2024 BLM Water Support Document for Oil and Gas Development in Oklahoma, Kansas, and Texas

NOVEMBER 2024

PREPARED FOR

Bureau of Land Management

PREPARED BY

SWCA Environmental Consultants

2024 BLM WATER SUPPORT DOCUMENT FOR OIL AND GAS DEVELOPMENT IN OKLAHOMA, KANSAS, AND TEXAS

Prepared for

Bureau of Land Management
New Mexico State Office
301 Dinosaur Trail
Santa Fe, New Mexico 87508

Prepared by

Lucy Parham, M.S., Nolan Perryman, M.S., and Austin Miller, B.S.

SWCA Environmental Consultants
7770 Jefferson St. NE
Albuquerque, New Mexico 87109
www.swca.com

SWCA Project No. 84075

November 2024

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	micrograms per liter
AF	acre-feet
bbl	barrel(s)
BLM	Bureau of Land Management
CAS	Chemical Abstracts Service
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
GWPC	Ground Water Protection Council
HUC	Hydrologic Unit Code
KCC	Kansas Corporation Commission
KDHE	Kansas Department of Health and Environment
KGS	Kansas Geological Survey
KWO	Kansas Water Office
MCL	maximum contaminant level
Mgal	million gallons
mg/L	milligrams per liter
NEPA	National Environmental Policy Act of 1969
NMSO	New Mexico State Office
OCC	Oklahoma Corporation Commission
OCWP	Oklahoma Comprehensive Water Plan
ODEQ	Oklahoma Department of Environmental Quality
OFO	Oklahoma Field Office
OWRB	Oklahoma Water Resources Board
PFAS	per- and polyfluoroalkyl substances
RFD	reasonably foreseeable development
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
WSD	Water Support Document

1 INTRODUCTION

1.1 Purpose and Scope

The intent of this Water Support Document (WSD) is to collect and present the data and information needed for water resources analysis to be incorporated by reference into National Environmental Policy Act (NEPA) documents, most specifically NEPA analysis related to federal oil and gas leasing and development under the jurisdiction of the Bureau of Land Management (BLM) New Mexico State Office (NMSO). This includes federally managed oil and gas leases within the Oklahoma Field Office (OFO) area, which comprises portions of the states of Oklahoma, Kansas, and Texas.

The content of this report is focused on existing water uses and projections of future water use based on past and current uses. The report also provides information regarding existing water quality and potential causes of water contamination related to oil and gas leasing and development.

This document does not include analysis of the following data types and sources:

- Surface water quality impacts from leasing and development: The states will have previously approved surface water use sources according to their own statutes (see Kan. Stat. Ann. § 82a-705; Okla. Stat. Ann. tit. 82, § 105.9; Tex. Water Code Ann. §§ 11.121, 11.142). Surface water quality impacts will be analyzed by the BLM at the leasing stage with consideration of the site-specific conditions and stipulations that are applied to protect them. Surface water quality impacts will again be analyzed by the BLM during site-specific development when specific facility placement details are known.
- Surface water quality assessment information: The Oklahoma Department of Environmental Quality (ODEQ), Kansas Department of Health and Environment (KDHE), and Texas Commission on Environmental Quality (TCEQ) administer Clean Water Act (CWA) Sections 303(d), 305(b), and 314 related to surface water quality assessment and reporting in their respective states. These entities define surface water quality beneficial uses and water quality criteria to evaluate if these uses are being attained. The BLM does not have responsibility to make use attainment evaluations based on water chemistry data.
- Water quality information for other areas mandated by the NMSO: The NMSO also manages federal oil and gas leasing and development within the state of New Mexico, specifically the Pecos District Office, Farmington Field Office, and Rio Puerco Field Office. Water quality and quantity information for these field offices was gathered, evaluated, and presented in the BLM Water Support Document for Oil and Gas Development in New Mexico (BLM 2024).
- Water uses related to oil and gas development beyond hydraulic fracturing: Although this WSD focuses on water use during the hydraulic fracturing process, water is also used for drilling fluid preparation, completion fluids, rig washing, coolant for internal combustion engines, dust suppression on roads/well pads, and equipment testing. The majority of water use is associated with stimulation activities (including hydraulic fracturing), and data are currently unavailable for the previously mentioned uses. Operators will provide information regarding estimated water use at the project-specific NEPA level.
- Environmental impacts of hydraulic fracturing: While the environmental impacts of hydraulic fracturing are relevant to the focus of this report, the fate and transport of chemicals used during hydraulic fracturing are complicated and have been the subject of human health and environmental concerns as oil and gas development continues throughout the United States. As such, the complexity of this subject would require substantial discussion that exceeds the

scope of this report. Readers interested in understanding the environmental impacts of hydraulic fracturing should review the comprehensive U.S. Environmental Protection Agency (EPA) report *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report)* (EPA 2016). In summary, this report presents scientific evidence that drinking water resources can be impacted by hydraulic fracturing under six conditions: 1) water withdrawals during periods of low water availability; 2) spills of hydraulic fracturing fluids/chemicals and/or produced water; 3) release of hydraulic fracturing fluids from wells with inadequate casing; 4) direct injection of hydraulic fracturing fluids into groundwater; 5) discharge of insufficiently treated wastewater to surface water; and 6) contamination of groundwater from unlined storage/disposal pits. The BLM and States of Oklahoma, Kansas, and Texas have put in place numerous requirements for oil and gas producers to prevent the contamination of surface water and groundwater resources in states of the OFO.

1.2 Report Organization

This report is organized by state, with Chapters 2 through 4 providing a presentation of data and information related to water quantity, water quality, and state-specific water planning efforts for Oklahoma, Kansas, and Texas. Chapter 5 contains a summary of data at the OFO scale concerning area-specific issues such as water use sources for potential development, induced seismicity, and per- and polyfluoroalkyl substances (PFAS). Chapter 5 also details future water use scenarios for the OFO and a drought and water availability analysis through the use of a variety of regional and state-specific tools. Chapter 6 contains the references pertinent to the analysis. This report is organized so that authors and data analysts may use state chapters as standalone reports when evaluating impacts to water resources associated with proposed future federal oil and gas leasing and development.

1.3 Data Sources

An in-depth description of the data sources used in the development of the WSD is presented in the *Data Inventory and Analysis Methodology Memorandum for the Oklahoma Water Support Document* in Appendix A. The memorandum also details the methodology employed to identify an appropriate spatial scale for the WSD data collection effort and analysis. This WSD summarizes data for a total of 74 counties across Oklahoma, Kansas, and Texas where oil and gas leasing and development has occurred over the last 10 years (2014-2024).

1.4 Updating the Report

During subsequent annual WSD updates, the list of targeted counties identified in the Appendix A memo will be revisited and revised, as needed, to capture any changes in oil and gas developmental trends within the planning area.

As new data become available throughout the states of Oklahoma, Kansas, and Texas, it will be necessary to update water use (water use by category data from the U.S. Geological Survey [USGS] and FracFocus), spill data (data from the Oklahoma Corporation Commission [OCC], Kansas Corporation Commission [KCC], and the TCEQ, water quality information, and drought and water availability information included in this report. Updates to data within this report will also include additional data, updates to the Reasonable Foreseeable Development (RFD), and regional studies and reports as they are made available.

At the time of drafting this 2024 report, updates to water usage estimates for the Dieter et al. (2018) water use analysis were published for the United States. Updates were made to water use estimate categories of public supply water, thermoelectric power, and irrigation water use. The update in 2023 was a reanalysis of water use for years 2000 to 2020, providing 5 additional years (years 2016 to 2020) to the original 2018 USGS water use data set. The updated water use estimates are delineated at the Hydrologic Unit Code (HUC)-12 boundary level rather than by county as found in the original 2018 USGS report. Due to this variance in reporting between years, and since all categories were not updated in 2024, analysis for the updated years of data has not been included in this WSD. It is expected that new data for all water use categories will be released in 2025 (self-supplied industrial, domestic, mining, livestock, and aquaculture) The updated USGS Water Use data will be incorporated into the next update of the WSD, and analyses will be completed at the HUC-12 level. See Appendix A for details regarding how USGS water use data are obtained, organized, and analyzed for use in this report.

The FracFocus registry is updated throughout each year, and updates may include changes to well data for previous years. To maintain consistency in data included in annual WSD updates, FracFocus data will be pulled during May of each year. This 2024 WSD includes all data from January 1, 2014, through December 31, 2023. The data utilized for this report were pulled from the FracFocus database during May 2024. Each subsequent iteration of the WSD will incorporate the latest FracFocus data and the previous year’s data will be reanalyzed to account for changes to well data. Thus, the FracFocus data presented in this WSD for the years 2014-2023 may differ slightly from following iterations of the WSD due to updates to FracFocus data made throughout 2023.

2 OKLAHOMA

This chapter contains an analysis and summary of the available water use and water quality data for the state of Oklahoma that support the evaluation of water resource impacts from oil and gas leasing and development (as described in Chapter 1). Section 2.1 presents an overview of the state’s water planning process and associated documentation. Water use estimates for all categories of consumptive water use (e.g., public drinking water supply, irrigation, thermoelectric power) are presented in Section 2.2. Additionally, Section 2.2 contains the summarized FracFocus water use data so that water use from hydraulic fracturing can be compared with statewide water use. Section 2.3 presents an overview of water quality for both surface water and groundwater and contains a summary of the chemicals used in hydraulic fracturing that are disclosed to FracFocus.

2.1 State of Oklahoma Water Planning

The State of Oklahoma’s approach to water resources management is primarily guided by the Oklahoma Comprehensive Water Plan (OCWP) developed and managed by the Oklahoma Water Resources Board (OWRB). The OCWP provides comprehensive water planning regarding supply, 50-year projected demands, projected surface water gaps and groundwater depletions, assessment of infrastructure needs, and analyses of local issues as reported by water experts in every sector for each of Oklahoma’s 13 planning regions (OWRB 2024a). The next iteration of the OCWP will be released in 2025, and the effort to update the document is well underway. A factsheet for the 2025 plan is available and presents the four primary topics of the 2025 OCWP as 1) supply and demand as evidenced by synthesis and analysis of water use data and projected population growth, industrial needs, and extreme weather, 2) water reliability as related to regional assessments to bolster supply and recommendations for policy adjustments, 3) key challenges for water supply, infrastructure needs, water quality, and drought/flooding preparedness, and 4) developing solutions for local water management strategies, policies, infrastructure needs, study needs, and funding gaps (OWRB 2024b).

2.2 Water Quantity

2.2.1 Surface Water and Groundwater Use

In 2015, the combined fresh and saline water withdrawals for all water use categories across the state of Oklahoma totaled 2,729,536 acre-feet (AF) (Table 2-1; Figure 2-1) (Dieter et al. 2018). Irrigation withdrawals accounted for the greatest water use within the state of Oklahoma at 38% (1,042,874 AF) in 2015. Public water supply and industrial water use represented the second (25%) and third (19%) greatest use within the state of Oklahoma (684,676 AF and 509,247 AF, respectively). Mining operations[1] (this includes oil and gas development, among other mining-related uses) used approximately 215,224 AF of water in 2015. Of the 215,224 AF of total water use, 178,024 AF (83% of total water use) was via groundwater withdrawals and 37,200 AF (17% of total water use) was fresh surface water. Groundwater withdrawals for mining were primarily saline water, which accounted for 97% of all groundwater withdrawals. Thermoelectric power and livestock constituted relatively minor proportions of the cumulative water use, ranging from 3% to 8% (79,138 AF to 215,224 AF). Finally, aquaculture and domestic water use constituted the lowest water use in the state of Oklahoma at 1% or lower (3,685 AF and 33,974 AF, respectively). Surface water and groundwater use are almost evenly split, with surface water representing 54% of the total withdrawals and groundwater representing 46% of the total water use. Irrigation withdrawals represented the greatest source of groundwater use at 881,686 AF. Public water sourced approximately 570,156 AF of water from surface water resources, representing the largest source of surface water withdrawals in 2015 (see Table 2-1; Figure 2-1).

It is important to consider the impacts of groundwater well pumping on surface water availability, especially since Oklahoma uses surface water for over half of its water use needs (Dieter et al. 2018). Groundwater pumping impacts the storage capacity of an aquifer. This reduction affects groundwater discharge zones, where groundwater naturally flows out of the aquifer, often connecting to surface water bodies like rivers, lakes, and streams. Altering aquifer storage capacity through groundwater pumping can change the local hydraulic gradient—the slope of the water table surface that determines groundwater flow direction and speed. Significant changes in this gradient can reduce groundwater discharge into surface water systems, thereby decreasing surface water availability (Barlow and Leake 2012).

Total annual water use associated with the hydraulic fracturing of oil and gas wells throughout Oklahoma generally remained consistent from 2014 to 2023; however, during the 3-year period from 2017 to 2019, water use was markedly higher, ranging from 48,493.8 AF to 59,840.5 AF, in contrast to all other years when hydraulic fracturing water use was less than 32,000 AF (Table 2-2). Most of the wells and associated water use are reported as non-federal and non-tribal; hydraulic fracturing water use for these wells totaled 338,761.9 AF from 2014 to 2023. During the same time period, hydraulic fracturing water use for federal wells and tribal wells totaled 5,780.9 AF and 2,509.6 AF, respectively. Federal water use represented around 2% of the total hydraulic fracturing water use, with 221 reported wells from 2014 to 2023. A total of 13,607 wells were reported across Oklahoma from 2014 to 2023 with an average 3-year water use (2021 to 2023) of 34.7 AF for hydraulic fracturing water purposes (see Table 2-2) (FracFocus 2024).

FracFocus reports on water use directly associated with hydraulic fracturing jobs only, which represents the majority of water use per well across the planning area (see Table 2-2). The amount of water used in fracturing operations varies significantly depending on the well configuration (vertical or horizontal), the

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[1] Mining water use is defined in Dieter at al. (2018:39) as "…water used for the extraction of minerals and rocks that may be in the form of solids, such as coal, iron, sand, and gravel; liquids, such as crude petroleum; and gases, such as natural gas. The category includes quarrying, milling of mined materials, injection of water for secondary oil recovery or for unconventional oil and gas recovery (such as hydraulic fracturing), and other operations associated with mining activities."

number of fractured stages, and the specific characteristics of the formation. In vertical wells with a single fractured stage, water use associated with hydraulic fracturing can be less than 50,000 gallons of water per fracture job, or approximately 0.15 AF. In contrast, a multi-stage fracture job in a horizontal well can require several million to tens of millions of gallons of water (FracFocus 2024). Although direct water usage associated with hydraulic fracturing jobs represents the majority of water usage for well development, well development requires other direct and indirect types of water use that are not associated with the hydraulic fracturing process (i.e., non-hydraulic fracturing water usage).

FracFocus does not report on non-hydraulic fracturing water use, which is largely associated with drilling activities. Non-hydraulic fracturing water use represents a small fraction of the total water use per well; however, this amasses to a substantial sum of additional water use across the planning area. Estimates for non-hydraulic fracturing water use are detailed in *Estimates of Water Use Associated with Continuous Oil and Gas Development in the Permian Basin, Texas and New Mexico, 2010–19* (Valder et al. 2021). Valder et al. (2021) characterize non-hydraulic fracturing water uses as either direct or indirect water uses, which are defined as follows:

- **Direct non-hydraulic fracturing water usage**: This includes water used directly in a wellbore for activities such as drilling, cementing, and maintaining the well during production.
- **Indirect non-hydraulic fracturing water usage**: This encompasses water used at or near the well site, including water for dust abatement, equipment cleaning, materials washing, worker sanitation, and site preparation.

Valder et al. (2021) provides the following estimates for direct and indirect non-hydraulic fracturing water use:

- Direct – cementing (0.014 million gallons [Mgal] per well)
- Direct – drilling (0.143 Mgal per well)
- Indirect (0.111 Mgal per well)

Total non-hydraulic fracturing water use is approximately 0.268 Mgal per well, equivalent to 0.82 AF per well. The value of 0.82 AF per well is an estimate developed using the best available data on non-hydraulic fracturing water use and serves to provide an estimate by which an approximation can be derived. It is estimated that non-hydraulic fracturing water use in the state of Oklahoma totaled 11,157.8 AF for 13,607 wells between the years 2014 and 2023 (see Table 2-2).

Total hydraulic fracturing water use and non-hydraulic fracturing water use between the years 2014 and 2023 is estimated to be 358,210.2 AF (see Table 2-2). The reported total is an estimation and does not consider variables such as differences in water use between vertical and horizontal wells and local geology; additionally, this total assumes that FracFocus data is accurate and represents the total number of wells across Oklahoma.

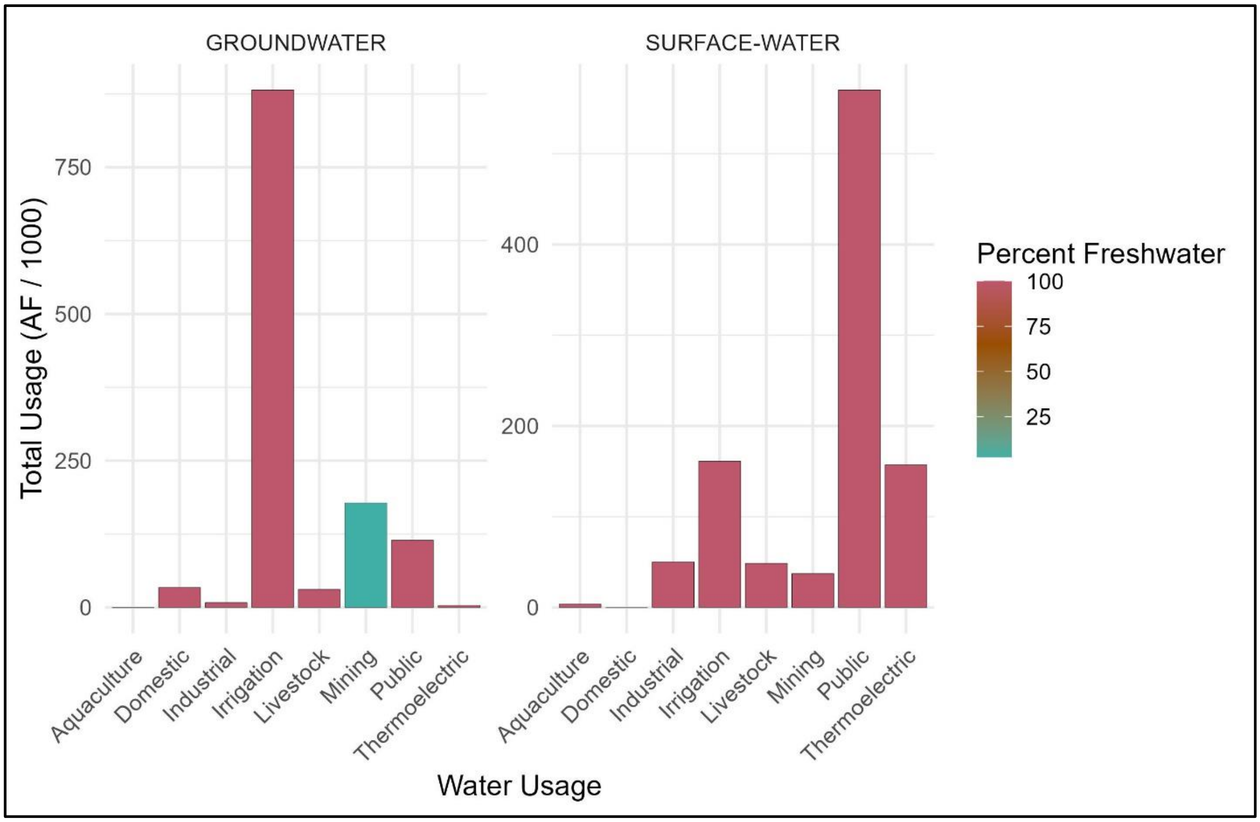


Figure 2-1. Water use by category for the state of Oklahoma in 2015, colored by the percentage of freshwater use out of the total water use (freshwater plus saline water use) (Dieter et al. 2018).

Table 2-1. State of Oklahoma Water Use by Category in 2015

Category	Surface Water				Groundwater				Total Withdrawals				Total	Total Use (%)
	Fresh	Saline*	Total	Total Use (%)	Fresh	Saline*	Total	Total Use (%)	Fresh	Total Use (%)	Saline*	Total Use (%)		
Aquaculture	3,618	0	3,618	<1%	67.2	0	67.2	<1%	3,685	<1%	0	0%	3,685	<1%
Domestic	0	–	0	<1%	33,974	–	33,974	1%	33,974	1%	–	0%	33,974	1%
Industrial	501,104	0	501,104	18%	8,143	0	8,143	<1%	509,247	19%	0	0%	509,247	19%
Irrigation	161,188	–	161,188	6%	881,686	–	881,686	32%	1,042,874	38%	–	0%	1,042,874	38%
Livestock	48,502	–	48,502	2%	30,636	–	30,636	1%	79,138	3%	–	0%	79,138	3%
Mining	37,200	0	37,200	1%	4,727	173,297	178,024	7%	41,927	2%	173,297	6%	215,224	8%
Public Water Supply	570,298	0	570,298	21%	114,378	0	114,378	4%	684,676	25%	0	0%	684,676	25%
Thermoelectric Power	157,156	0	157,156	6%	3,562	0	3,562	<1%	160,718	6%	0	0%	160,718	6%
Total	**1,479,066**	**0**	**1,479,066**	**54%**	**1,077,173**	**173,297**	**1,250,470**	**46%**	**2,556,239**	**94%**	**0**	6%	**2,729,536**	**100%**

Source: Dieter et al. (2018)

Note: Values may not sum to totals because of independent rounding (Dieter et al. 2018). Water use data are in AF/year unless otherwise indicated.

* Saline water is defined as water containing dissolved solids of 1,000 milligrams per liter (mg/L) or more. Saline water withdrawals are not reported for domestic, irrigation, or livestock water use (Dieter et al. 2018).

Table 2-2. Water Use by Oil and Gas Wells for Hydraulic Fracturing (HF) and Non-Hydraulic Fracturing (Non-HF) in Oklahoma from 2014 through 2023

Year	Federal HF Water Use	Tribal HF Water Use	Non-Federal/ Tribal HF Water Use*	Total HF Water Use	Federal HF Water Use (%)	Federal HF Cumulative Water Use	Total HF Cumulative Water Use	Average HF Water Use per Well*	Total No. of Federal Wells	Total No. of Wells	Total Non-HF Water Use[†]	Total Water Use (HF plus non-HF)
2014	550	–	29,824.6	30,374.6	2%	550	30,374.6	9.3	53	3,043	2,495.3	32,869.9
2015	1,403.7	0.1	24,043.7	25,447.5	6%	1,953.7	55,822.1	14.3	58	1,675	1,373.5	26,821.0
2016	204	148.9	28,906.8	29,259.8	<1%	2,157.7	85,081.9	24.7	13	1,137	932.3	30,192.1
2017	375.1	676.2	48,493.8	49,545.1	<1%	2,532.8	134,627	31.2	17	1,535	1,258.7	50,803.8
2018	799	788.2	59,840.5	61,427.6	1%	3,331.8	196,054.6	31.4	34	1,892	1,551.4	62,979.0
2019	1,442.2	597.4	50,785.8	52,825.3	3%	4,774	248,879.9	33.4	27	1,540	1,262.8	54,088.1
2020	418.1	–	15,303	15,721.1	3%	5,192.1	264,601	32.3	7	479	392.8	16,113.9
2021	–	–	19,239.9	19,239.9	–	5,192.1	283,840.9	29.7	–	628	515.0	19,754.9
2022	56.9	197.5	31,633.5	31,887.9	<1%	5,249	315,728.8	32.4	2	949	778.2	32,666.1
2023	531.9	101.3	30,690.3	31,323.6	2%	5,780.9	347,052.4	42.1	10	729	597.8	31,921.4
Total	**5,780.9**	**2,509.6**	**338,761.9**	**347,052.4**	**2%**	**5,780.9**	**347,052.4**	**34.7[‡]**	**221**	**13,607**	**11,157.8**	**358,210.2**

Source: FracFocus (2024). Data only for those wells that reported water use to FracFocus are presented; well data may be incomplete due to state reporting requirements and may not reflect total active wells and exact water use.

Note: All water use data are presented in AF. Produced water is naturally occurring water that exists in a formation that is being targeted for mineral extraction and is produced as a byproduct.

* Includes both non-federal and non-tribal wells.

† Non-HF water use estimates were calculated using 0.82 AF multiplied by total number of wells.

‡ 3-year average (2021–2023)

2.3 Water Quality

2.3.1 Surface Water

In the state of Oklahoma, the ODEQ administers CWA Sections 303(d), 305(b), and 314 related to surface water quality assessment and reporting. The ODEQ defines surface water quality beneficial uses and water quality standards to evaluate if these uses are being attained. Water quality standards include beneficial uses for surface waters of the state and associated water quality criteria to protect those uses. The ODEQ prepares a report every 2 years (the Integrated Report), where waterbodies not attaining their beneficial uses are reported. The Integrated Report also contains information on surface water quality and water pollution control programs in the state of Oklahoma. The most recent approved Integrated Report was published in 2022 (ODEQ 2022). The BLM does not have authority to make use attainment evaluations based on water chemistry data.

Beneficial uses in Oklahoma are assigned for both rivers and lakes. Uses identified as aesthetic, agriculture, fish consumption, warm water aquatic community, navigation, primary contact, public/private water supply, and emergency water supply are applied to both rivers and lakes (ODEQ 2022). Additionally, cool water aquatic community, habitat limited aquatic community, trout fishery, and secondary contact uses are identified for rivers. According to the 2022 Integrated Report, the primary pollutants for lakes are turbidity, mercury, and dissolved oxygen, whereas for rivers, the primary pollutants are members of the bacterial family Enterococcaceae, such as *Escherichia coli*, and turbidity (ODEQ 2022). Several sources are identified as contributing to degraded water quality that include mine tailings, grazing, septic systems, wildlife waste, pet waste, animal feeding operations, non-construction-related runoff, and petroleum/natural gas activities (EPA 2024a).

