer. The NIWR was derived by subtracting precipitation from crop evapotranspiration (ET)[156] using an ET Demands Model originally developed and modified by the University of Idaho, Desert Research Institute, and Reclamation as part of a collaborative West Wide Climate Risk Assessment (Reclamation, 2014). The ET Demands Model was based on the Penman Monteith dual-crop-coefficient method (PM Method), as described in the Food and Agriculture Organization of the United Nations (Allen et al., 1998).

[156] ET is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Jensen et al., 1990).

The acreage of irrigated lands by crop type were estimated using the Cropland Data Layer (CDL) generated by the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service, which combines satellite imagery and crop census data collected from farmers into digitized maps of crops[157] (Table 6-25). To distinguish between irrigated versus non-irrigated crops, the CDL was overlaid with a digitized map of groundwater permits issued by the OWRB (permitted lands were assumed to be irrigated). Weighted average soil conditions for the irrigated lands in each HUC sub-basin were input into the ET Demands Model. Soil information was based on data obtained from the Natural Resources Conservation Service (NRCS) (USDA-NRCS, 1991). Meteorological data for the NFRR and Elk City aquifers were taken from the Altus and Bessie Oklahoma Mesonet Sites, respectively.

Table 6-25. Total surface area and irrigated crop area within four HUCs making up the URRBS study area.

HUC Number	HUC Name	Total Surface Area (acres)	Irrigated Crop Area (acres)
11120301	Upper NFRR	754,992	63,308
11120302	Middle NFRR	1,058,834	86,162
11120303	Lower NFRR	885,942	65,137
11120304	Elm Fork	594,190	34,050
Basin Total		**3,293,958**	**248,657**

Crop 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 ET 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 6-26). 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

[157] https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php.

(Table 6-26). Putting this into perspective, this means that the future groundwater demands discussed above in Chapter 5.4.1, 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, 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 6-26. 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%*

Irrigation Demand Uncertainties

It is important to acknowledge the various uncertainties and limitations in modeling NIWR. One source of uncertainty was the assumption that future cropping patterns and farming practices would remain static. Reclamation (2017) used data from the USDA crop land data layer and the OWRB water rights data as the sources for quantifying the types of irrigated crops grown in the basin, and it was assumed these crop types and quantities did not change in the modeling. Obviously, increases or decreases in the overall land area irrigated would result in respective changes in demands. Another source of uncertainty in Reclamation

(2017) was the weighted average soil conditions used in the estimation of NIWR. Precipitation runoff and soil water holding capacity were a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. Furthermore, climatic data used in the NIWR analysis were limited to daily maximum and minimum temperatures and daily precipitation, so solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Integration of potential changes in solar radiation and evaluating the potential impact of such changes on irrigation water demands were not addressed in this analysis. Next, given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there was considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET. Finally, an important limitation in the application of the ET Demands model for this assessment was the lack of consideration as to how carbon dioxide potentially impacts crop development and water use. The impact of increased carbon dioxide on crop transpiration, water use efficiency, and crop yield was of particular interest and was probably one of the largest uncertainties pointed out in Reclamation (2017). Addressing the impacts of carbon dioxide on irrigation water demands was currently a focus of further research.

Impacts on Future M&I Demands

The only M&I user of Lugert-Altus Reservoir is the city of Altus, and although the city of Altus primarily receives its water from Tom Steed Reservoir, it was considered here because the city has and could demand its full contractual right to water from Lugert-Altus Reservoir. Reclamation (2017) analyzed the impacts of climate change on M&I demands on Tom Steed Reservoir, but the results are presented here because they included the city of Altus. Recall also that the projected 2060 M&I demands on Tom Steed Reservoir ranged from 6,000 acre-ft/yr to 12,600 acre-ft/yr, the city of Altus' share of which ranged from

4,700 acre-ft/yr to 8,800 acre-ft/yr (Chapter 5.4.2; Figure 5-68). Only outdoor water use was assumed to be vulnerable to climate change, such that GPCD use could increase to meet an increased NIWR of outdoor residential and commercial green areas. To estimate outdoor use, average monthly demands during the winter (December through February), which were assumed to be exclusively for indoor use, were subtracted from total demand for the year. Using the same ET Demands Model described above, Reclamation (2017) found that the net increases in future (2060) M&I water demand on Tom Steed Reservoir ranged from two percent (Warm-Wet) to ten (Hot-Dry) percent relative to baseline conditions. The city of Altus' share of these changes was not quantified, although it is the largest of the three M&I users of Tom Steed Reservoir, so a relatively large proportion of the climate change impacts quantified by Reclamation (2017) are likely attributable to the city of Altus.

6.5.7. Impacts on Tom Steed Reservoir Supply

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 6-33. Using the observed period of record, average annual inflow into Tom Steed Reservoir was 67,000 acre-ft/yr (Figure 6-34). 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 6-34). 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 6-34; Figure 6-35). 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 6-34; Figure 6-35). Similar trends resulted when evaluating the impacts of future climate change on dependability of MPMCD's water right permit (Table 6-27).

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.

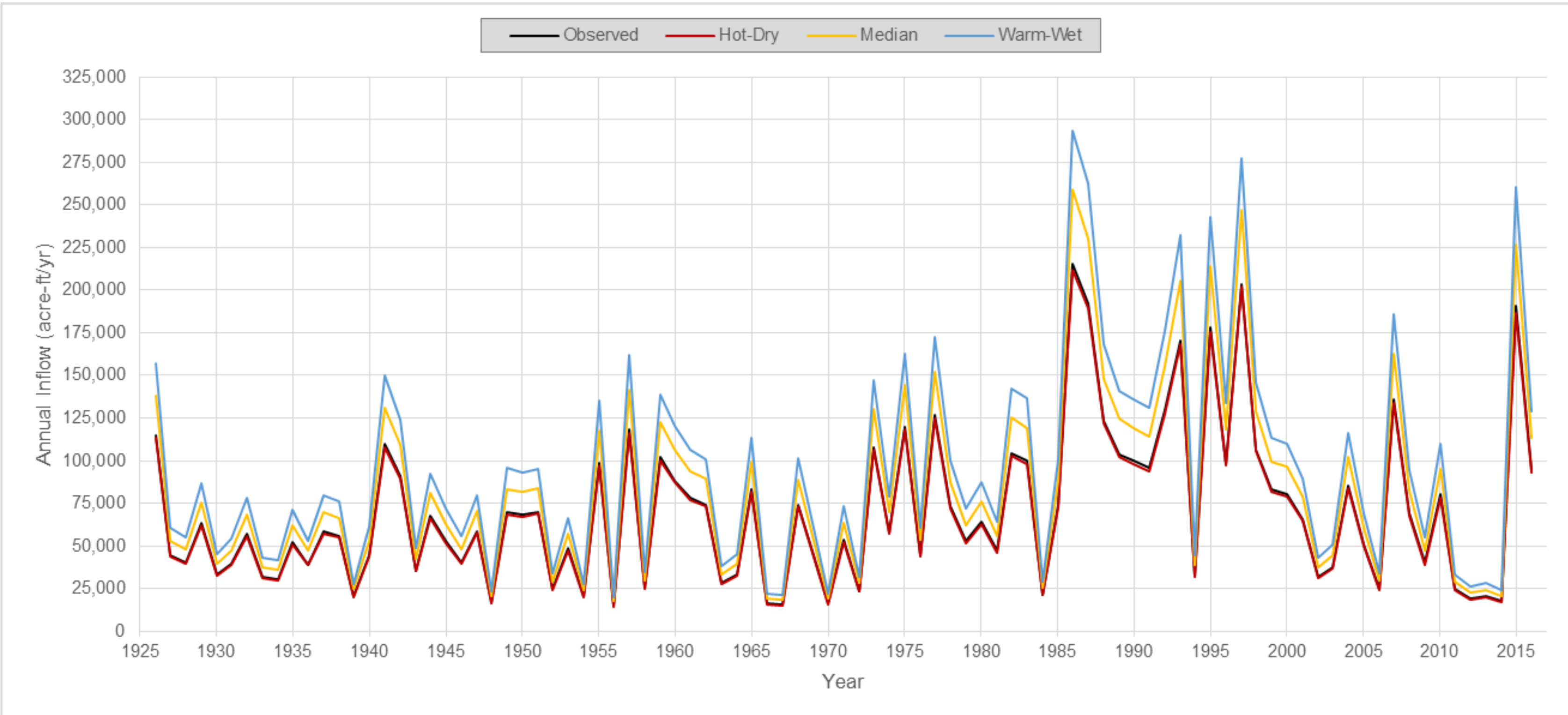


Figure 6-33. A comparison of annual inflows into Tom Steed Reservoir based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

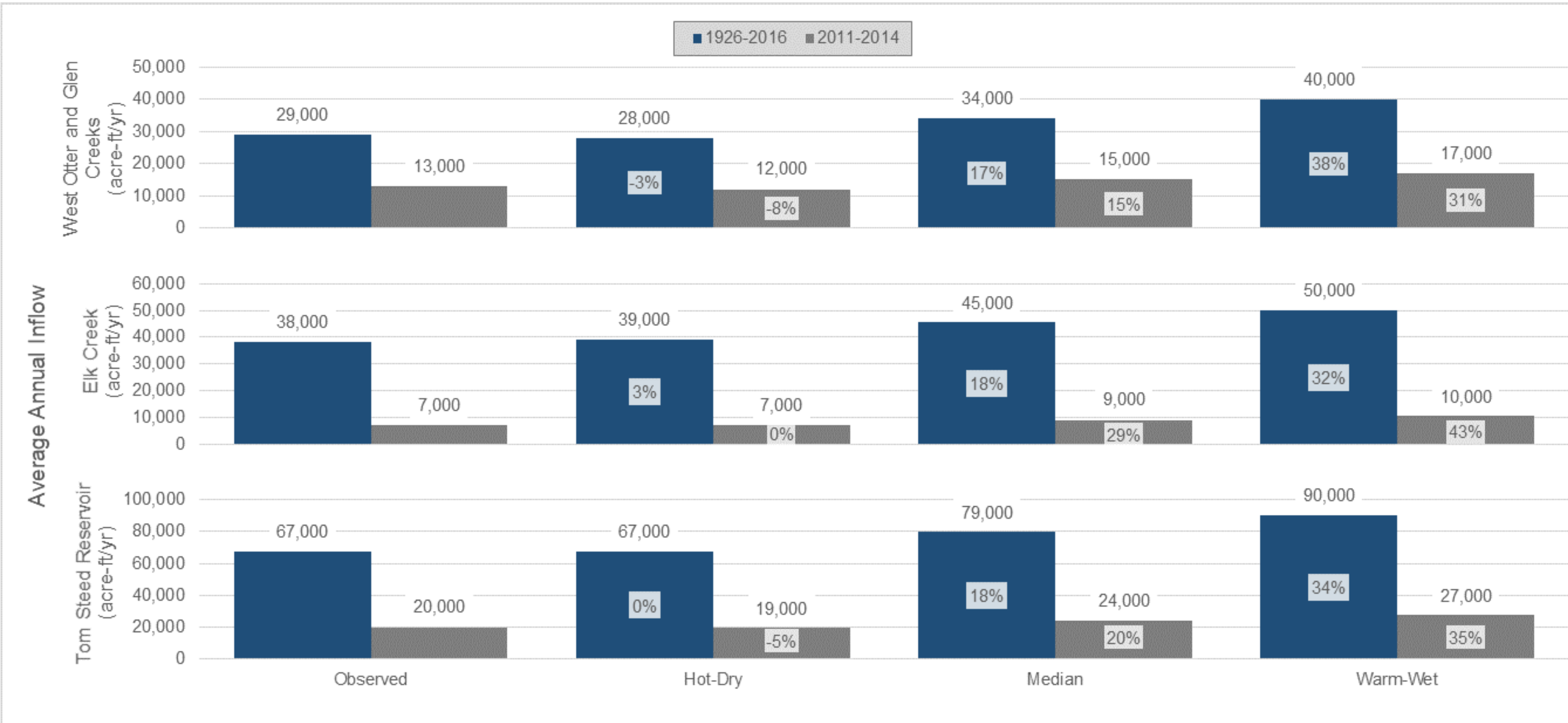


Figure 6-34. A comparison of average annual inflow into Tom Steed Reservoir based on the observed record (1926-2016) and during the drought of record (2011-2014) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

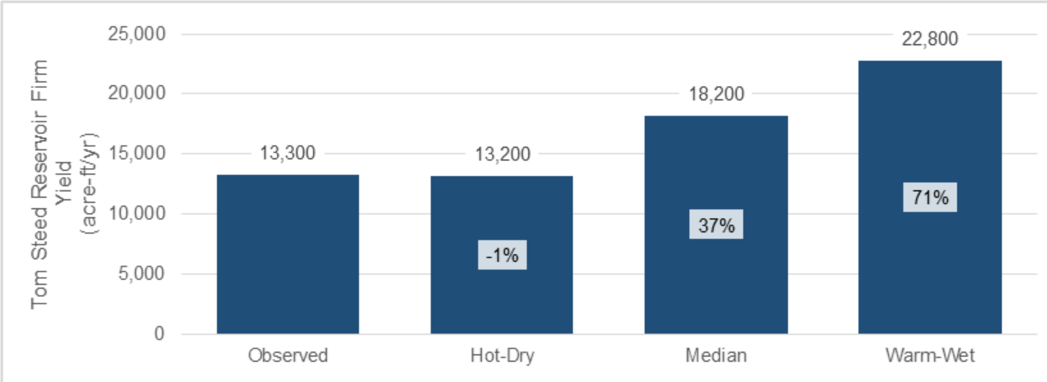


Figure 6-35. A comparison of Tom Steed Reservoir firm yield based on the observed record (1926-2016) versus three future (2045-2074) climate change scenarios (Hot-Dry; Median; Warm-Wet).

Table 6-27. 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

6.5.8. Impacts on Tom Steed Reservoir Demands

Reclamation (2017) analyzed the impacts of climate change on M&I demands on Tom Steed Reservoir. Recall that projected 2060 M&I demands on Tom Steed Reservoir ranged from 6,000 acre-ft/yr to 12,600 acre-ft/yr (Chapter 5.4.2). Only outdoor water use was assumed to be vulnerable to climate change, such that GPCD use could increase to meet an increased NIWR of outdoor residential and commercial green areas. To estimate outdoor use, average monthly demands during the winter (December through February), which were assumed to be exclusively for indoor use, were subtracted from total demand for the year. Using the same ET Demands Model described above, Reclamation (2017) found that the net increases in future (2060) M&I water demand ranged from two percent (Warm-Wet) to ten (Hot-Dry) percent relative to baseline conditions.

6.6. 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's Technical Memorandum, "Economic Impacts of Drought on Recreation and Irrigated Agriculture" [Reclamation (2018b) (Appendix I)]. The purpose of the economics analysis was to evaluate the extent to which changes in reservoir levels and water deliveries at Lugert-Altus and Tom Steed reservoirs impact recreational benefits, irrigation benefits associated with irrigation water deliveries to project lands within the Lugert-Altus Irrigation District, and overall regional economic activity associated with the two reservoirs. Data sources, methods, results, assumptions, and uncertainties are detailed in Reclamation, 2018b. Separately, an estimate of agricultural irrigation benefits also was calculated using the most recent available crop revenue data provided by Lugert-Altus ID.

It should be noted that throughout the entirety of this URRBS report, discussions on Lugert-Altus and Tom Steed reservoirs have generally been divided by separate subheadings to facilitate the readers access to information specific to one of the two reservoirs; however, when Reclamation (2018) was published, the methods and results for each of the two reservoirs was combined with the purpose of providing economic benefit information on the URRBS study area as a whole. In being consistent with Reclamation (2018), the summary below follows that format.

6.6.1. Local and Regional Economic Features

Recreation

Lugert-Altus Reservoir supports recreational and educational activities at Quartz Mountain State Park. Quartz Mountain State Park, managed by OTRD, is situated on the western side of Lugert-Altus Reservoir. The park provides opportunities for camping, swimming, boating, fishing, hiking, picnicking, etc. One of the prominent features within the park is the Quartz Mountain Resort Arts and Conference Center, which contains a lodge-style hotel, an Arts Institute, swimming beaches, cabins, camping, and numerous other amenities that support corporate retreats, conferences, workshops, and weddings. On the north end of Lugert-Altus Reservoir lies the Altus-Lugert WMA. The WMA is managed by the ODWC and is comprised of 3,600 acres of habitat that supports hunting and wildlife viewing. The WMA consists mainly of river bottom and slough areas with dense vegetation, cattail and other aquatic species. Because the NFRR flows through the area, occasional high lake levels back water into the WMA and create areas of flooded timber, resulting in excellent wetland habitats for waterfowl. Common game include bobcat, coyote, deer, rabbit, turkey, dove, and quail. The WMA supports diverse nongame species, including bald eagles during the winter.

Tom Steed Reservoir supports recreational activities at Great Plains State Park. Great Plains State Park, managed by the OTRD, is situated on the southern and eastern shores of Tom Steed Reservoir. The park covers over 480 acres and includes trails for mountain biking and hiking, boulder fields for rock climbing, and is the site of an abandoned mine. Recreation resources at Tom Steed Reservoir include over 30 miles of shoreline, a beach area, boat ramps, and developed camping and picnicking areas. Recreation activities include swimming, fishing, water-skiing, camping, picnicking, hiking, and sight-seeing. The campground includes 34 tent sites and 56 RV sites. Facilities at the Park also include comfort stations, a bait shop, and playgrounds. On the western and northern shores is the Mountain Park WMA which is managed by ODWC. The Mountain Park WMA is comprised of 5,400 acres of mixed grassland, scrub mesquite, and agricultural fields of winter wheat and milo. The area supports numerous upland game species, including deer, rabbit, bobcat, coyote, turkey, dove, and quail, as well as diverse nongame species, including migrating bald eagles during the winter. A 320-acre wetland unit is managed for waterfowl through agriculture plantings and native wetland plant enhancement.

Irrigated Agriculture

Lugert-Altus Reservoir provides irrigation water to 48,000 acres of privately-owned land located within the Lugert-Altus ID. Rainfall in the area is sufficient to grow crops with fairly good yields, although recurring droughts are prevalent. Cotton is the major irrigated crop in the Lugert-Altus ID. Other crops include wheat, alfalfa, grain sorghum, and specialty crops such as potatoes and onions. A study performed by Reclamation in 2015 found that average crop yields were 1.23 tons per acre for wheat, 1,110 pounds per acre for cotton, and 0.8 tons per acre for cotton seed (Reclamation, 2015)

Regional Economy

For the purposes of the regional analysis, the study area included five counties: Caddo, Comanche, Jackson, Greer, and Kiowa. A community profile for the URRBS study area by the Altus Southwest Area Economic Development Corporation (2018) indicated there are two major contributors to economic growth and stability in the region: Altus Air Force Base (AFB) and the agricultural industry, both of which benefit from, if not depend entirely on, Lugert-Altus and Tom Steed reservoirs. The Altus AFB is a customer of the city of Altus, which primarily receives its water from Tom Steed Reservoir, although the city of Altus also is allocated M&I water from Lugert-Altus Reservoir through a water right held by the U.S. Wheat, cattle, and cotton are important agricultural products produced in the area. Jackson County, which includes the city of Altus, is the highest cotton producing county in Oklahoma.

According to the 2016 U.S. Census, the total population of the five-county region was 195,277 with 69,511 households, including civilian labor force of 84,381. According to an Altus AFB Economic Impact Statement for Fiscal Year 2018, as of January 2017, there were 3,164 total military and dependents and 1,507 civilian personnel associated with the Altus AFB (Altus AFB, 2018). The Altus AFB Impact Statement also indicated that 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 indicated that Altus AFB had an annual employment impact of about 7,500 jobs over the 2011 to 2015 time period (Oklahoma Department of Commerce and The State Chamber of Oklahoma, 2011). A more up to date 2017 report by the Oklahoma Aeronautics Commission estimated that the Altus AFB directly and indirectly accounted for nearly 8,890 jobs per year in the region.

As indicated by the 2018 Altus Southwest Area Economic Development Corporation, agricultural production was an important part of the regional economy. Data from the 2012 USDA census showed that agricultural-related sales in 2012 were valued at nearly $370 million (USDA, 2014).

Crop acreage data were available for 2016, and livestock production data were available for 2017 from the United States Department of Agriculture, National Agricultural Statistics Service (USDA, NASS, 2017). Wheat and cotton represented the first and second greatest crop acreages in the region at 523,000 acres and 121,000 acres, respectively. Beef cattle for the five-county region totaled about 300,000.

Additional labor force and occupation data showed that the top ranked employment sector for all five study area counties was the educational services, health care, and social assistance sectors. Direct employment in the agriculture, forestry, fishing and hunting, and mining sectors has had indirect impacts on other sectors. Inputs are needed to support agricultural production and recreation activities, and income from agricultural and recreation service jobs is spent in other sectors of the economy.

6.6.2. Methods and Modeling Approach

Recreation Impacts Analysis

Visitation regression models were developed to evaluate the impact of changes in reservoir elevation on recreation at the two subject 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. Separate models were developed for the eight-month period from March through October (recreation season) and the four-month period from November through February (winter season), resulting in a total of six visitation models for the three recreation sites. The visitation models were developed using historical July 2000 to November 2016 monthly visitation data at the three sites, end of month reservoir elevation data, average monthly climatic data, and average monthly data for income and travel costs. The dollar value of recreation activities was estimated using a "benefits transfer" approach that incorporated data from previously-completed studies on similar recreation activities. The dollar value of recreation benefits was subsequently multiplied by visitation data and input into the regression models to predict impacts from changes in reservoir elevation on recreation visitation and values. Details are provided in Reclamation, 2018b (Appendix I).

Irrigated Agriculture Impacts Analysis

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. Details are provided in Reclamation, 2018b (Appendix I).

Separately, a supplemental estimate of agricultural irrigation benefits also was calculated using the most recent available crop revenue data provided by Lugert-Altus ID for the years 2015 to 2021 (after the drought of record).

Regional Economic Impact Analysis

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.

The IMPLAN model is capable of simulating impacts on up to 536 different economic sectors, both individually and cumulatively. Impacts were quantified in terms of estimated changes in the demand for goods and services, which were derived as a sum of the direct, indirect, and induced effects related to changes in reservoir elevation. Direct effects represented impacts on the industry that were immediately affected by the change. For example, if recreation visitation increased as a result of higher reservoir levels, then the amount of recreation services demanded would increase, and more inputs would be needed to meet that demand. The direct effect would be increased income and employment needed to satisfy increased demand for recreation services. Indirect effects accounted for transactions between different sectors. As such, if the recreation service industry expanded in the region to satisfy the increased demand, then the recreation service industry would increase demand for locally produced materials and labor to produce the needed recreation services. This results in additional jobs and income to meet the new recreation industry demand. Induced effects measured the effects of the changes in household income resulting from direct and indirect effects on the demand for goods and services such as housing, restaurants, and retail sales.

6.6.3. Results

Recreation Benefits

Based on an analysis of previously-conducted studies on similar recreation activities, recreation at Lugert-Altus and Tom Steed reservoirs was valued at $60 per trip for overnight trips and $20 per day per visitor for day use. Multiplying these values by visitor use statistics, 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 of Quartz Mountain Lodge and Quartz Mountain State Park was estimated to be $1.4 million annually, of which $942,700 was derived by Quartz Mountain Lodge and $424,000 was derived by Quartz Mountain State Park. 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

Reclamation (2018) estimated a total of 47,841 acres in the Lugert-Altus ID with average annual water deliveries of 76,197 acre-ft, yielding an estimated irrigation application of 1.59 acre-ft per acre. The total benefit of irrigation in the Lugert-Altus ID was estimated to equal 76,197 acre-ft of deliveries multiplied by the average benefit of $68.50 per acre-foot or $5.22 million annually in 2016 dollars. 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 in 2016 dollars.

The impacts from a one-foot change in reservoir elevation were estimated to be $72,100 annually or about 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 about 1.4 percent of the total crop revenues associated with the Lugert-Altus ID.

In addition to the analyses provided a 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-yr period averaged $1,355 per acre[158]. 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.

Impacts on Regional Economy

For Tom Steed Reservoir, IMPLAN modeling showed that direct, indirect, and induced recreation benefits associated with Great Plains State Park totaled

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

$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, IMPLAN modeling showed that direct, indirect, and induced recreation benefits associated with Quartz Mountain Lodge and Nature Park 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.

The Impact of 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 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.

Chapter 7. Identification of Adaptation Strategies

This chapter identifies a range of potential solutions that could address water supply needs facing the study area, along with the justification and process by which these solutions were identified and formulated. This chapter also specifies planning objectives that the range of potential solutions are intended to address. In Chapter 8, these strategies are evaluated to determine how well they perform at meeting planning objectives in terms of reducing water supply deficits and improving overall water supply reliability.

7.1. Overview and Approach

As described in Chapter 2, the study area has continued to experience a wide array of challenges related to managing water supplies and demands; infrastructure and operations; addressing data and model limitations; and navigating legal and policy issues. Yet, as Chapter 3 pointed out, many of these challenges are already being addressed through efforts by stakeholders, academia, the state, and non-Reclamation federal agencies. Accordingly, such efforts were eliminated from further consideration in the URRBS. Chapter 4 set forth the goals and objectives of this URRBS study, focusing on opportunities for new investigation where Reclamation could provide useful assistance that was not otherwise being provided through other efforts.

The first objective set forth was to characterize and quantify existing and future water supplies and demands in the Lugert-Altus Reservoir and Tom Steed Reservoir hydrologic basins. Existing demands, existing supplies, and future demands were covered under Chapter 5. The characterization and quantification of future supplies were covered in Chapter 6, which was made possible by accomplishing the second URRBS objective which included data collection and groundwater modeling to determine future groundwater availability, and to quantify impacts on the base flow of connecting streams that contribute inflow to Lugert-Altus and Tom Steed reservoirs. The analysis of future supply availability described in Chapter 6 also was made possible by accomplishing the third URRBS objective, which was to develop a surface water allocation model to evaluate how groundwater and surface water management options may affect the water supplies and water rights in the Lugert-Altus and Tom Steed Reservoir hydrologic basins. This model, tailored specifically to the NFRR, simulated the stream-reservoir system in its naturalized state, thus enabling an analysis on the impacts caused by a range of future groundwater and stream-water development scenarios. The results of this analysis, also provided in Chapter 6, addressed the third URRBS objective, which was to assess the current and future capability of existing infrastructure and operations to meet demands, including risks and reliability of Lugert-Altus and Tom Steed Reservoir supplies.

Indeed, the results presented in Chapter 6 showed that water supplies were insufficient to meet demands, both in terms of delivering the quantity of water that is currently being (or is projected to be) put to beneficial use and/or in terms of delivering the full volume of permitted stream water in the basins, including permits for water stored in Lugert-Altus and Tom Steed reservoirs. Results did not necessarily confirm whether existing infrastructure and operations of the W.C. Austin and Mountain Park Projects were sufficient to meet current or future demands. In other words, the capability of existing infrastructure and operations to sufficiently meet demands depends on how the term "sufficiently" is defined in the context of risk management. Whatever the case may be, when URRBS objectives were first formulated, both the Lugert-Altus ID and MPMCD, having just experienced very severe multi-year droughts, recognized that existing supplies and infrastructure were insufficient to meet existing and future demands, thus opening the door to an evaluation of both non-infrastructure and infrastructure strategies in the URRBS.

This approach was expressed in the fourth and final URRBS objective, which is the subject of Chapter 7 and Chapter 8. The fourth objective was to identify strategies to address infrastructure issues and water supply imbalances facing Lugert-Altus and Tom Steed reservoirs (Chapter 7), as well as to evaluate how well these strategies perform in terms of meeting specified planning objectives (Chapter 8). A continued discussion on the formulation of non-infrastructure and infrastructure strategies immediately follows, with the proceeding discussion focusing on the formulation of planning objectives for each of the two hydrologic basins, along with a more detailed description of adaptation strategies formulated for each respective basin.

The primary preferred non-infrastructure management strategy identified by study partners was to *protect existing stream-water rights* to Lugert-Altus and Tom Steed reservoirs through an administrative regulatory mechanism that curtails diversions from junior stream-water permit holders when one or more pre-determined trigger points (i.e., thresholds) has been met. As described in Chapter 3.2, this strategy was one of several high-priority recommendations outlined in the state-led OCWP. As the URRBS was being initiated, this strategy was largely considered to be the most important element of the URRBS, both in terms of the level of effort needed to develop a reasonable and defensible set of tools and parameters that study partners could agree on, as well as in terms of the potential to achieve significant benefits to the study area. The technical analysis supporting this strategy in the Lugert-Altus and Tom Steed Reservoir hydrologic basins are provided in the sections that follow.

In addition to agreeing on conducting a robust technical analysis supporting the protection of stream-water rights, study partners agreed that a review of the legal framework under which this strategy and others could be implemented would be equally beneficial. Study partners commissioned Dr. Drew Kershen, Emeritus Professor of Law at the University of Oklahoma, to perform the legal review[159]. This review included an overview of Federal and

[159] Financial Assistance Agreement Number R17AP00090 between Reclamation and the Board of Regents of the University of Oklahoma was signed September 22, 2017 in accordance with Scope of Work agreed upon by all study partners dated August 4, 2017. Foss and Fort Cobb Reservoirs also were included in the legal review because they are the subject of a separate and ongoing Basin Study in the Upper Washita River basin and share similar water management challenges as Lugert-Altus and Tom Steed Reservoir. Dr. Kershen was selected as the principal investigator due to his unique knowledge and expertise of Oklahoma water law and exceptional reputation among the water management community, including study partners.

state statutes governing water rights and water supply reliability related to Lugert-Altus and Tom Steed reservoirs, the OWRB regulations implementing state statutes, and Federal and state judicial decisions relating to water rights. The analysis also included an academic-level evaluation on the extent to which water management strategies, including protection of existing stream-water rights, may be consistent with existing state law and the OWRB regulations; and if not, identification of modifications that may be necessary to allow such strategies to be implemented.

Another preferred strategy selected by study partners to include in Dr. Kershen's legal review alongside the protection of stream-water permits, which also was identified in the state-led OCWP, was implementation of a form of *conjunctive management* to address potential declines in surface water flows and reservoir yields resulting from groundwater use in areas where these sources are hydrologically connected. Under conjunctive management, two strategies emerged from Kershen (2021): (1) execution of *voluntary dry-year lease or purchase agreements* and (2) consideration of a *conservation-oriented approach towards calculating aquifer maximum annual yield* and allocating groundwater use permits.

In addition to the preferred OCWP-related strategies selected by study partners for review, Kershen (2021) identified new strategies that had not yet been previously identified by study partners at the onset of the URRBS. These included *clarifying existing stream-water rights* and *applying for additional stream-water rights* to Lugert-Altus and Tom Steed reservoirs, as well as *reclassifying alluvial groundwater to stream water*. Kershen (2021) also noted the importance of continued water conservation and education to achieve win-win outcomes. All of these groundwater and stream-water management strategies are defined later in this chapter, with a more detailed summary of Dr. Kershen's legal review and findings provided in Chapter 8. The six-chapter, 291-page legal review in its entirety is included in Appendix A[160]. Next, the discussion turns

[160] This report also can be found here: https://www.usbr.gov/gp/otao/westokbasinstudies_academiclegalreview.pdf.

away from the legal review and briefly describes three more adaptation strategies identified by study partners to address water supply imbalances and potential infrastructure insufficiencies.

For Tom Steed Reservoir, two strategies were identified. The first strategy entailed *addressing Environmental Quality beneficial use* issues related to Hackberry Flat WMA. This strategy was comprised of a combination of various administrative and infrastructure alternatives that address challenges identified in Chapter 2.3.2 and Chapter 2.4.2. For the purposes of the URRBS, a range of potential alternatives related to delivering all EQ water, some EQ water, or no EQ water to Hackberry Flat WMA were identified and evaluated. The second strategy involved *expansion of the Bretch Diversion and Canal* to capture and transport additional flows from Elk Creek to Tom Steed Reservoir. In doing so, the strategy aimed to firm up storage needed to deliver the MPMCD's full permitted volume of 16,100 acre-ft/yr.

For Lugert-Altus Reservoir, a major new storage reservoir on the mainstem of the NFRR, namely *Cable Mountain Reservoir*, was considered as the primary infrastructure strategy. The objective of Cable Mountain Reservoir would be to offset storage reductions in Lugert-Altus Reservoir and provide supplemental water to the Lugert-Altus ID and beyond for agricultural irrigation and M&I purposes.

It is important to point out that when study partners initially identified the two infrastructure strategies (i.e., Expansion of the Bretch Diversion and Canal; Cable Mountain Reservoir) for inclusion into the URRBS, Reclamation agreed to perform a preliminary assessment on their costs and benefits using readily available data; Reclamation stressed that a detailed cost-benefit analysis, including a determination on project "feasibility", would require a significant investment of Federal resources and therefore was excluded from the URRBS[161].

For a lengthier summary of these adaptation strategies and the URRBS objectives by which they were formed, the reader is encouraged to review

[161] Directives and Standard FAC 09-01 https://www.usbr.gov/recman/fac/fac09-01.pdf.

Chapters 3 and 4. Next, this chapter uses the status-quo results presented in Chapter 6 to construct specific planning objectives that these strategies aim to address in the Lugert-Altus and Tom Steed Reservoir hydrologic basins.

7.2. Lugert-Altus Reservoir: Planning Objectives and Strategies

Planning Objectives

This section identifies specific planning objectives for the Lugert-Altus Reservoir hydrologic basin. The objectives generally entailed addressing specific supply imbalances identified through the status-quo results presented in Chapter 6, as well as addressing potential infrastructure insufficiencies. In Chapter 8, an analysis is performed on each strategy's ability to meet these 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 (Chapter 2.3.1). Providing this storage would effectively eliminate supply imbalances described below. 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 Lugert-Altus Reservoir).

As detailed in Chapter 6.4.3, the average annual yield of Lugert-Altus Reservoir ranged from 45,900 acre-ft/yr to 34,200 acre-ft/yr depending on the groundwater and stream-water development scenario (Figure 6-12). These values reflect a 60 percent to 70 percent storage deficit relative to the target of

115,000 acre-ft of water in storage, respectively. Irrigation permit dependability ranged from 21 to 19 percent, and M&I permit dependability ranged from 94 to 93 percent (Figure 6-13). The planning objective was to make these permits 100 percent dependable.

Under the naturalized scenario, the average annual yield of Lugert-Altus Reservoir was 58,300 acre-ft/yr (Figure 6-12). This means that even if the impacts of existing and future groundwater and stream-water development were mitigated, about 50 percent of the imbalance on average would still remain due to the climatological limitations in the basin. Potential future changes in climate (Chapter 6.5.6) could either increase or decrease this vulnerability. Whatever the case may be, 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.

As far as groundwater versus stream-water management, it is worth acknowledging here that the sections below show that existing stream-water permits and domestic use have no measurable impacts on Lugert-Altus Reservoir. With this perspective in mind, the results presented in Chapters 6.4.2 and 6.4.3 revealed two important conclusions: (1) the leading causes of water supply imbalances in the Lugert-Altus Reservoir 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.

These two conclusions can be drawn based on the following observations regarding impacts on the average annual yield of Lugert-Altus Reservoir (Figure 6-12). First, under the naturalized scenario, the average annual yield of Lugert-Altus Reservoir was 58,300 acre-ft/yr. This means that even if the impacts of human-induced development were completely eliminated, a water supply imbalance of about 56,700 acre-ft/yr (50 percent deficit) would still remain[162].

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[162] Relative to the 115,000 acre-ft water in storage planning objective (58,500/115,000 = 51%).

This remaining imbalance would therefore appear to be caused by climatological factors alone, meaning existing and future hydrologic conditions are incapable of supplying the necessary 115,000 acre-ft of water in storage prior to the irrigation season each year. Second, regarding the role of groundwater pumping (Figure 6-12), the “2013 GW” scenario caused a 21 percent reduction in average annual reservoir yield relative to the to the naturalized scenario, whereas the “OCWP GW” scenario caused a 22 percent reduction in average annual yield relative to the naturalized scenario; the latter is only a net reduction of one percent relative to the “2013 GW” scenario. The “Full GW” scenario caused a 32 percent reduction in average annual yield relative to the naturalized scenario, which represents a net reduction of ten percent relative to the “2013 GW” scenario. Similar trends were observed in permit dependability. Again, these results point towards existing groundwater permits as being the leading cause of human-induced impacts on Lugert-Altus Reservoir.

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[163]. 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.

[163] Such a proposed strategy would provide supplemental water *on average* to Lugert-Altus ID and should not be confused with the previously-identified strategy of applying for the unappropriated water (i.e., flashy rainfall and run-off) in the NFRR.

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 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 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. In the discussions that follow, discretion was used to summarize Kershen (2021), but in many cases, Dr. Kershen's own words are used as to protect the integrity of his writings and commentary.

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

Top of Conservation Pool

Lugert-Altus Reservoir has a conservation pool capacity of 128,000 acre-ft (Chapter 2.2.2). The volume of water permitted out of Lugert-Altus Reservoir totals 90,430 acre-ft/yr. This leaves up to 37,570 acre-ft/yr of unpermitted water that can be stored in the reservoir during very wet years. Due to hydrological conditions, Lugert-Altus ID has received less actual "wet" water on average than its "paper" water right allows, and even larger deficits when compared to their

115,000 acre-ft of water in storage target (Chapter 6.4.3). Some have questioned whether Lugert-Altus ID could claim a water right to the top of the conservation pool, effectively expanding its existing stream rights by 37,570 acre-ft to 128,000 acre-ft. Kershen (2021) explored the numerous legal issues involved if Lugert-Altus ID were to assert a water right of 128,000 acre-ft/yr. These issues are discussed in Chapter 8.2.1; yet the purposes here, it is necessary to cite Dr. Kershen's conclusion on the matter, which is that Lugert-Altus ID very likely could *not* make a valid claim to an existing water right to the top of conservation pool.

7.2.2. Protection of Existing Stream-Water Rights to Lugert-Altus Reservoir

Regulatory Protection

As discussed in Chapter 2.2.3 and Chapter 2.6, surface water in Oklahoma is managed under a joint Prior Appropriation/Riparian system. 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 statute, junior permit holders are not allowed to interfere with senior permit holders by taking their water out-of priority ahead of a senior permit holder. A senior permit holder can file a complaint with the OWRB, but Oklahoma statutes do not set forth any specific authority for the OWRB to be proactive in protecting an individual claimant's water rights from interference by others (Kershen, 2021).

Yet, the OWRB has authority to create an administrative enforcement procedure to protect senior priority stream-water permits, and the OWRB could create an administrative procedure to stop or prevent interference with senior priority rights or to prevent out-of-priority use of water rights (Kershen, 2021). What is lacking in the statutes, the regulations, and the case law is any definition of interference or any identification of triggers that can be invoked to protect the water rights of senior holders (Kershen, 2021). To this end, the Lugert-Altus ID and the OWRB could work together to identify interference triggers that take into account the relevant hydrological conditions and needed reservoir yield specific to the NFRR and Lugert-Altus Reservoir, respectively, and then the OWRB could adopt those triggers into new interference regulations that are specific to the Lugert-Altus Reservoir hydrologic basin.

However, given the relatively minor volume of stream-water permits in the Lugert-Altus Reservoir hydrologic basin, a determination had to be made as to whether managing existing junior stream permits above Lugert-Altus Reservoir could meaningfully address the planning objective of having 115,000 acre-ft of water in storage at the beginning of each irrigation season; and thus, the extent to which such a strategy should be evaluated in the URRBS. The logic supporting such a determination follows.

Lugert-Altus ID has operational responsibility for the two senior water rights on the NFRR totaling 90,430 acre-ft/yr, one held by Lugert-Altus ID for 85,630 acre-ft/yr and the other held by the U.S. for the city Altus for 4,800 acre-ft/yr. The volume of existing stream-water permits in the basin that are junior to these two senior permits totals only 1,422 acre-ft/yr (Chapter 5.2.2); of this amount, only 1,032 acre-ft/yr was modeled as a consumptive demand out of the NFRR; and of this amount, only 678 acre-ft/yr was consumed upstream of Lugert-Altus Reservoir, with the nearest permit about 20 miles upstream of the reservoir (Chapter 6.2.3). The volume of provisional temporary permits (PTs) also is relatively low; for example, during the drought of record, 51 PTs were issued averaging only 69 acre-ft annually (Chapter 5.2.2). Regarding new stream-water permits in the Lugert-Altus Reservoir hydrologic basin, according to a OCWP citation which was based on the OWRB's current practice of permitting based on average annual run-off between 1951 and 1980, the basin was closed to the appropriation of new stream-water permits. Status-quo results confirmed the

OCWP's findings, even based on the new 1951-2016 naturalized flow record utilized in the URRBS (Chapter 6.4.3).

In light of the minimal impact that existing junior stream-water permits have on Lugert-Altus Reservoir, it would be difficult to claim those permits create interference with the senior rights to the reservoir; and furthermore, the NFRR watershed above Lugert-Altus Reservoir does not appear to have sufficient water available for new regular stream-water permits. The combination of these two factors led study partners to question the merits of going through the complex and time-consuming process of performing water availability modeling as part of this URRBS in support of developing an administrative procedure to prevent interference with senior priority rights.

