2017 Oklahoma Groundwater Report

Beneficial Use Monitoring Program

OWRB
the water agency

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Executive Summary

The goal of the Groundwater Monitoring and Assessment Program (GMAP) is to determine baseline water quality and quantity against which future changes can be measured, detect and quantify water quality and quantity trends, assess beneficial use support as appropriate, and apply collected data towards the establishment of beneficial use criteria for the State's groundwater resources as well as strengthen existing beneficial use criteria.

It is the intent of the Oklahoma Water Resources Board (OWRB) to advance concepts and principles of the Oklahoma Comprehensive Water Plan (OCWP). Consistent with a primary OCWP initiative, this and other OWRB technical studies provide invaluable data crucial to the ongoing management of Oklahoma's water supplies as well as the future use and protection of the state's water resources. Oklahoma's decision-makers rely upon this information to address specific water supply, quality, infrastructure, and related concerns. Maintained by the OWRB and updated every 10 years, the OCWP serves as Oklahoma's official long-term water planning strategy. Recognizing the essential connection between sound science and effective public policy, incorporated in the Water Plan is a broad range of water resource development and protection strategies substantiated by hard data – such as that contained in this report – and supported by Oklahoma citizens.

Beneficial Use Monitoring Program Goal

The goal of the Beneficial Use Monitoring Program is to document beneficial use impairments, identify impairment sources (if possible), detect water quality trends, provide needed information for the Oklahoma Water Quality Standards (OWQS) and facilitate the prioritization of pollution control activities. Data collected from the Groundwater Monitoring and Assessment Program (GMAP) will serve to establish additional beneficial use criteria for the State's groundwater resources, strengthen existing criteria, detect water quality and quantity trends, and promote more accurate groundwater use guidelines for the major aquifers of the State.

The Beneficial Use Monitoring Program (BUMP) exists as a result of the vital economic and social importance of Oklahoma's lakes, streams, wetlands, and aquifers and the associated need for their protection and management. Surface water data has been collected and analyzed following procedures outlined in Use Support Assessment Protocols (USAP), developed by Oklahoma's environmental agencies. Specifically, USAPs establish a consistent method to determine if beneficial uses assigned for individual waters through OWQS are being supported. (Legitimacy of data analyzed following protocols other than those outlined in the USAP must be defended.) If the BUMP report indicates that a designated beneficial use is impaired, threatened, or otherwise compromised, measures must be taken to mitigate or restore the water quality. As groundwater does not currently have USAP's, the data are analyzed and compared to USEPA drinking water guidelines and benchmarks. Data generated by the program are collected in a scientifically defensible manner using industry accepted standards, so that beneficial use impairment assessments can ultimately be performed and potential development of robust numerical groundwater quality standards can be explored.

Traditionally, the State of Oklahoma has utilized numerous water monitoring programs conducted by individual state and federal agencies. These programs collect information for a specific purpose or project (e.g., development of Total Maximum Daily Loads, OWQS process, lake trophic status determination, water quality impact assessments from nonpoint and point source pollution, stream flow measurement, assessment of best management practices). Therefore, the information is specific to each project's data quality objectives (DQOs) and is often limited to a very small geographic area.

To synchronize Oklahoma's monitoring efforts related to water quality, the State Legislature appropriated funds in 1998 to create the Beneficial Use Monitoring Program under the direction of the Oklahoma Water Resources Board, which maintains Oklahoma's Water Quality Standards. The BUMP and other environmental monitoring activities bring the OWRB's overall water quality management program full circle. From the promulgation of OWQS, to permitting and enforcement of permits stemming from OWQS-established criteria, to non-point source controls—all agency water quality management activities are intended to work in concert to restore, protect, and maintain designated beneficial uses.

The specific objectives of the BUMP are to detect and quantify water quality trends, document and quantify impairments of assigned beneficial uses, and identify pollution problems before they become a pollution crisis. This report interprets current Oklahoma groundwater data collected as part of the State's first aquifer-based, long-term funded holistic groundwater quality and quantity monitoring program, GMAP. The GMAP joins established surface water monitoring programs as a vital component of the BUMP. As the program matures, the BUMP report is sure to continue to be one of the most important documents published annually in Oklahoma.

Beneficial Use Monitoring Program Components

- **Groundwater Monitoring and Assessment Program (GMAP)** – This new program was made possible as result of the increase in funding received from the Oklahoma Legislature for water quality/quantity monitoring based on recommendations of the 2012 Update of the Oklahoma Comprehensive Water Plan. These additional monies were utilized to restore funding levels of the Beneficial Use Monitoring Program as well as to implement the new groundwater program. The program prioritizes efforts on Oklahoma's 22 major groundwater aquifers, with the baseline phase completed at the conclusion of 2017 and long-term trend monitoring scheduled to begin in 2019. The baseline period focused on 4-6 aquifers per year, beginning in 2013, and assessed concentrations of nutrients, metals and major ion species. Sample size was predicated upon and proportional to the surface area of the aquifer with a general goal of 30 wells per aquifer. Some of the state's larger aquifers exceeded the goal and some of the smaller aquifers were represented by fewer wells (Table 1). At the conclusion of the baseline sampling period there were 695 wells sampled from major aquifers in the statewide groundwater quality network, with an additional 31 wells in minor aquifers. In addition, the OWRB's annual groundwater level measurement program nearly doubled in capacity from around 530 to 900 wells and has been spatially redistributed. Also over the 5-year baseline period, the OWRB installed 33 continuous water level recorders to obtain daily or hourly measurements that are more sensitive to detecting seasonal changes (brought on by drought or variable climate conditions) than can be obtained by annual measurements.

Table 1. Target sample networks based on aquifer areal extent.

Areal Extent Category	Sample Site Well Density	Sample Sizes Generated
> 5000 km^2	1 well per 150 km^2 (6 aquifers)	37 – 89
3001 – 5000 km^2	1 well per 100 km^2 (5 aquifers)	33 – 48
1501 – 3000 km^2	1 well per 75 km^2 (6 aquifers)	25 – 33
751 – 1500 km^2	1 well per 50 km^2 (2 aquifers)	16 – 19
≤ 750 km^2	2 aquifers	6 – 10

- **Monitoring Rivers & Streams** - The OWRB is currently monitoring approximately eighty-four (84) stations on a 6-week rotation. Fixed station monitoring is based largely upon the eighty-four (84) planning basins as outlined in the Oklahoma Comprehensive Water Plan (OCWP). In general, at least one (1) sample station was located at the terminal end of each of the planning basins. The OWRB also conducts sampling on 25-30 probabilistic monitoring stations annually.
- **Fixed Station Load Monitoring** - The OWRB is currently working with several partners including the United States Geological Survey (USGS), US Army Corp of Engineers (USACE), Grand River Dam Authority, and other partners to conduct flow monitoring on all of our fixed station sites that are not part of the Oklahoma/USGS Cooperative Gaging Network. This cooperative effort will allow for loadings to be calculated, trends to be assessed statewide, and provide much needed data for the Use Support Assessment process. Along with the USGS cost share program, Oklahoma's 319 program, Oklahoma's 314 program and the 303(d)-process will drive sample site locations associated with this task.
- **Fixed Station Lakes Monitoring** – As part of BUMP, the OWRB conducts sampling on lakes and reservoirs across the State of Oklahoma. To accomplish this task, the OWRB has taken a fixed station approach for the lakes monitoring program. This design allows the state's objectives to be met as well as ensure various sized waterbodies are represented adequately. The survey population includes all lakes above 50 surface acres, which encompasses approximately 206 different waterbodies. The population is then stratified into two groups – lakes greater than 500 surface acres and those below 500 surface acres. The greater than 500 surface acres group includes 68 lakes, of which approximately one-fifth are monitored annually (quarterly samples). They are then monitored again during a subsequent year in the 5-year rotation, so that each lake greater than 500 surface acres is sampled 2 non-consecutive years during each 5 year rotation. The lakes managed by our Federal partners, the USACE and Bureau of Reclamation (BOR) are included in the 68 large multipurpose lakes. Additionally, ten lakes of less than 500 surface acres are sampled annually (quarterly samples) over the 5 year sample frame. All lakes monitored have either the PPWS or SWS designation. Many of these smaller lakes have not been sampled historically through BUMP and include small municipal water supplies.
- **Intensive Investigations** - If beneficial use impairment is identified or suspected, then all appropriate state agencies will be alerted and an investigation will be initiated to confirm if beneficial use impairment is occurring. If routine monitoring cannot definitively identify

impairments, then an intensive study may be undertaken and if impairment is present, the source of the impairment will be identified if possible. Some potential causes of beneficial use impairment are improper beneficial use or criteria (Oklahoma Water Resources Board jurisdiction), point source problems (Oklahoma Department of Environmental Quality or Oklahoma Department of Agriculture), non-point source problems (Oklahoma Conservation Commission, Oklahoma Department of Agriculture, Oklahoma Corporation Commission, or Oklahoma Department of Environmental Quality), oil and gas contamination (Oklahoma Corporation Commission), agricultural activities (Oklahoma Department of Agriculture), or mining activities (Oklahoma Department of Mines). All monitoring activities will be cooperative in nature with the agency with statutory authority assuming the lead role for intensive monitoring. If water bodies are not identified for intensive study as part of this task, then monies will be reallocated for routine monitoring of beneficial use attainment. Other entities (i.e. tribal or governmental units outside of Oklahoma) will be involved as appropriate. All intensive-monitoring activities will be consistent with the OWQS and the USAP. If no protocols exist, then best professional judgment or State/Environmental Protection Agency guidance is used as appropriate.

Program History/Overview

Historically, groundwater monitoring in Oklahoma has focused its resources and efforts on compliance monitoring, resource conservation and groundwater protection through and by several Oklahoma State Environmental Agencies (Oklahoma Department of Agriculture, Food and Forestry, Oklahoma Conservation Commission, Oklahoma Corporation Commission, Oklahoma Department of Mines, Oklahoma Department of Environmental Quality and Oklahoma Water Resources Board).

Enforcement and oversight of groundwater regulatory programs is of vital importance to the ongoing efforts to protect and manage, and if necessary mitigate, affected groundwater resources from regulated contamination sources. Some of these programmatic areas include source water protection, underground injection control, water produced or trapped in mines, water produced from oil and gas production, waste water lagoons, hazardous materials storage, fuel storage tanks and lines, water quality standards, groundwater rights permitting, and groundwater technical studies governing water rights permitting.

The new Groundwater Monitoring and Assessment Program is not a regulatory program that targets a land use category or water use sector. Rather, the program is designed to characterize each aquifer utilizing existing groundwater wells drilled by licensed well drillers, records of which are maintained in the OWRB's online database. Based on defined areal and vertical aquifer boundaries, a spatially allocated, probabilistic (randomized) draw of wells within each aquifer yields monitoring sites that can be used to characterize the aquifer as whole.

GMAP baseline monitoring was initiated in the summer of 2013 with 6 of Oklahoma's major aquifers and continued with an additional 8 aquifers (8 major) in 2014, 7 (6 major; 1 minor) in 2015, 3 (2 major; 1 minor) in 2016 and 2 (1 major; 1 minor) in 2017. The baseline monitoring has been phased in over a five year interval schedule (Figure 1). This schedule was revised after Group B was completed due to budget considerations. Baseline monitoring will yield results about the current status of Oklahoma's groundwater quality in terms of major ions, nutrients and metals as well as benchmarking groundwater levels. Approximately twenty-five percent (25%) of the groundwater quality sites and fifty percent (50%) of the groundwater level sites will become fixed trend sites to observe water quality and water level changes over time.

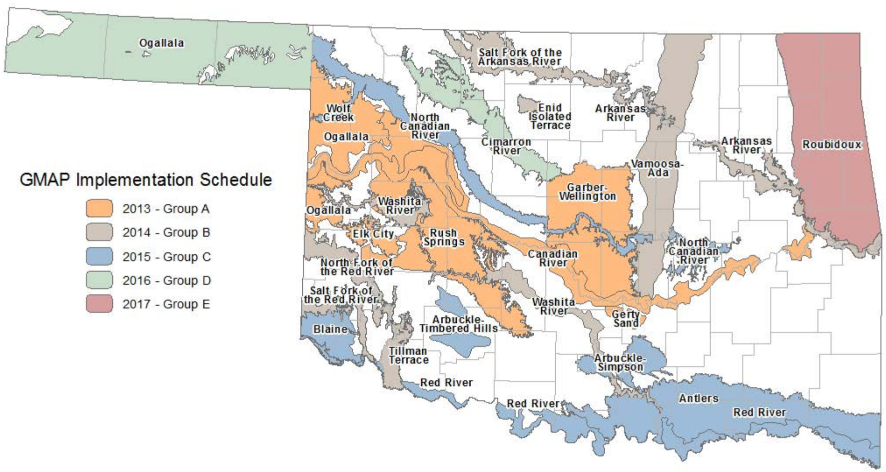

Figure 1. Revised GMAP implementation schedule (final).

Results of Groundwater Sampling Efforts

Group A baseline monitoring networks for water quality and water levels were implemented in 2013 (August-November) for the Canadian River, Elk City, Garber-Wellington, Gerty Sand, Ogallala-Northwest and Rush Springs aquifers. Two hundred three (203) wells were sampled and 299 groundwater level measurements were made. Work also began on expanding the groundwater level measurement program in January 2014 with the addition of 87 new wells to the program for a total of 619 measurements. One hundred ten (110) of these wells were designated trend network wells to be measured tri-annually. Water quality results are reported in the 2013 OWRB BUMP Report (available online) and the ongoing work with water level networks is reported here. Four (4) continuous water level recorders collecting hourly measurements were also installed in the Group A aquifers, along with 10 in other aquifers throughout the state during the first year of sampling.

Group B baseline monitoring networks for water quality and water levels were implemented in 2014 (August-October) for the Ada-Vamoosa, Arkansas River, Enid Isolated Terrace, North Fork of the Red River, Salt Fork of the Arkansas River, Salt Fork of the Red River, Tillman Terrace, and Washita River aquifers. One hundred seventy-nine (179) wells were sampled and 224 groundwater level measurements were made. Expansion of the groundwater level measurement program continued in January 2015 with the addition of 131 new wells to the program for a total of 707 measurements. Ninety-five (95) of these wells were designated trend network wells to be measured tri-annually, bringing the trend network to a total of 200 wells. Water quality results are reported in the 2014 OWRB BUMP Report (available online) and the ongoing work with water level networks is reported here. Additionally, two (2) continuous water level recorders were installed in Group B aquifers, along with one in another aquifer, in the second year of sampling.

Group C baseline monitoring networks for water quality and water levels were implemented in 2015 (July-September) for the Antlers outcrop, Arbuckle-Simpson, Arbuckle-Timbered Hills, Blaine, North Canadian River, Red River, and Wolf Creek aquifers. One hundred forty-two (142) wells were sampled and 185 groundwater level measurements were made. Expansion of the groundwater level measurement program continued in January 2016 with the addition of 102 new wells to the program for a total of 775 measurements. Fifty-six (56) of these wells were designated trend network wells to be measured tri-annually, bringing the trend network to a total of 254 wells. Water quality results are reported in the 2015 OWRB BUMP Report (available online) and the ongoing work with water level networks is reported here. Additionally, five (5) continuous water level recorders were installed during the third year of sampling.

Group D baseline monitoring networks for water quality and water levels were implemented in 2016 (July-October) for the Cimarron River, Dakota-Dockum, and Ogallala-Panhandle aquifers. One hundred fifty-two (152) wells were sampled and 194 groundwater level measurements were made. Expansion of the groundwater level measurement program continued in January 2017 with the addition of 97 new wells to the program for a total of 855 measurements. Fifty-four (54) of these wells were designated trend network wells to be measured tri-annually, bringing the trend network to a total of 278 wells. Water quality results are reported in the 2016 OWRB BUMP Report (available online) and the ongoing work with water level networks is reported here. Additionally, two (2) continuous water level recorders were installed during the fourth year of sampling.

Group E baseline monitoring networks for water quality and water levels were implemented in 2017 (September-November) for the Boone and Roubidoux aquifers. Fifty-one (51) wells were sampled and 51 groundwater level measurements were made, results of which are reported here. Table 2 reflects aquifer-wide median concentrations for a subset of the analytical and physical data collected during the first years along with an enumeration of the number of wells sampled by use category. Seven (7) continuous water level recorders collecting hourly measurements were installed during the fifth year, along with 24 throughout the state during the first four years of sampling.

Table 2. Baseline characteristics of Groups A, B, C, D and E aquifers (median values reported).

		Field Parameters		Analytical Parameters						Well Use Categories							
Sites	Aquifer	pH	Hard	TDS	NO3	Ca	Na	Cl	SO4	P	I	S	D	M	N	O	DTW
34	A- CNDN	7.01	394	533	1.19	112	45.9	33.9	99.9	4	8	3	13	4	2	0	15.1
13	A- ELKC	7.26	272	349	6.37	67.2	36.5	10.6	16.5	0	1	5	7	0	0	0	22.8
47	A- GSWF	6.97	261	328	0.89	55.6	31.8	18.8	17.4	0	0	0	47	0	0	0	69.9
5	A- GRTY	6.43	202	306	2.12	50.8	33.4	36.8	13.0	0	0	2	3	0	0	0	45.5
40	A- OGLLNW	7.12	219	340	6.02	72.2	26.6	14.2	16.0	3	3	6	18	10	0	0	74.2
64	A- RSPG	7.18	302	427	4.46	78.5	25.4	11.8	61.4	6	10	7	37	4	0	0	58.9
44	B- ADVM	7.05	224	344	0.52	48.3	36.6	17.7	24.2	2	1	1	40	0	0	0	71.9
29	B- ARKS	6.63	255	385	2.42	71	24.8	11.6	26.5	4	10	0	14	0	1	0	22.5
9	B- ENID	6.75	262	566	11.3	87.5	108	61.2	75.8	3	0	0	6	0	0	0	20.2
20	B- NFRR	7.06	342	543	7.95	94.9	37.4	24.5	142	1	5	3	11	0	0	0	33.1
30	B- SFAR	7.13	348	552	4.14	76.1	94.2	55.3	66.1	1	1	10	17	1	0	0	15.8
6	B- SFRR	7.06	260	403	9.73	78.2	35.6	<10	37.8	2	3	0	1	0	0	0	47.6

8	B- TILL	7.12	390	700	13.9	78.7	164	127	103	0	4	3	1	0	0	0	28.3
31	B- WASH	7.21	1030	990	0.88	127	58.1	31.0	111	4	11	9	5	1	1	0	23.9
30	C- ALRS(o)	6.68	94	254	0.15	31.2	23.6	13.2	17.9	0	0	4	26	0	0	0	45.9
8	C-ALRS(c)	8.25	21	635	<0.05	5.1	274	33.1	76.9	2	1	1	4	0	0	0	101
18	C- ABSMP	6.91	335	335	0.99	82.3	3.6	<10	14.4	4	0	2	11	0	0	1	24.9
6	C- ABTMB	8.60	21.5	562	<0.05	2.7	212	69.7	46.6	3	1	0	2	0	0	0	75.3
41	C- BNCR	6.88	283	396	6.56	80.7	27.9	25.5	48.5	3	5	5	21	2	4	1	18.0
36	C- RED	6.72	156	296	8.52	41.8	21.9	18.1	18.1	2	4	12	18	0	0	0	24.4
4	C- WOLF	7.27	260	365	3.32	79.0	26.6	17.6	64.8	1	0	1	1	0	1	0	24.5
37	D-CMRN	7.11	263	424	9.93	75.7	35.7	33.1	37.3	6	6	6	14	1	3	1	17.3
27	D-DAKD	7.52	204	362	1.88	40.7	34.7	14.9	50.0	0	2	16	6	1	1	1	170
88	D-OGLLP	7.38	240	377	3.21	51.1	26.1	19.8	56.6	2	34	24	18	5	4	1	181
34	E-BOON	7.09	195	235	0.766	78.9	3.33	4.95	4.74	0	0	0	34	0	0	0	33.9
17	E-RBDX	7.72	141	330	<0.05	29.4	25.0	27.4	12.4	14	1	1	0	0	0	1	216

n–number of samples collected. Aquifers: CNDN-Canadian River, ELKC-Elk City Sandstone, GSWF-Garber-Wellington, GRTY-Gerty Sand Aquifer, OGLLNW-Ogallala-Northwest, RSPG-Rush Springs Sandstone, ADVM-Ada Vamoosa, ARKS-Arkansas River, ENID-Enid Isolated Terrace, NFRR-North Fork of the Red River, SFAR-Salt Fork of the Arkansas River, SFRR-Salt Fork of the Red River, TILL-Tillman Terrace, WASH-Washita River, ALRS-Antlers(o-outcrop, c-confined), ABSMP-Arbuckle-Simpson, ABTMB-Arbuckle-Timbered Hills, BNCR-North Canadian River, RED-Red River, WOLF-Wolf Creek; CMRN-Cimarron River; DAKD-Dakota-Dockum; OGLLP-Ogallala-Panhandle; BOON-Boone; RBDX-Roubidoux. Parameters: Hard–Hardness, TDS–Total Dissolved Solids, NO3–Nitrate+Nitrite as N, Ca–Calcium, Na-Sodium, Cl-Chloride, SO4-Sulfate (excepting pH, parameter units are in mg/L). Well Use Categories: P-Public Water Supply, I-Irrigation, S-Stock, D-Domestic, M-Mining, N-Industrial, O-Other. DTW–Depth to water below land surface (ft).

Introduction

Protecting Oklahoma's valuable water resources is essential to maintaining the quality of life for all Oklahomans. Used for a myriad of purposes—such as irrigation, hydropower, public/private water supply, navigation, and a variety of recreational activities—the state's surface and groundwater resources provide enormous benefits to Oklahoma from both an economic and recreational standpoint.

It is estimated that Oklahoma's aquifers store approximately 386 million acre-feet of groundwater which fuels the state's economy, serving as supply for thousands of municipalities, rural water districts, industrial facilities, and agricultural operations. According to the 2012 update of the Oklahoma Comprehensive Water Plan (OCWP), groundwater represents the primary water supply for approximately 300 cities and towns and comprises 43 percent of the total water used in the state each year. Groundwater resources also supply approximately 90 percent of the state's irrigation needs, and around 8% of Oklahoma's citizens obtain their drinking water from private wells.

Oklahoma works to protect and manage its water resources through a number of initiatives, with the Oklahoma Water Quality Standards (OWQS) serving as the cornerstone of the state's water quality management programs. The Oklahoma Water Resources Board (OWRB) is designated by state statute as the agency responsible for promulgating water quality standards and developing or assisting the other environmental agencies with implementation framework. All state environmental agencies are currently required to implement OWQS within the scope of their jurisdiction through the development of an Implementation Plan specific for their agency. Protecting our waters is a cooperative effort between many state agencies and because the OWQS are utilized by all state environmental agencies and represent a melding of both science and policy, they are an ideal mechanism to manage water quality, facilitate best management practice initiatives, and assess the effectiveness of our diverse water quality management activities.

The OWQS are housed in Oklahoma Administrative Code 785:45 and consist of three main components: beneficial uses, criteria to protect beneficial uses, and an anti-degradation policy. An additional component, which is not directly part of the OWQS but necessary for resource protection, is a monitoring program. A monitoring program is required in order to ensure that beneficial uses are maintained and protected. Beneficial use designations are limited in groundwater due in part to lack of long-term water quality data. Data collected from the OWRB's Groundwater Monitoring and Assessment Program (GMAP), which was funded to address high-priority recommendations in the 2012 Update to the OCWP, will serve to establish additional beneficial use criteria for the State's groundwater resources, as well as to strengthen existing criteria.

Work to be performed towards development and implementation of the critical fourth component of the OWQS program, monitoring, is the subject of this report. All sampling activities described and conducted as part of this program were consistent with the USGS National Field Manual for the Collection of Water-Quality Data.

Background & Problem Definition

The State of Oklahoma has historically had numerous monitoring programs conducted by several state and federal agencies with varying degrees of integration and coordination with other state, municipal, or federal programs. Most water quality monitoring programs in Oklahoma are designed and implemented by each agency to collect information for one specific purpose or project (e.g., development of Total Maximum Daily Loads, OWQS process, lake trophic status determination, water quality impacts from point source dischargers, stream flow measurements, documenting success of best management practices). Information of this type is specific to each individual project's data quality objectives (DQOs) and is often limited to a very small geographic area. This document describes sampling activities of the first aquifer-based, long-term funded holistic groundwater quality and quantity monitoring program to be implemented in the State of Oklahoma that examines the groundwater resources of the state’s aquifers outside the context of the state’s regulated entities. The GMAP joins ongoing efforts on lakes and streams across Oklahoma as part of a comprehensive, long-term, statewide Beneficial Use Monitoring Program (BUMP).

Beneficial Use and Monitoring Program Overview

The goal of the BUMP is to detect and quantify water quality trends, document and quantify impairments of assigned beneficial uses, identify pollution problems before they become a pollution crisis, and provide needed information for the OWQS. Data collected from the Groundwater Monitoring and Assessment Program will serve to determine a baseline of water quality and quantity against which future changes can be measured, establish beneficial use criteria for the State’s groundwater resources, strengthen existing criteria, detect water quality and quantity trends, and promote more accurate groundwater use guidelines for the major aquifers of the State.

Components of BUMP include: GMAP, which prioritizes water level and water quality monitoring on Oklahoma’s 22 major groundwater aquifers; monitoring rivers and streams through fixed stations and probabilistic sites; load monitoring of rivers and streams through fixed stations in cooperation with multiple national and state partners; lakes monitoring through probabilistic surveys; and intensive investigations, if needed, to identify suspected beneficial use impairment in cooperation with all appropriate state agencies.

Groundwater Monitoring & Assessment Program

The Oklahoma state legislature adopted the 2012 update of the Oklahoma Comprehensive Water Plan (OCWP) and ultimately provided 1.5 million dollars toward expanding Oklahoma's surface and groundwater monitoring capacity. This funding enabled the establishment of a holistic Groundwater Monitoring & Assessment Program (GMAP). This is the first aquifer-based, long-term groundwater monitoring program to be implemented in the state.

Program Structure

Groundwater is water that has percolated downward from the surface, filling voids or open spaces in rock formations. The underground zone of water saturation begins at the point where subsurface voids are full or saturated. An aquifer is a subsurface rock formation capable of yielding groundwater to wells. Aquifers in Oklahoma range in geologic age from Cambrian (570 million years) to Quaternary (1.6 million years to present).

Oklahoma's aquifers are of two basic types: bedrock aquifers that are consolidated to semi-consolidated rock formations composed of sandstone, shale, limestone, dolomite, and gypsum; and, alluvial aquifers that are unconsolidated and composed of a heterogeneous mixture of sand, gravel, silt and clay. The OWRB defines major bedrock aquifers as those that yield an average of at least 50 gpm (gallons per minute) of water to wells, and major alluvial aquifers as those yielding, on average, at least 150 gpm. Groundwater occurs both at great depths and near the surface of the earth. In Texas County in the Panhandle, groundwater depths approach 400 feet below land surface. At certain times of the year, depth to water in alluvial aquifers may occur less than a foot below land surface. Springs, seeps and artesian wells reflect groundwater discharging to the land surface.

The Oklahoma Water Resources Board (OWRB) has identified 10 major bedrock and 12 major alluvial aquifers. The bedrock aquifers include the Antlers, Arbuckle-Simpson, Arbuckle-Timbered Hills, Blaine, Elk City, Garber-Wellington, Ogallala, Roubidoux, Rush Springs, and Ada-Vamoosa. The major alluvial aquifers are the Arkansas River, Canadian River, Cimarron River, North Canadian River, North Fork of the Red River, Red River, Salt Fork of the Arkansas River, Salt Fork of the Red River, Washita River, Enid Isolated Terrace, Gerty Sand, and Tillman Terrace. GMAP prioritizes efforts on these 22 major groundwater aquifers, along with some associated minor aquifers. The baseline monitoring period was phased in over 5 years, with trend water quality monitoring scheduled to begin in 2019 (Figure 1). The baseline period focused on 4-6 aquifers per year and assessed concentrations of nutrients, metals and major ion species to characterize regional groundwater quality and groundwater levels. At the conclusion of the baseline sampling period there were 695 wells sampled from major aquifers in the statewide groundwater quality network, with an additional 31 wells in minor aquifers. In addition, the OWRB's annual groundwater level measurement program nearly doubled in capacity from around 530 to 900 wells and has been spatially redistributed. Also over the 5-year baseline period, the OWRB installed 33 continuous water level recorders to obtain daily or hourly measurements that are more sensitive to detecting seasonal changes (brought on by drought or variable climate conditions) than can be obtained by annual measurements.

Methods and Materials

Sample Strategy and Site Selection

Sampling sites were derived from the Oklahoma Water Resources Board's (OWRB) licensed well drillers' well log database, which houses over 150,000 completion reports of groundwater and monitoring wells constructed within the state. Wells were filtered by aquifer, by well type and use, by depth according to each aquifer's geology, and by construction and lithology details. Well selection criteria required: 1) that the well be located within the geographic outcrop or subcrop of the aquifer; 2) that the well information included details of the borehole lithology; 3) that the screened or open hole interval of the well bore was completed in at least 75% of the subject aquifer and 4) that wells drilled for the purpose of monitoring regulated point sources (e.g., around waste water retention lagoons) would be excluded. The resulting lists of wells were provided to the Western Ecology Division of the U.S. Environmental Protection Agency (EPA) where a spatially balanced, randomized tessellation was run for each aquifer in the program. This probabilistic well selection was chosen to yield data representing the general water quality of each aquifer while using the existing network of available wells.

Once landowners gave permission for access, reconnaissance visits to each site were made to verify the correct well and to further assess the suitability for inclusion into the program based on details such as existing plumbing, current use, and measurement access. Wells were preliminarily screened based on specific conductance and hardness to ensure representativeness of formation water. If the well was deemed suitable, site information, including detailed elevation information, was entered into a Trimble GeoExplorer series handheld GPS unit.

Sample Collection

Information gathered in the reconnaissance visits was used to ascertain the best sample collection methodology, which varied based on well type and well use. Sampling was two-part: water level measurement and water quality sampling. Water level measurements were taken with an electric or steel tape.

During water quality sampling, wells were purged of stagnant water when necessary to ensure formation water was being sampled. In all purging and sampling scenarios water quality parameters were monitored with a YSI EXO sonde. Water was considered to be representative of the formation when water quality parameters had stabilized to within the stated limits for 3 consecutive measurements.

- pH ± 0.2 Standard Units
- Specific Conductance: ± 3.0% of reading
- Dissolved Oxygen: ± 0.2 mg/L or 10%

Samples were filtered and collected, preserved and stored on ice, and field analyses of alkalinity and hardness were performed using EPA-equivalent Hach field methods. Oklahoma Department of Environmental Quality (ODEQ) or Accurate Labs ran laboratory analyses for all parameters on all samples.

Gloves were worn while sampling and "Clean Hands, Dirty Hands" protocol was followed. All sampling equipment was decontaminated after every site by cleaning with a Liquinox solution and rinsing with deionized water.

Groundwater Constituents

The natural composition and character of groundwater is highly influenced by the rock and sediments it comes into contact with; therefore, water quality will differ between aquifers due to geologic and mineralogical differences. Constituents sampled in GMAP's baseline were chosen in part because they are naturally occurring substances in groundwater (Table 3). These water quality parameters can facilitate descriptions of general water chemistry as depicted by major ion concentrations, of physical characteristics related to general utility of the water (hardness & pH), and of salinity and overall mineralization of the water through examination of specific conductance and total dissolved solids. Some additional parameters address known water quality concerns in some of the state's aquifers such as local nitrate-N, chloride, sulfate, or arsenic levels. Several minor and trace elements that have EPA primary or secondary drinking water maximum contaminant levels and are known to occur locally in some of Oklahoma's aquifers were included. Lastly, some constituents (such as mercury) that have not been reported with substantial frequency as concerns in Oklahoma's groundwater were included in the baseline survey to alleviate any concern going forward.

Some explanations follow on how the State of Oklahoma and the USEPA regard these sampled constituents, along with some generalizations on how they are reported here. The OWRB designates a domestic beneficial use for groundwater in Oklahoma with total dissolved solids (TDS) concentrations below 3,000 mg/L. The EPA has set up guidelines used to evaluate drinking water provided by public systems, with thresholds for certain constituents (last issued in 2012; Table 3). A suite of parameters sampled in GMAP is regulated for health reasons. These have an enforceable Maximum Contaminant Level (MCL) threshold over which water is not considered safe for human consumption. A separate suite of parameters is regulated for aesthetic reasons such as taste, color, and odor. These are secondary maximum contaminant levels (SMCL) but are not enforceable and do not represent a safety consideration. In addition, the EPA has issued health advisories for a few constituents that do not have MCLs. Some parameters sampled in GMAP are not regulated for drinking water, although cobalt, molybdenum, and vanadium may be candidates for regulation by the EPA as part of their Final Contaminant Candidate List 4 (manganese, which has a SMCL and a nonregulatory health advisory, is also slated for review). Wells sampled during GMAP were of mixed uses and included both wells intended for human consumption and those not. In the presentation of this data, however, the average of the entire sampling is compared against these thresholds, regardless of well use. Of note is that nitrate+nitrite generally presents as nitrate in most ambient environmental conditions, so the MCL for nitrate was applied for this combination. For simplicity of reading, nitrate+nitrite samples will hereafter be referred to as nitrate samples (reported as nitrate-N), but the two were always tested together. Furthermore, groundwater samples collected for GMAP were filtered in the field, resulting in dissolved concentrations of constituents. The EPA issued thresholds are for total concentrations, and total concentrations for any given constituent may be higher for an unfiltered sample from the same source.