2.3.2 Groundwater

Groundwater is an important resource in Oklahoma, with 21 major and approximately 150 minor groundwater basins across the state (ODEQ 2022). The state's groundwater quality standards categorize groundwater uses based on total dissolved solid (TDS) concentrations. Groundwater with TDS less than 3,000 milligrams per liter (mg/L) supports public and private water supplies, agriculture, and industrial uses, whereas groundwater with TDS between 3,000 and 10,000 mg/L is primarily used for agriculture and industrial processes (ODEQ 2022).

The OCC monitors groundwater near oil and gas spill sites and may monitor in response to citizen complaints. To investigate possible groundwater pollution, samples may be collected from domestic wells, existing monitoring wells, springs, and other sources. These samples are tested for a variety of parameters that could include TDS, chlorides, sulfates, petroleum, and metals. The levels and location of contaminants will determine necessary actions to be taken to reduce pollution; however, because sampling often targets specific issues rather than providing a general overview, it may not fully represent statewide groundwater quality. The OWRB has also conducted statewide monitoring of samples of ambient groundwater quality across the state since 1937 (ODEQ 2022). They have an active statewide network of approximately 800 wells to assess long-term trends in groundwater quality, levels, and aquifers storage (OWRB 2024c).

The 2022 Integrated Report provides a list of major and minor aquifers that are experiencing degraded water quality due to anthropogenic activities. There are currently 16 major aquifers (defined as having a yield of 150 gallons per minute or greater) and seven minor aquifers with degraded water quality due to agricultural activities, animal feedlots, drainage wells, irrigation practices, pesticide/fertilizer application, storage tanks, waste piles, injection wells, septic systems, hazardous waste sites, mining, spills, and urban runoff (Table 2-3) (ODEQ 2022).

Table 2-3. Major and Minor Aquifers with Water Quality Degradation

Aquifer	Type	Water Quality Concern	Potential Source of Degradation
Alluvium and terrace deposits of the Salt Fork of the Arkansas River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Arkansas River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Enid isolated terrace deposits	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Cimarron River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Beaver-North Canadian River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Canadian River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Washita River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the North Fork of the Red River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Alluvium and terrace deposits of the Red River	Major	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Ogallala Formation	Major	Nitrate, selenium	Nitrate: Agricultural activities (animal feedlots, fertilizer application), septic systems Selenium: Naturally occurring
Antlers Sandstone	Major	Nitrate, low pH	Nitrate: Agricultural activities (animal feedlots, fertilizer application), septic systems
Rush Springs Sandstone	Major	Nitrate, hydrocarbons, chloride	Historic oil and gas activities
Garber Sandstone and Wellington formations	Major	Gross alpha, selenium, industrial solvents, nitrate, chloride, arsenic	Gross alpha: Naturally occurring Selenium: Naturally occurring Nitrate: Agricultural activities (animal feedlots, fertilizer application), septic systems Arsenic: Naturally occurring
Roubidoux Formation	Major	Iron, sulfate, TDS	Mine water contamination
Vamoosa Formation	Major	Fluoride, chloride	Naturally occurring
The Arbuckle Formation	Major	Fluoride, hardness	Naturally occurring
The Boone Formation/Boone Chert/Keokuk and Reeds Springs formations	Minor	Low pH, heavy metals	Historic mining
The Oscar "A" Formation	Minor	Nitrate, gross alpha	Nitrate: Agricultural activities (animal feedlots, fertilizer application), septic systems Gross alpha: Naturally occurring
McAlester and Hartshorne formations–Savanna Formation/McAlester Formation/Hartshorne Sandstone Formation	Minor	Low pH, heavy metals, chlorides, industrial waste	Historic mining

Aquifer	Type	Water Quality Concern	Potential Source of Degradation
Walnut Creek alluvium deposits	Minor	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
Tillman terrace deposits	Minor	Nitrate, selenium	Nitrate: Agricultural activities (animal feedlots, fertilizer application), septic systems Selenium: Naturally occurring
Little Sandy Creek alluvium deposits	Minor	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems
West Cache Creek terrace	Minor	Nitrate	Agricultural activities (animal feedlots, fertilizer application), septic systems

Source: ODEQ (2022)

2.3.3 Potential Sources of Contamination

The chemical composition of water used during the hydraulic fracturing process varies due to differences in fracturing techniques used by oil and gas companies. A typical oil/gas well uses approximately 20 to 25 unique chemicals during the hydraulic fracturing process, but in some cases, more than 60 distinct chemicals can be used. The most disclosed chemical constituents of hydraulic fracturing used in Oklahoma wells from 2014 through 2023 were nondisclosed chemical, followed by water, with 59,974 disclosures, and 50,527 disclosures, respectively (Table 2-4). Other major chemical constituent disclosures were methanol (n = 17,407) and hydrochloric acid (n = 9,465). In total, there were 523,841 chemical records entered in the FracFocus database; however, many chemicals recordings represent the same chemicals recorded differently (FracFocus 2024). Ingredient names and Chemical Abstracts Service (CAS) numbers are not standardized in FracFocus, leading to widespread differences and discrepancies in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in Table 2-4 are for general information only. Appendix A contains information on how FracFocus data are analyzed and summarized.

Oil and gas development spills have the potential to impact surface water directly by falling into a waterbody or indirectly by surface runoff, soil contamination, and ensuing transport during rainfall, or migration into groundwater and subsequent discharge from a spring into surface water. According to Oklahoma Administrative Code, major releases must be reported to OCC within 24 hours of the discovery of the release. According to the OCC, any spill amounting to 10 or more barrels of material related to oil and gas exploration or production must be reported. In addition, a spill of any quantity that comes in contact with water resources must be reported (OCC 2024a). All major and minor release reports (spills) are archived in the OCC spills database.

Spill data for Oklahoma was retrieved from the OCC (OCC 2024b). The data include information on the quantity of each reported spill, the amount recovered, and impacts on surface water. However, information on groundwater impacts is not provided. Due to many ambiguous or erroneous entries in the OCC dataset, numerical values for each spill and recovery are omitted from this analysis and each record is counted as a distinct spill entry with a non-zero quantity spilled. Additionally, each record includes two binary fields ("yes" or "no") that indicate whether the spill impacted water sources and whether it caused wildlife casualties. A total of 29,910 spills were reported to the OCC between 2014 and 2023. Between 2014 and 2023, a total of 950 spills (approximately 3% of all reported spills) were documented to have affected ground and/or surface water sources. Additionally, 181 spills (less than 1%) were associated with wildlife casualties. Notably, 2023 saw the highest number of reported spills within this period, with a total of 3,766 incidents. Of these, 104 spills (2.8% of the 2023 total) impacted surface water and/or groundwater, while 23 spills (less than 1%) were linked to wildlife casualties. Self-reported estimated quantities of wildlife casualties and waters impacted reported to OCC are included in Table 2-5 (OCC 2024b).

Table 2-4. Most Frequently Disclosed Ingredients Reported to FracFocus within Oklahoma from 2014 through 2024

Ingredient Name*	CAS Registry Number	Number of Disclosures	Percentage of Hydraulic Fracturing Jobs†	Percentage of Total Number of FracFocus Disclosures‡
Not Disclosed	N/A	59,974	N/A	11.45%
Water	7732-18-5	50,527	20.69%	9.65%
Methanol	14808-60-7	17,407	0.08%	3.32%
Hydrochloric Acid	64742-47-8	9,465	0.48%	1.81%
Sodium Chloride	68551-12-2	9,298	0.25%	1.77%
Isopropanol	77-92-9	7,186	0.04%	1.37%
Ethylene Glycol	67-63-0	6,755	0.06%	1.29%
Guar Gum	107-19-7	6,650	0.17%	1.27%
Citric Acid	1344-28-1	6,096	0.04%	1.16%
Acetic Acid	78330-21-9	5,805	0.01%	1.11%
Ethanol	68424-85-1	5,718	0.01%	1.09%
Propargyl Alcohol	64-19-7	4,984	0.00%	0.95%
Crystalline Silica, Quartz	7647-01-0	4,848	7.34%	0.93%
Methyl Alcohol	67-56-1	4,814	0.03%	0.92%
2-butoxyethanol	111-76-2	4,634	0.01%	0.88%
Glutaraldehyde	67-56-1	4,556	0.25%	0.87%
Ammonium Chloride	12125-02-9	4,186	0.01%	0.80%
Ammonium Persulfate	9000-30-0	4,159	0.03%	0.79%
Sodium Hydroxide	7727-54-0	3,314	0.01%	0.63%
Isopropyl Alcohol	67-63-0	3,299	0.02%	0.63%
Sodium Perborate Tetrahydrate	10486-00-7	3,228	0.02%	0.62%
Crystalline Silica	14808-60-7	2,995	6.36%	0.57%
Proprietary	N/A	2,894	0.13%	0.55%
Hydrotreated Light Petroleum Distillate	64742-47-8	2,792	0.05%	0.53%
Chlorine Dioxide	10049-04-4	2,587	0.06%	0.49%

Source: FracFocus (2024a)

Note: Ingredient names and CAS numbers are not standardized in FracFocus, leading to widespread differences and discrepancies in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in this table are for general information only.

N/A = Not applicable.

* FracFocus lists certain chemicals as proprietary, and no additional information is available regarding ingredient contents.

† The amount of the ingredient in the total hydraulic fracturing volume by percent mass (definition from FracFocus [2024a] data dictionary).

‡ Percentage represents the number of documented chemical disclosures out of the total number of disclosures.

Table 2-5. Summary of Spills in the State of Oklahoma from 2014 through 2023

Year	Reported Incidents	Reported Wildlife Casualties	Reported Waters Impacted
2014	2,214	6	80
2015	2,620	15	118
2016	2,358	16	93
2017	2,499	12	71
2018	3,253	12	87
2019	3,354	24	150
2020	3,059	19	100
2021	3,208	20	78
2022	3,579	34	69
2023	3,766	23	104
Total	**29,910**	**181**	**950**

Source: OCC (2024b)

Note: OCC spill reporting does not include sufficient detail to report on quantities of each spill and recovery efforts. Reported incidents are based on the number of unique incident IDs during each calendar year. Each reported incident may include an oil spill, a water spill, or both.

3 KANSAS

This chapter contains an analysis and summary of the available water use and water quality data for the state of Kansas that support the evaluation of water resource impacts from oil and gas leasing and development (as described in Chapter 1). Section 3.1 presents an overview of the state's water planning process and associated documentation. Water use estimates for all categories of consumptive water use (e.g., public drinking water supply, irrigation, thermoelectric power) are presented in Section 3.2. Additionally, Section 3.2 contains the summarized FracFocus water use data so that water use from hydraulic fracturing can be compared with statewide water use. Section 3.3 presents an overview of water quality for both surface water and groundwater and contains a summary of the chemicals used in hydraulic fracturing that are disclosed to FracFocus.

3.1 State of Kansas Water Planning

The State of Kansas's approach to water resources management is guided by the Kansas Water Plan (KWP) developed and managed by the Kansas Water Office (KWO). The most recent iteration of the KWP was published in 2022 and was developed as a collaborative effort between several state offices and academic institutions. The KWP is organized around five guiding principles: 1) conserve and extend the High Plains Aquifer, 2) secure, protect, and restore Kansas reservoirs, 3) improve the state's water quality, 4) reduce vulnerability to extreme events, and 5) increase awareness of Kansas water resources (KWO 2022). There are 14 regional planning areas in the state, with each area summarized in the KWP by geology, topography, demographics, and the five guiding principles. In addition, the Kansas Water Authority, a section of the KWO, develops annual reports on water resources for submission to the Governor and State Legislature. The most recent report published in 2024, provides recommendations for state policies, funding updates, KWP status updates as well as aquifer initiatives, water supply and sediment management, water quality initiatives, and other water issues (Kansas Water Authority 2024).

3.2 Water Quantity

3.2.1 Surface Water and Groundwater Use

In 2015, the combined fresh and saline water withdrawals for all water use categories across the state of Kansas totaled 8,417,399 AF (Table 3-1; Figure 3-1) (Dieter et al. 2018). The majority of water withdrawals in the state of Kansas come from irrigation (6,001,610 AF), constituting 71% of the total water withdrawals in 2015. Thermoelectric and public water supply represent the second (22%) and third (5%) greatest use within the state of Kansas (1,829,663 AF and 393,338 AF, respectively). Industrial (42,700 AF), mining (6,710 AF), livestock (116,416 AF), and aquaculture (7,158 AF) constituted relatively minor proportions of the cumulative water use, ranging from less than 1% to 1%. Groundwater resources constituted 72% of the total water withdrawals (6,056,923 AF) and surface water use constituted the remaining 28% (2,360,476 AF). Irrigation withdrawals represented the greatest source of groundwater use at 5,729,057 AF. Thermoelectric power withdrawals sourced approximately 1,812,166 AF of water from surface water resources, representing the largest source of surface water withdrawals in 2015 (see Table 3-1; Figure 3-1).

It is important to consider the impacts of groundwater well pumping on surface water availability. Groundwater pumping impacts the storage capacity of an aquifer. This reduction affects groundwater discharge zones, where groundwater naturally flows out of the aquifer, often connecting to surface water bodies like rivers, lakes, and streams. Altering aquifer storage capacity through groundwater pumping can change the local hydraulic gradient—the slope of the water table surface that determines groundwater flow direction and speed. Significant changes in this gradient can reduce groundwater discharge into surface water systems, thereby decreasing surface water availability (Barlow and Leake 2012).

Kansas ranks as one of the top 10 oil and gas producing states in the United States (Kansas Commerce 2024). From 2014 to 2023, FracFocus reports 454 total wells (Table 3-2) where the total annual water use associated with the hydraulic fracturing of reported oil and gas wells throughout Kansas generally decreased from 2014 to 2023. The year 2014 represented the greatest reported total water use at 1,185.5 AF (see Table 3-2). Most of the wells and associated water use are reported as non-federal and non-tribal; reported hydraulic fracturing water use for these wells totaled 1,611.5 AF from 2014 to 2023. During the same time period, three federal wells were reported to FracFocus and the total hydraulic fracturing water use for federal wells was 3 AF.

The average 3-year water use (2021 to 2023) is 0.5 AF for hydraulic fracturing water purposes (see Table 3-2) (FracFocus 2024). An average water use of 0.5 AF per well for hydraulic fracturing is lower compared to Oklahoma and Texas (34.7 AF and 50.6 AF, respectively). The two most likely reasons for this difference are: 1) the prevalence of vertical wells in Kansas (vertical wells generally require significantly less water than horizontal wells), and 2) the underlying geologic formations in Kansas generally require less water for hydraulic fracturing than formations in other states (BLM 2016).

FracFocus reports on water use directly associated with hydraulic fracturing jobs only, which represents the majority of water use per well across the planning area (see Table 3-2). The amount of water used in fracturing operations varies significantly depending on the well configuration (vertical or horizontal), the number of fractured stages, and the specific characteristics of the formation. In vertical wells with a single fractured stage, water use associated with hydraulic fracturing can be less than 50,000 gallons of water per fracture job, or approximately 0.15 AF. In contrast, a multi-stage fracture job in a horizontal well can require several million to tens of millions of gallons of water (FracFocus 2024). Although direct water usage associated with hydraulic fracturing jobs represents the majority of water usage for well development, well development requires other direct and indirect types of water use which are not associated with the hydraulic fracturing process (i.e., non-hydraulic fracturing water usage).

FracFocus does not report on non-hydraulic fracturing water use, which is largely associated with drilling activities. Non-hydraulic fracturing water use represents a small fraction of the total water use per well; however, this amasses to a substantial sum of additional water use across the planning area. Estimates for non-hydraulic fracturing water use are detailed in *Estimates of Water Use Associated with Continuous Oil and Gas Development in the Permian Basin, Texas and New Mexico, 2010–19* (Valder et al. 2021). Valder et al. (2021) characterizes non-hydraulic fracturing water uses as either direct or indirect water uses, which are defined as follows:

- **Direct non-hydraulic fracturing water usage**: This includes water used directly in a wellbore for activities such as drilling, cementing, and maintaining the well during production.
- **Indirect non-hydraulic fracturing water usage**: This encompasses water used at or near the well site, including water for dust abatement, equipment cleaning, materials washing, worker sanitation, and site preparation.

Valder et al. (2021) provides the following estimates for direct and indirect non-hydraulic fracturing water use:

- Direct – cementing (0.014 Mgal per well)
- Direct – drilling (0.143 Mgal per well)
- Indirect (0.111 Mgal per well)

Total non-hydraulic fracturing water use is approximately 0.268 Mgal per well, equivalent to 0.82 AF per well. The value of 0.82 AF per well is an estimate developed using the best available data on non-hydraulic fracturing water use and serves to provide an estimate by which an approximation can be derived. Using the total well count from 2014 to 2023 from FracFocus, coupled with the estimate of 0.82 AF per well from the USGS, it is estimated that non-hydraulic fracturing water use in the state of Kansas totaled 372.4 AF for 454 wells between 2014 and 2023 (see Table 3-2); however, this total likely only represents post-2015 well development.

Total hydraulic fracturing water use and non-hydraulic fracturing water use for 2014 through 2023 is estimated to be 1,986.9 AF, with the year 2014 recording the highest single-year water use associated with hydraulic fracturing, 1,342.9 AF (see Table 3-2). The reported total is an estimation and does not consider variables such as differences in water use between vertical and horizontal wells and local geology.

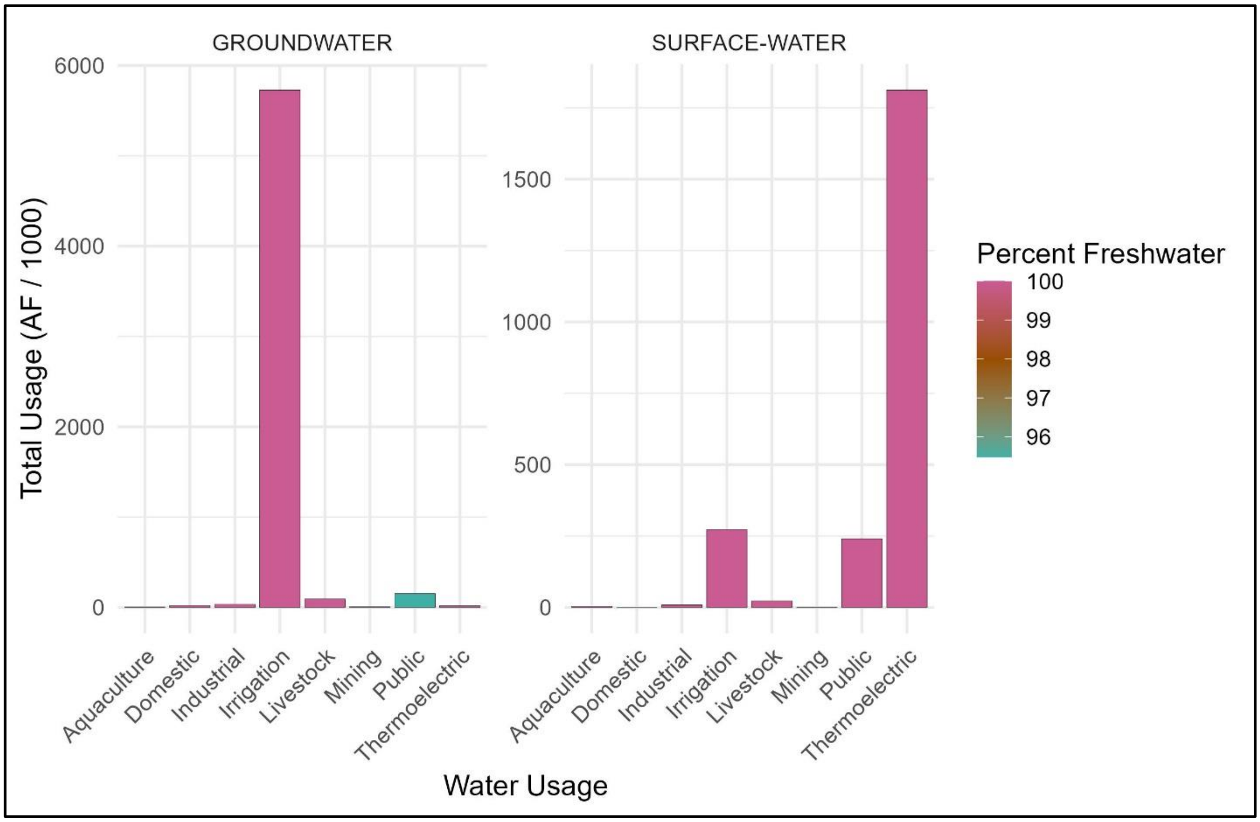


Figure 3-1. Water use by category for the state of Kansas in 2015, colored by the percentage of freshwater use out of the total water use (freshwater plus saline water use) (Dieter et al. 2018).

Table 3-1. State of Kansas Water Use by Category in 2015

Category	Surface Water				Groundwater				Total Withdrawals				Total	Total Use (%)
	Fresh	Saline*	Total	Total Use (%)	Fresh	Saline*	Total	Total Use (%)	Fresh	Total Use (%)	Saline*	Total Use (%)		
Aquaculture	3,618	0	3,618	<1%	3,540	0	3,540	<1%	7,158	<1%	0	0%	7,158	<1%
Domestic	0	–	0	0%	19,804	–	19,804	<1%	19,804	<1%	–	0%	19,804	<1%
Industrial	8,547	0	8,547	<1%	34,153	0	34,153	<1%	42,700	1%	0	0%	42,700	1%
Irrigation	272,553	–	272,553	3%	5,729,057	–	5,729,057	68%	6,001,610	71%	–	0%	6,001,610	71%
Livestock	22,907	–	22,907	<1%	93,509	–	93,509	1%	116,416	1%	–	0%	116,416	1%
Mining	616	0	616	<1%	6,094	0	6,094	<1%	6,710	<1%	0	0%	6,710	<1%
Public Water Supply	240,069	0	240,069	3%	146,347	6,922	153,269	2%	386,416	5%	6,922	<1%	393,338	5%
Thermoelectric Power	1,812,166	0	1,812,166	22%	17,497	0	17,497	<1%	1,829,663	22%	0	0%	1,829,663	22%
Total	**2,360,476**	**0**	**2,360,476**	**28%**	**6,050,001**	**6,922**	**6,056,923**	**72%**	**8,410,477**	**>99%**	**6,922**	**<1%**	**8,417,399**	**100%**

Source: Dieter et al. (2018)

Note: Values may not sum to totals because of independent rounding (Dieter et al. 2018). Water use data are in AF/year unless otherwise indicated.

* Saline water is defined as water containing dissolved solids of 1,000 mg/L or more. Saline water withdrawals are not reported for domestic, irrigation, or livestock water use (Dieter et al. 2018).

Table 3-2. Water Use by Oil and Gas Wells for Hydraulic Fracturing (HF) and Non-Hydraulic Fracturing (Non-HF) in Kansas from 2014 through 2023

Year	Federal HF Water Use	Non-Federal/Non-Tribal HF Water Use*	Total HF Water Use	Federal HF Water Use (%)	Federal HF Cumulative Water Use	Total HF Cumulative Water Use	Average HF Water Use per Well*	Total No. of Federal Wells	Total No. of Wells	Total Non-HF Water Use	Total water Use (HF plus non-HF)
2014	–	1,185.5	1,185.5	–	–	1,185.5	6.1	–	192	157.4	1,342.9
2015	2.6	290.5	293.1	1%	2.6	1,478.6	5.1	1	57	46.7	339.8
2016	–	38.3	38.3	–	–	1,516.9	4.8	–	8	6.6	44.9
2017	–	17.5	17.5	–	–	1,534.4	1	–	18	14.8	32.3
2018	0.4	30.2	30.6	1%	3	1,565.0	1	2	29	23.8	54.4
2019	–	12	12	–	–	1,577.0	0.2	–	52	42.6	54.6
2020	–	1.3	1.3	–	–	1,578.3	0.1	–	13	10.7	12
2021	–	3.8	3.8	–	–	1,582.1	0.1	–	38	31.2	35
2022	–	25.4	25.4	–	–	1,607.5	0.7	–	38	31.2	56.6
2023	–	7	7	–	–	1,614.5	0.8	–	9	7.4	14.4
Total	3	1,611.5	1,614.5	<1%	3	1,614.5	0.5†	3	454	372.4	1,986.9

Source: FracFocus (2024a). Data only for those wells that reported water use to FracFocus are presented.

Note: All water use data are presented in AF. Produced water is naturally occurring water that exists in a formation that is being targeted for mineral extraction and is produced as a byproduct.

* Includes both federal and non-federal wells.

† 3-year average (2021–2023)

3.3 Water Quality

3.3.1 Surface Water

In the state of Kansas, the KDHE administers CWA Sections 303(d), 305(b), and 314 related to surface water quality assessment and reporting. The KDHE defines surface water quality designated beneficial uses and water quality standards to evaluate if these uses are being attained. Water quality standards include designated beneficial uses for surface waters of the state and associated water quality criteria to protect those uses. The KDHE prepares a report every 2 years, where waterbodies not attaining their designated beneficial uses are documented and listed as “impaired.” The report also contains information on surface water quality and water pollution control programs in the state of Kansas. The most recent approved report was published in 2022 (KDHE 2022). The BLM does not have authority to make use attainment evaluations based on water chemistry data.

Designated beneficial uses in Kansas are identified as aquatic life, domestic water supply, food procurement, groundwater recharge, industrial water supply, irrigation, livestock watering, and recreation (KDHE 2022). According to the 2022 report, approximately 89% of the state’s stream mileage was impaired for one or more of its designated beneficial uses. Four primary causes of stream impairments were suboptimal aquatic macroinvertebrate community metrics, an indicator of aquatic life nonsupport; mercury in fish tissue, an indicator of food procurement nonsupport; and bacteria and metals in water (KDHE 2022). Additionally, the most widespread class of stressors responsible for designated beneficial use impairments were from agriculture and anthropogenic influences whereas urban stressors were less prevalent (KDHE 2022).