Regarding PTs, recall that the aforementioned junior stream-water permits are "regular" permits. The OWRB is authorized to issue non-regular PTs, as well as seasonal, temporary, or term permits, as long as those permits do not interfere with domestic uses or with existing stream-water rights, even when the OWRB finds that no water is available for the appropriation of a new regular stream permit (Chapter 2.2.3). During the 2010-2015 drought of record, although the NFRR was closed the appropriation of regular stream permits, the OWRB granted 51 PTs averaging 69 acre-ft/yr. The Lugert-Altus ID raised concerns with the OWRB that those non-regular permits were impairing and interfering with senior water rights to Lugert-Altus Reservoir. If the OWRB adopted interference regulations specific to Lugert-Altus Reservoir, as discussed above, the OWRB also could address interference by non-regular permits with regular permits (Kershen, 2021). However, given the very small volume of PTs, similar to the argument related to regular stream permits, it would be difficult to claim PTs create interference with the senior rights to the reservoir. In lieu of pursuing regulations on the matter, the Lugert-Altus ID could consider communicating with the OWRB and urging the OWRB to exercise its discretionary authority to not grant stream PTs during times of drought. Indeed, a set of pre-determined thresholds could be identified that could trigger the OWRB's discretionary moratorium on PTs (Kershen, 2021). These thresholds are discussed more under groundwater management strategies below.

A second factor pointed out by Kershen (2021) to consider regarding PTs follows. The OWRB recently adopted regulations allocating ownership rights of brackish groundwater to surface landowners overlying the brackish aquifer. Surface owners could voluntarily grant leases to companies, particularly oil and gas companies which are granted the majority of PTs, for the use of their brackish groundwater. With a valid lease from surface owners, oil and gas companies can then apply to the OWRB for a PT groundwater permit. Once these regulations become legally effective, Lugert-Altus ID could urge the OWRB to grant PT groundwater permits from brackish aquifers that have no impact on NFRR base flows rather than PT stream permits from NFRR alluvial aquifers.

After careful deliberation in light of the information discussed above, study partners decided to eliminate from further consideration the strategy of managing or otherwise curtailing junior stream-water permits upstream of Lugert-Altus Reservoir. Rather, study partners wanted to focus the URRBS evaluation on identifying hydrologic thresholds that could be used to manage permitted alluvial groundwater pumping upstream of Lugert-Altus Reservoir, which was known through this study as having a far greater impact on reservoir supplies than existing stream permits. Although such a strategy would likely require a future change in Oklahoma law that reclassified certain alluvial groundwater above Lugert-Altus Reservoir to stream water, it was considered by Lugert-Altus ID to be a preferred strategy worthy of detailed consideration in the URRBS. This option is discussed below in Chapter 7.2.5 “Reclassification of Alluvial Groundwater to Streamwater” and includes an extensive discussion on the development of the hydrologic thresholds that could be used to manage withdrawals of permitted alluvial groundwater pumping above Lugert-Altus Reservoir.

Non-Regulatory Protection

Another strategy to protect the existing irrigation and M&I rights to water stored in Lugert-Altus Reservoir is for Lugert-Altus ID to purchase existing water rights and/or enter into dry-year lease agreements with senior stream-water permit holders on the NFRR. The purchase of a senior water right would entail the voluntary sale of water by a willing senior permit holder to Lugert-Altus ID at a fair market price, while a dry-year lease agreement would entail the voluntary temporary exchange of water during agreed-upon conditions. Kershen (2021) did not discuss the purchase of senior water rights in the NFRR, but he did briefly discuss the leasing of upstream senior water rights on the NFRR as a means of protecting both the irrigation (held by Lugert-Altus ID) and M&I rights (held by the U.S. and contracted to the city of Altus) to water stored in Lugert-Altus Reservoir. However, Kershen (2021) dismissed this alternative because the irrigation and M&I rights in Lugert-Altus Reservoir, dated 1939 and 1925, respectively, are the most senior rights on the NFRR; therefore, there are no senior stream permit holders on the NFRR with which to lease water. Kershen (2021) then focused his discussion on dry-year lease agreements between Lugert-Altus ID and groundwater permit holders; this is discussed under Conjunctive Management below.

The analysis on water rights leases in Kershen (2021) focused entirely on negotiating with upstream users to protect both the irrigation and M&I rights stored in Lugert-Altus Reservoir. One potential strategy, not discussed in Kershen (2021), would be to either temporarily lease or permanently convert/assign the existing 4,800 acre-ft/yr M&I water right to an irrigation water right held by Lugert-Altus ID, bringing the total irrigation right from 85,630 acre-ft/yr to 90,430 acre-ft/yr. Recall that over the past 30 years, Lugert-Altus Reservoir has served as a secondary supply source for the city of Altus, with most of the M&I deliveries coming from Tom Steed Reservoir (Figure 5-25). Although the M&I right totals only 4,800 acre-ft/yr, leasing or converting/assigning all or a portion of the M&I right to irrigation would eliminate the need for Lugert-Altus ID to reserve the extra water in storage to deliver to the city of Altus in accordance with the 1954 Settlement Agreement and effectively free up to an additional 29,000 acre-ft/yr of water that could be delivered for irrigation purposes. This strategy is discussed in more detail in Chapter 8.2.2.

7.2.3. Additional Stream-Water Right for Lugert-Altus Irrigation District

The strategies discussed thus far have focused on clarifying and protecting the existing M&I and irrigation rights to water stored in Lugert-Altus Reservoir. The strategy discussed here focuses on Lugert-Altus ID applying for a new water right as a means of improving water supply reliability for Lugert-Altus Reservoir.

In light of Kershen's (2021) conclusion cited in the section above that Lugert-Altus ID likely cannot make a valid claim for an existing water right to the top of conservation pool, Kershen (2021) noted that an option exists for Lugert-Altus ID to file an application with the OWRB for a new water right for the 37,570 acre-ft of water that can be stored in Lugert-Altus Reservoir's conservation pool during very wet years. In the opinion of Dr. Kershen, Lugert-Altus ID could best claim this additional 37,570 acre-ft/yr of conservation pool water by filing an application for all unappropriated water on the NFRR. In the context of this strategy, unappropriated water would be all of the runoff and rainfall in the NFRR basin that occurs during very wet, infrequent years that fills Lugert-Altus Reservoir to its conservation pool capacity or, at least, fills Lugert-Altus Reservoir above the total amount of the present two senior water rights in the reservoir (90,430 acre-ft)[164]. The benefits of making such an application are discussed extensively in Kershen (2021) and summarized in Chapter 8.2.3.

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[164] According to Kershen (2021), by equating "all unappropriated water" with the runoff and rainfall of very wet, infrequent years, Lugert-Altus ID should not be contradicting the OWRB calculation in the OCWP that concluded that there is no unappropriated water on the NFRR. OWRB and the OCWP Report use average annual run-off to calculate whether unappropriated water exists or does not exist on a particular stream segment. In the case here, the claim would be for rainfall and runoff in a very wet, infrequent year, not an average annual runoff year used in OWRB's standard calculation.

Furthermore, with the help of Reclamation, Kershen (2021) noted that Lugert-Altus ID has a second path to claiming a new additional water right. Under Oklahoma stream water law, the United States has the statutory right to apply for water for Reclamation projects, and in that same statutory provision, the Oklahoma Legislature expressly gave the Oklahoma Water Resources Board the authority to reduce the amount of water requested by the United States, or attach conditions to the proposed withdrawal of water by the United States, or reject the request for withdrawal of water in its entirety (Kershen, 2021). In other words, as Reclamation begins to plan for a water project, Oklahoma can reduce, condition, or deny the water that Reclamation requests for the proposed project. If Reclamation cannot obtain sufficient water to justify the proposed project, Reclamation would likely decide against proceeding with the proposed project because Reclamation is not likely going to build a project without assuring itself that it has adequate water available to make the project viable (Kershen, 2021).

In light of this logic, Reclamation could file a notice of withdrawal for all unappropriated water on the NFRR above the Lugert-Altus Reservoir (Kershen, 2021). In accordance with state law, Reclamation would then have three years within which to file plans for the use(s) of this additional water and eight years to complete the project from the date of filing the plans with the OWRB. Once the plans were in place, Lugert-Altus ID could make the formal application for a new additional water right in its own name, and if Reclamation filed a notice of withdrawal, the new Lugert-Altus ID water right would carry a priority date of the date of the notice of withdrawal (Kershen, 2021).

7.2.4. Conjunctive Management

This strategy focuses on improving supply reliability of Lugert-Altus Reservoir by addressing impacts specifically caused by groundwater pumping in the NFRR alluvial aquifer. By managing the interconnected groundwater and stream-waters together, this strategy would be engaging in conjunctive management. Kershen (2021) began its discussion of conjunctive management by citing a conjunctive water management technical memorandum supporting the OCWP[165], in which the OWRB defined conjunctive water management as:

> "The management of hydraulically connected surface water and groundwater resources such that the total benefits of integrated management exceed the sum of the benefits that would result from an independent management of each water resource" (OCWP, 2010).

The OCWP (2010) cited examples of other conjunctive management definitions from a variety of sources, such as:

> "Conjunctive water use usually involves institutional agreements where an existing groundwater user will curtail extractions during wet years in favor of a surface water supply, thereby allowing the aquifer to naturally replenish" (California Water Plan).

> "Conjunctive management is defined as the 'legal and hydrologic integration of administration of the diversion and use of water under water rights from surface and ground water sources, including areas having a common ground water supply" (Idaho Administrative Code).

Kershen (2021) cited a study on conjunctive management in western water law which concluded that nine of the eleven most western states had adopted conjunctive management practices in their respective state water law (Hazad and Shively, 2011). He noted the varying approaches to conjunctive management across the western states, as demonstrated by Hazad and Shively (2011), as well as the OCWP technical memorandum which had surveyed conjunctive management practices of Oklahoma and seven other states (Texas, Kansas, Nebraska, Colorado, Utah, California, Oregon) (OWRB, 2010). The varying approaches employed by these states helped inform Dr. Kershen's analysis on conjunctive management, including how he addressed the specific factual and legal situations related to Lugert-Altus Reservoir.

Kershen (2021) stated quite clearly that with the exception of the Arbuckle-Simpson Aquifer, no legal mandate or statutory authority currently exists that allows the OWRB to adopt conjunctive water management in Oklahoma. As such, stream-water law and groundwater law in Oklahoma are

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[165] OWRB, Oklahoma Comprehensive Water Plan – Technical Memorandum: Conjunctive Water Management in Oklahoma and Other States (Nov. 2010). (Technical Memorandum: Conjunctive Water Management).

viewed and managed accordingly as separate, independent water law systems. Of course, the OWRB acknowledges the fact that just because Oklahoma water law does not mandate conjunctive management does not mean that streams and aquifers are not hydraulically connected (OWRB, 2010). In fact, as Reclamation, OWRB, and USGS studies clearly establish, the NFFR and the NFRR alluvial aquifer are interconnected and impact one another to a significant degree (Smith et al., 2017). That being said, Kershen (2021) concluded that even without the Legislature expressly mandating conjunctive water management for Oklahoma, the OWRB may have the authority indirectly to consider the hydrological interconnection between a groundwater aquifer and stream flows as it considers water management decisions. This point is particularly relevant to the strategy described below on development of a conservation-oriented aquifer maximum annual yield. But first, the discussion summarizes another conjunctive management strategy identified by Kershen (2021), namely dry-year lease agreements[166].

Voluntary Dry-Year Lease or Purchase Agreements

A dry-year lease allows two water users to exchange physical water without directly purchasing or exchanging water rights (Kershen, 2021). In western states, under the dry-year lease, a user seeking a water supply gains the ability to access another user's water under specified, preset conditions, such as the occurrence of a drought or when the user's demand for water reaches a certain intensity threshold (Kershen, 2021). Under the agreement, the water user leasing away its water supply is willing to accept the lease payments (i.e., money), and to cease using its physical water, when the preset conditions occur. Further discussion on the constraints and opportunities associated with dry-year lease agreements is discussed in Chapter 8.2.4 and in Kershen (2021).

[166] Kershen (2021) did not directly refer to dry-year lease agreements as a form of conjunctive management; yet, by definition, the strategy is a form of conjunctive management.

Conservation-Oriented Redetermination of Aquifer Maximum Annual Yield

In Chapter 2.6, an important legal question was raised: does Oklahoma law allow the OWRB to reduce a landowner's existing EPS, either directly or indirectly, if new data result in a lower MAY? As previously discussed, in accordance with Oklahoma groundwater law, groundwater permits are issued by the OWRB based on land owned or leased by applicants such that each acre of land overlying an aquifer is allocated an EPS of the aquifer's MAY. The MAY is the amount of water the aquifer can provide for beneficial use on 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-yr period, the aquifer would be almost fully depleted, with the remaining portion of the aquifer's saturated thickness reserved for domestic use. The MAY and corresponding EPS must be reviewed and updated based on hydrological surveys at least every 20 years. Furthermore, in setting the MAY for an aquifer, the OWRB must take into account "the rate of recharge to the basin or subbasin and total discharge from the basin or subbasin."

Another important legal question was raised in Chapter 2.6: what discretion does the OWRB have in advancing policy mandated by the Water for 2060 Act, by means of alternative strategies to manage water within the Lugert-Altus and Tom Steed Reservoir hydrologic basins? The Water for 2060 Act, passed by the Oklahoma legislature in 2012, made it the policy of the State to establish and work toward a goal of consuming no more fresh water in the year 2060 than is consumed statewide in the year 2012, while continuing to grow the population and economy. This would be achieved by utilizing existing water supplies more efficiently and expanding the use of alternatives provided those alternatives are not construed as amending provisions of existing law pertaining to rights or permits to use water.

Finally, regarding the interaction of groundwater on stream water, recall the technical findings presented in Chapters 6.4.1, 6.4.2, and 6.4.3 related to the impacts of groundwater pumping scenarios on base flow of the NFRR:

1. Without any groundwater pumping (referred to as the Naturalized scenario), the base flow of the NFRR was 56,683 acre-ft/yr;
2. With a groundwater pumping rate equal to that which was reported to the OWRB in 2013 (referred to as the 2013 use scenario), the base flow of the NFRR was 43,893 acre-ft/yr. This represents a 12,700 acre-ft/yr reduction in base flow (i.e., a 22 percent reduction);
3. With groundwater pumping rate as projected by the OWRB in 2060 (referred to as the OCWP use scenario), the base flow of the NFRR was 42,272 acre-ft/yr. This represents a 14,411 acre-ft/yr reduction in base flow (i.e., a 25 percent reduction);
4. With a groundwater pumping rate of a 50-yr life span for the NFRR aquifer of 0.52 acre-ft/yr EPS for every acre overlying the aquifer (referred to as a Full use scenario), the base flow of the NFRR was zero. This means a 56,683 acre-ft per year reduction in base flow (i.e., a 100 percent reduction); and finally
5. With a groundwater pumping rate of a minimum 20-yr life span for the NFRR aquifer of 0.59 acre-ft per year EPS for every acre overlying the aquifer (referred to as a Full use scenario), the base flow of the NFRR was zero. This also means a 56,683 acre-ft per year reduction in base flow (i.e., a 100 percent reduction).

In light of these just-described five groundwater scenarios, and in light of the three statutory obligations cited above, Kershen (2021) suggested that the OWRB would appear to have the authority to consider (to some extent) groundwater and surface water interactions as the OWRB sets a minimum aquifer basin life. And in light of the Water for 2060 Act specifically, the OWRB has the authority to select a minimum basin life with an emphasis on conservation, meaning that the OWRB legally could set a minimum basin life for the aquifers in the NFRR, Elk Creek, and the West Otter-Glen Creek catchment basins of fifty years (i.e., approximately 2070) (Kershen, 2021).

Kershen (2021) suggested that Lugert-Altus ID could encourage the OWRB, as the OWRB reviews and updates the MAY and EPS for the NFRR aquifer, to adopt a conservation-oriented, lesser EPS for future groundwater permit applicants. In doing so, Lugert-Altus ID could encourage the OWRB to consider the total discharge from basins (surface and groundwater) such that discharge protections could be determined that maintain base flows above certain thresholds. It also could encourage the OWRB to undertake the hydrological surveys and information needed to set an EPS for the aquifer that would be smaller than otherwise set under existing practice. For example, one strategy could be to set a MAY and an EPS that reflected the groundwater pumping rate for 2013 or the projected groundwater pumping rate for 2060, either of which would better protect the base flow of the NFRR relative to current practice and be more compatible with Oklahoma's Water for 2060 policy. Consideration also could be given towards evaluating the relative impacts on baseflow caused by localized aquifer storage reduction corresponding to a range of withdrawals varying by existing well locations within the Lugert-Altus Reservoir watershed. Such an analysis could account for the relative distance of wells from tributaries of concern and the corresponding time it takes for withdrawals to impact those tributaries. Whatever the case may be, by adopting a conservation-oriented MAY and EPS for the NFRR, the Lugert-Altus ID could gain indirect protection for the base-flows of the NFRR; and by protecting base flows, the Lugert-Altus ID protects the water supply in storage for Lugert-Altus Reservoir (Kershen, 2021).

Of course, as noted in Kershen (2021), overlying landowners who have already gained a permit for groundwater pumping have a vested right in the EPS applicable at the time the OWRB granted their permits so their pumping rate may not be diminished. By contrast, those overlying landowners who apply for a new permit after the review and update can only pump to the level of the redetermined EPS, even if the redetermined EPS is smaller than the original EPS for that aquifer. This strategy is evaluated further in Chapter 8.

7.2.5. Reclassification of Alluvial Groundwater to Stream Water

At the onset of the URRBS, there was initial agreement among study partners to identify hydrologic thresholds to manage existing stream-water rights above Lugert-Altus Reservoir, but URRBS modeling results demonstrated that permitted groundwater pumping, not stream water, posed a bigger threat to water supply reliability in the Lugert-Altus Reservoir hydrologic basin. The focus then turned to identifying a range of hydrologic thresholds that could be used to inform groundwater management in the Lugert-Altus Reservoir hydrologic basin. The likeliness of doing so may center on the formal and legal reclassification of certain alluvial groundwaters to stream water (discussed below in Chapter 7.3.5 and 8.2.5), meaning the newly-classified permitted alluvial groundwater withdrawals would be subject to curtailment if they are interfering with senior permits to Lugert-Altus Reservoir in accordance with Prior Appropriation Doctrine.

As part of the URRBS, Reclamation, OWRB and Lugert-Altus ID collaboratively prepared an analysis of drought indices and thresholds related to Lugert-Altus Reservoir. This analysis, regarded by study partners as one of the most notable achievements of the URRBS, is discussed extensively in Chapter 8.2.5, and the technical memorandum in its entirety is provided in Appendix J. The analysis was conducted jointly by Reclamation, OWRB, and MPMCD, and it provides important hydrologic factors that the OWRB could consider in adopting regulations specific to Lugert-Altus Reservoir if this strategy were to come to fruition. According to Kershen (2021), the OWRB could consider these technical analyses and, based on comments and evidence received during the process to develop the interference regulations, select the precise thresholds that the OWRB determines both protects the senior rights to water stored in Lugert-Altus Reservoir and maximizes beneficial use in the NFRR basin. Of course, the OWRB's choice of the precise thresholds depends upon the specific local and regional drought indicators selected. In Dr. Kershen's opinion, if reclassification were to occur, and if the OWRB adopted interference regulations based on hydrological factors (drought indicators) and defined senior water rights (dependable yield), the OWRB would be taking actions based on hydrology and science and which are consistent with Oklahoma stream water law.

According to Kershen (2021), reclassification of certain, specified Oklahoma groundwater as stream water would not mean that the OWRB would be engaged in conjunctive management of stream water and groundwater; rather, Kershen (2021) proposed that such a reclassification simply would move certain, specified Oklahoma groundwater from management under the groundwater laws to management under the stream-water laws. Kershen (2021) cited two legal arguments for reclassification: (1) "the alluvial waters argument", such that the Oklahoma legislature impermissibly moved alluvial waters from being public waters to private ownership waters in 1967 and 1972 amendments to Oklahoma's water laws; and (2) "the losing stream argument", such that Oklahoma water law could make a distinction between gaining streams (groundwater movement) and losing streams (stream water movement). Neither of these arguments have ever been presented to Oklahoma courts, so for reclassification to occur in either the Lugert-Altus or Tom Steed Reservoir hydrologic basins, litigation would likely need to be pursued (Kershen, 2021). Further discussion of this strategy is reserved for Chapter 8.2.5.

7.2.6. Cable Mountain Reservoir

The inclusion of Cable Mountain Reservoir into the URRBS was derived initially by Lugert-Altus ID, recognizing that their existing water supplies and infrastructure is insufficient to meet existing and future demands, particularly during times of drought. This assumption was validated by status-quo results, which showed that even if the impacts of existing and future groundwater and stream-water development were to be mitigated, about 50 percent of the water supply imbalance for Lugert-Altus Reservoir would still remain from climatological limitations of the basin. Cable Mountain Reservoir would help mitigate this water supply imbalance and provide additional mitigation against vulnerabilities related to potential future changes in climate.

The objective of Cable Mountain Reservoir would be to offset inflow depletions and storage reductions in Lugert-Altus Reservoir, and to provide supplemental water to the Lugert-Altus ID and beyond for agricultural irrigation. The proposed reservoir site is located on the NFRR about 40 miles downstream of Lugert-Altus Reservoir and below the confluence of the Elm Fork of the Red River and Elk Creek (Figure 7-1). The site was first identified by the OWRB in a 1967 planning report on water resources in western Oklahoma. In the report, the Cable Mountain reservoir site, referred to as the “Navajo” site, was identified as a potential source of irrigation water for the region, including Lugert-Altus ID, supplying an average annual yield of about 108,000 acre-ft/yr. Although the reservoir has never been built, interest in its development has continued for decades. The most recent analysis on Cable Mountain was completed by Reclamation in 2005 as part of a broader appraisal-level investigation into alternatives to augment water supplies to Lugert-Altus Reservoir (Reclamation, 2005). Reclamation’s appraisal investigation concluded that Cable Mountain had the potential to yield an abundant supply of water to the region, but the water was highly saline, and the costs to build, operate, and maintain the reservoir rendered the reservoir cost-prohibitive relative to other potential supply alternatives. Nevertheless, interest in Cable Mountain has continued, prompting URRBS partners to ask Reclamation to update preliminary cost estimates and conduct new modeling to determine the quantity of water that could be yielded from the potential reservoir. These results are provided in Chapter 8.2.6 Cable Mountain Reservoir.

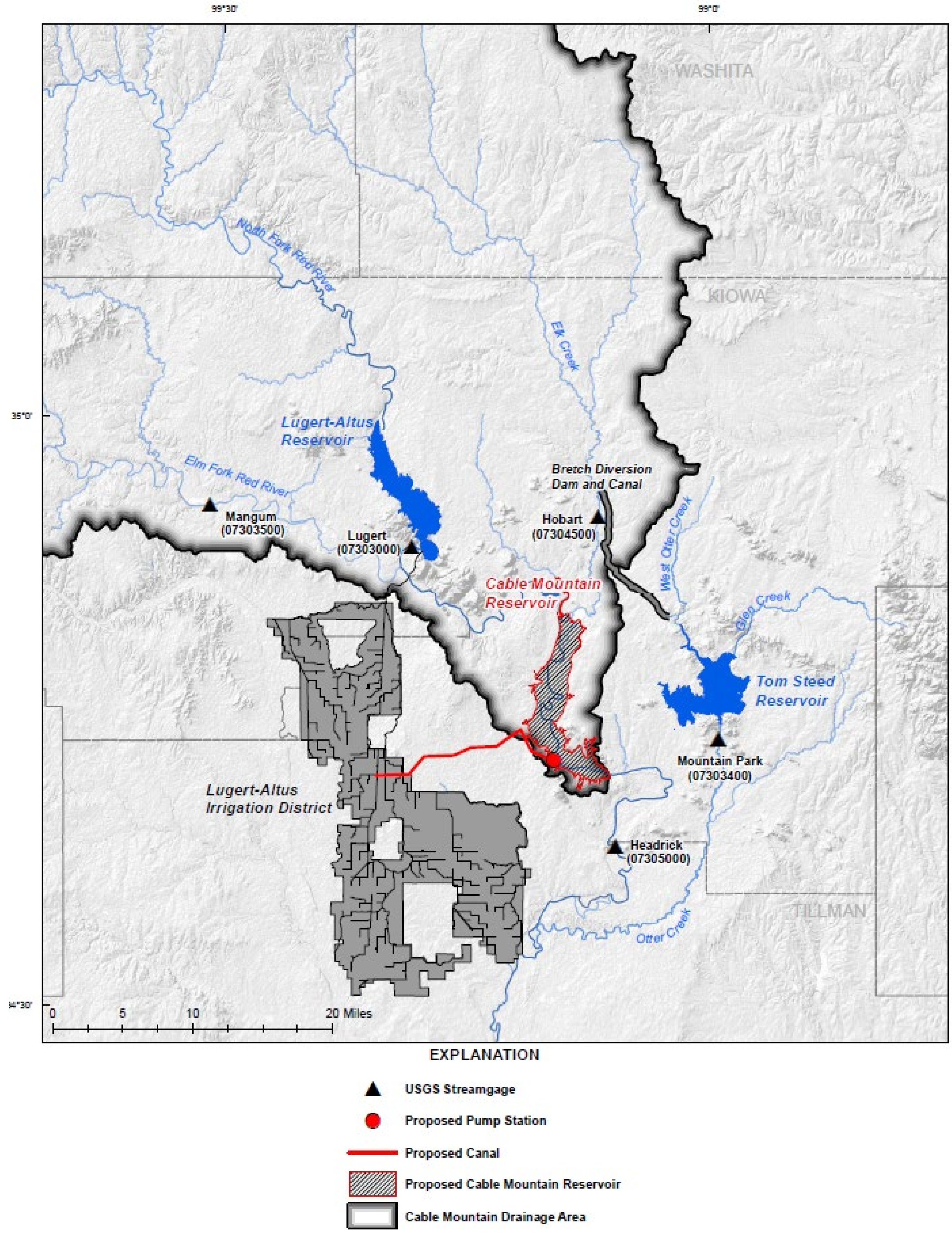

Figure 7-1. Proposed location of Cable Mountain Reservoir and conveyance canal to Lugert-Altus Irrigation District.

7.2.7. Water Conservation

Water conservation was identified as a key strategy to improve water supply reliability of Lugert-Altus Reservoir. Although this strategy 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 complement the other adaptation strategies identified in this URRBS by allowing more of the water stored in Lugert-Altus Reservoir to be put to beneficial use. District-level water conservation measures commonly include infrastructure improvements such as canal lining, piping of laterals, and flow control, regulation, and measurement. On-farm measures include improvements in crop selection, farmer operations, and the distance, location, and timing of conveyance. In Reclamation's appraisal-level investigation into water supply alternatives to augment Lugert-Altus Reservoir, Reclamation identified between 12,600 acre-ft/yr and 15,750 acre-ft/yr of water that could be saved by implementing measures that improve the efficiency of water deliveries from Lugert-Altus ID (Reclamation, 2005). Over the years, the Lugert-Altus ID has been taking steps to modernize its infrastructure and improve operations, including conducting a system optimization assessment (Styles, 2005), as well as installing gate rehabilitation, flow measurement/control, and telemetry improvements.

In 2021, as part of the Lugert-Altus ID five-yr update to its Water Conservation Plan, Lugert-Altus ID asked Reclamation to perform a technical analysis on water losses caused by seepage from laterals and canals throughout the Lugert-Altus ID delivery system. A copy of the Lugert-Altus ID's 2021 five-year WCP Update is located in Reclamation OTAO's central files and is available upon request. 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. The results of this analysis are presented in Chapter 8.2.7.

7.3. Tom Steed Reservoir: Planning Objectives and Strategies

Planning Objectives

This section identifies specific planning objectives for the Tom Steed Reservoir hydrologic basin. The objectives generally entailed addressing specific Tom Steed Reservoir firm yield supply imbalances identified through the status-quo results presented in Chapter 6, as well as addressing potential infrastructure insufficiencies. In Chapter 8, an analysis is performed on each strategy's ability to meet these 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. This volume was used as the demand placed on Tom Steed Reservoir during URRBS water availability modeling to analyze regulatory protection of MPMCD's existing water right to Tom Steed Reservoir, which is a strategy discussed at length in Chapter 8. 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).

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[167]. All three reservoir demand scenarios were included in surface water availability modeling analyses performed by the NFRR SWAM as discussed in Chapter 6.2.2.

Next, water supply deficits detailed in Chapter 6.4.4 warrant discussion again here before introducing adaptation strategies. For the sake of brevity, deficits are presented in terms of meeting the full permitted use planning objective of 16,100 acre-ft/yr for Tom Steed Reservoir. Recall that under Status-quo management, Tom Steed Reservoir firm yield ranged from 13,400 acre-ft/yr to 5,000 acre-ft/yr depending on the groundwater and stream-water development scenario modeled (Figure 6-19). These values represent a 17 to 69 percent delivery shortage relative to the target permit volume of 16,100 acre-ft/yr, respectively. If the reservoir was operated to maximize deliveries up to and including 16,100 acre-ft/yr[168], when available, then the most water that could be delivered during a repeat of the drought of record ranged from 14,100 acre-ft/yr to 4,500 acre-ft/yr (Table 6-19). These values represent a 12 to 72 percent delivery shortage relative to the target permit volume of 16,100 acre-ft/yr. The frequency that the full permit of 16,100 acre-ft/yr was available ranged from 97 percent to 90 percent of all years over the period of record depending on the development scenario. These findings show that there was sufficient water storage in Tom Steed Reservoir to deliver the full permit during most years; however, when shortages did occur during a repeat of the drought of record, they were significant. The planning objective was to make MPMCD's full 16,100 acre-ft/yr permit 100 percent dependable.

[167] 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.

[168] Recall that under the firm yield scenario, the model solves for maximum annual deliveries that can be made 100 percent of the time, including during the drought of record, without Lake Thunderbird going into the inactive pool. The maximum annual delivery volume is known as the "firm yield". Once this volume is known, it is delivered from the reservoir each and every year over the model period. In effect, this scenario assumes that the 1950s drought of record is imminent every time Tom Steed Reservoir drops below the top of conservation pool, and thus eliminates the potential for the reservoir to drop into the inactive pool.

The results presented in Chapter 6.4.2 and 6.4.4 revealed two important conclusions: (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 deliver a firm yield of 16,100 acre-ft/yr; and (2) the leading causes of human-induced water supply imbalances appeared to be caused by 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).

These two conclusions can be drawn based on the following observations. Regarding the role of climate and hydrology, under the Naturalized scenario, the firm yield of Tom Steed Reservoir was 16,100 acre-ft/yr. Recall that the Naturalized scenario removed the impacts from all reported permitted groundwater withdrawals and all reported permitted stream diversions upstream of Tom Steed Reservoir. Yet under the real-world conditions assumed here, the impacts of existing senior stream permit holders and unpermitted domestic users may not be removed. This leaves existing junior stream permits – and regardless of the strategy used to eliminate depletions caused by existing junior permits – and in light of the assumption that existing senior and domestic uses may not be removed from the stream, the firm yield of Tom Steed Reservoir may always be lower than 16,100 acre-ft/yr up to the approximate volume of water being withdrawn upstream by existing senior permit holders and domestic users[169]. As discussed below, this demonstrates the severity of the new 2010-2015 drought of record, while also demonstrating the potential ineffectiveness of providing the full 16,100 acre-ft/yr firm yield target through the mitigation or elimination of existing and/or future junior stream permits alone. And achieving a firm yield closer to the target of 16,100 acre-ft/yr would appear to require strategies that mitigate impacts from senior permit holders in the Tom Steed Reservoir hydrologic basin, as well as provide supplemental water beyond that which

[169] Assuming no actions are taken to address senior permit holders.

climatological and hydrological conditions in the basin can provide during a repeat of the drought of record.

Next, the discussion turns to a comparison between the URRBS's firm yield results with previous firm yield calculations made by Reclamation in its 1971 pre-construction Definite Planning Report (1971 DPR) for the Mountain Park Project. Reclamation's 1971 DPR estimated Tom Steed Reservoir's firm yield to be 16,100 acre-ft/yr for the year 2025 after 50 years of sediment accumulation, and 14,700 acre-ft/yr for the year 2075 after 100 years of sediment accumulation. The 50-yr firm yield of 16,100 acre-ft/yr was used to justify construction of the Mountain Park Project, and it ultimately formed the basis for MPMCD's stream-water permit of 16,100 acre-ft/yr that it holds today.

It is important to note that the 16,100 acre-ft/yr firm yield estimate calculated in Reclamation's 1971 DPR (used for the acquisition of MPMCD's permit) is only coincidentally equal to today's URRBS's firm yield estimate of 16,100 acre-ft/yr under the Naturalized scenario. The URRBS modeling scenario that provides the best "apples to apples" comparison with Reclamation's old 1971 DPR firm yield, which used observed hydrology and accounted for human-induced inflow depletions, would be the "2013 GW, Existing SW Permits, Existing Domestic SW" scenario. Applying the 1971 DPR's 50-yr sedimentation timeframe to this URRBS scenario results in a firm yield of 14,400 acre-ft/yr[170].

There are several reasons for the reduction in firm yield from 16,100 acre-ft/yr (as calculated by the 1971 DPR) to 14,400 acre-ft/yr (as calculated by the URRBS). The 1971 DPR used limited observed climatological and hydrologic records covering an early period between 1920s and 1960s, and the drought of record used to calculate the firm yield of Tom Steed Reservoir occurred in the 1960s. Furthermore, because Tom Steed Reservoir had not yet been constructed, reservoir-specific data on sedimentation and evaporation were nonexistent and had to be extrapolated using other methods; improvements in inflow measurement had not yet been made; and finally, future streamflows were

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[170] This calculation of a 50-yr firm yield is for comparison purposes only relative to the 1971 DPR; to be clear, all of the URRBS firm yield results included herein are for an 85-yr sedimentation timeframe for the year 2060.

depleted based only on an approximation of existing or planned Soil Conservation Service flood retention (Reclamation, 2021). On the other hand, today's URRBS's firm yield estimates included over 60 years of climatological, hydrologic, and/or reservoir storage data through the year 2016. The extended period of record showed that 2010-2015 was a new drought of record for the Tom Steed Reservoir hydrologic basin, surpassing the severity of the 1960s drought used for pre-construction planning (Reclamation, 2021). As well, today's URRBS firm yield estimates also include actual sedimentation and evaporation data measured at Tom Steed Reservoir; and finally, groundwater and stream-water withdrawals could be accounted for in the flow record using actual reported uses by upstream permit holders. Whatever the differences may be between the two methodologies, the URRBS provides a better approximation of Tom Steed Reservoir's firm yield given the current available climatological and hydrological data under a range of potential inflow depletion scenarios caused by human development through the year 2060. And one of the primary conclusions that can be drawn from this updated analysis is that the most recent climatological and hydrological conditions show that supplemental water would be needed for Tom Steed Reservoir to deliver a firm yield of 16,100 acre-ft/yr.

Regarding human-induced depletions, recall that a key result from the Status-quo analysis presented in Chapter 6.4.2 from Smith et al. (2017) was that permitted groundwater withdrawals out of the NFRR aquifer at year 2013 pumping rates had no measurable impact on base flows of Elk Creek[171]. This means that the 17 percent reduction in reservoir firm yield caused by the "2013 GW, Existing SW Permits, Existing Domestic SW" was solely attributable to existing stream-water use. The "Full GW, Existing Domestic SW, Existing SW Permits" scenario caused an 18 percent reduction in firm yield relative to the naturalized scenario, which represents a net reduction of only one percent relative to the "2013 GW, Existing SW Permits, Existing Domestic SW" and "OCWP GW, Existing SW Permits, Existing Domestic SW" scenarios. When adding low

[171] Recall that this study assumed the Southwestern Oklahoma aquifer would not be fully developed because it is a minor aquifer, meaning that base flow into Tom Steed Reservoir would not be fully depleted.

and high estimates of future domestic use [i.e., “Domestic SW (low)” and “Domestic SW (high)”], firm yield was reduced by 25 percent and 39 percent, respectively, relative to the naturalized scenario; this represented a net reduction of seven percent and 21 percent, respectively, relative to the “Full GW, Existing SW Permits, Existing Domestic SW” scenario. When adding the full permitted appropriation of all stream water to the low and high domestic use (i.e., “Full GW, Domestic SW (Low/High), Full SW Permits”), firm yield was reduced by 64 percent and 69 percent, respectively, relative to the naturalized scenario; this represented a net reduction of 39 percent and 30 percent, respectively, relative to the “Domestic SW (Low)” and “Domestic SW (High)” scenarios. Similar trends were observed in permit dependability. Again, these results point towards future stream-water development, in particular permitted stream water, as being the leading cause of impacts on Tom Steed Reservoir water availability, followed by existing stream-water use.

To address the planning objective of delivering 16,100 acre-ft/yr, these findings highlight the need for both an administrative strategy that would address human-induced issues related to junior stream permits, as well as new infrastructure and supplemental water supplies to build additional resilience to the climatological limitations of the basin. This is not to say that groundwater management strategies should be abandoned altogether. In fact, Kershen (2021) explored conjunctive management of groundwater and stream-water as a means of further improving water supply reliability of Tom Steed Reservoir.

Before turning to the formulation of adaptation strategies, two reservoir operation assumptions are worth noting because they bear significant impact on the effectiveness of any adaptation strategy in terms of meeting the planning objectives identified above. First, it was assumed that all divertible flows from Elk Creek would be conveyed to Tom Steed Reservoir. Second, it was assumed that during drought periods, MPMCD member entities would share water reductions in proportion to their contracted water rights in accordance with the “shared shortage” provision in their contracts. The importance of both of these assumptions is discussed in Chapter 2.4.2.

Adaption 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 through voluntary dry-year lease agreements; (6) conjunctive management through a conservation-oriented redetermination of aquifer maximum annual yield; (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. In the discussions that follow, discretion was used to summarize Kershen (2021), but in many cases, Dr. Kershen's own words are used as to protect the integrity of his writings and commentary.

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

Kershen (2021) discussed two key issues related to understanding and clarifying MPMCD's existing stream-water right. The first issue related to the volume of the permit, and the second issue related to the priority date of the permit. Regarding permit volume, there was an apparent reduction in MPMCD's permit from an average annual yield of 45,000 acre-ft/yr to a firm yield of 16,100 acre-ft/yr, and Kershen discussed two interrelated reasons as to why the reduction occurred, one pertaining to a change in the OWRB's policy related to the volume of water needed for carriage and delivery of 16,100 acre-ft/yr, and the other relating to a change in the OWRB policy related to whether reservoir evaporation could be counted as a beneficial use and considered part of the permitted volume. Kershen (2021) believed that one remedy to this issue was for MPMCD to claim non-consumptive beneficial uses of recreation, fish, and wildlife as part of its existing water rights, thereby increasing its right back to its original volume of 45,000 acre-ft/yr. Kershen (2021) also discussed claiming a water right to the top of the conservation pool of Tom Steed Reservoir, but he concluded that there was no merit to such a claim.

Nevertheless, in perfecting its water right to 45,000 acre-ft/yr for recreation, fish and wildlife purposes, Kershen (2021) suggested that MPMCD seek clarification on the second issue related to MPMCD's existing water right, namely the priority date. Specifically, Kershen (2021) noted that MPMCD's existing permit has a priority date of 1955, not 1967. Although 1967 is the year that MPMCD filed an application for the permit, it is the administrative year assigned to the permit by the OWRB[172], and was the year selected in the URRBS as the priority date for all hydrologic modeling. Kershen (2021) noted that the year 1955 is actually the priority date of MPMCD's permit 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.

Permit 67-671: 45,000 acre-ft/yr versus 16,100 acre-ft/yr

As of October 10, 1967, MPMCD had a permit (67-671) for stream water that read as follows: "... permit is issued for 45,000 acre-ft of water" for

[172] OWRB's water rights database labels MPMCD's water right permit as "1967061".

municipal, industrial, and irrigation purposes. In 1983, Permit 67-671 was amended as follows: "... permit is issued for ~~45,000~~ 16,100 acre-ft of water, an estimated average annual yield ...". The OWRB also specified a schedule of use for the 16,100 acre-ft/yr until the expiration of the life of the project (the year 2030) with which MPMCD would have to comply in order to maintain its permitted water-right (Kershen, 2021).