Table 3. Constituents sampled during the baseline of GMAP, their chemical category, and any drinking water guidelines associated.

Parameter	Category	Laboratory Analytic Method	USEPA MCL	USEPA SMCL	USEPA Health Advisory
Hardness	General Chemistry	-	-	-	-
Alkalinity	General Chemistry	-	-	-	-
pH	General Chemistry	-	-	<6.5 or >8.5	-
Total Dissolved Solids	General Chemistry	SM2540-C	-	500 mg/L	-
Nitrate+Nitrite as N	Nutrient	353.2	10 mg/L	-	-
Ammonia as N	Nutrient	350.1	-	-	30 mg/L
Phosphorus	Nutrient	365.1	-	-	-
Sulfate	Mineral	300.0	-	250 mg/L	500 mg/L
Chloride	Mineral	300.0	-	250 mg/L	-
Bromide	Mineral	300.0	-	-	-
Fluoride	Mineral	300.0	4 mg/L	2 mg/L	-
Deuterium*	Stable isotope	RSKSOP-334 v. 0			
Oxygen-18*	Stable isotope	RSKSOP-334 v. 0			
Aluminum, Dissolved	Metal/Trace Element	200.8	-	50-200 µg/L	-
Antimony, Dissolved	Metal/Trace Element	200.8	6 µg/L	-	-
Arsenic, Dissolved	Metal/Trace Element	200.8	10 µg/L	-	-
Barium, Dissolved	Metal/Trace Element	200.8	2,000 µg/L	-	-
Beryllium, Dissolved	Metal/Trace Element	200.8	4 µg/L	-	-
Boron, Dissolved	Metal/Trace Element	200.7	-	-	6,000 µg/L
Cadmium, Dissolved	Metal/Trace Element	200.8	5 µg/L	-	-
Calcium, Dissolved	Mineral	200.7	-	-	-
Chromium, Dissolved	Metal/Trace Element	200.8	100 µg/L	-	-
Chromium VI, Dissolved*	Metal/Trace Element	218.6	-	-	-
Cobalt, Dissolved	Metal/Trace Element	200.8	-	-	-
Copper, Dissolved	Metal/Trace Element	200.8	1,300 µg/L	1,000 µg/L	-
Iron, Dissolved	Metal/Trace Element	200.7	-	300 µg/L	-
Lead, Dissolved	Metal/Trace Element	200.8	15 µg/L	-	-
Lithium, Dissolved*	Metal/Trace Element	200.7			
Magnesium, Dissolved	Mineral	200.7	-	-	-
Manganese, Dissolved	Metal/Trace Element	200.8	-	50 µg/L	300 µg/L
Mercury, Dissolved	Metal/Trace Element	245.1	2 µg/L		-
Molybdenum, Dissolved	Metal/Trace Element	200.8	-	-	40 µg/L
Nickel, Dissolved	Metal/Trace Element	200.8	-	-	100 µg/L
Potassium, Dissolved	Mineral	200.7	-	-	-
Radium-226/228*	Stable Isotope	Georgia Tech	5 pCi/L	-	-
Selenium, Dissolved	Metal/Trace Element	200.8	50 µg/L	-	-
Silica, Dissolved	Mineral	200.7	-	-	-
Silver, Dissolved	Metal/Trace Element	200.8	-	100 µg/L	100 µg/L
Sodium, Dissolved	Mineral	200.7	-	-	-
Strontium, Dissolved*	Metal/Trace Element	200.7			4,000 µg/L
Thallium, Dissolved*	Metal/Trace Element	200.8	2 µg/L	-	-
Thorium, Dissolved*	Metal/Trace Element	200.8			
Titanium, Dissolved*	Metal/Trace Element	200.7			
Uranium, Dissolved	Metal/Trace Element	200.8	30 µg/L	-	-
Vanadium, Dissolved	Metal/Trace Element	200.8	-		-
Zinc, Dissolved	Metal/Trace Element	200.8	-	5,000 µg/L	2,000 µg/L

Laboratory methods for Group D only. For previous years’ methods, see archived reports. USEPA- US Environmental Protection Agency. MCL- Maximum Contaminant Level. SMCL- Secondary contaminant levels. *Not included in every year’s analyses.

Data Protocols

Only descriptive statistics are reported, as the main objective for this data is to summarize ambient water quality conditions in each aquifer. Full summary tables for each aquifer can be found in appendices at the end of this report. In the first four years of the program (Group A, 2013; Group B, 2014; Group C, 2015; and Group D, 2016), data was housed in a Microsoft Access 2002-2003 database. In 2017, data from Groups A-D were transferred to the Ambient Water Quality Monitoring System (AWQMS), an online cloud-based database designed specifically to house environmental data. Group E data was directly uploaded to AWQMS in 2017. Statistical tests and quality assurance checks were conducted using Microsoft Excel 2007-2010. Descriptive statistics on the baseline data were run on a per aquifer basis; reported statistics include mean, standard error of the mean, median, minimum value, maximum value, 25th percentile, and 75th percentile. For data that was less than the laboratory reporting limit, half of the limit was used as the value for that well. For parameters that had over 75 percent of wells below reporting limit, statistics were not run.

Outliers were identified utilizing both twice the standard deviation and 1.5 times the parameter's inter-quartile range as threshold values. For parameters with over 50 percent of wells below reporting limit, identified outliers were investigated but not considered noteworthy since they were often within expected ranges. Original data reports were used to confirm that outliers were not due to data entry errors; field notes were used to confirm nothing unusual was happening in the area at the time of sampling. All outliers were kept unless an acceptable explanation was discovered as to why that data point was unusual (lithology, screen interval, sampling error, etc.).

Water type was determined through Piper plot diagrams. These were constructed with raw data using AquaChem version 5.1 software.

Quality Assurance and Quality Control (QA/QC) for this data included replicate and blank samples to evaluate sampling procedure, parameter ratios to check water chemistry results, and analysis of statistical outliers. QA/QC will not be discussed in detail in this report. For a complete description of field QA/QC methods, please contact the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800. For laboratory QA/QC methods please contact the Oklahoma Department of Environmental Quality/Customer Services Division at (405) 702-6100 or Accurate Labs at (405) 372-5300. Comprehensive QA/QC has been performed on all data collected and utilized for this report.

Review of Groundwater Data

Groundwater quality is derived from the type of rock and minerals that compose the groundwater system, the solubility of the minerals in the rock and the amount of time water has been in contact with the rock. Important controls include atmospheric inputs (gases and aerosols), mineral weathering from rock-water interaction, biochemical processes associated with the life cycles of microbes, plants and animals, acidity and temperature, subsurface oxidation-reduction reactions, and cultural effects resulting from human activity.

Total dissolved solids content in a water sample is often used as a general indicator of water quality. Although the OWRB considers water with a dissolved solid concentration of less than 5,000 mg/L (milligrams per liter) to be fresh, water is usually considered undesirable for drinking if the quantity of dissolved minerals exceeds 500 mg/L. The primary ions in groundwater that compose or account for TDS are calcium, potassium, magnesium, sodium, chloride, sulfate, and bicarbonate. The concentrations of these ions provide the basis for describing the general characteristics of the water and can provide insight into its origin.

Groundwater level measurements, determined manually with graduated tapes or with down-hole pressure transducers, can be shown using well hydrographs that plot the time series versus the depth to water or water level elevation. Well hydrographs may be representative of a localized area if few sites are available or may be representative of parts of or entire areas of aquifers if an extensive network is available. When characterizing groundwater levels related to ambient hydrologic and climate effects, ideal target sites are unused wells isolated from areas of large groundwater withdrawals. However, in order to obtain spatial representativeness within an aquifer, a network of sites provides groundwater level data from areas of the aquifer that are not influenced by groundwater withdrawals and reflect ambient conditions along with those that are impacted by withdrawals. Data from both types of sites are useful for interpreting groundwater level changes resulting from natural and/or anthropogenic stressors.

When discussing groundwater levels and their change over time within Oklahoma's aquifers, references to the Oklahoma Climatological Survey's Climate Divisions (OCS; Figure 2) may be made to illustrate potential differences in groundwater conditions based on these climatic differences. The climate divisions represent geographical areas within the state that have similar meteorological characteristics like precipitation (rain/snow), temperature, barometric pressure, and wind velocity that may directly or indirectly influence groundwater availability and occurrence.

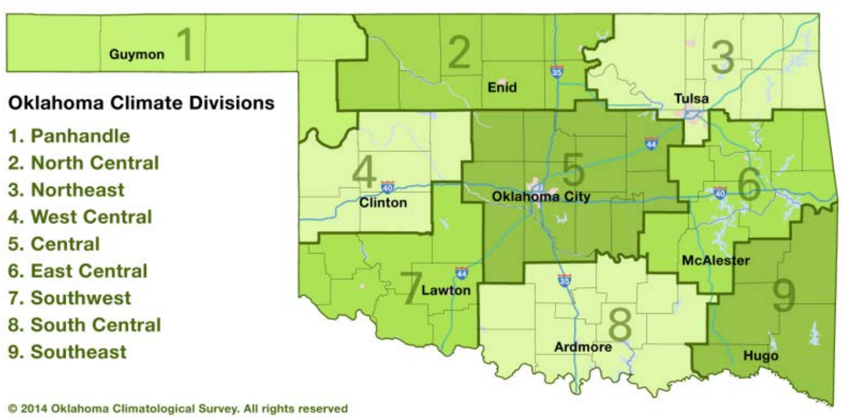

Figure 2. Oklahoma's Climate Divisions as mapped by the OCS.

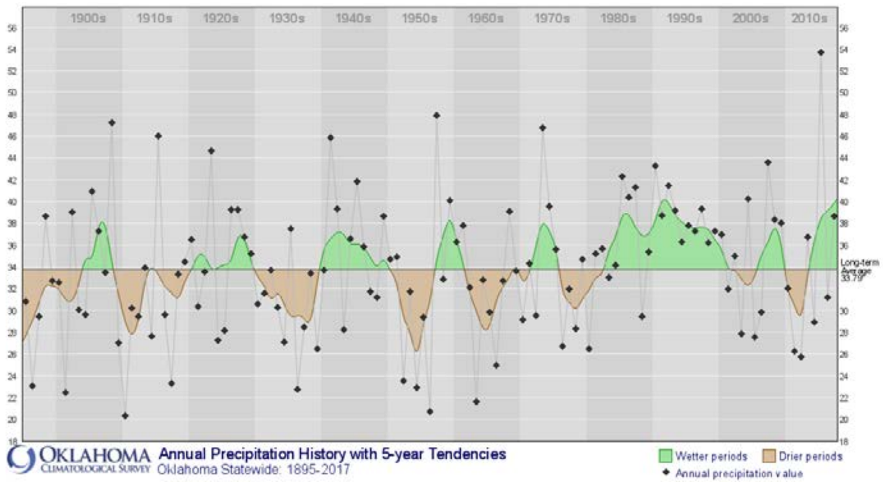

Figure 3. Statewide precipitation in Oklahoma over period of record (1895-2017) as presented by the OCS.

Statewide average precipitation was 6.03 inches above the 1981-2010 normal (Figure 3). Average precipitation across the climate divisions ranged from 5 percent below to 20 percent above normal, with 7 of 9 divisions recording above average precipitation (Figure 4). Aquifer response to these conditions varied but was generally modest, with small groundwater level increases tending to occur more in the western half of the state (though there were several exceptions to this trend) and the largest decreases occurring in the Southeast and South Central Climate Divisions between 2017 and 2018.

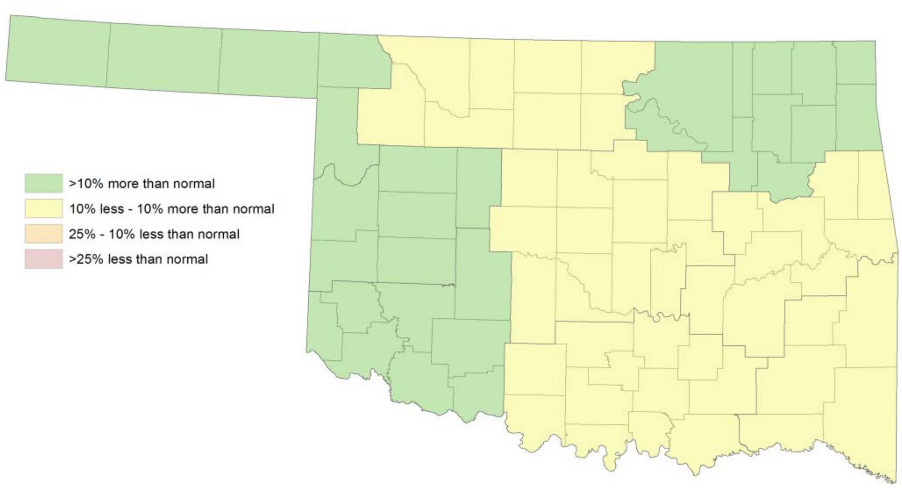

Figure 4. Precipitation for 2017 compared to normal (1981-2010) values by climate division.

The next section of the report will describe the results of baseline sampling and groundwater level depth determinations by individual aquifer. Sections for Group A, B C & D aquifers will include the general character of the resource and review the ongoing collection of water level data. More in depth discussions for water quality can be found on the OWRB's website in the 2013 BUMP Report for Group A aquifers, in the 2014 BUMP Report for Group B aquifers, in the 2015 BUMP Report for Group C Aquifers and in the 2016 BUMP Report for Group D aquifers. The aquifer summaries for Group E, investigated in 2017, will: 1) reflect the general character of the resource in terms of total dissolved solids (TDS) and water type; 2) discuss the major constituents that characterize the groundwater quality; 3) describe observed spatial patterns of concentrations of constituents; 4) review constituent concentrations in terms of EPA drinking water criteria; and 5) review the water level data collected for each aquifer. Data will be visually displayed through the use of piper plots, mapping of distributions, and depth to water hydrographs. Piper plots display the water chemistry of individual sample sites in terms of major cations (calcium, magnesium, sodium and potassium) and anions (bicarbonate, sulfate and chloride). These types of plots show how major ion data are grouped as to principal water type(s) and can be used to interpret their origins.

Ada-Vamoosa Aquifer

The Ada-Vamoosa aquifer, located in east central Oklahoma, is a large bedrock aquifer that stretches from the Kansas border in Osage County southward to the northern edge of Pontotoc County. The aquifer underlies portions of Creek, Lincoln, Okfuskee, Osage, Pawnee, Payne, Pontotoc, Pottawatomie, and Seminole Counties (Figure 5). It consists of the late Pennsylvanian-aged Vamoosa Formation and Ada Group. The Vanoss Formation marks the western surficial limit of the aquifer; however, the aquifer occurs at depths ranging from 300-500 feet below the top of the Vanoss. The Canadian River marks its southern boundary. The aquifer is composed of fine grained sandstone interbedded with siltstone, shale and thin limestone, with the proportion of shale increasing northward. The aquifer's thickness averages 400 ft with a maximum of 770 ft. For the purpose of discussing groundwater level data collected from the Ada-Vamoosa aquifer, hereafter referred to as ADVM, groundwater levels associated with wells constructed to depths of 300 feet or less will be considered unconfined and groundwater levels from deeper wells and/or underlying the Vanoss will be considered representative of confined conditions. Groundwater flows from the upper, unconfined part to the lower, confined part, except where major rivers and streams overlie the aquifer. Similar to the topography, regional groundwater flow is to the east.

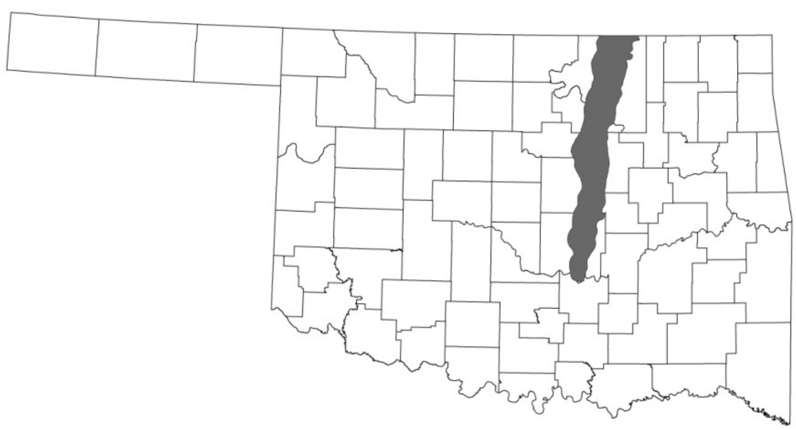

Figure 5. Location and extent of the ADVM.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 44 wells to assess the baseline water quality of the aquifer and concurrently measured 44 wells to assess the baseline water level (Figure 6). Overall, this aquifer contains water of good quality although groundwater mineralization is greater, in general, in areas overlain by the Vanoss Formation and Ada Group than within the outcrop area of the Vamoosa formation on the eastern side of the aquifer. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the ADVM can also be found in Appendix A of this report.

Figure 6. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ADVM in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were only being measured in 3 active ADVM wells and as a consequence, insufficient data exists to characterize historical groundwater level conditions. Data requirements to graphically represent groundwater levels for an aquifer over a long period of record should rely on multiple wells, spatially distributed and covering contemporaneous time periods. This was not the case prior to 2014 for the ADVM. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrograph shown in Figure 7 represents a single entry point into the aquifer with the longest period of record.

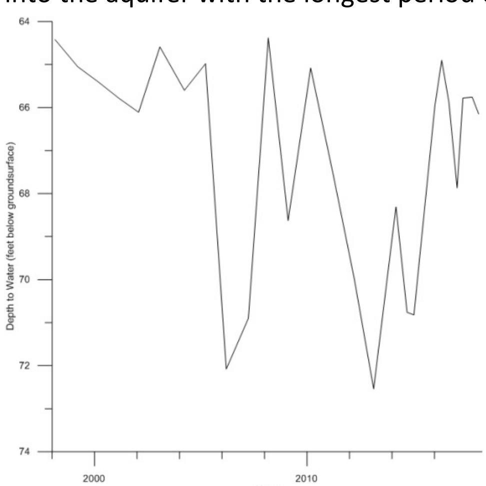

Figure 7. Groundwater level hydrograph of an unconfined ADVM record, Seminole County (1998-2018).

A baseline groundwater level network composed of 44 wells was measured in September 2014. Thirty-one (31) wells are currently in the annual trend network, a marked improvement over the historical network, with 11 of these sites measured seasonally. Unconfined conditions are reflected in 27 wells of the trend network, and 4 are considered to be in the deeper, confined parts of the aquifer.

2018 water levels in the unconfined portion of the ADVM averaged 60.21 ft, with a median value of 55.42 ft (N=27). Of the 27 wells in the unconfined ADVM network, 23 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in unconfined ADVM wells over the last year by an average 0.45 ft in the Northeast (N=8) and 0.27 ft in the Central (N=15) Climate Divisions (2017-2018). Because of small sample size, average change in water level is not calculated for the confined portion of the ADVM.

Antlers Aquifer

The Antlers aquifer located in southeastern Oklahoma, hereafter abbreviated ALRS, is a bedrock aquifer shared with Texas and Arkansas. It is known nationally as the Trinity aquifer which is part of the Edwards-Trinity system. In Oklahoma, the ALRS underlies portions of Love, Carter, Marshall, Johnston, Bryan, Atoka, Choctaw, Pushmataha, and McCurtain Counties (Figure 8). The Cretaceous-aged Antlers Sandstone is composed of around 900 feet of poorly consolidated sandstone with sandy shale and clay. The Antlers Sandstone outcrops in the northern third of the aquifer and is overlain by younger Cretaceous rocks, including the Woodbine Formation, in the southern portion. The northern boundary of the Antlers aquifer is its outcrop extent where it abuts older geologic formations ranging in age from Permian to Cambrian. Southward the Antlers dips below younger Cretaceous Formations and occurs at depth, several hundreds of feet below the land surface in Texas and Arkansas. Water is unconfined in its area of outcrop and confined in most areas of its subcrop. Groundwater generally flows south-southeast but may flow locally towards streams. The Red River and several of its tributaries drain the area.

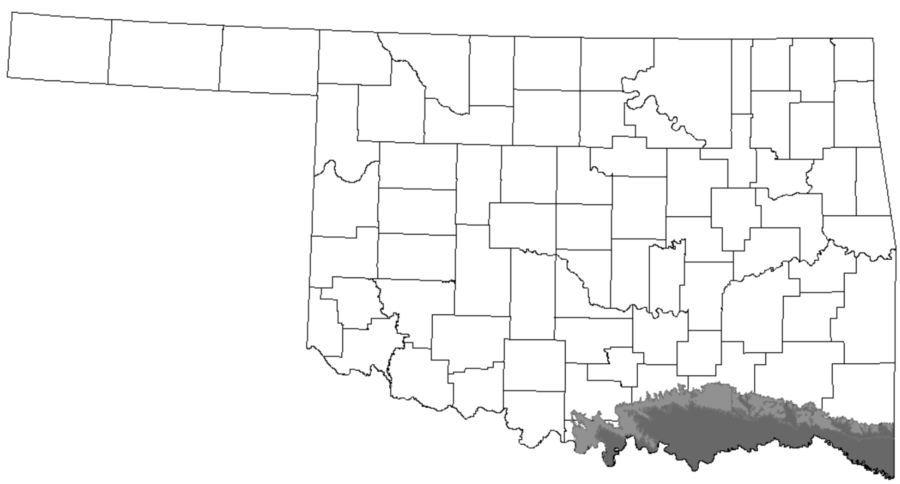

Figure 8. Location and extent of the ALRS (outcrop in light gray).

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 30 wells to assess the baseline water quality of the aquifer and concurrently measured 32 wells to assess the baseline water level (Figure 9). These measurements were made in the northern unconfined portions of the ALRS. An additional 8 wells were measured in the confined portions of the aquifer, and this set of data was discussed separately as a sub-study from the main set of unconfined data (Figure 10). Overall, water in the outcrop of ALRS was of good quality. Water in the eastern half (east of the Bryan/Choctaw county line) appears to be less mineralized with lower levels of metals. Overall, water in the subcrop of ALRS was of fair quality. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the ALRS can also be found in Appendix B of this report.

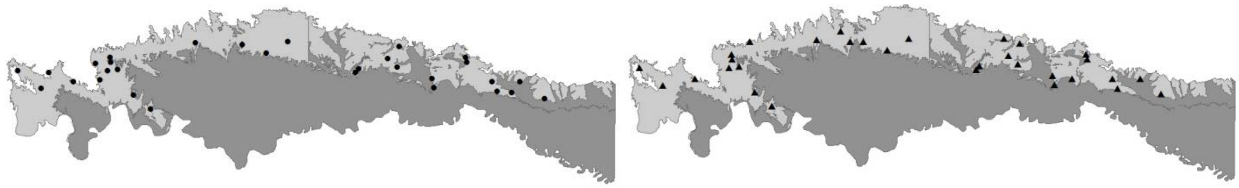

Figure 9. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ALRS outcrop in 2015.

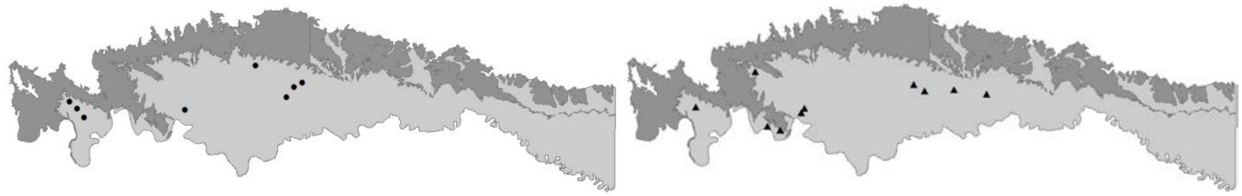

Figure 10. Confined sub-study water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ALRS subcrop in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were only being measured in 4 active outcropping ALRS wells and as a consequence, insufficient data exists to characterize historic groundwater level conditions in its area of outcrop. For the subcrop of the ALRS, 5 historical wells with contemporaneous water level measurements have been plotted along with their composite average water level (Figure 11).

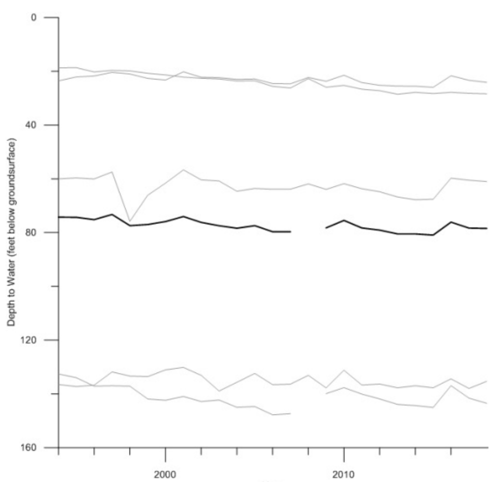

Figure 11. Composite average water level (bold line, N=5) and individual well water levels in the ALRS subcrop over period of record (1994-2018).

A baseline groundwater level network of 42 wells was measured in August 2015. Thirty-one (31) wells are currently in a trend network measured annually, with 11 of these measured seasonally. Unconfined conditions of the outcrop are reflected in 23 wells of the water level network, and 8 are considered to be in the confined subcrop of the aquifer. Several wells in this aquifer have over 30 years of record, with the longest record spanning over 40 years (Figure 12), so to maintain these long periods of record the baseline included 10 wells from the ALRS's historical network (4 outcrop; 6 subcrop).

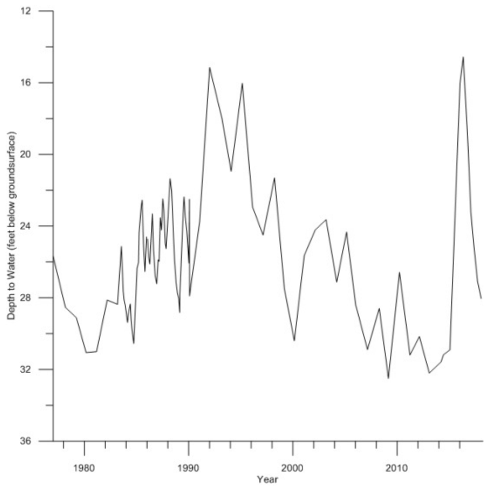

Figure 12. Groundwater level hydrograph of an unconfined ALRS record, Johnston County (1977-2018).

2018 water levels in the ALRS outcrop averaged 53.16 ft, with a median value of 47.42 ft (N=23). 2018 water levels in the subcrop averaged 106.45 ft, with a median value of 98.18 ft (N=8). The GMAP trend network recorded the average water level decreasing in the outcrop over the last year by an average 1.01 ft in the South Central (N=10) and 0.60 ft in the Southeast (N=10) Climate Divisions (2017-2018). Insufficient data exists to characterize water level changes in the subcrop by Climate Division. Water level across the entire subcrop decreased by an average of 0.45 ft over the last year (N=8; 2017-2018).

Arbuckle-Simpson Aquifer

The Arbuckle-Simpson aquifer, located in the Arbuckle Mountains of south central Oklahoma, is a bedrock aquifer composed of several formations in the Arbuckle and Simpson Groups. The outcrop of the aquifer, hereafter referred to as ABSMP, underlies portions of Murray, Carter, Johnston, Coal, and Pontotoc Counties (Figure 13). The Arbuckle Group consists of limestone and dolomite and dates to the late Cambrian period; the Timbered Hills Group consists of limestone and sandstone and dates to the late Cambrian; the Simpson Group consists of porous sandstone interbedded with shale and limestone and dates to the Ordovician. Rocks are folded, fractured, and faulted, underlain by low permeability igneous and metamorphic rocks. In areas where the aquifer is subsurface, various younger formations act as confining layers; therefore, groundwater is confined and unconfined dependent on the area. Although water in these Groups can be saline, the OWRB defines the boundaries of this aquifer by the extent that freshwater exists. Its thickness averages 3000ft with a maximum of 5000ft, and groundwater flows towards the southeast. Topography in the eastern Hunton Anticline is gently rolling plains overlying faulted limestone; topography in the western Arbuckle Anticline is a series of ridges formed by the folded rocks with a few small karst features.

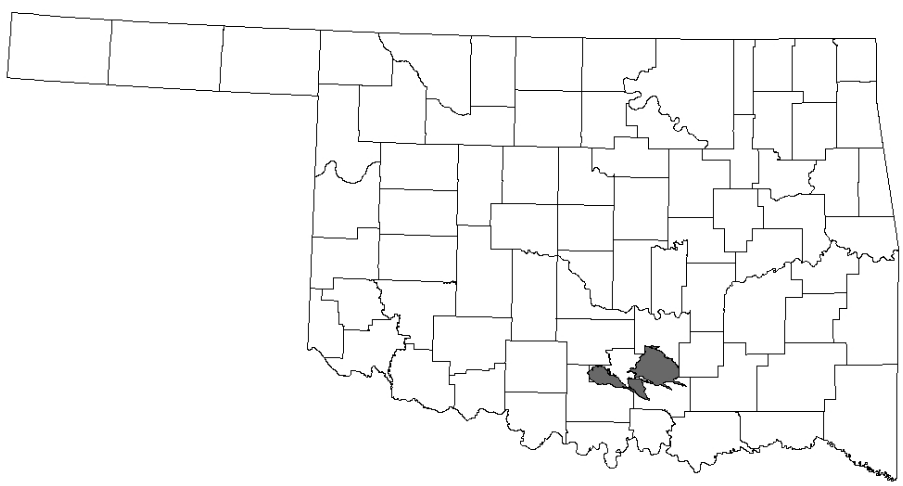

Figure 13. Location and extent of ABSMP.

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 18 wells to assess the baseline water quality of the aquifer and concurrently measured 29 wells to assess the baseline water level (Figure 14). Overall, this aquifer contains water of very good quality; no water quality concerns are evident in this aquifer. A joint study from 2003-2011 by the OWRB and USGS also found high-quality groundwater with no natural sources of contamination. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the ABSMP can also be found in Appendix C of this report.

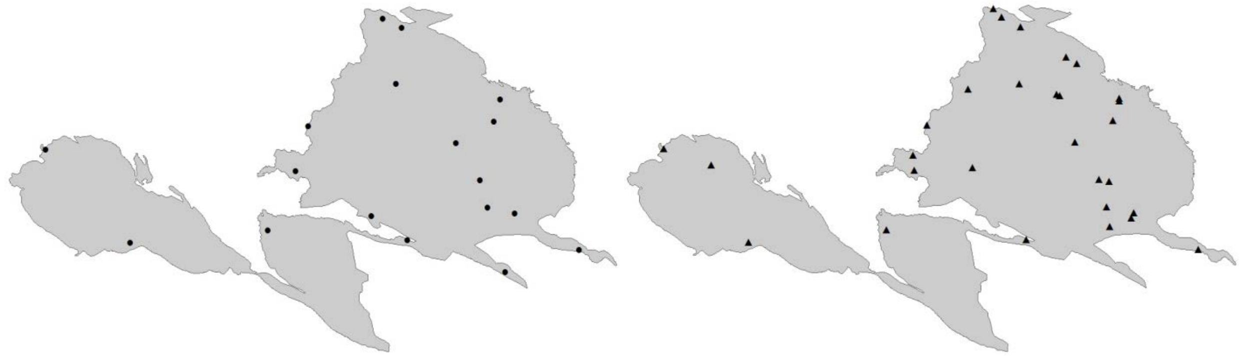

Figure 14. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ABSMP in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 13 active ABSMP wells. Five (5) of those historical wells had contemporaneous water level measurements and no data gaps for the period of record, allowing for an uninterrupted composite average water level over a 13-year period (Figure 15).

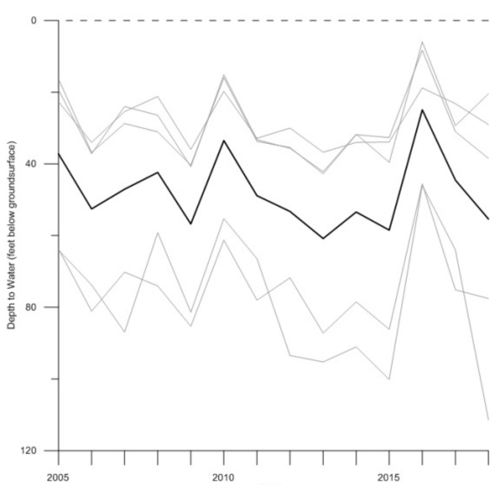

Figure 15. Composite average water level (bold line, N=5) and individual well water levels in the ABSMP over period of record (2005-2018).

A baseline groundwater level network of 29 wells was measured in July 2015. Several wells in this aquifer have over 20 years of record, and one has over 30 years (Figure 16). To maintain wells with long periods of record, the baseline included 11 wells from the ABSMP's historical network. The trend groundwater level network is currently 18 wells measured annually, with 11 of these measured seasonally.

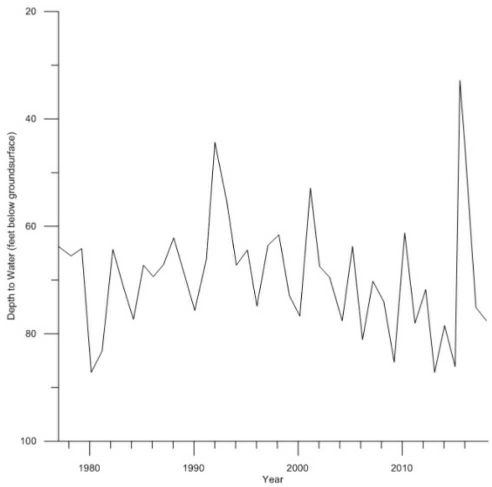

Figure 16. Groundwater level hydrograph for one of the longest ABSMP records, Pontotoc County (1977-2018).