3.3.2 Groundwater

The majority of the west half of the state of Kansas is underlain by the High Plains aquifer, a primary source of groundwater for various uses in the state (Kansas Geological Survey [KGS] 1993). The quality of the groundwater was assessed in 2015 and 2016 through a sampling of 80 public water supply wells that were spatially distributed across the aquifer, 11 of which were in the state of Kansas (USGS 2019). Samples were analyzed for a variety of water quality constituents that originate from both natural and human sources and then compared to established benchmarks to determine the overall level of contamination (USGS 2019). Contaminant categories of “high,” “medium,” and “low” were identified based on the magnitude of exceedance of established benchmarks for both human health (e.g., arsenic) and secondary non-health (e.g., TDS). Wells sampled in Kansas were generally in the moderate to high category for TDS (benchmark = 500 parts per million) and uranium (benchmark = 30 parts per billion), and in the moderate category for arsenic (benchmark = 10 parts per billion) and fluoride (benchmark = 2 parts per million) (USGS 2019).

3.3.3 Potential Sources of Contamination

The chemical composition of water used during the hydraulic fracturing process varies due to differences in fracturing techniques used by oil and gas companies. A typical oil/gas well uses approximately 20 to 25 unique chemicals during the hydraulic fracturing process, but in some cases, more than 60 distinct chemicals can be used. The most disclosed chemical constituents of hydraulic fracturing used in Kansas wells from 2014 through 2023 was water, followed by methanol, with 1,740 disclosures and 796 disclosures, respectively (Table 3-3). Other major chemical constituent disclosures included non-disclosed chemical (n = 537) and methyl alcohol (n = 525). In total, there were 16,460 chemical records entered in the FracFocus database; however, many chemical recordings represent the same chemicals recorded differently (FracFocus 2024). Ingredient names and CAS numbers are not standardized in FracFocus, leading to widespread differences and discrepancies in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in Table 3-3 are for general information only. Appendix A contains information on how FracFocus data are analyzed and summarized.

Oil and gas spills have the potential to impact surface water directly by falling into a waterbody or indirectly by surface runoff, soil contamination, and ensuing transport during rainfall, or migration into groundwater and subsequent discharge from a spring into surface water. According to Kansas Administration Regulations 82-3-603, major releases must be reported to KCC upon initial discovery of the release. Major releases are not defined by quantity; however, spills include unintended escape of saltwater, oil, or refuse from oil, gas, injection, service, or gas storage wells, or associated infrastructure like tanks, pipelines, dikes, or pits. This includes activities related to the exploration, drilling, storage, treatment, or gathering of oil or gas, and the operation or abandonment of well (Cornell Law School 2024). Minor spills such as drips and leaks do not require reporting according to the KCC; however, operators are required to clean up all spills, including those exempt from reporting (e.g., drips and leaks) within 24 hours of initial discovery (KCC 2024a). All major and minor release reports (spills) are archived in the KCC spills database.

Spill data for Kansas were retrieved from the KCC (KCC 2024b). Spill reporting across Kansas was quantified; however, spill quantities are clustered around specific, discrete volumes (e.g., 200 gallons), suggesting that many reported spill volumes do not accurately reflect the actual spill amounts. Spill quantities are clustered around specific, discrete volumes (e.g., 200 gallons), suggesting that many reported spill volumes do not accurately reflect the actual spill amounts. This clustering could result from administrative errors, the convenience of reporting specific discrete quantities, or potential incentives to report certain volumes (e.g., overreporting). As a result, the quantity of each spill is not reported herein, but instead, data were processed to conform to a consistent grouping scheme devised for this report. Spills are grouped by quantity of spills that either did or did not impact water sources.. Spills and associated recoveries are further broken down by saltwater, oil, and other spill types (e.g., undefined within the dataset).

A total of 11,008 spills were reported to the KCC between 2014 and 2023, with 10,822 incidents reporting no impacts to waters and 186 reporting impacts to waters. From 2014 to 2023, 56,411.2 barrels of oil were spilled with no reported impact to waters; approximately 48% of the total sum of oil spilled was recovered, equating to 27,310.7 barrels. During the same time period, 892.8 barrels of oil were spilled with reported impacts to water resources; approximately 54% of the total sum of spills was recovered, equating to 582.6 barrels of oil recovered (Tables 3-4 and 3-5; see Figure 3-2).

From 2014 to 2023, 10,235,469 gallons of saltwater were spilled with no reported impacts to water resources (recovery = 5,593,758 gallons; 55% recovered), whereas 1,447,950 gallons of saltwater were spilled with reported impacts to water resources (recovery = 1,273,650 gallons; 88% recovered). Finally, 5,987.3 barrels of unknown substances were spilled with no recorded impact to surface waters, with 5,767.3 barrels recovered (96% recovered) (see Tables 3-4 and 3-5; see Figure 3-2).

Table 3-3. Most Frequently Disclosed Ingredients Reported to FracFocus within Kansas from 2014 through 2024

Ingredient Name*	CAS Registry Number	Number of Disclosures	Percentage of Hydraulic Fracturing Jobs†	Percentage of Total Number of FracFocus Disclosures‡
Water	N/A	1,740	N/A	10.57%
Methanol	14808-60-7	796	0.01%	4.84%
Not Disclosed	N/A	537	N/A	3.26%

Ingredient Name*	CAS Registry Number	Number of Disclosures	Percentage of Hydraulic Fracturing Jobs†	Percentage of Total Number of FracFocus Disclosures‡
Methyl Alcohol	67-56-1	525	0.02%	3.19%
Isopropyl Alcohol	67-63-0	520	0.03%	3.16%
Propargyl Alcohol	107-19-7	462	0.00%	2.81%
Ethylene Glycol Butyl Ether	111-76-2	380	0.03%	2.31%
Cocamide Diethanolamine Salt	68603-42-9	352	0.02%	2.14%
Ammonium Salt	155716-06-6	352	0.00%	2.14%
Diethanolamine	111-42-2	352	0.00%	2.14%
Fatty acid Diethanolamide	684402-04-0	352	0.00%	2.14%
poly[osyethylene(dimethyliminio)ethylene (dimethyliminio)eth	31512-74-0	330	0.00%	2.00%
Alcohols, c14-15, Ethoxylated	68951-67-7	324	0.00%	1.97%
Crystalline Silica (Quartz)	14808-60-7	316	12.24%	1.92%
Diethylene Glycol	111-46-6	310	0.00%	1.88%
Potassium Metaborate	13709-94-9	296	0.02%	1.80%
Potassium Hydroxide	1310-58-3	292	0.00%	1.77%
Ethylene Glycol	107-21-1	286	0.01%	1.74%
Acetic Acid	78330-21-9	260	0.01%	1.58%
2-butoxy-1-ethanol	111-76-2	252	0.00%	1.53%
Alcohols, c12-c13, Ethoxylated	66455-14-9	252	0.00%	1.53%
Alcohols, c9-c11, Ethoxylated	68439-46-3	252	0.00%	1.53%
Hydrochloric Acid	64742-47-8	246	0.18%	1.49%
Tributyl Tetradecyl Phosphonium Chloride	81741-28-8	218	0.00%	1.32%
Ammonium Persulfate	9000-30-0	208	0.01%	1.26%

Source: FracFocus (2024a)

Note: Ingredient names and CAS numbers are not standardized in FracFocus, leading to widespread differences in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in this table are for general information only.

* FracFocus lists certain chemicals as proprietary, and no additional information is available regarding ingredient contents.

N/A = Not Applicable

† The amount of the ingredient in the total hydraulic fracturing volume by percent mass (definition from FracFocus [2024a] data dictionary).

‡ Percentage represents the number of documented chemical disclosures out of the total number of disclosures.

Table 3-4. Summary of Spills That Impacted Waters in the State of Kansas from 2014 through 2023

Year	Oil Spill (Barrels)				Saltwater Spill (Gallons)				Total Reported Spills
	Spill Quantity	Quantity Recovered	Percent Recovery	Reported Spills	Spill Quantity	Quantity Recovered	Percent Recovery	Reported Spills	
2014	134	96.5	72%	14	159,810	134,526	84%	13	27
2015	29.3	25.8	88%	7	42,462	17,850	42%	9	16
2016	54	15	28%	9	138,390	129,150	93%	10	19
2017	177.5	49	28%	11	203,280	196,854	97%	10	21
2018	61.1	0.5	0.8%	7	723,198	714,000	99%	10	17
2019	32.3	22.5	70%	12	88,788	12,600	14%	14	26
2020	153	52	34%	8	5,040	3,570	71%	6	14
2021	63.3	62	98%	11	38,556	28,560	74%	10	21
2022	166.3	142.8	86%	9	40,026	28,140	55%	12	21
2023	22	16.5	75%	2	8,400	8,400	100%	2	4
Total	**892.8**	**482.6**	**54%**	**90**	**1,447,950**	**1,273,650**	**90%**	**96**	**186**

Source: KCC (2024b)

Table 3-5. Summary of Spills That Were Not Reported to Impact Waters in the State of Kansas from 2014 through 2023

Year	Oil Spill (Barrels)				Saltwater Spill (Gallons)				Other Spill (Barrels)				Total Reported Spills
	Spill Quantity	Quantity Recovered	Percent Recovery	Reported Spills	Spill Quantity	Quantity Recovered	Percent Recovery	Reported Spills	Spill Quantity	Quantity Recovered	Percent Recovery	Reported Spills	
2014	6,486	3,375.4	52	536	1,440,948	852,113	59	729	5,831	5,670	97	11	1,276
2015	5,606	2,781.1	50	511	1,389,973	805,340	58	691	–	–	–	–	1,202
2016	5,544.7	2,328.4	42	510	1,108,671	585,055	53	669	36	5	14	8	1,697
2017	4,862.4	2,342.9	48	457	1,008,698	543,518	54	666	–	–	–	–	1,123
2018	7,730.2	2,380.6	31	517	1,113,210	568,155	51	731	47	40	85	5	1,253
2019	7,514.8	3,385.5	45	579	1,123,203	585,003	52	797	0.5	0.5	100	2	1,378
2020	4,829.4	2,407.3	50	354	937,467	471,623	50	515	52	47	90	5	874
2021	5,351.2	3,291.9	61	417	817,121	506,039	62	578	10	4	40	3	998
2022	4,582.8	3,007.4	66	316	722,881	409,597	57	498	11	0.75	6.8	3	817
2023	3,903.7	2,010.2	51	284	573,297	267,315	47	430	–	–	–	–	714
Total	**56,411.2**	**27,310.7**	–	**4,481**	**10,235,469**	**5,593,758**	–	**6,304**	**5,987.5**	**5,767.3**	–	**37**	**10,822**

Source: KCC (2024b)

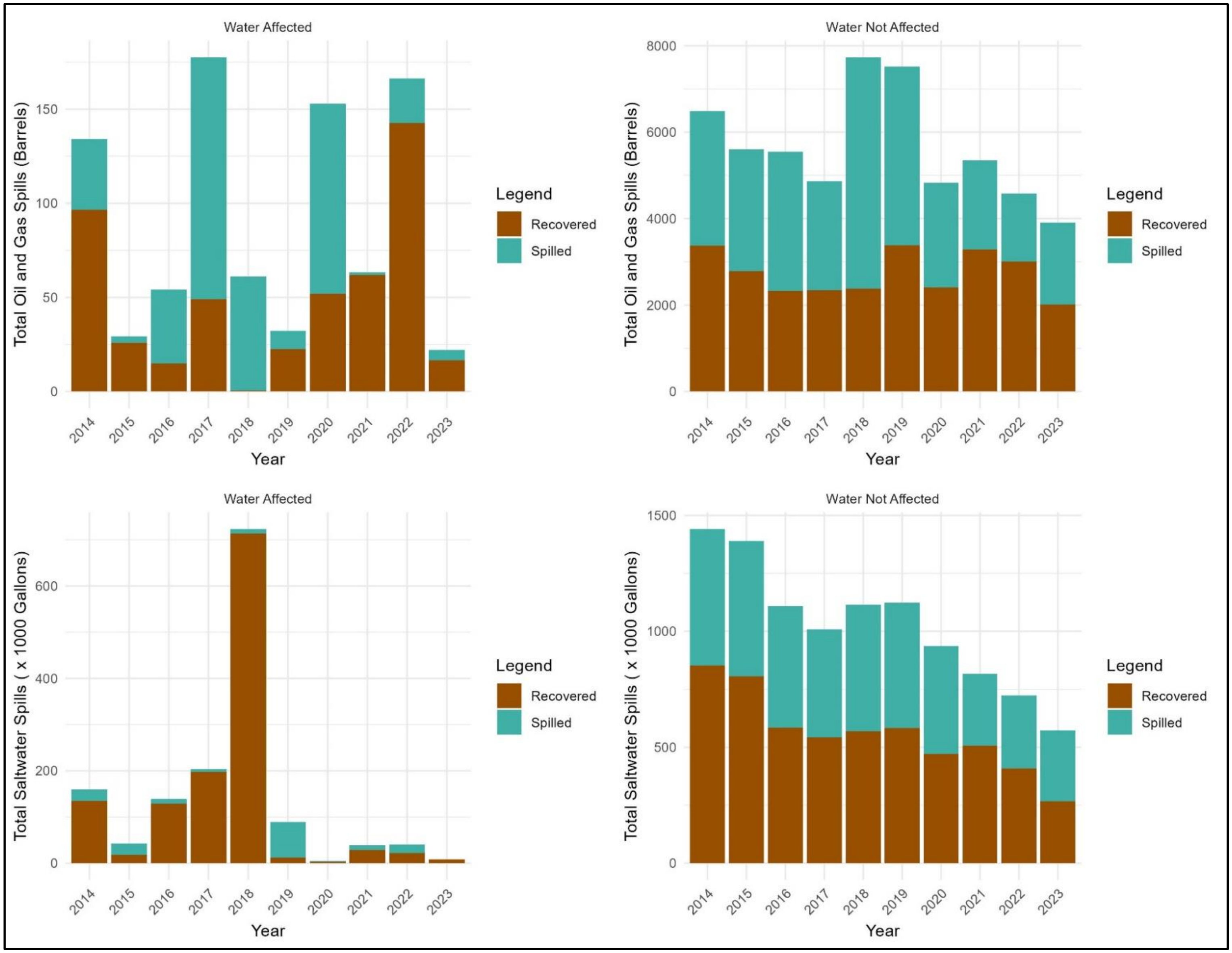


Figure 3-2. Summary of saltwater spills and oil and gas spills by year in the state of Kansas, colored by the percent of total spill quantity recovered.

4 TEXAS

This chapter contains an analysis and summary of the available water use and water quality data for the state of Texas that support the evaluation of water resource impacts from oil and gas leasing and development (as described in Chapter 1). Section 4.1 presents an overview of the state's water planning process and associated documentation. Water use estimates for all categories of consumptive water use (e.g., public drinking water supply, irrigation, thermoelectric power) are presented in Section 4.2. Additionally, Section 4.2 contains the summarized FracFocus water use data so that water use from hydraulic fracturing can be compared with statewide water use. Section 4.3 presents an overview of water quality for both surface water and groundwater and contains a summary of the chemicals used in hydraulic fracturing that are disclosed to FracFocus.

4.1 State of Texas Water Planning

The State of Texas's approach to water resources management is guided by the State Water Plan developed and managed by the Texas Water Development Board (TWDB). The State Water Plan is updated every 5 years with the most recent version published in 2022. The State Water Plan is based on 16 regional water plans and addresses the needs of several water user groups in the state that include municipal, irrigation, manufacturing, livestock, mining, and steam-electric power while also serving as a guide for policy recommendations and identifying sites of unique value (TWDB 2024a). The plan covers nine primary topics: 1) policy recommendations, 2) drought and drought response, 3) future population and water demand, 4) water availability and existing supplies, 5) water supply needs, 6) water management strategies and projects, 7) conservation, 8) financing, and 9) implementation and funding of the past state water plan (TWDB 2024b).

4.2 Water Quantity

4.2.1 Surface Water and Groundwater Use

In 2015, the combined fresh and saline water withdrawals for all water use categories across the state of Texas totaled 35,469,083 AF (Table 4-1; Figure 4-1) (Dieter et al. 2018). The majority of water withdrawals in the state of Texas came from thermoelectric power (23,292,575 AF) that constituted 66% of the total water withdrawals in 2015. Irrigation and public water supply represented the second (17%) and third (9%) greatest use within the state of Texas (6,148,786 AF and 3,231,981 AF, respectively). Industrial, mining, and livestock constituted relatively minor proportions of the cumulative water use, ranging from 1% to 4% (308,600 AF to 1,272,537 AF). Finally, aquaculture and domestic water use constituted the lowest water use in the state of Texas, at less than 1% (25,987 AF and 153,112 AF, respectively). Surface water resources constituted 77% of the total water withdrawals (27,365,110 AF) and groundwater use constituted the remaining 23% (8,103,973 AF). Irrigation withdrawals represented the greatest source of groundwater use at 5,014,351 AF. Thermoelectric power withdrawals sourced approximately 23,208,161 AF of water from surface water resources, which represented the largest source of surface water withdrawals in 2015 (see Table 4-1; Figure 4-1).

It is important to consider the impacts of groundwater well pumping on surface water availability, especially since Texas uses surface water for over half of its water use needs (Dieter et al. 2018). Groundwater pumping impacts the storage capacity of an aquifer. This reduction affects groundwater discharge zones, where groundwater naturally flows out of the aquifer, often connecting to surface water bodies like rivers, lakes, and streams. Altering aquifer storage capacity through groundwater pumping can change the local hydraulic gradient—the slope of the water table surface that determines groundwater flow direction and speed. Significant changes in this gradient can reduce groundwater discharge into surface water systems, thereby decreasing surface water availability (Barlow and Leake 2012).

Total annual water use associated with the hydraulic fracturing of oil and gas wells throughout Texas generally trends towards increased water use from 2014 (168,743.6 AF) to 2023 (339,097.9 AF); however, water use during certain years was markedly lower than neighboring years, such as 2016 (123,241.6 AF) and 2020 (192,678.3 AF) (see Table 4-1). Most of the wells and associated water use are reported as non-federal and non-tribal; hydraulic fracturing water use for these wells totaled 2,404,349 AF from 2014 to 2023. During the same time period, hydraulic fracturing water use for federal wells and tribal wells totaled 45,744.6 AF and 331.3 AF, respectively. Federal water use represented around 2% of the total hydraulic fracturing water use, with 1,416 reported wells from 2014 to 2023. A total of 70,009 wells were reported across Texas from 2014 to 2023 with an average 3-year water use (2021 to 2023) of 50.6 AF per well for hydraulic fracturing water purposes (see Table 4-1) (FracFocus 2024).

FracFocus reports on water use directly associated with hydraulic fracturing jobs only, which represents the majority of water use per well across the planning area (see Table 4-2). The amount of water used in fracturing operations varies significantly depending on the well configuration (vertical or horizontal), the number of fractured stages, and the specific characteristics of the formation. In vertical wells with a single fractured stage, water use associated with hydraulic fracturing can be less than 50,000 gallons of water per fracture job, or approximately 0.15 acre-feet. In contrast, a multi-stage fracture job in a horizontal well can require several million to tens of millions of gallons of water (FracFocus 2024). Although direct water usage associated with hydraulic fracturing jobs represents the majority of water usage for well development, well development requires other direct and indirect types of water use that are not associated with the hydraulic fracturing process (i.e., non-hydraulic fracturing water usage).

FracFocus does not report on non-hydraulic fracturing water use, which is largely associated with drilling activities. Non-hydraulic fracturing water use represents a small fraction of the total water use per well; however, this amasses to a substantial sum of additional water use across the planning area. Estimates for non-hydraulic fracturing water use are detailed in *Estimates of Water Use Associated with Continuous Oil and Gas Development in the Permian Basin, Texas and New Mexico, 2010–19* (Valder et al. 2021). Valder et al. (2021) characterizes non-hydraulic fracturing water uses as either direct or indirect water uses, which are defined as follows:

- **Direct non-hydraulic fracturing water usage**: This includes water used directly in a wellbore for activities such as drilling, cementing, and maintaining the well during production.
- **Indirect non-hydraulic fracturing water usage**: This encompasses water used at or near the well site, including water for dust abatement, equipment cleaning, materials washing, worker sanitation, and site preparation.

Valder et al. (2021) provides the following estimates for direct and indirect non-hydraulic fracturing water use:

- Direct – cementing (0.014 million gallons [Mgal] per well)
- Direct – drilling (0.143 Mgal per well)
- Indirect (0.111 Mgal per well)

Total non-hydraulic fracturing water use is approximately 0.268 Mgal per well, equivalent to 0.82 AF per well. The value of 0.82 AF per well is an estimate developed using the best available data on non-hydraulic fracturing water use and serves to provide an estimate by which an approximation can be derived. It is estimated that non-hydraulic fracturing water use in the state of Texas totaled 57,407.4 AF for 70,009 wells between the years 2014 and 2023 (see Table 4-2). In total, water use for the same time period, including both hydraulic fracturing water use and non-hydraulic fracturing water use, is estimated to be 2,507,832.1 AF (see Table 4-2). The reported total is an estimation and does not consider variables such as differences in water use between vertical and horizontal wells and local geology; additionally, this total assumes that FracFocus data is accurate and represents the total number of wells across Texas.

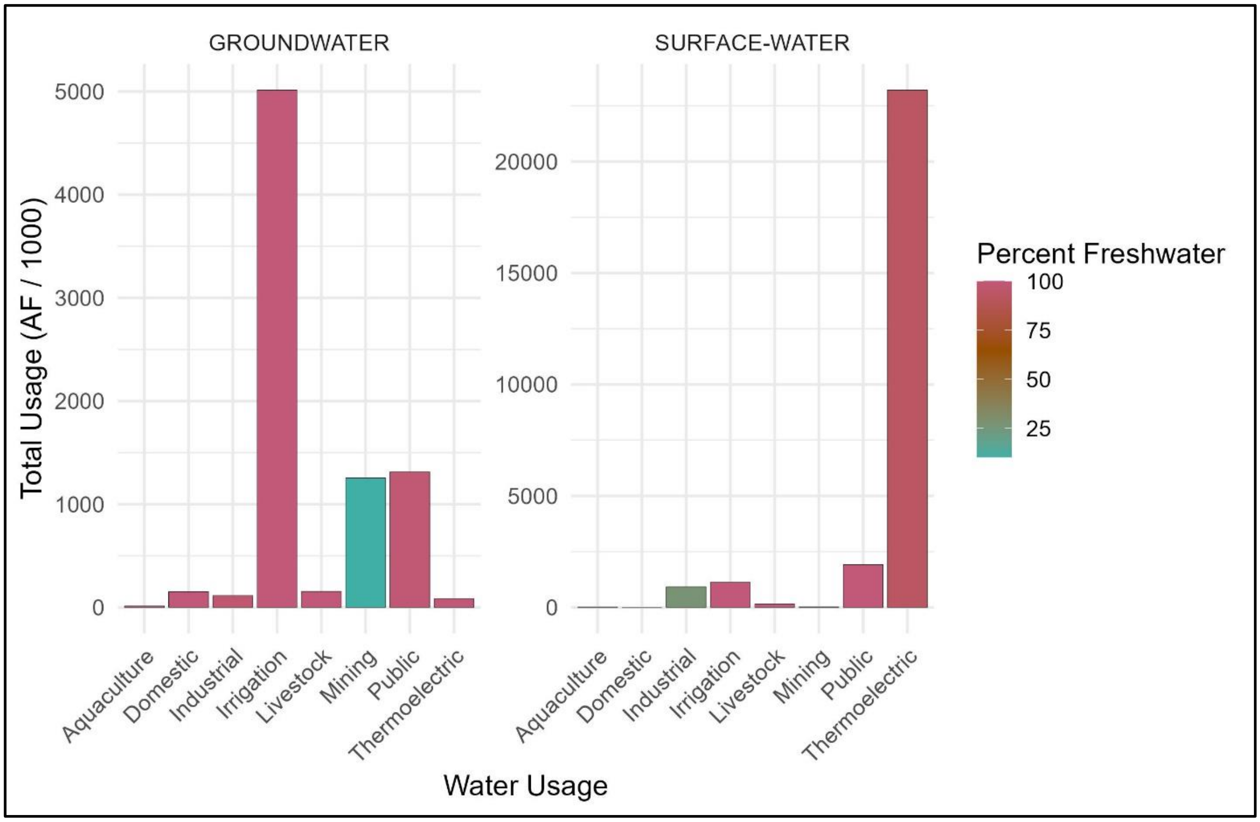


Figure 4-1. Water use by category for the state of Texas in 2015, colored by the percentage of freshwater use out of the total water use (freshwater plus saline water use) (Dieter et al. 2018).

Table 4-1. State of Texas Water Use by Category in 2015

Category	**Surface Water**				**Groundwater**				**Total Withdrawals**				**Total**	**Total Use (%)**
	Fresh	**Saline***	**Total**	**Total Use (%)**	**Fresh**	**Saline***	**Total**	**Total Use (%)**	**Fresh**	**Total Use (%)**	**Saline***	**Total Use (%)**		
Aquaculture	12,019	963	12,982	<1%	13,005	0	13,005	<1%	25,024	<1%	963	<1%	25,987	<1%
Domestic	0	–	0	0%	153,112	–	153,112	<1%	153,112	<1%	–	0%	153,112	<1%
Industrial	250,061	669,957	920,018	3%	111,813	3,674	115,487	<1%	361,874	1%	673,631	2%	1,035,505	3%
Irrigation	1,134,435	–	1,134,435	3%	5,014,351	–	5,014,351	14%	6,148,786	17%	–	0%	6,148,786	17%
Livestock	153,796	–	153,796	<1%	154,804	–	154,804	<1%	308,600	1%	–	0%	308,600	1%
Mining	17,799	11	17,810	<1%	129,421	1,125,306	1,254,727	4%	147,220	<1%	1,125,317	3%	1,272,537	4%
Public Water Supply	1,915,544	2,364	1,917,908	5%	1,291,995	22,078	1,314,073	4%	3,207,539	9%	24,442	<1%	3,231,981	9%
Thermoelectric Power	21,512,221	1,695,940	23,208,161	65%	84,414	0	84,414	<1%	21,596,635	61%	1,695,940	5%	23,292,575	66%
Total	**24,995,875**	**2,369,235**	**27,365,110**	**77%**	**6,952,915**	**1,151,058**	**8,103,973**	**23%**	**31,948,790**	**90%**	**3,520,293**	**10%**	**35,469,083**	**100%**

Source: Dieter et al. (2018)

Note: Values may not sum to totals because of independent rounding (Dieter et al. 2018). Water use data are in AF/year unless otherwise indicated.