OWRB and Reclamation/MPMCD were apparently not in agreement about the 1983 amendment to MPMCD's existing permit (Kershen, 2021). Oklahoma was concerned about the "use it or lose" doctrine of Oklahoma's prior appropriation system, and Reclamation and MPMCD were concerned about protecting the 45,000 acre-ft/yr average annual yield so as to protect the firm yield of 16,100 acre-ft/yr for M&I beneficiaries of Tom Steed Reservoir. In 1982-1983, the OWRB apparently considered the amount of water between the firm yield of 16,100 acre-ft/yr and the 45,000 acre-ft/yr average annual yield to be "unused water" and therefore subject to appropriation by other beneficial users. By contrast, Reclamation and MPMCD apparently considered the 45,000 acre-ft/yr average annual yield as the granted (perfected) water right needed to protect the firm yield of 16,100 acre-ft/yr. According to Kershen (2021), Reclamation and MPMCD held this legal position seemingly for two reasons: (1) as presented to the OWRB governing Board in 1967, 45,000 acre-ft/yr average annual yield was the amount of water right Reclamation required to justify the economic viability of the Mountain Park Project and to provide the economic basis upon which to proceed with construction; and (2) 45,000 acre-ft/yr average annual yield was a reasonable diversion at the point of diversion (the Tom Steed Reservoir) so as to protect the underlying firm yield of 16,100 acre-ft/yr of identified beneficial uses for M&I uses while taking into account yearly fluctuations in rainfall and yearly fluctuations in evaporation and seepage from the reservoir. Under prior appropriation law, appropriators have appropriative rights for the amount of water needed for reasonable carriage to the point of beneficial use where the water is physically put to use; in other words, appropriators have a water right for the amount of reasonable carriage plus the amount actually used for the beneficial purpose (Kershen, 2021).

Kershen (2021) proposed another explanation for the reduction from the 1967 permit of 45,000 acre-ft/yr to the 1983 permit of 16,100 acre-ft/yr. In 1967, the OWRB allowed evaporation to be part of the actual use of water and, thus, to be part of the amount permitted to the MPMCD by the OWRB. By the early 1980s, the OWRB had changed its position on evaporation and did not consider evaporation to be an actual use of water and, thus, did not consider that evaporation could be included within the amount the OWRB permitted to the MPMCD (Kershen, 2021). In Dr. Kershen's mind, the 45,000 acre-ft/yr that MPMCD claimed in 1967 included an amount of average annual evaporation as a component of the 1967 permit, and when the OWRB reduced the District's permit in 1983 to 16,100 acre-ft/yr, the OWRB excluded the average annual evaporation from the amount permitted to MPMCD.

In light of the facts and commentary provided above, Kershen (2021) proposed that the OWRB and Reclamation/MCMPD consider reaching an agreement as to whether the 45,000 acre-ft/yr average annual yield, as stated in the original 1967 permit, is a reasonable diversion; and if so, then the permitted (perfected) water right for MPMCD could be reinstated to the 45,000 acre-ft/yr average annual yield. The OWRB could then still properly impose a schedule of use for the firm yield of 16,100 acre-ft/yr as the identified beneficial uses for beneficiaries of the MPMCD water right (Kershen, 2021). Kershen (2021) also proposed two ways to approach evaporation loss. First, the OWRB and MPMCD could revert to the OWRB policy of the late 1960s to include evaporation in the amount permitted to MPMCD; and if the OWRB and MPMCD reverted to allowing evaporation as a component of the permit, the OWRB and MPMCD could possibly restore the MPMCD's water right as 45,000 acre-ft/yr. Alternatively, the OWRB could account for evaporation as it determines whether unappropriated water exist for future applicants for water rights and as it acts to protect water rights from interference by junior water-rights holders. This is discussed more in the proceeding section related to the protection of MPMCD's water right.

A separate yet related point regarding clarification of MPMCD's existing stream-water rights pertains to beneficial use. According to Kershen (2021), Reclamation consistently discussed recreation, fish, and wildlife purposes as additional uses for the water in the Mountain Park Project; and moreover, the OWRB had acknowledged these additional purposes as being in harmony with the policy of the State of Oklahoma for water development. Furthermore, even though MPMCD had received its stream-water permit in August 1967, Congress explicitly legislated fish and wildlife development and recreation enhancement as an authorized purpose for the Mountain Park Project in 1968. Kershen (2021) pondered whether MPMCD might have a claim in 1967 for a water right for fish, wildlife, and recreational purposes, based on the 1955 Reclamation withdrawal notice and subsequent Mountain Park Project plans that MPMCD failed to assert.

The Oklahoma Legislature has never specifically defined "beneficial use"; however, the Legislature has enacted two statutes that make reference to beneficial use by providing a non-exclusive list of identified purposes that qualify as beneficial use (Kershen, 2021). In the 1972 Oklahoma Ground Water Code, the Legislature identified agriculture, domestic, municipal, and industrial and other (unspecified) beneficial uses for groundwater resources, and in 1993, the Legislature stated a policy to "protect, maintain and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and aquatic life and for domestic, agricultural, industrial, recreational and other legitimate beneficial uses; ..."

According to Kershen (2021), the OWRB has defined the term "beneficial use" in its regulations. Namely, in 1964, the OWRB stated "Beneficial use" means the use of such quantity of stream or groundwater when reasonable intelligence and reasonable diligence are exercised in its application for a lawful purpose and as is economically necessary for that purpose." In 1973, the OWRB added a second sentence to the definition that reads: "Beneficial uses include but are not limited to municipal, industrial, agricultural, irrigation, recreation, fish and wildlife, etc." The OWRB defines "beneficial use" with these two sentences – the narrative sentence and the non-exclusive list sentence – as the regulatory definition today in 2021 (Kershen, 2021).

While the law of prior appropriation has long recognized that the term "beneficial use" is a term that changes with societal conceptions of "beneficial uses," in Oklahoma in 1967 when MPMCD applied for a water permit, the term "beneficial use" had not clearly been expanded, either legislatively or administratively, to include recreation, fish, or wildlife. Hence, cautious applicants and administrators in Oklahoma in 1967 might well have been reluctant to seek or to grant a water right in 1967 specifically for recreation, fish, and wildlife; by contrast, today those three uses are clearly beneficial uses of stream water in Oklahoma (Kershen, 2021).

Concurrently with cautiousness about the definition of "beneficial use," MPMCD also may have worried about another difficulty with asserting a water right for recreation, fish, and wildlife in 1967. Western prior appropriation law, including Oklahoma, conceptually had considered a physical diversion of the water as an element of a prior appropriation water right (Kershen, 2021). For reasons discussed in Kershen (2021), Dr. Kershen claimed that a water right in a reservoir indeed constitutes a "physical diversion" for a prior appropriation stream water right and assuredly satisfies any diversion requirement in Oklahoma stream water law.

In light of the factors above, Kershen (2021) proposed the option of MPMCD asserting a water right for beneficial purposes for recreation, fish and wildlife; and more importantly, in Dr. Kershen's mind, MPMCD could have asserted an existing water right for these three non-consumptive purposes without raising any legal objections as early as 1973 when the OWRB explicitly included these three non-consumptive purposes within the regulatory definition of beneficial use. According to Kershen (2021), if MPMCD sought a clarified water right in its permit for recreation, fish and wildlife, the following considerations would apply:

1. The OWRB might quantify the stream-water rights of MPMCD to include the beneficial uses of water as set forth in the filed plans for the Mountain Park Project.
2. The Reclamation plans from 1955 and all subsequent plans of August 1962, June 1963, and May 1966 for the Mountain Park Project expressly identified recreation, fish, and wildlife purposes for the waters of the Mountain Park Project.
3. By being identified in the Reclamation plans, these beneficial uses for recreation, fish, and wildlife would have the seniority date of the Reclamation withdrawal – May 4, 1955 – which is the same priority date as the M&I permit (discussed below).
4. While the quantified amount of the water right for MPMCD that includes recreation, fish and wildlife is subject to further discussion, it may well be that the most legally defensible quantified amount is the 28,900 acre-ft/yr of water above the firm yield amount of 16,100 acre-ft/yr (i.e., the 45,000 acre-ft/yr) that is set forth in the August 29, 1967 application and that the OWRB actually granted as the permitted (perfected) water right in the original the OWRB Permit 67-671 of August 29, 1967.

According to Kershen (2021), 45,000 acre-ft/yr would not be an arbitrary quantity but, rather, would reflect the amount that a cautious, uncertain applicant and regulator hesitated to seek or to grant in 1967. MPMCD now would only be clarifying the quantity and the purposes that MPMCD originally had asserted in its 1967 application, and MPMCD and the OWRB could finally be in agreement that the accurate perfected str9eam water right for the Tom Steed Reservoir is 45,000 acre-ft/yr with a seniority of May 4, 1955 (Kershen, 2021)[173].

[173] According to Kershen (2021), MPMCD is a junior water-right holder to those permits that have a priority date before the Reclamation withdrawal notice of May 1955; 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.

Top of Conservation Pool

Tom Steed Reservoir has a conservation pool capacity of 88,400 acre-ft (Chapter 2.2.2). The volume of water permitted out of Tom Steed Reservoir totals 16,100 acre-ft/yr. This leaves up to 72,300 acre-ft of unpermitted water that can be stored in the reservoir. Similar to Lugert-Altus Reservoir, some have questioned whether MPMCD could claim a water right to the top of the conservation pool, effectively expanding its existing stream rights by 72,300 acre-ft/yr to 88,400 acre-ft/yr. Kershen (2021) explored the numerous legal issues involved if MPMCD were to assert a water right of 72,300 acre-ft/yr. These issues are discussed in Chapter 8.2.1; yet for purposes here, Dr. Kershen's conclusion was similar to that reached regarding Lugert-Altus Reservoir, which is that MPMCD very likely could not make a valid claim to an existing water right to the top of conservation pool.

Permit Priority Date

In formulating his findings and recommendations on the volume of MPMCD's existing permit, Kershen (2021) noted the importance of clarifying the priority date for the water rights of MPMCD. Kershen (2021) suggested that when MPMCD coordinates with the OWRB to perfect the volume of its water right (as discussed above), MPMCD also could encourage an official adjudication by the OWRB to get the priority list of water rights to more accurately reflect that the MPMCD's water right has a May 4, 1955 priority date. Kershen (2021) concluded that May 4, 1955 was indeed the priority date of the MPMCD because this was the date on which Reclamation wrote the Oklahoma Planning and Resources Board (OPRB), predecessor of the OWRB, asking for the withdrawal of all waters in the Elk Creek and West Otter-Glen Creek watersheds for the Mountain Park Project. Kershen (2021) based this claim on Oklahoma Federal withdrawal statute, Oklahoma Supreme Court precedent, and OPRB/OWRB correspondence, the details of which can be found in Appendix A.

On July 14, 1964, in accord with the new Oklahoma stream water law of 1963, the OWRB issued Final Order No. 4 to set forth the priority water rights on the NFRR and its tributaries (Kershen, 2021). As the Mountain Park Project had not yet gained Congressional authorization, MPMCD did not yet exist to assert a water right claim in this 1964 administrative adjudication. When it became clear that Congress would approve the project, MPMCD came into existence in early 1967 and then applied for a water permit on August 29, 1967. The OWRB subsequently assigned Permit No. 67-671 (i.e., "1967671") to this MPMCD application, but Dr. Kershen noted that the OWRB permit number is an administrative assignment, not a priority date[174]. Accordingly, MPMCD's water right would be senior over all water rights in the Final Order No. 4 (July 14, 1964) that date after May 4, 1955. Recognizing that the OWRB has not yet updated the Final Order No. 4 to reflect MPMCD's seniority on the Final Order No. 4 list of water rights, Kershen (2021) noted the importance of MPMCD working with the OWRB to perfect/adjudicate the volume and/or priority date of MPMCD's existing permit, whether its separately, together, simultaneously, or consecutively.

Kershen (2021) noted the discrepancy between the priority listing of water right holders in the OWRB's 1964 Final Order No. 4 with the priority listing of water right holders used in the URRBS (Table 6-2) to evaluate water availability in the Tom Steed Reservoir hydrologic basin. However, he concluded that the differences between the two priority lists did not need to be reconciled for the purposes of his legal analysis and interpretation.

Yet, for the purposes of the URRBS, namely the modeling of water rights and water management in the Tom Steed Reservoir hydrologic basin, a priority date was assigned for each permit based on the permit number listed in the OWRB's water rights database. The permit number itself was defined by the OWRB in accordance with the permit application date. For example, MPMCD's permit was listed on the OWRB's water rights database as 19670671 based on MPMCD's permit application date of August 29, 1967; accordingly, for the

[174] Personal communications via email with Dr. Kershen on November 29, 2021.

purposes of the URRBS, MPMCD's permit was assigned a priority date of 1967. This made MPMCD's permit senior to ten of the 17 stream permits in the Tom Steed Reservoir hydrologic basin, with the remaining seven stream permits designated as senior to MPMCD (Table 6-2). Importantly, all of the hydrologic modeling results presented in Chapter 8.3.2 below were based on this assumption of seniority. Furthermore, it was considered beyond the scope this URRBS to attempt to reconcile the permit numbers listed in the OWRB's database and Table 6-2, whether pre- or post-1964, with the actual priority dates that the OWRB may assign as a result of a potential future adjudication of vested water rights in the Tom Steed Reservoir hydrologic basin.

7.3.2. Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District

Regulatory Protection

Unlike Lugert-Altus Reservoir, the need and opportunity exist for Tom Steed Reservoir and for MPMCD to work with the OWRB to identify and adopt hydrologic thresholds that protect Tom Steed Reservoir from existing and/or future stream-water permits. As discussed in Chapter 2.2.3 and Chapter 2.6, surface water is managed under a joint Prior Appropriation/Riparian system. 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 statute, junior permit holders are not allowed to interfere with senior permit holders by taking their water out-of priority ahead of a senior permit holder. A senior permit holder can file a complaint with the OWRB, but Oklahoma statutes do not set forth any specific process for the OWRB to be proactive in protecting an individual claimant's water rights from interference by others (Kershen, 2021). Yet, as previously discussed for Lugert-Altus Reservoir, the OWRB has authority to create an administrative enforcement procedure to protect senior priority stream-water permits, and the OWRB could create an administrative procedure to stop or prevent interference with senior priority rights or to prevent out-of-priority use of water rights (Kershen, 2021). What is lacking in the statutes, the regulations, and the case law is any definition of interference or any identification of thresholds that can be invoked to protect the water rights of senior holders (Kershen, 2021). To this end, the MPMCD and the OWRB could work together to identify interference thresholds that take into account the relevant hydrological conditions and needed reservoir yield specific to the NFRR and Tom Steed Reservoir, respectively, and then the OWRB could adopt those thresholds into new interference regulations that are specific to the Tom Steed Reservoir hydrologic basin.

In crafting regulations to protect MPMCD's senior water rights, according to Kershen (2021), the OWRB can consider hydrological factors in making a determination whether or not unappropriated water is available in a stream when an applicant applies for a regular water permit. By focusing on hydrological factors and dependable yield from the reservoir, the OWRB can craft interference regulations specific to MPMCD's senior water rights that clearly and directly reflect protections for the water supply of Tom Steed Reservoir. By focusing on hydrological factors and dependable yield from the reservoir, the OWRB also can identify an interference trigger that does not too often burden junior water-right holders and that promotes the maximization of beneficial uses for all water-right holders on West Otter-Glen Creeks and Elk Creek.

In January 2021, as part of the URRBS, Reclamation, OWRB and MPMCD collaboratively prepared an analysis of drought indices and thresholds related to Tom Steed Reservoir. This analysis, regarded by study partners as one of the most notable achievements of the URRBS, is discussed extensively in Chapter 8.2.2, and the technical memorandum in its entirety is provided in

Appendix K. The analysis was conducted jointly by Reclamation, OWRB, and MPMCD, and it provides important hydrologic factors that the OWRB could consider in adopting regulations specific to Tom Steed Reservoir. According to Kershen (2021), the OWRB could consider these technical analyses and, based on comments and evidence received during the process to develop the interference regulations, select the precise thresholds that the OWRB determines both protects the MPMCD's senior water rights and maximizes beneficial use in the West Otter-Glen Creek and Elk Creek basins. Of course, the OWRB's choice of the precise thresholds depends upon the specific local and regional drought indicators selected and on the actual quantity of MPMCD's defined senior water rights. In Dr. Kershen's opinion, if the OWRB adopted interference regulations based on hydrological factors (drought indicators) and defined senior water rights (dependable yield), the OWRB would be taking actions based on hydrology and science and which are consistent with Oklahoma stream water law.

Once the OWRB adopted interference regulations specific to Tom Steed Reservoir, the OWRB could also create an administrative procedure to enforce these interference regulations. For example, based on the thresholds of selected drought indicators, the OWRB could give junior stream water-right holders advanced warning that drought conditions are approaching the trigger point. When the threshold arrives, the OWRB could notify the junior permit holders to cease using stream water so as to protect MPMCD's senior stream water rights (Kershen, 2021).

As explained above, the OWRB has the delegated authority to protect senior stream-water rights, so adoption of interference regulations specific to Tom Steed Reservoir is within the OWRB's power to protect senior stream water rights (Kershen, 2021). Hence, the OWRB would not need to rewrite the permits of junior stream water-right holders because junior stream-water rights by being junior are always subject to curtailment to protect senior stream water rights. And, when the OWRB adopts these interference regulations for Tom Steed Reservoir, the OWRB could choose a threshold that indicates that all juniors need to cease taking water from West Otter-Glen Creeks and Elk Creek. By so doing, when the threshold arrives for protection of MPMCD's senior rights, the OWRB could order all juniors to stop taking water without the OWRB being required to begin with the most junior and work backward to the most senior junior[175]. In other words, the OWRB could select a threshold that would apply to all juniors collectively without violating the "first-in-time, first-in-right" principle of prior appropriation water law. Moreover, by the OWRB adopting thresholds based on hydrology and dependable yield that apply to all junior permit holders collectively, the OWRB may be able to avoid junior stream water-right holders arguing the "futile call" doctrine when a senior claims interference (Kershen, 2021).

If the OWRB were to adopt interference regulations for Tom Steed Reservoir, the OWRB would also need to address the endpoint of interference. According to Kershen (2021), the OWRB could also choose the endpoint of interference based on hydrological factors (drought conditions) and defined senior water rights (dependable yield) that indicate protection for senior stream water rights is no longer justified. The OWRB could do so by relying upon modeling analysis (discussed in Chapter 8.3.2) such as the Reclamation/OWRB/MPMCD analysis of Tom Steed Reservoir.

Regarding PTs, recall that the aforementioned junior stream-water permits are "regular" permits. The OWRB is authorized to issue non-regular PTs, as well as seasonal, temporary, or term permits, as long as those permits do not interfere with domestic uses or with existing stream-water rights, even when the OWRB finds that no water is available for the appropriation of a new regular stream permit (Chapter 2.2.3). During the 2010-2015 drought of record, the OWRB granted seven PTs in the Elk Creek hydrologic basin upstream of Tom Steed Reservoir totaling 43.5 acre-ft (i.e., average of nine acre-ft annually). The MPMCD raised concerns with the OWRB that those non-regular permits were impairing and interfering with senior water rights to Tom Steed Reservoir.

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[175] Compliance by junior permit holders with an OWRB order to cease using water is a distinct issue from the adoption of regulations and enforcement procedures when the trigger point arrives. Kershen (2021) did not address potential compliance issues, although they are discussed in Chapter 8.

According to Kershen (2021), if the OWRB adopted interference regulations specific to Tom Steed Reservoir, as discussed above, the OWRB could also address interference by non-regular permits. The OWRB could decree that the interference trigger selected for protecting senior water rights from junior water rights would also apply to protect regular permit water rights from non-regular permits. The OWRB could choose the same trigger point based on the same hydrology and reservoir levels because the drought conditions are such that any further removal of water from the West Otter-Glen Creek and Elk Creek basins would interfere with and impair MPMCD's vested water rights. By adopting the identical interference trigger for non-regular permits, the OWRB would be constraining its discretion to grant non-regular permits in the West Otter-Glen Creek and Elk Creek basins and making effective the mandatory provision that non-regular permits are subject to all prior appropriations (Kershen, 2021).

The OWRB could also adopt the identical end point for interference to resume granting non-regular permits in West Otter-Glen Creek and Elk Creek basins. When the need for protection ends, non-regular permit applicants should have access to water so as to maximize the beneficial use of Oklahoma's stream waters.

A second factor pointed out by Kershen (2021) to consider regarding PTs follows. The OWRB recently adopted regulations allocating ownership rights of brackish groundwater to surface landowners overlying the brackish aquifer. Surface owners could voluntarily grant leases to companies, particularly oil and gas companies which are granted the majority of PTs, for the use of their brackish groundwater. With a valid lease from surface owners, oil and gas companies can then apply to the OWRB for a PT groundwater permit. Once these regulations become legally effective, Lugert-Altus ID could urge the OWRB to grant PT groundwater permits from brackish aquifers that have no impact on NFRR base flows rather than PT stream permits from NFRR alluvial aquifers.

Non-Regulatory Protection

Another strategy MPMCD could consider in terms of protecting its existing stream-water right is to purchase existing senior water rights and/or enter into dry-year lease agreements with senior stream-water permit holders[176]. Kershen (2021) evaluated dry-year lease agreements but not the purchase of senior water rights, so most of the discussion here centers on dry-year lease agreements. The purchase of senior water rights would simply entail the voluntary sale of water by a willing senior permit holder to MPMCD at a fair market price. Dry-year lease agreements were first discussed in the Lugert-Altus Reservoir section, but only as it pertains to agreements with groundwater permit holders to protect base flow. For Lugert-Altus Reservoir, a surface water right purchase or dry-year lease agreement was not considered relevant because the rights to water stored in Lugert-Altus Reservoir are the most senior rights in the basin.

Recall that a dry-year lease allows two water users to exchange physical water without directly purchasing or exchanging water rights. In western states, under the dry-year lease, a user seeking a water supply gains the ability to access another user's water under specified, preset conditions, such as the occurrence of a drought or when the user's demand for water reaches a certain intensity threshold (Kershen, 2021). Under the agreement, the senior water user leasing away its water supply would be willing to accept the lease payments (i.e., money) from the junior user (i.e., MPMCD), and to cease using its physical water, when the preset conditions occur. In fact, the preset conditions that trigger the exchange of water could be defined by the same types of hydrologic thresholds discussed in the previous section, meaning that in addition to thresholds being adopted into interference regulations administered by the OWRB, the same thresholds could be adopted into voluntary, non-regulatory dry-year lease agreements between MPMCD and the senior permit holder(s).

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[176] MPMCD has a water right under Permit 67-671. MPMCD may acquire a new, additional water right for all unappropriated water. Hence, Kershen (2021) used the word "right(s)" regarding non-regulatory protection.

Kershen (2021) noted several attributes of dry-year agreements. First, by being a voluntary, temporary transfer of water rights (as opposed to permanent transfer of a water right), statutes applicable to permanent transfers or change in beneficial purposes of permitted water rights do not apply. Second, no person or entity should have standing to object to a senior permit holder voluntarily refraining to take water from a stream, and senior permit holders not entering dry-year option leases would still get to take their water in accord with their priority date. Furthermore, permit holders that are junior to MPMCD would not have a legal basis to complain because MPMCD is capturing this water for its water right that is senior to those of the juniors. Third, MPMCD could write the terms of the lease so that the lease operates for only six continuous years so that the senior does not lose its senior water right[177].

As noted by Kershen (2021), MPMCD also would likely need to consider other factors relating to dry-year option leases to protect its water rights. This includes the costs of leasing the water rights and the extent to which the dry-year lease agreement would result, in fact, in additional inflows into the Tom Steed Reservoir.

Finally, 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.

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[177] Okla. Stat. Tit. 82 § 105.17 (2011) (a water-right holder loses the water right if "for a period of seven (7) continuous years" the water-right holder does not appropriately use a permitted water right.)

7.3.3. Additional Stream-Water Rights of Mountain Park Master Conservancy District

As discussed repeatedly throughout this report, one of the major findings of this analysis was that if the OWRB used the 1950-2016 naturalized flow record in lieu of the 1951-1980 run-off record, then either 35,900 acre-ft/yr or 33,900 acre-ft/yr of unappropriated stream water could be available for new regular permits upstream of Tom Steed Reservoir depending on whether future domestic use was low or high, respectively (Chapter 6.4.4). The strategy discussed in the previous section assumed this unappropriated water was eventually fully permitted and focused on hydrologic thresholds that could be used to protect MPMCD's right by curtailing these future junior stream permits. However, Kershen (2021) identified yet another strategy to protect MPMCD's permitted and clarified (quantified) water right, which is for MPMCD to apply for water rights to all of the unappropriated water in Elk Creek and West Otter-Glen Creeks, whether in the volume calculated by this study or otherwise agreed upon by MPMCD and the OWRB. Specifically, MPMCD could apply for these unappropriated water rights for non-consumptive uses (i.e., for recreation, fish, and wildlife purposes). These "unappropriated" recreation, fish, and wildlife water rights were considered by Kershen (2021) to be completely distinct and separate from the recreation, fish, and wildlife water rights discussed above with regards to quantifying MPMCD's water rights under its existing permit.

As recreation, fish and wildlife are beneficial purposes under Oklahoma law, Kershen (2021) discussed several advantages MPMCD gains if it were granted water rights to all unappropriated waters in West Otter-Glen Creeks and Elk Creek upstream from the Tom Steed Reservoir. MPMCD gains these advantages even though MPMCD would have the most junior water right on West Otter-Glen Creeks and Elk Creek as the new water right would have the priority date as of the date of application (i.e., because MPMCD would be seeking a new water right, MPMCD would not be able to claim a priority date based on the

Reclamation withdrawal notice of May 4, 1955). The benefits of making such an application were discussed extensively in Kershen (2021) and summarized in Chapter 8.3.3.

Kershen (2021) proposed a second, alternative approach to securing additional, new water rights for MPMCD for recreation, fish and wildlife purposes. In the 1968 legislation authorizing the Mountain Park Project, Congress expressly stated that the Mountain Park Project could engage in activities "conserving and developing fish and wildlife resources, providing outdoor recreation opportunities ...". In 1994, Congress expanded the authority of the Mountain Park Project to include "environmental quality activities." In light of these 1968 and 1994 enactments, Reclamation has the authority to seek new water for recreation, fish, wildlife and environmental quality for the Mountain Park Project (Kershen, 2021). Using this authority, Reclamation could provide a new, additional withdrawal notice to the OWRB for all unappropriated waters in the West Otter-Glen Creeks and Elk Creek basins above Tom Steed Reservoir. By giving a withdrawal notice, Reclamation and MPMCD gain the date of the notice as the priority date, have three years to develop a plan for these non-consumptive uses at Tom Steed Reservoir, and eight years to complete the project from the date of filing the plans with the OWRB. With Reclamation's plans in hand, MPMCD could then make the formal application for a new, additional water right for recreation, fish, wildlife, and environmental quality that Oklahoma now recognizes as beneficial uses of water (Kershen, 2021).

7.3.4. Conjunctive Management

As discussed in the Lugert-Altus Reservoir section above[178], Kershen (2021) began his discussion of conjunctive management by citing a conjunctive water management technical memorandum supporting the OCWP[179], in which the OWRB defined conjunctive water management as:

> "The management of hydraulically connected surface water and groundwater resources such that the total benefits of integrated management exceed the sum of the benefits that would result from an independent management of each water resource." (OCWP, 2010).

The OCWP (2010) cited examples of other conjunctive management definitions from a variety of sources, such as:

> "Conjunctive water use usually involves institutional agreements where an existing groundwater user will curtail extractions during wet years in favor of a surface water supply, thereby allowing the aquifer to naturally replenish" (California Water Plan).

> "Conjunctive management is defined as the 'legal and hydrologic integration of administration of the diversion and use of water under water rights from surface and ground water sources, including areas having a common ground water supply" (Idaho Administrative Code).

Kershen (2021) cited a study on conjunctive management in western water law which concluded that nine of the eleven most western states had adopted conjunctive management practices in their respective state water law (Hazad and Shively, 2011). Kershen (2021) noted the varying approaches to conjunctive management across the western states, as demonstrated by Hazad and Shively (2011), as well as the OCWP technical memorandum which had surveyed conjunctive management practices of Oklahoma and seven other states (Texas, Kansas, Nebraska, Colorado, Utah, California, Oregon) (OWRB, 2010). The varying approaches employed by these states helped inform Dr. Kershen's

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[178] Because some readers of this report may skip to particular sections relevant to either Lugert-Altus or Tom Steed Reservoir, to avoid a situation where those readers miss important information, some discussions are repeated in both the Lugert-Altus Reservoir and Tom Steed Reservoir sections.

[179] OWRB, Oklahoma Comprehensive Water Plan – Technical Memorandum: Conjunctive Water Management in Oklahoma and Other States (Nov. 2010), (Technical Memorandum: Conjunctive Water Management).

analysis on conjunctive management, including how he addressed the specific factual and legal situations related to Tom Steed Reservoir.

Kershen (2021) stated quite clearly that with the exception of the Arbuckle-Simpson Aquifer, no legal mandate or statutory authority currently exists that allows the OWRB to adopt conjunctive water management in Oklahoma. As such, stream-water law and groundwater law in Oklahoma are viewed and managed accordingly as separate, independent water law systems. Of course, the OWRB acknowledges the fact that just because Oklahoma water law does not mandate conjunctive management does not mean that streams and aquifers are not hydraulically connected (OWRB, 2010). In fact, as Reclamation, OWRB, and USGS studies clearly establish, the NFFR and the NFRR alluvial aquifer are interconnected and impact one another to a significant degree (Smith et al., 2017). That being said, Kershen (2021) concluded that even without the Legislature expressly mandating conjunctive water management for Oklahoma, the OWRB may have the authority indirectly to consider the hydrological interconnection between groundwater aquifer and stream flows as it considers water management decisions. This point is particularly relevant to the strategy described below on development of a conservation-oriented aquifer maximum annual yield. But first, the discussion summarizes another conjunctive management strategy identified by Kershen (2021), namely dry-year lease agreements[180].

Voluntary Dry-Year Lease or Purchase Agreements

One conjunctive management strategy that MPMCD could consider is dry-year lease agreements with landowners holding groundwater permits so as to protect base-flow for West Otter-Glen Creeks and Elk Creek. If landowners refrained from pumping their allocated EPS, then the base flows of the two creeks should increase. As previously described, a dry-year lease allows two water users to exchange physical water without directly purchasing or exchanging water

[180] Kershen (2021) did not directly refer to dry-year lease agreements as a form of conjunctive management; yet, by definition, the strategy is a form of conjunctive management.

rights (Kershen, 2021). In western states, under the dry-year lease, a user seeking a water supply gains the ability to access another user's water under specified, preset conditions, such as the occurrence of a drought or when the user's demand for water reaches a certain intensity threshold (Kershen, 2021). Under the agreement, the water user leasing away its water supply is willing to accept the lease payments (i.e., money), and to cease using its physical water, when the preset conditions occur. Further discussion on the constraints and opportunities associated with dry-year lease agreements is discussed in Chapter 8 and in Kershen (2021).

In developing a dry-year lease agreement, as Kershen (2021) noted, an important question that would need to be answered relates to defining the preset conditions that could trigger the exchange between the water user (i.e., MPMCD) and the water seller (groundwater permit holder). Once a drought is underway, MPMCD could pay to protect base-flow for the Tom Steed Reservoir water supply. The hydrologic thresholds previously discussed in the management of stream-water permits could be a plausible option to inform management of groundwater permits through dry-year lease agreements as well. As landowners own their groundwater and have a vested right in their allocated EPS, there should be no barriers in statutes or regulations to impede the negotiation of voluntary contracts between MPMCD and landowners (Kershen, 2021).

Conservation-Oriented Maximum Annual Yield Determination

Like other strategies presented by Kershen (2021) for Lugert-Altus Reservoir, this strategy also applies to Tom Steed Reservoir. In Chapter 2.6, an important legal question was raised: does Oklahoma law allow the OWRB to reduce a landowner's existing EPS, either directly or indirectly, if new data result in a lower MAY? As previously discussed, in accordance with Oklahoma groundwater law, groundwater permits are issued by the OWRB based on land owned or leased by applicants such that each acre of land overlying an aquifer is allocated an EPS of the aquifer's MAY. The MAY is the amount of water the aquifer can provide for beneficial use on 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-yr period, the aquifer would be almost fully depleted, with a portion of the aquifer's saturated thickness reserved for domestic use. The MAY and corresponding EPS must be reviewed and updated based on hydrological surveys at least every 20 years. Furthermore, in setting the MAY for an aquifer, the OWRB must take into account "the rate of recharge to the basin or subbasin and total discharge from the basin or subbasin."

Another important legal question was raised in Chapter 2.6: what discretion does the OWRB have in advancing policy mandated by the Water for 2060 Act, by means of alternative strategies to manage water within the Lugert-Altus and Tom Steed Reservoir hydrologic basins? The Water for 2060 Act, passed by the Oklahoma legislature in 2012, made it the policy of the State to establish and work toward a goal of consuming no more fresh water in the year 2060 than is consumed statewide in the year 2012, while continuing to grow the population and economy. This would be achieved by utilizing existing water supplies more efficiently and expanding the use of alternatives provided those alternatives are not construed as amending provisions of existing law pertaining to rights or permits to use water.

Regarding the influence of groundwater on stream water, there are three groundwater aquifers within the Elk Creek and West Otter-Glen Creek watersheds. The NFRR aquifer is a major alluvial aquifer of which a very small portion underlies Elk Creek above the Bretch Diversion to Tom Steed Reservoir (Chapter 6.4.2). The Elk City aquifer is a major bedrock aquifer in the upper reaches of Elk Creek and has permitted groundwater rights of 9,400 acre-ft/yr. The Southwest Oklahoma aquifer is a minor bedrock aquifer underlying most of the land in the catchment basins of Elk and West Otter-Glen Creeks and has permitted groundwater rights of 600 acre-ft/yr. The Southwest Oklahoma aquifer is considered to be too thinly saturated to support irrigation uses beyond short-term domestic uses (OWRB, 1998).

In its modeling of groundwater flows, USGS concluded that Tom Steed Reservoir is primarily replenished by surface water runoff, but that on average, a portion of Elk Creek flows upstream of the Bretch Diversion Dam are attributable to groundwater base flow (Smith et al., 2017). As noted in Chapter 6.4.2, 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. The remaining portion of base flows in Elk Creek were presumably attributable to the Elk City aquifer, and pursuant with the OWRB's existing EPS pumping rate of 1.0 acre-ft/acre/yr, this study assumed that Elk Creek's base flows would be fully depleted to zero if both the NFRR and Elk City aquifers were fully developed.

In light of these just-described technical findings, and in light of the statutory obligations cited above, Kershen (2021) suggested that the OWRB would appear to have the authority to consider (to some extent) groundwater and surface water interactions as the OWRB sets a minimum aquifer basin life. And in light of the Water for 2060 Act specifically, the OWRB has the authority to select a minimum basin life with an emphasis on conservation, meaning that the OWRB legally could set a minimum basin life for the aquifers in the NFRR, Elk Creek, and the West Otter-Glen Creek watersheds of 50 years (i.e., approx. 2070) (Kershen, 2021).

The OWRB had previously determined the EPS for two of the three aquifers in the Elk and West Otter-Glen Creek watersheds, and those determinations are currently being updated. The OWRB has set an EPS of 1.0 acre-ft/yr for the NFRR aquifer and 1.0 acre-ft/yr for the Elk City aquifer. As for the Southwestern Oklahoma aquifer, it carries a temporary default EPS of 2.0 acre-ft/yr because hydrological surveys and investigations on this aquifer have not been completed[181]. However, as previously stated, the Legislature also gave the OWRB the authority the review and update the hydrological surveys and investigations every 20 years. When the OWRB reviews and updates

[181] It remains unclear if a hydrologic investigation and MAY/EPS determination will ever be conducted on this aquifer.

information for an aquifer, the OWRB can redetermine the MAY and the EPS for that aquifer.

Similar to Lugert-Altus ID, Kershen (2021) suggested that MPMCD could encourage the OWRB, as the OWRB reviews and updates the MAY and EPS for the NFRR and Elk City aquifers, to redetermine the MAY and EPS for the aquifer, and to adopt a conservation-oriented, lesser EPS for future groundwater permit applicants. MPMCD and Lugert-Altus ID could work collaboratively because they have shared interests in management of the NFRR aquifer which impacts both Lugert-Altus and Tom Steed reservoirs. In doing so, MPMCD and Lugert-Altus ID could encourage the OWRB to consider the total discharge from basins (surface and groundwater) such that discharge protections could be determined that maintain base flows above certain thresholds. They also could encourage the OWRB to undertake the hydrological surveys and information needed to set an EPS for the aquifer that would be smaller than otherwise set under existing practice. For example, one strategy could be to set a MAY and an EPS that reflected the groundwater pumping rate for 2013 or the projected groundwater pumping rate for 2060, either of which would better protect the base flow of the NFRR relative to current practice and be more compatible with Oklahoma's Water for 2060 policy. Consideration also could be given towards evaluating the relative impacts on baseflow caused by localized aquifer storage reduction corresponding to a range of withdrawals varying by existing well locations within the Lugert-Altus and Tom Steed Reservoir watersheds. Such an analysis could account for the relative distance of wells from tributaries of concern and the corresponding time it takes for withdrawals to impact those tributaries. Whatever the case may be, by adopting a conservation-oriented MAY and EPS for the NFRR, the Lugert-Altus ID and MPMCD could gain indirect protection for the base flows of the NFRR; and by protecting base flows, Lugert-Altus ID and MPMCD could protect the water supply in storage for Tom Steed Reservoir (Kershen, 2021). Similarly, MPMCD could work collaboratively with the OWRB to adopt a similar approach for the Elk City aquifer.

Of course, as noted in Kershen (2021), overlying landowners who have already gained a permit for groundwater pumping have a vested right in the EPS applicable at the time the OWRB granted their permits so their pumping rate may not be diminished. By contrast, those overlying landowners who apply for a new permit after the review and update can only pump to the level of the redetermined EPS, even if the redetermined EPS is smaller than the original EPS for that aquifer. This strategy is evaluated further in Chapter 8.3.4.

7.3.5. Reclassification of Alluvial Groundwater to Stream Water

This strategy was discussed for Lugert-Altus Reservoir but also applies to Tom Steed Reservoir. As presented in Kershen (2021), reclassifying groundwater as stream water under certain, specified conditions, would subsequently allow these reclassified waters to be managed in accordance with Oklahoma's surface water prior appropriation laws. This would effectively make MPMCD's permit senior to groundwater use permitted after the dates of the reservoir permit, and then MPMCD could use interference regulations developed by the OWRB to gain protection for its senior stream permit against junior stream permits, including those groundwater wells that would be taking alluvial waters or losing stream waters that would now be reclassified as stream water.

To be clear, reclassification of certain, specified Oklahoma groundwater as stream water would not mean that the OWRB would be engaged in conjunctive management of stream water and groundwater; rather, Kershen (2021) proposed that such a reclassification simply would move certain, specified Oklahoma groundwater from management under the groundwater laws to management under the stream-water laws. Kershen (2021) cited two legal arguments for reclassification: (1) "the alluvial waters argument", such that the Oklahoma legislature impermissibly moved alluvial waters from being public waters to private ownership waters in 1967 and 1972 amendments to Oklahoma's water laws; and (2) "the losing stream argument", such that Oklahoma water law could make a distinction between gaining streams (groundwater movement) and losing streams (stream water movement). Neither of these arguments have ever been presented to Oklahoma courts, so for reclassification to occur in either the Lugert-Altus or Tom Steed Reservoir hydrologic basins, litigation would likely need to be pursued (Kershen, 2021). Further discussion of this strategy is reserved for Chapter 8.3.5.

7.3.6. Environmental Quality Beneficial Use

About 85 percent of MPMCD's 16,100 acre-ft/yr water right is allocated for M&I purposes, with the remaining 15 percent (2,352 acre-ft/yr) allocated for EQ purposes. As discussed in Chapter 1.2.2, the city of Frederick's desire to relinquish 60 percent of its M&I allocation helped prompt Federal legislation in 1994 authorizing EQ benefits at the Mountain Park Project. Reclamation, the MPMCD, ODWC, and the city of Frederick developed an Environmental Quality Plan in 1995 (EQ Plan) that reallocated Frederick's 60 percent M&I allotment to the Hackberry Flat WMA for EQ purposes. The Hackberry Flat WMA was being restored by ODWC from a remnant playa basin into a large wetland complex with moist soil management units aimed at attracting migratory birds. In exchange for Frederick's relinquishment, the U.S. reduced Frederick's cost-share of the MPMCD's repayment and O&M obligations. In accordance with the EQ Plan, the ODWC, which owns and manages Hackberry Flat WMA, installed a 15.9-mile aqueduct (i.e., Hackberry Flat Pipeline) beginning near the terminus of Reclamation's Frederick Aqueduct and extending to a National Resource Conservation Service (NRCS) flood regulation reservoir at the Hackberry Flat WMA (Figure 7-2). Construction of the pipeline was completed in 1999, and MPMCD began delivering water to ODWC for use at Hackberry Flat WMA that same year[182]. While deliveries to Hackberry Flat continued for more than a

[182] Although deliveries to Hackberry Flat WMA began in 1999, it was not until several years later (2005) that a water supply contract was signed by MPMCD and ODWC that officially allowed MPMCD to deliver up to 2,352 acre-ft/yr to the WMA.

decade, no deliveries have been made to Hackberry Flat WMA since 2013. The ODWC and MPMCD have indicated to Reclamation that a leading cause of the discontinuance of deliveries is that the Hackberry Flat Pipeline appears to be leaking a substantial volume of water and is likely no longer in a viable operating condition[183].

[183] The pipeline connecting the Frederick Aqueduct to Hackberry Flat WMA was apparently donated to ODWC by an oil company that had used the pipeline to convey oil.