Because of its karst nature, the ABSMP is prone to large fluctuations in water level. Following record rainfalls in 2015 the state returned to closer to average precipitation levels with periodic drought; annual precipitation over the ABSMP measured at 4.7 inches below normal. The above hydrograph reflects a sharp increase in 2015-2016, followed by a sharp decrease in 2016-2017. 2018 water levels in the ABSMP averaged 53.38 ft, with a median value of 43.48 ft (N=18). Of the 18 wells in the ABSMP network, 16 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing over the last year by an average 6.92 ft (N=16, 2017-2018). Average water levels across the aquifer have increased by 6.19 ft during the last 5 years (N=11, 2013-2018). The Arbuckle-Simpson Aquifer has three GMAP recorders that were installed January 2014, two in Pontotoc (one of which is associated with an Oklahoma Mesonet station) and one in Johnston County (Figure 17).

Figure 17. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire ABSMP water level network.

Arbuckle-Timbered Hills Aquifer

The Arbuckle-Timbered Hills aquifer in southwestern Oklahoma is a bedrock aquifer, composed of several formations in the Arbuckle and Timbered Hills Groups. The aquifer, hereafter referred to as ABTMB, underlies portions of Kiowa, Caddo, and Comanche Counties (Figure 18). Carbonate rock is the main water-yielding geologic unit and dates back to the Ordovician period. It consists of limestone and dolomite with interbedded sandstone, siltstone, and shale that is fractured and faulted. This aquifer occurs in two distinct areas. The aquifer outcrops in the Limestone Hills, north of the Wichita Mountains, where water is generally under artesian conditions. In the Cache-Lawton area, south of the Wichita Mountains, the aquifer is overlain by younger rocks. Its thickness ranges 5,000-6,000 feet, and most groundwater movement is made possible by solution of the limestone and dolomite along bedding planes, fractures, and faults. The area overlying the ABTMB is drained primarily by East and West Cache Creek, with the far eastern portion of the overlying land draining to Beaver Creek and its tributaries and the far northwestern portion draining to the Upper Washita River and its tributaries.

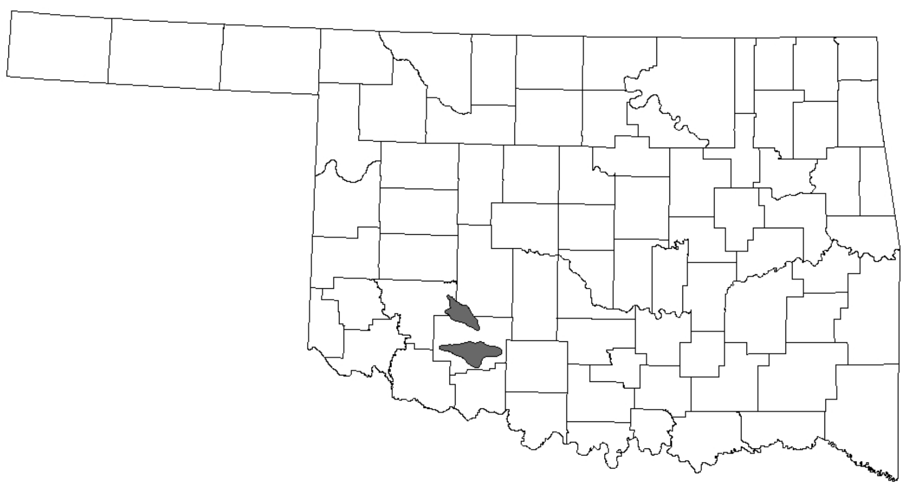

Figure 18. Location and extent of ABTMB.

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 6 wells to assess the baseline water quality of the aquifer and concurrently measured 3 wells to assess the baseline water level (Figure 19). The ABTMB was designed with a smaller network compared to the other GMAP aquifers due to its limited areal extent. A limited number of wells actually tapping into the aquifer, along with difficulties finding suitable wells and acquiring landowner permission, resulted in the uneven spatial distribution. With these two caveats, this aquifer contains water of fair quality. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the ABTMB can also be found in Appendix D of this report.

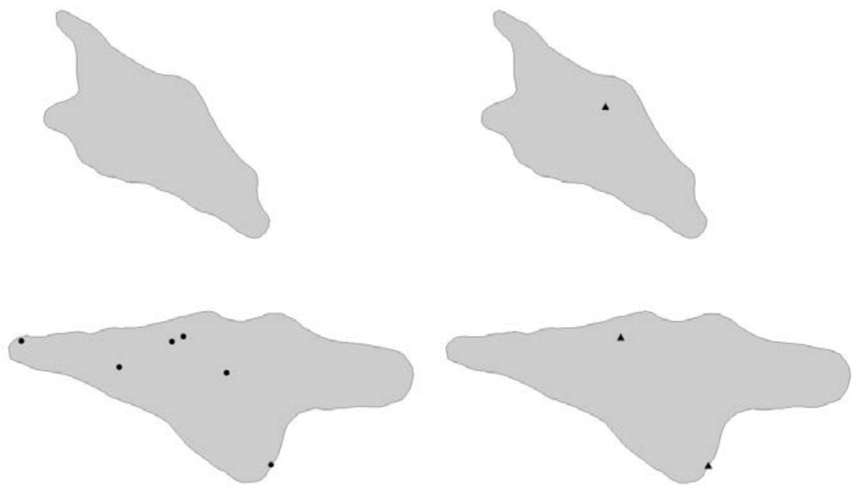

Figure 19. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ABTMB in 2015.

Groundwater Level Measurements

There were no wells with historical groundwater level measurements in the ABTMB prior to GMAP implementation; therefore all wells are new to the program.

Only 3 wells were able to be included for the baseline groundwater level network in July 2015. Two of those wells have been incorporated into the trend network measured annually. Because of small sample size, average change in water level is not calculated for the ABTMB.

Arkansas River Alluvial & Terrace Aquifer

The Arkansas River enters Oklahoma from Kansas through Kay County and generally flows southeast through eastern Oklahoma, encountering Kaw Lake, Keystone Lake, Webbers Falls Reservoir, and Robert S. Kerr Reservoir. It then continues east out of Oklahoma as the county line between Sequoyah and Le Flore counties. The Arkansas has about 332 river miles in Oklahoma, draining 45,091 mi^2 and comprising much of the McClellan-Kerr Navigation System (Figure 20).

The Arkansas River Alluvial and Terrace Aquifer, hereafter shortened to ARKS, is an unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, and clay. Deposits are commonly 50-100 feet thick for the alluvium and terraces, respectively. Aerially, deposits may occur on either side of the river for a distance of up to 15 miles but typically are less than 5 miles beyond the river banks.

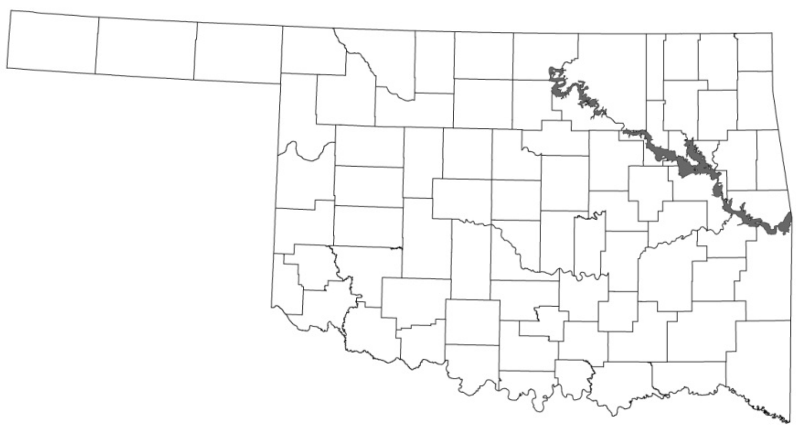

Figure 20. Location and extent of the ARKS.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 29 wells to assess the baseline water quality of the aquifer and concurrently measured 22 wells to assess the baseline water level (Figure 21). Overall, this aquifer contains water of good quality. Keystone Lake, at the confluence of the Arkansas and Cimarron Rivers, appears to be a boundary for water quality in this aquifer. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the ARKS can also be found in Appendix E of this report.

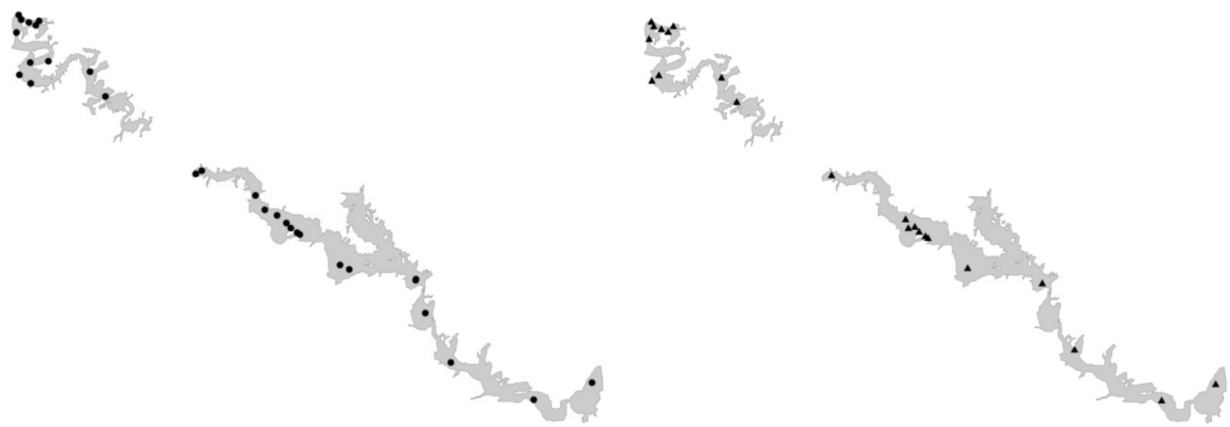

Figure 21. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ARKS in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 6 active ARKS wells. Although 5 of those historical wells have contemporaneous water level measurements, most of them are clustered in the easternmost extent of the aquifer and are therefore insufficient to characterize historical water level conditions throughout the extent of the aquifer. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrograph shown in Figure 22 represents a single entry point into the aquifer with the longest period of record.

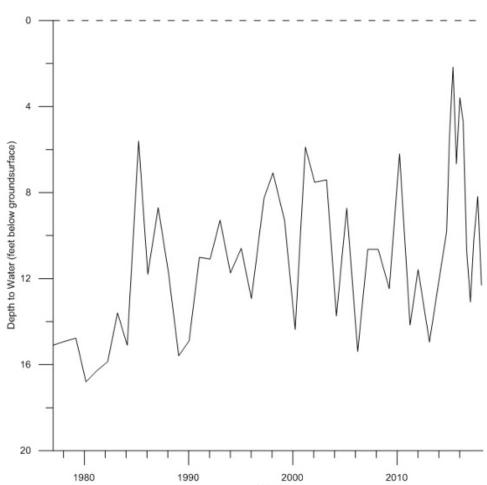

Figure 22. Groundwater level hydrograph of an ARKS well, Sequoyah County (1977-2018).

A baseline groundwater level network for the ARKS of 22 wells was measured in September-October 2014. Sixteen (16) wells are currently in the annual trend network, with 7 of these sites measured seasonally. To maintain some wells with long periods of record, the network incorporated 6 wells from the aquifer's historical groundwater level network. The longest active site spans almost 40 years (Figure 22).

Fluctuation in alluvial and terrace aquifers is normal due to their sensitivity to use and climate. 2018 water levels in the ARKS averaged 21.44 ft, with a median value of 19.00 ft (N=16). Of the 16 wells in the ARKS network, all 16 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in ARKS wells over the last year by an average 0.07 ft in the Northeast (N=11) and 0.12 ft (N=5) in the East Central areas (2017-2018).

Blaine Aquifer

The Blaine aquifer in southwestern Oklahoma, hereafter abbreviated DCBG, is a bedrock aquifer underlying portions of Harmon, Greer, and Jackson Counties (Figure 23). The aquifer extends south and west into northern Texas. The aquifer consists of the Permian age Blaine Formation, comprised of interbedded gypsum, shale, and dolomite, and the overlying Dog Creek Shale in the west. Some areas are extremely karst and the aquifer is underlain by confining Permian rocks. Karst features may include sinkholes, springs and waterfalls that are observable to the naked eye. In the DCBG, sinkholes are locally prevalent and portions of the subsurface are described as “honeycombed” with enlarged openings, which have created interconnected vertical and horizontal flow paths that enhance flow through the aquifer. Karst aquifers can be characterized by rapid recharge after precipitation events as well as relatively rapid discharge during non-wet periods. Its northern and eastern boundaries follow the lines of the Salt Fork of the Red River; its southern and western boundaries are the State of Texas. Its thickness ranges 300-400 ft. Groundwater flows regionally towards the southeast, and the area is drained by the Red River and the Salt Fork of the Red River.

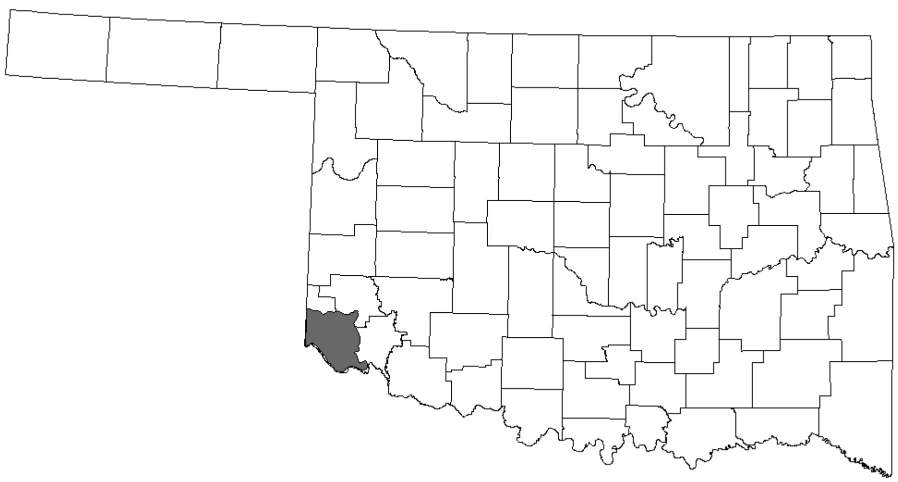

Figure 23. Location and extent of the DCBG.

Data Collection Results- Group C

The Blaine is an aquifer with marginal water quality; though it is an important source of water for irrigation and agricultural uses, it is considered non-potable. Therefore, there was no water quality network set up for the Blaine aquifer. In 2015, the Groundwater Monitoring and Assessment Program measured 22 wells to assess the baseline water level of the aquifer (Figure 24).

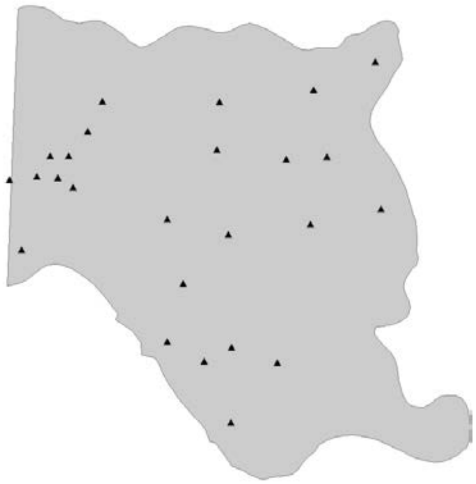

Figure 24. Baseline water level sites (triangles) measured in the DCBG in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 20 active DCBG wells. Of the 9 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5 were selected to generate a composite average water level hydrograph with the fewest number of data gaps (Figure 25).

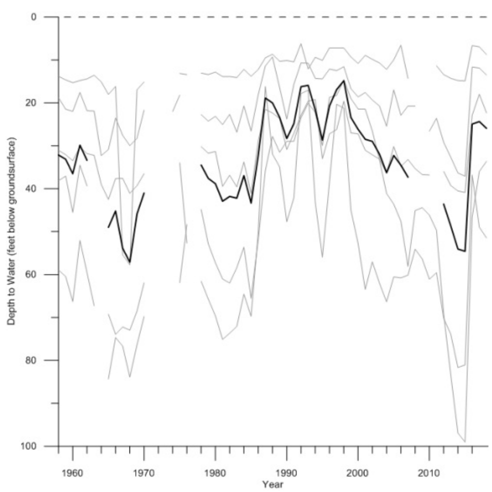

Figure 25. Composite average water level (bold line, N=5) and individual well water levels in the DCBG over period of record (1958-2018).

A baseline groundwater level network comprising 22 wells was implemented in September 2015. The baseline network incorporated 17 wells from the aquifer's historical groundwater level network to continue sites with long-term records (Figure 26). The trend water level network is currently 25 wells measured annually; eight (8) of these wells are measured seasonally.

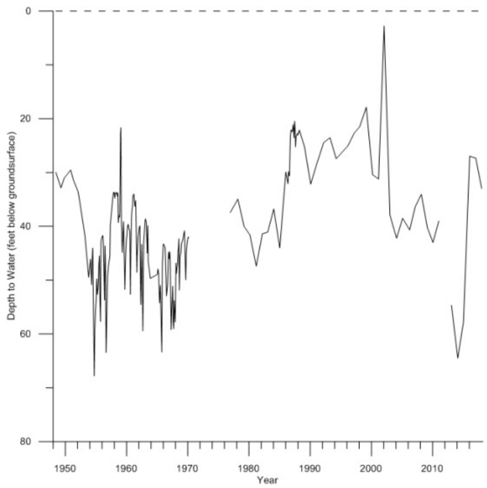

Figure 26. Groundwater level hydrograph for one of the longest DCBG records, Jackson County (1948-2018).

Because of its karst nature, the DCBG is prone to large fluctuations in water level. Following record rainfalls in 2015 the state returned to closer to average precipitation levels with periodic drought. 2018 water levels in the DCBG averaged 34.81 ft, with a median value of 32.96 ft (N=25). Of the 25 wells in the DCBG network, all 25 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in DCBG wells over the last year by an average 0.56 ft (N=25, 2017-2018). Average water levels across the aquifer have increased by 25.51 ft during the last 5 years (N=16, 2013-2018). A continuous water level recorder was installed in Harmon County in March 2015 where depth to water in feet below land surface is being recorded in hourly increments (Figure 27).

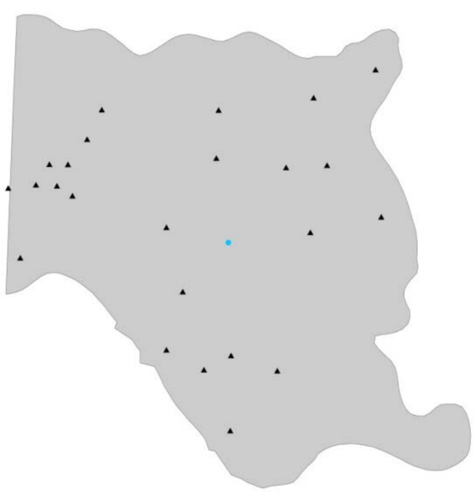

Figure 27. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire DCBG water level network.

Boone Aquifer

The Boone Aquifer is a minor bedrock aquifer composed of Mississippian age geologic units. (Figure 44). The Boone Aquifer (hereafter referred to as BOON) is composed of the Keokuk and Reeds Spring Formations and the St. Joe Group. The rocks of these formations consist of highly fractured, fine grained limestone and massive gray chert. The BOON is an unconfined aquifer except in areas overlain by younger Mississippian and Pennsylvanian strata in western and southern portions of the aquifer. The thickness of the BOON typically ranges from 250 to 400 feet.

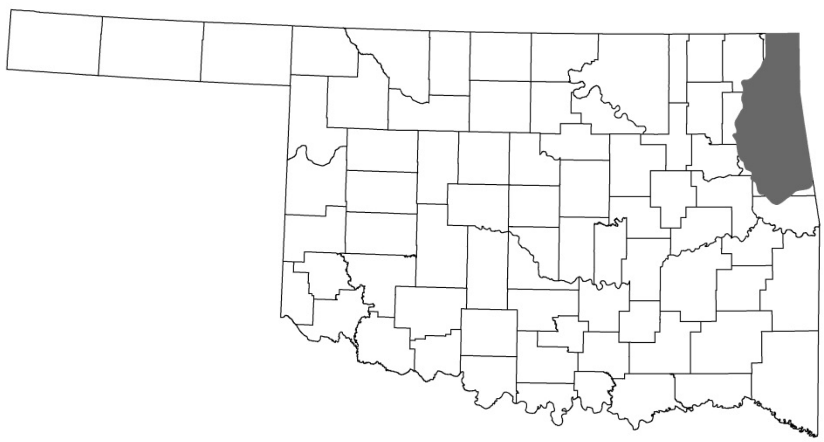

Figure 28. Location and extent of BOON.

The aquifer is encompassed by the state's Grand and Lower Arkansas Planning Regions. This aquifer begins in Oklahoma's Northeast Climate Division with averages of 60.78°F and 42.67 inches of precipitation annually. It continues south into the East Central Climate Division, which averages 60.79°F and 46.14 inches of precipitation annually. Recharge of the BOON comes almost entirely from infiltration of precipitation at an estimated rate of 10 inches per year. Natural discharge occurs mainly through base flow contribution to rivers, primarily the Grand (Neosho), Spring, and Illinois Rivers. In areas where mining is prevalent, small amounts of water from the BOON discharge downward through underlying geologic layers to the Roubidoux aquifer. In Ottawa County, BOON water can be influenced by mine water from abandoned lead-zinc mines in the Boone Formation. The BOON has an estimated aerial extent of 7,938 km^2 and stores 27 million acre-feet of water. Well yields generally are less than 10 gallons per minute, but can produce water at rates as high as 100 gallons per minute. Hydraulic conductivity has been estimated to be about 22 feet per day.

Groundwater in this aquifer supplies water primarily for domestic use, but a few public water supply entities provide water from the BOON as well. The OWRB has on file more than 5,900 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of May 2018, 319 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 54,163 acre-feet of water per year. Due to regional well drilling practices and similarity to underlying geology, it is difficult to differentiate BOON wells from wells with mixed lithology without individual analysis of permits. Therefore, for the purposes of this report, these permit numbers represent combined permits for both the Boone and Roubidoux aquifers. The maximum withdrawal rate from the aquifer has been temporarily set to 2.0 acre-feet per acre per year, subject to change by the OWRB. The BOON is designated by the OWRB as having a high vulnerability level to contamination from the land surface.

Data Collection Results

In 2017, the Groundwater Monitoring and Assessment Program sampled 34 wells to assess the baseline water quality of the aquifer and concurrently measured 42 wells to assess the baseline water level (Figure 35).

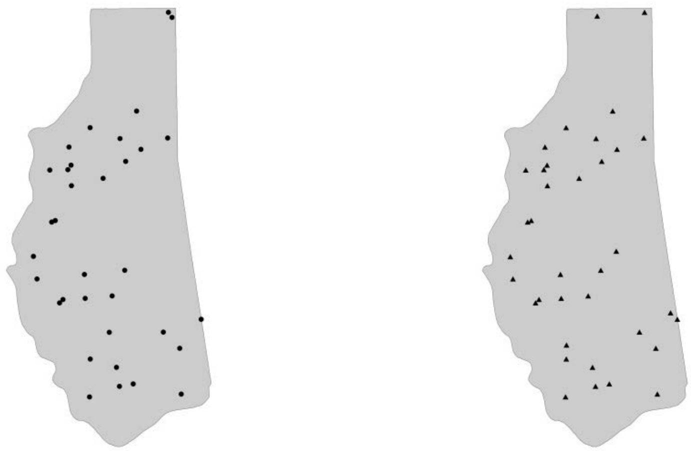

Figure 29. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the BOON in 2017.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content was low. Groundwater in the aquifer was very hard with moderately low alkalinity, averaging 195 mg/L and 170 mg/L, respectively. Mean total dissolved solids (TDS) were low at 236 mg/L, ranging from 122-472 mg/L with a median concentration of 235 mg/L. Average specific conductance and pH were 403 µS/cm and 7.09, respectively. There are no major water quality concerns for the BOON, however there are isolated areas that showed elevated levels of dissolved iron. A study by the OWRB in 2001 also showed groundwater of good quality.

The piper plot shows the majority of water types in the BOON being classified as calcium-bicarbonate (94%), with calcium-chloride/bicarbonate (3%) and calcium/sodium-chloride/bicarbonate (3%) also present (Figure 30). The spatial distributions of water type and TDS are shown in Figure 31**.**

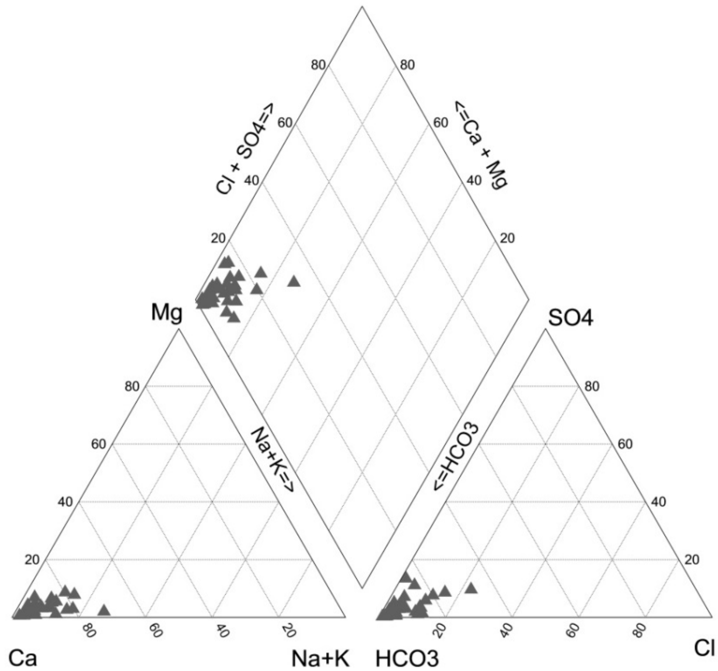

Figure 30. Piper plot diagram of constituents of the BOON.

Figure 31. Water type (left) and TDS concentrations (right) in the BOON.

Chloride, magnesium, potassium, silica, sodium, and sulfate were found at low levels in the aquifer. Calcium was detected at moderate levels of concentration, whereas bromide was not detected.

Nutrients in the aquifer reflect low concentrations of nitrate-N and phosphorus, and ammonia-N was rarely detected, but was at low concentrations when present.

The BOON had mostly low levels of metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, lead, mercury, nickel, silver, and thallium. Barium, chromium, copper, manganese, uranium, and zinc were present at low concentrations. Arsenic, boron, molybdenum, selenium, and vanadium were rarely detected but were low when present. Iron was also rarely detected, but was generally detected at a range of levels ranging from 38.2 µg/L to 340 µg/L when present.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The BOON had some constituents exceed these thresholds. Table 4 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the BOON water quality, see Appendix F.

Table 4. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the BOON.

Parameter	>MCL	>SMCL	>Health Advisory
Nitrate-N	1	--	--
Iron	--	1	--
Manganese	--	1	--

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were only being measured in 3 active BOON wells and as a consequence, insufficient data exists to characterize historical groundwater level conditions. Data requirements to graphically represent groundwater levels for an aquifer over a long period of record should rely on multiple wells, spatially distributed and covering contemporaneous time periods. This was not the case prior to 2017 for the BOON. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrograph shown in Figure 32 represents a single entry point into the aquifer with the longest period of record.

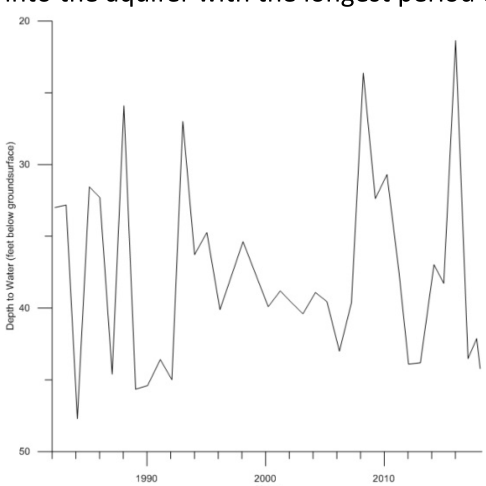

Figure 32. Groundwater level hydrograph of the longest BOON record, Adair County (1982-2018).

A baseline groundwater level network for the BOON was comprised of 42 wells and implemented in September-November 2017. To maintain some wells with long periods of record, the baseline network incorporated 3 wells from the aquifer's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from 7.27-181.9 feet below ground surface with a mean of 43.77 ft over the entire aquifer; averages were 34.15 ft in the Northeast and 59.57 ft in the East Central climate divisions. The total depth of wells used in the network ranged from 50-410 feet and averaged 159 ft. Thirty-seven (37) wells have been incorporated into a trend network measured annually, with 15 of these measured seasonally.

The BOON has 3 GMAP recorders in Ottawa, Delaware, and Cherokee counties, installed during July, August, and November (respectively) of 2017 (Figure 43).

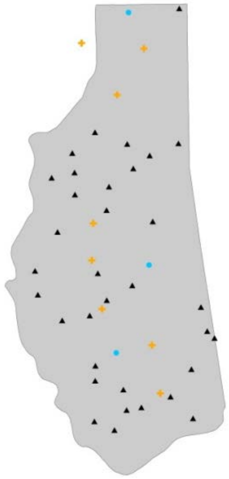

Figure 33. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate USGS hydrologic study (orange crosses) against the entire BOON water level network.

Canadian River Alluvial & Terrace Aquifer

The Canadian River enters Oklahoma from the Texas panhandle, forming the geographic boundary between Ellis and Roger Mills Counties. The Canadian then generally flows east-southeast through the central part of the state until its confluence with the Arkansas River at Robert S. Kerr Reservoir in eastern Oklahoma. The Canadian has about 460 river miles in Oklahoma, draining 6,786 mi^2 (Figure 34).

The Canadian River Alluvial and Terrace Aquifer, hereafter referred to as CNDN, is an unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, and clay. Absent previous hydrologic investigations of this aquifer, the areal and vertical extent and hydrology are poorly defined (In 2012, the U.S. Geological Survey initiated a study of two reaches of the Canadian River to define the aquifer's boundaries and yield characteristics). For alluvial and terrace aquifers in central and western Oklahoma, subsurface boundaries are defined by the depth below land surface that Permian bedrock ("red beds") occurs. Areally, deposits may occur on either side of the river for a distance of up to 15 miles but typically are less than 6 miles beyond the river banks.

Figure 34. Location and extent of the CNDN.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 34 wells to assess the baseline water quality of the aquifer and concurrently measured 44 wells to assess the baseline water level (Figure 35). Overall, the water quality is fair-good but highly variable across the aquifer. More detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the CNDN can also be found in Appendix G of this report.

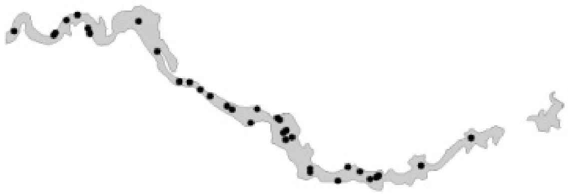

Figure 35. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the CNDN in 2013.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 10 active CNDN wells. Although most of those historical wells have contemporaneous water level measurements, the spatial distribution and small number of sites make the data collected insufficient to characterize aquifer-wide historical water level conditions. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrographs shown in Figure 36 represent single entry points into the aquifer with the longest periods of record.

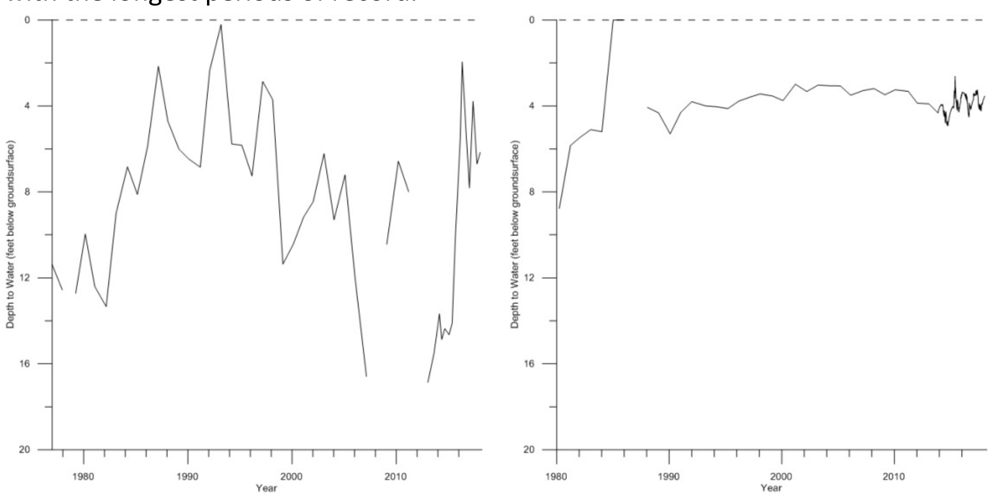

Figure 36. Groundwater level hydrographs for two of the longest CNDN records, McClain County (1977-2018; left) and Roger Mills County (1980-2018; right).

A baseline groundwater level network comprising 46 wells was measured in August-September 2013. The annual trend network is currently composed of 36 wells, with 21 of these sites measured seasonally (Figure 37). Fluctuating groundwater levels in alluvial and terrace aquifers, as depicted by these hydrographs, generally reflect variation in year to year rainfall amounts. Historically, measurements have been made in the winter when the effects of groundwater withdrawals and evapotranspiration are less significant.