* Saline water is defined as water containing dissolved solids of 1,000 mg/L or more. Saline water withdrawals are not reported for domestic, irrigation, or livestock water use (Dieter et al. 2018).

Table 4-2. Water Use by Oil and Gas Wells for Hydraulic Fracturing (HF) and Non-Hydraulic Fracturing (Non-HF) in Texas from 2014 through 2023

Year	Federal HF Water Use	Tribal HF Water Use	Non-Federal/ Tribal HF Water Use*	Total HF Water Use	Federal HF Water Use (%)	Federal HF Cumulative Water Use	Total HF Cumulative Water Use	Average HF Water Use per Well*	Total No. of Federal wells	Total No. of Wells	Total Non-HF Water Use	Total Water Use (HF plus non-HF)
2014	4,112.7	–	164,630.9	168,743.6	2%	4,112.7	168,743.6	12.0	431	13,723	11,252.9	179,996.5
2015	1,581.5	–	133,828.6	135,410.1	1%	5,694.2	304,153.7	17.6	107	7,501	6,150.8	141,560.9
2016	1,443.2	9.3	123,241.6	124,694.2	1%	7,137.4	428,847.9	26.6	1	4,573	3,749.9	128,444.1
2017	4,870.7	–	223,716.9	228,587.6	2%	12,008.1	657,435.5	34.5	117	6,457	5,294.7	233,882.3
2018	3,646.5	–	312,586.5	316,233.0	1%	15,654.6	973,668.5	39.3	104	7,846	6,433.7	322,666.7
2019	3,220.1	29.3	341,152.0	344,401.4	1%	18,874.7	1,318,069.9	43.9	102	7,657	6,278.7	350,680.1
2020	2,270.6	76.3	190,331.5	192,678.3	1%	21,145.3	1,510,748.2	48.3	66	3,936	3,227.5	195,905.8
2021	5,890.0	28.2	259,293.2	265,211.4	2%	27,035.3	1,775,959.6	46.3	117	5,633	4,619.1	269,830.5
2022	9,122.9	188.2	326,056.1	335,367.2	3%	36,158.2	2,111,326.8	49.1	183	6,740	5,526.8	340,894.0
2023	9,586.4	–	329,511.5	339,097.9	3%	45,744.6	2,450,424.7	56.5	188	5,943	4,873.3	343,971.2
Total	**45,744.6**	**331.3**	**2,404,349**	**2,450,424.7**	2%	**45,744.6**	**2,450,424.7**	**50.6**[†]	**1,416**	**70,009**	**57,407.4**	**2,507,832.1**

Source: FracFocus (2024a). Data only for those wells that reported water use to FracFocus are presented; well data may be incomplete due to state reporting requirements and may not reflect total active wells and exact water use.

Note: All water use data are presented in AF. Produced water is naturally occurring water that exists in a formation that is being targeted for mineral extraction and is produced as a byproduct.

* Includes both federal and non-federal wells.

[†] 3-year average (2021–2023)

4.3 Water Quality

4.3.1 Surface Water

In the state of Texas, the TCEQ administers CWA Sections 303(d), 305(b), and 314 related to surface water quality assessment and reporting. The TCEQ defines surface water quality beneficial uses and water quality standards to evaluate if these uses are being attained. Water quality standards include beneficial uses for surface waters of the state and associated water quality criteria to protect those uses. The TCEQ prepares a report every 2 years that identifies waterbodies not attaining their beneficial uses and lists them as “impaired.” The report also contains information on surface water quality and water pollution control programs in the state of Texas. The most recent approved report was published in 2022 (TCEQ 2022a) although a draft of the 2024 report is available (TCEQ 2024a). The BLM does not have authority to make use attainment evaluations based on water chemistry data.

Beneficial uses in Texas are identified as recreation, domestic water supply, aquatic life, navigation, agricultural water supply, industrial water supply, and wetland water quality functions (TCEQ 2024b). According to the 2022 report, a total of 1,051 waterbodies are listed as impaired across several different uses that include recreation, aquatic life, and fish consumption (TCEQ 2022b). The primary pollutants causing water quality impairments are bacteria, dissolved oxygen, dioxin/Polychlorinated biphenyls (PCBs) dissolved solids, and pH extremes (TCEQ 2022b).

4.3.2 Groundwater

The Groundwater Division of the TWDB oversees all aspects of groundwater studies in the state for nine major and 22 minor aquifers (TWDB 2024c). As a primary source of water, groundwater provides approximately 55% of the 14.7 million AF of water used in the state (TWDB 2024c). The TWDB conducts an extensive groundwater monitoring program across the state with an inventory of approximately 140,000 wells. The TCEQ developed a comprehensive groundwater assessment in April of 2022 that summarizes groundwater protection policies, ambient monitoring data, and groundwater contamination (TCEQ 2022b). Water quality constituents with a maximum contaminant level (MCL) or secondary standard were assessed by the number of wells that exceeded the MCL or standard (Table 4-3). The highest number of wells that exceeded an MCL or standard were for dissolved nitrate-nitrogen, fluoride, sulfate, and dissolved solids (see Table 4-3) (TCEQ 2022b). The major sources of contamination identified by the report include storage tanks, landfills, septic systems, agricultural activities, abandoned wells, oil and gas activities, and natural occurrence (TCEQ 2022b).

Table 4-3. Groundwater Quality Summary by Assessed Wells

Parameters with an MCL	Primary MCL or Secondary Standard*	Total Number of Wells	Number of Wells That Exceed the MCL or Secondary Standard*	Percentage of Wells That Exceed the MCL or Secondary Standard*
Dissolved Arsenic	10 µg/L	2,292	151	7
Dissolved Barium	2 mg/L	2,296	1	< 1
Dissolved Cadmium	5 µg/L	2,266	0	0
Dissolved Chromium	100 µg/L	2,291	0	0
Dissolved Fluoride	4 mg/L	2,373	107	5
Dissolved Mercury	2 µg/L	2,238	0	0
Dissolved Nitrate-Nitrogen	10 mg/L	2,305	533	23%

Parameters with an MCL	Primary MCL or Secondary Standard*	Total Number of Wells	Number of Wells That Exceed the MCL or Secondary Standard*	Percentage of Wells That Exceed the MCL or Secondary Standard*
Dissolved Selenium	50 µg/L	2,292	82	4%
Chloride	300 mg/L	2,363	275	12%
Fluoride	2 mg/L	2,373	492	21%
Sulfate	300 mg/L	2,316	361	16%
Copper	1 mg/L	2,292	0	0%
Iron	0.3 mg/L	2,371	272	11%
Manganese	50 µg/L	2,311	189	8%
Dissolved Solids	1,000 mg/L	2,376	453	19%
Zinc	5 mg/L	2,291	3	< 1%

µg/L = micrograms per liter

*Secondary standard is a concentration above which water in a public system may only be used with written approval from the TCEQ (TCEQ 2022b).

4.3.3 Potential Sources of Contamination

The chemical composition of water used during the hydraulic fracturing process varies due to differences in fracturing techniques used by oil and gas companies. A typical oil/gas well uses approximately 20 to 25 unique chemicals during the hydraulic fracturing process, but in some cases, more than 60 distinct chemicals can be used. The most disclosed chemical constituents of hydraulic fracturing used in Texas wells from 2014 through 2023 were nondisclosed chemicals, followed by water, with 256,980 disclosures and 247,725 disclosures, respectively (Table 4-4). Other major chemical constituent disclosures were methanol (n = 70,477) and hydrochloric acid (n = 38,748). In total, there were 2,711,294 chemical records entered in the FracFocus database; however, many chemical recordings represent the same chemicals recorded differently (see Table 4-4) (FracFocus 2024). Ingredient names and CAS numbers are not standardized in FracFocus, leading to widespread differences and discrepancies in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in Table 4-4 are for general information only. Appendix A contains information on how FracFocus data are analyzed and summarized.

Oil and gas development spills have the potential to impact surface water directly by falling into a waterbody or indirectly by surface runoff, soil contamination, and ensuing transport during rainfall, or migration into groundwater and subsequent discharge from a spring into surface water. The jurisdiction over different spill types in Texas is divided among several state and federal agencies, each with specific responsibilities based on the nature and location of the spill. The TCEQ oversees spills that involve hazardous materials, chemicals, and other pollutants that affect state waters and land, including but not limited to oil-related spills (TCEQ 2022a). The Texas General Land office handles oil spills in Texas coastal waters, including bays, estuaries, and the Gulf of Mexico (Texas General Land Office 2024). The Railroad Commission of Texas is primary agency for handling reporting and handling oil and gas spills, particularly those related to exploration, production, and transportation within the oil and gas sector (Railroad Commission of Texas 2024).

According to the Texas Administrative Code Title 30, Section 327.3, the release of oil, petroleum products, used oil, hazardous substances, industrial solid waste, or other materials into the environment must be reported to the TCEQ within 24 hours of the discovery. Rule § 327.4 specifies exact threshold quantities that trigger reporting to the TCEQ; for example, any quantity of water spilled into waters of the state that are sufficient to create a sheen, or any spill onto land of 210 gallons (5 barrels) or more (Texas

Secretary of the State 1996). All major and minor release reports (spills) are archived in the TCEQ spills database, which can be downloaded online (TCEQ 2024c).

Spill data for Texas were retrieved from the TCEQ (2024b). Spill data for Texas include a variety of metadata, such as the type of spill (e.g., waste, water, air), the spill classification (e.g., oil, water, hazardous, other), and the specific material released (e.g., produced water, diesel). At least one of these metadata categories are included for each spill entry; however, not all entries include sufficient detail to classify the spill down to the material released. Using these metadata, a hierarchical classification scheme was devised to group spills into the following groups: gaseous spills, hazardous, oil, waste, and produced water. Additional details on frequently reported materials spilled are included herein; however, the list is not used to group spill types due to quantity of reported spill materials across the state. Additionally, the TCEQ includes the name of receiving waterbody, which was used to create a ternary grouping scheme with the following levels: Waters Impacted, Waters Not Impacted, and Unknown Impact to Waters. The TCEQ spill data does not include data on the quantity of each spill that was recovered.

In total, 6,059 spills were reported to the TCEQ between 2014 and 2023; with the majority of spill incidents reported in 2018 (n = 822). In total, 544 (9.0% of total spills) incidents reported no impacts to waters, 1,314 (21.7% of total spills) incidents reported impacts to waters, and 4,201 (69.3% of total spills) incidents were reported to be unknown (unknown if waters were impacted). The most frequently reported spill classification was oil, accounting for 2,247 of all spills between 2014 and 2023. Of the 2,247 oil spills, 606 (27% of total oil spills) spills were reported to impact water resources, 321 (14.3% of total oil spills) spills were reported to not impact water resources, and 1,320 (58.7% of total oil spills) spills were reported as having unknown impacts to water resources (see Table 4-4; Figure 4-2). A full spill summary for all spills reported to the TCEQ are presented in Table 4-4.

In 2023, the TCEQ received 92 reported oil spills, totaling 1,234 barrels. Of the total quantity of oil spilled, 121 (9.8%) barrels were reported to impact water resources, 4.5 (<1%) barrels were reported to not impact water resources, and the impact on water resources was unknown for 1,109 (90%) barrels. Additionally, the following cumulative total spills were reported to the TCEQ in 2023: 79,112 pounds of gaseous material (classified as air), 2,640 barrels and an additional 613 pounds of waste, 813 barrels and an additional 34,626 pounds of hazardous material, and 2,526 barrels of water (see Tables 4-5 and 4-6 for additional details on reported spills, units, and cumulative totals, as reported to the TCEQ).

Within the state of Texas, the most frequently reported spill type is diesel fuel (in barrels), with 774 reported incidents between the years 2014 and 2023. Other frequently reported spill materials during the same time period include sewage (in barrels; n = 234), benzene (in pounds; n = 174), and sulfur dioxide (in pounds; n = 140) (Table 4-7).

Table 4-4. Most Frequently Disclosed Ingredients Reported to FracFocus within the State of Texas from 2014 through 2023

Ingredient Name[*]	CAS Registry Number	Number of Disclosures	Percentage of Hydraulic Fracturing Jobs[†]	Percentage of Total Number of FracFocus Disclosures[‡]
Not Disclosed	N/A	256,980	N/A	9.48%
Water	N/A	247,725	N/A	9.14%
Methanol	14808-60-7	70,477	0.03%	2.60%
Sodium Hydroxide	7727-54-0	38,945	0.01%	1.44%
Hydrochloric Acid	64742-47-8	38,748	0.21%	1.43%
Sodium Chloride	68551-12-2	37,423	0.04%	1.38%

Ingredient Name[*]	**CAS Registry Number**	**Number of Disclosures**	**Percentage of Hydraulic Fracturing Jobs**[†]	**Percentage of Total Number of FracFocus Disclosures**[‡]
Ethylene Glycol	67-63-0	36,024	0.02%	1.33%
Acetic Acid	78330-21-9	33,420	0.00%	1.23%
Proprietary	N/A	29,825	0.02%	1.10%
Guar Gum	107-19-7	28,458	0.16%	1.05%
Crystalline Silica, Quartz	14808-60-7	28,006	8.41%	1.03%
Citric Acid	1344-28-1	24,955	0.01%	0.92%
Glutaraldehyde	67-56-1	24,932	0.03%	0.92%
Ethanol	68424-85-1	24,740	0.01%	0.91%
Ammonium Chloride	111-30-8	24,350	0.01%	0.90%
Ammonium Persulfate	9000-30-0	23,187	0.02%	0.86%
Hydrogen Chloride	7647-01-0	22,360	0.13%	0.82%
Isopropanol	77-92-9	22,300	0.01%	0.82%
Propargyl Alcohol	64-19-7	22,247	0.01%	0.82%
Crystalline Silica	12125-02-9	16,934	8.18%	0.62%
Methyl Alcohol	67-56-1	16,795	0.01%	0.62%
Potassium Hydroxide	1310-58-3	15,863	0.01%	0.59%
Distillates (Petroleum), Hydro Treated Light	64742-55-8	14,882	0.04%	0.55%
Surfactant	Unknown	14,767	0.03%	0.54%
Crystalline Silica (Quartz)	14808-60-7	14,390	8.35%	0.53%

Source: FracFocus (2024a)

Note: Ingredient names and CAS numbers are not standardized in FracFocus, leading to widespread differences and discrepancies in CAS numbers, number of disclosures, and ingredient names. For this reason, the values and ingredients presented in this table are for general information only.

N/A = Not Applicable

* FracFocus lists certain chemicals as proprietary, and no additional information is available regarding ingredient contents.

† The amount of the ingredient in the total hydraulic fracturing volume by percent mass (definition from FracFocus [2024a] data dictionary).

‡ Percentage represents the number of documented chemical disclosures out of the total number of disclosures.

Table 4-5. Summary of Spill Counts Reported across the State of Texas from 2014 through 2023

Year	Waters Impacted						Waters Not Impacted						Unknown Impact to Waters						Total Spills
	Air	Hazardous	Oil	Waste	Water	Total	Air	Hazardous	Oil	Waste	Water	Total	Air	Hazardous	Oil	Waste	Produced Water	Total	
2014	2	33	72	41	10	158	ND	34	58	10	7	109	14	44	76	56	31	221	488
2015	3	29	83	34	23	172	2	30	55	12	1	100	15	107	129	74	30	355	627
2016	3	28	63	18	39	151	ND	16	27	7	2	52	31	228	205	62	35	561	764
2017	ND	31	62	20	36	149	–	12	25	7	1	45	60	240	226	73	19	618	812
2018	3	24	68	32	43	170	ND	15	29	9	ND	53	103	190	201	83	22	599	822
2019	1	22	71	22	21	137	1	12	55	6	1	75	51	86	147	65	22	371	583
2020	4	16	66	21	23	130	1	7	43	6	ND	57	106	62	99	39	36	342	529
2021	1	13	69	18	22	123	ND	5	19	2	ND	26	163	69	108	85	92	517	666
2022	1	6	26	17	13	63	ND	2	5	2	1	10	93	30	67	92	87	369	442
2023	3	8	26	15	9	61	ND	2	5	10	ND	17	26	11	62	79	70	248	326
Total	**21**	**210**	**606**	**238**	**239**	**1,314**	**4**	**135**	**321**	**71**	**13**	**544**	**662**	**1,067**	**1,320**	**708**	**444**	**4,201**	**6,059**

Source: TCEQ (2024c)

Note: ND = No Data

Table 4-6. Summary of 2023 Spills Reported across the State of Texas, Including Those That Impacted Waters, Did Not Impact Waters, and Had Unknown Impacts on Waters

Spill Type	Waters Impacted				Waters Not Impacted				Unknown Impact to Waters				Total Barrels spilled	Total Pounds spilled	Total Spills
	Barrels Spilled	Pounds Spilled	Total Spill Count Including Known Units	Total Spill Count Including Unknown Units	Barrels Spilled	Pounds Spilled	Total Spill Count Including Known Units	Total Spill Count Including Unknown Units	Barrels Spilled	Pounds Spilled	Total Spill Count Including Known Units	Total Spill Count Including Unknown Units			
Air	–	259	1	2	–	–	–	–	ND	73,853	19	7	–	79,112	29
Waste	10	–	4	11	929	25	9	1	1,701	611	43	35	2,640	613	103
Hazardous	39	13,496	7	1	1	–	3	–	773	21,130	11	1	813	34,626	23
Water	ND	–	6	3	–	–	–	–	2,526	–	58	12	2,526	–	79
Oil	121	–	25	1	4.5	–	4	–	1,109	–	55	7	1,234.5	–	92
Total	170	13,755	43	18	935	25	16	1	6,109	95,594	186	62	7,214	114,351	326

Source: TCEQ (2024c)

Note: "–" = No numeric data, representing entries with known units and no numeric spill entry. For the purposes of this report, it is assumed that these entries represent unknown spill quantities.

ND = No data due to no reporting

Although many spill entries with unknown units include numeric entries, these values are not reported herein to avoid reporting across different units. Regardless, the spill is reported here as a spill with a non-zero quantity spilled.

Table 4-7. Summary of the Top 10 Most Reported Spill Materials to the State of Texas from 2014 to 2023, Further Categorized by Unit of Spill

Material	Unit	Spills Reported	Total Reported Quantity Spilled
Diesel Fuel	Barrels	774	10,319
Sewage	Barrels	234	13,0351
Other	Barrels	136	204,592
Gasoline	Barrels	129	36,307
Diesel/Gasoline/Water Mixture	Barrels	117	5,302
Hydraulic Oil	Barrels	114	420
Crude Oil	Barrels	109	7,532
Wastewater Discharge, Municipal	Barrels	95	32,218
Gasoline, Automotive, or Aviation	Barrels	87	1,215
Diesel Oil #2/Guar Gum	Barrels	78	546
Benzene	Pounds	174	11,604
Sulfur Dioxide	Pounds	140	45,4454
Vinyl Chloride	Pounds	82	217
Ethylene Dichloride	Pounds	54	44,462
Ethylene Oxide	Pounds	39	2,325
Hydrogen Sulfide	Pounds	39	8,033
1,3 Butadiene	Pounds	37	3,702
Butadiene, 1-3	Pounds	35	2,525
1,3-BUTADIENE	Pounds	33	270
Butadiene	Pounds	31	1,027
N/A	Unknown	408	0
Other	Unknown	109	0
Diesel Fuel	Unknown	50	164
Unknown	Unknown	36	0
Gasoline	Unknown	33	0
Unknown Substance	Unknown	29	0
Vinyl Chloride	Unknown	26	0
Wastewater Discharge, Industrial	Unknown	22	0
Unknown or Other Oil	Unknown	21	0
OIL	Unknown	20	0
Smoke	Unknown	20	0

N/A = Not Applicable

Source: TCEQ (2024c)

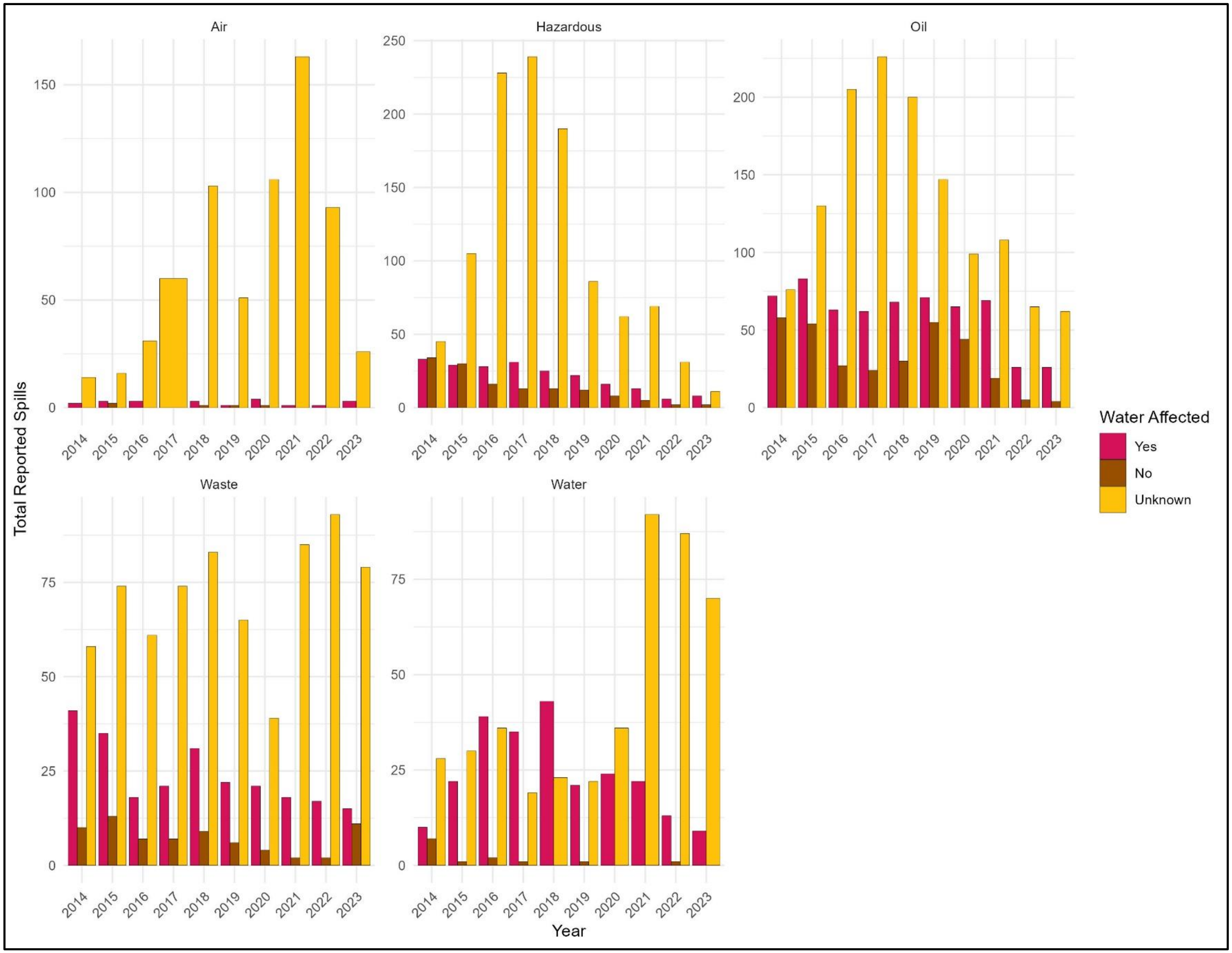


Figure 4-2. Total reported spills across Texas from 2014 to 2023, categorized by spill type and water impact.

5 OKLAHOMA FIELD OFFICE

5.1 Potential Sources of Water Use for the OFO

The OFO oil and gas plays across Kansas, Texas, and Oklahoma predominantly use a combination of ground and surface water for oil and gas activities (BLM 2016). Kansas and Oklahoma rely predominantly on surface water for hydraulic fracturing, while the more arid regions, especially southwest Texas, rely on groundwater sources (BLM 2016). Until recently, most groundwater used for hydraulic fracturing came from freshwater sources; however, saline, produced, and flowback water are now being utilized for many hydraulic fracturing jobs (BLM 2016). Groundwater underlying oil and gas lease areas represents a significant source of water for oil and gas development in the OFO planning area. Table 5-1 presents each county in the OFO where oil and gas leasing and development has occurred over the last 10 years (2014–2024), with each county's associated principal aquifer.

Three major aquifers are present within the OFO's jurisdictional boundary. Most water utilized for oil and gas development is primarily sourced from five principal aquifers (High Plains, Rio Grande, Texas Coastal uplands, Coastal lowlands, and Pecos River Basin) (Figure 5-1).