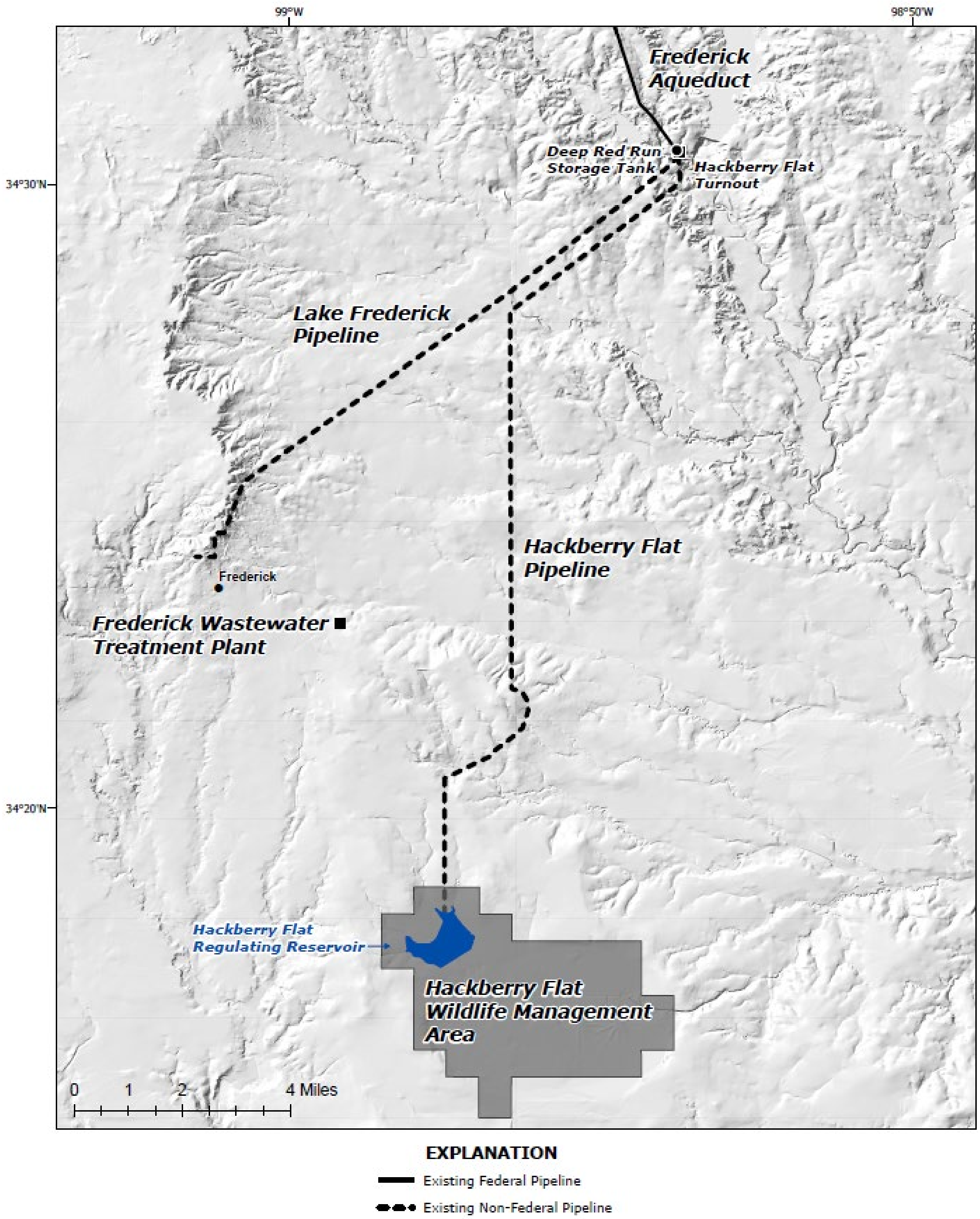

Figure 7-2. Existing infrastructure used to deliver water to Hackberry Flat Wildlife Management Area, Mountain Park Project, Oklahoma

Reevaluate EQ and M&I Needs

Understanding that the relatively high costs to address the Hackberry Pipeline are likely to delay or even prevent further deliveries to Hackberry Flat WMA, a reevaluation of Mountain Park Project benefits is warranted. The reevaluation should begin with an assessment of the EQ water needs at Hackberry Flat WMA. The EQ needs should be evaluated from a new perspective that considers an up-to-date analysis on the management objectives of Hackberry Flat WMA, whether local and natural climatological/hydrological conditions may be sufficient to support those objectives, and whether delivering a lesser volume than 2,352 acre-ft/yr, or no EQ water at all, would impact achievement of the newly-developed management objectives at Hackberry Flat WMA. An optimization assessment also should be performed that identifies opportunities to conserve water through improved water management and instrumentation within the Hackberry Flat WMA complex.

The discretion to perform this EQ reevaluation is provided in recognition of two key facts. First, although the Mountain Park Project was authorized in 1994 to provide EQ benefits, this does not mean that the Mountain Park Project is required to provide EQ benefits. Second, although the 1995 EQ Plan established a range of objectives, terms, and conditions by which the reallocation of M&I water to EQ water would occur, there is no reason why the provisions in the EQ plan cannot be modified to reflect the needs and objectives of today, or why the EQ Plan itself could not be terminated. After all, the original volume of EQ water assigned to Hackberry Flat WMA (i.e., 2,352 acre-ft/yr volume) was derived not from a specified need at Hackberry Flat WMA (although the water was assuredly desired to achieve restoration goals at the time), but as a byproduct from the city of Frederick's desire to relinquish 60 percent of its M&I allocation within MPMCD's permit; and Frederick's relinquishment itself was a byproduct of Frederick's inability to pay for a portion of Tom Steed Reservoir water that was considered to be in excess of their needs in the 1980s and 1990s. It very well may be that the management objectives of Hackberry Flat WMA could still be met by delivering a lesser volume than 2,352 acre-ft/yr, or by not delivering any EQ water at all. An up-to-date analysis on the current management objectives and needs of Hackberry Flat WMA would provide valuable insight into the matter.

In addition to reevaluating the current EQ needs of Hackberry Flat WMA, a reevaluation of M&I needs is warranted. This analysis should take into account the best available data of today, namely the supply and demand information contained within this URRBS. For example, at the onset of the 2010s Drought of Record, water deliveries to the cities of Altus, Frederick, and Snyder were equivalent to 67 percent, 96 percent, and 129 percent of their respective M&I allocations (Figure 2-30). The deliveries to all three cities represented 70 percent of the total M&I allocation, with Snyder using more than its allocation, and Frederick using almost its full allocation. Looking at a larger dataset and future projections, M&I water deliveries to Altus, Frederick, and Snyder between 2010 and 2018 ranged from 5,496 acre-ft/yr to 9,506 acre-ft/yr (Table 5-5). Projected future (year 2060) M&I demands ranged from 6,030 acre-ft/yr to 12,600 acre-ft/yr (Figure 5-68). Status-quo results showed that the firm yield of Tom Steed Reservoir would be insufficient [(as low as 5,000 acre-ft/yr under higher development scenarios (Figure 6-19)] to supply the combined needs of MPMCD's three member cities; in fact, the firm yield may not be sufficient to supply even city of Altus' M&I needs based on these projections. The information above highlights the potential benefits of reallocating EQ water back to its original M&I purpose.

Reevaluate EQ Objectives and Alternatives to Achieve EQ Benefits

Depending on the continued viability of the Hackberry Pipeline, and 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 all or a portion of EQ water remains unused, then an incentive may exist for the MPMCD to coordinate with any or all of its member cities, along with ODWC and Reclamation, to identify and implement steps to reallocate any unused EQ water back to M&I purposes. Of course, agreement would need to be made among parties regarding the volume of increased M&I water deliveries needed as this would result in a corresponding volume of reduced EQ deliveries to Hackberry Flat WMA. To this end, consideration also could be given towards reallocating the full EQ volume of 2,352 acre-ft/yr for M&I purposes. Although doing so would result in discontinuing EQ deliveries to Hackberry Flat WMA, as previously stated, it may not necessarily jeopardize the ecosystem and recreation benefits that Hackberry Flat WMA continues to provide. This should remain a viable option until the needs and objectives of Hackberry Flat WMA have not been fully investigated.

However, if the objective is to resume all or some deliveries of EQ water to Hackberry Flat WMA, then the viability of the Hackberry Flat Pipeline must be addressed. Two alternatives were identified in the URRBS to address this need: (1) replace the Hackberry Flat pipeline with a new pipeline; or (2) install a slip-line into the existing Hackberry Flat pipeline. A pipeline condition assessment should be performed to assess which of the two alternatives would be most cost effective or if another solution is available. A preliminary cost evaluation of these alternatives is provided in Chapter 8.3.6.

To further inform a determination on the objectives moving forward in terms of delivering all EQ water, some EQ water, or no EQ water to Hackberry Flat WMA, another alternative considered in this URRBS was the delivery of water to Hackberry Flat WMA from alternative, non-EQ water sources. For example, the city of Frederick currently disposes of about 750 acre-ft/yr of effluent from its nearby wastewater treatment plant, and this effluent could be recycled and put to beneficial use at Hackberry Flat WMA. As part of the URRBS, Reclamation performed a preliminary engineering and cost analysis to deliver Frederick's recycled water to Hackberry Flat WMA. The results of this analysis are provided in Chapter 8.3.6.

Summary and Stakeholder Interest

The issues surrounding EQ benefits of the Mountain Park Project are very complicated, and the context, need, and opportunities that are present today may be different than those that existed in the 1980s and 1990s when the EQ issue first came to light. As of the writing of this URRBS, deliveries have not been made by MPMCD to Hackberry Flat WMA for seven years (since 2013). Three alternatives were proposed in this URRBS to remedy this problem: (1) deliver all EQ water to Hackberry Flat WMA; (2) deliver some EQ water to Hackberry Flat WMA, and (3) deliver no EQ water to Hackberry Flat WMA. If the objective is to deliver all or some EQ water to Hackberry Flat WMA, then a pipeline condition assessment is needed to determine the condition and viability of the Hackberry Flat Pipeline. In addition, a reevaluation of the EQ needs and objectives of Hackberry Flat WMA is needed so that the benefits of providing EQ water can be compared with the M&I needs that are known to exist and are projected to increase into the future. If the objective is to resume delivery of some or all EQ water (and the means exist to do so) or to stop delivering EQ water to Hackberry Flat WMA altogether, then alternative, non-EQ water supply sources (e.g., Frederick recycled water) could be considered for use at Hackberry Flat WMA, allowing some or all of the EQ water from Tom Steed Reservoir to be repurposed to M&I. These alternatives, and combinations thereof, are described in more detail in Chapter 8.3.6

Multiple stakeholders have an interest in resolving this issue. As the owner of the Mountain Park Project, the U.S. has an interest in ensuring that the Federally authorized benefits of the Mountain Park Project continue to be met. When 60 percent of Frederick's M&I allocation was reallocated for EQ purposes to the Hackberry Flat WMA, the U.S. effectively "purchased" (and continues to incur O&M costs for) the EQ water, and MPMCD's Project repayment and annual O&M obligations were proportionally reduced to reflect the volume of water reallocated from M&I to EQ. As a result, the U.S. has an interest in ensuring Project EQ benefits are achieved, and as such, there is an interest in ensuring the EQ water is delivered to Hackberry Flat WMA. This entails addressing the viability of the Hackberry Flat WMA pipeline. In alignment with the broad authority of the Mountain Park Project to provide both EQ benefits and M&I benefits, the U.S. has an interest in investigating how much water is actually required for EQ purposes at Hackberry Flat WMA; if any of the water currently allocated for EQ purposes could be reallocated to M&I; and if there are alternative water supply sources for EQ water.

The MPMCD holds the 16,100 acre-ft/yr permit for Tom Steed Reservoir and has an interest in ensuring that permitted water is put to beneficial use. The MPMCD's M&I customers have a demonstrated, quantifiable water supply need. If permitted water is not put to beneficial use, then the unused water could be removed from the permit in accordance with Oklahoma's "use it or lose it" policy. To this end, MPMCD and its customers have an interest in investigating the viability of the Hackberry Flat Pipeline to ensure MPMCD's permitted water supply is fully put to beneficial use.

The MPMCD also has an interest in investigating the extent to which Hackberry Flat WMA needs EQ water to supplement the natural inflow to the wetlands and comparing Hackberry Flat WMA's needs to the relative needs of MPMCD's three member cities for M&I purposes. If investigations into Hackberry Flat WMA demonstrate a continued need for supplemental EQ water, then MPMCD has an interest in evaluating alternative EQ water supply sources for Hackberry Flat WMA, and the benefits and costs of developing these alternative supplies so that all or a portion of the EQ water from Tom Steed Reservoir could be reallocated to M&I purposes.

The ODWC owns and operates the Hackberry Flat WMA, maintains ownership of the Hackberry Flat pipeline, and has a contract with MPMCD to receive EQ water from Tom Steed Reservoir. The ODWC has an interest in ensuring that Hackberry Flat WMA continues to provide regional ecosystem and fish and wildlife benefits, and therefore, ODWC has an interest in addressing the viability of the Hackberry Flat pipeline, and in investigating Hackberry Flat WMA's continued need for supplemental water. In so far as resources may not exist to address the viability of the pipeline, either through replacement of the pipeline or slip-lining the existing pipeline, or the costs associated with operation, maintenance, and replacement of the pipeline are not justified by the associated benefits, then ODWC might support the reallocation of EQ water to M&I water in the interest of the citizens of southwestern Oklahoma. If investigations into Hackberry Flat WMA demonstrate a continued need for supplemental water, then ODWC has an interest in evaluating alternative EQ water supply sources to Hackberry Flat WMA in so far as the outcome of such studies fulfills ODWC's interest in ensuring Hackberry Flat WMA continues to provide ecosystem and fish & wildlife benefits.

7.3.7. Expansion of the Bretch Diversion and Canal

Recall the infrastructure and operational challenges described in Chapter 2.4.2. The Mountain Park Project was designed such that Tom Steed Reservoir would receive its supply from two sources: (1) natural inflows from West Otter Creek and Glen Creek and (2) out-of-basin diversions from Elk Creek. Of the two watersheds, the West Otter-Glen Creek watershed is smaller, and while it provides less inflow into Tom Steed Reservoir on average relative to Elk Creek, the base flows are higher which would help sustain Tom Steed Reservoir during prolonged drought periods. Elk Creek, on the other hand, is located within a much larger watershed, which enables it to capture more run-off from rain events. On average, Elk Creek provides relatively more inflows into Tom Steed Reservoir; however, its base flow is lower, making it less reliable during prolonged drought periods. The system was designed to convey Elk Creek flow to supplement Tom Steed storage when the reservoir drops below the top of conservation pool.

Diversions from Elk Creek are made by storing water behind the Bretch Diversion Dam (Figure 2-38; Figure 7-3) and releasing it into the Bretch Canal for conveyance into Tom Steed Reservoir. The Bretch Diversion Dam and Canal are currently sized with capacities of 970 acre-ft and 1,000 cfs, respectively. Their capacities were determined as the most efficient means of maximizing reservoir firm yield based on an analysis included in the original 1962 Plan of Development for the Mountain Park Project. The

Figure 7-3. Bretch Diversion and Canal, Mountain Park Project.

original analysis used available hydrology data through 1959[184], including the 1950s drought of record (at that time).

Over the 30-yr-period since the original analysis and prior to the 2010s Drought of Record, conditions were generally wet and Elk Creek diversions were minimal, in part to offset operation and maintenance costs, but also because Tom Steed Reservoir levels were fairly stable. As the 2010s Drought of Record unfolded and the reservoir elevation dropped, diversions were initially kept to a minimum. As conditions worsened, operations were eventually modified in the fall of 2013 such that all divertible flows from Elk Creek would be conveyed to Tom Steed Reservoir. At its lowest point, Tom Steed Reservoir dropped to only 17 percent of storage (15,400 acre-ft), a record low, before the drought ended in 2015. Had Elk Creek diversions been initiated in 2010 when the reservoir first dropped below conservation pool rather than waiting until 2013 (a.k.a., "Optimized Bretch Diversions"), simulated storage of Tom Steed Reservoir would have only dropped to 25 percent of storage (23,500 acre-ft), assuming similar water demands (Figure 2-39; Figure 7-4). Assuming that optimized Elk Creek diversions are the new "status quo", as part of this URRBS, MPMCD wanted to know if there would be any benefit to Tom Steed's firm yield by expanding the capacity of the diversion system to capture additional flows from Elk Creek.

In Chapter 8.3.7, this strategy is evaluated by comparing the supply benefits and costs of various Bretch Diversion and Canal expansion options (Figure 7-5). These options are compared to a status-quo condition such that the diversion system remains unchanged but is operated as intended to optimize reservoir supply in accordance with the 1962 Plan of Development.

[184] Monthly data from 1926 to 1959; daily data from 1949 to 1959.

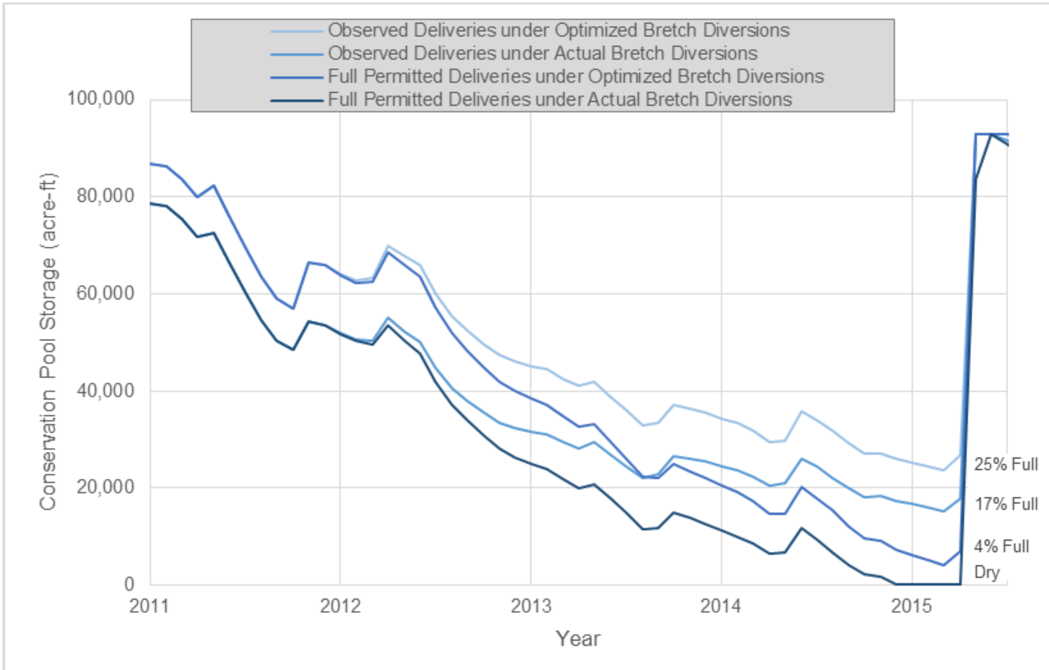

Figure 7-4. Tom Steed Reservoir storage under observed diversions from Elk Creek during the 2010s Drought of Record compared to modeled reservoir storage under optimized diversions, each shown with observed M&I deliveries and full permitted deliveries of 16,100 acre-ft/yr.

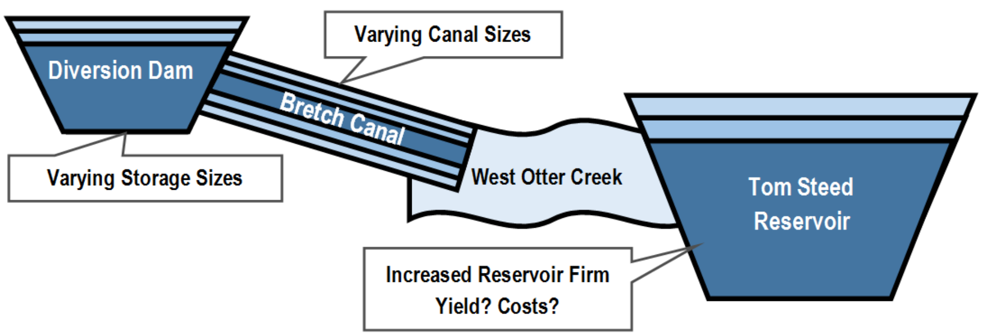

Figure 7-5. Conceptual illustration of the analysis of sizing the Bretch Diversion Dam and Canal System, Mountain Park Project.

7.3.8. Development of Supplemental Groundwater Supplies

The MPMCD is developing engineering plans to install new groundwater wells yielding up to 2.0 million gallons per day (2,240 acre-ft/yr) to supplement Tom Steed Reservoir and fulfill Project purposes by helping ensure that the MPMCD's full water right of 16,100 acre-ft/yr can be delivered during a repeat of the 2010s Drought of Record. Upon the request of MPMCD, Reclamation has determined that the supplemental groundwater could be considered "Project Water" in accordance with the existing Project authorization, Reclamation Policy, and the Repayment Contract[185]. Reclamation's determination was based on the assumption that: (1) the groundwater would be used for authorized M&I purposes only; and (2) the groundwater would supplement the existing surface water supply from Tom Steed Reservoir and would be used conjunctively with Project water from Tom Steed Reservoir such that the combined total volume of groundwater and surface water delivered through Project infrastructure does not exceed 16,100 acre-ft/yr, the total volume of permitted water allocated under the MPMCD's existing water supply contracts. This determination is an important step toward MPMCD delivering the supplemental groundwater through existing Mountain Park Project infrastructure.

The MPMCD plans to obtain all necessary groundwater permits from the OWRB. In accordance with Oklahoma water law, in order for MPMCD to obtain the necessary groundwater permit(s) from OWRB, the MPMCD must acquire or otherwise "dedicate" a proportionate amount of land associated with the groundwater permit's proposed volume; furthermore, the land (acreage) acquired or dedicated for the groundwater permit may be in a different location than the corresponding groundwater well(s) as long as the well(s) and dedicated land are associated with the same aquifer. The Mountain Park Project is comprised of approximately 12,000 acres of Federally-owned land surrounding Tom Steed

[185] Federal law prohibits Reclamation from using its infrastructure to convey "non-project water" for M&I purposes. By deeming this groundwater source "Project water", the proposed project would be allowable under Federal law.

Reservoir; and as previous stated, the NFRR aquifer supplying the proposed groundwater wells extends beneath Federally-owned Project lands and is hydrologically connected with the streams that make up the Tom Steed Reservoir drainage basin. Therefore, Reclamation made a determination that any and all Federally-owned Project lands could be dedicated to the groundwater permit(s) sought or obtained by MPMCD; this presumes that the dedication does not constitute a transfer of ownership/title of Project lands from the United States to MPMCD.

Key steps remain on implementation of the well field(s). First, plans 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. These plans will require Reclamation's review and approval. 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.

7.3.9. Water Conservation

Water conservation is always an important consideration in water resources management. Water conservation measures could be incorporated and applied to any target demand volume to arrive at "with" and "without" water conservation planning objectives. For example, during the 2010-2015 drought of record, M&I deliveries were reduced by 42 percent from 9,500 acre-ft/yr in 2011 to 5,500 acre-ft/yr in 2014, representing the largest percentage of water conserved since water deliveries began in the 1970s. As such, 42 percent could be assumed as a maximum percentage of M&I water that could reasonably be conserved during a repeat of the drought of record. Therefore, if the full 16,100 acre-ft/yr permit is being utilized, a 42 percent conservation rate would result in a reservoir demand of 9,300 acre-ft/yr[186].

Another consideration could be future projected demands on Tom Steed Reservoir in the year 2060. These demands were projected to range from 7,830 acre-ft/yr to 14,950 acre-ft/yr (Chapter 5.4.2). As discussed earlier in this section, a reasonable planning objective for an adaptation strategy could be the higher projected demand of 14,950 acre-ft/yr; applying a 42 percent water conservation rate to this volume would result in a 2060 reservoir demand of 8,700 acre-ft/yr.

And finally, one could consider the maximum volume of historical deliveries made by MPMCD, which was 12,700 acre-ft/yr in the year 2006 (Chapter 5.2.2), applying a 42 percent water conservation rate to this volume would result in a reservoir demand of 6,800 acre-ft/yr.

Again, the primary planning objective under this URRBS for Tom Steed Reservoir was to maximize water deliveries through a repeat of the 2010-2015 drought of record, including the historical maximum reservoir use of 12,700 acre-ft/yr and up to the volume of MPMCD's water right permit of 16,100 acre-ft/yr, and the modeling analyses included herein reflected this approach. The lesser demands that include water conservation could be considered only as a means of adding additional flexibility into the adaptation strategies in terms of testing their ability to protect the volume within the MPMCD permit that is either currently being put to beneficial use or could be put to beneficial use during prolonged and severe droughts.

[186] It is recognized that 13,618 acre-ft/yr (~ 85 percent) of the 16,100 acre-ft/yr permit is allocated for M&I purposes, and 2,352 acre-ft/yr (~15 percent) is allocated for EQ purposes; but for planning purposes, it is reasonable to assume that the full 16,100 acre-ft/yr could be allocated for M&I purposes, which is why 42 percent was applied to 16,100 acre-ft/yr rather than 13,618 acre-ft/yr.

Chapter 8. Evaluation of Adaptation Strategies

8.1. Overview and Approach

Chapter 6 quantified the impacts of a future under a range of status-quo management and development scenarios within the Lugert-Altus and Tom Steed Reservoir hydrologic basins. Impacts were quantified based on several performance metrics, including aquifer storage and yield, base flow, streamflow, reservoir inflow, reservoir and permit dependability, and basin-wide stream permit availability. Chapter 7 used the results in part to identify planning objectives for the Lugert-Altus and Tom Steed Reservoir hydrologic basins. Planning objectives largely centered on eliminating water supply imbalances and maximizing permit availability and beneficial use of water. Chapter 7 also described a range of adaptive strategies that could be considered to address these planning objectives. Included was the justification and process by which these strategies were identified and formulated as opposed to other strategies that were considered but eliminated from further consideration.

In this chapter, the adaptive strategies identified in Chapter 7 are 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 – both under baseline climate conditions (as compared to results presented in Chapter 6.4) and under possible climate change scenarios (as compared to results presented in Chapter 6.5). Some evaluations include a direct quantitative comparison between the proposed adaptive strategy and the "do nothing" future under status quo; while other evaluations are qualitative in nature and do not lend themselves to a quantitative comparison either among the strategies themselves or between the strategy and a status-quo future. It should be pointed out here again, as noted in Chapter 1.1, that Reclamation's Basin Study Program includes a set of requirements that all basin studies must address. One of those requirements, which particularly relates to the analysis of adaptive strategies included here, is to perform a "trade off" analysis of adaptation strategies identified in the basin study. Specifically, it states that the following is required:

> *"A quantitative or qualitative trade-off analysis of the adaptation and mitigation strategies identified. Such analysis will examine all proposed strategies in terms of their ability to meet the study objectives, the extent to which they minimize imbalances between water supply and demand and address the possible impacts of climate change, the level of stakeholder support, the relative cost (when available), the potential environmental impacts, or other attributes common to the strategies."*[187]

This term "trade-off analysis" of "attributes common to the strategies" could be interpreted by some as meaning all adaptation strategies must be compared to one another based on a common set of criteria, and that the result will be one or more strategies selected as the best solution(s) for implementation. While that type of analysis is warranted and even required for Federal planning investigations that culminate in recommendations for action or result in an official position of the agency, what sets basin studies apart from those types of planning investigations is that basin studies, including the URRBS, are explicitly *prohibited* from making recommendations or from making findings that represent a position of the agency. According to WTR 13-01, a basin study is defined as follows:

[187] Reclamation's Directives and Standards on Basin Studies (WTR 13-01); https://www.usbr.gov/recman/wtr/wtr13-01.pdf.

"A comprehensive study, or update of an existing study, that identifies imbalances between water supply and demand and includes the development of mitigation and adaptation strategies in direct response to current or future water supply and demand imbalances resulting from climate change and other stressors. Basin studies are technical assessments and do not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the funding partners. Basin studies do not propose or address the feasibility of any specific project, program, or plan and do not represent a commitment for provision of Federal funds."[188]

With the two aforementioned provisions in mind, it should be stated clearly that this study did include a trade-off analysis of adaptive strategies, but the analysis was cursory and qualitative in nature, and it did not culminate in a recommendation by Reclamation or any of the study partners on implementation of any particular strategy over another. Specifically, the trade-off analysis included a comparison of each alternative's ability to meet four criteria that are used by Reclamation in its more traditional planning studies as described in the Principles, Requirements and Guidelines for Water and Land Related Resources Implementation Studies[189]. These four criteria, defined later in this chapter, are: acceptability, efficiency, effectiveness, and completeness.

To the extent possible and applicable, comparisons among strategies were made in terms of their relative ability to meet planning objectives and improve water supply availability, but in some cases, the strategies are either too different or not mutually exclusive to warrant a meaningful comparison. Not being mutually exclusive means that two or more strategies could be implemented at the same time and that one

[188] Reclamation's Directive and Standard on Basin Studies (WTR 13-01); https://www.usbr.gov/recman/wtr/wtr13-01.pdf.
[189] https://www.doi.gov/ppa/principles-and-guidelines.

strategy does not necessarily need to be selected over another (e.g., multiple legal or administrative strategies could be pursued simultaneously).

Where applicable, findings supported by quantitative analyses did demonstrate that some strategies, or subcomponents within strategies, performed better than others at addressing planning objectives or otherwise reducing or eliminating water supply imbalances. Such is the case for the quantitative performance analysis of thresholds that trigger management of water rights and stream-water permits (i.e., see "Protection of Existing Stream-Water Rights of the Mountain Park Master Conservancy District"), which showed that some thresholds performed quantitatively better than others in terms of protecting the yield of Tom Steed Reservoir.

8.2. Lugert-Altus Reservoir

Recall that the planning objective for Lugert-Altus Reservoir was to maximize the volume of water held in storage such that 115,000 acre-ft/yr 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 and including the agreed-upon storage reserve (Chapter 2.3.1). Providing this storage would effectively eliminate supply imbalances presented in Chapter 6.4.3.

In the sections that follow, the six strategies identified in Chapter 7.2 are evaluated in terms of their potential to address these planning objectives.

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

Top of Conservation Pool

As a point of clarifying the quantity of existing stream-water rights to Lugert-Altus Reservoir, Kershen (2021) examined the merits of claiming a water right to the top of conservation pool. Depending on merits of such a claim, insight can be provided into the extent to which this strategy addresses the planning objective of having 115,000 acre-ft of water in storage in Lugert-Altus Reservoir at the beginning of each irrigation season.

When discussing water rights and ownership of those rights, Kershen (2021) explained the distinction between storage rights and beneficial use rights. According to Kershen (2021), Oklahoma distinguishes between storage rights (i.e., the right to trap water within a reservoir to the reservoir capacity) and the right to use water for a beneficial purpose (e.g., the beneficial purpose of irrigation). Lugert-Altus Reservoir has State permission to trap water within the reservoir to the top of conservation pool. Moreover, Reclamation is entitled to payment reimbursement from project beneficiaries for building the dam and other project facilities and for providing the storage capacity of the reservoir to hold water. But according to Kershen (2021), storage rights do not carry the same legal classification as property rights when compared to beneficial use rights. In Oklahoma, water rights in stream waters, the recognized property right in water most clearly and firmly attaches when a person applies for unappropriated water for a beneficial use and then actually uses the water for that beneficial use. In other words, the storage of water itself does not create a water right; rather, the water right is legally recognized only when a specified quantity of water is put to a beneficial use as defined by Oklahoma law (Kershen, 2021). Based on this analysis, one could conclude that clarifying existing stream-water rights to Lugert-Altus Reservoir by means of claiming a right to the top of conservation pool would obviously not meet the planning objective of having 115,000 acre-ft of water in storage at the beginning of each irrigation season. However, not everyone may agree with this analysis, and it is clearly not the intent of this study to make a determination one way or another. If claiming a water right to the top of conservation pool was legally validated or otherwise approved by the OWRB, then clearly 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. The reader is encouraged to read Kershen (2021), Chapter 4.II.b, for a lengthy examination of this issue.

8.2.2. Protection of Existing Stream-Water Rights to Lugert-Altus Reservoir

Regulatory Protection

This strategy entailed the protection of the senior existing irrigation and M&I water rights to Lugert-Altus Reservoir from interference from junior water right holders upstream of Lugert-Altus Reservoir. As discussed in Chapter 7.2 and drawing on the analysis included in Kershen (2021), a determination was made by study partners that an administrative enforcement procedure managing stream-water permit holders upstream of Lugert-Altus Reservoir would not meaningfully address the planning objective of having 115,000 acre-ft/yr of water in storage at the beginning of each irrigation season. Rather, study partners wanted to pursue an evaluation of pre-determined hydrologic thresholds that curtail use of permitted alluvial groundwater pumping upstream of Lugert-Altus Reservoir. Such a strategy would likely require a future change in Oklahoma law that reclassified certain alluvial groundwater above Lugert-Altus Reservoir to stream water. As such, this option is discussed in more detail below in Chapter 8.2.5 "Reclassification of Alluvial Groundwater to Stream Water"; this section includes an extensive discussion on the development of the hydrologic thresholds that could be used to manage withdrawals of permitted alluvial groundwater pumping above Lugert-Altus Reservoir.

Non-Regulatory Protection

This strategy was comprised of two alternatives: (1) protection of the combined M&I and irrigation rights to water stored in Lugert-Altus Reservoir through the voluntary purchase or leasing of existing senior permitted rights on the NFRR upstream of Lugert-Altus Reservoir; and (2) protection of only the irrigation right by leasing or converting/assigning the M&I right to an irrigation right held by Lugert-Altus ID. 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 additional water supply for irrigation that otherwise has to remain in storage to protect the city of Altus' senior right to M&I water[190].

The first alternative was dismissed because the irrigation and M&I rights in Lugert-Altus Reservoir, dated 1939 and 1925, respectively, are the most senior rights on the NFRR, so no senior stream permit holders on the NFRR exist from which to purchase or lease water rights. For reasons discussed in Chapter 7.2, the second alternative was considered reasonable and is discussed here in terms of its potential in achieving the planning objective of having 115,000 acre-ft of water in storage at the beginning of each irrigation season.

Recall the quantitative basis supporting the 115,000 acre-ft water in storage planning objective was comprised of Lugert-Altus ID's irrigation right of 85,630 acre-ft/yr plus the 29,000 acre-ft/yr in additional storage needed to deliver the city of Altus' contractual right to 4,800 acre-ft/yr M&I right to water in accordance with the 1954 Settlement Agreement between the Lugert-Altus ID and the city of Altus (Chapter 2.3.1). Consequently, reassigning the M&I right to an irrigation right would eliminate the need for Lugert-Altus ID to reserve extra water in storage, thereby freeing up the additional 29,000 acre-ft/yr of water for irrigation that otherwise would be reserved in storage to meet M&I delivery obligations to the city of Altus. At the same time, this strategy assumes that Lugert-Altus Reservoir would continue to serve as the primary M&I water source for the city of Altus. Henceforth, this option is referred to as the "Without Operating Rules" strategy.

To evaluate the benefits to water supply reliability of Lugert-Altus Reservoir, the RRY model was used to simulate the impacts of the "Without Operating Rules" strategy on the average annual yield and permit availability of Lugert-Altus Reservoir. Results were compared to the status quo "With Operating Rules" alternative (as presented in Chapter 6), which assumed the

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[190] The 4,800 M&I water right is held by the U.S. and contracted to the city of Altus. This strategy assumes that the city of Altus' right to water could be converted, assigned, or otherwise transferred to Lugert-Altus ID, but that ownership of the M&I right would remain with the U.S. This assumption may or may not be valid, but the purpose here was to explore conversion of the water right in concept, not to analyze the legal mechanism for such a conversion.

4,800 acre-ft/yr M&I water right would continue to be contracted to the city of Altus, and Lugert-Altus ID would continue to reserve storage in accordance with the 1954 Settlement Agreement.

Modeling results show that the “Without Operating Rules” strategy could increase the average annual yield of Lugert-Altus Reservoir by between 20,600 acre-ft/yr (45 percent increase compared to “With Operating Rules”) and 27,200 acre-ft/yr (80 percent increase compared to “With Operating Rules”) depending on the development scenario (Figure 8-1). Furthermore, the “Without Operating Rules strategy increased the dependability of the full 85,630 acre-ft/yr irrigation permit by between 31 percent and 23 percent depending on the development scenario (Figure 8-2). Similar trends were observed for the overall dependability of permit water for irrigation across all development scenarios (Figure 8-3).