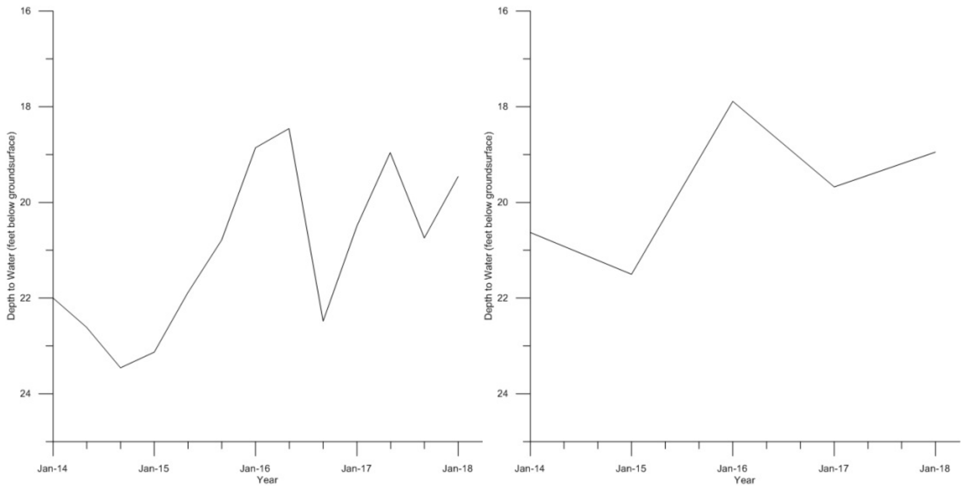

Figure 37. Average water level in the GMAP trend water level network on a seasonal (left, N=9) and annual (right, N=29) basis for CNDN (2014-2018).

Average water levels across the aquifer have increased by 1.84 ft over this period (N=31, 2014-2018). 2018 water levels in the CNDN averaged 19.29 ft, with a median value of 14.95 ft (N=34). Of the 34 wells in the CNDN network, 33 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in CNDN wells over the last year by an average 0.93 ft in the West Central Climate Division (N=15) and increasing 0.58 ft in the Central Climate Division (N=16, 2017-2018). There are insufficient data points in the East Central Climate Division to characterize a change in water level in this reach of the aquifer. A continuous water level recorder was installed in Roger Mills County in November 2013 where depth to water in feet below land surface is being recorded in hourly increments; 2 additional continuous water level recorders were installed in Dewey & McClain County in April 2016 (Figure 38).

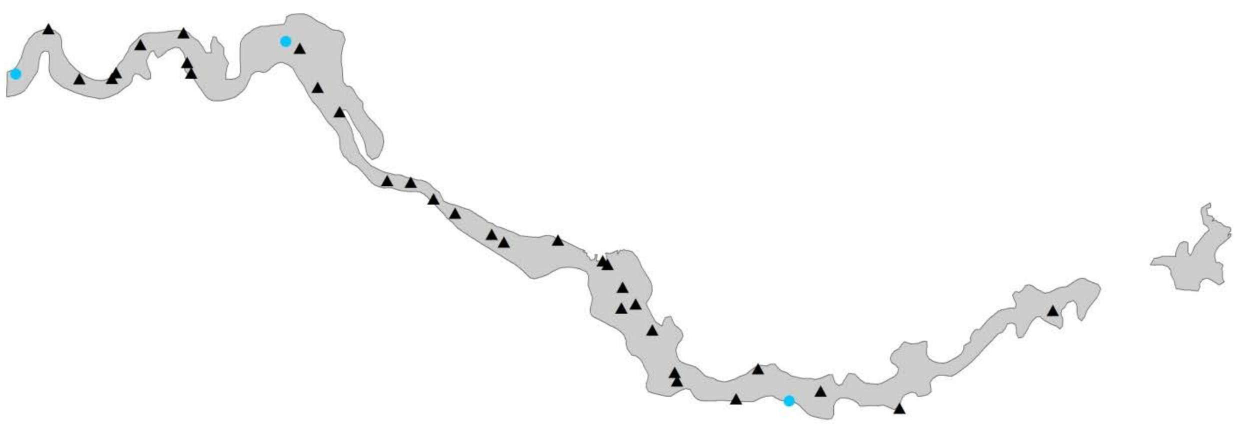

Figure 38. Location of continuous water level recorders (blue circles) against the entire CNDN water level network.

Cimarron River Alluvial & Terrace Aquifer

The Cimarron River originates in New Mexico, enters Oklahoma through northwest Cimarron County in the Panhandle before winding across parts of southeast Colorado, Beaver County in Oklahoma, and southwest Kansas. It re-enters Oklahoma, forming the border between Harper and Woods Counties, and flows southeast through Northwest Oklahoma before turning east-northeasterly in Kingfisher and Logan Counties. It maintains the east-northeasterly flow through north-central Oklahoma then terminates at its confluence with Keystone Lake and the Arkansas River in Creek County. The Cimarron has 420 river miles in Oklahoma, draining 8,352 mi^2 (Figure 39).

The Cimarron River Alluvial and Terrace Aquifer, hereafter referred to as CMRN, is an unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, clay, sandy clay, and fine gravel. Although the river is present in the Oklahoma Panhandle, the aquifer boundaries begin in southern Woods County where the deposits become a reliably good source of ground water. Thickness of deposits varies but may reach a maximum of 120 ft; sand dunes commonly overlay the terrace deposits. Most of the underlying geology is low permeability Permian red beds that locally contain deposits of rock salt and gypsum which can contribute to the presence of chloride and sulfate in the aquifer. Aerially, deposits range in width from 3 to 15 miles, but average a width of about 10 miles. Deposits may occur on either side of the river but will tend to have wider areas of deposits on the northeastern side.

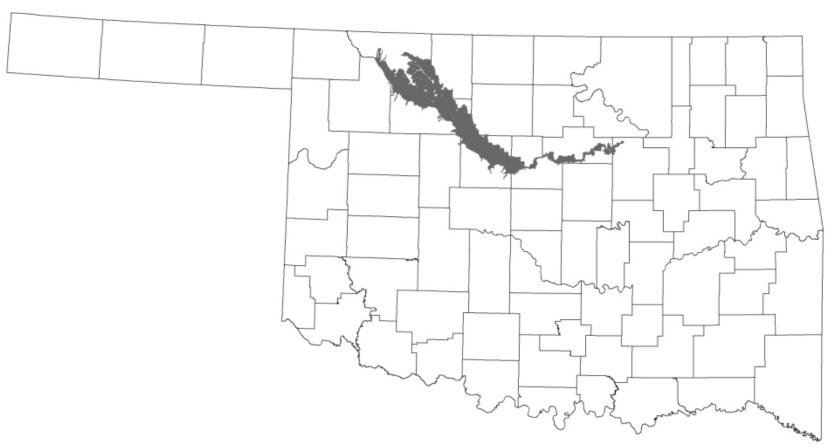

Figure 39. Location and extent of CMRN.

Data Collection Results- Group D

In 2016, the Groundwater Monitoring and Assessment Program sampled 37 wells to assess the baseline water quality of the aquifer and concurrently measured 60 wells to assess the baseline water level (Figure 40). Overall, the water quality is fair. More detailed information and figures can be found on the OWRB's website in the 2016 BUMP Report; the statistics for the CMRN can also be found in Appendix H of this report.

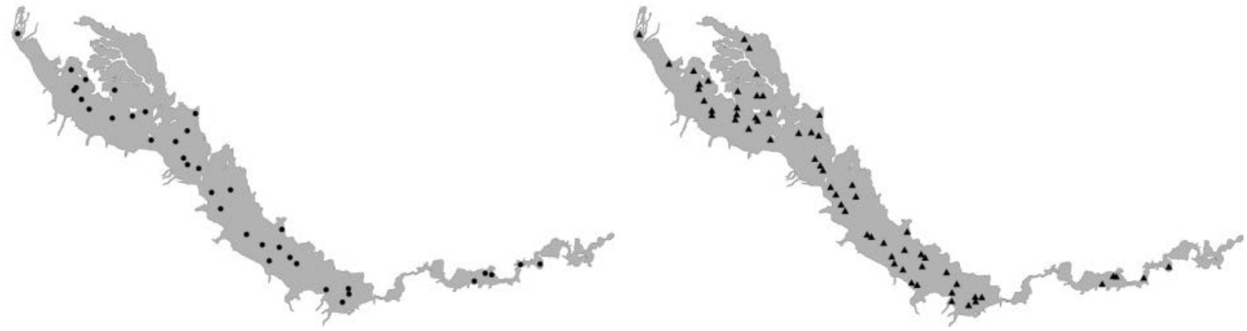

Figure 40. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the CMRN in 2016.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 33 active CMRN wells. Of the 17 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 8 were selected to generate a spatially representative composite average water level hydrograph with the fewest number of data gaps (Figure 41).

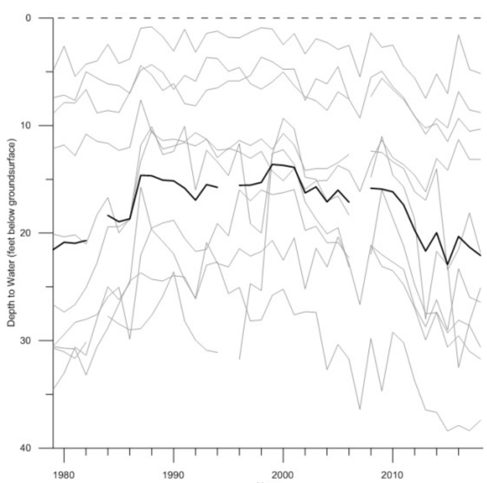

Figure 41. Composite average water level (bold line, N=8) and individual well water levels in the CMRN over period of record (1979-2018).

A baseline groundwater level network for the CMRN was comprised of 62 wells and implemented in July-August 2016. Several wells in this aquifer have over 30 years of measurements (Figure 42). To maintain some wells with long periods of record, the baseline network incorporated 33 wells from the aquifer's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from 4.29-52.4 feet below ground surface with a mean of 19.38 ft over the entire aquifer; averages were 19.31 ft in the North Central and 19.47 ft in the Central climate divisions. The total depth of wells used in the network ranged from 25-100 feet and averaged 58.4 ft. Seventy-three (73) wells have been incorporated into a trend network measured annually, with 18 of these measured seasonally.

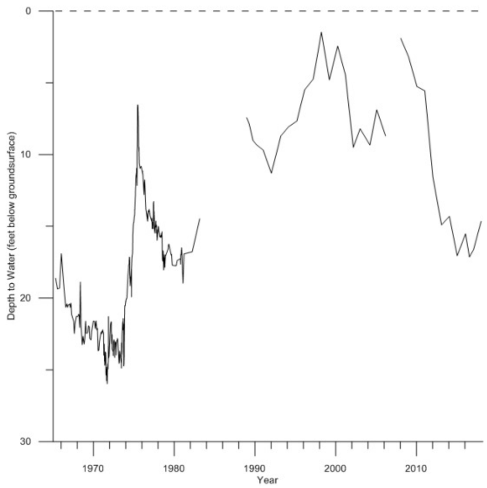

Figure 42. Groundwater level hydrograph for one of the longest CMRN records, Major County (1965-2018).

Fluctuating groundwater levels in alluvial and terrace aquifers, as depicted by these hydrographs, generally reflect variation in year to year rainfall amounts. Historically, measurements have been made in the winter when the effects of groundwater withdrawals and evapotranspiration are less significant. 2018 water levels in the CMRN averaged 18.18 ft, with a median value of 15.42 ft (N=73). Of the 73 wells in the CMRN network, all 73 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in CMRN wells over the last year by an average 0.19 ft in the Central Climate Division (N=24) and by an average 0.31 ft in the North Central Climate Division (N=48, 2017-2018). Average water levels across the aquifer have increased by 0.23 ft in the Central Climate Division (N=13) and by 1.46 ft in the North Central Climate Division (N=20) during the last 5 years (2013-2018). The CMRN has two GMAP recorders in Woods and Logan counties, installed during December 2013. Water level in the CMRN is also being monitored by continuous water level recorders deployed by the OWRB for a separate hydrologic study (Figure 43).

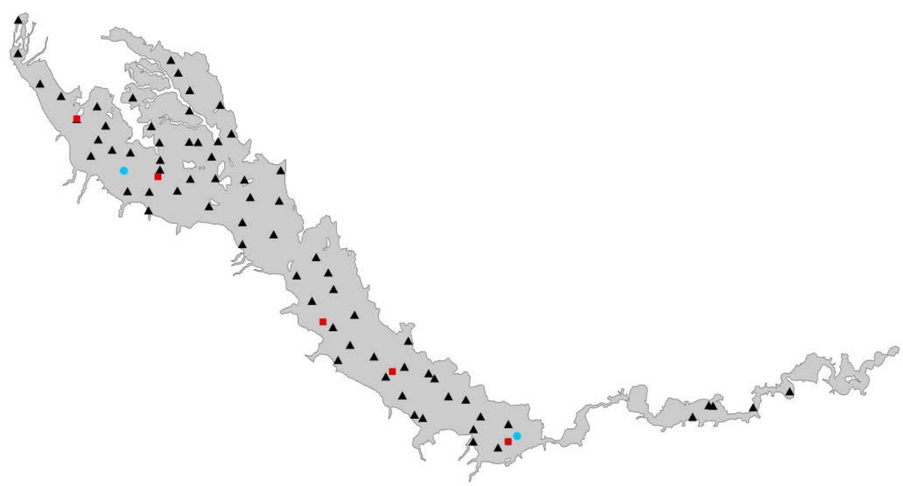

Figure 43. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire CMRN water level network.

Dakota-Dockum Aquifer

The Dakota-Dockum Aquifer is a confined/semi-confined minor bedrock aquifer composed of geologic units ranging in age from Cretaceous to Triassic (Figure 44). The principal water-bearing units of the Dakota-Dockum Aquifer (hereafter referred to as DAKD) from youngest to oldest are the Dakota Sandstone, a fine-medium grained sandstone unit ranging in thickness from 0-200 feet; the Cheyenne Sandstone member of the Purgatoire Formation, a fine-medium grained sandstone unit ranging in thickness from 0-125 feet; and the Dockum Group, consisting of an upper unit composed of shale and fine grained sandstone and a lower unit composed of medium grained sandstone (the lower unit yields more water than the upper unit of the Dockum). The thickness of the Dockum Group ranges from 0-650 feet. Lesser quantities of water are obtained from other units within the DAKD including the Exeter Sandstone and Morrison Formation. The Colorado Group, the youngest Cretaceous formation, is composed of shale and limestone and is not known to yield water to wells. Excepting the Dockum Formation, the other formations that make up the DAKD cited above occur only in the western third to half of Cimarron County. Most of the DAKD is overlain by the Ogallala Formation, the preeminent major groundwater aquifer in the panhandle. The sum aggregate total of all geologic units that compose the DAKD is around 1,750 feet, but the maximum thickness is probably around 1,100 feet in western Cimarron County. Topography in the panhandle is an eastward sloping plateau and surface drainage flows into the Cimarron and Beaver Rivers, along with their associated tributaries, or into local depressions.

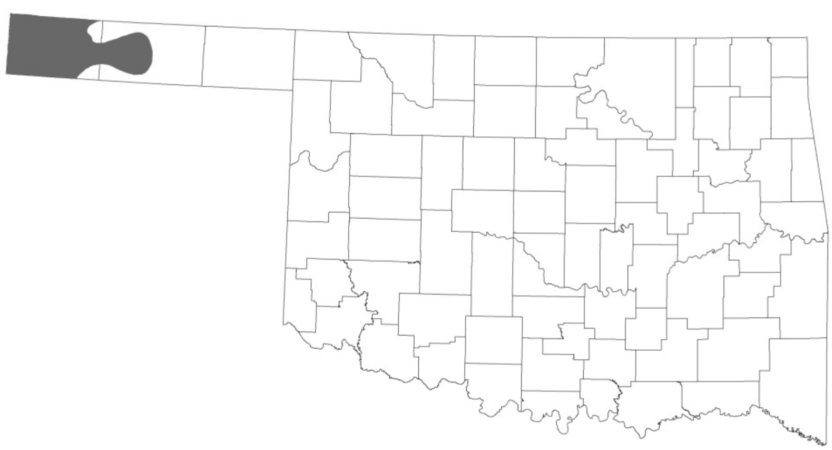

Figure 44. Location and extent of the DAKD.

Data Collection Results- Group D

The Dakota-Dockum is classified as a minor aquifer due to well yields, but a baseline assessment was completed due to its high use in the state. In 2016, the Groundwater Monitoring and Assessment Program sampled 27 wells to assess the baseline water quality of the aquifer and concurrently measured 13 wells to assess the baseline water level (Figure 45). Overall, the water quality is good. More detailed information and figures can be found on the OWRB's website in the 2016 BUMP Report; the statistics for the DAKD can also be found in Appendix I of this report.

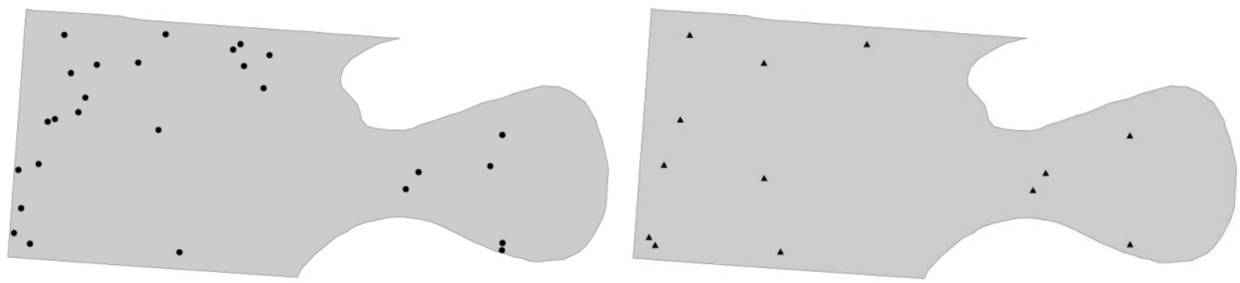

Figure 45. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the DAKD in 2016.

Groundwater Level Measurements

The DAKD is classified as a minor aquifer due to well yields, but it is highly utilized in the state. Prior to GMAP implementation, groundwater levels were only being measured in 3 active DAKD wells concentrated in southwestern Cimarron County and as a consequence, insufficient data exists to characterize recent historical groundwater level conditions. Data requirements to graphically represent groundwater levels for an aquifer over a long period of record should rely on multiple wells, spatially distributed and covering contemporaneous time periods. This was not the case prior to 2016 for the DAKD. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrograph shown in Figure 46 represents a single entry point into the aquifer with the longest period of record.

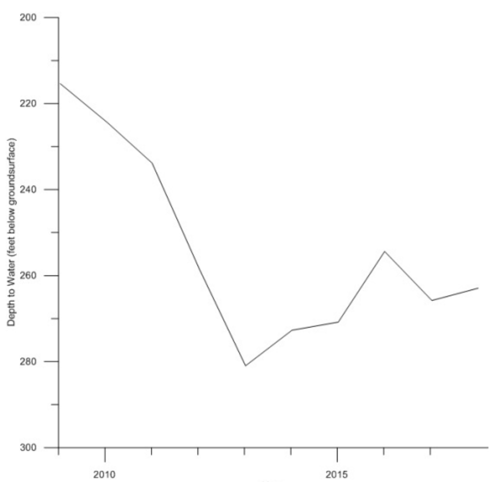

Figure 46. Groundwater level hydrograph for the longest DAKD record, southwest Cimarron County (2009-2018).

A baseline groundwater level network for the DAKD was comprised of 13 wells and implemented in August-October 2016. This aquifer was designed with a larger network due to its areal extent; however, there was difficulty finding suitable wells that had an access port to measure water level and that were not actively pumping during the baseline period. To maintain some wells with longer periods of record, the baseline network incorporated 3 wells from the aquifer's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from 33.3-274.83 feet below ground surface with a mean of 159.02 ft over the entire aquifer. The total depth of wells used in the network ranged from 100-530 feet and averaged 281.9 ft. Sixteen (16) wells have been incorporated into a trend network measured annually.

2018 water levels in the DAKD averaged 178.47 ft, with a median value of 175.93 ft (N=16). Of the 16 wells in the DAKD network, 15 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in DAKD wells over the last year by an average 0.03 ft (N=15, 2017-2018).

Elk City Aquifer

The Elk City aquifer, hereafter abbreviated as ELKC, located in western Oklahoma and underlying portions of Roger Mills, Beckham and Washita counties, is an unconfined bedrock aquifer (Figure 47). It is composed of the Permian-age Elk City Sandstone that is reddish-brown, fine grained and very friable. The sandstone is weakly cemented by calcium carbonate, iron oxide, or gypsum, and the maximum thickness of the Elk City Sandstone is around 185 feet. The Doxey Shale, composed of reddish-brown silty shale and siltstone, underlies and bounds the ELKC and as a result, groundwater flow into and out of the aquifer is limited. Locally, unconsolidated sediments of clay, silt, sand and gravel overlie the aquifer along tributary streams flowing northeast toward the Washita River and south towards the North Fork of the Red River, with Elk Creek being the most prominent tributary that drains the area.

Figure 47. Location and extent of the ELKC.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 13 wells to assess the baseline water quality of the aquifer and concurrently measured 25 wells to assess the baseline water level (Figure 48). Overall, this aquifer contains water of good quality. Water quality across the aquifer was relatively uniform; no obvious spatial patterns were observed. More detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the ELKC can also be found in Appendix J of this report.

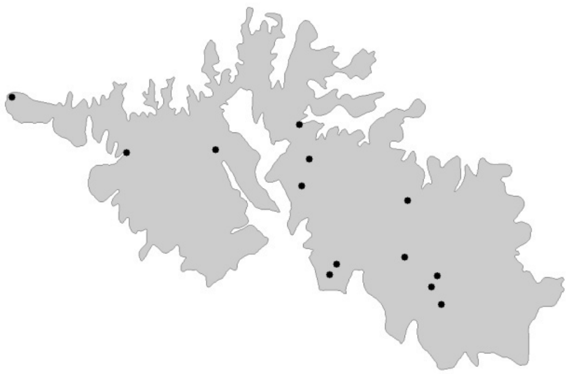

Figure 48. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ELKC in 2013.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 8 active ELKC wells. Of the 7 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5 were selected to generate a composite average water level hydrograph with no data gaps (Figure 49). All 8 historical wells were incorporated into the new water level network.

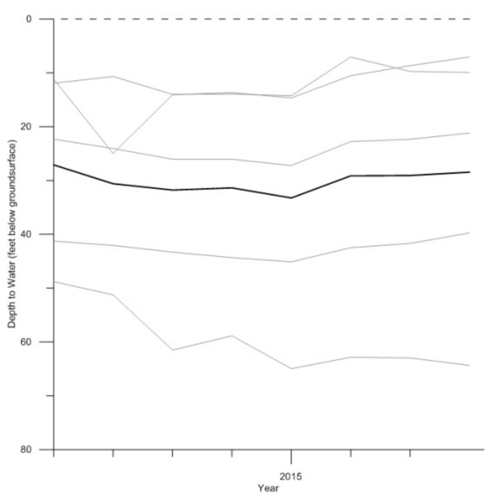

Figure 49. Composite average water level (bold line, N=5) and individual well water levels in the ELKC over period of record (2011-2018).

A baseline groundwater level network comprising 25 wells was measured in July-August 2013. Twenty-two (22) wells are currently in the network measured annually, with 7 of these sites measured seasonally (Figure 50).

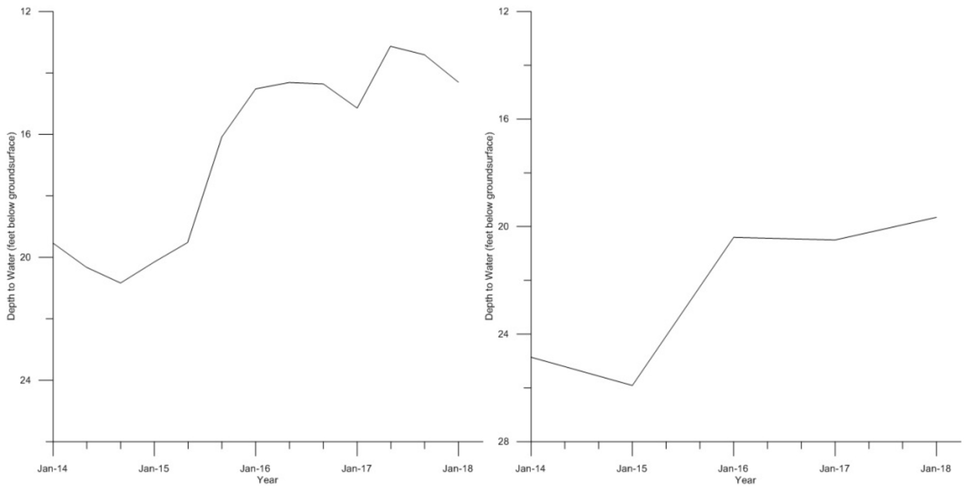

Figure 50. Average water level in the GMAP trend water level network on a seasonal (left, N=6) and annual (right, N=22) basis for ELKC (2014-2018).

Average water levels across the aquifer have increased by 5.20 ft over this period (N=22, 2014-2018). 2018 water levels in the ELKC averaged 19.66 ft, with a median value of 13.82 ft (N=22). Of the 22 wells in the ELKC network, all 22 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in ELKC wells over the last year by an average 0.80 ft (N=22, 2017-2018). Figure 51 is a depth to water hydrograph of the one well with a 25 year period of record. Taped measurements of the well depicted in Figure 51 have been made annually since 1989. This well was equipped with a continuous water level recorder in November 2013 that is collecting hourly water level data (Figure 52).

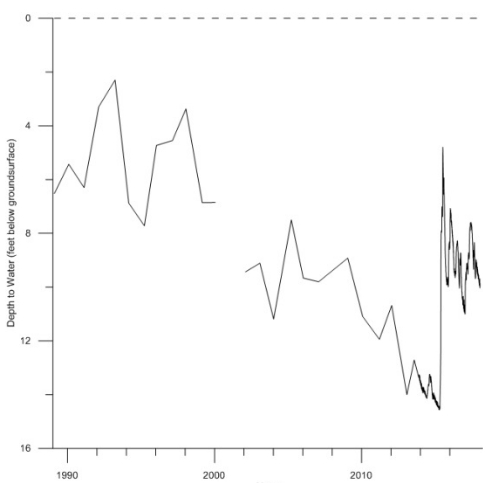

Figure 51. Groundwater level hydrograph of the longest ELKC record, Washita County (1989-2018).

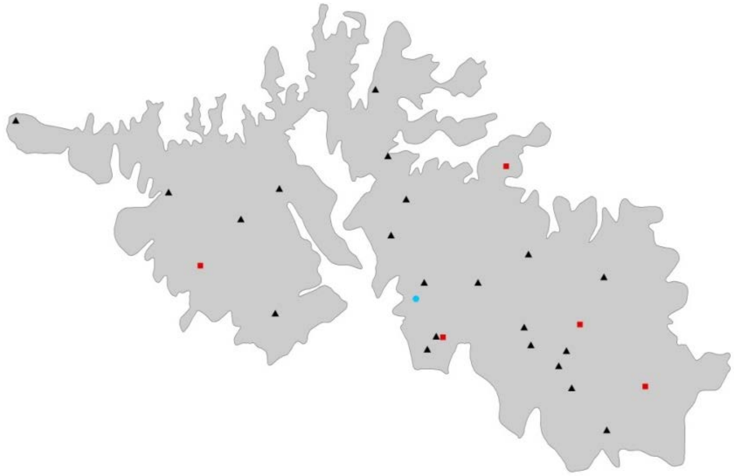

Figure 52. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire ELKC water level network.

Enid Isolated Terrace Aquifer

The Enid Isolated Terrace aquifer, located in north central Oklahoma and underlying Garfield County, is an isolated terrace aquifer separated from the Cimarron River by erosion (Figure 53). It overlies two Permian-age formations, the Hennessey group on the east and the Cedar Hills Sandstone Formation on the west where the aquifer is undifferentiated. The deposits are of Quaternary Age and are unconsolidated, discontinuous layers of clay, sand, and gravel. The aquifer's water table surface is unconfined, and the mean aquifer thickness is 60 feet, although thickness varies widely. Lower permeability Permian shale and sandstone underlie the Enid Isolated Terrace, hereafter shortened to ENID, limiting flow through. Groundwater flows southeast, mirroring surface topography.

Figure 53. Location and extent of the ENID.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 9 wells to assess the baseline water quality of the aquifer and concurrently measured 15 wells to assess the baseline water level (Figure 54). Overall, this aquifer contains water of fair quality. The availability of potential wells to be included in the network for the eastern half of the aquifer was sparse, and unfortunately no wells were suitable for inclusion in the water quality network due to wells not meeting program guidelines and/or landowner constraints. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the ENID can also be found in Appendix K of this report.

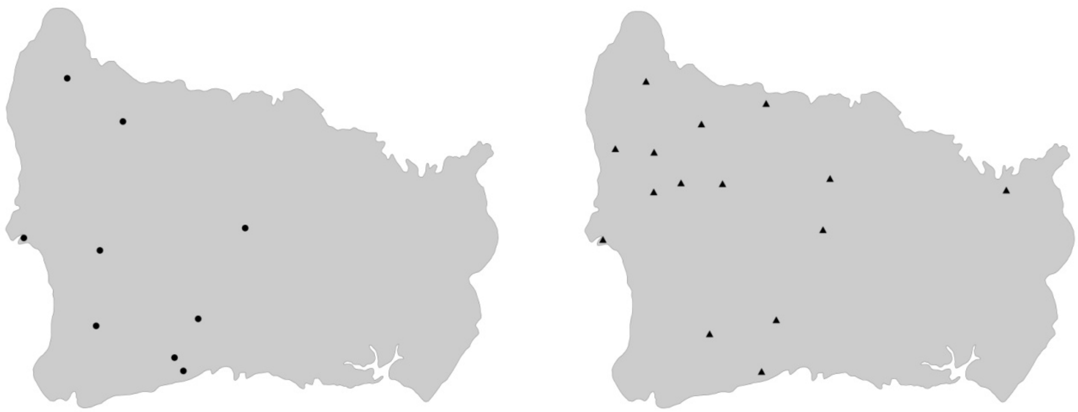

Figure 54. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ENID in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 9 active ENID wells. A composite average water level hydrograph was generated from the 5 historical wells that spanned the entire period of record and had contemporaneous water level measurements (Figure 55).

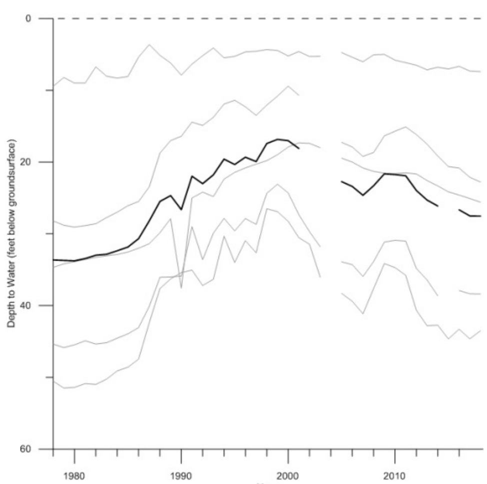

Figure 55. Composite average water level (bold line, N=5) and individual well water levels in the ENID over period of record (1978-2018).

A baseline groundwater level network of 18 wells was measured in September 2014. Eighteen (18) wells are currently in the network measured annually, with 5 of these sites measured seasonally. The network includes 9 wells from the aquifer's historical groundwater level network to continue long-term records. Figure 56 is a depth to water hydrograph of one of the two ENID wells that has nearly 70 years of measurements.

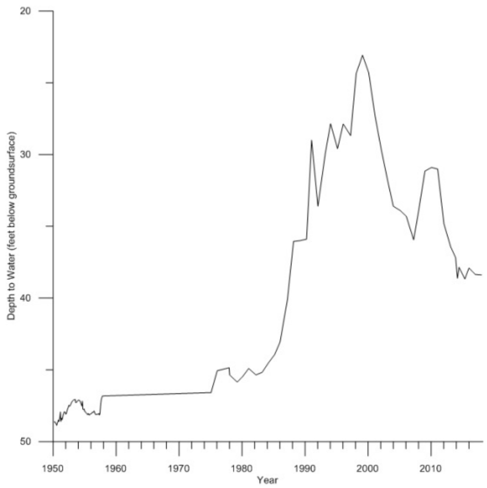

Figure 56. Groundwater level hydrograph of one of the longest ENID records, Garfield County (1950-2018).

Taped measurements of the well depicted in Figure 56 began in 1950, with a hiatus from 1958-1975, and then continued until 2013. A continuous water level recorder was installed from November 2013 to May 2015 and collected hourly depth to water measurements; the well is currently measured manually once a year. The second well with a 60 year period of record has a similar measurement history and is also a part of the water level network.

2018 water levels in the ENID averaged 24.81 ft, with a median value of 20.55 ft (N=18). Of the 18 wells in the ENID network, all 18 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in ENID wells over the last year by an average 0.01 ft (N=18, 2017-2018). Average water levels across the aquifer have decreased by 1.29 ft during the last 5 years (N=8; 2013-2018).