Table 5-1. Principal Aquifers by State and County in the OFO

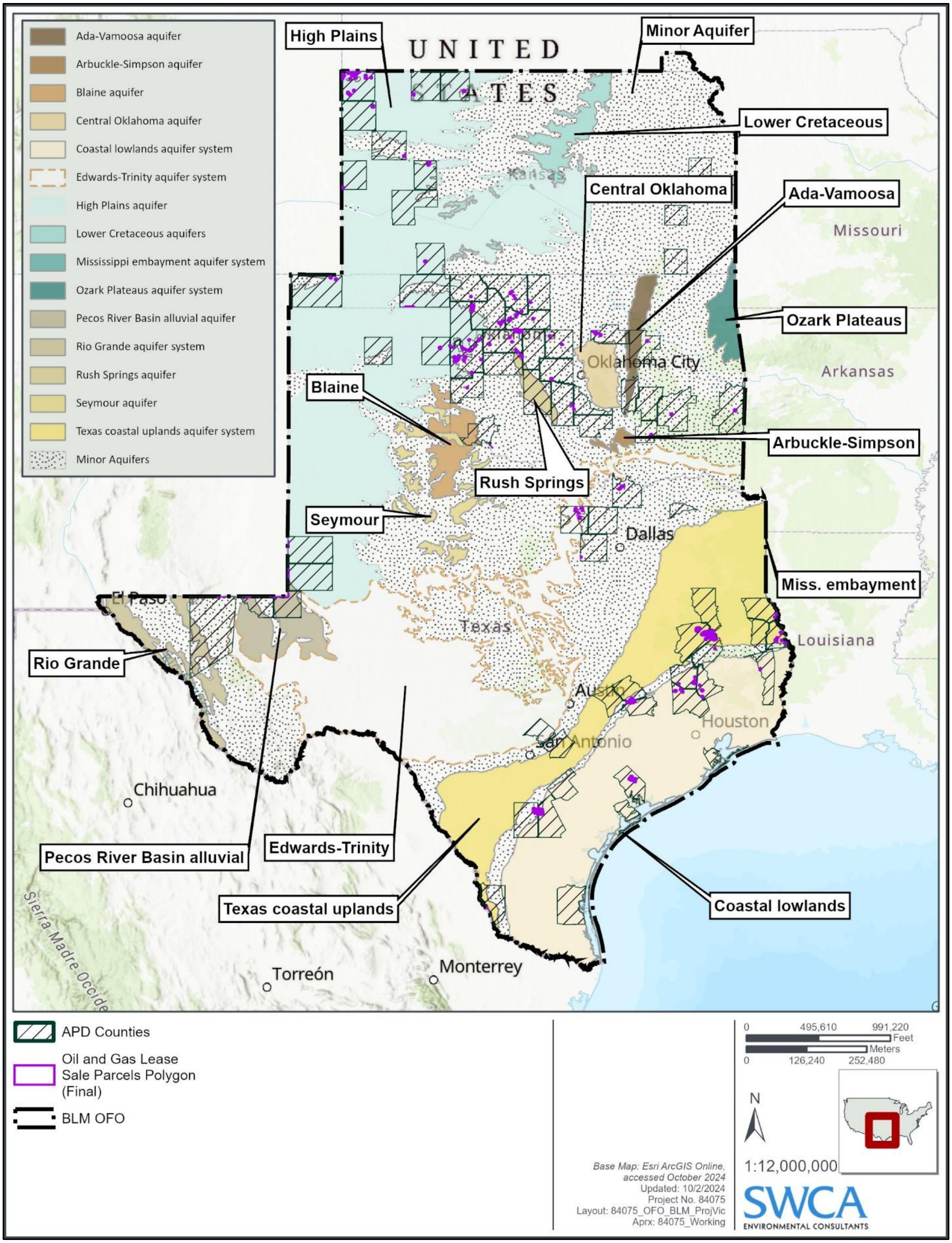
State	County*	Principal Aquifer
Kansas	Cheyenne	High Plains Aquifer
	Decatur	High Plains Aquifer
	Finney	High Plains Aquifer
	Franklin	High Plains Aquifer
	Greeley	High Plains Aquifer
	Lane	High Plains Aquifer
	Logan	High Plains Aquifer
	Meade	High Plains Aquifer
	Montgomery	High Plains Aquifer
	Norton	High Plains Aquifer
	Sherman	High Plains Aquifer
	Woodson	High Plains Aquifer
Oklahoma	Alfalfa	High Plains Aquifer
	Beaver	High Plains Aquifer
	Beckham	High Plains Aquifer
		Blaine Aquifer
	Blaine	Rush Springs Aquifer
	Caddo County	Rush Springs Aquifer
	Canadian	Rush Springs Aquifer
	Cimarron	High Plains Aquifer
	Coal	Arbuckle-Simpson Aquifer
	Creek	Ada-Vamoosa Aquifer
	Custer	Rush Springs Aquifer

State	County*	Principal Aquifer
	Dewey	High Plains Aquifer
	Ellis	High Plains Aquifer
	Garvin	Arbuckle-Simpson Aquifer
	Grady	Rush Springs Aquifer
	Harper	High Plains Aquifer
	Hughes	Minor aquifers
	Jackson	Blaine Aquifer
		Seymour Aquifer
	Kingfisher	Minor aquifers
	Le Flore	Minor aquifers
	Major	Minor aquifers
	McClain	Minor aquifers
	Payne	Ada-Vamoosa Aquifer
		Central Oklahoma Aquifer
	Pittsburg	Minor aquifer
	Roger Mills	High Plains Aquifer
	Seminole	Ada-Vamoosa Aquifer
	Woods	Minor aquifers
	Woodward	High Plains Aquifer
Texas	Andrews	High Plains Aquifer
		Pecos River Basin Alluvial Aquifer
	Burleson	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Calhoun	Coastal Lowlands Aquifer System
	Cherokee	Texas Coastal Uplands Aquifer System
	Comal	Edwards-Trinity Aquifer system
	Culberson	Edwards-Trinity Aquifer system
		Rio Grande Aquifer system
	Delta	Minor aquifers
	Denton	Edwards-Trinity Aquifer system
	Gaines	High Plains Aquifer
	Galveston	Coastal Lowlands Aquifer System
	Grayson	Edwards-Trinity Aquifer System
	Guadalupe	Texas Coastal Uplands Aquifer System
	Hemphill County	High Plains Aquifer
	Houston County	Texas Coastal Uplands Aquifer System
	Hutchinson County	High Plains Aquifer
	Jackson County	Coastal Lowlands Aquifer System
	Jasper County	Minor aquifers

State	County*	Principal Aquifer
	Karnes County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Kenedy County	Coastal Lowlands Aquifer System
	Lee County	Texas Coastal Uplands Aquifer System
	Live Oak County	Coastal Lowlands Aquifer System
	Loving County	Pecos River Basin Alluvial Aquifer
	McMullen County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Montgomery County	Coastal Lowlands Aquifer System
	Sabine County	Coastal Lowlands Aquifer System
		Mississippi Embayment Aquifer System
		Texas Coastal Uplands Aquifer System
	San Augustine County	Texas Coastal Uplands Aquifer System
	San Jacinto County	Coastal Lowlands Aquifer System
	Shelby County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Tarrant County	Edwards-Trinity Aquifer System
	Trinity County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Walker County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System
	Washington County	Coastal Lowlands Aquifer System
	Winkler County	Edwards-Trinity Aquifer System
		High Plains Aquifer
		Pecos River Basin Alluvial Aquifer
	Wise County	Edwards-Trinity Aquifer System
	Zapata County	Coastal Lowlands Aquifer System
		Texas Coastal Uplands Aquifer System

* Targeted counties were selected through review of BLM OFO oil and gas lease sales over the last 10 years (2014–2024) and BLM OFO applications for permit to drill (APDs) over the last 10 years (2014–2024).

Note: A "minor aquifer" is a groundwater reservoir that is smaller in size, less permeable, or less well-connected than major aquifers, and which might be more limited in its capacity or recharge rate.



Base Map: Esri ArcGIS Online, accessed October 2024
Updated: 10/2/2024
Project No. 84075
Layout: 84075_OFO_BLM_ProjVic
Aprx: 84075_Working

Figure 5-1. Oil and gas leases and associated principal aquifers in the OFO.

5.1.1 High Plains Aquifer

The High Plains Aquifer spans from northern Texas to southern South Dakota, covering an area of approximately 174,000 square miles across eight states. The High Plains Aquifer underlies primary agricultural regions in the United States. Water production for irrigation began in the late 1800s; however, groundwater withdrawals increased throughout the early twentieth century to an estimated 19 million AF in 1974 (McGuire and Strauch 2024). In 2015, water withdrawals from the High Plains Aquifer were estimated to be around 13 million AF (McGuire and Strauch 2024). Recent analyses during pre-development and post-development (1950 and 2019, respectively) indicate that the recoverable water in storage is approximately 2.91 billion AF, representing a decline of 286.4 million AF (or about 10%) since the 1950s (McGuire and Strauch 2024). From the pre-industrial era (around 1950) to 2019, the depth to groundwater declined by approximately 26.1 feet in Kansas, New Mexico, Oklahoma, and Texas, with levels ranging between -14.2 feet in Oklahoma and -44.1 feet in Texas (see Table 5-1) (McGuire and Strauch 2024). In 1980, the depth to groundwater was reported to be less than 100 feet below the surface across half of the aquifer and less than 200 feet across Nebraska and Kansas (Miller and Appel 1997). In 1992, the average saturated thickness of the aquifer was approximately 190 feet; however, in some areas, it could be as much as 1,000 feet (Miller and Appel 1997). Groundwater withdrawals currently exceed recharge rates across large portions of the aquifer. Aquifer recharge is primarily derived from intermittent and ephemeral surface flow from streams and infiltration of precipitation. An estimated two-thirds of recharge—approximately 196,000 AF per year—occurs in a large part of the aquifer underlying Colorado (USGS 1995). Additional details on groundwater development and sustainability, including projected water use, are detailed in *The High Plains Aquifer, USA: Groundwater development and sustainability* (Dennehy et al. 2002). Table 5-2 presents each of the states in the OFO with each state's respective change in depth to water from 1950 to 2019.

Table 5-2. High Plains Aquifer Analysis Across the OFO from 1950 to 2019

State	USGS Principal Aquifer	Average Change in Depth to Aquifer from Pre-Industrial Era (1950 vs. 2019) (feet)
Kansas	High Plains Aquifer	-27.0
Oklahoma	High Plains Aquifer	-14.2
Texas	High Plains Aquifer	-44.1

Source: Dennehy et al. 2002.

5.1.2 Rio Grande Aquifer

The Rio Grande Aquifer spans portions of Colorado, New Mexico, and Texas, representing a major source of public domestic and irrigational water supply. The aquifer ranks 18th in the nation for public water supply, providing approximately 240 Mgal per day, with an additional 867 Mgal per day used for irrigation and 18 Mgal per day for domestic water use. In total, the Rio Grande Aquifer supplies 1.125 billion gallons of water per day, or about 3,450 AF per day. Albuquerque, New Mexico, and El Paso, Texas, represent major cities that heavily rely on the Rio Grande Aquifer (USGS 2017). Precipitation and runoff from surrounding mountains are the principal sources of recharge to the aquifer—namely, runoff into the San Luis valley from the San Juan Mountains to the west and the Sangre De Cristo Mountains to the east (USGS 1995).

5.1.3 Texas Coastal Uplands Aquifer System

The Texas Coastal Uplands Aquifer System, consisting of the subcrop and outcrop of the Carrizo Wilcox Aquifer system, underlies approximately 48,000 square miles of the Coastal Plain Physiographic Province across the majority of Texas and provides large quantities of freshwater for agriculture, industry, and public needs. The Texas Coastal Uplands Aquifer System is a principal aquifer that is composed of four smaller aquifers and two hydrologically unique confining units (Ryder 1988). These are, from shallowest to deepest, the upper Claiborne Aquifer; the middle Claiborne confining unit; the middle Claiborne Aquifer; the lower Claiborne confining unit; the lower Claiborne-upper Wilcox Aquifer; and the middle Wilcox Aquifer. (Ryder 1988). The entire Texas Coastal Uplands Aquifer System is underlain by the highly impermeable Midway confining layer (Ryder 1988). Horizontal hydraulic conductivity values are variable across the Texas Coastal Uplands Aquifer System and range between approximately 1 and 102 feet per day (Ryder 1988). Recharge to the Texas Coastal Uplands Aquifer System occurs primarily through direct precipitation and downward percolation to the aquifer system. The Texas Coastal Uplands Aquifer System averages between 21 and 50 inches of precipitation per year; however, it has an approximate recharge rate of 0.52 inch/year (Ryder 1988). The Texas Coastal Uplands Aquifer System has a thickness that ranges between approximately 0 and 3,000 feet (Ryder 1988). The aquifer is primarily characterized by high permeability unconsolidated materials that consist mainly of sand, gravel, and clay (Ryder 1988).

5.1.4 Coastal Lowlands Aquifer System

The Coastal Lowlands Aquifer System, also known as the Gulf Coast Aquifer, is composed of seven distinct hydrologic units. The Coastal Lowlands Aquifer System, from oldest formation to youngest, contains the lower Miocene-upper Oligocene permeable zone; lower Miocene-upper Oligocene confining unit; middle Miocene permeable zone; middle Miocene confining unit; lower Pliocene-upper Miocene permeable zone; lower Pleistocene-upper Pliocene permeable zone; and Holocene-upper Pleistocene permeable zone (Ryder 1988). In the Coastal Lowlands Aquifer System, water containing permeability zones are contained by near-impermeable confining layers (Ryder 1988). Aquifer thickness is variable across the Coastal Lowlands Aquifer System but typically ranges from 0 to 4,000 feet (Ryder 1988). Water-bearing aquifer material primarily consists of high-porosity sands intermixed with semi-permeable clay lenses (Ryder 1988). Horizontal hydraulic conductivity values typically range from 60 to 170 feet per day across the Coastal Lowlands Aquifer System (Ryder 1988). Higher hydraulic conductivity values are typically found in the younger shallower aquifers and generally decrease in the older aquifers (Ryder 1988). Recharge to the Coastal lowlands aquifer system occurs primarily through direct precipitation and percolation to the water table (Ryder 1988). Some cross-aquifer flows occur between the overlying and underlying aquifers; however, recharge from cross-aquifer flow is negligible (Ryder 1988).

5.1.5 Pecos River Basin Alluvial Aquifer

The Pecos River Basin Alluvial Aquifer, consisting of the Edwards-Trinity Plateau Aquifer, the Edwards (Balcones Fault Zone) Aquifer, and the outcrop of the Trinity Aquifer, underlies approximately 8,650 square miles across West-Texas and New Mexico and provides a substantial source of freshwater for irrigation, public supply, and industrial purposes (Meyer et al. 2012). The Pecos River Basin Alluvial Aquifer is separated by two distinct hydrologic units, the north-south-trending Pecos and Monument Draws. The Pecos and Monument Draws are filled with approximately 1,700 feet of tertiary and quaternary alluvial sediments (Meyer et al. 2012). The Pecos River Basin Alluvial Aquifer is primarily composed of alluvial material that consists of unconsolidated silt, sand, gravel, and clay (Meyer et al. 2012). The Pecos River Basin Alluvial Aquifer contains approximately 15 million AF of freshwater and approximately 85 million AF of brackish water (1,000 to 10,000 mg/L of TDS) (Meyer et al. 2012).

Recharge to the Pecos River Basin Alluvial Aquifer generally occurs from the northwest via subsurface flow from the Edwards-Trinity Aquifer System and discharge to springs, streams, and seeps found in the Pecos Valley (Clark et al. 2014). Due to the presence of high-porosity alluvial aquifer materials, the Pecos River Basin Alluvial Aquifer has a relatively high mean hydraulic conductivity of 8.6 feet per day (Meyer et al. 2012). Transmissivity values range widely (approximately 0 to 14,000 feet) due to changes in aquifer thickness (Meyer et al. 2012).

5.2 Future Water Use Associated with Reasonably Foreseeable Oil and Gas Development

The 2016 *Reasonable Foreseeable Development Scenario for the Oklahoma Field Office* (BLM 2016) provides future projections associated with oil and gas development. The 2016 RFD provides a 20-year development scenario to predict oil and gas development across the entire OFO. The 2016 RFD uses data from the Energy Information Administration to derive the average yearly increase in well construction across the OFO (BLM 2016) by extrapolating Energy Information Administration production data for the OFO. The 2016 RFD estimates that there could be between 775 and 3,054 new federal and trust wells within the OFO planning area by 2040 (BLM 2016). In an effort to project water use associated with oil and gas into the future, three well construction projections (conservative, modest, aggressive) are presented using the range of well construction estimates from the 2016 RFD: conservative (775 new wells), moderate (1,527 new wells), and aggressive (3,054 new wells) (Figure 5-2).

The BLM estimates that approximately 50% of oil and gas wells constructed after year 2018 will be horizontal fracture wells; however, the 2016 RFD does not estimate water use associated with hydraulic fracturing into future years (BLM 2016). Wells that utilized hydraulic fracturing are assumed to use 25% more water when compared to other fracturing processes (BLM 2016). The BLM estimates that between 5% and 40% of water used during the fracturing process is returned via hydraulic flowback; however, flowback is generally flushed out during well testing or in the early stages of production, making it difficult to quantify (BLM 2016). For all projected scenarios, flowback will not be considered, and both fracturing and refracturing hydraulic wells will assume 0% recoverable water.

To calculate cumulative water use for each well construction projection, the average per-well water use estimates for the states of Oklahoma, Kansas, and Texas (presented in Chapters 2, 3 and 4, respectively) were averaged to create a per-well water use estimate for the OFO planning area. The OFO per-well water use estimate was multiplied by each well construction forecast to find the cumulative water use for each well construction scenario (Table 5-3a, see Figure 5-2). The average water use per well for the OFO planning area is estimated at 28.6 AF.

Table 5-33a. RFD Federal Well Projections and Associated Water Use

RFD Scenario (2040 new well development [annual well development])*	Cumulative Water Use (AF) (2012-2040)†	Annual Water Use (AF)
Conservative (775 wells [27 wells per year])	22,165	792
Moderate (1,527 wells [53 wells per year)	43,672	1,560
Aggressive (3,054 wells [105 wells per year])	87,344	3,119

*RFD well development projections (see Chart 50 of the 2016 RFD [BLM 2016]) begin in the year 2012 and end in the year 2040.

†Water use estimates are calculated using an average water use per well of 28.6 AF across the OFO planning area.

The OFO contains federal, non-federal, and tribal wells (as reported in FracFocus), but the 2016 RFD provides projections only for federal wells and wells held in trust for Tribes. These historically make up a small percentage of all wells drilled in the OFO, so current well construction across the OFO is significantly higher than estimates in the 2016 RFD. Table 5-3b shows the total number of wells reported to FracFocus (regardless of well ownership) and compares the federal wells reported to FracFocus with the 2016 RFD federal and trust well projections.

Between the years 2014 and 2023, 84,072 wells were constructed across the OFO according to FracFocus, with 1,640 being federal wells. In contrast, annual well projections from the 2016 RFD (105 wells per year under the most aggressive scenario) result in an estimated 1,050 wells over this same time frame, which is 36% less than the actual number of federal wells reported to FracFocus (see Table 5-3b).

The cumulative water use reported by FracFocus from 2014 to 2023 was 2,799,091.6 AF, with 51,525.5 AF accounted for by federal wells. In contrast, the water use estimate for the most aggressive RFD scenario (105 wells per year) totals 30,115.8 AF over the same time frame, which is 42% less than the actual number of federal wells reported to FracFocus (see Table 5-3b). Table 5-4 estimates RFD water use based on the OFO average per-well water consumption according to FracFocus (28.6 AF per well).

Table 5-3b. RFD and FracFocus Federal Well Construction Across the OFO

Year	Total Well Construction Across the OFO	Federal Well Construction Across the OFO	RFD Federal and Trust Well Projection (Aggressive)
2014	16,960	484	105
2015	9,233	166	105
2016	5,718	14	105
2017	8,010	134	105
2018	9,767	140	105
2019	9,249	129	105
2020	4,428	73	105
2021	6,299	117	105
2022	7,727	185	105
2023	6,681	198	105
Total	**84,072**	**1,640**	**1,050**
Yearly Average	**8,407**	**164**	**105**

Note: Well construction totals for Oklahoma, Texas, and Kansas were summed to get yearly well construction across the OFO (FracFocus 2024). Total and federal well construction numbers come from FracFocus (2024), and RFD projections come from BLM (2016).

Table 5-4. RFD and FracFocus Cumulative Water Use

Year	FracFocus Cumulative Water Use (AF)	FracFocus Federal Water Use (AF)	RFD Federal and Trust Water Use Projection (Aggressive) (AF)
2014	200,303.7	4,662.7	3,003
2015	361,454.4	7,650.5	6,034.6
2016	515,446.7	9,295.1	9,037.6
2017	793,596.9	14,540.9	12,040.6
2018	1,171,288.1	18,989.4	15,072.2
2019	1,568,526.8	23,648.7	18,075.2
2020	1,776,927.5	26,337.4	21,078.2

Year	FracFocus Cumulative Water Use (AF)	FracFocus Federal Water Use (AF)	RFD Federal and Trust Water Use Projection (Aggressive) (AF)
2021	2,061,382.6	32,227.4	24,081.2
2022	2,428,663.1	41,407.2	27,112.8
2023	2,799,091.6	51,525.5	30,115.8

Note: Because no average AF was present in the 2016 RFD, the average AF for the OFO (28.6 AF) was taken from FracFocus and multiplied by the RFD well construction projections (105 wells per year under the aggressive scenario) to get cumulative water use per year.

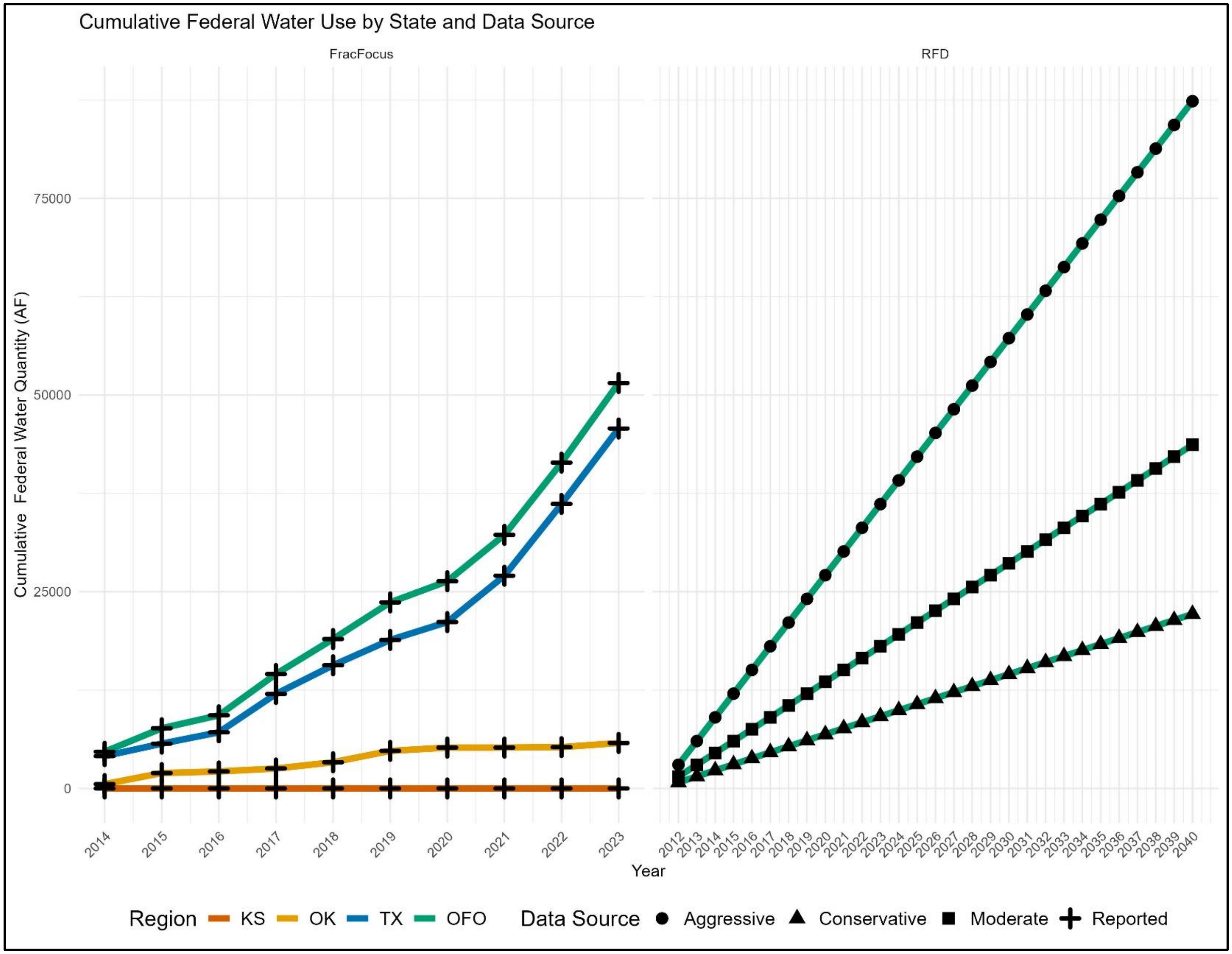


Figure 5-2. Projected and reported cumulative water use for federal wells across the OFO and further broken down by state. Reported data is based on FracFocus federal well data (FracFocus 2024) for the OFO and its constituent states, whereas projected water use is based on federal well estimates from the RFD for the OFO.

5.3 Drought and Water Availability in the OFO

To standardize drought reporting across federally managed lands, the BLM requested the use of ClimateEngine.org to calculate and categorize predicted drought impacts across various jurisdictions. ClimateEngine.org integrates multiple drought indices and weights them differently to produce both long- and short-term drought blend summaries. "Blends" are a compilation of multi-temporal drought indices that represent different drought timescales to assess both short- and long-term processes and associated impacts across regions (ClimateEngine.org 2024). Both the long- and short-term drought blend assessments provide analysis at the same temporal levels (current, 3-month, and 1-year); however, the data indices utilized are weighed differently to produce a different drought blend (long- and short-term). ClimateEngine.org evaluates the following indices and spatial data to determine drought severity at the landscape level:

- Palmer-Z Index
- Palmer Drought Severity Index
- Standardized Precipitation Index
- Palmer Hydrological Drought Index
- Soil Moisture from NOAH land surface model

The short-term drought blend provides insights into drought impacts over a brief period (days to months), which is useful for assessing effects on agriculture and soil moisture. In contrast, the long-term drought blend assesses impacts related to precipitation over extended periods (months to years) and is more effective for evaluating groundwater levels and overall water availability at a landscape level. The long-term drought blend will be used in evaluating drought severity across the OFO. The drought blend figures presented below combine the current, 3-month, and 1-year drought summaries to produce each blend figure.