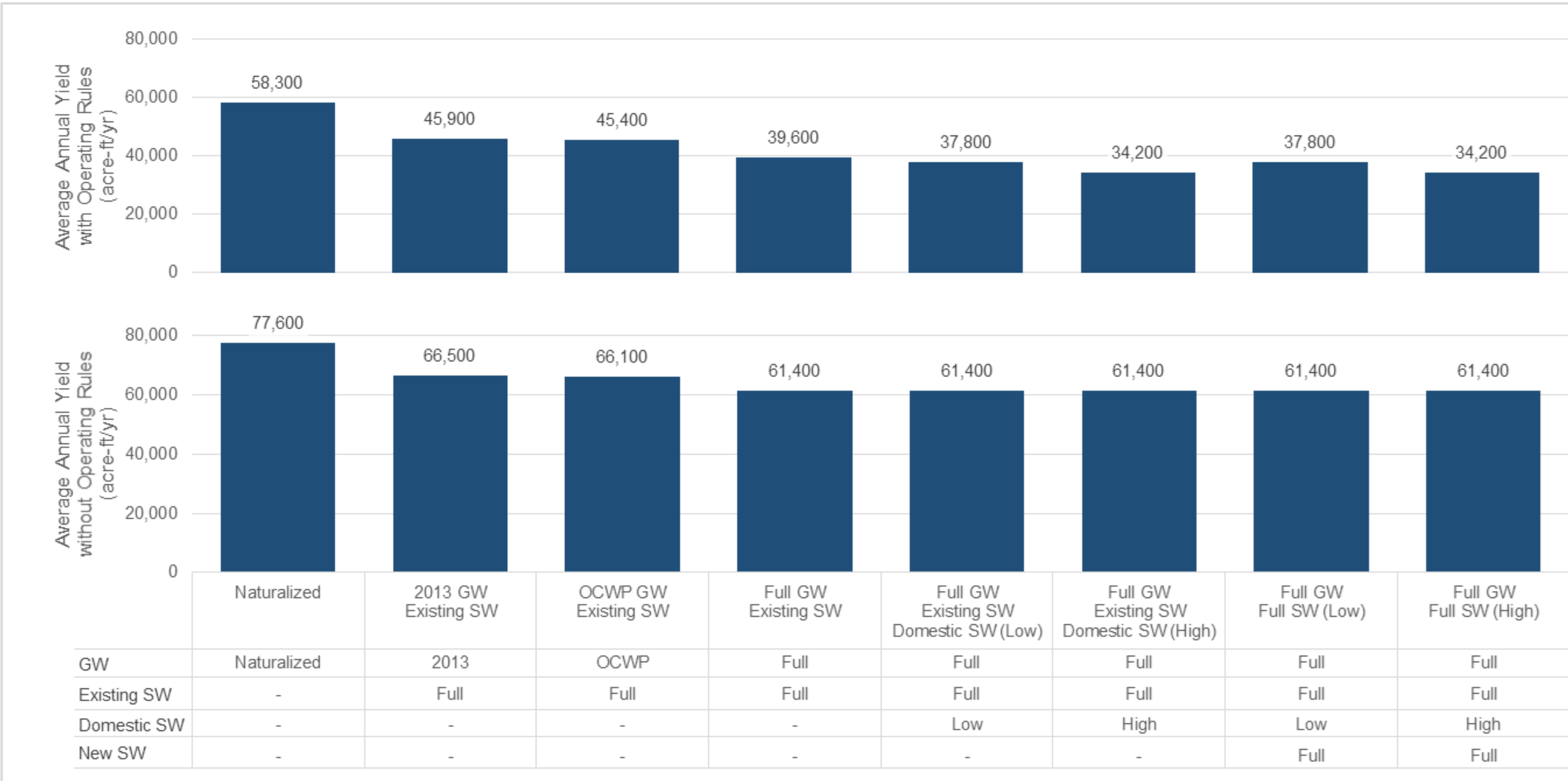
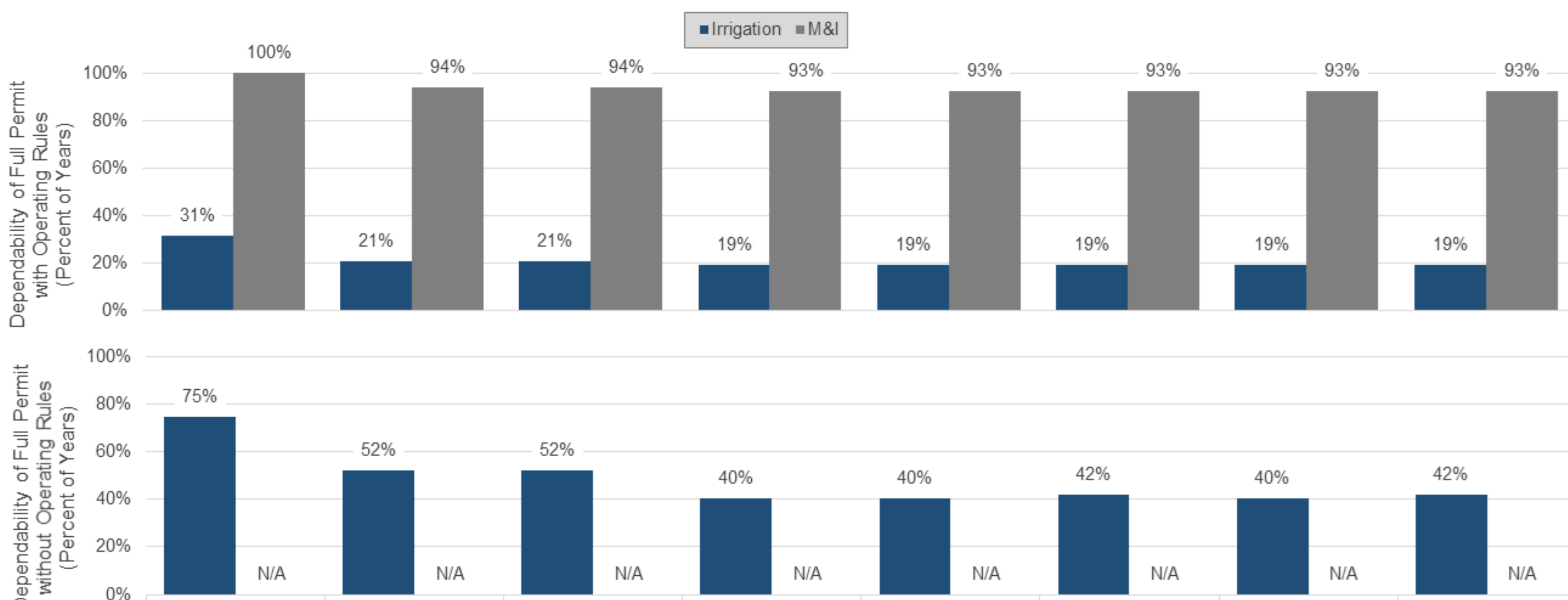
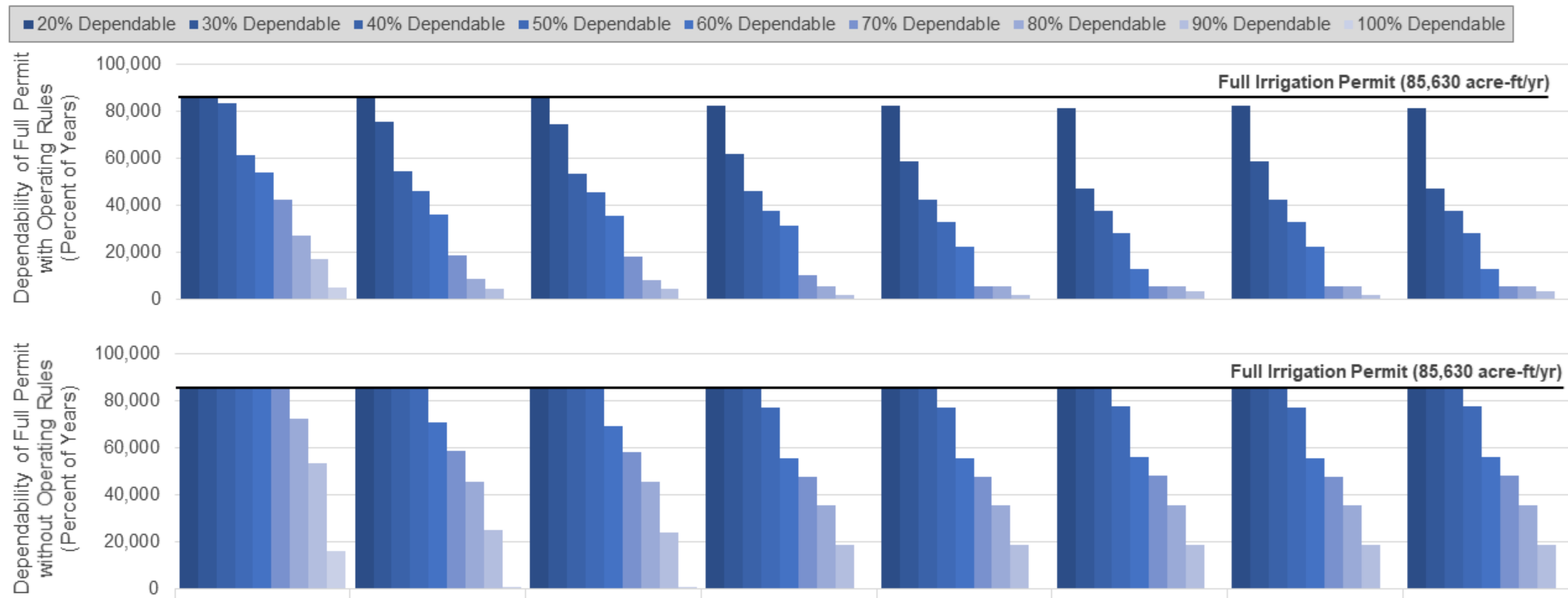


Figure 8-1. A comparison of the impacts between the "Without Operating Rules" strategy and the "With Operating Rules" status-quo condition on average annual yield of Lugert-Altus Reservoir.



	Naturalized	2013 GW Existing SW	OCWP GW Existing SW	Full GW Existing SW	Full GW Existing SW Domestic SW (Low)	Full GW Existing SW Domestic SW (High)	Full GW Full SW (Low)	Full GW Full SW (High)
GW	Naturalized	2013	OCWP	Full	Full	Full	Full	Full
Existing SW	-	Full	Full	Full	Full	Full	Full	Full
Domestic SW	-	-	-	-	Low	High	Low	High
New SW	-	-	-	-	-	-	Full	Full

Figure 8-2. A comparison of the impacts between the "Without Operating Rules" strategy and the "With Operating Rules" status-quo condition on the dependability of the irrigation and municipal and industrial (M&I) permits to water stored in Lugert-Altus Reservoir.



	Naturalized	2013 GW Existing SW	OCWP GW Existing SW	Full GW Existing SW	Full GW Existing SW Domestic SW (Low)	Full GW Existing SW Domestic SW (High)	Full GW Full SW (Low)	Full GW Full SW (High)
GW	Naturalized	2013	OCWP	Full	Full	Full	Full	Full
Existing SW	-	Full	Full	Full	Full	Full	Full	Full
Domestic SW	-	-	-	-	Low	High	Low	High
New SW	-	-	-	-	-	-	Full	Full

Figure 8-3. A comparison of the impacts between the "Without Operating Rules" strategy and the "With Operating Rules" status-quo condition on the dependability of delivering permitted water for irrigation out of Lugert-Altus Reservoir.

This type of a transaction would need to be coordinated jointly between the city of Altus and Lugert-Altus ID, and it would require approvals by the U.S. that involve coordination with other stakeholders, including recreation interests. The value of the M&I water right is among the many factors that would likely need to be investigated. While it is beyond the scope of this URRBS to analyze the value the M&I water right, several factors are summarized below that could be considered. Some of these factors add to the value of the water, while others would reduce the value of the water. If this strategy is pursued further outside the URRBS, a qualified water marketing professional that specializes in water supply transactions would likely need to be engaged.

First, the fair market value of water is typically governed by basic principles of supply-demand economics, meaning the value of any good or service is dictated by supply volume and the demand on that good or service, including a buyer's willingness to pay. For example, a buyer may be more willing to pay for a water supply that is drought-proof versus one that is not; or for a supply that is locally controlled versus one that is purchased from another provider; or for a supply that does not incur adverse impacts to the environment versus one that does. This is why the cost of water in water-scarce areas of western states is far higher than the cost of water in other areas where supply options are less limited. This is important context to consider when valuing water in southwest Oklahoma, especially in light of the items discussed below.

As a baseline value of the city of Altus' right to 4,800 acre-ft/yr of M&I water, one could begin by looking at the price that the city of Altus has paid for raw M&I water from Tom Steed Reservoir provided by MPMCD. In 2015, MPMCD provided Reclamation with the wholesale raw water costs charged to their member cities for the period 2009 to 2014. The prices ranged from \$106/acre-ft to \$113/acre-ft. The price that member cities paid included debt service for MPMCD's share of capital costs for construction of the dam, reservoir, and pipelines, and operating costs for water delivery and project maintenance. These prices did not include costs for treatment, which brings attention to the second factor to consider.

Because water from Lugert-Altus Reservoir is brackish (i.e., slightly salty), it may be less attractive (and less valuable) to a potential buyer that would intend to use it for M&I purposes as opposed to irrigation. The total dissolved solids (TDS) levels (i.e., salt concentration) of Lugert-Altus water ranges from 1,000 milligrams per liter (mg/L) to 1,400 mg/L according to the OWRB's 2015-2016 water quality monitoring report. To determine the cost of removing those salts, the city of Altus might first look at the actual costs incurred for construction and operation of its existing reverse osmosis facility. To further the understanding of the costs of brackish water treatment, Reclamation published a document in 2014 titled, "Estimating the Cost of Brackish Groundwater Desalination in Texas" (Reclamation, 2014). Reclamation's cost analysis included a broad range of capital and operation & maintenance costs of a desalination plant, respectively, for TDS levels ranging between 2,000-3,000 mg/L (year 2000 dollars). Applying these curves to the city of Altus' right to 4,800 acre-ft/yr of water, an estimate of the capital costs for a reverse osmosis plant could range between $3.5 million and $15 million with operations, maintenance, and replacement costs between $60,000 and $300,000 per year. Indexed to 2021 dollars, a rough estimate of annualized costs assuming a 50-yr project life could range between $80/acre-ft and $360/acre-ft. These costs exclude brine disposal, which is complicated and expensive in its own right.

A third item to consider in valuing the city of Altus' right to Lugert-Altus Reservoir would be to identify the costs of developing and delivering an equal volume of new water from alternative supply sources for an equal end use. Like any good or service being sold based on supply-demand economics, a potential buyer or leaser of the city's right to water would be expected to shop the water market and compare prices from various sources in the free market. The Southwest Oklahoma Water Supply Action Plan identified the types of alternative supply sources that have been considered in the area (e.g., new groundwater supplies). Again, development of costs would need to consider treating the water to meet the end use of the new supply source (i.e., M&I, agricultural irrigation, etc.).

A fourth item to consider in valuing the city of Altus' right to the water would be the extent to which the water could have benefits to the local economy, including direct and indirect impacts on businesses, jobs, income, etc. Some of these benefits may be correlated with other non-consumptive benefits, both quantifiable and non-quantifiable, such as aesthetics, recreation, and fish and wildlife. For example, these types of benefits may be realized by maintaining storage in the city's local reservoir and/or by maintaining storage in Lugert-Altus Reservoir rather than consuming the water, particularly during drought periods. As part of this URRBS, Reclamation completed an economics analysis on the water supply benefits of Lugert-Altus and Tom Steed reservoirs (Chapter 6.6; Appendix I). The analysis evaluated how long-term changes in reservoir levels (and water deliveries) at Lugert-Altus and Tom Steed reservoirs could impact irrigation and recreation benefits, as well as overall regional economic output.

Finally, the value of the city of Altus' right to the Lugert-Altus Reservoir water should be considered through the lens of public acceptability. When assessing potential impacts of a range of potential alternatives and future outcomes, it is prudent to include robust communications and stakeholder involvement throughout the process. If a water marketing transaction was selected as a preferred alternative, Reclamation approval would likely be required. As such, this action would be subject to review in accordance with the National Environmental Policy Act (NEPA), and Reclamation would be required to coordinate with the public and with all involved parties in evaluating the environmental and socioeconomic impacts of the proposed action pursuant to NEPA. If applicable, this process would culminate in a finding by Reclamation as to whether or not impacts would be considered significant and to what extent mitigation may be required.

The discussion turns back to the planning objective of providing a volume of 115,000 acre-ft of water in storage at Lugert-Altus Reservoir at the beginning of each irrigation season. Given the fact that the planning objective was formulated based on an assumed storage reserve of 29,000 acre-ft, and understanding that this strategy assumes that the storage reserve would no longer be required, then it would seem clear that this strategy would effectively render the 115,000 acre-ft water in storage planning objective as not applicable. Instead, the question should focus on the extent to which this strategy could maximize average annual yield of Lugert-Altus Reservoir, up to and including a yield close to Lugert-Altus ID's permit volume of 85,630 acre-ft/yr, as well as maximize the dependability frequency of the full irrigation permit volume of 85,630 acre-ft/yr. Based on the modeling results presented above, this strategy would be effective at doing both.

8.2.3. Additional Stream-Water Right for Lugert-Altus Reservoir

Additional Water Rights

In light of the conclusion noted in Kershen (2021) that Lugert-Altus ID likely cannot make a valid claim for an existing water right to the top of conservation pool, Kershen (2021) noted that an option exists for Lugert-Altus ID to file an application with the OWRB for a new water right for the 37,570 acre-ft of water that could be stored in Lugert-Altus Reservoir's conservation pool during very wet years.

Lugert-Altus Reservoir has capacity to hold 128,000 acre-ft in its conservation pool. The two water rights to Lugert-Altus Reservoir total 90,430 acre-ft. Depending on heavy rainfall and runoff, additional water (i.e., the 37,570 acre-ft of water to the top of conservation pool) exists for which Lugert-Altus ID could make a claim to a new water right. As noted in Chapter 7.2.3, Kershen (2021) suggested that the best method for claiming this right would be to file an application for all unappropriated water on the NFRR. All unappropriated water would be the runoff and rainfall in the NFRR basin in very wet, infrequent years that fills Lugert-Altus Reservoir to its conservation pool capacity or, at least, fills Lugert-Altus Reservoir above the total amount (90,430 acre-ft) of the two senior water rights.

In terms of meeting the planning objective of having 115,000 acre-ft/yr in storage at the beginning of each irrigation season, this discussion outlines several of the benefits noted in Kershen (2021). First, by claiming additional water in a new water right, Lugert-Altus ID would protect itself from having to allow this additional water to be withdrawn, through a surplus water permit, by another water-right holder[191]. By claiming a water right to the additional

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[191] Kershen (2021) discussed "surplus" waters extensively. Surplus water is water stored in the reservoir that is not being put to beneficial use. Oklahoma considers surplus waters in reservoirs to be public stream waters of the state, so it can grant rights of prior appropriation to these surplus waters to applicants under the general stream water laws of the State (Kershen, 2021). Lugert-Altus ID has a storage right, as trustee, for other excess (or surplus) water in the reservoir above 90,430 acre-ft.

37,570 acre-ft/yr, Lugert-Altus ID changes its legal status from a trustee of surplus, stored water into an owner of a water right (Kershen, 2021).

Second, according to Kershen (2021), by claiming this additional water in a new water right, Lugert-Altus ID would turn the OWRB policy of not granting any new prior appropriations 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 a new water right to all additional water, then legally there would be no unappropriated water available for other applicants. That said, 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, according to the statute (and to the OWRB), 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, the OWRB can only issue permits 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.

Third, Lugert-Altus ID could collaborate with the Oklahoma Department of Higher Education and the ODWC to dedicate additional water to fish and wildlife and recreation purposes; in other words, Lugert-Altus ID could gain a water right explicitly for a non-consumptive purpose that furthers conservation and environmental goals of the State of Oklahoma (Kershen, 2021). As Kershen (2021) extensively explained, Oklahoma prior appropriation law now recognizes recreation, fish and wildlife as permissible beneficial uses of water. Lugert-Altus ID thus could apply for a non-consumptive use of the additional water in very wet years on the NFRR with a priority date as of the date of the application. This new water right would be junior to other NFRR water rights but, as will be explained shortly in this Chapter, being a junior water right would not be a significant diminishment of this new water right (Kershen, 2021).

Fourth, if Lugert-Altus ID gained this new, non-consumptive water right, 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 and, effectively, accounting for evaporation loss. Furthermore, if Lugert-Altus ID were to apply for a new additional water right to wet-year water, the presently existing junior stream water-rights, which are known to have negligible impacts on Lugert-Altus Reservoir storage, would also have negligible impact upon Lugert-Altus ID's new water-right for wet-year water. As well, although the presently existing junior water rights would now be senior to Lugert-Altus ID's new junior water right, Lugert-Altus ID need not worry because this issue would only become relevant in very wet years so the senior permit holders should have no problems accessing their water. Thus, even though Lugert-Altus ID's new water right legally would be the most junior water right on the NFRR, its new water right would be a meaningful water right that occasionally would result in Lugert-Altus Reservoir having additional "wet" water in storage, not just a "paper" water right (Kershen, 2021).

Given the analysis presented above, the strategy of applying for all unappropriated water in the NFRR would appear to be effective at achieving the reservoir water in storage target of 115,000 acre-ft, albeit only during infrequent and favorable wet conditions.

Evaporation

As previously stated, the 115,000 acre-ft water in storage target takes into account evaporation loss from the Lugert-Altus Reservoir. Also, the OWRB no longer allows Reservoir claimants to include evaporation in their stream water appropriation. However, according to Kershen (2021), the fact that the OWRB has adopted this legal approach to evaporation does not mean that the OWRB cannot account for evaporation in the issuance and enforcement of stream water rights. Kershen (2021) noted two ways to handle evaporation loss.

First, the OWRB could revert to its position of the late 1960s that evaporation could be included in the water right as a form of actual use. At that time, the OWRB may have considered evaporation as includable within the water right because a reservoir was considered a diversion point of the water. A water-right holder has a water right to the amount actually used and to the amount of water for a reasonably efficient carriage of that water from the diversion point to the water-right holder's fields, municipal water plant, or industrial plant. If the reservoir, by storing the water, is reasonably efficient in carrying the water until the reservoir releases the water for ultimate beneficial users of the water, then Lugert-Altus ID might claim evaporation as part of the water right for actual use (Kershen, 2021). Indeed, the OWRB and Lugert-Altus ID may agree to a water right that is closer to the top of the conservation pool (i.e., 128,000 acre-ft/yr) or to 115,000 acre-ft/yr. Similar to the strategy cited above, this strategy would appear be effective at achieving the reservoir water in storage target of 115,000 acre-ft at the start of the irrigation season when conditions are favorably wet.

Second, Kershen (2021) noted that the OWRB could account for evaporation as it determines whether unappropriated water exists for future applicants for water rights and as it acts to protect water rights from interference by junior water-right holders. Although, as noted previously, unappropriated water does not appear to exist upstream of Lugert-Altus Reservoir, this strategy could be relevant if the OWRB were to appropriate water upstream of the reservoir for use during very wet years.

8.2.4. Conjunctive Management

Voluntary Dry-Year Lease or Purchase Agreements

The first conjunctive management strategy identified in Chapter 7.2.4 was dry-year lease agreements. Recall that a dry-year lease would allow Lugert-Altus ID to pay for another user's water (i.e., groundwater pumped by a well permit holder, under specified, preset conditions) (Kershen, 2021). Under the agreement, the well permit holder that would lease away its water supply is willing to accept the lease payments (i.e., money), and to cease using its physical water, when the preset conditions occur.

However, for reasons cited below, this strategy may not meaningfully address the 115,000 acre-ft water in storage target without a more detailed investigation into groundwater and surface water interactions above Lugert-Altus Reservoir. There are 480 groundwater-right holders that already exist for 96,330 acre-ft/yr from the NFRR alluvial aquifer. Kershen (2021) considered it impractical for Lugert-Altus ID to reach a dry-year lease agreement with all 480 groundwater-right holders because: (1) the high transaction costs of negotiating, managing and enforcing the leases with such a large number of groundwater permits holders; (2) the high costs of leasing a sufficient number of acres to provide protection to the NFRR baseflow and the storage in Lugert-Altus Reservoir; and (3) the hydrological uncertainties associated with leasing any specific acreage less than all acres covered by the groundwater permits. According to Kershen (2021), if Lugert-Altus ID could identify those groundwater pumpers with the greatest impact on the NFRR baseflow and the inflows to the Lugert-Altus Reservoir, then Lugert-Altus ID may have a manageable number of landowners with whom to negotiate dry-year leases and sufficient confidence that these dry-year leases would increase the amount of water in storage in the Reservoir. Indeed, Lugert-Altus ID would largely benefit from targeting groundwater wells that fall within "proximity zones" that clearly influence the baseflow from the NFRR alluvial aquifer into the NFRR itself. Identifying these groundwater pumpers was beyond the scope of this URRBS and would require additional modeling of the interconnections between the NFRR aquifer, groundwater wells, and the NFRR. This is a subject of further investigation at the time of the writing of the URRBS.

Conservation-Oriented Redetermination of Aquifer Maximum Annual Yield

Another conjunctive management strategy identified by study partners and evaluated by Kershen (2021) was implementation of a conservation-oriented aquifer MAY. As discussed in Chapter 7.2.4, given the known and quantified interconnection of groundwater and inflows into Lugert-Altus Reservoir, along with multiple relevant statutes providing the OWRB with either discretion or obligations on the matter, Kershen (2021) suggested that the OWRB would appear to have the authority to consider groundwater and surface water interactions as it sets a minimum basin life for the NFRR alluvial aquifer. As such, when the OWRB reviews and updates the MAY and EPS for the NFRR alluvial aquifer, it could redetermine the MAY and EPS for the aquifer and adopt a conservation-oriented, lesser EPS for future groundwater permit applicants. In doing so, Lugert-Altus ID could encourage the OWRB to consider the total discharge from basins (surface and groundwater) such that discharge protections could be determined that maintain base flows above certain thresholds. It also could encourage the OWRB to undertake the hydrological surveys and information needed to set an EPS for the aquifer that would be smaller than otherwise set under existing practice. For example, one strategy could be to set a MAY and an EPS that reflected the groundwater pumping rate for 2013 or the projected groundwater pumping rate for 2060, either of which would better protect the base flow of the NFRR relative to current practice. Such an approach would emphasize the importance of water conservation and sustainability, which is consistent with the Water for 2060 Act. Consideration also could be given towards evaluating the relative impacts on baseflow caused by localized aquifer storage reduction corresponding to a range of withdrawals varying by existing well locations within the Lugert-Altus Reservoir watershed. This is the same type of analysis noted above as needed to inform future dry-year lease agreements. If a conservation-oriented MAY and EPS for the NFRR were adopted by the OWRB, then Lugert-Altus ID could gain indirect protection for the base flows of the NFRR, and subsequently on the water supply stored in Lugert-Altus Reservoir (Kershen, 2021).

The extent to which this strategy could address the 115,000 acre-ft water in storage target depends on some key factors. First, consideration must be given towards the quantified impacts of existing versus future permitted groundwater withdrawals, along with the volume of existing versus future groundwater withdrawals that could actually be reduced under current state law. Recall the modeling results which showed that existing permitted wells have a more pronounced impact on Lugert-Altus Reservoir than future permitted groundwater use; in fact, reservoir yield was reduced two times more by existing wells than by future wells (Chapter 6.4.3). However, most of the existing wells appear to be regular permits with prior rights that cannot be diminished under Oklahoma law (Chapter 5.2.1). For these permit holders, the OWRB has already set a 1.0 acre-ft per acre EPS for the NFRR aquifer, and the OWRB is prohibited by law from reducing the EPS of those overlying landowners who already have prior rights through existing, vested regular groundwater permit under a prior MAY and EPS determination (Kershen, 2021). After the OWRB redetermines the MAY and EPS of the NFRR aquifer through a 20-yr review, only new groundwater permits would be subjected to the amount of the redetermined EPS. This would apply to the 0.59 acre-ft per acre EPS (20-yr life span), the 0.52 EPS acre-ft per acre EPS (50-yr life span), or a more conservation-oriented EPS based on an aquifer life span beyond 50 years. 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 no doubt be preferred by Lugert-Altus ID over an EPS that promotes a policy of depleting the NFRR alluvial aquifer within 20 to 50 years.

One could further argue that because base flows would eventually be fully depleted regardless of the time-frame that the OWRB adopts for the NFRR alluvial aquifer (Chapter 6.4.1), implementing a conservation-oriented EPS would ultimately be ineffective at protecting reservoir yield or otherwise contributing towards the 115,000 acre-ft water in storage target. However, about 70 percent of the overlying land remains open to the dedication of future groundwater permits (Chapter 6.4.1), meaning the time frame it could take to fully develop the NFRR alluvial aquifer, if ever, could extend several decades, leaving ample time to allow the potential benefits of a conservation-oriented EPS to be realized. During this time, educational and water conservation programs could be implemented that encourage overlying landowners to use groundwater minimally or not at all, and certainly not to the level approaching full utilization of allowable groundwater rights (Kershen, 2021). Possible educational and water conservation activities that might protect the base flow of the NFRR include changes such as irrigation improvements (e.g., drip-irrigation), or crop and variety selection that requires less water while still producing a profitable harvest (e.g., drought-tolerant crops or varieties), or the change from irrigation farming to dry-land farming or pasture ranching. These educational and conservation activities that are outside the Oklahoma groundwater legal regime appear to be valid approaches to protect Lugert-Altus Reservoir (Kershen, 2021).

8.2.5. Reclassification of Alluvial Groundwater to Stream Water

The final strategy identified by Kershen (2021) was reclassification of alluvial groundwater to stream water. Under certain, specified conditions, this would allow the reclassified waters to 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. Kershen (2021) cited two legal arguments that could support reclassification:
(1) the "the alluvial waters argument", which contends that the Oklahoma legislature impermissibly moved alluvial waters from being public waters to private ownership waters in 1967 and 1972 amendments to Oklahoma's water laws; and (2) "the losing stream argument", which contends that groundwater adjacent and connected to losing streams could be considered stream water. Kershen (2021) noted that because neither of these arguments have ever been presented to Oklahoma courts, reclassification would likely require litigation. He did not suggest the merits or outcome of such litigation, but he did provide key insights into how and why this strategy may be justified in the Lugert-Altus Reservoir hydrologic basin.

The alluvial waters argument is discussed at length in Kershen (2021), where he cites the history of various Legislative actions defining the terms "definite stream" and "groundwater" with regard to distinguishing groundwater from stream water. As it stands today, groundwater is owned by the overlying landowners and accessed through the groundwater law, and stream water is public water accessed by the public for beneficial use through prior appropriation doctrine, but a key question that remains, according to Kershen (2021), is whether alluvial waters (i.e., waters in alluvial aquifers) are groundwater or stream-waters. Kershen (2021) cited two Oklahoma Supreme Court cases related to the distinguishment between groundwater and stream-waters, but neither case resolved the alluvial waters question. In the first case related to an applicant who sought to encase a natural spring, the Court ruled that a natural spring that flowed into a definite stream[192] was public water from its inception and may not be diverted for private use unless appropriated as stream water. In the second case, the Court ruled that an applicant seeking to drill wells into land within one mile of a major river was taking groundwater subject to the Oklahoma Groundwater Law. The ruling was made even though neighboring landowners argued that the wells would cause nearby springs, that flow to definite streams, to go dry. Based on the facts and the ruling of the latter case in particular, Kershen (2021) noted that the Court arguably has determined that alluvial water in alluvial aquifers is groundwater until the water surfaces as springs serving as a definite source of a definite stream or until the water seeps into a definite stream. Moreover, the OWRB has long applied the Oklahoma Groundwater Law to alluvial aquifers, and the OWRB has issued several MAY and EPS determinations for identified alluvial aquifers (Kershen, 2021). Yet, there may be viable legal arguments that alluvial aquifers are stream water for two different and independent reasons.

First, in 1949, Oklahoma adopted a groundwater law that purported to govern groundwater using the prior appropriation system of water law. In fact, the OWRB never used the prior appropriation system to manage groundwater and instead, roughly appropriated groundwater proportional to the acreage of overlying land. Nevertheless, groundwater at the time was considered public water. The 1949 definition of groundwater was "water under the surface of the earth regardless of the geologic structure in which it is standing or moving; it does not include water flowing in underground streams *with ascertainable beds and banks*". Kershen (2021) concluded that an important implication of the 1949 definition is that the underground definite stream must have had "*ascertainable beds and banks*." In 1967, the Legislature amended the 1949 groundwater definition by deleting the clause "it does not include water flowing in underground streams with ascertainable beds and banks." And then in 1972, the Legislature again amended the definition of groundwater to read as follows,

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[192] A "Definite Stream" means a watercourse in a definite, natural channel, with defined beds and banks, originating from a definite source or sources of supply. Laws 1972, c. 256 § 1 (eff. July 1, 1973).

"…the term "Ground Water" shall mean water under the surface of the earth regardless of the geologic structure in which it is standing or moving outside the cut bank of any definition stream", which is the definition today.

Kershen (2021) then raised what he viewed as an unresolved question in terms of whether alluvial aquifers are "flowing in underground streams with ascertainable beds and banks – or are the alluvial aquifers outside the ascertainable beds and banks of an underground stream?" In other words, what is an "underground stream?" For purposes of Oklahoma water law, is an "underground stream" the same as a "definite stream" which requires "cut beds and banks?" As far as Kershen (2021) was concerned, no caselaw exists on these questions and, additionally, no significant discussion of these questions exists in legal treatises or law review articles. Even assuming that alluvial aquifers are "flowing in underground streams with ascertainable beds and banks," Kershen (2021) questioned whether the Legislature of the State of Oklahoma had the constitutional authority to change what was once a public resource into a private resource – that is, to change public (ground) water into (ground) water owned privately by the overlying landowners as this precise question has never arisen within the caselaw or the legal literature about Oklahoma water law.

Second, Kershen (2021) noted that the Supreme Court has never addressed the hydrological distinction between gaining streams and losing streams. According to Kershen (2021), losing streams are losing waters to the surrounding groundwater aquifer, and gaining streams are gaining waters from the surrounding groundwater aquifer, whether it is an alluvial aquifer or a bedrock aquifer or both. Under Oklahoma water law, as soon as water from a losing stream moves past the cut bank of the definite stream into the surrounding geological formation, the water is groundwater. As such, if a landowner were using a well that increased the loss of water from the stream to the surrounding groundwater aquifer, it could be argued that the landowner is taking stream water, not groundwater. In effect, the landowner's pumping is increasing the magnitude of the loss of water from the losing stream and is as if the landowner has placed the pump directly into the stream bed itself (Kershen, 2021).

To make a viable case in favor of reclassification in terms of the losing stream argument, Kershen (2021) first pointed towards the URRBS modeling results presented in Chapter 6.4.3, which confirmed that groundwater pumping has a measurable impact on the Lugert-Altus Reservoir. Second, Kershen (2021) pointed to technical studies on the hydrology of the NFRR and NFRR alluvial aquifer, which confirmed that the NFRR above Lugert-Altus Reservoir is a losing stream. Specifically, Smith et al. (2017) included a hydrological map of the NFRR showing the NFRR as a losing stream between the Texas border to the Lugert-Altus Reservoir. Also, Reclamation and OWRB sponsored a study that found that beginning with the month of May and through the summer months, the NFRR is a losing stream on all its segments (Stephens, 2003). During non-summer months, this same report concluded that the NFRR is a gaining stream. As noted by Kershen (2021), the time-period when the NFRR is a losing stream coincides with the months when groundwater pumping is greatest for crop irrigation and M&I use, and one could conclude the negative impact of groundwater pumping upon Lugert-Altus Reservoir is not because groundwater pumpers are taking water moving through the NFRR alluvial aquifer toward the river (a gaining stream). Rather, Kershen concluded that groundwater pumpers are taking water that is flowing from the NFRR into the alluvial aquifer (a losing stream) as crop irrigation and municipal use increases in the summer months.

Formulation of Hydrologic Threshold Alternatives

If certain alluvial groundwater was reclassified as stream water under Oklahoma law, then the NFRR stream-water rights for water stored in Lugert-Altus Reservoir would be senior to almost all groundwater permits in the NFRR alluvial aquifer. Furthermore, the impact of alluvial groundwater pumping upon Lugert-Altus Reservoir is of sufficient magnitude, as demonstrated in Chapter 6.4.3, that Lugert-Altus ID and OWRB may have incentive to work together to adopt interference regulations specific to protecting senior stream-water rights for NFRR water stored in Lugert-Altus Reservoir from interference caused by junior alluvial groundwater pumpers (Kershen, 2021).

And similar to the strategy of protecting senior stream-water rights to Tom Steed Reservoir (to be discussed in detail later in Chapter 8.3.2), the OWRB could use hydrological information to identify thresholds that could define interference in order to protect the senior stream-water rights from interference, while maximizing beneficial use for junior groundwater pumpers from the NFRR alluvial aquifer. Kershen (2021) concluded that it was unclear how the Legislature would handle this issue in the context of the arid, agricultural setting of southwestern Oklahoma when the competing claimants are primarily surface irrigation farmers in Lugert-Altus ID and groundwater irrigation farmers on lands overlying the NFRR alluvial aquifer. Nevertheless, study partners wanted to use the URRBS to perform an analysis on a range of reasonable and defensible hydrologic thresholds that could inform management of permitted groundwater in the Lugert-Altus Reservoir hydrologic basin.

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. Yet, if reclassification of alluvial groundwater to stream water were to eventually occur, this strategy could be very effective at improving water supply reliability of Lugert-Altus Reservoir.

Next, setting aside any assumptions with regard to the likelihood of this strategy coming to fruition, the discussion turns to the hydrologic thresholds that could be used in the future to manage the newly-classified stream-water under Oklahoma's Prior Appropriation Doctrine. The details of the analysis can be found in Reclamation's Technical Memorandum "Formulation of Hydrologic Thresholds to Support Water Management in the Lugert-Altus Reservoir Hydrologic Basin" [(Reclamation, 2021b) (Appendix J)]. 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[193]. The document is summarized 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 Standard 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 four 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

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[193] 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.

inflow-SPI thresholds were selected as preferred thresholds that would make up the Hydrologic Threshold Alternatives described in Part VI as follows:

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-yr period of record when inflow and SPI conditions were at or below the four inflow-SPI thresholds is provided in Figure 8-4. 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 8-1.

Table 8-1. 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

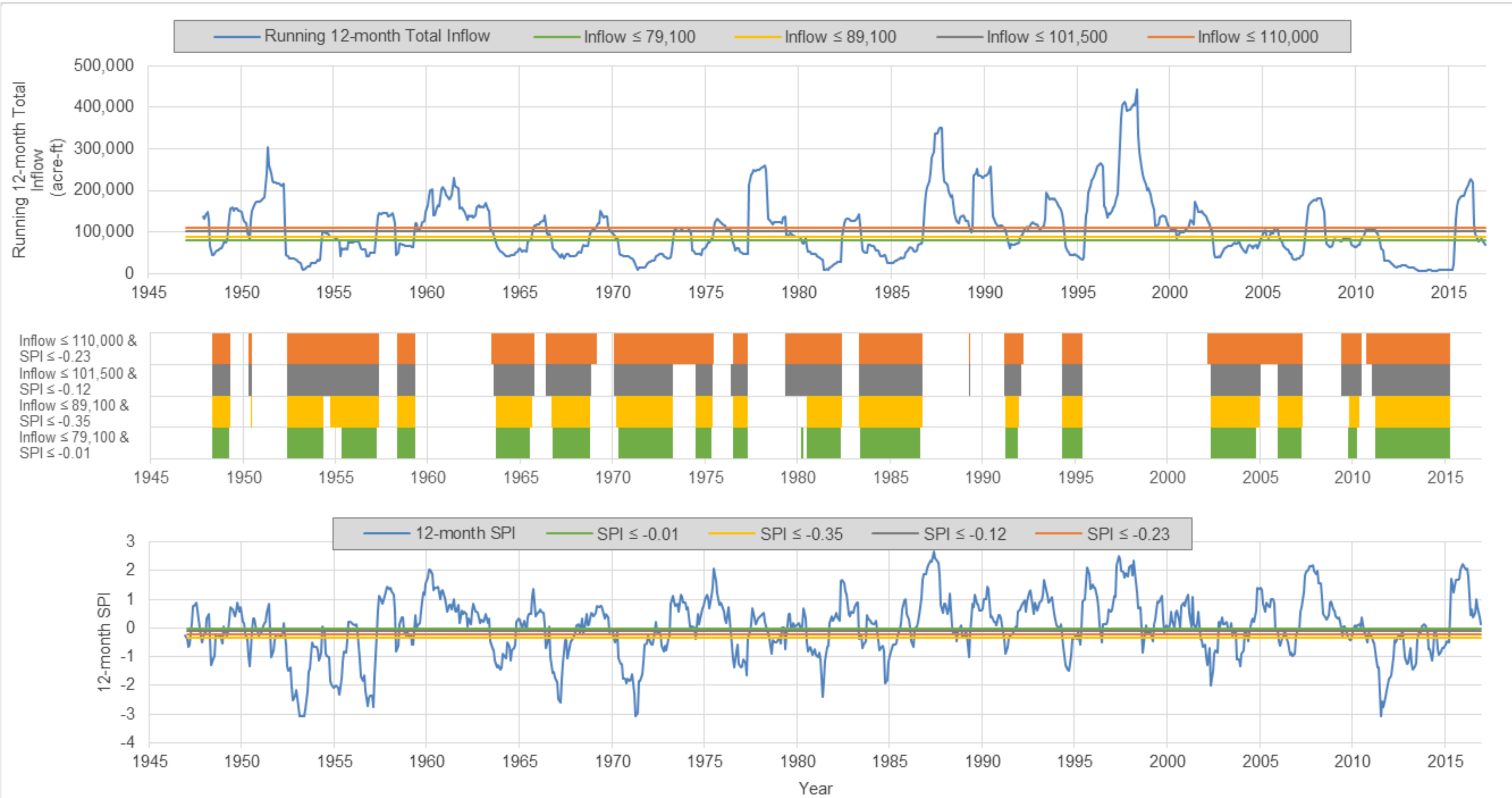

Figure 8-4. Occurrence frequency of a range of reservoir storage and inflow-SPI thresholds alone and in combination over the period of record, 1926-2016.

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 to any particular month would likely *not* have a measurable impact on the accuracy of predicting drought conditions. 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.

8.2.6. Cable Mountain Reservoir

Cable Mountain Reservoir was identified by URRBS partners as one option to provide supplemental water to Lugert-Altus Irrigation District. The proposed reservoir site is located on the NFRR about 40 miles downstream of Lugert-Altus Reservoir and below the confluence of the Elm Fork of the Red River and Elk Creek (Figure 7-1). Although the reservoir has never been built, interest in its development has continued for decades. The most recent analysis on Cable Mountain by Reclamation was completed in 2005 as part of a broader appraisal-level investigation into alternatives to augment water supplies to Lugert-Altus Reservoir (Reclamation, 2005). Reclamation's appraisal investigation concluded that Cable Mountain had the potential to yield an abundant supply of water to the region, but the water was highly saline, and the costs to build, operate, and maintain the reservoir rendered the reservoir cost-prohibitive relative to other potential supply alternatives. Nevertheless, interest in Cable Mountain has continued, prompting URRBS partners to ask Reclamation to develop up-to-date costs and conduct new modeling to estimate the water supply that could be yielded from the potential reservoir. These results are provided below and are also are summarized in a Technical Memorandum, "Cable Mountain Reservoir Hydrology and Costs" [(Reclamation, 2022) (Appendix L)].

Hydrology and Reservoir Yield

Approach

The proposed location of Cable Mountain Dam and Reservoir is on the NFRR below Lugert-Altus Reservoir and below the confluence of the NFRR with both the Elm Fork of the North Fork of the Red River (Elm Fork Red River) and with Elk Creek; it is located about five river miles upstream of the Headrick streamgage [(USGS 07305000) (Figure 7-1)]. A reservoir yield model was developed to simulate yield and water supply dependability of Cable Mountain

Reservoir. Similar to the RRY models developed for Lugert-Altus and Tom Steed reservoirs, the model was comprised of a mass balance equation developed in Microsoft Excel that simulated inputs (e.g., inflow, precipitation) and outputs (e.g., evaporation, sedimentation, deliveries) on a monthly time step (Figure 2-42).

Reservoir inflows were calculated using Headrick streamgage data recorded over a 65-yr period between Jan 1951 and Dec 2016. The year 1951 was selected as the beginning of the period of record because this was the first year after initial irrigation deliveries began following construction of Lugert-Altus Reservoir on the NFRR. Monthly divertible flows from Elk Creek to Tom Steed Reservoir, as calculated in accordance with methods described in Reclamation (2021) (Appendix E), were subtracted from the Headrick streamgage flow record. Elm Fork Red River flows were not adjusted because no impoundments exist on the Elm Fork Red River. The drought of record was found to occur between Sept 2007 and May 2015. A full list of model inputs, data sources, and assumptions are provided in Table 8-2.

Table 8-2. Inputs and data sources for the reservoir yield model developed to estimate potential water availability from Cable Mountain Reservoir.