Garber-Wellington Aquifer

The Garber-Wellington aquifer, hereafter shortened to GSWF, located in central Oklahoma and underlying portions of Cleveland, Lincoln, Logan, Oklahoma, Payne, and Pottawatomie counties, includes the Garber Sandstone and Wellington Formations and the Admire, Chase and Council Grove Groups (Figure 57). In the west, the aquifer is overlain by the Hennessey Formation that acts as a confining layer. The Vanoss Formation defines the aquifer's eastern boundary, the Cimarron River its northern boundary and the Canadian River its southern boundary. The Garber Sandstone and Wellington Formation consist of cross-bedded, fine-grained sandstone with interbedded shale or mudstone. The Admire, Chase and Council Grove Groups are composed of cross-bedded, fine-grained sandstone, shale and limestone. The Vanoss Formation consists of shale with intermittent beds of limestone and sandstone. The Hennessey formation consists of interbedded red shale, clay and some fine-grained sandstone. Locally, the aquifer is overlain by stream and river alluvial and terrace deposits. The maximum thickness of the Garber Sandstone and Wellington Formations is around 1,600 feet. Water is considered to be unconfined in the upper 100 feet of the aquifer and may be confined or unconfined at depths greater than 100 feet.

Figure 57. Location and extent of the GSWF.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 47 wells to assess the baseline water quality of the aquifer and concurrently measured 61 wells to assess the baseline water level (Figure 58). Overall, this aquifer contains water of good quality although variability exists depending on location within the aquifer. Wells included in the program were constrained by depth; more detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the GSWF can also be found in Appendix L of this report.

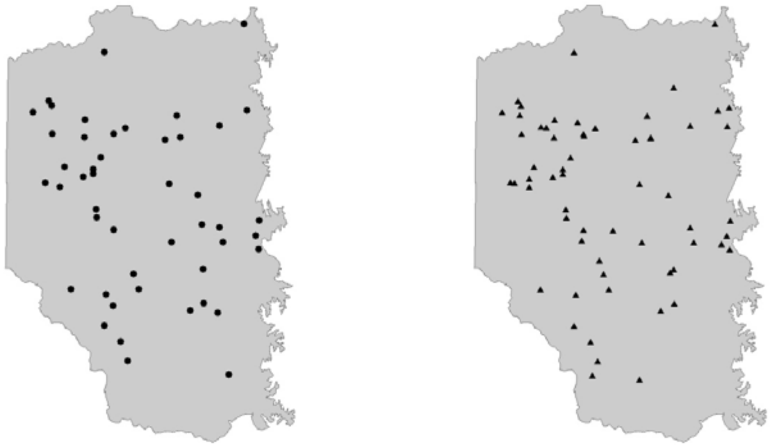

Figure 58. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the GSWF in 2013.

Groundwater Level Measurements

For the purpose of comparing and contrasting water levels in the GSWF, water levels obtained from wells 300 feet or less in total depth were considered representative of unconfined conditions and water levels associated with total depths greater than 300 feet representative of confined conditions. Prior to GMAP implementation, groundwater levels were being measured in 15 active GSWF wells. Of the 6 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5 were selected to generate a composite average water level hydrograph with the fewest number of data gaps (Figure 59).

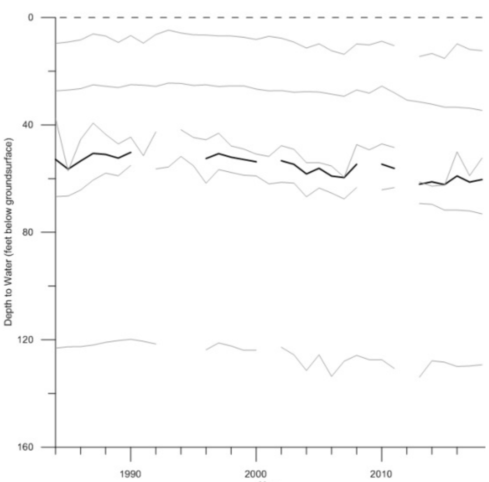

Figure 59. Composite average water level (bold line, N=5) and individual well water levels in the GSWF over period of record (1984-2018).

A baseline groundwater level network comprising 61 wells was measured during October-November 2013. Forty-nine (49) wells are currently in the network measured annually, with 25 measured seasonally (Figure 60). To continue long-term records, the trend network included 20 wells from the aquifer's most recent historical network. Unconfined conditions are reflected in 45 wells of the water level network, and 4 are considered to be in the deeper, confined parts of the aquifer.

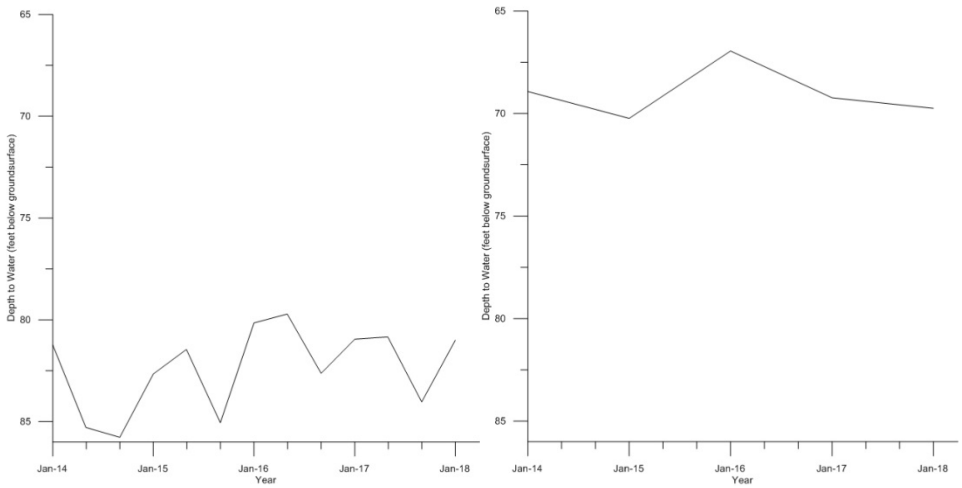

Figure 60. Average water level in the GMAP trend water level network on a seasonal (left, N=19) and annual (right, N=44) basis for GSWF (2014-2018).

Figure 61 is a depth to water hydrograph for an unconfined well with over 40 years of measurements. Taped measurements of the well in Figure 61 have been made annually since 1976 and have continued in the GMAP water level network.

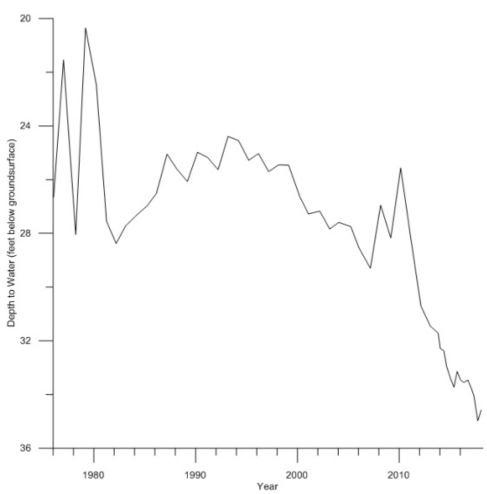

Figure 61. Groundwater level hydrograph of a GSWF well, Oklahoma County (1976-2017).

Average water levels across the aquifer have decreased by 0.82 ft over this period (N=45, 2014-2018). 2018 water levels in the GSWF averaged 69.75 ft, with a median value of 66.76 ft (N=45). Of the 45 wells in the unconfined GSWF network, all 45 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in GSWF wells over the last year by an average 0.51 ft (N=45, 2017-2018). Hourly measurements of depth to water are being collected from three continuous water level recorders installed in Cleveland and Logan Counties, along with two others deployed by the OWRB at the Oklahoma Mesonet stations in Oklahoma and Pottawatomie Counties (Figure 62).

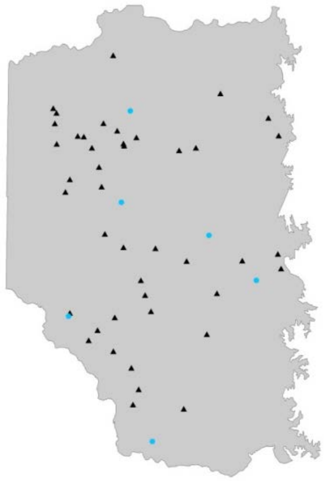

Figure 62. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire GSWF water level network.

Gerty Sand

The Gerty Sand aquifer, hereafter referred to as GRTY, located in south central Oklahoma and underlying portions of Garvin, McClain, and Pontotoc counties (Figure 63), is an isolated terrace aquifer separated from the Canadian River by erosion. The deposits are of Quaternary Age, and the aquifer's water table surface is unconfined. The deposits are unconsolidated and comprise rose colored quartzite cobbles and yellow and tan medium to coarse grained sands with admixtures of silt and clay. Dune deposits blanket parts of the aquifer and locally are believed to be the entry point for recharge to the aquifer. The mean aquifer thickness is 28 feet with a maximum of around 200 feet. Lower permeability Permian units (Admire, Chase and Council Grove Groups) underlie the Gerty Sand, limiting flow through.

Figure 63. Location and extent of the GRTY.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 5 wells to assess the baseline water quality of the GRTY and concurrently measured 5 wells to assess the baseline water level (Figure 64). Overall, this aquifer contains water of good quality. More detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the GRTY can also be found in Appendix M of this report.

Figure 64. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the GRTY in 2013.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were only being measured in 1 active GRTY well. Measurements of this well reflect rising groundwater levels for most of the period of record (Figure 65).

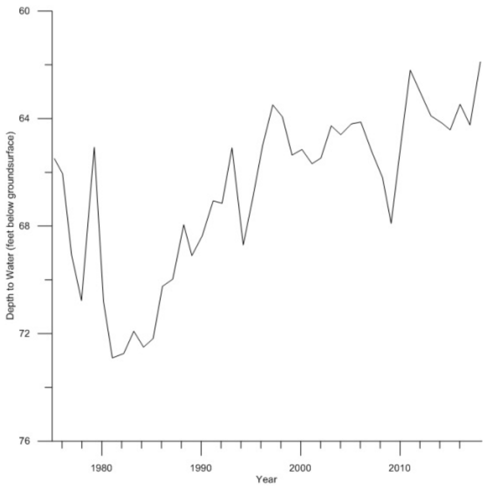

Figure 65. Groundwater level hydrograph of a GRTY well, Garvin County (1975-2018).

A baseline network of 5 wells was measured in August 2013. Four (4) wells are currently in the water level network measured annually, with 1 of these sites measured seasonally. Because of small sample size, average change in water level is not calculated for the GRTY. Water level in the GRTY is currently being monitored by continuous water level recorders deployed by the OWRB for a separate hydrologic study (Figure 66).

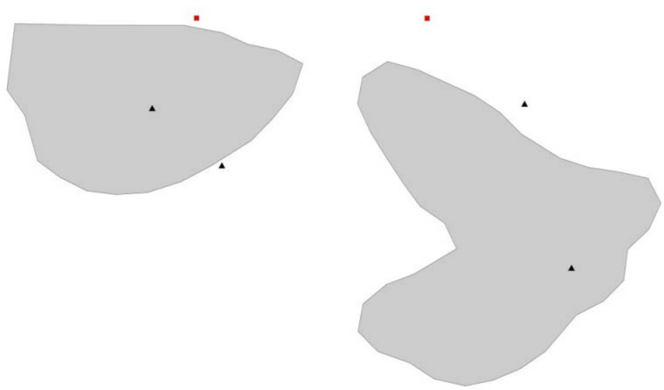

Figure 66. Location of continuous water level recorders (red squares) in a current OWRB hydrologic study against the entire GRTY GMAP water level network.

North Canadian River Alluvial & Terrace Aquifer

The North Canadian River, also known as Beaver/North Canadian, originates in New Mexico and enters Oklahoma through southwest Cimarron County. It winds through the Oklahoma panhandle before turning southeasterly in Harper County. It generally maintains the southeast-easterly flow through western Oklahoma and into the central region, passing through Fort Supply Lake, Canton Lake, and Lake Overholser before terminating at its confluence with Lake Eufaula and the Canadian River in McIntosh County. The North Canadian has 765 river miles in Oklahoma, draining 11,901 mi^2 (Figure 67).

The North Canadian River Alluvial and Terrace Aquifer, hereafter referred to as BNCR, is an unconfined aquifer composed of unconsolidated, discontinuous deposits of gravel, sand, silt, and clay. Deposits are commonly 30 to 80 feet thick for the alluvium and terraces, depending on the reach of the river. Dune sands overlie much of the alluvium in the northwest. Width, thickness, and yield vary as it travels through the state. Aerially, deposits may occur on either side of the river for a distance of up to 15 miles but typically are less than 10 miles beyond the river banks.

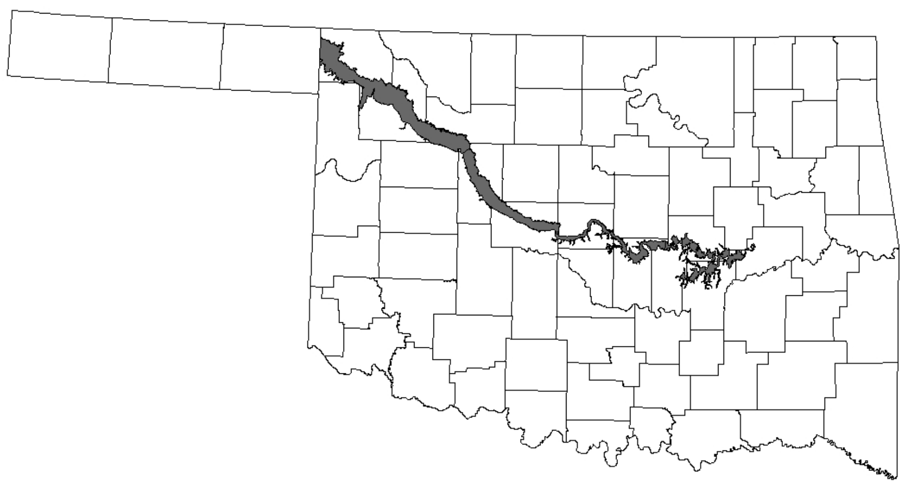

Figure 67. Location and extent of BNCR.

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 41 wells to assess the baseline water quality of the aquifer and concurrently measured 67 wells to assess the baseline water level (Figure 68). Overall, this aquifer contains water of fair quality. Reach 2 of the BNCR, through Blaine and Canadian counties, exhibits higher mineralization with higher levels of metals than the rest of the aquifer. Though water in the other reaches may also exhibit these characteristics, sites are situated among water of lower concentrations and there is not a clear delineation. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the BNCR can also be found in Appendix N of this report.

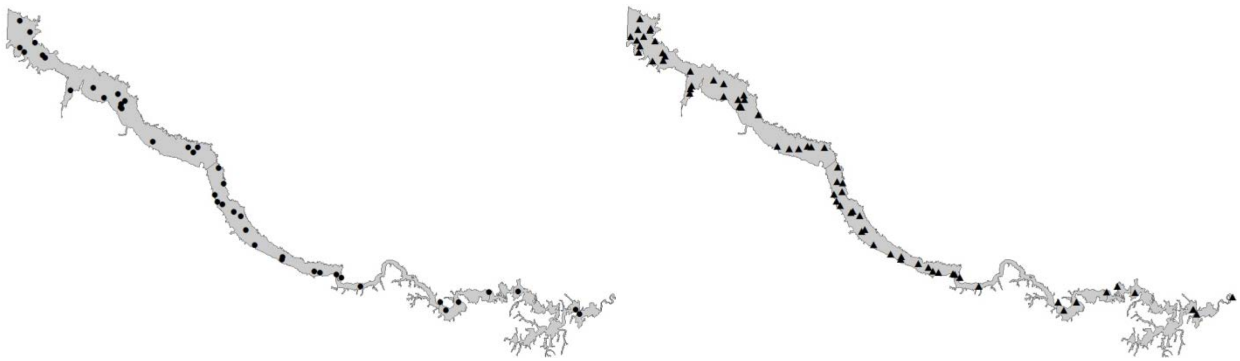

Figure 68. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the BNCR in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 31 active BNCR wells. Although 16 of those wells contemporaneous water level measurements and spanned the entire period of record, data gap years were so varied among wells that it was necessary to graph water levels by climate division in order to generate a meaningful, spatially representative composite (Figure 69).

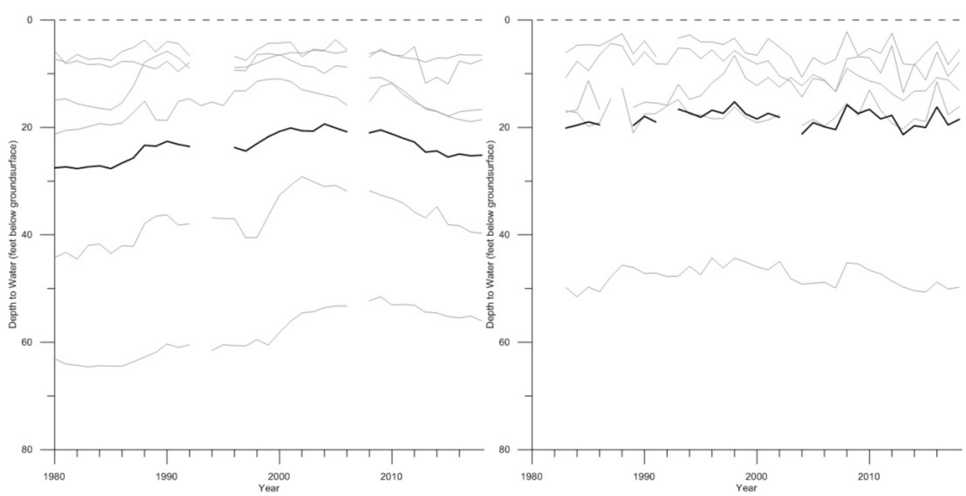

Figure 69. Composite average water level (bold line) and individual well water levels in the Panhandle and North Central (left, N=7) and in the West Central and Central Climate Divisions (right, N=5) of the BNCR over period of record (1980-2018 and 1983-2018, respectively).

A baseline groundwater level network for the BNCR was comprised of 67 wells and implemented in August-September 2015. To maintain some wells with long periods of record, the baseline network incorporated 29 wells from the aquifer's historical groundwater level network. Fifty-three (53) wells are currently in a trend network measured annually, with 16 of these measured seasonally.

Alluvial and terrace aquifers are sensitive to use and climate which can lead to large fluctuations in water levels. 2018 water levels in the BNCR averaged 22.93 ft, with a median value of 18.79 ft (N=53). Of the 53 wells in the BNCR network, 52 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in CMRN wells over the last year by an average 0.74 ft in the Central Climate Division (N=15), decreasing by an average 0.23 ft in the North Central Climate Division (N=16), increasing by an average 0.49 ft in the Panhandle Climate Division (N=11), and increasing by an average 0.44 ft in the West Central Climate Division (N=10, 2017-2018). Average water levels across the aquifer have increased by 3.83 ft in the Central Climate Division (N=7), decreased by 0.61 ft in the North Central Climate Division (N=9), increased by 1.13 ft in the Panhandle Climate Division (N=6), and increased by 2.40 ft in the West Central Climate Division (N=6) during the last 5 years (2013-2018). This aquifer had two GMAP recorders installed in Okfuskee and Woodward counties during winter 2013 (Figure 70).

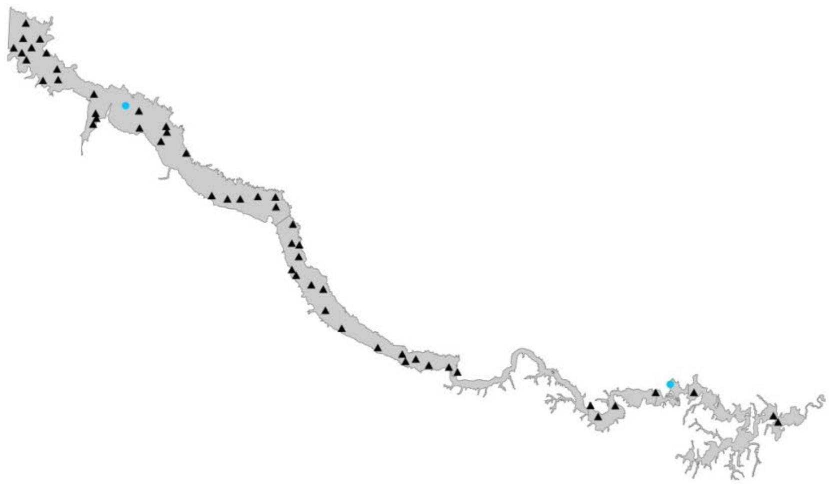

Figure 70. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire BNCR water level network.

North Fork of the Red River Alluvial & Terrace Aquifer

The North Fork of the Red River originates in the Texas Panhandle and enters Oklahoma through Beckham County. It flows east before turning south, passing through Altus-Lugert Reservoir, and terminating at its confluence with the Red River on the border of Jackson and Tillman Counties. The North Fork of the Red has about 181 river miles in Oklahoma, draining 2,801 mi^2 (Figure 71).

The North Fork of the Red River Alluvial and Terrace aquifer, hereafter referred to as NFRR, is an unconfined aquifer composed of unconsolidated, discontinuous deposits of gravel, sand, silt, and clay. It is bounded on its southern side by the Tillman Terrace aquifer. The deposits are mostly covered by dune sands and are underlain by Permian bedrock. Deposits average 40 feet thick with a maximum of 150 feet; aerially, deposits may occur on either side of the river for a distance of up to 15 miles but typically are less than 5 miles beyond the river banks.

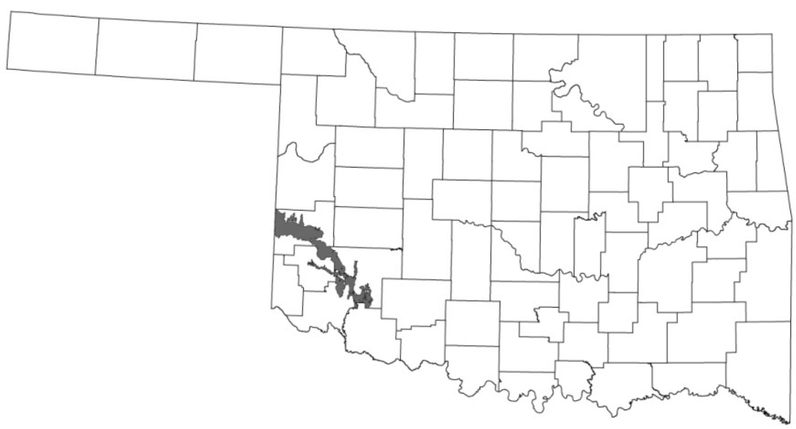

Figure 71. Location and extent of the NFRR.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 20 wells to assess the baseline water quality of the aquifer and concurrently measured 43 wells to assess the baseline water level (Figure 72). Overall, this aquifer contains water of fair quality. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the NFRR can also be found in Appendix O of this report.

Figure 72. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the NFRR in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 30 active NFRR wells. Of the 20 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 10 were selected to generate a spatially representative composite average water level hydrograph with the fewest number of data gaps (Figure 73).

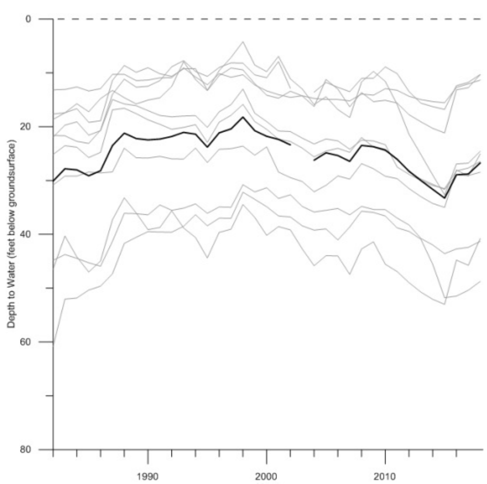

Figure 73. Composite average water level (bold line, N=10) and individual well water levels in the NFRR over period of record (1982-2018).

A baseline groundwater level network of 43 wells was measured in July-August 2014. Thirty-six (36) wells are currently in the network measured annually, with 14 of those sites measured seasonally. The trend network incorporated many wells from the NFRR's historical groundwater level network to continue these long-term records (Figure 74).

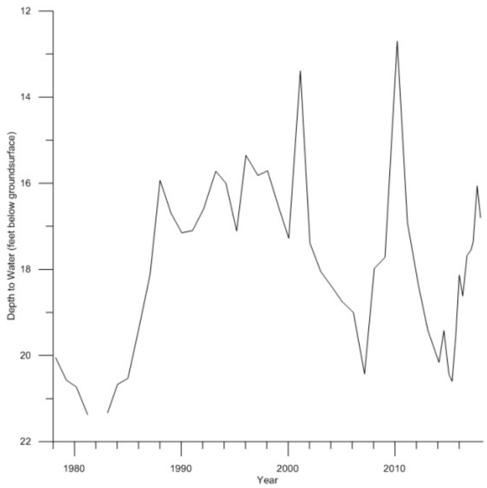

Figure 74. Groundwater level hydrograph of an NFRR record, Kiowa County (1978-2018).

Though fluctuation in alluvial and terrace aquifers is normal due to their sensitivity to use and climate, measurements have been made in the winter when the effects of groundwater withdrawals and evapotranspiration are less significant. 2018 water levels in the NFRR averaged 32.08 ft, with a median value of 27.88 ft (N=36). Of the 36 wells in the NFRR network, all 36 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in NFRR wells over the last year by an average 1.10 ft in the Southwest Climate Division (N=18) and by an average 0.64 ft in the West Central Climate Division (N=18, 2017-2018). Average water levels across the aquifer have increased by 4.01 ft in the Southwest Climate Division (N=13) and decreased by 0.17 ft in the West Central Climate Division (N=9) during the last 5 years (2013-2018). A continuous water level recorder was installed in Beckham County in April 2015 where depth to water in feet below land surface is being recorded in hourly increments (Figure 75).

Figure 75. Location of continuous water level recorder deployed for GMAP long-term seasonal monitoring (blue circle) against the entire NFRR water level network.

Ogallala-Northwest Aquifer

The Tertiary Ogallala Aquifer is part of the regional High Plains Aquifer System and is an unconfined bedrock aquifer. The area designated 'Northwest' is located in western Oklahoma and underlies portions of Dewey, Ellis, Harper, Roger Mills and Woodward counties (Figure 76). It is composed of semi-consolidated layers of sand, gravel, silt, and clay that are light gray, tan or white in color with intermittent zones cemented by calcium carbonate. The maximum thickness of the Ogallala-Northwest Aquifer (hereafter abbreviated as OGLLNW) is 500 feet thinning eastward, and groundwater typically moves toward the east. Surface drainage in the area flows into the Canadian River, Washita River, and North Fork of the Red River as they move eastward. The Ogallala continues into the panhandle of western Oklahoma in the area designated 'Panhandle' and underlies Cimarron, Texas, and Beaver counties; information from this area can be found in the 'Ogallala-Panhandle' section of this report.

Figure 76. Location and extent of the OGLLNW.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 40 wells to assess the baseline water quality of the aquifer and concurrently measured 49 wells to assess the baseline water level (Figure 77). Overall, this aquifer contains water of good quality. More detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the OGLLNW can also be found in Appendix P of this report. The statistics for the OGLLP region can be found in Appendix Q of this report.

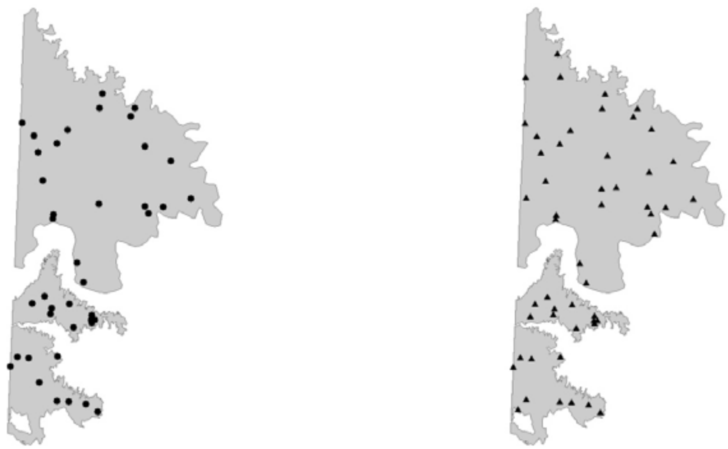

Figure 77. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the OGLLNW in 2013.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in about 50 active OGLLNW wells. Of the 28 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5 each were selected from north and south of the Canadian River to generate a spatially representative composite average water level hydrograph with the fewest number of data gaps (Figure 78).

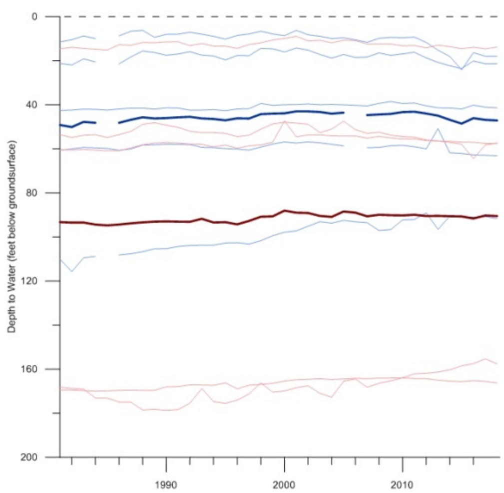

Figure 78. Composite average water levels (bold lines, N=5 each) and individual well water levels in the OGLLNW north (red lines) and south (blue lines) of the Canadian River over period of record (1981-2018).

A baseline groundwater level network comprising 49 wells was measured in August-September 2013. Fifty-seven (57) wells are currently in the network measured annually, with 13 of these sites measured seasonally (Figure 79). Many wells from the aquifer's historical groundwater level network were included in the water level network to continue these long-term records (Figure 80).

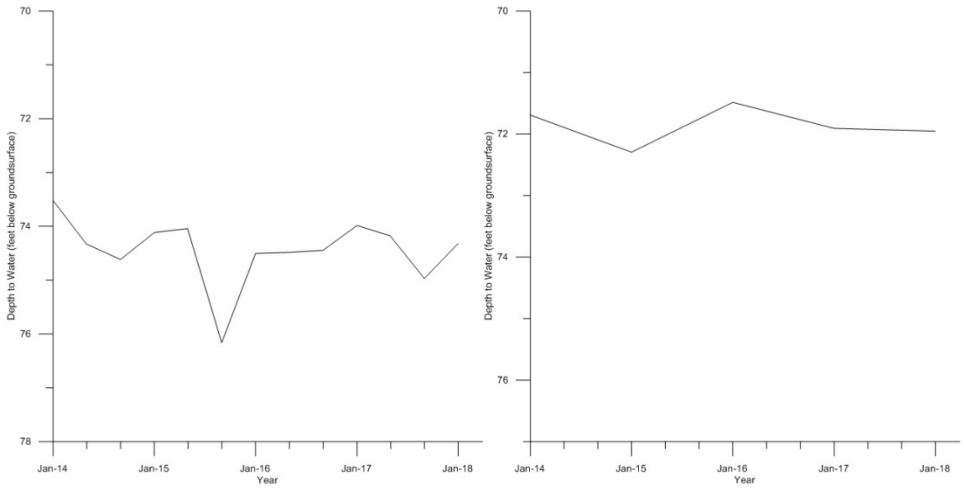

Figure 79. Average water level in the GMAP trend water level network on a seasonal (left, N=11) and annual (right, N=56) basis for OGLLNW (2014-2018).

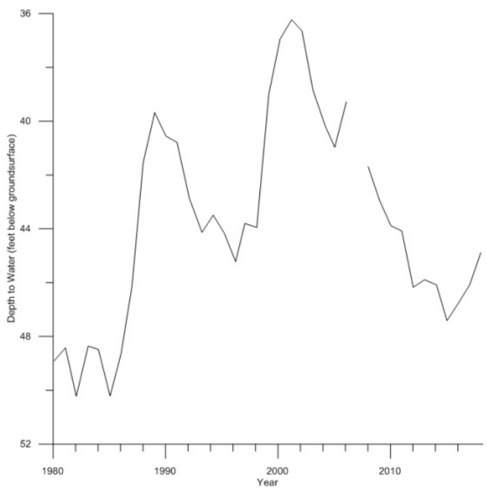

Figure 80. Groundwater level hydrograph of a record in OGLLNW, Ellis County (1980-2018).

Two (2) wells which were part of the baseline network but not the trend network were included for water level analysis. These wells are currently being measured as part of a separate hydrologic study of the Ogallala. Average water levels across the aquifer have decreased by 0.26 ft over this period (N=56, 2014-2018). 2018 water levels in the OGLLNW averaged 71.41 ft, with a median value of 62.98 ft (N=59). Of the 59 wells used for water level analysis, all 59 had measurements for both 2017 and 2018. The GMAP trend network (plus the additional 2 wells) recorded the average water level decreasing in OGLLNW wells over the last year by an average 2.11 ft north of the Canadian River (N=39) and by an average 0.27 ft south of the Canadian River (N=20, 2017-2018). A continuous water level recorder was installed in an Ellis county well during November 2013 to record hourly depth to water measurements (Figure 81).

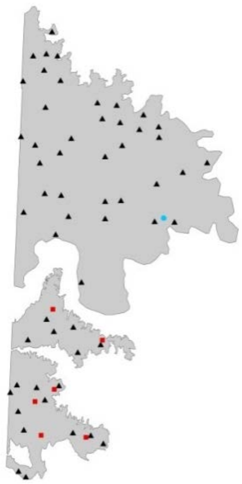

Figure 81. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circle) and for a separate OWRB hydrologic study (red squares) against the entire OGLLNW water level network.