5.3.1 Drought Blend Summaries for the OFO

Since July 29, 2023, 41.6% of the OFO has experienced some long-term drought, with moderate drought severity making up the largest percent drought category (29.7%). Currently (as of July 23, 2024) 25.2% of the OFO is experiencing some severity of drought (D0-D4). Only 0.4% of the OFO is currently experiencing exceptional drought conditions. A full summary of drought conditions at various periods is presented in Table 5-5 and Figure 5-3.

Table 5-5. Drought Blend Summary Results (as Percent Area) across the OFO

Term	Time Period	D0-D4 (Abnormally Dry to Exceptional Drought)	D1-D4 (Moderate to Exceptional Drought)	D2-D4 (Severe to Exceptional Drought)	D3-D4 (Extreme to exceptional Drought)	D4 (Exceptional Drought)
Long-Term	Current (07/23/2024)	25.2	17.3	6.4	2.9	0.4
	3-Month (04/29/2024)	25.1	15.5	3.2	0.7	0.0
	1-Year (07/29/2023)	41.6	29.7	8.7	2.8	0
Short-Term	Current (07/23/2024)	1.2	7.1	2.2	1.0	0.0
	3-Month (04/29/2024)	30.8	21.6	7.3	3.5	0.0
	1-Year(07/29/2023)	38.0	28.8	10.0	4.2	0.1

Source: ClimateEngine.org (2024)

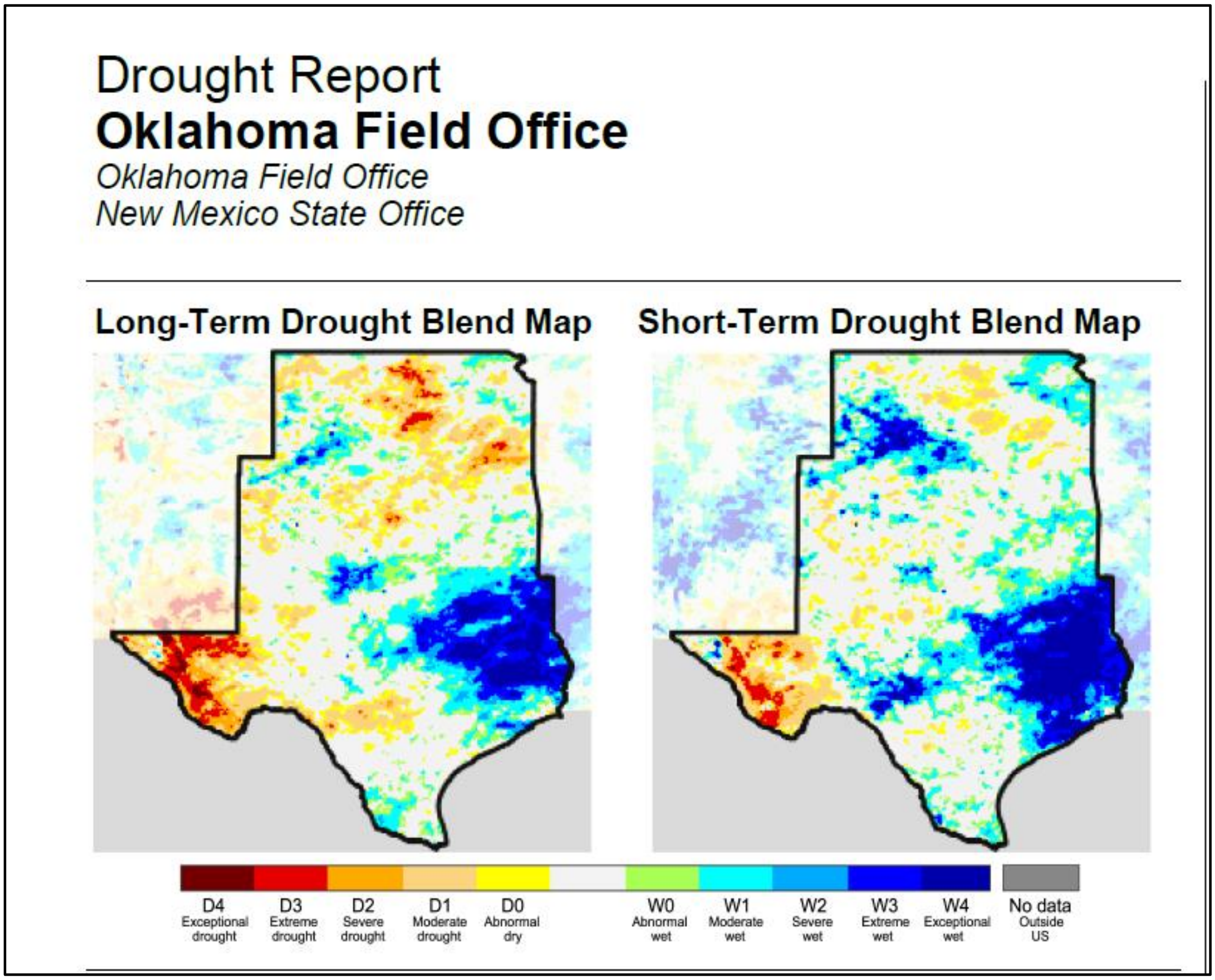
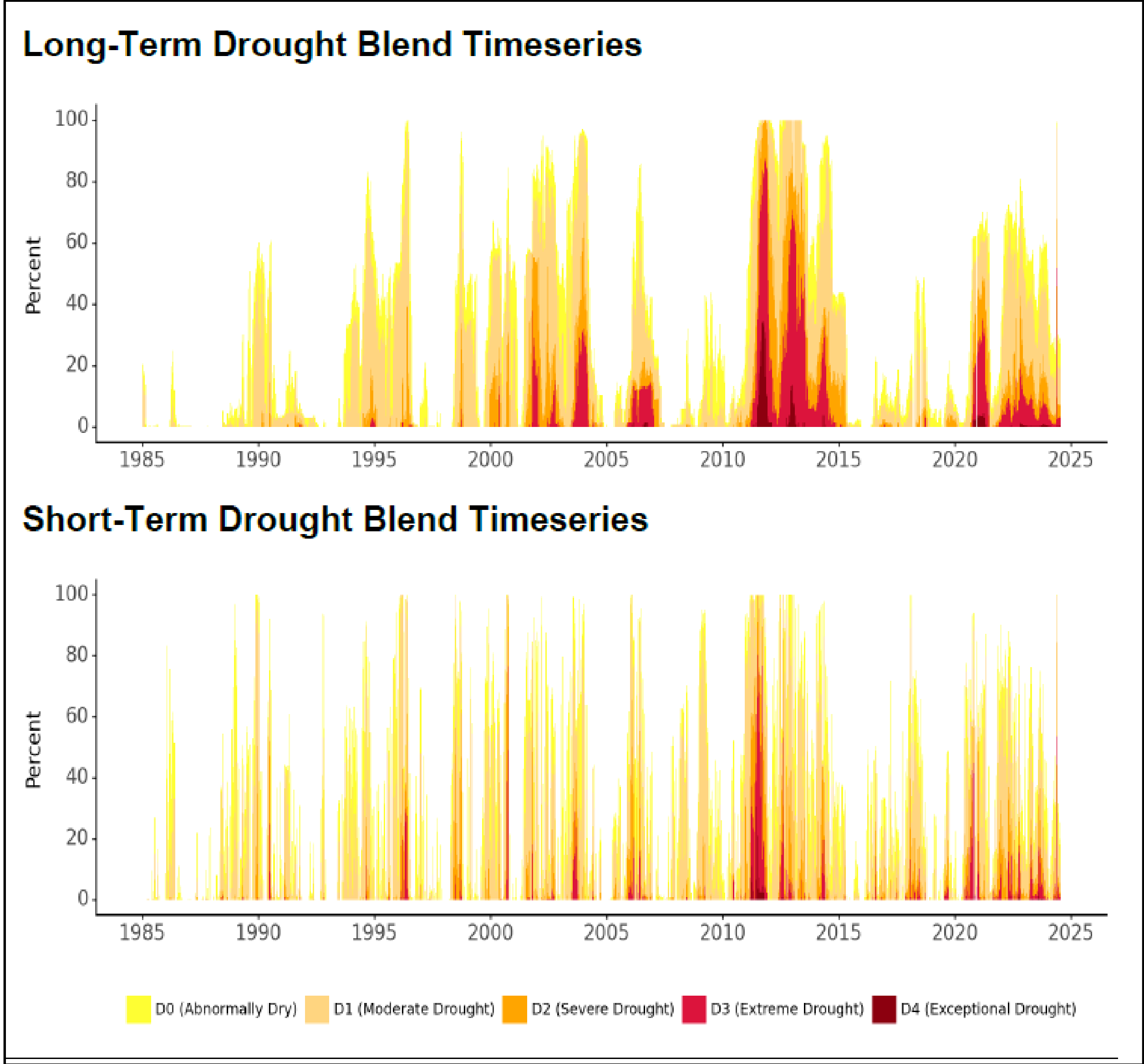


Figure 5-3. Drought blend summaries across the OFO.

Source: ClimateEngine.org (2024)

Long-term drought across the OFO is characterized primarily by dry conditions with short periods of extreme and exceptional drought. Before 2001, instances of extreme and exceptional drought were rare. However, since the year 2000, the intensity of drought has escalated, with significant periods of extreme and exceptional drought occurring during 2010-2015 and 2020-2024 (Figure 5-4).



Long-Term Drought Blend Timeseries

Short-Term Drought Blend Timeseries

Figure 5-4. Drought blend timeseries since 1985 across the OFO.

Source: ClimateEngine.org (2024)

5.3.2 U.S. Drought Monitor

According to the U.S. Drought Monitor (U.S. Drought Monitor 2024), the OFO planning area includes regions that have been subjected to a prolonged period of drought, which puts further strain on sources of water that are accessible via surface water diversion or groundwater pumping. Over the past decade (2014-2023), approximately 52.6% to 54.9% of the OFO planning area has been affected by varying levels of drought, ranging from abnormally dry (D0) to exceptional drought (D4).. Notably, the Kansas segment of the OFO planning area experienced the highest drought impact, with 54.9% of the state affected by drought conditions (D0-D4). Table 5-6 provides a detailed breakdown of drought conditions across Oklahoma, Texas, and Kansas, including drought classifications and their associated percent area.

Table 5-6. Mean Percent Area of Drought across Oklahoma, Kansas, and Texas from 2014 to 2023

State	No Drought	D0-D4 (Abnormally Dry-Exceptional Drought)	D1-D4 (Moderate Drought-Exceptional Drought)	D2-D4 (Severe Drought-Exceptional Drought)	D3-D4 (Extreme Drought-Exceptional Drought)	D4 (Exceptional Drought)
Oklahoma	47.4%	52.6%	36.5%	23.7%	11.8%	2.79%
Kansas	45.1%	54.9%	34.7%	19.5%	9.1%	3.08%
Texas	47.1%	52.9%	35.1%	19.9%	9.2%	2.45%

Source: U.S. Drought Monitor (2024)

Figure 5-5 highlights the change in drought severity categories from 2014 to 2023. Drought across all severity categories has markedly increased, with a sharp increase occurring from 2021 to 2023 (see Figure 5-5). The years 2021 to 2023 experienced the largest increase in extreme and exceptional drought severity.

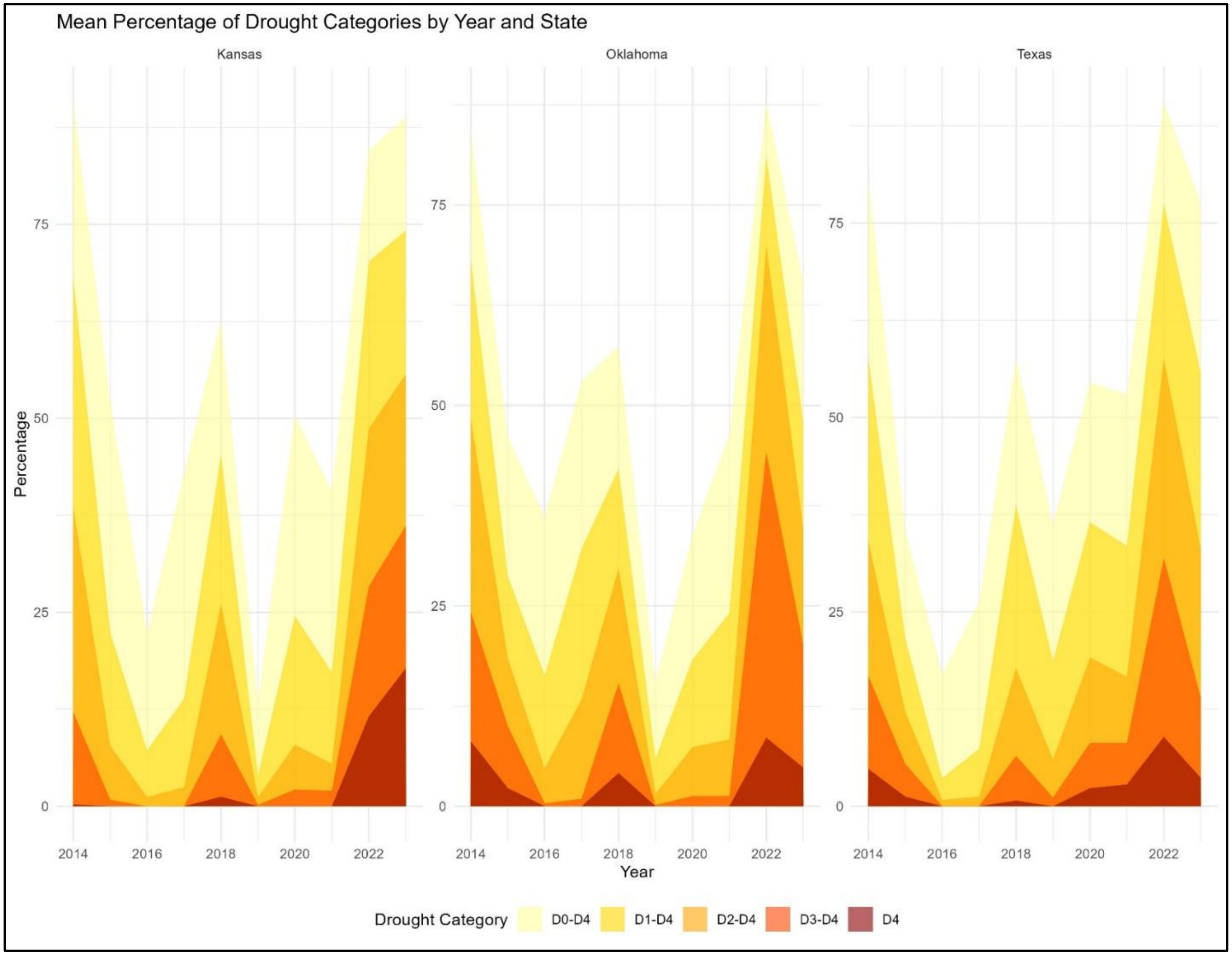


Figure 5-5. Average percentage of each state experiencing different drought categories (D0-D4) across Kansas, Oklahoma, and Texas from 2014 to 2023.

Source: U.S. Drought Monitor (2024)

In 2023, drought severity in the OFO planning area intensified, with 65.4% of the OFO planning area experiencing some level of drought (D0-D4). Kansas was particularly hard hit, with 88.8% of the state affected by some severity of drought. Kansas had the largest percent area of exceptional drought, impacting 17.8% of the state. In comparison, Texas and Oklahoma experienced much smaller proportions of exceptional drought, with 3.64% and 4.83% of their respective areas affected (Table 5-7).

Table 5-7. Mean Percent Area of Drought across Oklahoma, Kansas, and Texas in 2023

State	No Drought	D0-D4 (Abnormally Dry-Exceptional Drought)	D1-D4 (Moderate Drought-Exceptional Drought)	D2-D4 (Severe Drought-Exceptional Drought)	D3-D4 (Extreme Drought-Exceptional Drought)	D4 (Exceptional Drought)
Oklahoma	34.6%	65.4%	48.0%	34.7%	20.1%	4.83%
Kansas	11.6%	88.8%	74.2%	55.7%	36.1%	17.80%
Texas	22.6%	77.4%	55.7%	33.1%	14.0%	3.64%

Source: U.S. Drought Monitor (2024).

5.3.3 State Resources

In the state of Oklahoma, the OWRB authors the Oklahoma Drought Management Plan (OWRB 1997) and maintains a website that presents all state and federal resources regarding drought in the state (OWRB 2024c). Additionally, projections of water availability are periodically updated and presented in the Oklahoma Comprehensive Water Plan (OCWP). The next iteration of the OCWP is currently under development to be completed in 2025, therefore water availability projections are not available (see Section 2.1 for additional description of the OCWP).

In the state of Kansas, the KWO has documented an analysis of the state’s future water supply in the Vision for the Future Water Supply in Kansas (KWO 2015). The current plan presents a comprehensive strategy and identifies action by region but does not include future projections. An update to the report is underway but it’s unclear when that update will be available.

In the state of Texas, the TWDB hosts a *Drought Outlook* resource that compiles drought conditions for the state at various time scales (TWDB 2024d). Projected drought is assessed at both one month and three-month timeframes but also takes into consideration larger regional climate patterns (e.g., El Nino) to assess longer term outlooks. The state water plan (see section 4.1) identifies strategies to secure and improve future water availability that responds to changes in population, technological improvements, water supplies, and policy changes (TWDB 2024d). It presents a robust analysis of future surface and groundwater supply by major basin, Specifically, total groundwater availability is projected to decline by approximately 32% from 2020 to 2070 due to reductions in availability in the Ogalla/Edwards-Trinity (High Plains), Ogalla/Rita Blanca, and Ogalla Aquifers whereas surface is predicted to decline by 2 percent primarily due to sedimentation in reservoirs (TWDB 2024b).

5.4 Per- and Polyfluoroalkyl Substances

PFAS is a broad term classification for a large group of human-made chemicals that are found in a wide variety of industrial processes and common household items. They are widely used in disposable food packaging, cookware, outdoor equipment, furniture, and carpet for their hydrophobic and oleophobic properties (Sunderland et al. 2018). PFAS substances are a main component of aqueous film forming foams, which are used regularly in fire suppression and prevention activities performed at airports and military bases (Sunderland et al. 2018). Aqueous film forming foam is a major source of PFAS groundwater contamination and has been recognized as a nationally significant challenge in the United States (Sunderland et al. 2018). Approximately 4,700 distinct chemicals are categorically grouped as PFAS (Cousins et al. 2020), with the most common and widely studied PFAS including PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid) (EPA 2024b). PFAS persistence has been linked to bioaccumulation in both the environment and human body, which may lead to adverse effects on human health (EPA 2024b).

Surveys conducted by the U.S. Centers for Disease Control and Prevention show that most people in the United States have been exposed to some PFAS. People can be exposed to PFAS through their occupations (e.g., firefighting or chemicals manufacturing and processing); drinking PFAS-contaminated water; eating PFAS-contaminated food (e.g., fish); swallowing PFAS-contaminated soils or dust; breathing PFAS-contaminated air; or interacting with products and packaging that contain PFAS. While most people’s known exposure levels are relatively low, some people have higher exposures to PFAS than others because of their occupations or where they live. Additionally, infants and children may be more sensitive to the harmful effects of chemicals such as PFAS (EPA 2024b).

Current peer-reviewed scientific studies have shown that exposure to certain levels of PFAS may lead to adverse health effects such as: reproductive effects; developmental effects or delays in children; increased risk of some cancers; reduced immune functioning; hormonal effects; and increased cholesterol levels and/or risk of obesity. However, research is still ongoing to determine how different levels of exposure to different PFAS can effect human health (EPA 2024b).

5.4.1 State PFAS Planning

In April 2024, the EPA finalized drinking water regulations for six PFAS compounds in drinking water under the Safe Drinking Water Act as part of its *PFAS Strategic Roadmap* (EPA 2024c). This step, along with prior action to reduce PFAS in the past several years, has sparked an increased effort by states to better understand and document PFAS contamination within their jurisdictions. Data collection efforts of PFAS constituents are underway in states of the OFO; however, data do not appear to be publicly available. In Oklahoma, the ODEQ has developed a quality assurance program to monitoring PFAS from a variety of media including surface water, drinking water, and groundwater (OWRB 2024c). In Kansas, the KDHE has taken steps to address PFAS in drinking water through coordinated efforts with the Bureau of Environmental Remediation and the Bureau of Water. This effort includes development of a statewide inventory and prioritization of potential PFAS sources that will inform development of a public water supply monitoring program (KDHE 2024). In Texas, the TWDB has made available a significant amount of funding to reduce PFAS through wastewater and water infrastructure updates (TWDB 2024a).

5.4.2 PFAS Sources in Hydraulic Fracturing

PFAS may be used during the hydraulic fracturing process due to their stability at high temperatures and pressures and may be used in well drilling (in the form of drilling fluids), well completion, and workover operations (Gaines 2022). PFAS can be used as a surfactant to enhance recovery in oil and gas wells (Gaines 2022) to decrease friction during the drilling and hydraulic fracturing processes to allow for better drilling efficiency. In addition to drilling efficiency purposes, PFAS are utilized as an effective method to mitigate oil spills in water. PFAS can be injected into contaminated water to promote the formation of a barrier between oil and water. This allows for an increased efficiency in skimming oil spills from water during the remediation process (Gaines 2022).

PFAS utilized in hydraulic fracturing are generally categorized into four groups in the FracFocus database; perfluoroalkyl alkanes/cycloalkanes, fluoroalkyl alcohol substituted polyethylene glycol, nonionic fluorosurfactants, and polytetrafluoroethylene (Connor et al. 2021). However, the true occurrence of PFAS chemical usage in hydraulic fracturing is difficult to determine because PFAS chemicals reported in FracFocus include misspellings, ambiguity, alternative naming, etc. Additionally, there are a large number of non-disclosed and proprietary chemical reporting in FracFocus which may include additional PFAS chemicals.

PFAS chemicals were grouped into one of four categories as previously described (Connor et al. 2021). Using this approach, no occurrences of perfluoroalkyl alkanes/cycloalkanes reporting were uncovered across the OFO (Table 5-8). Using this approach, the results indicate that reported PFAS chemicals make up a minimal proportion—less than 1%—of the chemical constituents disclosed to FracFocus for hydraulic fracturing within each state of the OFO planning area from 2014 to 2023 (FracFocus 2024a). However, out of 3,256,846 chemical disclosures, 317,491 were not disclosed, which likely includes additional PFAS chemicals. The uncertainty within FracFocus chemical disclosure data indicates that the actual use of PFAS chemicals across the OFO planning area could be significantly higher. The highest number of PFAS chemical disclosures occurs in Texas (4,134), followed by Oklahoma (1,115), and Kansas (2) (see Table 5-8).

Table 5-8. Summary of PFAS Spills Reported Spill Materials to the State of Texas from 2014 to 2023, Further Categorized by Unit of Spill

State	Fluoroalkyl Alcohol Substituted Polyethylene Glycol	Nonionic Surfactants	Poly-Tetra-fluoroethylene	Total PFAS	Potential PFAS	Total Non-PFAS Chemical Disclosures	Total chemical Disclosures	PFAS Percentage out of total disclosure
Oklahoma	0	832	283	1,115	59,974	462,752	524,956	0.21
Kansas	0	2	0	2	537	15,921	16,462	0.01
Texas	53	2,469	1,612	4,134	256,980	2,450,180	2,715,428	0.15
OFO Planning Area Total	53	3,303	1,895	5,251	317,491	2,928,853	3,256,846	0.16

Source: U.S. FracFocus (2024a).

Note: PFAS chemicals grouping is based on Connor et al. (2021). Potential PFAS includes non-disclosed data.

5.5 Induced Seismicity

Induced seismicity refers to seismic events that are triggered by human activities rather than natural tectonic forces. A broad range of human activities have been attributed to induced seismicity, including but not limited to underground fluid injection (e.g., for wastewater and hydraulic fracturing) and oil and gas extraction (Ground Water Protection Council [GWPC] 2021). Between 2008 and 2015, seismicity events increased in the mid-continental United States and studies pointed to a connection between increasing seismic events and the widespread disposal of wastewater into deep Class II injection wells (GWPC 2021). Seismic events can occur when specific geologic conditions are present (e.g., sufficient pore pressure build-up near a pre-existing fault of concern) (GWPC 2021; OCC 2018).

The risk for induced seismicity increases with high-volume injections into deep wells carried out through wastewater injections and enhanced oil recovery techniques. A combination of many factors is necessary to induce felt earthquakes: the injection rate and total volume injected, the presence of faults that are large enough to produce felt earthquakes, stresses that are large enough to produce earthquakes, and the presence of pathways for the fluid pressure to travel from the injection point to faults (Machette et al. 2000; USGS 2021). High injection rates of greater than 300,000 barrels per month are much more likely to be associated with earthquakes, and any earthquake within approximately 10 to 30 kilometers (6.2-18.6 miles) of an active injection well could be associated with that well (OCC 2018; Weingarten et al. 2015). Although hydraulic fracturing can also contribute to induced seismicity, seismic events triggered by hydraulic fracturing are relatively uncommon and generally have smaller magnitudes than injection-induced seismicity and are therefore considered to pose less risk (GWPC 2021). Even relatively extreme seismic events associated with hydraulic fracturing have been well below the damage threshold for modern building codes (Petersen et al. 2018; USGS 2021).

State agencies in each of the three states in the OFO closely monitor and track earthquake activity. In Oklahoma, from 2015–2024, there were 4,811 earthquakes greater than 2.7 magnitude, although the trend from year to year has been steadily decreasing, with 2,000 earthquakes in 2015 versus just 39 in 2023 (OCC 2024c). In Kansas, from 2015–2024, there were 302 earthquakes equal to or greater than 3.0 magnitude primarily located in the north-to-south centerline of the state (KGS 2024). Finally, in Texas, from 2017–2024, 1,024 earthquakes of magnitude greater than 3 were documented in various portions of the state, although concentrated heavily in the western panhandle and south of San Antonio (Texas Bureau of Economic Geology 2024).