Model Input	**Data Source**	**Dates Available**
Inflow		
Inflow equals USGS Stream Gage (adjusted proportionally for drainage area difference) minus the maximum divertible flows from Elk Creek to Tom Steed Reservoir	USGS Stream Gage 07305000 North Fork Red River near Headrick, OK (mean daily flow)	Jan 1951 – Dec 2016
	Reclamation's Reservoir Yield Model for Tom Steed Reservoir	Jan 1951 – Dec 2016
Net Evaporation		
Calculated based on pre-construction evaporation estimates and measured pan evaporation rates at Tom Steed Reservoir. Multiplied post-construction pan evaporation measurements from Tom Steed Reservoir by a free surface coefficient factor of 0.7 (Kohler et al., 1955), and then multiplied by reservoir surface area to obtain monthly evaporative losses out of Cable Mountain Reservoir.	Plan of Development for Mountain Park Project, Oklahoma: Appendix A, Table A-21, "Mountain Park Reservoir Net Evaporation Rate (inches)".	Jan 1951 – Sept 1959
	Mountain Park Water Supply Report, Total Monthly Pan Evaporation times free surface coefficient (0.7) and previous months reservoir surface area.	Oct 1959 – Dec 2016
Sedimentation		
Reservoir Area and Capacity	Developed using the ACAP-32 Program based on 5-ft contours from the 2016 USGS Topographic Survey.	
Sediment distribution	Assumed year 2060 sediment conditions and a sedimentation rate of 417 acre-ft/yr, which is the rate calculated by Reclamation for Lugert-Altus Reservoir based on its 2007 Sediment Survey.	
Seepage		
Assumed 300 acre-ft per month over the period of record, which was the largest of the pre-construction seepage estimates for three Reclamation earthen dams in Oklahoma (i.e., Fort Cobb Reservoir, Foss Reservoir, and Lake of the Arbuckles).		
Annual Municipal & Industrial (M&I) Delivery Distribution		
Assumed a monthly distribution of M&I deliveries based on observed deliveries from Tom Steed Reservoir	Mountain Park Master Conservancy District Water Supply Report	Jan 1979 – Dec 2016
Annual Irrigation Delivery Distribution		
Assumed a monthly distribution of irrigation deliveries based on observed deliveries from Lugert-Altus Reservoir.	Lugert-Altus Irrigation District Water Supply Report	Jan 1951 – Dec 2016
Downstream Release Requirements		
Environmental mitigation	None	
Senior downstream water rights	None	

Results

The reservoir yield model was used to calculate the 80 percent and 98 percent dependable yields of Cable Mountain Reservoir. These are the dependable yields considered under Oklahoma regulations (OAC 785:20-5-5) for the appropriation of water out of a reservoir for irrigation and M&I purposes, respectively. A 100 percent dependable firm yield also was calculated.

Modeling results showed that the 80 percent dependable yield of Cable Mountain Reservoir for irrigation purposes was 60,700 acre-ft/yr (Figure 8-5). Assuming an annual irrigation demand of 60,700 acre-ft/yr, the average annual yield of Cable Mountain Reservoir was estimated to be 54,800 acre-ft/yr. The firm yield was estimated to be 23,700 acre-ft/yr.

In terms of addressing the 115,000 acre-ft/yr water in storage target for Lugert-Altus Reservoir, Cable Mountain Reservoir would not directly augment the storage of Lugert-Altus Reservoir. However, it would indirectly improve overall water supply reliability by delivering augmentation water directly to Lugert-Altus ID. Recall that Status-quo results showed the average annual yield of Lugert-Altus Reservoir ranged from 45,900 acre-ft/yr to 34,200 acre-ft/yr depending on the development scenario. The results presented above showed that the average annual yield of Cable Mountain Reservoir was 54,800 acre-ft/yr. 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.

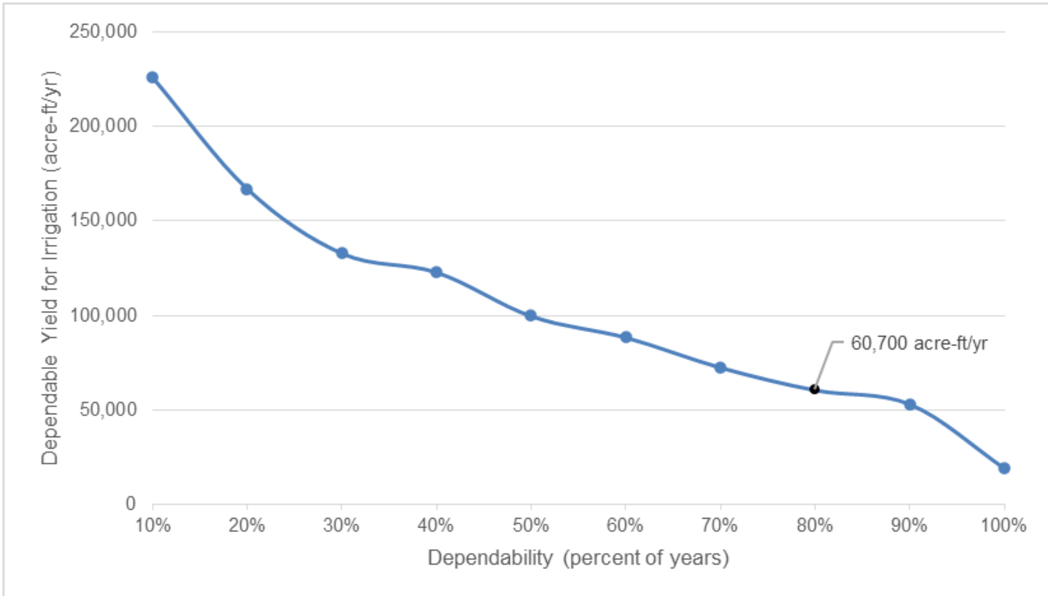

Figure 8-5. Range of dependable yields for irrigation purposes from Cable Mountain Reservoir, 2060 sediment conditions.

Infrastructure Design Narratives and Assumptions

Cable Mountain Reservoir was assumed to be comprised of three main project features: (1) dam; (2) pumping plant; and (3) conveyance canal to the Lugert-Altus ID. General design narratives for each project feature are provided below. Narratives also are summarized in a Technical Memorandum, "Cable Mountain Reservoir Hydrology and Costs" [(Reclamation, 2022) (Appendix L)]. Detailed quantity sheets are located in Reclamation OTAO's central files and are available upon request. Several key assumptions used in developing cost estimates are cited below.

Cable Mountain Dam

The dam would be an earthen structure with two dikes to contain the reservoir body. The dam would have a maximum elevation of 1,430 ft, a maximum height of 80 ft above the stream bed, and a storage volume of 413,000 acre-ft. The reservoir would inundate approximately 11,000 acres of land. The length of the dam would be approximately 2,400 ft with a crest width of 30 ft. A cut-off trench approximately 80 ft in length and 20 ft deep was assumed to be needed through the river section. The construction of the dam and dikes would require 1.65 million and 270,000 cubic yards of fill, respectfully. The location and dimensions of the dam and dikes, as well as reservoir pool size, were determined using Google Earth. Specific features such as the spillway, outlet works, drains, etc. were inferred based on similar-type reservoirs evaluated in the development of cost estimates provided below.

Pumping Plant

An open-air pumping plant would be located on the south shore of Cable Mountain Reservoir immediately northwest of the granite outcrop near the town of Cable Mountain. The pumping plant would lift water about 75 vertical ft from the reservoir to the head of a gravity-flow canal through two 2,000-ft parallel pipelines sized to deliver a total of 600 cfs on the west side of the proposed reservoir. The pumping plant would include an intake and pipe discharge into an open canal.

Canal

A 12.5-mile open canal would convey water to the middle portion of the Lugert-Altus ID (Figure 7-1). The alignment and topography for the canal were developed in Google Earth. The canal would be lined with a 20 mm PVC liner and covered with four inches of concrete. Earthfill quantities were developed using a balanced cut/fill for the length of the canal. The dimensions were as follows: Base (10 ft); height (10 ft); side slopes (1.5 ft to 1 ft); water depth (7.5 ft); and drop (0.25 ft per mile).

Cost Estimate

Cost estimates were prepared by Reclamation's OTAO to "preliminary" standards as defined by Reclamation's Directives and Standards (D&S) Cost Estimating (FAC) 09-01[194] (Table 8-3).   Preliminary cost standards are considered the most basic planning-level costs and are intended to be for comparative purposes only. Development of these estimates does not imply support by Reclamation for project authorization or any specific language in an appropriation bill. All costs were developed in 2016 dollars primarily using RS Means, edition 2016. Costs were then indexed to 2021 using Reclamation's construction cost trend modeling[195].

Contract, non-contract, and contingency costs (i.e., for unexpected or unknown conditions, circumstances, etc.) were comprised of the following: mobilization (5 percent); design contingencies (15 percent); procurement strategies (3 percent); construction contingency (25 percent); planning (5 percent), designs and specifications (4 percent); and construction management (1 percent). Environmental mitigation costs were assumed to equal the cost of land acquired to

[194] https://www.usbr.gov/recman/fac/fac09-01.pdf.
[195] https://www.usbr.gov/tsc/techreferences/mands/cct.html.

construct the reservoir. O&M of the main project features were derived primarily from existing O&M costs of existing dams and reservoirs within OTAO. Pumping plant O&M costs included electricity, labor, and equipment maintenance. Power costs were estimated using the average power cost in Oklahoma for industrial customers.

Table 8-3. Capital costs and operations and maintenance costs of Cable Mountain Reservoir. Costs are considered "preliminary" in accordance with Reclamation's Cost Estimating Directives and Standards FAC 09-01. Costs do not include salinity control.

Project Cost Components	**July 2016 RS Means**	**2016 Cost Indexed to July 2021[5]**
Dam and Reservoir	$82,100,000	$98,600,000
Pumping Plant	$35,623,000	$41,400,000
Canal	$20,250,000	$24,100,000
Land Acquisition Cost	$55,900,000	$66,000,000
Subtotal	*$193,900,000*	*$230,000,000*
Contract Costs[1]	$44,600,000	$53,000,000
Subtotal	*$238,500,000*	$283,000,000
Construction Contingencies[2]	$59,600,000	$70,800,000
Subtotal	*$298,100,000*	*$353,800,000*
Non-Contract Costs[3]	$29,800,000	$35,000,000
Environmental Mitigation[4]	$55,900,000	$66,000,000
Total Construction Cost	**$384,000,000**	**$455,000,000**
Annual O&M Cost	$2,060,000	$2,500,000

[1] Contract costs (23%) includes: Mobilization (5%), Design Contingencies (15%), and Procurement Strategies (3%).
[2] Construction Contingency (25%).
[3] Non-Contract costs (10%) include: Planning (5%), Designs and Specifications (4%), Construction Management (1%).
[4] Environmental compliance and mitigation costs were assumed to be equal to the land acquisition costs.
[5] Indexed using Reclamation Construction Cost Trends (https://www.usbr.gov/tsc/techreferences/mands/cct.html).

Chloride Control

A significant challenge that should be considered when assessing the viability of Cable Mountain Reservoir relates to water quality. Reclamation's analysis of Cable Mountain Reservoir did not consider the costs to treat and remove the high concentration of chlorides that are known to exist in the Elm Fork of the NFRR upstream of Cable Mountain Reservoir. The source of the chlorides, known as "Area VI", is comprised of brine sources from three canyons along the south bank of the Elm Fork about three miles east of the Texas-Oklahoma State line, the drainage area of which is about seven square miles with a chloride load of about 510 tons per day (U.S. Army Corps of Engineers, 2012). The USACE has performed numerous studies on chloride control in the area over the years dating back to the 1950s. In 2004, following Federal appropriations and a request by the Oklahoma governor to re-evaluate chloride control measures at Area VI, the USACE re-initiated investigations into chloride control at Area VI above Cable Mountain Reservoir.

Around the same time, Reclamation completed a preliminary evaluation of chloride control at Area VI as a necessary component to enhance the viability of Cable Mountain Reservoir in its 2005 investigation into alternatives to augment the supplies to Lugert-Altus ID (Reclamation, 2005). The method of brine control conceptualized in this alternative included intercepting the flow at the salt emission area and transferring it off-site by a pump station and pipeline for disposal by deep-well injection. Reclamation (2005) concluded that effective control of salt loading in the Elm Fork of the NFRR would be critical towards determining whether water stored in Cable Mountain Reservoir could be suitable for beneficial uses.

Meanwhile, the USACE continued its detailed investigation into chloride control measures at Area VI, but the study was moved to inactive status by the USACE in 2013 after funds were exhausted, shortly after the USACE published a report in September 2012 titled, "Area VI Feature Reevaluation, Feasibility Scoping Meeting Document, Chloride Control Project, Texas, Louisiana, and

Oklahoma"[196]. The 2012 USACE report contains a detailed chronology of chloride control activities in the Red River Basin, including at Area VI. It also contains results of the USACE's analysis on Area VI, including its findings on the problems and needs, future with- and without-project conditions, planning objectives, and a range of proposed collection and disposal alternatives to reduce chlorides from 510 tons per day to 400 tons per day. The USACE 2012 report did not include estimated costs to implement chloride control at Area VI.

Red River Compact

Another potential challenge associated with Cable Mountain Reservoir relates to the Red River Compact (Compact). The Compact was signed by member states in 1978 to resolve and prevent disputes over waters of the Red River Basin that are shared between the neighboring states of Arkansas, Louisiana, Oklahoma and Texas, and to assure the receipt by member states of adequate surface flows and releases. While provisions of the Compact specifically state how much water each state is allowed to develop or store on an interstate stream, the Compact generally provides a means of working out problems between member states in an orderly manner, thus preventing the likelihood of litigation in most cases. As part of the Compact, the Red River is divided into "Reaches" both above and below Lake Texoma (Figure 1-2). Reach I, upstream of Lake Texoma, is further divided into three subbasins, with Subbasin I containing the NFRR which flows across the Texas state border into Lugert-Altus Reservoir in Oklahoma. According to Section 4 of the Compact, 60 percent of the surface waters in Subbasin I are apportioned to Texas and 40 percent to Oklahoma. In so far as the development of the apportioned water resources in Texas could affect inflow into Cable Mountain Reservoir, projected growth and planned development of water resource activities within Subbasin I should be considered when assessing the viability of Cable Mountain Reservoir. According to the Texas Region A Water Plan (Freese and Nichols Inc. et al.,

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[196] https://www.swt.usace.army.mil/Portals/41/docs/library/chloride_control/Area_VI_Reevaluation_Report_for_FSM_28Sep2012_withCorrespondence.pdf.

2016), which encompasses Subbasin I, little to no growth is projected in this area, water supplies are provided almost exclusively by groundwater, and development of surface water supplies are not anticipated. However, if Texas developed its entire Compact apportionment, the water supply of Cable Mountain Reservoir could be significantly reduced.

8.2.7. Water Conservation

Water conservation was identified as a key strategy to improve water supply reliability of Lugert-Altus Reservoir. Although this strategy did 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 complement the other adaptation strategies identified in this URRBS by allowing more of the water stored in Lugert-Altus Reservoir to be put to beneficial use. 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. As part of this update, Reclamation performed a technical analysis on water losses caused by seepage from laterals and canals throughout the Lugert-Altus ID delivery system. A copy of the Lugert-Altus ID's 2021 five-yr WCP Update is located in Reclamation OTAO's central files and is available upon request.

As part of the WCP 2021 Update, Reclamation identified the types of soils present in the Lugert-Altus ID in terms of low-, moderate-, and highly permeable soils; estimated seepage losses based on length of soil permeability and the average wetter perimeter for each stretch of laterals and canals within different zones of the District; and identified which laterals, canals, and DRDs within the Lugert-Altus ID that would benefit most from infrastructure improvements that reduce or eliminate seepage (i.e., canal lining or conversion to pipe).

Reclamation collected annual water releases and water sales from the Lugert-Altus ID for the years 2015-2019; from those data, delivery efficiencies were calculated for each of the ten DRDs and for the Lugert-Altus ID as a whole. Reclamation found that District-wide losses averaged 20,455 acre-ft/yr over a five-yr period between 2015 and 2019 with an average delivery efficiency of 68 percent. This included undefined losses (i.e., water releases not accounted for in water sales) of 1,605 acre-ft/yr. If one excluded these undefined losses and only considered DRD water sales, the five-yr water losses averaged 18,850 acre-ft/yr with an average delivery efficiency of 70 percent.

Seepage and evaporative losses were estimated by Reclamation to determine the extent to which they account for the water losses reported by the Lugert-Altus ID between 2015-2019. The principal factors that influence seepage in earthen canals include the permeability of the soil material within the wetted perimeter and the depth of water within the canal. Secondary factors such as sedimentation, canal operational time and flow rate, shape of the canal's wetted perimeter, uniformity of the soil or canal lining, and soil and water chemistry were not addressed in Reclamation's analysis. Seepage-related water losses within the Lugert-Altus ID delivery system were estimated by evaluating the location of canals and laterals within low-, moderate-, and highly permeable soils and overlaying soil survey maps onto the Lugert-Altus ID delivery system using a Geographic Information System. Ground truthing was not conducted due to the preliminary nature of the analysis. Soil permeability was categorized based on water loss rates established from previous studies for seven soil types. Seepage loss was calculated by multiplying the length of canal/lateral by the water loss rate of the applicable soil permeability type, and then multiplying by the average wetted perimeter of the canal/lateral. Evaporative losses were estimated by multiplying average five-yr (2015 – 2019) pan evaporation data for Lugert-Altus Reservoir over a 70-day irrigation season (July 1 – September 9) by the length and top width of the canal/lateral. Canals/laterals that already had been converted to pipe were accounted to the extent data were available.

Table 8-4 compares the results of the calculated seepage and evaporation losses for the ten DRDs compared to the five-yr averages reported by the Lugert-Altus ID based on water releases and water sales. As shown in Table 8-4, Reclamation's calculated annual water losses totaled 15,059 acre-ft/yr as compared to the reported average annual water losses between 2015 and 2019 of 18,850 acre-ft/yr.

As previously stated, water conservation measures would not directly address the planning objective of having 115,000 acre-ft of water in storage at the beginning of the irrigation season, but they 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 WCP 2021 Update were significant. In 2022, the Lugert-Altus ID was working to secure about $20 million in state funding to convert a portion of its open canals to buried pipelines. At the time of this URRBS, the Lugert-Altus ID also had recently applied for a federal grant under Reclamation's WaterSMART program using the state funding as a non-federal match, effectively doubling the number of laterals and canals that could potentially be converted to pipelines.

Table 8-4. A comparison between water losses reported by the Lugert-Altus ID for the period 2015-2019 and calculated losses caused by open canal/lateral seepage and evaporation.

Ditch-Rider District	Reported Average Annual Water Loss Between 2015-2019[a] (Acre-ft/yr)	Calculated Annual Water Loss (Acre-ft/yr)
1	1,968	1,928
2	1,338	1,019
3	2,550	1,103
4	1,075	1,030
5	1,567	934
6	2,795	631
7	2,130	863
8	2,101	3,880
14	2,291	3,338
18	1,035	333
Total	18,850	15,059

[a] *Excludes undefined water losses.*

8.2.8. Trade-Off Analysis of Adaptation Strategies

Each of the nine strategies evaluated in this chapter were compared to one another through a trade-off analysis in accordance with requirements set forth in Reclamation's Directives and Standard WTR 13-01 on Basin Studies. A trade-off analysis is defined by WTR 13-01 as a quantitative or qualitative analysis of proposed strategies in terms of "their ability to meet the study objectives, the extent to which they minimize imbalances between water supply and demand and address the possible impacts of climate change, the level of stakeholder support, the relative cost (when available), the potential environmental impacts, or other attributes common to the strategies." 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)[197]. 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.

For this URRBS, a cursory and qualitative level of analysis was considered appropriate. The goal was only to provide Lugert-Altus ID and MPMCD, and (to some extent) OWRB, with guidance on some key criteria to

[197] 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).

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 (Chapter 2.3.1).

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 its agriculture and M&I customers; water users in the Lugert-Altus Reservoir hydrologic basin; 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 8-5).

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 8-5. Scoring rubric for the trade-off analysis of adaptation strategies to improve water supply reliability of Lugert-Altus Reservoir.

Favorable	↑
Neutral	→
Less Favorable	↓

Results

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 8-6. 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 8-6. 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.

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. The reader is encouraged to read Kershen (2021) for a lengthy examination of this strategy.

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.

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; furthermore, the NFRR above Lugert-Altus Reservoir appears to be closed to 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.

Effectiveness: Favorable

- This was considered an effective strategy 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[198] 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.

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[198] 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.

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.

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.

- 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, according to the statute (and to the OWRB), 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, the OWRB can only issue permits 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.

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.

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 MAY 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.

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

- The risks implementing of this strategy would depend on the level of stakeholder support and the extent to which a lack of support generates significant protests or prolonged litigation; these factors would ultimately influence the likelihood of the OWRB agreeing to implement a lesser, more conservation-oriented EPS.

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.
- 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. A thorough description of this analysis is provided in Chapter 8.2.5 and in Appendix J.

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 would likely 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.

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 ID's 2021 five-yr WCP Update is located in Reclamation OTAO's central files and is available upon request.

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.

8.3. Tom Steed Reservoir

Recall that the primary planning objective for Tom Steed Reservoir was to maximize water deliveries through prolonged and severe droughts, including and up to the volume of MPMCD's water right permit, which is 16,100 acre-ft/yr. Providing this reliability would effectively eliminate supply imbalances presented in Chapter 6.4.4. To add flexibility into the adaptation strategies that could be considered, a secondary planning objective 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).

In the sections that follow, the eleven strategies identified Chapter 7.3 are evaluated in terms of their potential to address these planning objectives. However, it is important to point out again a key result from the Status-quo analysis presented in Chapter 6.4.4. This result was that under naturalized conditions, the firm yield of Tom Steed Reservoir equaled but never exceeded 16,100 acre-ft/yr. Recall that the naturalized scenario removes the impacts from all reported groundwater withdrawals and all permitted stream diversions upstream of Tom Steed Reservoir, including those from permit holders that are senior to MPMCD's permit. Although groundwater withdrawals were found to have negligible impacts on the reservoir, existing stream-water permits senior to MPMCD total 1,856 acre-ft/yr. Assuming these senior permits are withdrawing their water, then no matter what strategy is implemented to improve water supply reliability, the actual firm yield of Tom Steed Reservoir will always be lower than 16,100 acre-ft/yr by up to the approximate volume of water being withdrawn upstream by senior permit holders. As noted in the planning objectives identified in Chapter 7.3, this highlights the need to identify a strategy that mitigates losses caused by climatological and hydrological factors as opposed to human-induced development.

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

Recall in Chapter 7.3.1, the two key issues and remedies related to understanding and clarifying MPMCD's existing stream-water right, presented by Kershen (2021). The first key issue related to the permitted volume being reduced from an average annual yield of 45,000 acre-ft/yr to a firm yield of 16,100 acre-ft/yr. Kershen provided interrelated explanations as to why the reduction occurred, one pertaining to a change in the OWRB's policy related to the volume of water needed for carriage and delivery of 16,100 acre-ft/yr, and the other relating to a change in the OWRB policy related to whether reservoir evaporation could be counted as a beneficial use and considered part of the permitted volume. The second key issue explored whether non-consumptive beneficial uses of recreation, fish, and wildlife could be claimed by MPMCD as part of its existing stream-water right.

Permit 67-671: 45,000 acre-ft/yr versus 16,100 acre-ft/yr

When the OWRB reduced MPMCD's permit in 1983 from 45,000 acre-ft/yr to 16,100 acre-ft/yr, it did so because the OWRB changed its policy and no longer considered the amount of water between the firm yield of 16,100 acre-ft/yr and the 45,000 acre-ft/yr average annual yield to be necessary for the permit and useable by the MPMCD; rather, it considered the amount between 16,100 acre-ft/yr and 45,000 acre-ft/yr to be unusable and subject to appropriation. Reclamation and MPMCD disagreed with the OWRB because they considered the 45,000 acre-ft/yr to be the amount needed (in accordance with existing policy at the time) for reasonable carriage (including evaporative losses) to the point of beneficial use where the water is physically put to use. In other words, it was the volume of water needed on an average annual basis to protect and deliver the firm yield of 16,100 acre-ft/yr. Nevertheless, the OWRB reduced MPMCD's permit from 45,000 acre-ft/yr to 16,100 acre-ft/yr.

Beyond accounting for carriage and evaporation, Kershen (2021) identified another strategy to clarify and increase MPMCD's existing water right. In light of the factors discussed in Chapter 7.3, Kershen (2021) proposed the option of MPMCD asserting an existing water right for beneficial purposes for recreation, fish and wildlife with a seniority of May 4, 1955, which is the date of Reclamation's temporary withdrawal of water rights in accordance with Project plans that expressly identified recreation, fish, and wildlife purposes for the waters of the Mountain Park Project. Recall that Kershen (2021) suggested that the most legally defensible quantified amount may be the 28,900 acre-ft of water between the firm yield amount of 16,100 acre-ft/yr and below 45,000 acre-ft/yr that was set forth in the August 29, 1967 application and that the OWRB actually granted as the permitted (perfected) water right in the original the OWRB Permit 67-671 of August 29, 1967.

Kershen (2021) suggested that MCMPD and OWRB consider reaching an agreement as to whether the permitted (perfected) water right for MPMCD could be increased or reinstated to 45,000 acre-ft/yr, including but not limited to accounting for evaporation, other factors needed for reasonable carriage to the point of beneficial use, and non-consumptive beneficial uses. Given that the additional water would be for non-consumptive uses, MPMCD effectively would have the ability to better protect its core water rights for municipal, industrial, and other beneficial uses (i.e., EQ) for which MPMCD is contractually obligated to protect. Even if an agreement was not reached, Kershen (2021) suggested that the OWRB could still account for evaporation as it determines whether unappropriated water exists for future applicants for water rights and as it acts to protect water rights from interference by junior water-rights holders.

The extent to which increasing MPMCD's permit from 16,100 acre-ft/yr to 45,000 acre-ft/yr could address the planning target of reliably delivering 16,100 acre-ft/yr is discussed next. First, 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. And having a larger volume of water rights, 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 in Chapter 8.3.2, "Protecting Existing Stream-Water Rights of MPMCD". Finally, if MPMCD has a quantified right to divert and store up to 45,000 acre-ft/yr, arguably there is no need for a "Schedule of Use" in the permit because MPMCD would have the right to divert and store 45,000 acre-ft/yr regardless of the amount of water actually conveyed to contractual water users and is at less risk of a reduction in water rights under a "loss it or use it" approach implied by having a Schedule of Use in its water permit (Kershen, 2021).

Second, but equally as important, by increasing MPMCD's permit volume, the OWRB would be effectively changing how it currently calculates water available for the appropriation of new regular stream permits. Recall Chapter 2.5.6, when calculating permit water availability for a regular permit upstream of Tom Steed Reservoir, the OWRB currently sets aside only the "dependable yield" of Tom Steed Reservoir (i.e., 16,100 acre-ft/yr). By subtracting only the dependable yield (among other variables) from average annual run-off between 1951 and 1980, one could argue that the OWRB is over-estimating the amount of water upstream that is available for appropriation of regular permits, and upon issuing those permits, increases the likelihood that inference may occur during a repeat of the drought of record. However, this concern applies to existing junior permits and may not be applicable for new regular permits given the fact that the current flow record used by the OWRB to calculate permit availability (average run-off between 1951 and 1980) indicates that no water is currently available upstream of Tom Steed Reservoir. That said, if the OWRB changed its calculation and instead used the 1950-2016 naturalized flow record in lieu of the 1951-1980 run-off record, then this study found that either 35,900 acre-ft/yr or 33,900 acre-ft/yr of water could be available for new regular stream permits upstream of Tom Steed Reservoir depending on whether future domestic use was low or high, respectively (Chapter 6.4.4). Therefore, 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.

As previously discussed, 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. Consequently, it would seem that no person or entity should be thinking about applying for a water right in the Tom Steed Reservoir hydrologic basin. And, notwithstanding the URRBS's finding that unappropriated water could exist if the OWRB used 1950-2016 naturalized flows in lieu of 1951-1980 run-off records, it may sound contradictory to say that the OWRB's increasing MPMCD's permit to 45,000 acre-ft/yr would significantly reduce all unappropriated waters when the OCWP stated that no unappropriated waters exist; however, MPMCD could argue that increasing its water permit to 45,000 acre-ft/yr would all but legally effectuate closure of the basins in conformity with the OCWP (Kershen, 2021)[199].

Returning to the planning objective of 16,100 acre-ft/yr, although this strategy would reduce projected water supply deficits caused by future permits, this strategy in and of itself could not provide the 16,100 acre-ft/yr firm yield target because the previously-explained climatological and hydrological conditions are simply too dry during a repeat of the 2010-2015 drought of record. To be more precise and quantitatively speaking, this strategy would prevent reservoir firm yield from being depleted beyond 12,100 acre-ft/yr or

[199] Kershen (2021) did not explicitly draw this conclusion for this strategy, but this conclusion was drawn for other strategies that would effectively involve managing or eliminating unappropriated waters even though unappropriated waters supposedly do not exist according to the OCWP.

9,880 acre-ft/yr depending on whether assumed future domestic uses are low or high, respectively.

The reader is encouraged to review Kershen (2021) in its entirety for a thorough examination of these permit issues, as well as other issues and commentary related to increasing the volume of MPMCD's existing permit that are deemed too elaborate for discussion here.

Top of Conservation Pool

Similar to Lugert-Altus Reservoir, Kershen (2021) examined the merits of claiming a water right to the top of conservation pool of Tom Steed Reservoir as a method for clarifying the quantity of existing stream-water rights. Depending on the merits of such a claim, insight can be provided into the extent to which this strategy addresses the planning objective of sustaining a firm yield of 16,100 acre-ft/yr out of Tom Steed Reservoir.

Similar to the insights provided for Lugert-Altus Reservoir, Kershen (2021) explained the distinction between storage rights and beneficial use rights. According to Kershen (2021), Oklahoma distinguishes between storage rights (i.e., the right to trap water within a reservoir to the reservoir capacity) and the right to use water for a beneficial purpose (e.g., the beneficial purpose of irrigation). Some of the commentary provided by Kershen (2021) specific to Tom Steed Reservoir follows. If MPMCD were to claim a right to the top of conservation pool of Tom Steed Reservoir, the OWRB could point to MPMCD's original existing water right in the amount of 45,000 acre-ft/yr on average (to produce a firm yield of 16,100 acre-ft/yr) for municipal, industrial, and irrigation purposes. The permit explicitly authorized MPMCD to store additional waters above 45,000 acre-ft so as to prevent waste and to anticipate future water needs for beneficial users (appropriators) in the Otter Creek and Elk Creek basins. However, emphasizing the distinction between a water right and a storage right, the OWRB could assert that the amount of water above 45,000 acre-ft, granted to assure the firm yield of 16,100 acre-ft/yr for identified beneficial uses, constitutes the storage right held by MPMCD as a fiduciary for others' future beneficial-use water needs. In other words, the OWRB could say that the difference between 88,400 acre-ft (storage at the top of the conservation pool) and the permitted 45,000 acre-ft/yr to be available annually for beneficial use is the MPMCD storage right of 43,500 acre-ft in the Tom Steed Reservoir (Kershen, 2021).

By contrast, MPMCD could emphasize that the Reclamation withdrawal notice of May 4, 1955, specified all unappropriated waters of Otter and Elk creeks and that "…no adverse claim to the use of water required in connection with such [Mountain Park Project] plans, initiated subsequent to the date of such notice, shall be recognized under the laws of the State ..." MPMCD could argue that 88,400 acre-ft in the conservation pool and 45,000 acre-ft/yr average inflow is required to produce a dependable "firm" yield of 16,100 acre-ft/yr as demonstrated in the Reclamation plans for the Mountain Park Project. More specifically, MPMCD could argue that without this protection to the top of the conservation pool, MPMCD would not be able to fulfill, in times of drought, its water supply contracts with the municipal, industrial, and, since 1994, the EQ users of Tom Steed Reservoir water. MPMCD could argue further that if MPMCD cannot deliver water per its contracts, MPMCD is in jeopardy of being unable to fulfill its repayment obligations.

Kershen (2021) cited counter arguments to a potential MPMCD interpretation of statutes governing Reclamation withdrawal of waters from Oklahoma streams. First, the OWRB could point to the Reclamation plans relating to the Mountain Park Project. In these documents, Reclamation repeatedly focused on firm annual yield (ultimately 16,100 acre-ft/yr) as the water required in connection with such plans. However, while Reclamation documents do not explicitly refer at any point to protection of that firm annual yield by claiming the water to the top of the conservation pool, the reservoir yield analysis included in those planning documents demonstrated that an average annual inflow of 45,000 acre-ft/yr was required to provide the 16,100 acre-ft/yr firm yield, and that conservation capacity and associated depletion of sediment accumulation are tied to the firm annual yield calculation (Kershen, 2021). Based on the verbatim transcript from the October 10, 1967, the OWRB governing Board meeting approving the 45,000 acre-ft/yr water right, Board members understood that an average annual inflow of 45,000 acre-ft/yr was required to produce a dependable "firm" yield of 16,100 acre-ft/yr. If the Board had offered a permit for less than 45,000 acre-ft/yr, Reclamation likely would not have had a sufficient water right to support the economic viability of the Mountain Park Project, thereby jeopardizing its construction. By 1967 and earlier, the State of Oklahoma and the OWRB had repeatedly endorsed and requested construction of the Mountain Park Project.

In contrast, referring to Reclamation's withdrawal in accordance with plans for the Mountain Park Project, if MPMCD were to interpret the statutory words "required in connection with such plans" to mean to the top of the conservation pool, such interpretation presents issues about properly interpreting Section 8 of the Reclamation Act (Kershen, 2021). Section 8 defers to the laws of the State of Oklahoma to create and to define the water rights for Reclamation projects, and as in Kershen (2021), the Supreme Court and other case law has adopted this "state-preferred" interpretation of Section 8. In addition, the Reclamation Act Section 8 provision provides that "beneficial use shall be the basis, the measure, and the limit of the right." Protecting the identified beneficial use (45,000 acre-ft/yr average annual yield required to produce the firm yield of 16,100 acre-ft/yr) for municipal, industrial and irrigation purposes with water simply sitting in storage is arguably not itself a beneficial use according to Kershen (2021). Hence, the OWRB could argue that protection for an additional 43,400 acre-ft (between 45,000 acre-ft and 88,900 acre-ft) is a violation of MPMCD's fiduciary duty to manage its storage right to prevent waste and in anticipation of others' future beneficial uses. In other words, if MPMCD were to claim a water right to the top-of-the-conservation-pool, such interpretation may run counter to fundamental water law principles, articulated in both Section 8 of the Reclamation Act and various Oklahoma statutes and regulations governing Oklahoma stream water law, about the beneficial use of water in the prior appropriation legal system for stream water (Kershen, 2021).

Based on this legal analysis, one could conclude that claiming a right to the top of conservation pool may be a legal impossibility and therefore not provide the 16,100 acre-ft/yr firm yield of Tom Steed Reservoir. However, not everyone may agree with the analysis in Kershen (2021), and it is clearly not the intent of this study to make a determination one way or another. If claiming a water right to the top of conservation pool was legally validated or otherwise approved by the OWRB, then this strategy may be effective at providing a reservoir firm yield of 16,100 acre-ft/yr. In fact, in Chapter 8.3.2 that follows, the top of conservation pool is one of numerous drought thresholds evaluated to protect MPMCD's existing right by curtailing junior stream-water permits upstream of Tom Steed Reservoir.

Permit Priority Date

Another strategy identified by Kershen (2021) was for MPMCD to encourage the OWRB to perform an updated adjudication of water rights in the Tom Steed Reservoir hydrologic basin and perfect the priority date of MPMCD's existing water right to May 4, 1955. Kershen (2021) concluded that May 4, 1955 was the priority date of the MPMCD permit because this was the date on which Reclamation requested the withdrawal of unappropriated waters in the Elk Creek and West Otter-Glen Creek watersheds for development of the Mountain Park Project. Kershen (2021) based this claim on Oklahoma Federal withdrawal statute, Oklahoma Supreme Court precedent, and OPRB/OWRB correspondence, the details of which can be found in Appendix A.

For the purposes of the URRBS, namely the modeling of water rights and water management in the Tom Steed Reservoir hydrologic basin, a priority date was assigned for each permit based on the permit number listed in the OWRB's water rights database. The permit number itself was defined by the OWRB in accordance with the permit application date. For example, MPMCD's permit was listed on the OWRB's water rights database as 19670671 based on MPMCD's permit application date of August 29, 1967; accordingly, for the purposes of the URRBS, MPMCD's permit was assigned a priority date of 1967. This made

MPMCD's permit senior to ten of the 17 stream permits in the Tom Steed Reservoir hydrologic basin, with the remaining seven stream permits designated as senior to MPMCD (Table 6-2). Importantly, all of the hydrologic modeling results presented in Chapter 8.3.2 below were based on this assumption of seniority.

However, 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 listed in Table 6-2 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. Furthermore, it was considered beyond the scope this URRBS to attempt to reconcile the permit numbers listed in the OWRB's database and Table 6-2, whether pre- or post-1964, with the actual priority dates that the OWRB may assign as a result of a potential future adjudication of water rights in the basin.

That said, looking at the permit numbers listed in Table 6-2, one could speculate, perhaps incorrectly so, that 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 also 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 in accordance with the regulatory protection strategy described in Chapter 7.3.1 and Chapter 8.3.2 to protect MPMCD's permit. However, these are only speculations meant to provide the reader with insight into the potential benefits of clarifying MPMCD's permit seniority date. 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.

8.3.2. Protection of Existing Stream-Water Rights of Mountain Park Master Conservancy District

This strategy proposed the adoption of interference thresholds that protect Tom Steed Reservoir from existing and/or future junior stream-water permits. Under Oklahoma statute, junior permit holders are not allowed to interfere with senior permit holders by taking their water out-of priority ahead of a senior permit holder. A senior permit holder can file a complaint with the OWRB, but Oklahoma statutes do not set forth any specific authority for the OWRB to be proactive in protecting an individual claimant's water rights from interference by others (Kershen, 2021). Yet, as previously discussed, the OWRB has authority to create an administrative enforcement procedure to protect senior priority stream-water permits, and the OWRB could create an administrative procedure to stop or prevent interference with senior priority rights or to prevent out-of-priority use of water rights (Kershen, 2021). What is lacking in the statutes, the regulations, and the case law is any definition of interference or any identification of thresholds that can be invoked to protect the water rights of senior holders (Kershen, 2021). To this end, the MPMCD and OWRB could work together to identify interference thresholds that take into account the relevant hydrological conditions and needed reservoir yield specific to the NFRR and Tom Steed Reservoir, respectively, and then the OWRB could adopt those thresholds into new interference regulations that are specific to the Tom Steed Reservoir hydrologic basin.

A range of potential interference thresholds (i.e., stream-water rights management alternatives) were evaluated by Reclamation and OWRB in collaboration with MPMCD. The full analysis can be found in Reclamation's Technical Memorandum, "Formulation of Stream-Water Rights Management

Alternatives in the Tom Steed Reservoir Hydrologic Basin" [(Reclamation, 2021) (Appendix K)]. This analysis, regarded by study partners as one of the most notable achievements of the URRBS, is comprised of six "Parts" that are described below under the heading, "Interference Threshold Analysis". Out of the thousands of interference thresholds evaluated, 50 combinations were selected. These 50 combinations were subsequently combined with timing options and curtailment types (curtailing both existing and new junior stream-water permits or curtailing only new junior permits), resulting in up to 200 management scenarios. The results of the NFRR SWAM analysis are provided under the heading, "Water Availability Modeling Results". First, the discussion begins by describing how interference thresholds were identified and evaluated.

Regulatory Protection

Formulation of Stream-Water Rights Management Alternatives

The interference threshold analysis was divided into six "Parts" that are summarized below. The details of the analysis can be found in Reclamation's Technical Memorandum "Formulation of Stream-Water Rights Management Alternatives in the Tom Steed Reservoir Hydrologic Basin" [(Reclamation, 2021) (Appendix K)].

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

Part II: Identified several drought 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 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 of the indicators. 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 atmospheric science methods used to test meteorological forecasting. 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-yr period of record when inflow and PDSI conditions were at or below four inflow-PDSI thresholds is provided in Figure 8-6.

Next, ten reservoir storage thresholds were selected. Combining the four inflow-PDSI thresholds with the ten reservoir storage thresholds, a total of 50 inflow-PDSI-reservoir storage threshold combinations were selected as presented in Table 8-7.

Table 8-7. 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

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 2.3.2. 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.