Ogallala–Panhandle Aquifer

The Ogallala Aquifer is part of the regional High Plains Aquifer and is an unconfined bedrock aquifer. The aquifer system underlies 174,000 mi^2, extending north into Kansas, Colorado, Nebraska, South Dakota, and Wyoming and extending south into Texas and New Mexico. The area designated 'Panhandle' is located in the panhandle of western Oklahoma and underlies Cimarron, Texas, and Beaver counties (Figure 82). The Ogallala continues in western Oklahoma in the area designated 'Northwest' and underlies portions of Dewey, Ellis, Harper, Roger Mills and Woodward counties; information from this area can be found in the 'Ogallala-Northwest' section of this report. It is primarily composed of tertiary-aged semi-consolidated layers of sand, gravel, silt, and clay that are light gray, tan or white in color with intermittent zones cemented by calcium carbonate. The maximum thickness of the Ogallala-Panhandle Aquifer (hereafter referred to as OGLLP) approaches 700 feet in Northeast Texas County. Topography in the panhandle is an eastward sloping plateau and groundwater in OGLLP generally moves east-southeast. Surface drainage flows into the Cimarron and Beaver Rivers, along with their associated tributaries, or into local depressions.

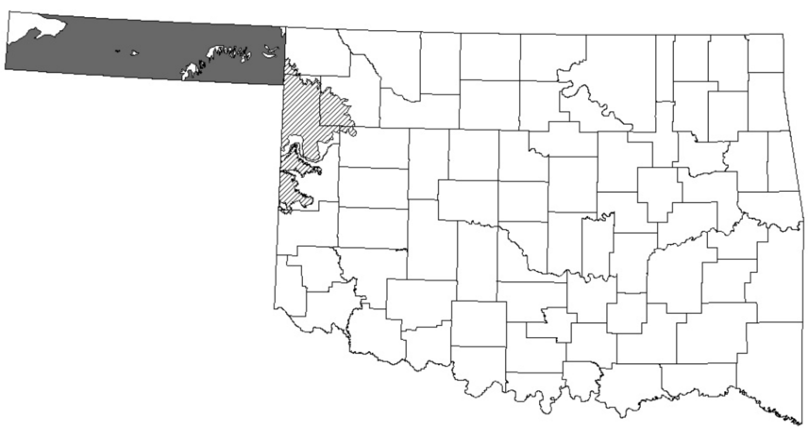

Figure 82. Location and extent of the OGLLP (dark gray) and OGLLNW (hatch marked; sampled 2013).

Data Collection Results- Group D

In 2016, the Groundwater Monitoring and Assessment Program sampled 88 wells to assess the baseline water quality of the aquifer and concurrently measured 114 wells to assess the baseline water level (Figure 83). Overall, the water quality is good. More detailed information and figures can be found on the OWRB's website in the 2016 BUMP Report; the statistics for the OGLLP can also be found in Appendix Q of this report. The statistics for the OGLLNW region can be found in Appendix P of this report.

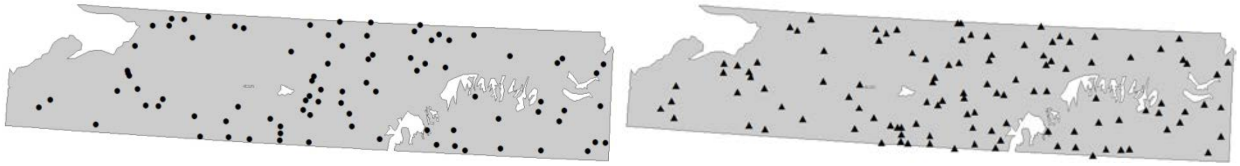

Figure 83. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the OGLLP in 2016.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 105 active OGLLP wells (27 in Cimarron County, 60 in Texas County, and 18 in Beaver County). Of the historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5-6 were selected from each county to generate spatially representative composite average water level hydrographs with the fewest number of data gaps (Figure 84).

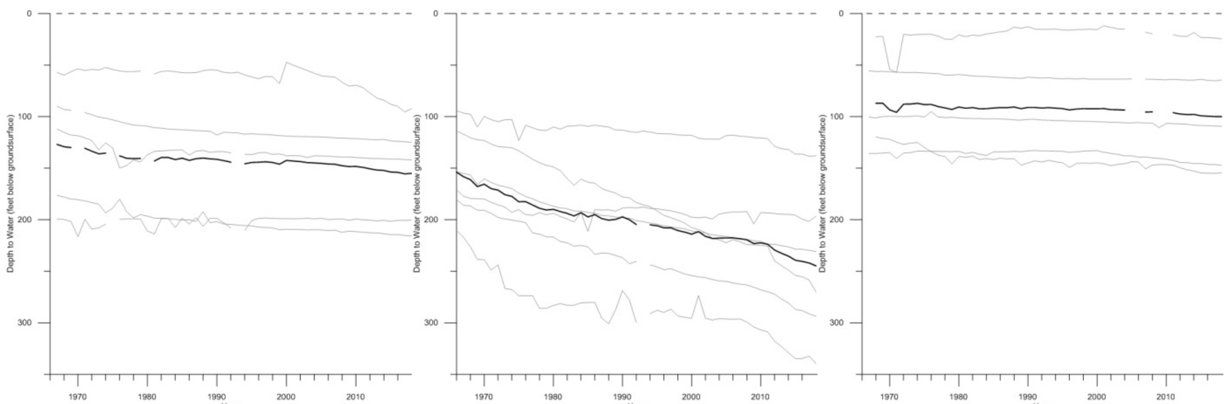

Figure 84. From left to right, composite average water levels (bold lines) and individual well water levels in the OGLLP for Cimarron (N=5, 1967-2018), Texas (N=6, 1966-2018), and Beaver (N=5, 1968-2018) Counties.

A baseline groundwater level network comprising 117 wells was implemented in July-October 2016. Many wells measured in this aquifer, including a few in Beaver County, have a period of record that spans over 40 years (Figure 85). The baseline network incorporated 66 wells from the historical network to maintain long-term periods of record. Measurements of depth to water made during baseline water quality sampling in 2016 ranged from 6.2-355.35 feet with an average 176.98 ft across the OGLLP, with county averages shown in Table 5; the total depth of wells used in the network ranged from 60-696 feet. A trend network composed of 145 wells was also initiated (39 in Cimarron, 68 in Texas, and 38 in Beaver Counties) to be measured annually, with 30 of these wells measured seasonally.

Table 5. Average depth to water (by county) for baseline water quantity sampling of the OGLLP.

County	n	Depth to Water (ft)
Beaver	38	124.53
Cimarron	22	205.54
Texas	57	200.92

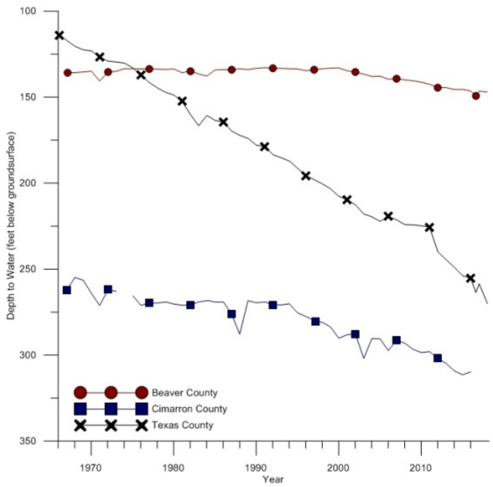

Figure 85. Groundwater level hydrographs for three of the longest OGLLP records, one in each county (1966-2018).

2018 water levels in the OGLLP averaged 187.46 ft, with a median value of 193.39 ft (N=142). Of the 145 wells in the OGLLP network, 140 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in OGLLP wells over the last year by an average 0.83 ft in Cimarron County (N=37), decreasing by an average 0.46 ft in Texas County (N=65), and decreasing by an average 0.18 ft in Beaver County (N=38, 2017-2018). Average water levels across the aquifer have decreased by 5.17 ft in Cimarron County (N=24), by 8.09 ft in Texas County (N=54), and by 2.15 ft in Beaver County (N=19) during the last 5 years (2013-2018). The OGLLP has three GMAP recorders, one each in Beaver, Texas, and Cimarron counties, installed in January 2014.

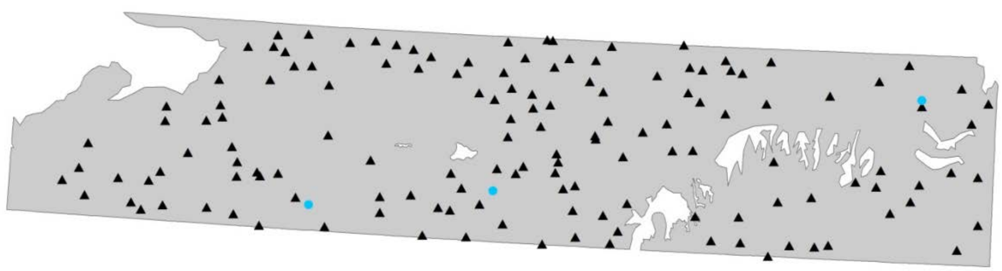

Figure 86. Location of continuous water level recorders (blue circles) against the entire OGLLP water level network.

Red River Alluvial & Terrace Aquifer

The Red River originates in the Texas Panhandle, and enters Oklahoma through southern Harmon County to form the state boundary between Texas and Oklahoma. It flows in a general easterly direction, encountering Lake Texoma and exiting the state in southern McCurtain County. The Red River has 517 river miles in Oklahoma, draining 22,841 mi^2 (Figure 87).

The Red River Alluvial and Terrace Aquifer, hereafter shortened to RED, is an unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, and clay. Alluvial and terrace deposits of the RED may average 30 to 70 feet thick. Primarily Permian formations underlie and adjoin the deposits from Harmon to western Love County, and Cretaceous formations underlie and adjoin the deposits from Love to McCurtain County. Aerially, deposits may occur on the Oklahoma side of the river for a distance of up to 16 miles but typically are less than 15 miles beyond the river banks.

Figure 87. Location and extent of the RED.

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 36 wells to assess the baseline water quality of the aquifer and concurrently measured 38 wells to assess the baseline water level (Figure 88). Overall, this aquifer contains water of fair to good quality. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the RED can also be found in Appendix R of this report.

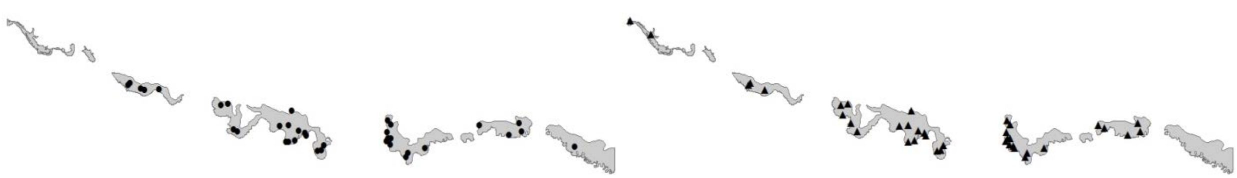

Figure 88. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the RED in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were only being measured in 4 active RED wells clustered in the South Central Climate Division. Small sample size and lack of spatial representation make existing historical measurements insufficient to characterize water level conditions throughout the extent of the aquifer. Therefore, no attempt was made to present data on this aquifer in this format. The individual hydrograph shown in Figure 89 represents a single entry point into the aquifer with the longest period of record.

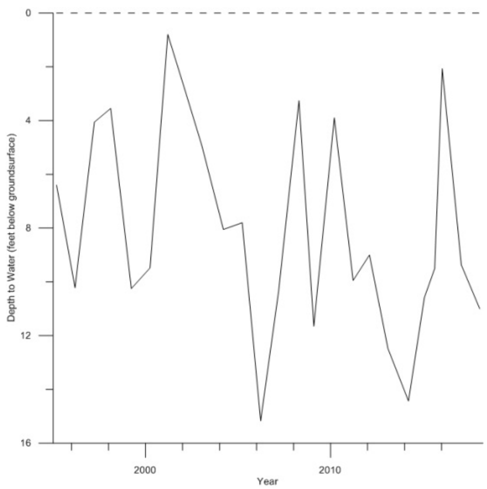

Figure 89. Groundwater level hydrograph for one of the longest current RED records, Bryan County (South Central climate division; 1995-2018).

A baseline groundwater level network comprising 38 wells was implemented in August 2015. A trend network currently composed of 29 wells was also initiated to be measured annually, with 10 of these wells measured seasonally.

Fluctuating groundwater levels in alluvial and terrace aquifers generally reflect variation in year to year climate and use, so measurements have historically been made in the winter when the effects of groundwater withdrawals and evapotranspiration are less significant. 2018 water levels in the RED averaged 26.91 ft, with a median value of 25.94 ft (N=28). Of the 29 wells in the RED network, 28 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in RED wells over the last year by an average 0.33 ft in the Southwest Climate Division (N=5), decreasing by an average 1.58 feet in the South Central Climate Division (N=18), and increasing by an average 0.09 ft in the Southeast Climate Division (N=5, 2017-2018).

Roubidoux Aquifer

Oklahoma's Roubidoux (RBDX) aquifer is part of the Ozark Plateaus regional aquifer system that underlies portions of SW Missouri, SE Kansas, NW Arkansas and NE Oklahoma. The RBDX underlies all of Ottawa, Delaware, Adair and Cherokee counties and parts of Craig, Mayes and Sequoyah counties. The aquifer is confined in Oklahoma and is composed of limestone, dolostone, sandstone and shale units. The RBDX typically ranges from 850-1000 feet in thickness but is much thinner in localities where Pre-Cambrian rocks are at or near the surface. Locally, in Cherokee County, the aquifer is present at the surface. The upper most subsurface boundary of the aquifer is defined by the base of the Devonian Chattanooga Shale. Overlying the Chattanooga are the Mississippian "Boone" formation and younger Pennsylvanian formations in west-central and northwestern areas of the aquifer. The principal water bearing units of the RBDX are the Roubidoux and Gasconade formations of Ordovician age. The Roubidoux formation is a loosely to firmly cemented sandstone and dolostone. The Gasconade Dolomite is a dolostone with a definitive basal permeable sandstone member called the Gunter. The top of the Roubidoux formation typically occurs at depths ranging from 750-1000 feet below land surface. Overlying the Gasconade and Roubidoux formations within the RBDX aquifer are the Jefferson City and Cotter Dolomite formations that yield small to moderate quantities of water. The contact of the Cotter Dolomite with the Chattanooga Shale represents the top of the RBDX aquifer.

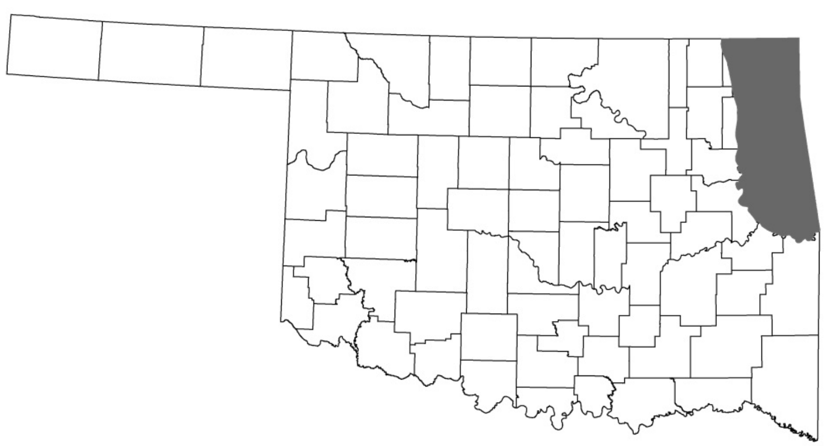

Figure 90. Location and extent of RBDX.

The aquifer is encompassed by the state's Grand and Lower Arkansas Planning Regions. This aquifer begins in Oklahoma's Northeast Climate Division with averages of 60.78°F and 42.67 inches of precipitation annually. It continues south into the East Central Climate Division, which averages 60.79°F and 46.14 inches of precipitation annually. Subsurface groundwater flow in the RBDX is generally described as W-SW with ground water discharge occurring within the Neosho River Valley drainage basin. Locally in Ottawa County, recharge to the RBDX likely occurs from the overlying Boone. Elsewhere, the recharge source(s) to the aquifer are not well understood. The estimated recharge rate is 2.5 inches per year.

The Oklahoma portion of the RBDX has an estimated aerial extent of 11,655 km^2 and stores 43 million acre-feet of water. Well yields range from 100-1,000 gallons per minute and hydraulic conductivity values range from around to 0.4-1.5 feet per day.

Groundwater in this aquifer supplies water primarily for public supply. The OWRB has on file over 1,600 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of May 2018, 319 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 54,163 acre-feet of water per year. Due to regional well drilling practices and similarity to overlying geology, it is difficult to differentiate RBDX wells from wells with mixed lithology without individual analysis of permits. Therefore, for the purposes of this report, these permit numbers represent combined permits for both the Boone and Roubidoux aquifers. The maximum withdrawal rate from the aquifer has been temporarily set to 2.0 acre-feet per acre per year, subject to change by the OWRB. The RBDX is designated by the OWRB as having a low vulnerability level to contamination from the land surface.

Data Collection Results

In 2017, the Groundwater Monitoring and Assessment Program sampled 17 wells to assess the baseline water quality of the aquifer and concurrently measured 9 wells to assess the baseline water level (Figure 35).

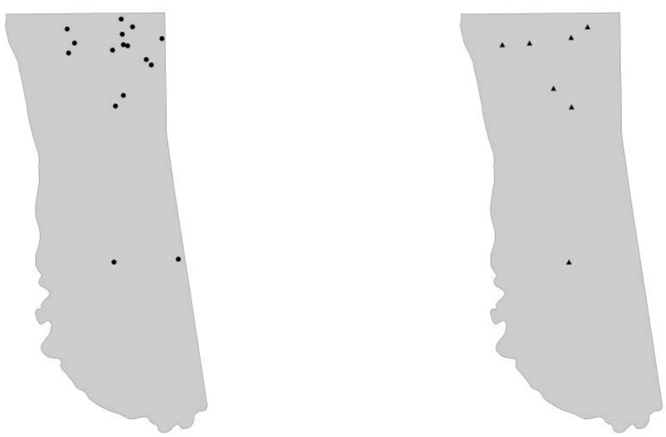

Figure 91. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the RBDX in 2017.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content was mostly low. Groundwater in the aquifer was hard with low alkalinity, averaging 159 mg/L and 157 mg/L, respectively. Mean total dissolved solids (TDS) were moderately low at 474 mg/L, ranging from 136-1281 mg/L with a median concentration of 330 mg/L. Average specific conductance and pH were 874 µS/cm and 7.72, respectively. There are no primary water quality concerns in the aquifer, however there were slightly elevated levels of fluoride and potassium. A 1994 study by the USGS showed higher mineralization and levels of sodium and chloride in the western part of the Roubidoux, which was also reflected in GMAP data.

The piper plot shows a variety of water types in the RBDX, with sodium-chloride/bicarbonate (29%) and calcium/magnesium-bicarbonate (24%) being the most prevalent. The range of other water types had cations dominated by mixed calcium/magnesium/sodium, mixed calcium/magnesium, mixed calcium/sodium, calcium, or sodium; anions were dominated by either bicarbonate, mixed chloride/bicarbonate, chloride, mixed bicarbonate/sulfate, or mixed chloride/bicarbonate/sulfate anions (Figure 92). The spatial distributions of water type and TDS are shown in Figure 93.

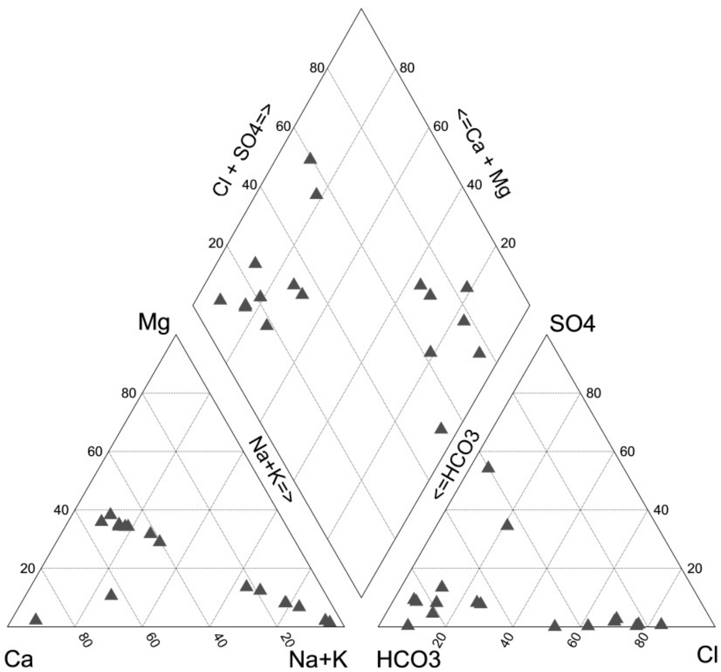

Figure 92. Piper plot diagram of constituents of the RBDX.

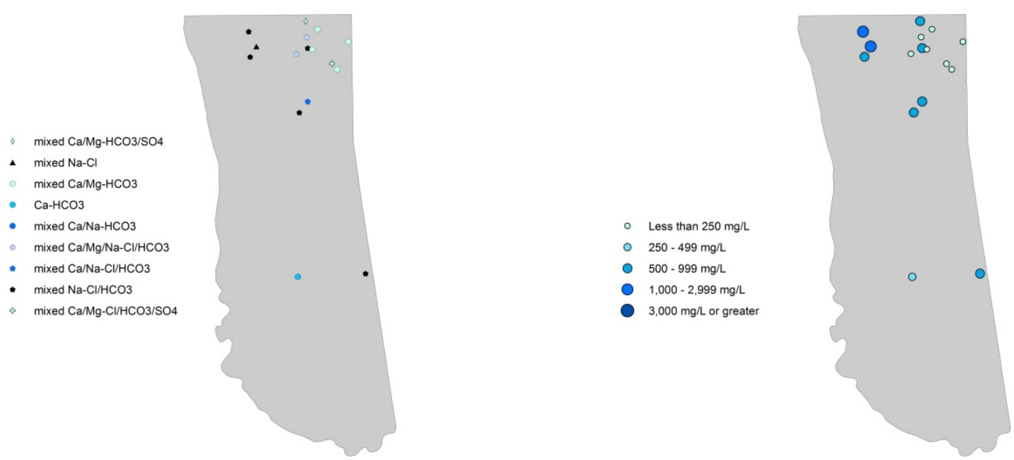

Figure 93. Water type (left) and TDS concentrations (right) in the RBDX.

Calcium, chloride, magnesium, silica, and sulfate were found at low levels in the aquifer. Bromide was rarely detected but was at low concentrations when present. Sodium was detected at moderately low concentrations, and fluoride and potassium were present at moderate levels.

Nutrients in the aquifer reflect ammonia-N being detected at low levels; nitrogen and phosphorous were rarely detected but at low and moderate levels when present, respectively.

The RBDX had mostly low levels of metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, mercury, silver, thallium, and uranium. Arsenic, barium, boron, iron, manganese, molybdenum, selenium, and vanadium were present at low concentrations, and chromium was detected at moderately low levels. Copper, hexavalent chromium, nickel, and zinc were rarely detected but were low when present. Lead was also rarely detected, but was moderately low when present. Combined radium 226/228 was present at high levels.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The RBDX had some constituents exceed these thresholds. Table 6 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the RBDX water quality, see Appendix S.

Table 6. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the BOON.

Parameter	>MCL	>SMCL	>Health Advisory
pH	--	1	--
TDS	--	8	--
Radium (combined)	3 ± 1	--	--
Iron	--	1	--
Manganese	--	1	0

Intermediate BOON/RBDX Wells

Although deep wells exist throughout the areal extent of the RBDX, finding wells to characterize the aquifer was a challenge. Sampling protocol for GMAP dictates that at least 75% of the screened interval of the well must be in the study aquifer. Open well hole construction is common throughout northeast Oklahoma, so the majority of wells drilled to appropriate depth were unable to be used to characterize the RBDX because they were "screened" (i.e., open hole) through newer geologic units such as the Boone Formation or the Chattanooga Shale as well as into the RBDX, or because lithology or screened interval could not be confirmed. Characterization of the RBDX was not possible due to small sample number and limited spatial distribution of the sites. As a consequence, a subset of mixed lithology wells screened through both the BOON and the RBDX were sampled in order to potentially provide a more complete picture. The 9 intermediate wells sampled exhibited characteristics of both BOON and RBDX (Figure 94. Piper plot diagram of constituents of intermediate BOON/RBDX wells, compared with BOON and RBDX wells.Figure 94).

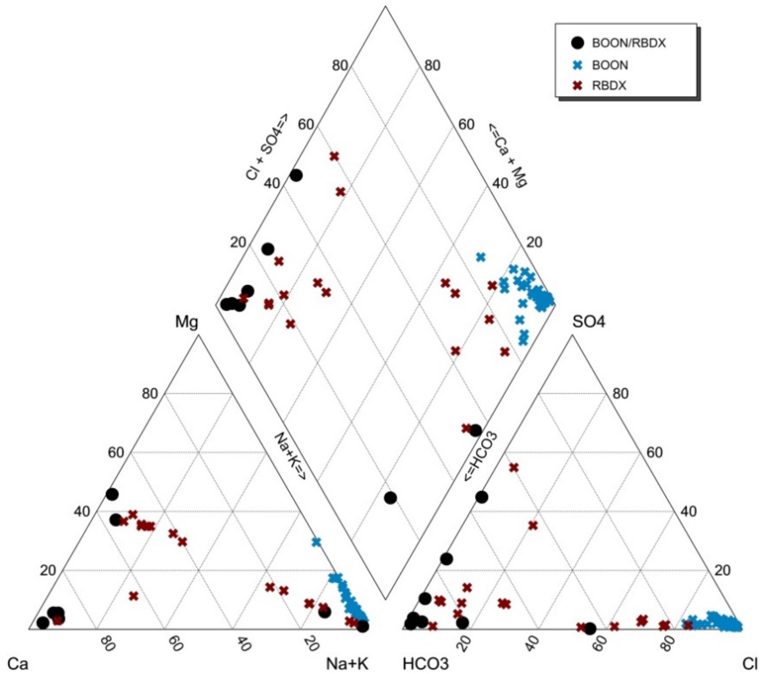

Figure 94. Piper plot diagram of constituents of intermediate BOON/RBDX wells, compared with BOON and RBDX wells.

Total dissolved solids (TDS) ranged from 134-951 mg/L, specific conductance ranged from 255-1,720 µS/cm, and pH ranged from 6.75-9.21. The most common water type was calcium-bicarbonate (33%). Other calcium-magnesium water types made up 33% of samples, and sodium water types accounted for 22%. One MCL exceedance was reported for fluoride, and SMCL exceedances were reported for chloride, fluoride, iron, manganese, pH, and TDS

Groundwater Level Measurements

A baseline groundwater level network is projected for implementation in 2017. No sites from the historical groundwater level network are located in this aquifer. Therefore, there are no wells with groundwater level measurements in the RBDX and all additions will be new to the program.

A baseline groundwater level network for the RBDX was comprised of 9 wells and implemented in September-November 2017. Measurements of depth to groundwater made during baseline water quality sampling ranged from 128-393 feet below ground surface with a mean of 240 ft over the entire aquifer; average was 233.08 ft in the Northeast (n=8), and an additional well in the East Central Climate Division measured 299.00 ft to water. The total depth of wells used in the network ranged from 600-1,526 feet and averaged 1,137 ft. Seven (7) wells have been incorporated into a trend network measured annually, with 5 of these measured seasonally.

The RBDX has 3 GMAP recorders in Craig (1) and Ottawa (2) counties, installed during August, June, and July (respectively) of 2017 (Figure 43).

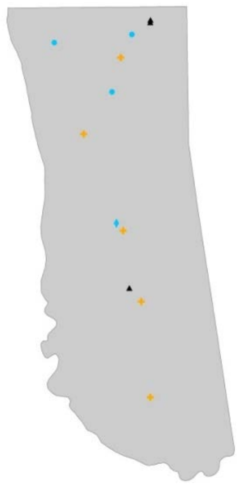

Figure 95. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring of the RBDX (blue circles) and one mixed BOON/RBDX well (blue diamond) and for a separate USGS hydrologic study (orange crosses) against the entire RBDX water level network.

Rush Springs Aquifer

The Rush Springs Aquifer, hereafter shortened to RSPG, located in west-central Oklahoma, underlies portions of Woodward, Dewey, Custer, Blaine, Washita, Caddo, and Grady counties (Figure 96). The aquifer unit includes the Rush Springs Sandstone and the underlying Marlow Formation. The Cloud Chief Formation overlies the aquifer in the west. The Permian-aged Rush Springs Sandstone is composed primarily of red to orange, fine grained silica sands (quartz and feldspar) loosely cemented with calcite and iron oxide. Locally, minor to moderate amounts of gypsum and dolomite occur within the formation. The maximum thickness of the Rush Springs Sandstone is 330 feet. The underlying Marlow Formation is described as an interbedded sandstone, siltstone, and mudstone with gypsum and dolomite that limits flow into or out of the RSPG. The Marlow yields only small amounts of water of fair to poor quality in most areas. The Cloud Chief Formation is composed of shale and interbedded siltstone with dolomite and much gypsum in the lower part. It yields small amounts of water that are highly mineralized. Water in the RSPG is considered unconfined in the majority of the aquifer, except in deeper portions and where overlain by the Cloud Chief Formation where it is confined or partly confined. Regionally, groundwater movement is south-southeast toward the Washita River.

Figure 96. Location and extent of the RSPG.

Data Collection Results- Group A

In 2013, the Groundwater Monitoring and Assessment Program sampled 64 wells to assess the baseline water quality of the aquifer and concurrently measured 107 wells to assess the baseline water level (Figure 97). Overall, this aquifer contains water that ranges from fair to good quality. More detailed information and figures can be found on the OWRB's website in the 2013 BUMP Report; the statistics for the RSPG can also be found in Appendix T of this report.

Figure 97. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the RSPG in 2013.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in at least 60 active RSPG wells. Of the 16 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 6 were selected to generate a spatially representative composite average water level hydrograph with the fewest number of data gaps (Figure 98).

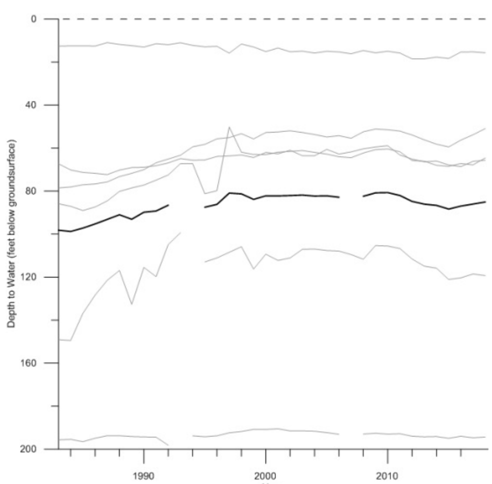

Figure 98. Composite average water level (bold line, N=6) and individual well water levels in the RSPG over period of record (1983-2018).

A baseline groundwater level network comprising 104 wells was measured during September-October 2013. Eighty-three (83) wells are currently in the water level network measured annually, with 31 of these sites measured seasonally (Figure 99).

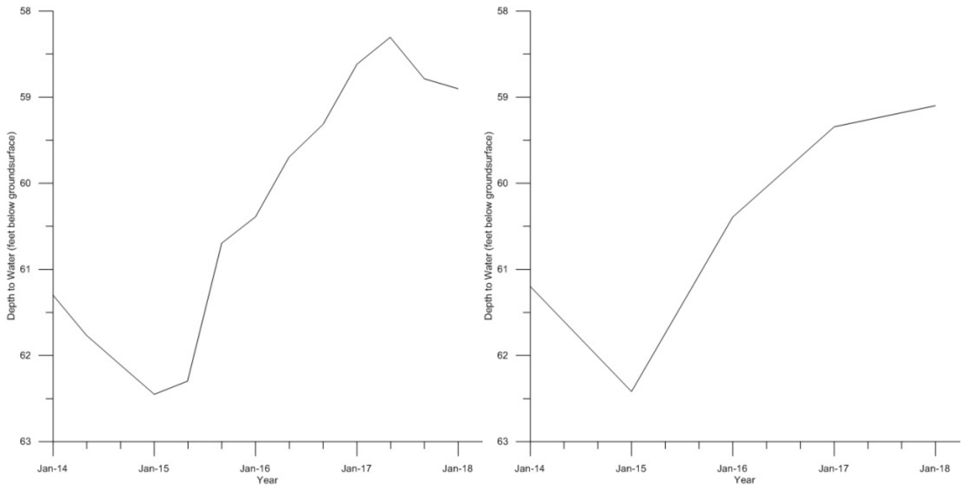

Figure 99. Average water level in the GMAP trend water level network on a seasonal (left, N=21) and annual (right, N=75) basis for RSPG (2014-2018).

Some wells have intermittent records spanning 50 years, so 69 historical wells were intentionally incorporated in the RSPG's water level network to continue long-term measurement records (Figure 100).