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APPENDIX A

Data Inventory and Analysis Methodology Memorandum for the Oklahoma Water Support Document

Data Inventory and Analysis Methodology Memorandum for the Oklahoma Water Support Document

NOVEMBER 2024

PREPARED FOR

Bureau of Land Management

PREPARED BY

SWCA Environmental Consultants

DATA INVENTORY AND ANALYSIS METHODOLOGY MEMORANDUM FOR THE OKLAHOMA WATER SUPPORT DOCUMENT

Prepared for

Bureau of Land Management
New Mexico State Office
301 Dinosaur Trail
Santa Fe, New Mexico 87508

Prepared by

Lucy Parham, M.S., and Nolan Perryman, M.S.

SWCA Environmental Consultants
7770 Jefferson St. NE
Albuquerque, New Mexico 87109

SWCA Project No. 84075

November 2024

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1 PURPOSE AND SCOPE

This memorandum outlines the data sources that will be utilized in the development of the Bureau of Land Management (BLM) Oklahoma Field Office (OFO) 2024 Water Support Document for Oil and Gas Development in Oklahoma, Kansas, and Texas (hereinafter referred to as the Water Support Document, or WSD). It also outlines the methodology for data analysis and processing, so that the process can be replicated accurately by others or updated in subsequent years, as needed, due to changes in technologies, the inclusion of other operators' data, or other factors.

Section 2 describes the spatial scale of the analysis, whereas Section 3 presents the sources of data to be used for water quantity and water quality analyses, as well as the proposed methodology for analyzing and processing data sources, as applicable. For each dataset described in this report, various data processing applications may be used to process the data, depending on user preference (e.g., Excel or R statistical software [R]). Additionally, there are multiple approaches within each application to generate the same information (e.g., in Excel, the use of pivot tables, copying data into new tabs to use the Remove Duplicates button, or using filters; in R, various functions to aggregate and summarize data). Therefore, these instructions provide basic aggregation rules and specific column names in the datasets to accommodate different user preferences and styles of approaching data management.

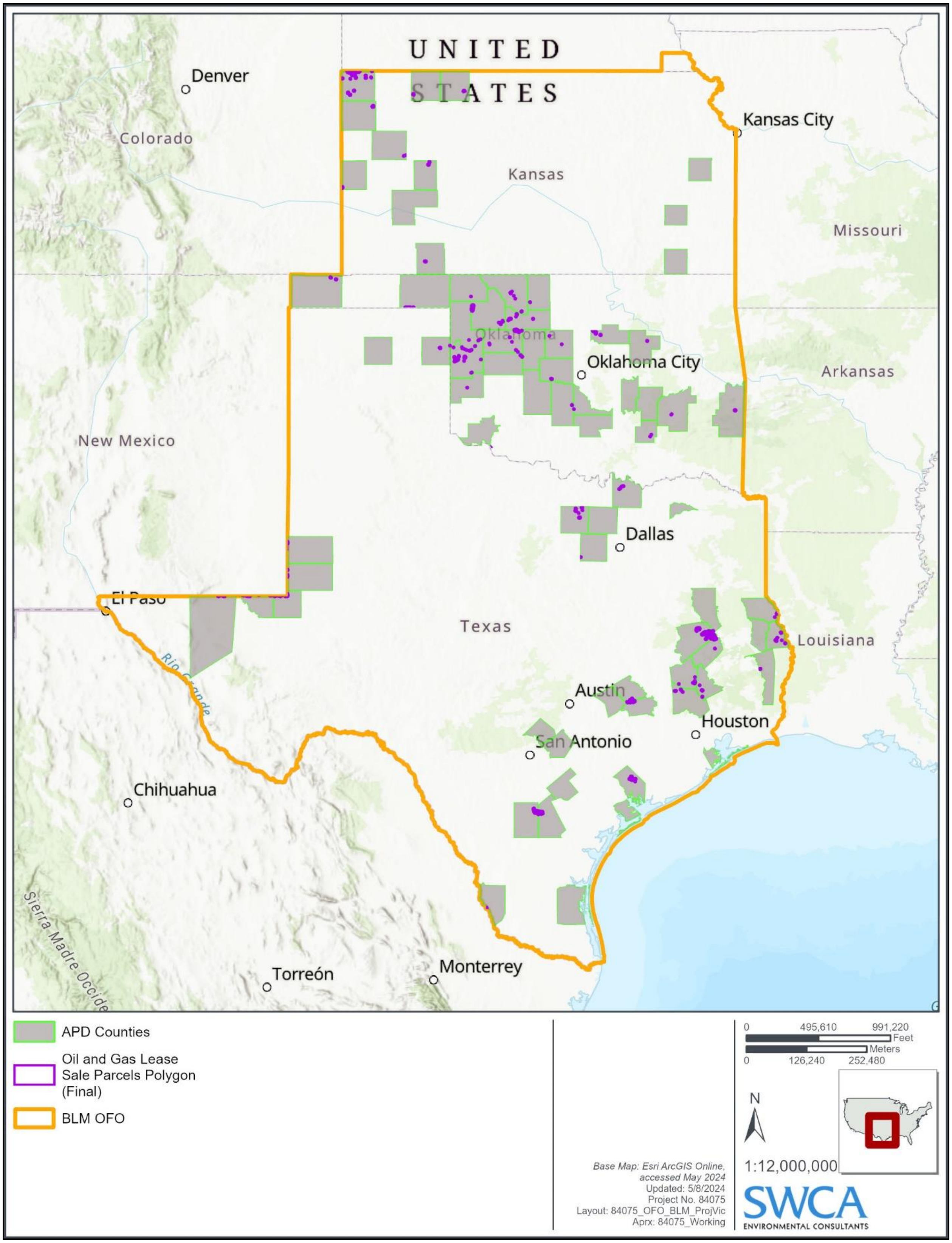
2 SCALE OF ANALYSIS

The BLM OFO is responsible for the management of 4,810,900 acres of federal minerals across the 269,650,000-acre OFO planning area, which encompasses the states of Kansas, Oklahoma, and Texas, as well as one county in Nebraska (BLM 2020). The BLM OFO also assists the Bureau of Indian Affairs (BIA) with oil and gas permitting on 2,667,800 acres of BIA-managed mineral estate in the OFO planning area. The analysis area for this memorandum and the associated OFO WSD is the approximately 270 million-acre OFO planning area. Given the large geographic scale of the OFO planning area, a subset of targeted counties was identified within the planning area to allow for more focused data analysis efforts for the OFO WSD. Targeted counties include those where oil and gas development is currently happening, or is likely to happen (e.g., based on historic activity and/or resource potential) in the future, and are therefore most relevant to the WSD analysis. Targeted counties were selected through review of the following two data sources: 1) BLM OFO oil and gas lease sales over the last 10 years (BLM 2024) and 2) BLM OFO applications for permit to drill (APDs) over the last 10 years. Based on review of these two data sources, a total of 74 counties across Kansas, Oklahoma, and Texas were identified as having oil and gas lease sales or APDs over the last 10 years (Table 1, Figure 1). These 74 counties will be the focus of data gathering efforts for the 2024 OFO WSD. During subsequent annual WSD updates, this list of targeted counties should be re-visited and revised, as needed, to capture any changes in oil and gas developmental trends within the planning area.

Table 1. Targeted Counties for the 2024 OFO WSD

State	Lease Sale Occurrence Counties (2014–2024)	APD Occurrence Counties (2014–2024)	Lease Sale and APD Occurrence Counties (2014–2024)
Kansas	Cheyenne, Decatur, Greeley, Lane, Logan, Meade, Norton	Finney, Franklin, Montgomery, Sherman, Woodson	Not applicable
Oklahoma	Alfalfa, Beaver, Beckham, Cimarron, Custer, Harper, Le Flore, Payne, Woods, Woodward	Blaine, Caddo, Canadian, Garvin, Hughes, Seminole	Coal, Creek, Dewey, Ellis, Grady, Jackson, Kingfisher, Major, McClain, Pittsburg, Roger Mills
Texas	Andrews, Burleson, Cherokee, Culberson, Gaines, Grayson, Hemphill, Houston, Jackson, Lee, Loving, Montgomery, San Jacinto, Tarrant, Trinity, Walker, Washington, Winkler, Zapata	Calhoun, Comal, Delta, Denton, Galveston, Guadalupe, Hutchinson, Karnes, Kenedy, San Augustine	Jasper, Live Oak, McMullen, Sabine, Shelby, Wise

Source: BLM (2024)



Base Map: Esri ArcGIS Online, accessed May 2024
Updated: 5/8/2024
Project No. 84075
Layout: 84075_OFO_BLM_ProjVic
Aprx: 84075_Working

Figure 1. Targeted counties in the 2024 BLM OFO WSD.

3 DATA SOURCES

Several sources of data will be reviewed, compiled, and analyzed where appropriate to address all relevant topics of the WSD. Table 2 provides a summary of data sources and the context in which they will be presented in the WSD. Data for three of the sources—FRACFocus, U.S. Geological Survey (USGS) water use, and state spill data—will be downloaded and analyzed per the methodologies presented in Sections 3.1 through 3.3. Other sources of data include state and federal agency reports that will be reviewed and summarized to meet the informational needs of the WSD. Table 2 provides an overview of major data sources considered for the WSD; however, the data sources listed are not comprehensive, and the final document is expected to include some additional sources for a more comprehensive assessment.

Table 2. Data Sources by WSD Topic

WSD Topics	Data Sources
Statewide water quality and quantity data associated oil and gas development	USGS Estimated Use of Water in the United States in 2015 Kansas, Oklahoma, Texas Integrated Reports
Overview of regional water sources, hydraulic fracturing practices/technologies, and water use	2016 Reasonably Foreseeable Development Scenario BLM OFO Environmental Impact Statement (EIS) Resource Management Plan (RMP)
Description of produced water reuse in oil and gas development	Oil and Gas Produced Water Reuse: Opportunities, Treatment Needs, and Challenges
Water sources utilized during oil and gas development on federally managed lands	2016 Reasonably Foreseeable Development Scenario
Groundwater trends	USGS – A Dataset of Scanned Historical Well and Geophysical Logs From 96 Counties in Texas, 1925–2020.
Overview of existing water quality and quantities within the OFO	USGS Estimated Use of Water in the United States in 2015 BLM OFO EIS/RMP Kansas, Oklahoma, Texas Integrated Reports
Summary of known impacts of hydraulic fracturing to water quality and quantity	U.S. Environmental Protection Agency's (EPA's) Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States Kansas, Oklahoma, Texas spill data
Summary of water use per well associated with oil and gas development	FracFocus
Future water use scenarios	2016 Reasonably Foreseeable Development Scenario
Potential nonpoint source pollutants associated with oil and gas development during stormwater runoff events	EPA's Demonstrating the Impacts of Oil and Gas Exploration on Water Quality and How to Minimize Impacts through Targeted Monitoring
Drought and water availability	Climate Engine Water Development Board planning documents for the states of Texas, Oklahoma, and Kansas
Per- and polyfluoroalkyl substances (PFAS)	USGS Assessment of PFAS EPA Strategic Roadmap EPA PFAS usage literature review FracFocus
Induced seismicity	USGS Induced earthquakes overview Kansas, Oklahoma, Texas seismicity planning

For data sources where data will be downloaded and analyzed, all data will be read, cleaned, summarized, and aggregated in R. R serves as a powerful tool for data manipulation, cleaning, summarization, aggregation, and visualization. Data scientists use a variety of functions and techniques tailored to specific needs to process raw data efficiently and accurately. In addition to its manipulation and analytical capabilities, R enables data scientists to perform detailed data-quality checks, ensuring accuracy and reliability throughout the analysis process. The approach outlined herein represents the general approach and proposed methodology; however, the methodology is subject to change to accommodate factors such as poor data quality or unexpected issues encountered during the data processing and analysis phases in R. All code will be annotated and provided to the BLM with the final WSD to ensure ease of reproducibility.

The following is a dictionary of key functions and example functions commonly used in R:

- **Data Manipulation:**
    - **subset() or filter():** Subsetting data frames based on conditions.
    - **merge()**: Merging multiple data frames by common variables.
    - **mutate()**: Adding new variables or modifying existing ones.
    - **transform()**: Creating new variables or transforming existing ones.
- **Data Cleaning:**
    - **na.omit()**: Removing rows with missing values.
    - **outlier()**: Identifying and handling outliers.
    - **gsub()**: Replacing or modifying text patterns.
- **Data Summarization:**
    - **summarize()**: Generating summary statistics for data frames.
    - **table()**: Creating frequency tables.
- **Data Aggregation:**
    - **aggregate()**: Aggregating data by groups.
    - **group_by()**: Grouping data into subsets for analysis.
    - **summarize()**: Summarizes data.
- **Data Visualization:**
    - **ggplot2**: Creating customizable plots and visualizations.

3.1 Fracfocus Data

3.1.1 Data Summary

The FracFocus database serves as the national registry for hydraulic fracturing chemicals and water used in hydraulic fracturing across the United States. When the site was initiated in 2011, many companies voluntarily disclosed hydraulic fracturing chemicals; however, some states later permitted disclosure to FracFocus to fulfill mandatory reporting requirements. Oklahoma and Texas began requiring disclosures to FracFocus in 2012, whereas Kansas began requiring reporting in 2015. As of August 2021, FracFocus emerged as the exclusive national regulatory reporting system used by many states. Housing a repository of data with over 184,000 disclosures and exceeding 5 million chemical records sourced from over 1,600 registered companies, FracFocus stands as the best available resource for hydraulic fracturing data (FracFocus 2024).

3.1.2 Data Preparation

FracFocus data requires substantial cleaning, processing, and data checks prior to reporting. After the dataset is read into R, the data will be checked, reorganized, and summarized to develop summary reports for the WSD. A master dataset will be created that includes each state within the OFO. The master dataset will include many of the original columns from the FracFocus registry and additional columns created for ease of downstream grouping and summarizing (e.g., unit conversions).

The following data checks are intended to evaluate and validate the consistency, completeness, and uniqueness of FracFocus data. In this process, records that do not meet the specified data quality criteria are reviewed and addressed using case-specific techniques. The data is systematically evaluated, verified, and adjusted based on reasonable assumptions until all identified discrepancies are resolved. Data is not removed during the data cleaning process. The following steps will be taken to clean, organize, and generate the master dataset:

1. Download FracFocus data from https://fracfocus.org/data-download
    a. The 2024 Water Support Document will consider FracFocus data from 2014 to 2023.
    b. The file named readme.txt in the data download packet is the FracFocus data dictionary and should be retained with the original downloads.
2. FracFocus data is divided into registries (Registry 1 through Registry 13) to reduce file size. Each registry can be read into R simultaneously as a csv file.
3. Filter all data to Isolate data for desired years (e.g., 2014 through 2023) and states using column heading JobStartDate, which is the “date on which the hydraulic fracturing job was initiated” (FracFocus 2024) and state (e.g., Oklahoma).
4. Screen the data and perform quality control.
    a. Create a new column titled “Job” containing the well name and the start date. For the purpose of this analysis, a drilling activity (a job) is defined as the job start date (“JobStartDate”) and the well name (“WellName”).
    b. Create three new columns for month, day, and year based on the original job start date. Code will be applied to create three additional columns: Month, Day, and Year, each containing the corresponding parts of the date. For example, **"2024-04-11"** will be recoded as 2024, April, and 11 within three separate columns for each state.
        i. The same well may have multiple job start dates within the same year; however, these are not necessarily duplicate entries because multiple jobs may occur within the same year. The “Job” column will contain a hyper-unique ID based on the well, API number, month, day, year, and time that can be used to determine if there is a duplicate entry for any given job within a year.
        ii. Duplicate jobs are acceptable as long as each contains a unique water use volume. These entries are duplicated across jobs within FraFocus to account for each chemical used during hydraulic fracturing jobs. If a job includes multiple reported water use volumes, these volumes will be adjusted by randomly sampling from the duplicates and recoding all entries for a job to reflect a single reported volume. This random sampling ensures that unknown water usage is accounted for by assigning one water usage value without over- or underestimating usage or removing any data.
    c. American Petroleum Institute (API) well identification numbers are assumed to be a unique identifier in the data, and there should be a 1:1 relationship between API number and well name. To ensure a 1:1 relationship between well name and API number, the data

is first grouped by API number and well name to find the most common well name associated with each API. If there are multiple well names for the same API number (e.g., a 1:2 relationship), the most frequent well name is retained; if there is a tie, a random selection is made from the most frequent entries. The same process is applied for cases where a well name is associated with multiple API numbers. The most common API for each well is selected, and if there is a tie, a random API is chosen. This approach ensures consistency and avoids duplicate entries while resolving non-unique relationships through frequency-based selection and random sampling. See the example script below:

```
<script>

# Step 1: Identify the most common well name for each API
most_common_well_per_api <- frac_all1 %>%
  group_by(APINumber, WellName) %>%
  dplyr::summarise(count = n(), .groups = 'drop') %>%
  arrange(desc(count)) %>%
  group_by(APINumber) %>%
  filter(count == max(count)) %>%
  sample_n(1) %>%
  ungroup() %>%
  select(APINumber, WellName)

# Step 2: Recode all entries to match the most common well name for each API
frac_all1_intermediate <- frac_all1 %>%
  select(-WellName) %>%
  left_join(most_common_well_per_api, by = "APINumber")

# Step 3: Identify the most common API for each well
most_common_api_per_well <- frac_all1_intermediate %>%
  group_by(WellName, APINumber) %>%
  dplyr::summarise(count = n(), .groups = 'drop') %>%
  arrange(desc(count)) %>%
  group_by(WellName) %>%
  filter(count == max(count)) %>%
  sample_n(1) %>%
  ungroup() %>%
  select(WellName, APINumber)

# Step 4: Recode all entries to match the most common API for each well
frac_all1_final <- frac_all1_intermediate %>%
  select(-APINumber) %>%
  left_join(most_common_api_per_well, by = "WellName")

# Step 5: Check the ratio of API to WellName
frac_all1_final %>%
  summarise(count = n_distinct(WellName))

frac_all1_final %>%
  summarise(count = n_distinct(APINumber))
```

d. Federal well designation should be mutually exclusive. A well can either be federal or non-federal but not both. If any wells are given both designations, they will be reclassified as non-federal wells. Similarly, tribal well designation should be mutually exclusive. A well can either be tribal or non-tribal but not both. Wells that are given both designations will be reclassified as non-federal wells.

    i. **Note**: federal and tribal well reporting uses binary entries, including “TRUE” or “FALSE.” Therefore, any well marked as “FALSE” under Federal or Tribal ownership will be classified as “Non-federal/tribal.”

e. TotalBaseWaterVolume refers to the total volume of water used as a carrier fluid for the hydraulic fracturing job (in gallons) (FracFocus 2024). If a row shows TotalBaseWaterVolume = 0 gallons, it indicates that the well has been drilled but has not undergone hydraulic fracturing, resulting in zero water usage for the hydraulic fracturing job. Wells with TotalBaseWaterVolume = 0 still use water during drilling and will remain in the dataset. These wells are necessary during the summarization stage and will be corrected to account for water used during the drilling phase for all individual wells (See section 3.1.5).
   i. A new column will be created to classify wells that show TotalBaseWaterVolume = 0 gallons as “non-hydraulically fractured,” whereas all other wells will be classified as “hydraulically fractured.”

f. For each job (note that a job is the well name and job start date) in the FracFocus data, there are many rows to document the various ingredients and chemicals used in the drilling activity. As a result, the total base water volume is duplicated across multiple jobs to document each ingredient used in a hydraulic fracturing job (see step 4b above). To account for these duplicate entries while retaining all ingredient data, duplicate rows will be removed only when summarizing water use data, thereby ensuring that only one water use volume is reported for each hydraulic fracturing job. The master dataset will retain duplicate jobs which will permit accurate reporting of hydraulic fracturing ingredients. Duplicate rows can be removed during water use summarization using the Dplyr package in R (e.g., the “unique()” function).

g. The dataset now includes water usage associated with jobs. However, a new summary dataset will be created, and corrections will be applied to account for water usage during the drilling phase.
   i. **Note:** because FracFocus does not report on these values, these estimates will need to be applied to the summarized data (See section 3.1.5 for further details).

3.1.3 Unit Conversions

Water use in FracFocus is reported in gallons and water use in the Water Support Document is reported in acre-feet (AF). A new column will be created within the master dataset with converted units. The following conversion factors can be used to convert from gallons to AF and vice versa:

$$1 \text{ AF} = 325{,}851 \text{ gallons}$$
$$1 \text{ gallon} = 3.0689 \times 10^{-6} \text{ AF}$$

3.1.4 FracFocus Data Aggregation and Summaries

To present the summarized information in tables summarizing water use by oil and gas wells for hydraulic fracturing in the states of Oklahoma, Kansas, and Texas from 2014 through 2023, FracFocus data are processed and aggregated by various factors such as year and water use by both federal and non-federal wells. The following instructions describe the general process by which the summarized totals are obtained. The data totals do not include the records that were flagged in step 4 of Section 3.1.2.

Once the data has been cleaned and a master dataset has been generated with each state and associated counties, a within-state regional grouping scheme will be developed to group adjacent counties into single units for reporting. This grouping scheme will be based on concentration of oil and gas development and where water usage is clustered geographically across counties with oil and gas lease sales or APDs. Oklahoma, Kansas, and Texas include 27, 12, and 35 counties with oil and gas lease sales or APDs, respectively (see Figure 1). Once FracFocus data, water use data (see Section 3.2), and spill data (see

Section 3.3) have been evaluated to determine where data is clustered geographically, counties will be grouped into single units, representing multi-county regions (hereafter referred to as “region” or “regional grouping scheme”). This step is necessary to avoid reporting separately on 74 counties. This process will be conducted once data has been evaluated to ensure that counties or locations with minimal or zero quantities do not get reported as a region. Furthermore, this measure will ensure that locations with similar levels of oil and gas development get grouped accordingly. Regions will be included as a new column in the dataset and all datasets hereafter. Data will be grouped and summarized at the state level and the regional level within the WSD.

Data aggregation and table construction will be conducted at the state level and at the regional level using the Dplyr package in R, which easily summarizes data based on defined grouping schemes (e.g., mean county water usage by year). Data tables will be built in R and used to populate tables within the WSD. The following data summaries will be conducted at the state and regional level and will only include water usage associated with hydraulic fracturing jobs:

1. **Federal Water Use**: the sum of the total base water volumes for each federal job in AF.
2. **Tribal Water Use**: the sum of the total base water volumes for each tribal job in AF.
3. **Non-Federal Water**: the sum of the total base water volumes for each non-federal job in AF.
4. **Total Water Use**: the accumulating sum of base water volumes for federal, tribal, and non-federal jobs from 2014 to 2023 in AF.
5. **Federal Water Use (%)**: The percentage of federal water use out of the total water use.
6. **Federal Combined Water Use:** For any given year in the FracFocus data, the federal cumulative water use is that year’s federal water use plus the sum of all previously reported federal water use estimates.
    a. For example: $2020_{FCWU} = 2020_{FWU} + 2019_{FWU} + 2018_{FWU} + 2017_{FWU} + 2016_{FWU} + 2015_{FC} + 2014_{FC}$
        i. Where FCWU is federal cumulative water use and FWU is federal water use
7. **Total Combined Water Use**: the year’s total water use plus the sum of all previously reported total water use estimates.
8. **Average Water Use Per Well**: The average water use for federal, tribal, and non-federal wells
9. **Total Well Count**: The total number of federal, tribal, and non-federal wells in a given year.
10. **Percentage of hydraulically fractured wells**: the percentage of wells out of the total that have been hydraulically fractured.

3.1.5 Total Water Usage Calculations and Summaries

The FracFocus data aggregation and summaries in Section 3.1.4 are based on the total water usage for hydraulic fracturing jobs across the planning area. FracFocus does not include the water usage associated with the initial drilling process. Non-hydraulic fracturing water usage can significantly increase the total water usage for individual wells, and as a result, the overall water use across the OFO planning area will be substantially higher when accounting for this additional water use. In order to incorporate these estimates, a literature review will be conducted to determine the estimated water usage for drilling of wells (referred to as “non-hydraulic fracturing water usage”). Depending on the quality and depth of the available data on non-hydraulic fracturing water usage, one of the following approaches will be used to generate water use estimates: if the data is less detailed or incomplete, Option A will be applied as a more general approach. However, if comprehensive data is available, Option B will be used for a more detailed and accurate estimation.

A. Option A: A non-hydraulic fracturing water use estimate will be determined following a literature review. The estimate will be applied to each well across the planning area to generate total water use estimates.

B. Option B: A literature review will be conducted to determine 1) the proportion of wells that are classified as vertical across the planning area (**denoted as *a***), 2) the average quantity of water associated with drilling of horizontal wells (**denoted as *b***), and 3) the average quantity of water associated with the drilling of vertical wells (**denoted as *c***). Additionally, the Total Combined Water Use (shown above) **denoted as *d*** represents the total water usage for hydraulic fracturing jobs across the planning area. Because the data cannot be broken down by year due to potential incongruencies between well drilling and fracturing jobs, the total well count, and the total water usage will be summarized across the 10-year time series to generate totals by which the below calculations can be performed. The approximations will be generated and summarized using the following:

   1. **Horizontal well count** (**denoted as *v***): the approximate number of wells that are horizontal.
      a. Equation: $v = \text{total wells} \times (1 - a)$
   2. **Vertical well count** (**denoted as *w***): the approximate number of wells that are vertical.
      a. Equation: $w = \text{total wells} \times a$
   3. **Horizontal well total water usage (denoted as *x*)**: the total water usage for horizontal wells, across the planning area, including water usage associated with drilling and hydraulic fracturing.
      a. Equation: $x = \frac{db}{b+c} + vb$
      b. Where $\frac{db}{b+c}$ represents the portion of the total combined water use for hydraulic fracturing d allocated to horizontal wells, and vb represents the total water usage based on the average quantity of water used during drilling b and the number of horizontal wells v.
   4. **Approximate vertical water usage**: **(denoted as *y*)**: the total water usage for horizontal wells, across the planning area, including water usage associated with drilling and hydraulic fracturing.
      a. Equation: $y = \frac{dc}{b+c} + vc$
      b. Where $\frac{dc}{b+c}$ represents the portion of the total combined water use for hydraulic fracturing d allocated to vertical wells, and vc represents the total water usage based on the average quantity of water used during drilling b and the number of horizontal wells v.
   5. **Total water usage (denoted as *z*):** the total water usage for vertical and horizontal wells across the planning area, including water usage associated with drilling and hydraulic fracturing.
      a. Equation: $z = y + x$

3.2 U.S. Geological Survey Data

3.2.1 Data Summary

The USGS provides water use estimates for 2015 at the county level across the United States, compiled by the USGS's National Water Use Science Project in collaboration with local, state, and federal agencies. These data offer insights into water resource management and utilization trends at the state and county levels (Dieter et al. 2018).