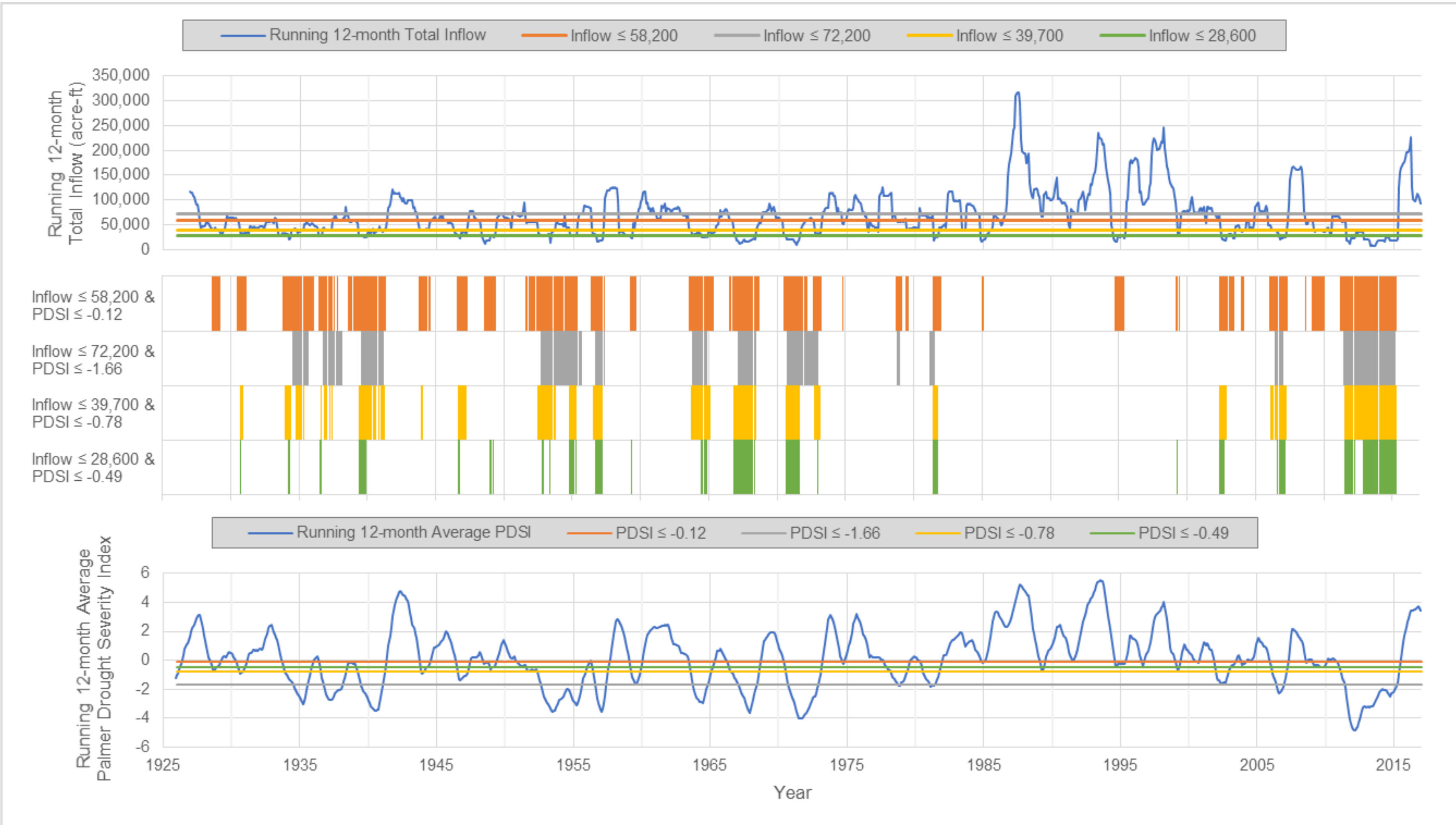

Figure 8-6. Frequency and duration of events over the observed 90-yr period of record when inflow and PDSI conditions were at or below four inflow-PDSI thresholds.

Part VI. Describes 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[200]. 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.

[200] 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.

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

Water Availability Modeling Results

Approach

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 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. A portion 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 five hydrologic thresholds previously selected in Chapter 8.3.2. 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. Because of the large number of modeling scenarios, only summary tables of the results are provided. Within Appendix M, detailed results are presented and are organized into separate subsections in order of increasing groundwater and surface water development as defined in Table 6-16. For all results, including summary results here and detailed results in Appendix M, impacts under the existing and new groundwater permitting scenarios were combined[201].

[201] Recall that Chapter 6.4 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.

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. 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 selected in Chapter 8.3.2: (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 one example of how results could be evaluated[202]. 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 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

[202] 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.

curtailed[203]. 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 to develop a full understanding of how implementation of these curtailment thresholds impact 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 8-8. The thresholds are herein referred to by their assigned color.

Table 8-8. 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

[203] As discussed in Chapter 6.4.4 and 7.3.1, Kershen (2021) noted that MPMCD's existing permit has 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.

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. Recall in Chapter 6.3.3 that to evaluate reservoir *firm yield*, the model solved for maximum annual deliveries that can be made out of Tom Steed Reservoir 100 percent of the time, including during the drought of record, without reservoir storage dropping into the inactive pool. This maximum annual delivery volume is known as the "firm yield". Once this volume was known, it was delivered from the reservoir each and every year over the model period. In effect, this scenario assumed that the drought of record was imminent every time Tom Steed Reservoir dropped below the top of conservation pool, and thus eliminated the potential for the reservoir to drop into the inactive pool. To evaluate *Tom Steed Reservoir supply dependability*, the model simulated the delivery of three different reservoir demand (use) scenarios out of Tom Steed Reservoir: (1) "Existing" reservoir use, which assumed that MPMCD would utilize 12,700 acre-ft/yr, the maximum volume of water that has ever been reported by MPMCD to the OWRB as being used out of Tom Steed Reservoir in a given year ; (2) "Mid" reservoir use, which assumed that MPMCD would utilize

14,400 acre-ft/yr, the mid-point between "Existing" and "Full"; and (3) "Full" reservoir use, which assumed that MPMCD would utilize 16,100 acre-ft/yr, the full volume permitted to MPMCD. For each demand scenario, if the assigned reservoir use was not available (e.g., during the drought of record) in any given calendar year, the model solved for the volume of permit water that was available during that time, and if a gap existed between the volume demanded out of the reservoir and the volume in reservoir storage that was available, the gap in storage was reported as a "shortage" for that calendar year.

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 8-7; Table 8-9). Curtailing existing upstream permits based on the blue threshold increased reservoir firm yield to 14,300 acre-ft/yr (seven percent increase) (Figure 8-7; Table 8-9). 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 8-7; Table 8-9).

- 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 8-10). Regardless of the threshold selected, curtailing existing upstream permits had no impacts on reservoir storage (Table 8-10).
- 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 8-10). 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 8-10).
- 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 8-10). 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 8-10).

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 8-11). 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 8-7; Table 8-11). 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 8-7; Table 8-11). Overall, the thresholds curtailed upstream permits between eight percent and 69 percent of the time[204] (Figure 8-7).

- The impacts of curtailments on each individual permit in the Tom Steed Reservoir hydrologic basin are provided in Appendix M. 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 8-7).
- 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.

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[204] 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.

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 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 8-7; Table 8-9). When curtailing only new upstream permits, the five thresholds equally increased reservoir firm yield to 13,400 acre-ft/yr (11 percent increase) (Figure 8-7; Table 8-9). 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 8-7; Table 8-9).

- 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 8-10). Regardless of the threshold selected, curtailing existing upstream permits had no impact on reservoir storage (Table 8-10).
- Under Status Quo, the reservoir had sufficient water in storage 97 percent of all years to deliver "Mid"-level demands on the reservoir with a maximum calendar-year shortage of 1,900 acre-ft (Table 8-10). 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 8-10). 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 8-10).
- Under Status Quo, the reservoir had sufficient water in storage 97 percent of all years to deliver the "Full" permit reservoir demand with a maximum calendar-year shortage of 2,300 acre-ft (Table 8-10). 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 8-10). 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 8-10).

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 8-11). 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 8-7; Table 8-11).
- 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 8-7; Table 8-11). 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 8-7; Table 8-11).
- While curtailing both new and existing junior upstream permit use resulted in 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 8-7). 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 8-7).
- 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 8-7; Table 8-9). 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 8-7; Table 8-9). 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 8-9). 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 8-10). 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 8-10). 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 8-10).

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 8-11). 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 8-7; Table 8-11).
- 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 8-7; Table 8-11). 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:

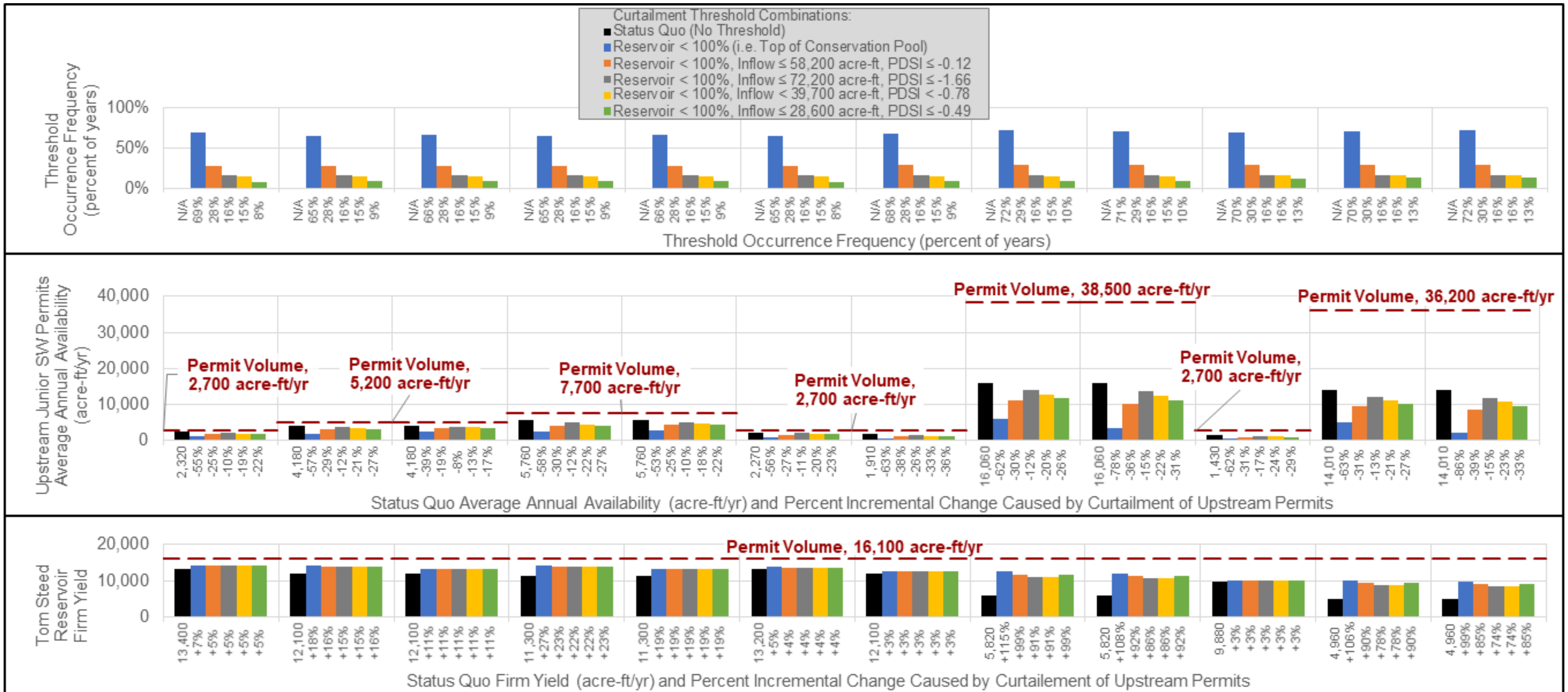
- The incremental impacts on reservoir firm yield and average annual reservoir permit availability among the five curtailment thresholds were generally the same, regardless of whether new upstream permits were curtailed alone or if new permits were curtailed in combination with existing upstream junior 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 8-7).
- 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 8-7, Table 8-9, Table 8-10, and Table 8-11.



GW Permits	Existing and New	Existing and New	Existing and New	Existing and New	Existing and New	Full	Full	Full	Full	Full	Full	Full
SW Domestic	Existing	Existing	Existing	Existing	Existing	Existing	New (Low)	New (Low)	New (Low)	New (High)	New (High)	New (High)
SW Permits	Existing	New (Low)	New (Low)	New (High)	New (High)	Existing	Existing	Full	Full	Existing	Full	Full
Curtailing	Existing	Existing and New	New Only	Existing and New	New Only	Existing	Existing	Existing and New	New Only	Existing	Existing and New	New Only

Figure 8-7. 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. See Tables 24-52 for additional details regarding the impact of the curtailment thresholds on these GW/SW use scenarios; and reference Appendix M for the full results of the water availability modeling analysis, including results for the 90 percent, 70 percent, and 50 percent reservoir storage thresholds.

Table 8-9. 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. See Tables 24-52 for additional details regarding the impact of the curtailment thresholds on these GW/SW use scenarios; and reference Appendix M for the full results of the water availability modeling analysis, including results for the 90 percent, 70 percent, and 50 percent reservoir storage thresholds.

		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 8-10. 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.

			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 8-10. Continued.

			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)															
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 8-11. 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. See Tables 24-52 for additional details regarding the impact of the curtailment thresholds on these GW/SW use scenarios; and reference Appendix M for the full results of the water availability modeling analysis, including results for the 90 percent, 70 percent, and 50 percent reservoir storage thresholds.

		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 4,760	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

Non-Regulatory Protection

In addition to adopting the previously-described hydrologic thresholds into interference regulations administered by the OWRB, another strategy could be to use the thresholds as the basis for voluntary, non-regulatory dry-year lease agreements between MPMCD and senior permit holder(s) in the Tom Steed Reservoir hydrologic basin – meaning, water would only be exchanged temporarily when the agreed-upon hydrologic thresholds have been met during periods of drought. In lieu of or in addition to leasing the senior rights, MPMCD also could transact a permanent purchase of the senior rights from one or more willing senior permit holders. Whatever the case may be, the exchange would be voluntary and based on the fair market value of the water being leased and/or purchased.

In terms of addressing the planning objective of providing a Tom Steed Reservoir firm yield of 16,100 acre-ft/yr, this strategy could be very effective depending on the volume of senior rights exchanged. Recall the planning objectives discussion in Chapter 7.3. The statement was made that regardless of the strategy used to eliminate depletions caused by existing junior permits, if one assumes that existing senior and domestic uses cannot be removed from the stream, then the firm yield of Tom Steed Reservoir would always be lower than 16,100 acre-ft/yr up to the approximate volume of water being withdrawn upstream by existing senior permit holders and domestic users, thus demonstrating the potential ineffectiveness of providing the full 16,100 acre-ft/yr firm yield target through the mitigation or elimination of existing and/or future junior stream permits alone. However, if steps were taken to address both junior and senior permits in the basin, then the firm yield of Tom Steed Reservoir could be far closer to 16,100 acre-ft/yr. In fact, if the full volume of existing upstream senior permits (1,856 acre-ft/yr)[205], existing junior permits (2,700 acre-ft/yr), and potential future new junior permits (35,900 acre-ft/yr or 33,900 acre-ft/yr) were

[205] Assumed MPMCD's permit priority date is 1967.

removed from the basin, then the firm yield would only be lower than 16,100 acre-ft/yr by the volume of existing and/or future domestic withdrawals.

Finally, 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.

8.3.3. Additional Stream-Water Rights of Mountain Park Master Conservancy District

In the last section, it was assumed that all unappropriated water could be permitted in the Elk Creek and West Otter-Glen Creek basins upstream of Tom Steed Reservoir, and that in order to protect MPMCD's permit from these future new junior permits, pre-determined interference thresholds could be adopted by the OWRB that curtail diversions from these junior stream permits during drought periods. Rather than assuming a future with the appropriation of new stream permits, this strategy focuses on MPMCD applying for any and all of the unappropriated water in Elk Creek and West Otter-Glen Creeks. This would consequently render the previously-identified thresholds as irrelevant, at least as it concerns curtailment of future junior stream permits[206]. Specifically, as noted by Kershen (2021), MPMCD could apply for these unappropriated water rights for non-consumptive uses (i.e., for recreation, fish, and wildlife purposes) that are above and beyond the "vested" recreation, fish, and wildlife water rights evaluated above in Chapter 8.3.1 as part of MPMCD's existing permit. The

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[206] Recall one of the non-regulatory strategies to protect MPMCD's water right was to use the hydrologic thresholds to inform voluntary dry-year lease agreements between MPMCD and existing senior permit holders in the basin.

extent to which this strategy addresses the 16,100 acre-ft/yr firm yield target is discussed below in terms of the benefits described in Kershen (2021).

First and foremost, MPMCD would no longer need to worry about future persons or entities applying for and receiving newly permitted prior appropriation rights, and MPMCD would be in better position legally by having the most junior water rights to all unappropriated water in its reservoir drainage basins than by having other, new non-MPMCD water-right holders in the Tom Steed Reservoir watersheds. After all, if MPMCD had the most junior water right for all unappropriated water, MPMCD would not have to sue itself in order to protect its senior water-right (Permit 67-671) during times of drought. If other non-MPMCD water-right holders were to come into existence, MPMCD would have even a greater number of junior water-right holders against whom MPMCD would have to seek interference protection in times of drought.

Second, MPMCD might face little opposition to its application for all unappropriated waters in Elk Creek and West Otter-Glen Creeks above Tom Steed Reservoir. As previously discussed, 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. Consequently, it would seem that no one should be thinking about applying for a water right in the Tom Steed Reservoir hydrologic basin. And, notwithstanding the URRBS's finding that unappropriated water could exist if the OWRB used 1950-2016 naturalized flows in lieu of 1951-1980 run-off records, it may sound contradictory to say that MPMCD can apply for water rights in all unappropriated waters when the OCWP stated that no unappropriated waters exist; however, MPMCD could argue that granting it a water permit for all unappropriated waters within the Elk Creek and West Otter-Glen Creek watersheds legally effectuates closure of the basins in conformity with the OCWP (Kershen, 2021). 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. Granting MPMCD a permitted water right for all unappropriated water rights these watersheds for non-consumptive beneficial uses thereby legally precludes the OWRB from granting any additional consumptive use water rights within those two watersheds. And once MPMCD has a water right to all unappropriated waters within the Tom Steed Reservoir hydrologic basin, there literally is no unappropriated water remaining for which any person or entity could apply for a prior appropriation (Kershen, 2021).

Third, other existing senior and junior permit holders in the Tom Steed Reservoir hydrologic basin also could benefit if MPMCD has a water right for all unappropriated waters. URRBS results show that existing senior and junior permit holders in Elk Creek and West Otter-Glen Creeks already have unstable and unpredictable water rights. 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. Existing senior and junior water-right holders in the basin would therefore likely support MPMCD's application or refrain from protesting MPMCD's application (Kershen, 2021).

Fourth, recognizing that MPMCD has a schedule of use in its existing permit, MPMCD's current schedule of use shows that 14,190 acre-ft/yr (88 percent) would be used by the year 2020 and that 16,100 acre-ft/yr (100 percent) would be used by the year 2030. Under Oklahoma law, MPMCD faces the possible reduction of its core water rights under the "use it or lose it" principle of prior appropriation water law. 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 lost some amount of acre-ft from its core water rights, existing junior appropriators upstream or downstream from Tom Steed Reservoir would have a claim to the "lost" water that now, once again, belongs to the stream system. But this loss would be offset by the inflow of the newly granted non-consumptive MPMCD water rights for recreation, fish, and wildlife. Furthermore, if MPMCD had water rights to all unappropriated waters in the basin, then MPMCD has precluded any additional juniors from coming into existence to make a claim for “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 (Kershen, 2021).

Fifth, if MPMCD obtained a water right to 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 to all water in Tom Steed Reservoir would be that no person or entity could apply for a water permit in “excess” water in storage because there would be no “excess” water in storage because all water in storage would be permitted water rights held by MPMCD (Kershen, 2021).

In terms of addressing the planning objective of providing a Tom Steed Reservoir firm yield of 16,100 acre-ft/yr, this strategy, like others discussed thus far, could not provide the target firm yield of 16,100 acre-ft/yr for reasons previously explained. However, this strategy would protect the firm yield from depletions caused by future new stream-water permits that were found to cause the largest depletions in firm yield. And 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 prevent Tom Steed Reservoir’s firm yield from being depleted to worst-case scenario conditions of either 5,800 acre-f/yr or 5,000 acre-ft/yr (depending on low or high domestic use, respectively); and in doing so, protect the firm yield from be reduced beyond a range of between 13,400 acre-ft/yr to 9,900 acre-ft/yr depending on the development scenario (Chapter 6.4.4; Figure 6-19).

8.3.4. Conjunctive Management

Another strategy to address the Tom Steed Reservoir firm yield target of 16,100 acre-ft/yr was to mitigate impacts from groundwater pumping in the NFRR and Elk City aquifers. By managing the interconnected groundwater and stream-waters together, this strategy would be engaging in conjunctive management. The reader is encouraged to review Chapter 7.3.4 for a discussion summarizing the legal basis included in Kershen (2021) from which conjunctive management could be implemented in the Tom Steed Reservoir hydrologic basin. The focus here is on the extent to which addressing groundwater pumping could address the 16,100 acre-ft/yr firm yield target for Tom Steed Reservoir.

Voluntary Dry-Year Lease or Purchase Agreements

Just as MPMCD might consider dry-year lease agreements or purchase agreements to protect its stream-water rights, MPMCD could consider dry-year lease agreements or purchase agreements with landowners holding groundwater permits so as to protect base flow of Elk Creek and West Otter-Glen Creeks. Similar to stream water, agreed-upon, non-regulatory hydrologic thresholds could be used as the basis for lease agreements that trigger a temporary exchange of groundwater during drought periods to protect base flows.

In terms of achieving the 16,100 acre-ft/yr reservoir firm yield planning objective, managing groundwater permits would present some unique challenges as opposed to leasing and/or purchasing stream-water permits directly. First, the number of landowners having permits to groundwater in the NFRR and Elk City aquifers are far greater than the number of senior stream-water permits. Hence, the transaction and maintenance costs of entering into and maintaining these lease/purchase agreements would be far higher. And most importantly, the hydrological impacts of groundwater pumping on base flow would likely be more complicated with greater uncertainty about actually producing “wet” water in the Tom Steed Reservoir. For example, groundwater modeling results in Smith et al. (2017) revealed the physical extent of the NFRR alluvial aquifer, of which only a small portion extends underneath Elk Creek upstream of the Bretch Diversion (Figure 6-8). In fact, base flows in Elk Creek originate partly from the NFRR aquifer around the proximity off the Bretch Diversion Dam, but also from the Elk City aquifer further upstream in Washita and Beckham counties (Smith et al., 2017; OWRB, 2019 in press).

That said, status-quo modeling results showed that existing groundwater permits in the NFRR aquifer had no measurable impact on Elk Creek, and full development of the NFRR aquifer reduced Elk Creek base flow by 30 percent (i.e., 6,700 acre-ft/yr) or by 34 percent [(i.e., 7,500 acre-ft/yr) depending on whether the aquifer was developed in accordance with the 50-yr or 20-yr EPS (Chapter 6.4; Table 6-8)]. And even assuming the remaining 70 percent or 66 percent of Elk Creek's base flow, respectively, were depleted to zero under full development of the Elk City aquifer, impacts on Tom Steed Reservoir firm yield were still negligible (Figure 6-19).

In light of these modeling results, MPMCD may not want to pay a landowner to refrain from pumping groundwater unless MPMCD could be assured that the reduction in pumping would protect and increase base flows of Elk Creek and/or West Otter-Glen Creeks. Hence, dry-year lease agreements with landowners holding groundwater permits would likely not be an effective strategy at protecting the firm yield of Tom Steed Reservoir.

Conservation-Oriented Maximum Annual Yield Determination

Another conjunctive management strategy to address the Tom Steed Reservoir firm yield target of 16,100 acre-ft/yr was to mitigate impacts from groundwater pumping through the implementation of a conservation-oriented maximum annual yield on the NFRR and Elk City aquifers. Kershen (2021) suggested that MPMCD could encourage the OWRB, as the OWRB reviews and updates the MAY and EPS for the NFRR and Elk City aquifers, to redetermine the MAY and EPS and adopt 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. Kershen (2021) suggested that MPMCD and

Lugert-Altus ID could work collaboratively because they have shared interests in management of the NFRR aquifer which impacts both Lugert-Altus and Tom Steed reservoirs. In doing so, MPMCD and Lugert-Altus ID could encourage the OWRB to consider the total discharge from basins (surface and groundwater) such that discharge protections could be determined that maintain base flows above certain thresholds. They also could encourage the OWRB to undertake the hydrological surveys and information needed to set an EPS for the aquifer that would be smaller than otherwise set under existing practice. As discussed in Chapter 7.3.4, one strategy could be to set a MAY and an EPS that reflected the groundwater pumping rate for 2013 or the projected groundwater pumping rate for 2060, either of which would likely better protect the base flow of the NFRR relative to current practice. Consideration also could be given towards evaluating the relative impacts on baseflow caused by localized aquifer storage reduction corresponding to a range of withdrawals varying by existing well locations within the Tom Steed Reservoir watershed. Such an analysis could account for the relative distance of wells from tributaries of concern and the corresponding time it takes for withdrawals to impact those tributaries.

Turning more specifically to the planning objective of achieving a Tom Steed Reservoir firm yield of 16,100 acre-ft/yr, the groundwater and surface water modeling results discussed in the previous sections under voluntary dry-year lease and purchase agreements also apply here. While results confirm that groundwater pumping out of the NFRR alluvial aquifer has a relatively large impact on Lugert-Altus Reservoir, groundwater pumping impacts on Tom Steed Reservoir are negligible. Therefore, while Lugert-Altus and MPMCD would appear to have a shared interest in mitigating the impacts of groundwater withdrawals out of the NFRR alluvial aquifer, a more compelling case could be made by Lugert-Altus ID in support of implementing a more conservation-oriented, lesser EPS. That said, as Kershen (2021) pointed out, a lesser EPS in the NFRR aquifer would most certainly be preferred by MPMCD than one that reflects the policy of full depletion of the aquifer; and despite what the modeling results demonstrate regarding benefits (or lack thereof) to Tom Steed Reservoir, MPMCD may recognize that what is good for Lugert-Altus ID may be good for MPMCD. And the two districts could consider collaborating together in their encouragement of the OWRB as it redetermines the MAY and EPS of the NFRR alluvial aquifer. Regarding the Elk City aquifer, a numerical groundwater model was not developed as part of the URRBS so the impacts of existing pumping on Elk Creek remains unknown; however, as previously stated, this study did model the impacts of full development of the Elk City aquifer and the subsequent depletion of Elk Creek base flows to zero, and results showed that even full development of the Elk City aquifer has negligible impact on Tom Steed Reservoir firm yield.

In light of the modeling results noted above, this strategy may not be effective at providing any meaningful protection of Tom Steed Reservoir firm yield. However, implementation of a lesser, more conservation-oriented EPS in either or both of the NFRR and Elk City aquifers would appear to be preferred over implementation of an EPS that fully depletes the aquifers.

8.3.5. Reclassification of Alluvial Groundwater to Stream Water

Kershen (2021) suggested that reclassifying groundwater as stream water under certain, specified conditions, would subsequently allow these reclassified waters to be managed in accordance with Oklahoma's surface water prior appropriation laws. This would effectively make MPMCD's permit senior to groundwater use permitted after the dates of the reservoir permit, and then MPMCD could use interference regulations developed by the OWRB to gain protection for its senior stream permit against junior stream permits, including those groundwater wells that would be taking alluvial waters or losing stream waters that would now be reclassified as stream water.

In terms of addressing the 16,100 acre-ft/yr Tom Steed Reservoir firm yield target, given the modeling results and lack of demonstrated impacts from groundwater pumping on Tom Steed Reservoir, this strategy, like the conjunctive management strategies discussed above, may not be effective at providing meaningful protection of Tom Steed Reservoir firm yield. Notwithstanding these results, this strategy was given the full analytic attention that was given to Lugert-Altus Reservoir.

Kershen (2021) proposed that reclassification would move certain, specified Oklahoma groundwater from management under the groundwater laws to management under the stream-water laws; it would not mean that the OWRB would be engaged in conjunctive management as described in the previous section. Kershen (2021) cited two legal arguments that could support reclassification:

> (1) the “alluvial waters argument”, which contends that the Oklahoma legislature impermissibly moved alluvial waters from being public waters to private ownership waters in 1967 and 1972 amendments to Oklahoma’s water laws; and
>
> (2) the “losing stream argument”, which contends that groundwater adjacent and connected to losing streams could be considered stream water. Kershen (2021) noted that because neither of these arguments have ever been presented to Oklahoma courts, reclassification would likely require litigation. He did not suggest the merits or outcome of such litigation, but he did provide key insights into how and why this strategy may be justified in the Tom Steed Reservoir hydrologic basin.

The alluvial waters argument is discussed at length in Kershen (2021), where he cites the history of various Legislative actions defining the terms “definite stream” and “groundwater” with regard to distinguishing groundwater from stream water. As it stands today, groundwater is owned by the overlying landowners and accessed through the groundwater law, and stream water is public water accessed by the public for beneficial use through prior appropriation doctrine. But a key question that remains, according to Kershen (2021), is whether alluvial waters (i.e., waters in alluvial aquifers) are groundwater or stream waters. Kershen (2021) cited two Oklahoma Supreme Court cases related to the distinguishment between groundwater and stream-waters, but neither case resolved the alluvial waters question. In the first case related to an applicant who sought to encase a natural spring, the Court ruled that a natural spring that flowed into a definite stream[207] was public water from its inception and may not be diverted for private use unless appropriated as stream water. In the second case, the Court ruled that an applicant seeking to drill wells into land within one mile of a major river was taking groundwater subject to the Oklahoma Groundwater Law. The ruling was made even though neighboring landowners argued that the wells would cause nearby springs, that flow to definite streams, to go dry. Based on the facts and the ruling of the latter case in particular, Kershen (2021) noted that the Court arguably has determined that alluvial water in alluvial aquifers is groundwater until the water surfaces as springs serving as a definite source of a definite stream or until the water seeps into a definite stream. Moreover, the OWRB has long applied the Oklahoma Groundwater Law to alluvial aquifers, and the OWRB has issued several MAY and EPS determinations for identified alluvial aquifers (Kershen, 2021). Yet, there may be viable legal arguments that alluvial aquifers are stream water for two different and independent reasons.

First, in 1949, Oklahoma adopted a groundwater law that purported to govern groundwater using the prior appropriation system of water law. In fact, the OWRB never used the prior appropriation system to manage groundwater and instead, roughly appropriated groundwater proportional to the acreage of overlying land. Nevertheless, groundwater at the time was considered public water. The 1949 definition of groundwater was "water under the surface of the earth regardless of the geologic structure in which it is standing or moving; it does not include water flowing in underground streams *with ascertainable beds and banks*". Kershen (2021) concluded that an important implication of the 1949 definition is that the underground definite stream must have had "*ascertainable beds and banks*." In 1967, the Legislature amended the 1949 groundwater definition by deleting the clause "it does not include water flowing in underground streams with ascertainable beds and banks." And then in 1972, the Legislature again amended the definition of groundwater to read as follows,

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[207] A "Definite Stream" means a watercourse in a definite, natural channel, with defined beds and banks, originating from a definite source or sources of supply. Laws 1972, c. 256 § 1 (eff. July 1, 1973).

"…the term "Ground Water" shall mean water under the surface of the earth regardless of the geologic structure in which it is standing or moving outside the cut bank of any definition stream", which is the definition today.

Kershen (2021) then raised what he viewed as an unresolved question in terms of whether alluvial aquifers are "flowing in underground streams with ascertainable beds and banks – or are the alluvial aquifers outside the ascertainable beds and banks of an underground stream? In other words, what is an "underground stream?" For purposes of Oklahoma water law, is an "underground stream" the same as a "definite stream" which requires "cut beds and banks?" As far as Kershen (2021) was concerned, no caselaw exists on these questions and, additionally, no significant discussion of these questions exists in legal treatises or law review articles. Even assuming that alluvial aquifers are "flowing in underground streams with ascertainable beds and banks," Kershen (2021) questioned whether the Legislature of the State of Oklahoma had the constitutional authority to change what was once a public resource into a private resource – that is, to change public (ground) water into (ground) water owned privately by the overlying landowners as this precise question has never arisen within the caselaw or the legal literature about Oklahoma water law.

Second, Kershen (2021) noted that the Supreme Court has never addressed the hydrological distinction between gaining streams and losing streams. According to Kershen (2021), losing streams are losing waters to the surrounding groundwater aquifer, and gaining streams are gaining waters from the surrounding groundwater aquifer, whether it is an alluvial aquifer or a bedrock aquifer or both. Under Oklahoma water law, as soon as water from a losing stream moves past the cut bank of the definite stream into the surrounding geological formation, the water is groundwater. As such, if a landowner were using a well that increased the loss of water from the stream to the surrounding groundwater aquifer, it could be argued that the landowner is taking stream-water, not groundwater. In effect, the landowner's pumping is increasing the magnitude of the loss of water from the losing stream and is, as if, the landowner has placed the pump directly into the stream bed itself (Kershen, 2021).

In the Lugert-Altus Reservoir hydrologic basin, Kershen (2021) made a case in favor of reclassification through the losing stream argument by pointing to technical studies on the hydrology of the NFRR and NFRR alluvial aquifer, which confirmed that the NFRR above Lugert-Altus Reservoir is a losing stream, and that modeling results demonstrated a measurable (and substantive) impact from groundwater pumping on Lugert-Altus Reservoir. In the Tom Steed Reservoir hydrologic basin, Smith et al., (2017) showed that Elk Creek is a losing stream in the reach downstream of Hobart and above Tom Steed Reservoir; however, one may question the relevance of this factor given the negligible impacts from groundwater pumping on Elk Creek. Also, recall that the USGS did not model the Elk City aquifer and its impacts on Elk Creek base flow, so whether or not the more upstream reaches of Elk Creek are gaining or losing remains unknown.

In light of the discussion above, this strategy is unlikely to meaningfully address the 16,100 acre-ft/yr Tom Steed Reservoir firm yield target. Notwithstanding the significant and complicated legal challenges that would need to be overcome, because URRBS modeling results showed that even if reclassification was to occur, reducing or eliminating groundwater pumping would have minimal and uncertain benefits to Elk Creek and to Tom Steed Reservoir.

8.3.6. Environmental Quality Beneficial Use

The reader is encouraged to review the background and challenges related to EQ benefits, including the preliminary formulation of alternatives to address these challenges, in Chapter 2.3.2 and Chapter 7.3.

Existing Infrastructure

Hackberry Flat WMA is comprised of 7,120 acres with 35 individual wetland units inundating about 3,750 acres. Natural run-off drains into a regulating reservoir constructed by the Natural Resource Conservation Service (NRCS), also known as "NRCS Site 7B" (Hackberry Flat Regulating Reservoir). The Hackberry Flat Regulating Reservoir can store 1,028 acre-ft of water. Natural run-off is supplemented by deliveries into the regulating reservoir from the 15.9-mile Hackberry Pipeline, which connects to the Frederick Aqueduct at a turnout near the Deep Red Run storage tank. The Hackberry Pipeline, installed in 1999, is comprised of steel pipe of various sizes (18-inch, 20-inch, and 30-inch), which transitions into an 18-inch PVC pipe that conveys water the final 1,940 linear ft to an outfall into the Hackberry Flat Regulating Reservoir. The design drawing for the Hackberry Flat Pipeline does not indicate a flow rate, but a review of the head loss indicates that the pipeline is capable of an approximate maximum flow rate of 4.5-5.0 cfs. The Hackberry Pipeline is in poor condition and has not delivered water to Hackberry Flat since 2013.

Alternatives Analysis

Three alternatives were identified to address the variety of challenges associated with authorized EQ benefits of the Mountain Park Project. These alternatives varied in terms of their delivery objectives to Hackberry Flat WMA. The three alternatives were as follows: (1) deliver all EQ water to Hackberry Flat WMA; (2) deliver some EQ water to Hackberry Flat WMA; and (3) deliver no EQ water to Hackberry Flat WMA. Depending on the delivery objective, two additional components were considered: (1) the type and volume of water supply sources (both EQ and non-EQ) to Hackberry Flat WMA; and (2) the infrastructure needed for water delivery as determined based on the delivery objective and supply source. A summary of the three alternatives, including infrastructure components, supply source, volume, and estimated preliminary construction costs is provided in Table 8-12 at the end of this section. Illustrations of the alternatives are provided in Figure 8-8 and Figure 8-9. Quantity estimates supporting costs for each alternative are available within Reclamation OTAO's central files and available upon request.

Overall, these alternatives were considered too complex to perform an analysis with sufficient detail to inform a decision on how to address the EQ challenges. However, due to the important nature of the EQ issue at the Mountain Park Project, the URRBS found it prudent to bring EQ issues to light and identify a range of potential solutions that could be evaluated through a future collaborative effort between Reclamation, MPMCD, and ODWC.

Alternative 1: Deliver all EQ Water to Hackberry Flat WMA

Under this alternative, Tom Steed Reservoir would supply the full 2,352 acre-ft/yr allocation of EQ water to Hackberry Flat WMA. This would require either replacing the Hackberry Flat Pipeline with a new pipeline or slip-lining the existing Hackberry Flat Pipeline.

New Pipeline

The existing Hackberry Flat Pipeline would be replaced by a new 20-inch High-Density Polyethylene (HDPE) pipe that is 82,280 linear ft in length. The new pipeline would begin at the Frederick Aqueduct turn-out near the existing Deep Red Run storage tank and connect to the existing 18-inch PVC pipe that flows into the existing regulation reservoir. The new pipeline would be capable of delivering approximately 5.0 cfs. Construction would occur within existing easements, and features from the original pipeline, as well as existing roads, railroads, and stream crossing piers, would be utilized where possible. New air release and blowoffs structures would be required. Although this alternative assumes replacement of the entire existing pipeline, a condition assessment should be performed to determine if portions of the existing pipeline could still be used. This alternative assumed the existing 1,940 linear ft of existing 18-inch PVC pipe at the terminus of the Hackberry Flat Pipeline is still viable. The total estimated preliminary cost of this alternative was $13.4 million in 2021 dollars.

Slip-Line Existing Pipeline

The existing Hackberry Flat Pipeline would be left in place and slip-lined with a new HDPE pipe that is pushed or pulled into the existing Hackberry Flat Pipeline. The slip-lined pipe would have an outside dimension smaller than the inside dimension of the existing Hackberry Flat Pipeline. The slip-line would consist of 72,180 linear ft of 18-inch HDPE pipe placed inside portions of the existing Hackberry Flat Pipeline that are 20-inch and 30-inch diameter steel pipes; another 16,100 linear ft of 16-inch HDPE pipe would be placed inside the existing 18-inch diameter steel pipe. The new HDPE pipe would connect to the existing 18-inch PVC pipe near the terminus of the Hackberry Flat Pipeline. Because smaller HDPE pipe is required for the slip-line, the conveyance capacity would slightly decrease. The existing pipeline would need to be inspected and cleaned before slip-lining. Connections at existing air release and blowoff locations would be required. Existing structures would be utilized for air release and blowoffs if they are in satisfactory condition and new valves would be installed. The total estimated preliminary cost of this alternative was $9.8 million in 2021 dollars.

Alternative 2: Deliver Some EQ Water to Hackberry Flat WMA

Under this alternative, some but not all EQ water would be delivered to Hackberry Flat WMA. The yet-to-be-determined volume of EQ water would depend on the outcome of a present-day assessment of the needs of both Hackberry Flat WMA and M&I customers of Tom Steed Reservoir. Unused EQ water was assumed to be reallocated for M&I purposes, the volume of which also would depend on the outcome of a proper needs assessment.

Similar to Alternative 1, this alternative would require either replacing the Hackberry Flat Pipeline with a new pipeline or slip-lining the existing Hackberry Flat Pipeline, albeit under a conveyance capacity that assumes deliver of a volume less than 2,352 acre-ft/yr.

This alternative assumed that a portion of the EQ water would be reallocated for M&I purposes, and that non-EQ water from another source could be used to supply Hackberry Flat WMA as a replacement for all or some of the portion of EQ water that is reallocated for M&I purposes. The replacement non-EQ water was assumed to derive from one of two sources: (1) natural run-off through enhanced storage of the Hackberry Flat Regulating Reservoir; or (2) reclaimed wastewater from the city of Frederick. The volume of non-EQ replacement water available from each of these two sources was evaluated, along with the infrastructure needed to deliver the water to Hackberry Flat WMA.

Regulating Reservoir Storage Expansion

Multiple options were considered to increase the storage in the Hackberry Flat Regulating Reservoir ("NRCS Site B"), including dredging, raising the dam, and utilizing the reservoir's flood pool. Rainfall records between 2015 and 2019 were evaluated at the Granfield and Tipton weather stations, and preliminary results showed that the pool of the existing regulating reservoir is appropriately sized and that increasing the storage capacity would increase supply availability by only a minimum amount, in part due to offsetting losses caused by an increase in evaporation. Therefore, it was determined that expanding the storage capacity of the Hackberry Flat Regulating Reservoir would not provide a meaningful and dependable alternative supply source to Hackberry Flat WMA. This alternative was eliminated from further consideration.

EQ Water (New Pipeline) and Non-EQ Water (Reclaimed Water)

This option assumed that some volume of EQ water would be delivered to Hackberry Flat WMA through installation of a new replacement pipeline, and that reclaimed wastewater from the city of Frederick could be used as a non-EQ alternative supply source to Hackberry Flat WMA in lieu of unused/reallocated EQ water. The city of Frederick is located approximately seven miles northwest of Hackberry Flat WMA. Frederick owns and operates a wastewater treatment plant located about two miles southeast of town. The plant consists of a lagoon treatment system with an agricultural use application. Based on Frederick's average winter water usage (November- February) between 2012 and 2015, the volume of wastewater effluent generated by the plan was estimated to range between 700 acre-ft/yr and 800 acre-ft/yr. For this alternative, delivery of 750 acre-ft/yr of reclaimed water to Hackberry Flat WMA was assumed. Support from and coordination with the city of Frederick would be necessary for this option to be considered viable. Consultation with the Oklahoma Department of Environmental Quality also would be required to determine the water quality and treatment requirements prior to utilizing this water. For the purposes of this analysis, it was assumed that no additional treatment would be required prior to use at Hackberry Flat WMA.