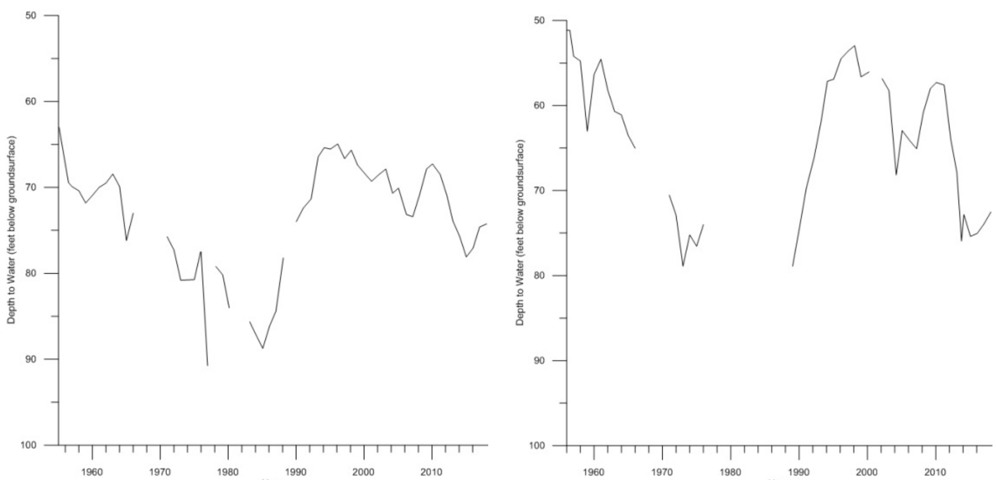

Figure 100. Groundwater level hydrographs for two of the longest RSPG records, Caddo County (1955-2018; left) and Caddo County (1956-2018; right).

Average water levels across the aquifer have increased by 1.88 ft over this period (N=81, 2014-2018). 2018 water levels in the RSPG averaged 59.86 ft, with a median value of 56.32 ft (N=82). Of the 83 wells in the RSPG network, 79 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in RSPG wells over the last year by an average 1.38 ft in the Central Climate Division (N=5), decreasing by an average 1.32 ft in the North Central and West Central Climate Divisions (N=48), and increasing by an average 0.83 ft in the Southwest Climate Division (N=26, 2017-2018). Hourly measurements of depth to water in the RSPG are being collected from two continuous water level recorders installed in Dewey and Washita Counties, along with three others deployed by the OWRB at the Oklahoma Mesonet stations in Caddo, Custer, and Grady Counties (Figure 101).

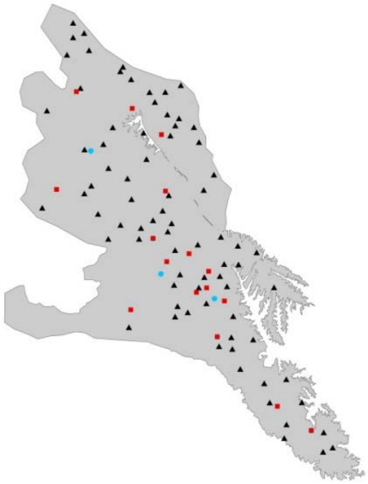

Figure 101. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire RSPG water level network.

Salt Fork of the Arkansas River Alluvial & Terrace Aquifer

The Salt Fork of the Arkansas River originates in Kansas and enters Oklahoma in eastern Woods County. It runs east through northern Oklahoma, encountering Great Salt Plains Lake, and terminates at its confluence with the Arkansas River near the intersection of Kay, Noble, and Osage Counties. The Salt Fork of the Arkansas has about 172 river miles in Oklahoma, draining 2,850 mi^2 (Figure 102).

The Salt Fork of the Arkansas River Alluvial and Terrace Aquifer, hereafter abbreviated to SFAR, is an unconfined aquifer composed of unconsolidated deposits of clay and silt with fine to coarse sand and local lenses of fine gravel. Dune sands are present along parts of the aquifer, mainly following the river in narrow bands but with heavy deposits blanketing a large portion of Alfalfa County. It is underlain by Permian-age siltstone and shale and by the Oscar Group in the eastern-most portion. Alluvial deposits are up to 60 feet thick, while terrace deposits can be up to 150 feet thick. Aerially, deposits may occur on either side of the river for a distance of up to 10 miles beyond the river banks.

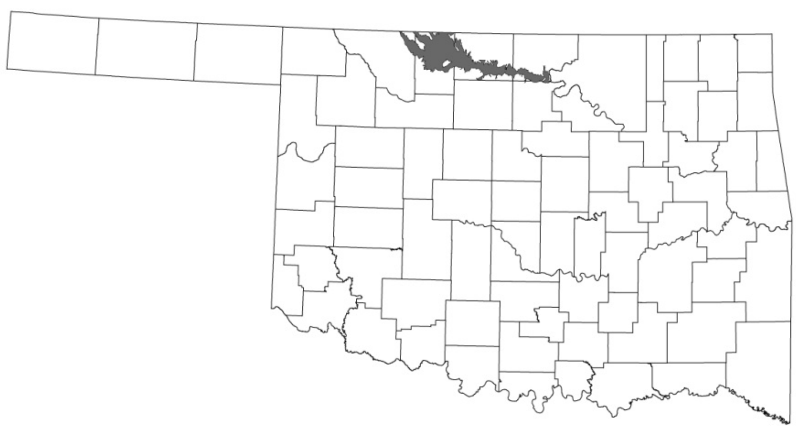

Figure 102. Location and extent of the SFAR.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 30 wells to assess the baseline water quality of the aquifer and concurrently measured 46 wells to assess the baseline water level (Figure 103). Overall, this aquifer contains water of fair quality. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the SFAR can also be found in Appendix U of this report.

Figure 103. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFAR in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in about 20 active SFAR wells. Fourteen (14) of those historical wells had contemporaneous water level measurements and no data gaps for the period of record, allowing for an uninterrupted composite average water level over a 9-year period (Figure 104).

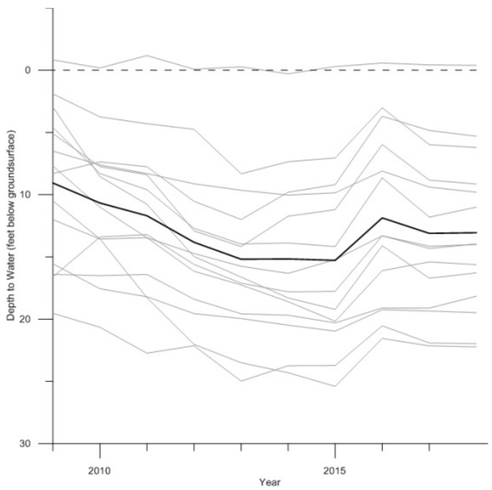

Figure 104. Composite average water level (bold line, N=14) and individual well water levels in the SFAR over period of record (2009-2018).

A baseline groundwater level network comprising 46 wells was measured in July 2014. Thirty-three (33) wells are currently in the water level network measured annually, with 13 of these sites measured seasonally. Some historical wells were included in the new network to maintain long-term records (Figure 105).

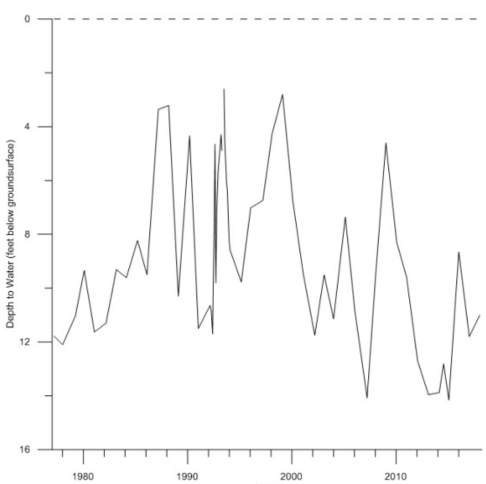

Figure 105. Groundwater level hydrographs for a SFAR record, Grant County (1977-2018).

2018 water levels in the SFAR averaged 13.72 ft, with a median value of 14.00 ft (N=33). Of the 33 wells in the SFAR network, all 33 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in SFAR wells over the last year by an average 0.03 ft (N=33, 2017-2018). Average water levels across the aquifer have increased by 2.16 ft during the last 5 years (N=16, 2013-2018). A continuous water level recorder was installed in Grant County (Figure 106) in December 2014 where depth to water in feet below land surface is being recorded in hourly increments.

Figure 106. Location of continuous water level recorder (blue circle) against the entire SFAR water level network.

Salt Fork of the Red River Alluvial & Terrace Aquifer

The Salt Fork of the Red River originates in the Texas Panhandle and enters Oklahoma in Harmon County. It flows east into Greer County before turning south and eventually terminating at its confluence with the Red River in Jackson County. The Salt Fork of the Red has about 73 river miles in Oklahoma, draining 708 mi^2 (Figure 107).

The Salt Fork of the Red River Alluvial and Terrace Aquifer, hereafter referred to as SFRR, is considered a minor unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, and clay. Absent previous hydrologic investigations of this aquifer, the areal and vertical extent and hydrology are poorly defined. For alluvial and terrace aquifers in central and western Oklahoma, subsurface boundaries are defined by the depth below land surface that Permian bedrock ("red beds") occurs.

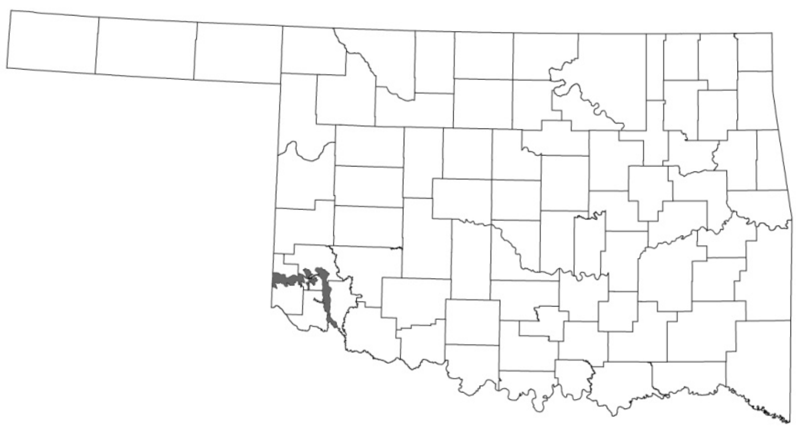

Figure 107. Location and extent of the SFRR.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 6 wells to assess the baseline water quality of the aquifer and concurrently measured 7 wells to assess the baseline water level (Figure 108). The SFRR is a minor aquifer, and the sample size for the water quality network was small with uneven spatial distribution. With this caveat, this aquifer contains water of fair but variable quality. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the SFRR can also be found in Appendix V of this report.

Figure 108. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFRR in 2014.

Groundwater Level Measurements

There are no wells with historical groundwater level measurements prior to the implementation of GMAP in the SFRR, therefore all wells are new to this program.

A baseline groundwater level network comprising 6 wells was measured in August 2014 for the SFRR. Six (6) wells are currently in the water level network measured annually, with one of those sites measured seasonally. 2018 water levels in the SFRR averaged 22.09 ft, with a median value of 10.91 ft (N=5). Of the 6 wells in the SFRR network, only 4 had measurements for both 2017 and 2018. Because of small sample size, average one-year change in water level is not calculated for the SFRR.

Tillman Terrace Aquifer

The Tillman Terrace aquifer, underlying part of Tillman County in southwestern Oklahoma, is an alluvial & terrace aquifer (Figure 109). This aquifer is bounded on the northern side by Kiowa County and the North Fork of the Red River, on the west by the North Fork of the Red River, on the southern side by the Red River, and on the east by an outcrop of Permian red bed. The deposits are of Quaternary Age, and are composed of unconsolidated dark grey to red-brown sands, silt, clay, and quartzite gravel with some shale. Caliche may be encountered throughout the terrace deposits. Dune sands overlie parts of the aquifer but are not a source of groundwater. The aquifer's water table surface is unconfined, and mean aquifer thickness is 70 feet. Lower permeability Permian units (Garber Sandstone and Hennessey Groups) underlie the area, limiting flow through. Groundwater in the Tillman Terrace, hereafter shortened to TILL, flows north toward Otter Creek, south toward the Red River, and west toward the North Fork of the Red River.

Figure 109. Location and extent of the TILL.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 8 wells to assess the baseline water quality of the aquifer and concurrently measured 17 wells to assess the baseline water level (Figure 110). Overall, this aquifer contains water of fair-poor quality. More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the TILL can also be found in Appendix W of this report.

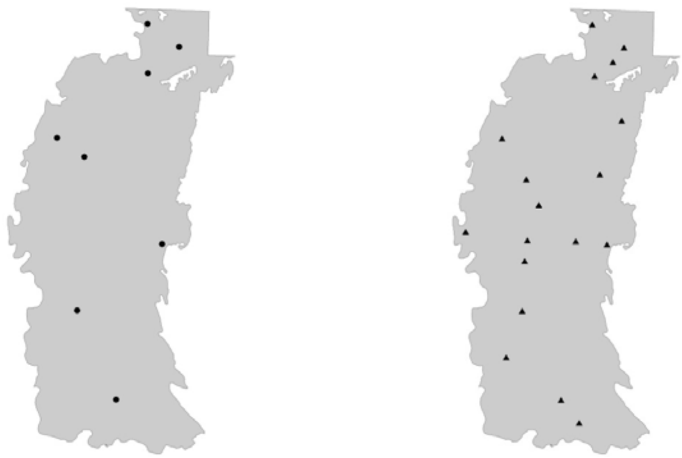

Figure 110. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the TILL in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 12-15 active TILL wells. Of the 6 historical wells that spanned the entire period of record and had contemporaneous water level measurements, 5 were selected to generate a composite average water level hydrograph with the fewest number of data gaps (Figure 111).

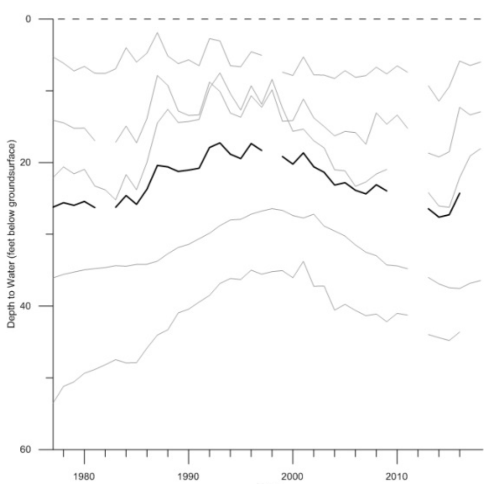

Figure 111. Composite average water level (bold line, N=5) and individual well water levels in the TILL over period of record (1977-2018).

A baseline groundwater level network of 17 wells was measured during August 2014. Several wells in the TILL have a measurement record of more than 50 years, so the baseline network incorporated 10 wells from the aquifer's historical groundwater level network to continue these long-term records. Nineteen (19) wells are currently in the network measured annually, with 9 of these sites measured seasonally.

2018 water levels in the TILL averaged 21.14 ft, with a median value of 23.23 ft (N=19). Of the 19 wells in the TILL network, 18 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level increasing in TILL wells over the last year by an average 0.40 ft (N=18, 2017-2018). Average water levels across the aquifer have increased by 3.41 ft (N=10, 2013-2018).

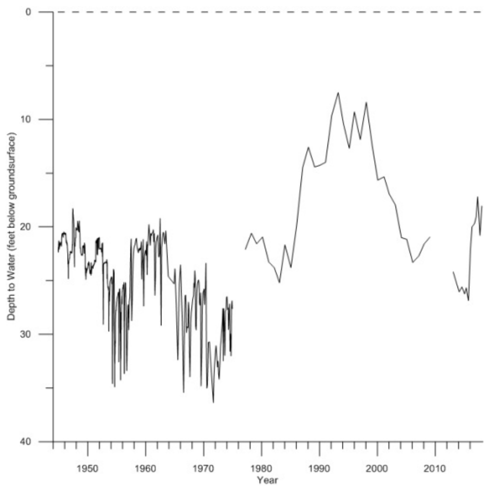

Figure 112. Groundwater level hydrograph for the longest TILL record, Tillman County (1944-2018).

A groundwater observation well was drilled during Fall 2014 near the Town of Tipton, and a continuous water level recorder was installed in January 2015 where depth to water in feet below land surface is being recorded in hourly increments to complement the real-time climate data collected by the Oklahoma Climate Survey's Mesonet Weather Station nearby (Figure 113). The well drilling was made possible by a sub-award grant the OWRB received as a result of funding through a National Science Foundation grant to Oklahoma's Experimental Program to Stimulate Competitive Research (EPSCOR).

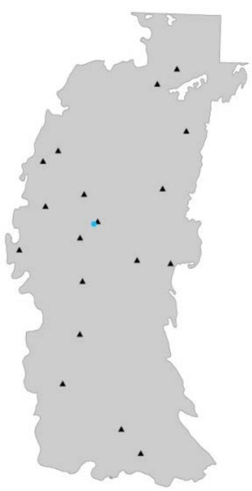

Figure 113. Location of continuous water level recorder (blue circle) at an Oklahoma Mesonet station against the entire TILL water level network.

Washita River Alluvial & Terrace Aquifer

The Washita River originates in the Texas Panhandle, enters Oklahoma through central Roger Mills County, and runs southeast through Oklahoma before discharging into Lake Texoma at the Red River. The Washita has about 547 river miles in Oklahoma, draining 7,909 mi^2 (Figure 114).

The Washita River Alluvial and Terrace Aquifer, hereafter shortened to WASH, is an unconfined aquifer composed of unconsolidated deposits of silts and clays with fine to coarse sands. Older terraces are generally not continuous with younger terraces and alluvium. Various Permian-age bedrock formations underlie the majority of the aquifer, except in the southern-most portion where bedrock age ranges from Precambrian to Cretaceous. Deposits have an average thickness of 70 feet. Aerially, deposits may occur on either side of the river for a distance of up to 15 miles but typically are less than 5 miles beyond the river banks.

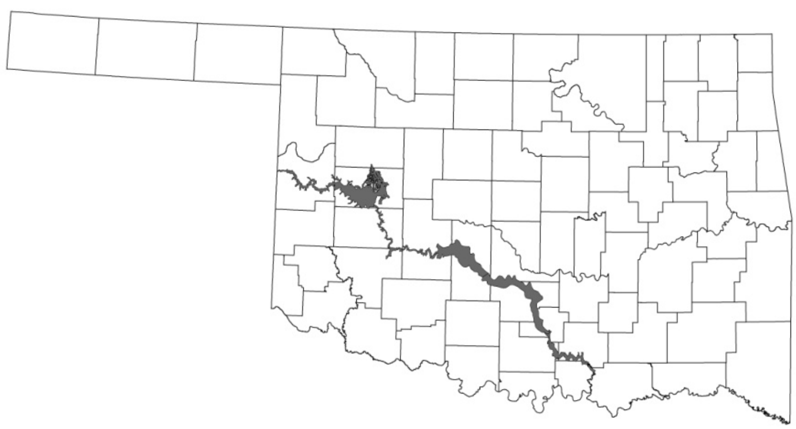

Figure 114. Location and extent of the WASH.

Data Collection Results- Group B

In 2014, the Groundwater Monitoring and Assessment Program sampled 31 wells to assess the baseline water quality of the aquifer and concurrently measured 30 wells to assess the baseline water level (Figure 115). Overall, this aquifer contains water of fair quality with moderately high mineral content. There is a clear water quality delineation between sites in Reach 1 (most western; overlying Roger Mills and Custer county) and those in the rest of the aquifer (Caddo county down through Johnston). More detailed information and figures can be found on the OWRB's website in the 2014 BUMP Report; the statistics for the WASH can also be found in Appendix X of this report.

Figure 115. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the WASH in 2014.

Groundwater Level Measurements

Prior to GMAP implementation, groundwater levels were being measured in 8 active WASH wells. The number and location of these sites in the WASH prevents creation of an aquifer-wide composite hydrograph. The individual hydrographs shown in Figure 116 represent single entry points into the aquifer with the longest periods of record. The baseline network incorporated 5 wells from the WASH's historical groundwater level network to continue these long-term monitoring records.

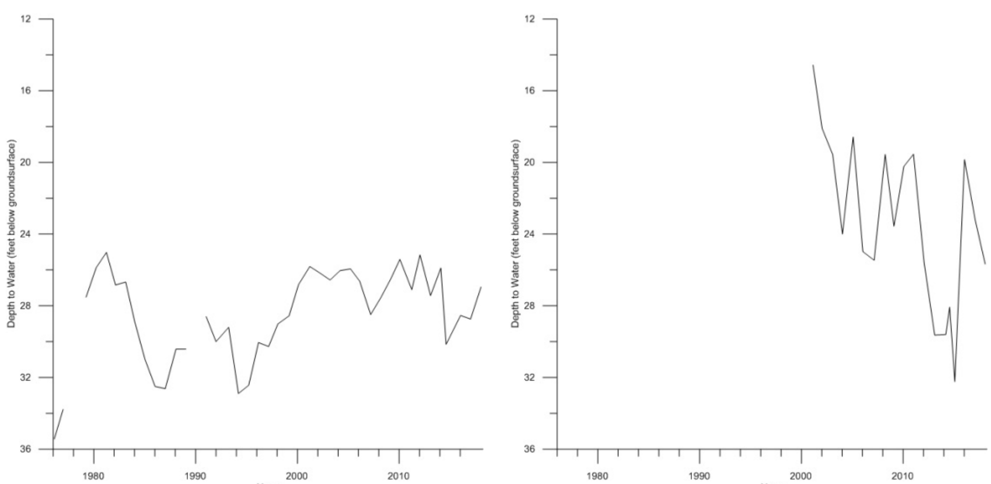

Figure 116. Groundwater level hydrographs for two of the longest WASH records, Roger Mills County (1976-2018; left) and Garvin County (2001-2018; right).

A baseline groundwater level network composed of 31 wells was measured during GMAP sampling in July-August 2014. Twenty-six (26) wells are currently in the network measured annually, with 11 of those sites measured seasonally.

Alluvial and terrace aquifers are sensitive to use and climate which can lead to large fluctuations in water levels. 2018 water levels in the WASH averaged 16.72 ft, with a median value of 14.85 ft (N=25). Of the 26 wells in the WASH network, 25 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing in WASH wells over the last year by an average 2.21 ft in the South Central Climate Division (N=8) and increasing by an average 0.09 ft in the West

Central Climate Division (N=13, 2017-2018). There are insufficient data points in the Central and Southwest Climate Divisions to characterize a change in water level in these reaches of the aquifer. Water level in the WASH is currently being monitored by a continuous water level recorder deployed by the OWRB at the Oklahoma Mesonet stations in Grady County (Figure 117).

Figure 117. Location of continuous water level recorder (red square) at an Oklahoma Mesonet station against the entire WASH GMAP water level network.

Wolf Creek Alluvial & Terrace Aquifer

The Wolf Creek originates in the Texas panhandle and enters northwestern Oklahoma in Ellis County. It flows east-northeast into Woodward County where it passes through the Fort supply Reservoir and terminates at its confluence with the North Canadian River. The Wolf Creek has about 35 river miles in Oklahoma (Figure 118).

The Wolf Creek Alluvial and Terrace Aquifer, hereafter referred to as WOLF, is considered a minor unconfined aquifer composed of unconsolidated deposits of gravel, sand, silt, and clay. Absent previous hydrologic investigations of this aquifer, the areal and vertical extent and hydrology are poorly defined. For alluvial and terrace aquifers in central and western Oklahoma, subsurface boundaries are defined by the depth below land surface that Permian bedrock ("red beds") occurs.

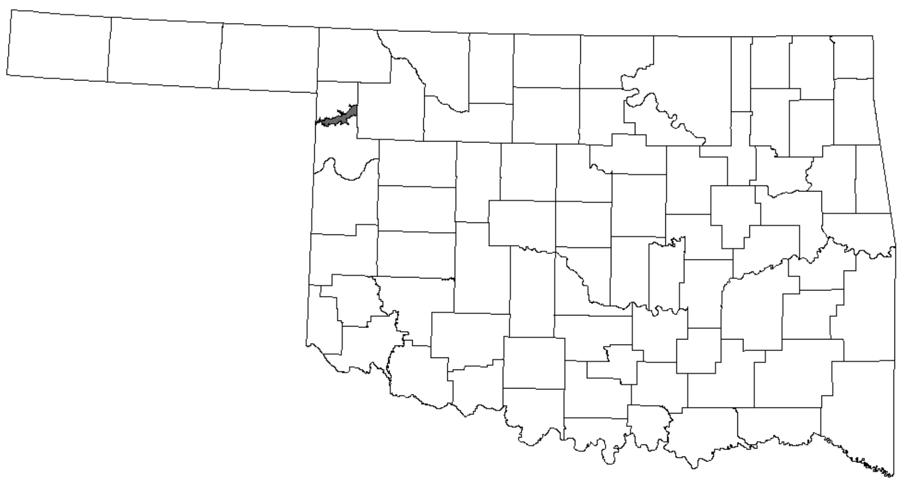

Figure 118. Location and extent of the WOLF.

Data Collection Results- Group C

In 2015, the Groundwater Monitoring and Assessment Program sampled 4 wells to assess the baseline water quality of the aquifer and concurrently measured 7 wells to assess the baseline water level (Figure 119). In spite of landowner cooperation and staff's best efforts, the sample size was small due to the size of this aquifer, the small number of wells completed within the aquifer, and sampling access issues. With this caveat, this aquifer contains water of good quality. More detailed information and figures can be found on the OWRB's website in the 2015 BUMP Report; the statistics for the WOLF can also be found in Appendix Y of this report.

Figure 119. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the WOLF in 2015.

Groundwater Level Measurements

Prior to GMAP implementation, no active WOLF wells were being measured. A composite hydrograph of 5 historical wells is presented below (Figure 120). None of these historical wells were incorporated into the WOLF baseline network, either due to lack of construction information or inability to locate and access.

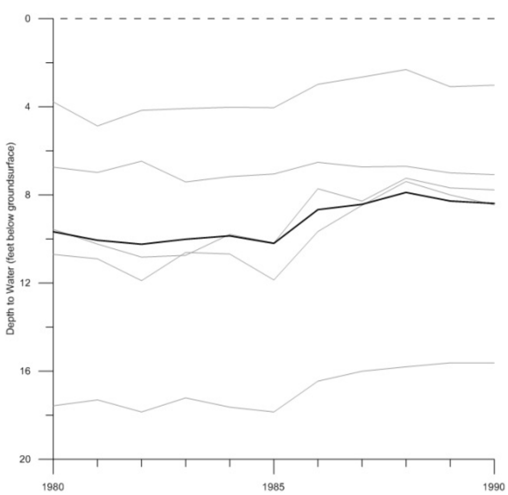

Figure 120. Composite average water level (bold line, N=5) and individual well water levels in the WOLF over period of record prior to GMAP implementation (1980-1990).

A baseline groundwater level network composed of 7 wells was measured during GMAP sampling in September 2015. Six (6) wells are currently in the trend water level network measured annually, with 2 of these measured seasonally. 2018 water levels in the WOLF averaged 28.83 ft, with a median value of 28.99 ft (N=5). Of the 6 wells in the WOLF network, 5 had measurements for both 2017 and 2018. The GMAP trend network recorded the average water level decreasing over the last year by an average 3.47 ft (N=5, 2017-2018).

Historical Water Level Measurements

An annual winter period (January-March) water level measurement program implemented and operated by the OWRB has been in place for approximately 40 years with a few sites having records that date to the 1940s. The water level network in the mid-late 1980s was composed of over 1,000 observation wells and all of the state's major aquifers (except the Arbuckle-Timbered Hills) had some representation of observation wells. Lack of dedicated funding and personnel for operation and maintenance of this network has led to the intentional decommissioning/abandonment of many existing observation well stations, and wells have been removed due to landowner requests or mechanical defects. Prior to the implementation of GMAP, this mass measurement network was composed of about 530 wells unevenly distributed throughout the major aquifers (Figure 121). These data were used to evaluate aquifer response to climatic conditions, land use, and water use; determine aquifer storage for allocation of water rights; conduct aquifer studies and model groundwater systems; and map areas of water level change in the High Plains aquifer.

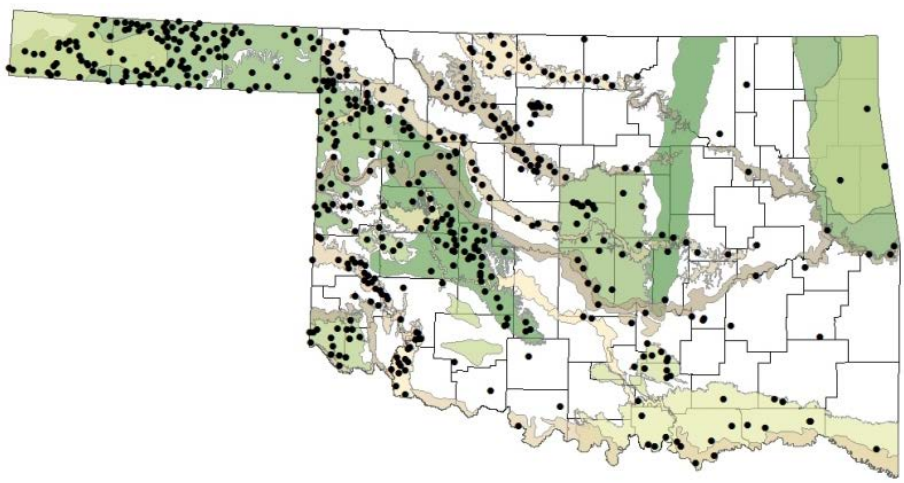

Figure 121. Historical groundwater level measurement sites in Oklahoma prior to the implementation of GMAP (2013).

The mass measurement well network was composed of private wells where landowner authorization had already been granted to access the property to measure the wells. While this network had some limitations, many of these sites have valuable long-term historical water level records documenting the steady decline in water levels in the Ogallala-Panhandle aquifer, response patterns to variable precipitation, and response to water use. Given the long term data available from some of the network wells along with pre-existing landowner relationships through the historical mass measurement program, some of these wells are included in the GMAP network.

Groundwater level measurements combined with land surface elevation (determined by GPS) and base of aquifer depths (determined through well log analysis) can be used for point determinations of aquifer subsurface water level elevation and saturated thickness. In combination with a spatially distributed network of wells, maps of aquifer saturated thickness, water table horizon, groundwater flow direction and hydraulic gradient can be generated. With an expanded, spatially distributed network of wells, assessments of aquifer-wide groundwater level changes are possible, in addition to how those changes over time are related to drought, seasonal variation and groundwater usage. GMAP's network design provides data that more comprehensively reflects the range of possible water level fluctuations in an aquifer through increased frequency of measurements and measurement periods that coincide with discharge (Spring-Summer) and recharge (Fall-Winter) intervals.

Incorporation of Major Aquifers into GMAP

As aquifers were phased into the GMAP program, existing mass measurement wells were included in the water level baseline network. These wells, along with additional water level sites, increased the number of wells and improved the distribution in each aquifer, allowing for more complete water level data across the state. During GMAP, 298 wells were measured for water level in the Group A aquifers, 224 wells were measured in the Group B aquifers, and 212 wells were measured in the Group C aquifers, 193 wells were measured in the Group D aquifers, and 51 wells were measured in the Group E Aquifers. Eight hundred eighty-three (883) wells in Group A, B, C, D & E aquifers have been incorporated into the annual water level monitoring network, 469 of which are new additions to these aquifers that provide significantly improved spatial representativeness (Figure 122). Two hundred ninety-nine (299) of the 883 wells have been placed into the seasonal trend network (measured tri-annually). An additional 21 wells were measured for water level across the state in minor aquifers that were not sampled for GMAP, measurements for which are summarized below.

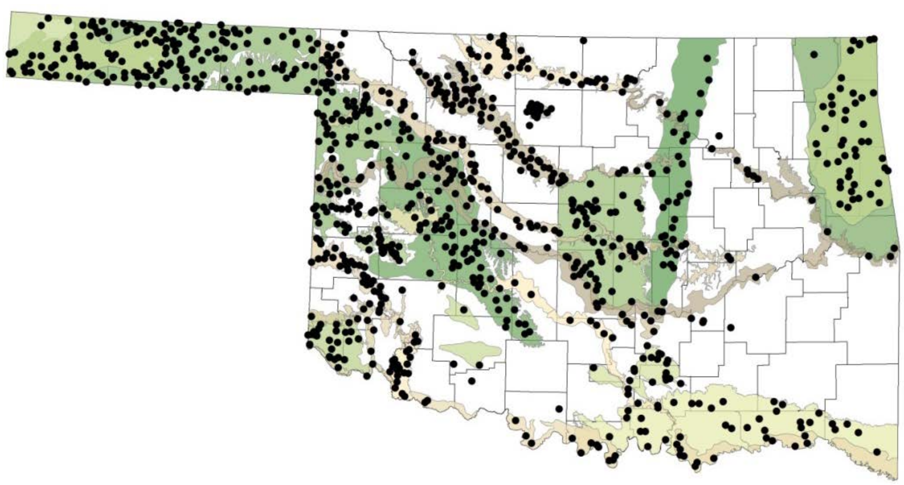

Figure 122. Groundwater level measurement sites after four years of GMAP implementation (2018).

Water Level Measurement in Other Minor Aquifers

There are a number of minor aquifers across the state that are not slated for a baseline groundwater level network due to low demand. Seventeen (17) wells have depth to water measurements in these aquifers for 2018. The inadequate number of sites for the size of any of these minor aquifers prevents the generation of aquifer-wide composite hydrographs for the period of record. Several wells in these aquifers have over 30 years of measurements, and the longest measurement recorded in any of these minor aquifers spans 42 consecutive years (Figure 123).