3.2.2 Data Preparation

To present the summarized water use data in tables throughout the WSD, USGS data will be processed and aggregated by state and county. The following instructions describe the process by which the summarized totals will be obtained.

State Water Use and County Water Use: For each county in the USGS data, there are many columns to document the various types of water usage. The total water use is listed per county in each state, so total water use per category for the state must be manually generated through summing county-level data. Water use for counties within Oklahoma, Kansas, and Texas and state totals can be generated by:

1. Download *Estimated Use of Water in the United States County-Level Data for 2015* from https://www.sciencebase.gov/catalog/item/get/5af3311be4b0da30c1b245d8
    a. File name: usco2015v2.0.xlsx "All Data XLSX"
2. Reading the *Estimated Use of Water in the United States County-Level Data for 2015* into R.
3. Reading the data dictionary into R (The excel tab named DataDictionary in the downloaded data file is the data dictionary and should be retained with the original data; see Table 1 for data dictionary).
4. The data dictionary can be used to change the column names from abbreviations to the associated description to allow for ease of grouping schemes and table creation. See the following script:

```
<script>

# Iterate over column names of data and replace those with matching abbreviations from the data
dictionary
for (i in seq_along(names(data))) {
  match_index <- match(names(data)[i], dataset_two$Abbreviation)
  if (!is.na(match_index)) {
    names(data)[i] <- dataset_two$Description[match_index]
  }
}
```

5. Begin by filtering data according to the state of interest (e.g., Texas).
6. Because the water use estimates are broken down into county-level estimates, a new data frame is created that sums all county-level numeric water use values to develop state-level estimates. The new data frame will include column headers with water use category, and associated state total estimates.
    a. This dataset can then be gathered (i.e., converting column headers into levels within a single column) in R to provide a dataset with two columns for the state summary: Water Use Type and Water Use Estimate.

7. To develop county-level projections, similarly filter the data by state to generate data that includes only counties within the state of interest (e.g., Texas).
8. The data can then be split into a list of separate data frames according to each county. In R, a list is a versatile data structure that can contain elements of different types, such as vectors, matrices, and data frames. Lists allow you to store and organize data (e.g., county-level water use data) in a single object for further summarization and analysis. See the following script:

```
<script>

# Split the gathered data into separate data frames for each county. The data will be stored within
a list.
county_dfs <- gathered_data %>%
  group_split(COUNTY) %>%
  setNames(unique(gathered_data$COUNTY))

#now View the dataframe of interest for the county.
View(county_dfs["Beckham County"])
```

9. Once county-level data frames have been generated and stored within a list, counties will be cross-referenced with the FracFocus data, and counties that do not include oil and gas development will be filtered out for the final summary.
10. Counties with oil and gas development will be grouped into regional grouping schemes based on oil and gas development across adjacent counties. This step will eliminate the need for reporting at the level of individual counties. The final county grouping scheme will be the same grouping scheme used for FracFocus data (see Section 3.1.4).
    a. This can be done in R using the list of county-level data frames constructed above. From the list, a new data frame can be created that sums water use values for combined counties within each region (e.g., sum of total water use for Adair County and Alfalfa County). The example script below code takes two county-level data frames with the same structure, adds their corresponding column values together, and stores the sums in a new data frame, maintaining the original column structure.

    ```
    <script>

    # Use apply() to apply the addition operation to each column within the county-level
    dataframes.
    Regional.df <- apply(County1 + County2, MARGIN = 2, FUN = identity) %>% as.data.frame()

    # Assign column names to the new dataframe
    colnames(Regional.df) <- colnames(County1)
    ```

    b. The regional water use data frame will be stored separately from the state-level data frames for further downstream summarization (see Section 3.2.4)

3.2.3 Unit Conversions

Water use in the USGS data is reported in million gallons per day (MGD), and water use in the Water Support Document is reported in AF. The following conversion factors can be used to convert from gallons to AF and vice versa.

Grand total in AF per year = (Grand Total [MGD] × 1.121) × 1,000

3.2.4 Data Aggregation and Summaries

Once the data has been cleaned and grouped by state and then separately by the regional grouping scheme defined in Step 10 of Section 3.2.2, data aggregation and table construction will be conducted. Water usage is broken down into the following categories for the combined state and regional data:

- Aquaculture
- Domestic
- Industrial
- Irrigation
- Livestock
- Mining
- Public Water Supply
- Thermoelectric Power

The above variables are broken down separately and totaled for fresh water and saline water usage between groundwater and surface water sources (see Table 3).

Data will be aggregated and summarized in tables using the Dplyr package in R. The summary tables will be grouped by state and region therein. The Dplyr package provides a set of functions that offer a consistent and intuitive way to perform common data manipulation tasks such as filtering, sorting, summarizing, and joining data frames such as the summarize() function in combination with other functions such as group_by() for grouping summaries. Table 3 provides a template summary table that will be used for water use data in the WSD.

Table 3. Example Water Use Table for State and Regional Water Use Summaries

Category	Surface Water				Groundwater				Total Withdrawals				Total	Total Use (%)
	Fresh	Saline	Total	Total Use (%)	Fresh	Saline	Total	Total Use (%)	Fresh	Total Use (%)	Saline	Total Use (%)		
Aquaculture														
Domestic														
Industrial														
Irrigation														
Livestock														
Mining														
Public Water Supply														
Thermoelectric Power														
County Totals														

3.3 Spill Data

3.3.1 Data Summary

Oklahoma (OCC 2024c), Kansas (Kansas Department of Health and Environment 2024), and Texas (TCEQ 2024b) require reporting of spills to the state. State agencies are required to make this data publicly available either online or through open records requests. Spill data for each state will be acquired, quality-checked, and aggregated to report spill quantities across each state. It is important to note that each state has separate reporting criteria; therefore, one state dataset may be limited in scope or quality of data relative to another state dataset. Spill data should not be compared across state. However, for this analysis, it is assumed that any within-state reporting error is constant, and therefore, spill data can be compared within each state. Additionally, each dataset includes different date ranges for spill reporting and different quantities of entries; therefore, it is assumed that reported totals represent the best available spill data for the state. It is not assumed that spill data accurately and equally reflect spill totals and quantities recovered for the state-specified date range. Nonetheless, each dataset will be similarly cleaned and evaluated for data quality and erroneous data entries. The final cleaned dataset will inform summaries within the report with the following information:

- The date on which the spill occurred.
- The material that was spilled.
- The location of the spill.
- The quantity of the spill.
- The amount of the spill that was recovered.
- Impacts to surface waters or groundwater.

Oklahoma

Spill data for Oklahoma is made available upon public records request from the Oklahoma Corporation Commission (2024). The entire spills database contains records with incident dates ranging from 2009 to 2024 (through the month in which this report was written). Spill data for Oklahoma includes data on the quantity of each reported spill, the amount recovered, and impacts on surface water. Information on groundwater impacts is not provided.

Kansas

Spill data for Kansas is made available upon public records request from the Kansas Corporation Commission (2024). The entire spills database contains records with incident dates ranging from 1989 to 2024 (through the month in which this report was written). Spill data for Kansas includes data on the quantity of each reported spill, the amount recovered, impacts on surface water, and impacts on groundwater.

Texas

Spill data are available for download from the Texas Commission of Environmental Quality (TCEQ) Spills database located at the Texas Commission on Environmental Quality – Emergency Response Spills Open Data Portal (TCEQ 2024).

The entire spills database contains records with incident dates ranging from 2001 to 2024 (through the month in which this report was written). The database includes records of all types of spills, as well as general reporting, many of which are not relevant for the purposes of this report, such as sewage, smoke, and dead fish. For this analysis, reporting that is not related to oil and gas will be filtered out of the data, leaving only oil and gas and water-related spills. Many data entries represent oil spill incidents; however, no amount is specified (e.g., leak in oil pipeline).

Texas spill data includes information on the quantity of each reported spill and impacts on surface water. Texas spill data does not include data on the quantity of oil that was recovered from the spill; therefore, the percentage of oil recovered cannot be calculated. Additionally, information on groundwater impacts is not available for Texas.

3.3.2 Spill Data Processing

The Oklahoma Corporation Commission, the Kansas Corporation Commission, and the TCEQ do not include data dictionaries with spill data reporting. Therefore, several assumptions and definitions will be made about the data. These assumptions are summarized above, and additional data-related assumptions are detailed below.

After each state dataset is read into R, a master dataset will be created that includes all states, or a single data set will be developed for each state, depending on similarities in state-level datasets. Datasets will be a subset of the state-level data, including relevant data for this analysis. Spill datasets will include the following columns:

- State
- County
- Date of incident
- Type of spill
- Quantity of spill
- Quantity of spill recovered
- Percentage of spill recovered
- Waterway or groundwater affected

To create this data, the following steps will be taken:

1. The above columns will be extracted or calculated when applicable from each state dataset in R and stored in a new data frame with the same column order as listed above.
    a. This will remove all additional column data that is not relevant to this report.
    b. This will yield three data frames that can be merged if necessary.
2. The three datasets will then be merged, yielding one master dataset with the same data for each state.

The above steps will yield data that will be easy to use and filter according to a variable of interest. However, data entries will still need to be checked for quality, and spill entries with no defined quantity will need to be quantified accordingly. These data checks are intended to evaluate and validate the consistency, completeness, and uniqueness of spill data. In this process, records that do not meet the specified data quality criteria are reviewed and addressed using case-specific techniques. The data is systematically evaluated, verified, and adjusted based on reasonable assumptions until all identified discrepancies are resolved. In general, data is not removed during the data cleaning process. For example, if a spill type is not clear, the entry would be reclassified as “Spill Type: Unknown,” or if a spill volume represented an outlier in the data, the volume would be recoded as “Unknown.” To further clean and process the master spill dataset, the following general steps will be applied for each of the data columns defined above. These steps outline a broad workflow but do not account for potential data discrepancies, unexpected patterns, or challenges that may arise during the deeper analysis phase. Adjustments will be made as needed to address unforeseen issues as they emerge.

1. *State* will be a column with factors including three levels: Oklahoma, Kansas, Texas.
2. *County* will be a column with factors including *x* levels, with *x* equaling the total counties within each state in which oil spills have been reported.
3. *Date of Incident* will be broken apart into month, day, and year. Code will be applied to create three additional columns: Month, Day, and Year, each containing the corresponding parts of the date. For example, **"2024-04-11"** will be recoded as 2024, April, and 11 within three separate columns for each state.
   a. Data structure will be checked, and problematic date entries will be corrected, if possible; otherwise, data will be mutated and defined as “Unknown Date.”
4. *Type of Spill* will be factored to ensure that all entries are consistent. Ambiguous entries will be corrected (e.g., misspelling) if possible; otherwise, ambiguous or undefined data entries will be mutated and defined as “Other.” Spill type data will include multiple levels based on the types of spills reported (e.g., Gasoline, Pipeline, Crude Oil, Water, Natural Gas, Other).
5. *Quantity of Spill* will require numeric data quality checks.
   a. An upper threshold will be used to flag entries that may be erroneous (e.g., accidental additional digit added). For this analysis, outlier entries are defined as spills that are greater than 1,000 barrels. Spills greater than 1,000 barrels will be flagged and checked against the spill notes to determine if the entry is valid. If it is determined that the value is erroneous., the value will be mutated and reclassified as “Unknown.” To do this, outliers can be calculated, flagged, and visualized in R, allowing the user to manually check the entry ID against the “spill notes” to determine the validity of the entry. See the following example script:

```
<script>

#outliers
# Calculate outliers (using IQR method)
spill6$is_outlier <- with(spill6, Volume.Released < quantile(Volume.Released, 0.25) - 1.5 *
IQR(Volume.Released) | Volume.Released > quantile(Volume.Released, 0.75) + 1.5 * IQR(Volume.Released))

# Create the plot
# Go in and check outliers if necessary. This plot is very useful for checking outiers against their notes.

ggplot(spill6, aes(x = Incident_year, y = Volume.Released)) +
  geom_jitter() +  # Add jittered points
  geom_point(data = filter(spill6, is_outlier), aes(color = "Outlier"), size = 3) +  # Highlight outliers in red
  geom_text(data = filter(spill6, is_outlier), aes(label = Incident.Number), vjust = -0.5, color = "red") +  # Label
outliers
  scale_color_manual(values = c(Outlier = "red", "black")) +  # Color scale for outliers
  theme_minimal()  # Optional: Choose your desired theme
```

   b. In addition, a lower threshold numeric data check will be required. Many spill data entries are ambiguous or deductively erroneous (e.g., “Null” or “0”), thereby necessitating global corrections based on the following assumption*: If a spill data was* *reported, it is assumed that the quantity of the material spilled is non-zero; therefore, all data entries represent a spill quantity greater than zero.*

   c. Corrections based on the above assumption will vary between each state due to observed differences in the quality of oil spill reporting. The following corrections will be applied to the three states within this analysis:
      i. For the Oklahoma spill data, the majority of oil spill quantity entries are classified as "Null" or "0." For this analysis, it is assumed that Oklahoma spill data reporting does not provide sufficient evidence to quantify ambiguous entries. Therefore, all such entries will be reclassified as "Quantity of Oil Spilled: Unknown." This ensures that each entry is reclassified as unspecified, but non-zero.
      ii. Kansas spill data generally includes sufficient numeric data on spill quantity and quantity recovered. However, occasional spill entries are not defined, or are classified as "0." Often, these entries coincide with small-scale spills. For this analysis, it is assumed that quantity of oil spill reporting in Kansas is sufficiently stringent, and that "0" or missing entries can be mutated and reclassified as "less than 1" to reflect a small-scale oil spill with a quantity no greater than one barrel of oil.
      iii. Texas spill data includes numeric entries for oil spilled, including "0." For this analysis, it is assumed that quantity of oil spill reporting in Kansas is sufficiently stringent, and that "0" can be mutated and reclassified as "less than 1" to reflect a small-scale oil spill with a quantity no greater than one barrel of oil.

6. *Quantity of Spill Recovered* pertains to Oklahoma and Kansas; however, this value is not reported for Texas. Therefore, this entry will be coded as "ND" (No Data) for Texas. For this column, the quantity of oil recovered will be denoted as percentage of the original volume of oil spilled.

7. *Waterway or Groundwater Affected* is reported for each state; however, the level of reporting is not assumed to be equally stringent between states. The final column will include factored data with the following four levels: Unknown, Surface Water, Non-Surface Water, and Groundwater. The following corrections will be applied to each state to eliminate ambiguity and ensure consistency in reporting:
   a. Oklahoma reports if the spill affected a waterbody with "Yes," "No," or "NULL."
      i. All "NULL" entries will be mutated and reclassified as "Unknown."
      ii. All "Yes" entries will be mutated and reclassified and "Surface Water."
      iii. All "No" entries will be mutated and reclassified as "Non-Surface Water."
   b. Kansas reports if the spill affected a waterway with "Soil," "Groundwater," or "Surface Water."
      i. All "Soil" entries will be mutated and reclassified as "Non-Surface Water."
      ii. All "Surface Water" entries will remain "Surface Water."
      iii. All "Groundwater" entries will remain "Groundwater."
   c. Texas reports if the spill affected a waterway with details related to the specific waterway (e.g., Rio Grande). Due to the quantity of various entries including misspellings and variation (e.g., NA, na, N/A), a sweeping mutation will be applied to the dataset to split the data between non-surface water spills and surface water spills.
      i. The sweeping mutation will use the Ifelse function in R to split data surface water spills and non-surface water spills. The function applies the correction based on the following logic: *If the data is defined as non-surface water spills*

(e.g., "None," N/A), then classify as "Non-Surface Water"; otherwise, classify as "Surface Water" (e.g., Rio Grande, Gulf of Mexico).

3.3.3 Unit Conversions

Spills within each dataset may be reported differently. All oil spills will be reported in barrels (Bbl), all gaseous spills will be reported in thousands of cubic feet (MCF), and all water spills will be reported in gallons (Gal). In R, code will be applied to universalize spill reporting and ensure all spill types are reported correctly and consistently. Values will be converted accordingly, and units will be updated. See the following example R code, which first converts gallons to barrels and then changes "GAL" to "Bbl":

```
<script>

convert all Gal reports to Bbl in spill6 and drop unused levels. This will globally get rid of gallons.
# Convert all gallon measurements to BBL for Volume.Released, Volume.Recovered, and Volume.Lost
spill6 <- spill5 %>%
  mutate(
    Volume.Released = if_else(Unit.Of.Volume == "GAL", Volume.Released / 42, Volume.Released),
    Volume.Recovered = if_else(Unit.Of.Volume == "GAL", Volume.Recovered / 42, Volume.Recovered),
    Volume.Lost = if_else(Unit.Of.Volume == "GAL", Volume.Lost / 42, Volume.Lost)
  ) %>%
  # Convert all GAL entries in Unit.Of.Volume to BBL
 mutate(Unit.Of.Volume = if_else(Unit.Of.Volume == "GAL", "BBL", Unit.Of.Volume)) %>%
 mutate(Unit.Of.Volume = as.factor(Unit.Of.Volume)) %>% #factor units
 mutate(Unit.Of.Volume = droplevels(Unit.Of.Volume)) #Drop unused levels.

levels(spill6$Unit.Of.Volume) #gallons dropped.
summary(spill6$Volume.Released)
summary(spill6$Volume.Recovered)
summary(spill6$Volume.Lost)
```

Conversion examples:

- Acre-feet to gallons: $Gal = AF \times 325{,}851$
- Gallons to barrels: $Bbl = Gal \times 0.023810$

Barrels to thousands of cubic feet: $MCF = Bbl / 5.615$

3.3.4 Data Aggregation and Summaries

Once the data has been cleaned and a master dataset has been generated that consists of spills at the county and state levels, data will be filtered and grouped by the regional grouping scheme outlined in Section 3.1.4. This grouping scheme consists of grouping targeted counties (see Table 1) into single units based on proximity and similarities in oil and gas development.

Data aggregation and table construction will be conducted using the Dplyr package in R, which easily summarizes data based on defined grouping schemes (e.g., mean spill quantity by year). State and regional data will be grouped by date of spill and type of spill, and summary tables will be generated to report quantity of spill, quantity of spill recovered, and percentage of spill recovered. Finally, the tables will also include a column that specifies if a waterway was affected by the spill. Note, some states will not include certain summaries due to incomplete, missing, or insufficient reporting. See example script for summarizing spill data below:

```
<script>

#generating summaries for the state of NM for the year 2023.

spill6 %>%
  filter(Incident_year == 2023) %>%
  group_by(Material) %>%
  summarise(
    Spill.Count = n(),
    Volume.Spilled = sum(Volume.Released),
    Volume.Lost = sum(Volume.Lost),
    Units = first(Unit.Of.Volume),  # Unit of volume should be the same for rows within groups.
    Average_spill.V = mean(Volume.Released),
    Mean_Perc_lost = 100 - mean(Percent.recovery),
    Waterway.Affected = sum(ifelse(Waterway.Affected == "Yes", 1, 0)),  # Count "Yes" values
    Groundwater.affected = sum(ifelse(Ground.Water.Impact == "Yes", 1, 0))  # Count "Yes" values
  ) %>% as_tibble() -> sum.state.1

View(sum.state.1)
```

3.4 USGS – A Dataset of Scanned Historical Well and Geophysical Logs From 96 Counties in Texas, 1925–2020

This dataset was compiled to digitally preserve the historical collection of well and geophysical logs housed at the USGS Oklahoma-Texas Water Science Center. This dataset was published in 2024; however, it was temporarily retracted in 2024, and will not be available for analysis in the 2024 iteration of the Oklahoma WSD. The dataset facilitates public access to data on hydrogeological conditions from wells spanning across 96 Texas counties. The dataset consists of 6,058 scanned and indexed records in PDF format, organized by county and supplemented by a publicly accessible Microsoft Access database and a comma-separated values (CSV) text file containing comprehensive well header information (USGS 2024c).

The dataset includes data related to groundwater from various wells across Texas, reporting on top depth, bottom depth, and total well depth over time. Upon availability of this dataset, the average change in depth to groundwater will be calculated over time at the county level. To do this, the following steps will be taken:

1. A county-level baseline will be calculated based on the average depth to groundwater. Baseline conditions will be defined as the average depth to groundwater for the first 5 years of reporting within the dataset. A new column will be created with county-level baseline conditions.
2. County-level average depths to groundwater will be calculated for each year of reporting. A new column will be created to store county-level averages for each year.

3. Change in groundwater from baseline conditions will be calculated by subtracting county-level baseline conditions from county-level depths to groundwater. A new column will be created to store county-level changes in groundwater depth for each year.
4. County-level average groundwater depth and associated changes in groundwater depth relative to the baseline period will be aggregated and visualized within the report.

3.5 Other Relevant Reports and Studies

3.5.1 Per-and Polyfluoroalkyl Substances

Consideration of water quality and water quantity should take into account the pervasive presence of per- and polyfluoroalkyl substances (PFAS) throughout the nation's water resources, particularly as the oil and gas industry can be a source of contamination (Gaines 2022). No data processing will be conducted for this data source but a review of reports and studies regarding PFAS contamination in surface water and groundwater, the impact of the oil and gas industry on PFAS contamination, and strategies to address contamination will be summarized. Studies to be reviewed include but are not limited to the following:

- USGS *Assessment of per-and polyfluoroalkyl substances in water resources of New Mexico, 2020-21* (USGS 2024a)
- U.S. Environmental Protection Agency (EPA) *Historical and current usage of per- and polyfluoroalkyl substances (PFAS): A literature review* (Gaines 2022)
- EPA *PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024* (EPA 2021)

Additionally, PFAS used in hydraulic fracturing are categorized into four distinct groups in the FracFocus database; perfluoroalkyl alkanes/cycloalkanes, fluoroalkyl alcohol substituted polyethylene glycol, nonionic fluorosurfactants, and polytetrafluoroethylene (Connor et al. 2021). Chemicals in FracFocus will be categorized according to these four PFAS groupings.

PFAS chemicals reported in FracFocus include misspellings, ambiguity, alternative naming, etc. Additionally, the large occurrence of non-disclosed and proprietary chemicals presents an additional challenge in determining the occurrence of PFAS chemicals. To account for these discrepancies, key words and phrase will be used to identify PFAS chemicals groupings within FracFocus by searching for relevant terms, phrases, and patterns used to classify PFAS chemicals and ensuring that irrelevant spacing, punctuation, and ordering is omitted in PFAS determination. This approach allows for a more thorough and accurate process of PFAS chemical identification by capturing a wide range of variations in how they may be reported; however, due to the complex nature of chemical reporting within FracFocus, this approach fails to capture the true occurrence of PFAS chemicals.

3.5.2 Induced Seismic Activity

There is evidence that seismic activity can be induced by disposal of high volumes of produced water from oil and gas production into disposal wells in underlying formations. Several sources will be reviewed and summarized to present the state-specific scenarios for induced seismicity due to oil and gas development and the mitigation strategies that federal and state agencies are conducting to address issues. No data will be processed for this source, but the following resources will be summarized:

- Congressional Research Service *Earthquakes Inducted by Underground Fluid Injection and the Federal Role in Mitigation* (Congressional Research Service 2023)
- Kansas Seismic Action Plan (Kansas Geological Survey 2015)

- Oklahoma Induced Seismicity and UIC Resources (Oklahoma Corporation Commission 2024b)
- Texas Railroad Commission Seismicity Review and Response (Texas Railroad Commission 2023)

3.5.3 Other Reports

Several additional reports and analyses were identified as relevant sources of data and information to be used in development of the WSD, each of which is described below in more detail and listed by relevant WSD topic in Table 2.

- Reasonably Foreseeable Development Scenario: The latest Reasonably Foreseeable Development (RFD) Scenario was created in 2016 to provide a long-term 20-year projection of fluid mineral exploration, development, and production for the Kansas, Oklahoma, and Texas Resource Management Plan (BLM 2016). This is comprehensive documentation of development scenarios not only for oil and gas, but also for minerals and geothermal, wind, and solar resources. A discussion of data sources, methodology for predicting exploration, and understanding the relationship between resource occurrence and activity is presented in the RFD that includes relevant information for the OFO WSD development, such as 1) information on hydraulic fracturing and water use, 2) source of water commonly used, and 3) water use by USGS-defined Hydrologic Unit Code 8 watersheds.
- BLM OFO Joint Environmental Impact Statement/BLM Resource Management Plan and BIA Integrated Resource Management Plan: The RMP provides information on water resources data specific to the OFO that includes quantity, quality, and source information.
- EPA’s Hydraulic Fracturing for Oil and Gas: This 2016 report provides a comprehensive look at the impacts of hydraulic fracturing on water quality and covers spills, withdrawal impacts, fluid injection impacts on groundwater and surface water, and disposal practices that result in contamination (EPA 2016).
- EPA’s Demonstrating the Impacts of Oil and Gas Exploration on Water Quality: A comprehensive analysis of oil and gas activities and impacts to water quality, particularly during storm runoff events (EPA 2015).
- Kansas, Oklahoma, and Texas Integrated Reports: Each state produces a report every 2 years documenting the status of surface water quality. These reports will be reviewed to better understand the water quality condition of streams and lakes within the targeted counties.
- Oil and Gas Produced Water Reuse: Opportunities, Treatment Needs, and Challenges: This 2021 report provides several case studies regarding the reclamation and reuse of produced water and how incorporating standardized analytical techniques is critical to maximizing reuse in the future (Cooper et al. 2021).

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