Given the assumed reclaimed water delivery volume of up to 750 acre-ft/yr, to achieve a targeted delivery of up to 2,352 acre-ft/yr to Hackberry Flat WMA, this alternative assumed an EQ delivery volume of up to 1,600 acre-ft/yr. The EQ water would be conveyed through a new 16-inch HDPE pipeline approximately 72,180 linear ft in length connecting the Frederick Aqueduct turnout near the existing Deep Red Run storage tank to a new surge tank at the terminus of the new Hackberry Flat pipeline. The new pipeline would be capable of delivering approximately 2.5 cfs. Features from the original pipeline, along with existing roads, railroads, and stream crossings would be utilized where possible. New air release and blowoffs would be required.

This alternative assumed that a new pump station would be needed at Frederick's wastewater treatment plant to provide an additional 25 ft of head to achieve the desired flow rate of 2.5 cfs[208]. The non-EQ reclaimed water would be conveyed from the new pump station through a new 14-inch HDPE pressurized pipeline approximately 23,400 linear ft in length and connect to a new surge tank at the terminus of the new Hackberry Flat Pipeline.

The EQ and non-EQ flows would be combined in the new surge tank, which was assumed to be 12 ft in diameter and 20 ft high. From the new surge tank, the combined flows would be conveyed through a new 18-inch HDPE pipe approximately 10,050 linear ft in length and then connect to the existing 18-inch PVC pipe. The water would then flow another 1,940 linear ft through the existing pipe into the Hackberry Flat Regulating Reservoir. The total capacity of the system was assumed to be approximately 5.0 cfs. The total estimated preliminary cost of this alternative was $12.9 million in 2021 dollars.

EQ Water (Slip-Line Existing Pipeline) and Non-EQ Water (Reclaimed Water)

Similar to the option above, this option also assumed delivery of up to 1,600 acre-ft/yr of EQ water and up to 750 acre-ft/yr of reclaimed water, resulting in a total delivery volume of up to 2,350 acre-ft/yr to Hackberry Flat WMA; but instead of replacing the existing Hackberry Flat Pipeline, a slip-line would be installed within the existing Hackberry Flat Pipeline. The slip-lined pipe would have an outside dimension smaller than the inside dimension of the existing Hackberry Flat Pipeline. The slip-line would consist of 72,180 linear ft of 16-inch HDPE pipe placed inside portions of the existing Hackberry Flat Pipeline that are 18-inch, 20-inch, and 30-inch diameter steel pipes. The new slip-lined HDPE pipe would be capable of delivering 2.5 cfs. Similar to the option above, it would connect to a new surge tank at the terminus of the Hackberry Flat pipeline, where it would be combined with non-EQ reclaimed water. The existing pipeline would need to be inspected and cleaned before slip-lining. Connections at existing air release and blowoff locations would be required. Existing structures

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[208] Preliminary analyses indicated that installation of a gravity pipeline may be viable alternative over installing a lift station and pressurizing the pipeline. Additional investigations would be needed to select a preferred option.

would be utilized for air release and blowoffs if they are in satisfactory condition and new valves would be installed.

Similar to the option above, a new pump station would be installed at the Frederick wastewater treatment plant. The new pump station would provide an additional 25 ft of head needed to achieve the desired flow rate of 2.5 cfs. The non-EQ reclaimed water would be conveyed through a new 14-inch HDPE pressurized pipeline approximately 23,400 linear ft in length and connect to a new surge tank at the terminus of the new Hackberry Flat Pipeline.

The new surge tank was assumed to be 12 ft in diameter and 20 ft high and would store the combined EQ and non-EQ flows. From the new surge tank, the combined flows would be conveyed through a new 18-inch HDPE pipe approximately 10,050 linear ft in length and then connect to the existing 18-inch PVC pipe. The water would then flow another 1,940 linear ft through the existing pipe into the Hackberry Flat Regulating Reservoir. The total capacity of the system was assumed to be approximately 5.0 cfs. The total estimated preliminary cost of this alternative was $11.2 million in 2021 dollars.

Alternative 3: No Delivery of EQ Water to Hackberry Flat WMA

Under this alternative, no EQ water would be delivered to Hackberry Flat WMA. This alternative was considered under the assumption that the viability of the Hackberry Flat Pipeline may not be addressed due to a lack of willingness or capability to pay for the costly replacement or slip-lining of the existing pipeline. Also, the outcome of a present-day assessment on the needs of both Hackberry Flat WMA and M&I customers of Tom Steed Reservoir could result in a desire by stakeholders to reallocate all of the EQ water back to its original M&I purpose.

Nevertheless, this alternative assumed that non-EQ water could be used to supply Hackberry Flat WMA as a replacement to unused EQ water that is reallocated for M&I purposes. Because enhanced storage was eliminated from consideration, reclaimed wastewater from the city of Frederick was the assumed water supply source for Hackberry Flat WMA. Similar to the alternatives above, 750 acre-ft/yr of reclaimed water was assumed as available for delivery to Hackberry Flat WMA. Support from and coordination with the city of Frederick would be necessary for this option to be considered viable, and consultation with the Oklahoma Department of Environmental Quality also would be required to determine the water quality and treatment requirements prior to utilizing this water. And similar to the alternative above, it was assumed that no additional treatment would be required prior to use at Hackberry Flat WMA.

Non-EQ reclaimed water would be conveyed from a new pump station at Frederick's wastewater treatment plant through a new 14-inch HDPE pressurized pipeline approximately 33,500 linear ft in length. The pump station would provide 25 ft of head to achieve the desired flow rate of 2.5 cfs. Because no EQ water would be delivered, a new surge tank would not be required; rather, the new pipe would connect directly to the existing 18-inch PVC pipe, where it would flow 1,940 linear ft into the Hackberry Flat Regulating Reservoir. The total estimated preliminary cost of this alternative was $3.7 million in 2021 dollars. Although this alternative assumed a pressurized system, as previously stated, additional investigations should be undertaken to assess whether a gravity-fed system may be viable.

Table 8-12. Summary of alternatives, including costs, and source and volume of water to deliver all Environmental Quality (EQ) water, some EQ water, or no EQ water to Hackberry Flat Wildlife Management Area (WMA). All costs are in 2021 dollars and are considered preliminary and should be used for comparison purposes only.

	Alternatives for Hackberry Flat WMA				
	1 Deliver All EQ Water to Hackberry Flat WMA		2 Deliver Some EQ Water to Hackberry Flat WMA with Remaining EQ Water Reallocated for M&I Purposes		3 No Delivery of EQ Water to Hackberry Flat WMA with Remaining EQ Water Reallocated for M&I Purposes
	Pipeline Replacement	Slip-Line	Pipeline Replacement	Slip-Line	N/A
EQ Water Only	Construction Cost: $13.4 million Total Hackberry Delivery: 2,352 acre-ft/yr Water Source and Volume: EQ: 2,352 acre-ft/yr Reuse: 0 acre-ft/yr	Construction Cost: $9.8 million Total Hackberry Delivery: 2,352 acre-ft/yr Water Source and Volume: EQ: 2,352 acre-ft/yr Reuse: 0 acre-ft/yr	Construction Cost: $12.9 million Total Hackberry Delivery: < 2,352 acre-ft/yr Water Source and Volume: EQ: < 2,352 acre-ft/yr Reuse: 0 acre-ft/yr	Construction Cost: $11.2 million Total Hackberry Delivery: < 2,352 acre-ft/yr Water Source and Volume: EQ: < 2,352 acre-ft/yr Reuse: 0 acre-ft/yr	N/A
EQ Water and Reclaimed Water	N/A	N/A	Construction Cost: $13.1 million Total Hackberry Delivery: < 2,352 acre-ft/yr Water Source and Volume: EQ: ≤ 1,600 acre-ft/yr Reuse: ≤ 750 acre-ft/yr	Construction Cost: $11.3 million Total Hackberry Delivery: < 2,352 acre-ft/yr Water Source and Volume: EQ: ≤ 1,600 acre-ft/yr Reuse: ≤ 750 acre-ft/yr	N/A
Reclaimed Water Only	N/A	N/A	N/A	N/A	Construction Cost: $3.7 million Total Hackberry Delivery: ≤ 750 acre-ft/yr Water Source and Volume EQ: 0 acre-ft/yr Reuse: ≤ 750 acre-ft/yr

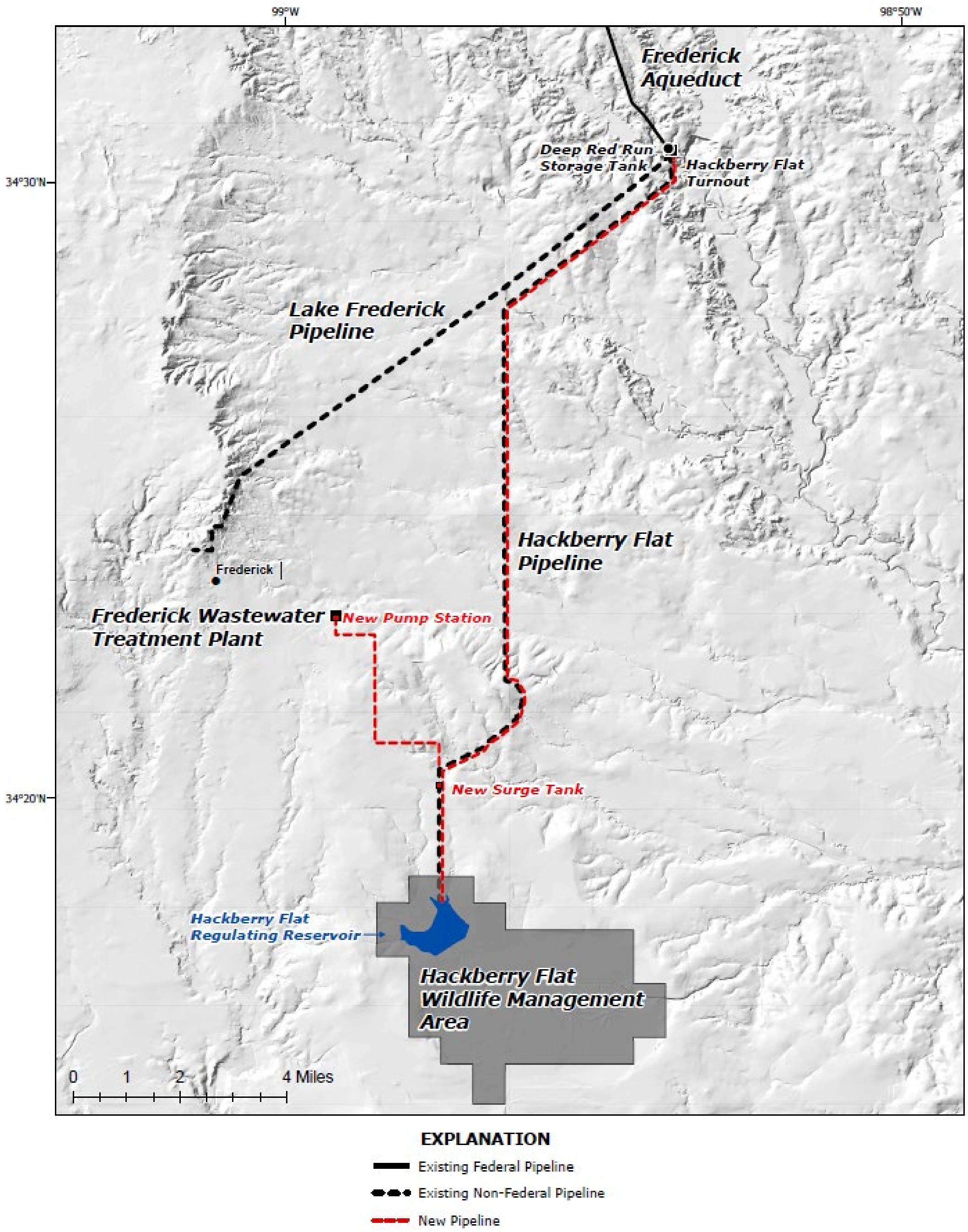

Figure 8-8. Existing and proposed infrastructure to deliver water to Hackberry Flat Wildlife Management Area, Mountain Park Project, Oklahoma.

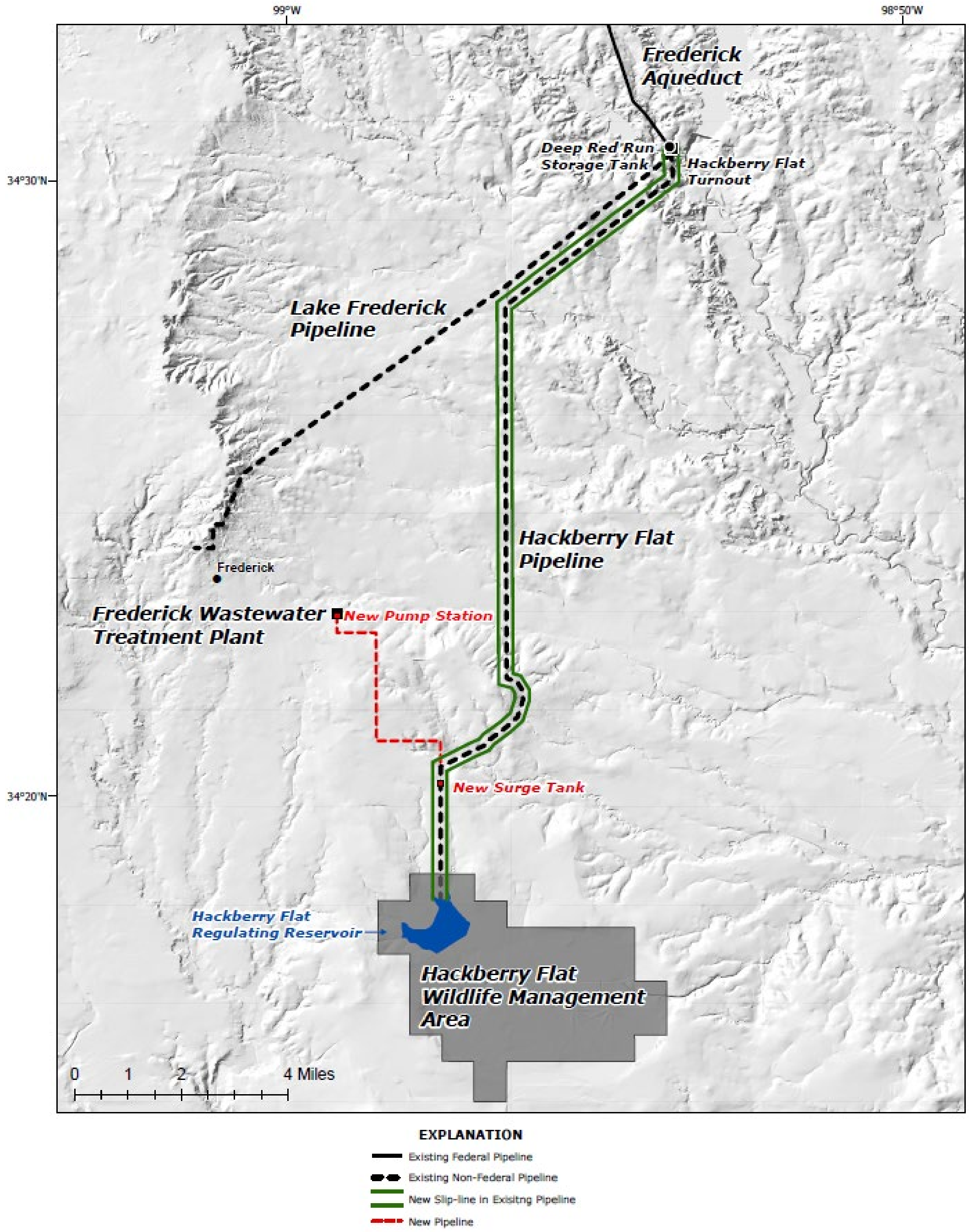

Figure 8-9. Existing and proposed infrastructure to deliver water to Hackberry Flat Wildlife Management Area, Mountain Park Project, Oklahoma.

8.3.7. Expansion of the Bretch Diversion and Canal

Reclamation's 1962 Plan of Development (POD) considered four canal capacities in its analysis of benefits and costs of the Mountain Park Project: 400 cfs, 600 cfs, 1,000 cfs, and 1,400 cfs. At the time of the 1962 POD, daily data were available from Oct 1949 to Sept 1959, and monthly data were available from Jan 1926 to Sept 1959. Although the data were limited, the 1962 POD included the drought of the 1950s, which was the drought of record at the time and as such, provided the critical period needed for the hydrologic analysis of Tom Steed Reservoir. Based on an analysis of divertible flows and reservoir firm yield, 1,000 cfs was selected in the 1962 POD as the optimal canal capacity to maximize reservoir firm yield per unit of estimated costs.

Expansion Alternatives Formulation

The Bretch canal has a capacity of 1,000 cfs and can divert flows greater than 10 cfs from Elk Creek (Reclamation, 1983). Before entering the canal, flows are regulated by a small reservoir formed by the diversion dam with a storage capacity of up to 970 acre-ft consisting of 810 acre-ft of active capacity that can be diverted through the canal and the remaining 160 acre-ft considered dead pool storage reserved for sediment accumulation.

An analysis was conducted to determine the extent to which the firm yield of Tom Steed Reservoir could be increased by modifying the Bretch Diversion Dam and Canal to accommodate additional storage and flows. Alternatives were formulated based on physical constraints of existing infrastructure, topography, construction level of effort, and flood operational constraints during construction. Two storage expansion alternatives were considered: expansion to either 1,390 acre-ft and 2,170 acre-ft. Options were considered to either excavate and remove material from the bottom of the regulation reservoir, or to modify/expand the diversion dam gate structure. The No Action storage alternative was 970 acre-ft. In addition, three canal expansion alternatives were considered: expansion to

1,250 cfs, 1,500 cfs, and 1,750 cfs. The No Action canal alternative was 1,000 cfs. Combining storage and conveyance alternatives, a total of 11 storage-canal combinations were evaluated (Table 8-13). Each of these alternatives was analyzed to determine potential benefits to the firm yield of Tom Steed Reservoir. Engineering design narratives and cost estimates also are provided.

Table 8-13: Summary of eleven storage and conveyance expansion alternatives for the Bretch Diversion and Canal system, Mountain Park Project.

Alternative Names and Combinations		Existing Bretch Diversion Dam Storage	Bretch Diversion Dam Storage Expansion Alternatives	
		970 acre-ft	1,390 acre-ft	2,170 acre-ft
Existing Bretch Canal Capacity	1,000 cfs	No Action	1	2
Bretch Canal Capacity Expansion Alternatives	1,250 cfs	A	1A	2A
	1,500 cfs	B	1B	2B
	1,750 cfs	C	1C	2C

Impacts on Tom Steed Reservoir Firm Yield

Using the daily extended flow record for Elk Creek between Oct 1949 and Dec 2016, the 11 storage-canal expansion alternatives were evaluated to determine monthly divertible flows in Elk Creek and impacts on the firm yield of Tom Steed Reservoir. First, the impacts of the three canal expansion alternatives were evaluated alone and in combination with the two storage expansion alternatives in terms of impacts on divertible flows of Elk Creek. Results showed that 74 percent of all divertible flows were able to be conveyed under the No Action alternative [(i.e., existing canal capacity of 1,000 cfs and storage of 970 acre-ft) (Figure 8-10)]. Expansion of storage capacity alone (in combination with the existing canal capacity) to 1,390 acre-ft and 2,167 acre-ft resulted in an increase in divertible flows of one percent and three percent, respectively (Figure 8-10). Expansion of the canal capacity alone (in combination with the existing storage capacity) to 1,250 cfs, 1,500 cfs, and 1,750 cfs resulted in an increase in divertible flows of four percent, six percent, and eight percent of divertible flows, respectively (Figure 8-10). When combining expansion of both storage and canal capacity, the increase in divertible flows ranged from five percent (1,390 acre-ft storage with 1,250 cfs canal capacity) to ten percent [(2,167 acre-ft storage with 1,750 cfs canal capacity) (Figure 8-10)]. Overall, these data show that increasing canal and/or storage capacity of the Bretch Diversion Dam and Canal system resulted in only minor increases in divertible flows of Elk Creek over the entire period of record.

While the results over the entire period of record are useful in terms of evaluating overall water availability on an average annual basis, they shed little light into the impacts on Tom Steed Reservoir firm yield, which is driven by inflow during the 2010-2015 drought of record. To evaluate impacts of storage and canal expansion alternatives on reservoir firm yield, divertible Elk Creek flows were evaluated over the 55-month drought of record between Sept 2010 and Mar 2015. Results showed that none of the 11 storage-canal expansion alternatives increased divertible flows during the critical drought period, and therefore the firm yield of Tom Steed Reservoir never exceeded 13,300 acre-ft/yr regardless of the storage and/or canal expansion alternative (Table 8-14). This is because the volume of water and rate of flow in Elk Creek during that drought period did not exceed the existing capacity of the diversion dam and canal, and consequently, none of the 11 delivery system expansion alternatives would result in additional diversions into Tom Steed Reservoir. In light of these results, this strategy would not meaningfully address the planning objective of providing a reservoir firm yield of 16,100 acre-ft/yr.

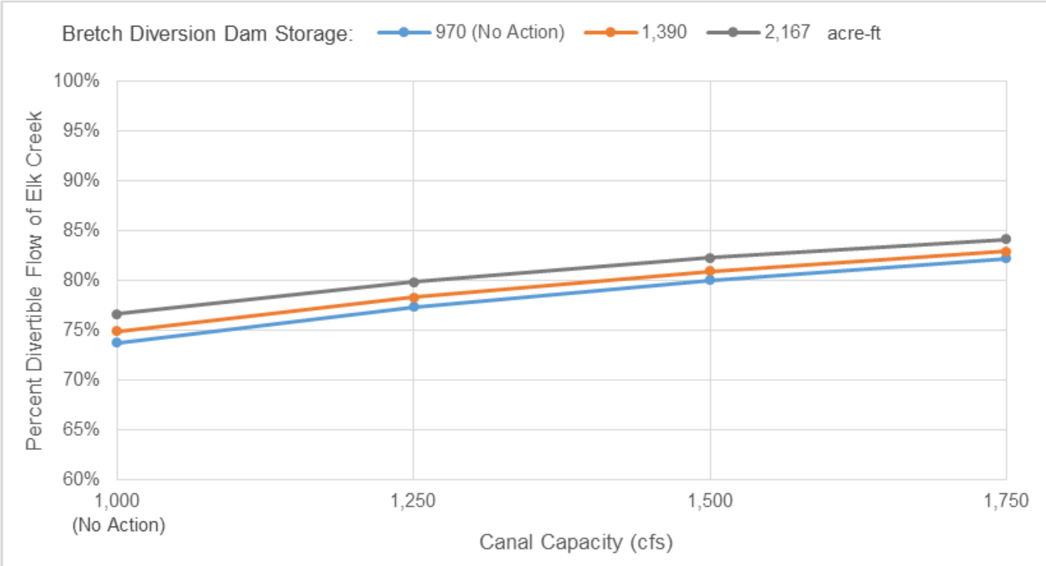

Figure 8-10. Percent of divertible flow from Elk Creek under the existing Bretch Diversion and Canal system (i.e., No Action alternative) and under eleven alternatives to expand the storage and/or canal capacity of the Bretch Diversion Dam and Canal system, Mountain Park Project, Oct 1949-Dec 2016.

Table 8-14. Tom Steed Reservoir firm yield under the existing Bretch Diversion and Canal system (i.e., No Action alternative) and under eleven alternatives to expand the storage and/or canal capacity of the Bretch Diversion Dam and Canal system, Mountain Park Project, 2060 sediment conditions.

Reservoir Firm Yield (acre-ft/yr)		Period of Record (1926-2016) Bretch Diversion Dam Storage Alternatives:		
		970 acre-ft (No Action)	1,390 acre-ft	2,170 acre-ft
Bretch Canal Capacity Alternatives	1,000 cfs (No Action)	13,300	13,300	13,300
	1,250 cfs	13,300	13,300	13,300
	1,500 cfs	13,300	13,300	13,300
	1,750 cfs	13,300	13,300	13,300

Designs and Cost Estimates of Expansion Alternatives

Canal Expansion Narrative and Assumptions

The evaluation considered expanding the capacity of the 9.5-mile Bretch Canal to 1,250 cfs, 1,500 cfs, or 1,750 cfs by raising the height of the banks of the canal, with the flowline and slope of the canal remaining consistent with the original design. The criteria used to determine the dimensions of the canal are shown in Table 8-15. The cross-sections for different design capacities are displayed in

Figure 8-11. Several key assumptions used in developing cost estimates are provided Reclamation OTAO's central files and are available upon request.

Table 8-15: Bretch canal profile configurations for the existing canal (1,000 cfs) and three canal expansion alternatives (1,250 cfs, 1,500 cfs, and 1,750 cfs).

	Bretch Canal Capacity (cfs)			
Inflow	1,000 (No Action)	1,250	1,500	1,750
Slope (ft/ft)	0.000175	0.000175	0.000175	0.000175
Roughness Coefficient, n	0.014	0.014	0.014	0.014
Bottom Width, B (ft)	10 FT	10	10	10
Side Slope	1V:1.5H	1V:1.5H	1V:1.5H	1V:1.5H
Water Depth, D (ft)	9.62	10.67	11.60	12.45
Velocity, V (ft/s)	4.26	4.51	4.72	4.90
Freeboard from Water to Top of Concrete, H (ft)	1.79	1.71	1.80	1.88
Total Concrete Lining Depth (ft	11.00	12.38	13.40	14.33
Earthen Bank (Height Above Water) (ft)	3.36	3.76	3.92	4.05
Total Depth of Bretch Canal (ft)	14.00	14.43	15.52	16.5
Added Concrete Lining Height (ft)	N/A	1.38	2.40	3.33

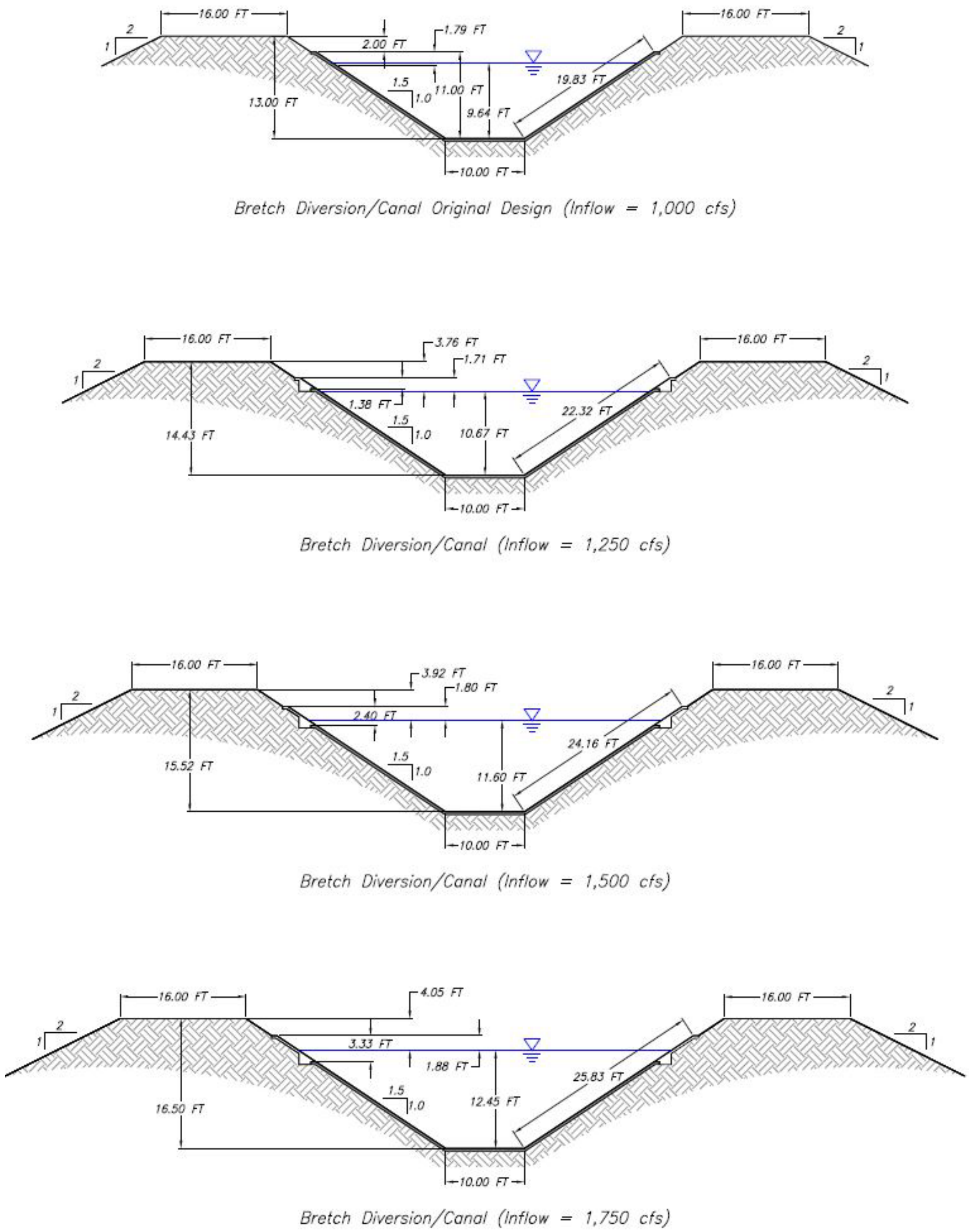

Figure 8-11: Configurations of the Bretch canal and berms for the existing canal (1,000 cfs) and three canal expansion alternatives (1,250 cfs, 1,500 cfs, and 1,750 cfs).

Diversion Dam Expansion and Assumptions

Two diversion pool storage expansion alternatives were considered: expansion to 1,390 acre-ft and expansion to 2,170 acre-ft. For each alternative, an excavation option was evaluated, as well as an option of modifying the diversion dam gate structure or increasing the height of the dike. Several key assumptions used in developing cost estimates are provided Reclamation OTAO's central files and are available upon request.

Cost Estimates

Cost estimates were prepared by Reclamation's OTAO to "preliminary" standards as defined by Reclamation's Directives and Standards (D&S) Cost Estimating (FAC) 09-01[209]. Preliminary cost standards are considered the most basic planning-level costs and are intended to be for comparative purposes only. Development of these estimates does not imply support by Reclamation for project authorization or any specific language in an appropriation bill. All costs were developed in 2016 dollars primarily using RS Means, edition 2016. Other major cost sources were Rubicon Water and AquaLastic, as well as local demolition companies for any demolition activities. The unit prices were based on historical bid data, as well as industry reference cost information. Quantity estimates for each project feature are available within Reclamation OTAO's central files and available upon request. Contract and non-contract cost contingencies (i.e., for unexpected or unknown conditions, circumstances, etc.) were comprised of the following: 25 percent for planning, design, and environmental compliance; 25 percent for construction; five percent for mobilization; and four percent for project and construction management. Capital costs were developed for storage and canal expansion components separately and in combination (Table 8-16). Operations and maintenance (O&M) costs were considered negligible relative to No Action conditions and therefore were not prepared.

[209] https://www.usbr.gov/recman/fac/fac09-01.pdf.

Capital costs of increasing the Bretch Diversion Dam storage alone to 1,390 acre-ft and 2,170 acre-ft were $12.2 million and $34.8 million, respectively; and the capital costs of increasing the Bretch Canal capacity to 1,250 cfs, 1,500 cfs, and 1,750 cfs were $16 million, $22 million, and $29 million, respectively (Table 8-16). The capital costs of combining both storage and canal expansion ranged from $28.2 million to $63.8 million (Table 8-16).

Table 8-16: Capital costs of eleven storage and conveyance expansion alternatives for the Bretch Diversion and Canal system, Mountain Park Project. Costs are considered "preliminary" in accordance with Reclamation's Cost Estimating Directives and Standards FAC 09-01.

Alternative Names and Combinations		Existing Bretch Diversion Dam Storage	Bretch Diversion Dam Storage Expansion Alternatives	
		970 acre-ft	1,390 acre-ft	2,170 acre-ft
Existing Bretch Canal Capacity	1,000 cfs	Cost of Individual Project Expansion Feature	$12,200,000	$34,800,000
Bretch Canal Capacity Expansion Alternatives	1,250 cfs	$16,000,000	$28,200,000	$50,800,000
	1,500 cfs	$22,000,000	$34,200,000	$56,800,000
	1,750 cfs	$29,000,000	$41,200,000	$63,800,000

8.3.8. Development of Supplemental Groundwater Supplies

This strategy assumes the new well field could provide up to 2,240 acre-ft/yr in supplemental groundwater supplies during drought periods. In terms of addressing the planning objective, depending on the development scenario, 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.

Key steps remain on implementation of this strategy. First, plans 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. As well, additional coordination is needed to determine if any contractual changes are required; to formally establish when and how much groundwater will be conveyed; to establish who would be responsible for funding operation and maintenance costs for the groundwater wells; to determine who would hold the groundwater permit from the OWRB; to determine ownership of the wells; and to ensure compliance with the NEPA.

8.3.9. Water Conservation

As previously stated, all water availability modeling included in the URRBS assumed that MPMCD’s full permit volume of 16,100 acre-ft/yr was being delivered from Tom Steed Reservoir, and it was considered beyond the scope of this study to model the impacts of deliveries less than 16,100 acre-ft/yr. Future studies could consider alternative demand scenarios, such as the maximum volume of water that could potentially be put to beneficial use by MPMCD based on projected 2060 demands and/or the maximum volume of water that has historically been put to beneficial use based on observed deliveries from Tom Steed Reservoir. Water conservation measures could be incorporated and applied to any target demand volume to arrive at "with" and "without" water conservation planning objectives. For example, during the 2010-2015 drought of record, M&I deliveries were reduced by 42 percent from 9,500 acre-ft/yr in 2011 to 5,500 acre-ft/yr in 2014, representing the largest percentage of water conserved since water deliveries began in the 1970s. As such, 42 percent could be assumed as a maximum percentage of M&I water that could reasonably be conserved during a repeat of the drought of record. Therefore, if the full 16,100 acre-ft/yr permit is being utilized, a 42 percent conservation rate would result in a reservoir demand of 9,300 acre-ft/yr.

Another consideration could be future projected demands on Tom Steed Reservoir in the year 2060. These demands were projected to range from 7,830 acre-ft/yr to 14,950 acre-ft/yr (Chapter 5.4.2). A reasonable planning target for an adaptation strategy could be the higher projected demand of 14,950 acre-ft/yr; applying a 42 percent water conservation rate to this volume would result in a 2060 reservoir demand of 8,700 acre-ft/yr.

Another option one could consider is the maximum volume of historical deliveries made by MPMCD, which was 12,700 acre-ft/yr in the year 2006 (Chapter 5.2.2); applying a 42 percent water conservation rate to this volume would result in a reservoir demand of 7,400 acre-ft/yr.

The lesser demands described above could be considered only 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 is either currently being put to beneficial use or could be put to beneficial use during prolonged and severe droughts.

Again, the primary planning objective under this URRBS for Tom Steed Reservoir was to maximize water deliveries through a repeat of the 2010s Drought of Record, including and up to the volume of MPMCD's water right permit of 16,100 acre-ft/yr, and the modeling analyses included herein reflected this approach. Based on the status quo water availability modeling results presented in Chapter 6.4.4, there was sufficient water in storage in Tom Steed Reservoir to deliver 16,100 acre-ft/yr between 99.5 percent (800 out of 804 months) and 95.4 percent (767 out of 804 months) of all months on record depending on the development scenario. Yet during a repeat of the 2010-2015 drought of record, results showed that storage was not sufficient to deliver 16,100 acre-ft/yr, and that regardless of any of the adaptation strategies evaluated in this study, the target delivery of 16,100 acre-ft/yr was not achievable. Clearly, the effectiveness of adaptation strategies considered in this URRBS would be improved if target deliveries from Tom Steed Reservoir during a critical drought period were lower than 16,100 acre-ft/yr.

Another related strategy could be to utilize the drought response thresholds that were evaluated in Chapter 8.3.2 for the purposes of protecting MPMCD's permit from junior stream-water permits as a means of triggering water conservation measures by MPMCD and its customers in accordance with the "shared shortage" provisions in their water supply contracts. Recall that the "shared shortage" provision within each contract states that all participating entities shall, "share in the available water supply in the ratio of their contract rights during periods of scarcity when rationing is in the opinion of the MPMCD required". The contracts address shortages further by stating that during such years that the MPMCD "determines" that "available project water supply" shall be less than the total combined amount of contracted water supply, then the amount of water available to the participating entity shall be limited to each entity's percent allocation of available project water supply. A key challenge identified in Chapter 2.3.2 was that an agreed-upon threshold does not currently exist to support the MPMCD's "opinion" or "determination" on whether the "available project water supply" constitutes a "scarcity".

Indeed, the same hydrologic thresholds identified in support of regulatory protection of MPMCD's permit could be used to support MPMCD's determination of water scarcity as it invokes shared shortage provisions within its water supply contracts. In doing so, MPMCD and its customers would have a reasonable and predictable basis by which to implement water conservation measures during times of drought. And assuming junior permit holders above Tom Steed Reservoir also would be curtailing or eliminating water usage upon reaching whatever regulatory hydrologic threshold may be set, the implementation of complementary water conservation measures by MPMCD and its customers would likely provide a cumulative benefit and improve overall water supply reliability for permit holders in the entire hydrologic basin, not just for MPMCD.

8.3.10. Trade-Off Analysis of Adaptation Strategies

Similar to the Lugert-Altus Reservoir hydrologic basin, each of the eleven strategies to improve water supply reliability of Tom Steed Reservoir were compared to one another through a trade-off analysis in accordance with requirements set forth in Reclamation's Directives and Standard WTR 13-01 on Basin Studies. A trade-off analysis is defined by WTR 13-01 as a quantitative or qualitative analysis of proposed strategies in terms of "their ability to meet the study objectives, the extent to which they minimize imbalances between water supply and demand and address the possible impacts of climate change, the level of stakeholder support, the relative cost (when available), the potential environmental impacts, or other attributes common to the strategies." 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 PR&Gs[210]. 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

[210] 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).

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.

For this URRBS, a cursory and qualitative level of analysis was considered appropriate. The goal was only 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 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. If a strategy was effective at maximizing water deliveries 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[211].

To add flexibility into the adaptation strategies that could be considered, a secondary planning objective 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 anticipated 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 involves 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 MPMCD and customers of Tom Steed Reservoir; water users in the Tom Steed

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[211] 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.

Reservoir hydrologic basin; 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 8-17).

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 8-17. Scoring rubric for the trade-off analysis of adaptation strategies to improve water supply reliability of Tom Steed Reservoir.

Favorable	↑
Neutral	→
Less Favorable	↓

Results

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 8-18. 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 8-18. 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

- This strategy proposed to clarify MPMCD's existing stream-water right with regards to permit volume, beneficial uses, and priority date.

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.
- 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.

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, 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 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 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 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.

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[212] 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).

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

[212] 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.

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 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.

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.

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

- The risks implementing of this strategy would depend on the level of stakeholder support and the extent to which a lack of support generates significant protests or prolonged litigation; these factors would ultimately influence the likelihood of the OWRB agreeing to implement a lesser, more conservation-oriented EPS.

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.

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.

Effectiveness: Favorable

- Unlike other strategies which aimed to maximize water supply availability and help Tom Steed Reservoir deliver MPMCD's full permit volume 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.

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 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 NEPA.

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.

Effectiveness: Neutral

- 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 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 newly-developed, science-driven technical findings developed through the URRBS 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

Chapter 9. References

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3. Appendix C: North Fork of the Red River System Model Naturalization Update (Lynker Technologies, 2022) (106 pp.)

4. Appendix D: Lugert-Altus Reservoir Yield Analysis (Reclamation, 2021) (137 pp.)

5. Appendix E: Tom Steed Reservoir Yield Analysis (Reclamation, 2021) (178 pp.)

6. Appendix F: Technical Memorandum No. 86-68210-2016-05, Upper Red River Basin Study Climate and Hydrology Projections (Reclamation, 2016) (32 pp.)

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.)

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.)

9. Appendix I: Economic Impacts of Drought on Recreation and Irrigated Agriculture (Reclamation, 2018) (89 pp.)

10. Appendix J: Formulation of Hydrologic Thresholds to Support Water Management in the Lugert-Altus Reservoir Hydrologic Basin (Reclamation and OWRB, 2022) (264 pp.)

11. Appendix K: Formulation of Stream-Water Rights Management Alternatives in the Tom Steed Reservoir Hydrologic Basin (Reclamation and OWRB, 2020) (151 pp.)

12. Appendix L: Cable Mountain Reservoir Hydrology and Costs (15 pp.)

13. Appendix M: Water Availability Modeling Results for the Tom Steed Hydrologic Basin (172 pp.)

14. Appendix N: Peer Review Report (66 pp.)