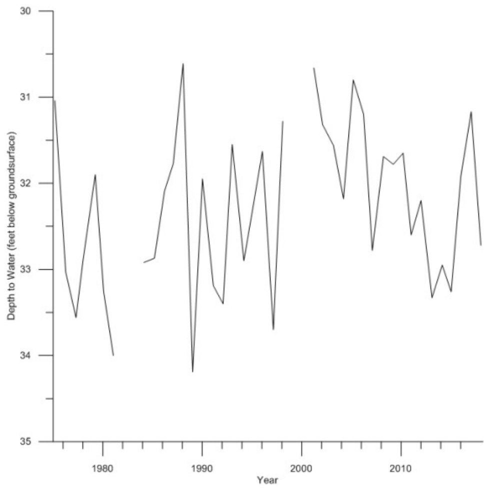

Figure 123. Groundwater level hydrograph of the longest Chickaskia Minor A&T record, Kay County (1975-2018).

Statewide Water Level Changes

The previous sections discuss water levels in the context of individual aquifers; however, it is also useful to compare them statewide. The maps that follow depict 1-, 5-, and 10-year changes to average water levels in each aquifer. Larger aquifers have been split into sections according to climate division to inform subtle differences between wells that fall into different areas. Statewide average precipitation was 6.03 inches above the 1981-2010 normal. Average precipitation across the climate divisions ranged from 5 percent below to 20 percent above normal, with 7 of 9 divisions recording above average precipitation. Aquifer response to these conditions varied but was generally modest, with small groundwater level increases tending to occur more in the western half of the state (though there were several exceptions to this trend) and the largest decreases occurring in the Southeast and South Central Climate Divisions between 2017 and 2018 (Figure 124).

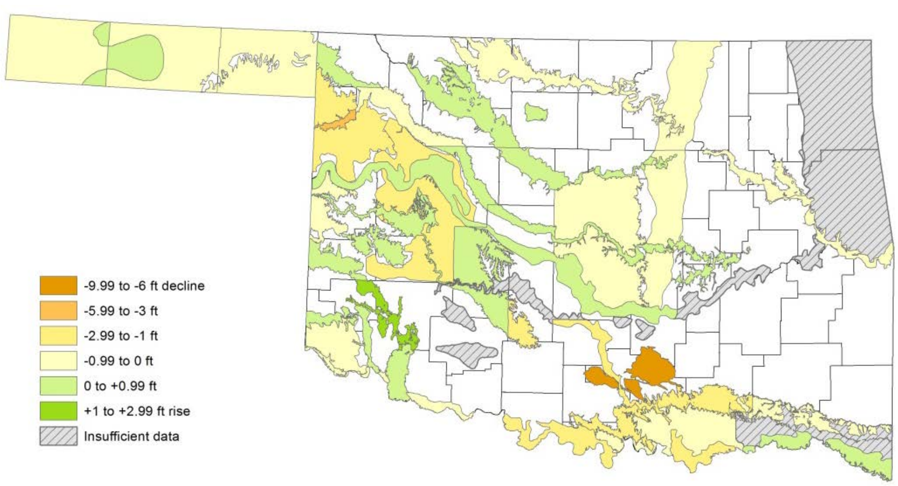

Figure 124. Average one-year water level change, by major aquifer and climate division (2017-2018).

Over the last five years, average water levels have exhibited a range of responses across the state (2013-2018; Figure 125). The largest groundwater increases were observed in the karst bedrock aquifers:

Arbuckle-Simpson and Blaine. The largest average declines were detected in the Ogallala-Panhandle in Texas and Cimarron Counties.

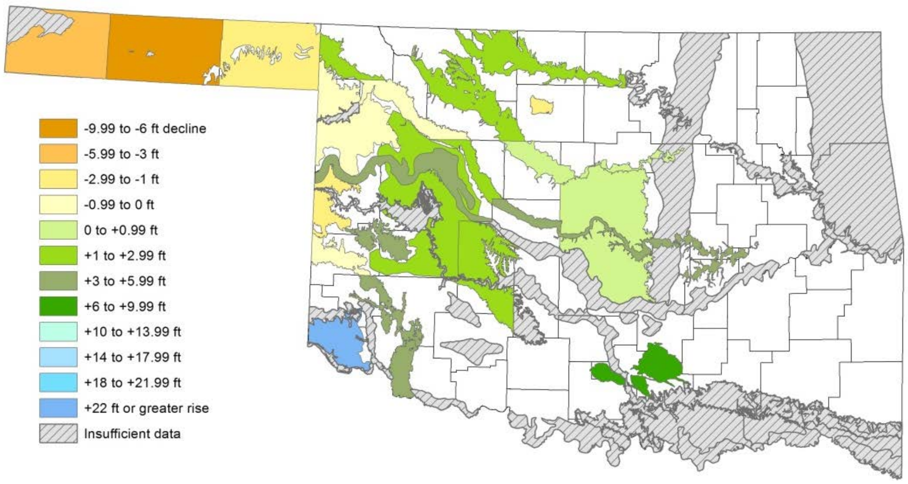

Figure 125. Average five-year water level change, by major aquifer and climate division (2013-2018).

Over the past ten years, average water levels in the state have generally declined (2008-2018; Figure 126). The largest average declines were detected in the Ogallala-Panhandle in Texas and Cimarron Counties. The largest groundwater increase was observed in the Blaine.

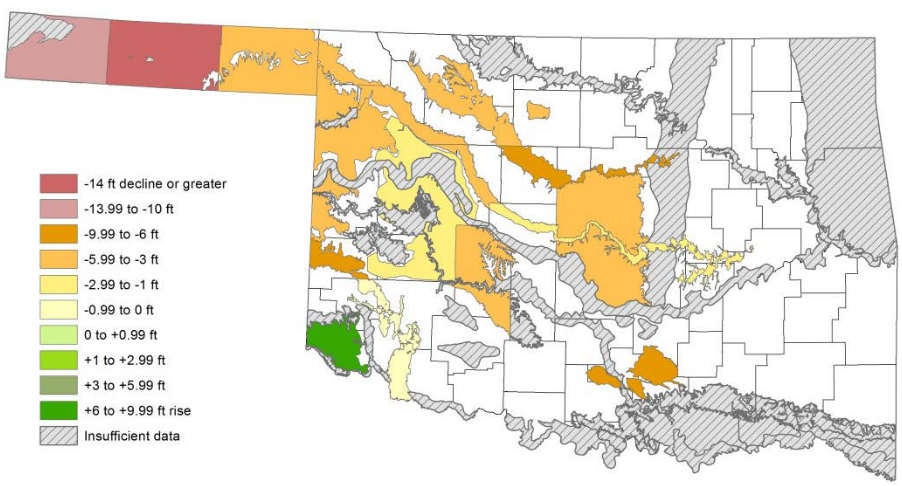

Figure 126. Average ten-year water level change, by major aquifer and climate division (2008-2018).

Continuous Water Level Recorders

Along with the annual measurements, a select number of dedicated wells in each aquifer are equipped with continuous water level recorders to monitor changes on a scale of hours or days. Across 17 aquifers, 33 recorders have been installed since 2013. The GMAP recorders represent a long-term commitment to monitor groundwater level conditions throughout the year (as opposed to annual taped measurements) and to provide data that complements intensive single-aquifer hydrologic studies conducted by the OWRB and their deployment of recorders for shorter intervals (2-5 years; Figure 127, open circles).

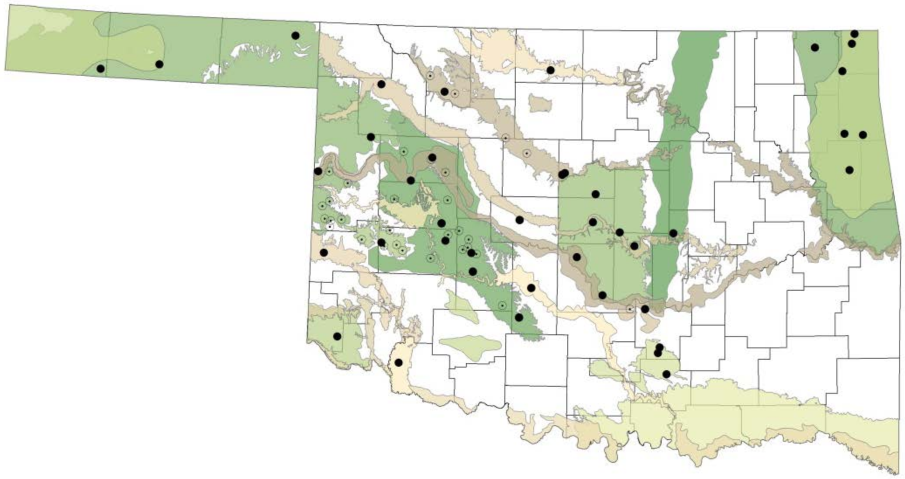

Figure 127. Sites with OWRB continuous water level recorders installed (closed circles indicate those in the GMAP program).

Details on installed recorders can be found in those aquifers' specific sections of this report. There are currently recorders in the Arbuckle-Simpson, Blaine, Boone, Canadian River, Cimarron River, Elk City, Garber-Wellington, Gerty Sand, North Canadian River, North Fork of the Red River, Ogallala-Northwest, Ogallala-Panhandle, Roubidoux, Rush Springs, Salt Fork of the Arkansas River, Tillman Terrace, and Washita River aquifers.

Since 2004 the OWRB has collaborated with the Oklahoma Climatological Survey to drill groundwater level observation wells at 9 Oklahoma Mesonet Stations. These wells are equipped with OWRB down-hole continuous recorders for hourly depth to water measurements (Figure 128). These groundwater level data are synced with the Mesonet station that captures real-time climate data on 20 variables including precipitation, soil moisture, air temperature, and barometric pressure. Continuous, simultaneous capture of day to day weather phenomena and long-term climate events in association with groundwater levels will allow researchers to study the relationships between changing climate and groundwater recharge and storage.

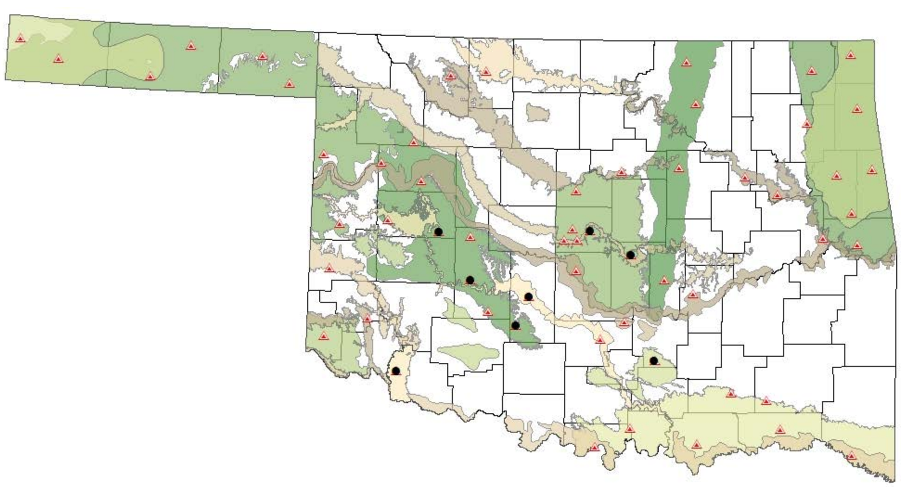

Figure 128. Continuous water level recorders (circles) deployed at Mesonet stations (triangles) in major aquifers across the state.

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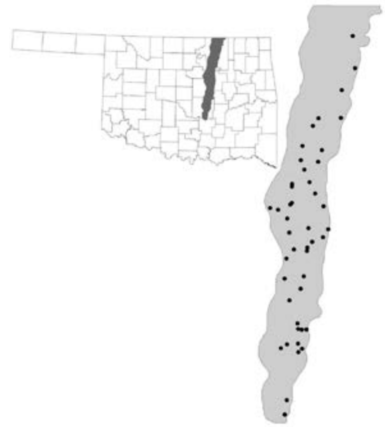
Table of Appendices

Appendix A– Descriptive Statistics for Ada-Vamoosa Aquifer



Baseline Sample Period	Sampling Sites	Water Level Sites
September 2014	44	44

General	**Location**	North Central to Central Oklahoma
	Area	6,713 km^2
	Capacity	14.9 million acre-feet
	Primary Use	Public Supply; Domestic; Industrial
	Category	Bedrock- inter-bedded shale/sandstone

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Mercury, Nickel, Selenium, & Silver.

Table A1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	216	18.3	72	141	180	254	850	N=50
Depth to Water (ft)	79.29	8.01	11.65	43.33	71.99	104.7	321.20	Below ground surface
Temperature (°C)	19.76	0.188	17.47	18.59	19.67	20.71	23.00	
Specific Conductance (µS/cm)	685	49.5	170	466	627	839	1680	
Dissolved Oxygen (mg/L)	2.78	0.408	0.18	0.42	1.64	5.45	8.56	
pH (units)	7.02	0.075	5.98	6.79	7.05	7.22	8.41	
Oxidation Reduction Potential (mV)	315	18.4	-28.0	252	343	391	493	N=43
Field Alkalinity (mg/L)	234	12.8	55.0	179	250	293	391	
Field Hardness (mg/L)	221	17.6	11.8	123	224	280	499	
Field calculated Bicarbonate (mg/L)	288	15.7	67.8	221	308	361	482	
Total Dissolved Solids (mg/L)	393	32.4	97.5	255	344	460	1120	SMCL: 500; 10 over

Table A2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	0.124	0.020	<0.1	<0.1	<0.1	0.14	0.54	
Nitrate+nitrite as N (mg/L)	1.48	0.47	<0.05	<0.05	0.52	1.69	18.9	MCL: 10; 1 over
Phosphorus (mg/L)	0.029	0.009	<0.005	<0.005	<0.005	0.023	0.351	

Table A3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	336	24.1	102	230	310	407	695	
dissolved Calcium (mg/L)	49.4	3.81	3.0	29.8	48.3	62.3	105	
Chloride (mg/L)	31.6	4.49	<10	11.65	17.65	41.15	117	SMCL: 250; 0 over
Fluoride (mg/L)	0.280	0.062	<0.2	<0.2	<0.2	0.27	2.29	MCL: 4; 0 over
dissolved Magnesium (mg/L)	21.8	1.93	1	11.7	23.6	29.4	62.1	
dissolved Potassium (mg/L)	1.96	0.130	0.7	1.3	1.9	2.6	4.3	
dissolved Silica (mg/L)	14.4	0.623	7.8	11.5	14.4	16.8	29.4	
dissolved Sodium (mg/L)	67.9	12.4	5.9	14.7	36.6	80.9	351	
Sulfate (mg/L)	75.4	19.6	<10	13.3	24.2	76.6	721	SMCL: 250; 3 over

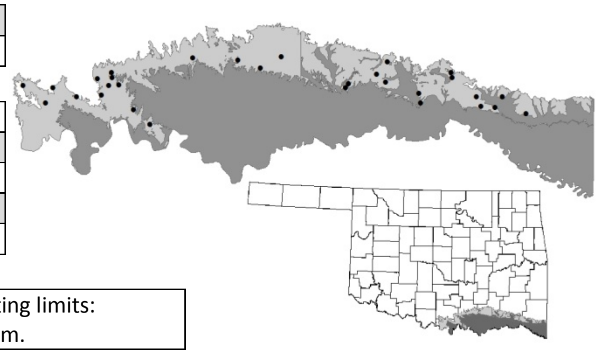
Table A4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	1.28	0.157	<1	<1	1.1	1.5	4.1	MCL: 10; 0 over
dissolved Barium (µg/L)	91.2	12.5	8.6	36.5	64.5	111	348	MCL: 2000; 0 over
dissolved Boron (µg/L)	507	145	<20	45.0	99.1	502	4810	HA: 6000; 0 over
dissolved Copper (µg/L)	All Values <5, except 9 (5.1, 5.6, 5.6, 5.8, 6.3, 6.4, 9.5, 16.4, 755)							MCL: 1300; 0 over
dissolved Iron (µg/L)	108	42.1	<20	<20	21.4	44.7	1570	SMCL: 300; 5 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Lead (µg/L)	All Values <0.5, except 6 (0.8, 0.8, 0.9, 0.9, 1.3, 1.3)							MCL: 15; 0 over
dissolved Manganese (µg/L)	34.3	11.3	<5	<5	7.4	19.1	366	SMCL:50; 6 over. HA:300; 1 over.
dissolved Molybdenum (µg/L)	All Values <5, except 1 (7)							HA: 40; 0 over
dissolved Uranium (µg/L)	1.09	0.229	<1	<1	<1	1.2	8.1	MCL: 30; 0 over
dissolved Vanadium (µg/L)	8.74	0.784	<5	<5	8.2	13.5	22.3	
dissolved Zinc (µg/L)	18.8	5.08	<5	<5	6.1	14.3	164	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix B– Descriptive Statistics for Antlers Aquifer outcrop

Baseline Sample Period	Sampling Sites	Water Level Sites
August 2015	30	32



General	Location	South Central to Southeast Oklahoma
	Area	1,093 km^2
	Capacity	53.5 million acre-feet
	Primary Use	Public Supply; Irrigation; Domestic; Industrial
	Category	Bedrock - sandstone

The following were sampled for and not found above laboratory reporting limits:
Antimony, Cadmium, Fluoride, Mercury, Molybdenum, Silver, & Thallium.

Table B1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	130	11.9	20	100	117	146	380	N=36
Depth to Water (ft)	54.46	6.83	0	27.05	46.94	79.57	132.10	Below ground surface
Temperature (°C)	20.93	0.224	18.49	20.13	20.94	21.64	22.87	
Specific Conductance (µS/cm)	511	75.6	31.0	113	456	784	1570	
Dissolved Oxygen (mg/L)	3.09	0.462	0.18	0.48	3.31	5.49	7.43	
pH (units)	6.52	0.158	4.48	6.02	6.68	7.18	7.93	SMCL: 6.5-8.5; 12 under
Oxidation Reduction Potential (mV)	378	33.4	82.5	239	362	536	880	
Field Alkalinity (mg/L)	153	22.9	<10	32.4	125	260	378	
Field Hardness (mg/L)	148	25.7	<10	38.0	94.0	213	510	N=29
Field calculated Bicarbonate (mg/L)	187	27.9	<12	39.5	153	317	461	
Total Dissolved Solids (mg/L)	275	37.5	15.0	71.6	254	410	694	SMCL: 500; 6 over

Table B2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 6 (0.14, 0.25, 0.26, 0.26, 0.28, 0.56)							
Nitrate+nitrite as N (mg/L)	0.768	0.188	<0.05	<0.05	0.15	1.09	3.43	MCL: 10; 0 over
Phosphorus (mg/L)	0.024	0.006	<0.005	<0.005	0.014	0.028	0.157	

Table B3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	290	47.5	<100	<100	248	362	1080	
dissolved Calcium (mg/L)	42.9	7.46	1.1	8.8	31.2	60.8	133	
Chloride (mg/L)	28.1	7.87	<10	<10	13.2	23.7	191	SMCL: 250; 0 over
dissolved Magnesium (mg/L)	8.48	1.70	<0.5	2.3	4.5	11.6	37.6	
dissolved Potassium (mg/L)	1.64	0.203	<0.5	0.8	1.4	2.3	5.6	
dissolved Silica (mg/L)	17.9	0.840	9.4	13.9	18.5	21.4	26.1	
dissolved Sodium (mg/L)	48.3	12.4	1.1	6.0	23.6	54.4	293	
Sulfate (mg/L)	39.1	8.66	<10	<10	17.9	47.6	165	SMCL: 250; 0 over

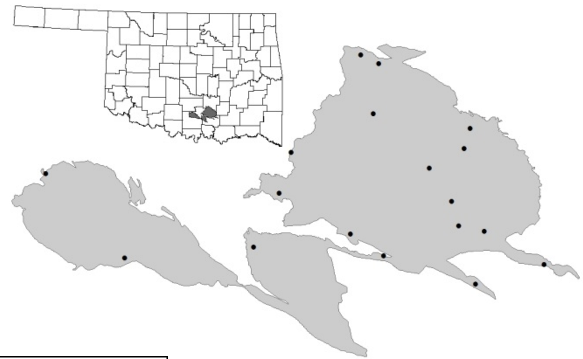
Table B4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Dissolved Aluminum (µg/L)	All Values <50, except 1 (323)							SMCL: 200, 1 over
dissolved Arsenic (µg/L)	All Values <1, except 4 (1, 1.1, 1.3, 2.9)							MCL: 10; 0 over
dissolved Barium (µg/L)	49.6	8.62	<1	16.9	30.0	61.1	176	MCL: 2000; 0 over
dissolved Beryllium (µg/L)	All Values <1, except 1 (1.5)							MCL: 4; 0 over
dissolved Boron (µg/L)	80.0	25.9	<20	<20	30.5	73.3	716	HA: 6000; 0 over
dissolved Chromium (µg/L)	4.66	1.40	<1	<1	<1	5.4	33.7	MCL: 100; 0 over
dissolved Cobalt (µg/L)	All Values <5, except 1 (16.7)							
dissolved Copper (µg/L)	7.67	2.45	<1	<1	2.6	9.7	69.4	MCL: 1300; 0 over
dissolved Iron (µg/L)	166.3	51.9	<20	<20	28.3	187	1180	SMCL: 300; 5 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Lead (µg/L)	0.582	0.140	<0.5	<0.5	<0.5	<0.5	3.2	MCL: 15; 0 over
dissolved Manganese (µg/L)	109	37.8	<5	6.2	31.7	99.7	920	SMCL: 50; 12 over. HA: 300; 2 over.
dissolved Nickel (µg/L)	1.70	0.256	<1	<1	1.4	1.9	5.7	HA: 100; 0 over
dissolved Selenium (µg/L)	1.71	0.316	<1	<1	1.2	1.6	7.6	MCL: 50; 0 over
dissolved Uranium (µg/L)	All Values <1, except 6 (1.1, 2, 2.2, 2.8, 3.2, 8.3)							MCL: 30; 0 over
dissolved Vanadium (µg/L)	All Values <5, except 4 (5.3, 6.9, 8.4, 15.3)							
dissolved Zinc (µg/L)	29.5	10.8	<5	<5	6.8	16.1	279	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix C– Descriptive Statistics for Arbuckle-Simpson Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July 2015	18	29



General	**Location**	South Central Oklahoma
	Area	1,586 km^2
	Capacity	9.4 million acre-feet
	Primary Use	Public supply; Domestic; Industrial; Agriculture; Recreational
	Category	Bedrock – karst limestone, sandstone, dolomite

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Mercury, Silver, Thallium, & Vanadium.

Table C1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	260	40.6	55	117	190	289	1116	N=32
Depth to Water (ft)	32.96	6.00	0.00	11.58	24.92	41.34	157.00	Below ground surface
Temperature (°C)	19.75	0.594	17.51	18.47	19.03	20.00	28.55	
Specific Conductance (µS/cm)	662	29.2	403	592	618	719	932	
Dissolved Oxygen (mg/L)	3.65	0.582	0.36	1.86	3.25	5.88	7.76	
pH (units)	6.88	0.052	6.48	6.71	6.91	7.05	7.33	SMCL: 6.5-8.5; 1 under
Oxidation Reduction Potential (mV)	410	28.1	228	364	375	401	765	
Field Alkalinity (mg/L)	319	12.6	195	301	313	353	444	
Field Hardness (mg/L)	341	16.7	192	296	335	375	507	
Field calculated Bicarbonate (mg/L)	390	15.4	238	367	382	431	542	
Total Dissolved Solids (mg/L)	352	17.0	218	303	335	391	529	SMCL: 500; 1 over

Table C2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	1.74	0.492	<0.05	0.39	0.99	1.94	6.86	MCL: 10; 0 over
Phosphorus (mg/L)	0.015	0.007	<0.005	<0.005	<0.005	0.010	0.120	

Table C3. Descriptive statistics on mineral constituents.

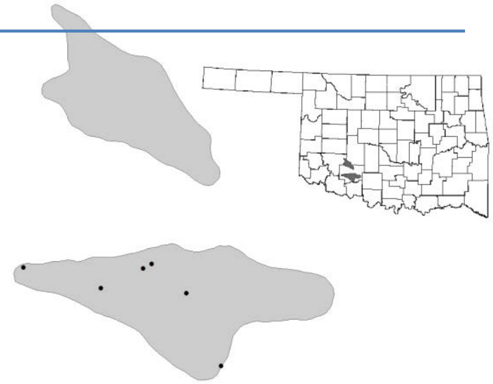
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	291	14.6	193	244	278	326	398	
dissolved Calcium (mg/L)	86.1	5.03	68.8	70.9	82.3	90.5	146	
Chloride (mg/L)	10.1	2.27	<10	<10	<10	11.1	41.1	SMCL: 250; 0 over
Fluoride (mg/L)	All Values <0.2, except 1 (0.21)							MCL: 4; 0 over
dissolved Magnesium (mg/L)	29.8	3.80	2.6	22.0	32.2	28.5	56.9	
dissolved Potassium (mg/L)	1.57	0.24	<0.5	1.1	1.5	1.8	4.7	
dissolved Silica (mg/L)	11.7	0.671	6.87	10.1	11.2	12.5	16.5	
dissolved Sodium (mg/L)	6.00	1.07	1.7	2.8	3.6	8.2	15.1	
Sulfate (mg/L)	16.0	2.53	<10	<10	14.4	18.4	39.4	SMCL: 250; 0 over

Table C4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	60.1	8.44	20.9	40	52.6	69.0	177	MCL: 2000; 0 over
dissolved Boron (µg/L)	20.5	3.09	<20	<20	<20	25.8	47.1	HA: 6000; 0 over
dissolved Copper (µg/L)	5.57	1.67	<1	2.4	3.3	6.9	30	MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <20, except 1 (207)							SMCL: 300; 0 over
dissolved Lead (µg/L)	All Values <0.5, except 4 (0.83, 0.91, 0.95, 1.4)							MCL: 15; 0 over
dissolved Manganese (µg/L)	All Values <5, except 1 (13.5)							SMCL:50; 0 over.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								HA:300; 0 over.
dissolved Molybdenum (µg/L)	All Values <5, except 1 (5.6)							HA: 40; 0 over
dissolved Nickel (µg/L)	0.817	0.130	<1	<1	<1	1.0	2	HA: 100; 0 over
dissolved Selenium (µg/L)	1.42	0.145	<1	1.0	1.4	1.9	2.6	MCL: 50; 0 over.
dissolved Uranium (µg/L)	All Values <1, except 2 (1.7, 1.8)							MCL: 30; 0 over
dissolved Zinc (µg/L)	12.5	3.20	<5	<5	6.7	17.9	49.2	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix D– Descriptive Statistics for Arbuckle-Timbered Hills Aquifer



Baseline Sample Period	Sampling Sites	Water Level Sites
July 2015	6	3

General	**Location**	Southwest Oklahoma
	Area	973 km^2
	Capacity	962 thousand acre-feet
	Primary Use	Public Supply; Domestic; Industrial
	Category	Bedrock – inter-bedded limestone, dolomite, sandstone

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Lead, Mercury, Nickel, Silver, Thallium, Uranium, & Vanadium.

Table D1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	1212	218.3	618	908	1200	1305	2243	N=7
Depth to Water (ft)	109.90	40.20	64.50	--	75.25	--	190.10	Below ground surface
Temperature (°C)	21.53	1.05	19.41	--	20.80	--	26.23	
Specific Conductance (µS/cm)	1280	407	547	--	1010	--	3250	
Dissolved Oxygen (mg/L)	1.42	0.564	-0.01	--	1.37	--	3.69	
pH (units)	8.55	0.135	8.03	--	8.56	--	8.92	SMCL: 6.5-8.5; 4 over
Oxidation Reduction Potential (mV)	78.8	44.7	-64.2	--	66.7	--	237	
Field Alkalinity (mg/L)	283	27.8	199	--	276	--	383	
Field Hardness (mg/L)	23.5	4.09	12.0	--	21.5	--	41.0	
Field calculated Bicarbonate (mg/L)	345	33.9	243	--	336	--	467	
Total Dissolved Solids (mg/L)	708	218	326	--	562	--	1760	SMCL: 500; 4 over

Table D2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	0.147	0.023	<0.1	--	0.17	--	0.20	
Nitrate+nitrite as N (mg/L)	All Values <0.05, except 1 (0.06)							MCL: 10; 0 over
Phosphorus (mg/L)	All values <0.005, except 1 (0.013)							

Table D3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	788	367	255	--	460	--	2590	
dissolved Calcium (mg/L)	3.63	1.03	1.4	--	2.7	--	7.0	
Chloride (mg/L)	169	97.9	28.4	--	69.7	--	648	SMCL: 250; 1 over
Fluoride (mg/L)	8.56	1.95	3.41	--	7.90	--	15.9	MCL: 4; 5 over
dissolved Magnesium (mg/L)	1.52	0.662	<0.5	--	0.9	--	4.4	
dissolved Potassium (mg/L)	1.50	0.461	0.7	--	1.1	--	3.7	
dissolved Silica (mg/L)	10.6	0.287	9.96	--	10.4	--	11.7	
dissolved Sodium (mg/L)	274	89.0	121	--	212	--	705	
Sulfate (mg/L)	70.1	35.9	<10	--	46.6	--	243	SMCL: 250; 0 over

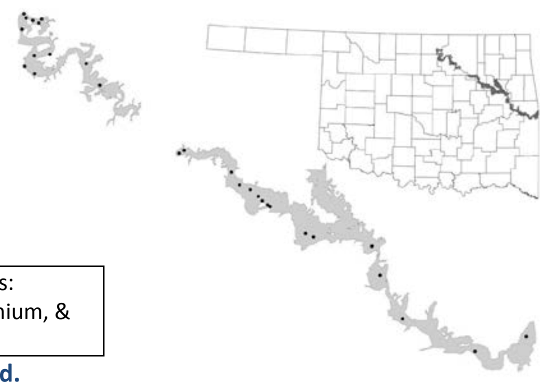
Table D4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	24.2	11.5	<1	--	14.6	--	79.5	MCL: 10; 5 over
dissolved Barium (µg/L)	14.3	3.64	3	--	15.1	--	26.2	MCL: 2000; 0 over
dissolved Boron (µg/L)	1830	502	571	--	1590	--	3490	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <1, except 1 (1)							MCL: 100; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Copper (µg/L)	All Values <1, except 1 (1)							MCL: 1300; 0 over
dissolved Iron (µg/L)	46.4	29.9	<20	--	<20	--	193	SMCL: 300; 0 over
dissolved Manganese (µg/L)	All Values <5, except 1 (6.7)							SMCL: 50; 0 over. HA: 300; 0 over.
dissolved Molybdenum (µg/L)	17.6	6.22	<5	--	13.1	--	44.2	HA: 40; 1 over
dissolved Selenium (µg/L)	3.48	1.49	1.4	--	2	--	10.8	MCL: 50; 0 over
dissolved Zinc (µg/L)	All Values <5, except 1 (13.1)							SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix E– Descriptive Statistics for Arkansas River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
September-October 2014	29	22



General	Location	runs North Central - East Central Oklahoma
	Area	2,223 km^2
	Capacity	946 thousand acre-feet
	Primary Use	Irrigation; Public Supply; Domestic; Industrial
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Lead, Mercury, Nickel, Selenium, & Silver.

Table E1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	45.4	3.07	26	35.3	40	49.5	116	N=34
Depth to Water (ft)	24.63	2.97	0.00	16.28	22.51	27.23	60.31	Below ground surface
Temperature (°C)	19.39	0.402	16.49	17.92	18.98	19.70	27.25	
Specific Conductance (µS/cm)	651	68.0	123	428	641	917	1690	
Dissolved Oxygen (mg/L)	3.89	0.491	0.24	1.28	3.89	5.81	8.70	
pH (units)	6.57	0.072	5.69	6.37	6.63	6.83	7.25	
Oxidation Reduction Potential (mV)	304	22.2	48.6	264	370	378	561	
Field Alkalinity (mg/L)	234	25.5	39.0	124	224	333	489	
Field Hardness (mg/L)	264	26.8	27.0	179	255	404	484	
Field calculated Bicarbonate (mg/L)	283	31.5	48.0	153	269	410	597	
Total Dissolved Solids (mg/L)	387	36.3	88.8	279	385	515	914	SMCL: 500; 9 over

Table E2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 5 (0.15, 0.17, 0.18, 0.21, 0.91)							
Nitrate+nitrite as N (mg/L)	3.46	0.716	<0.05	0.22	2.42	5.50	17.4	MCL: 10; 1 over
Phosphorus (mg/L)	0.148	0.041	0.025	0.063	0.100	0.125	1.17	

Table E3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	362	44.9	<100	212	291	481	1080	
dissolved Calcium (mg/L)	70.7	7.06	7.6	49.4	71	104	133	
Chloride (mg/L)	41.4	12.7	<10	<10	11.6	53.6	342	SMCL: 250; 1 over
Fluoride (mg/L)	0.204	0.017	<0.2	<0.2	0.24	0.26	0.40	MCL: 4; 0 over
dissolved Magnesium (mg/L)	16.0	1.74	1.9	11.0	14.6	20.6	36.8	
dissolved Potassium (mg/L)	1.96	0.25	0.5	1.1	1.6	2.3	5.7	
dissolved Silica (mg/L)	26.0	1.93	7.8	19.4	22.2	33.1	45.2	
dissolved Sodium (mg/L)	38.8	8.80	7.8	14.1	24.8	40.1	240	
Sulfate (mg/L)	37.0	5.75	<10	16.5	26.5	51.4	125	SMCL: 250; 0 over

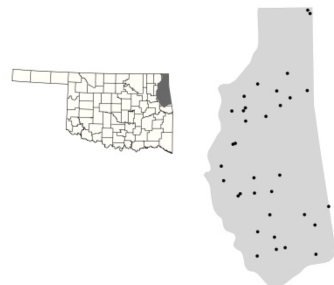
Table E4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	0.983	0.164	<1	<1	<1	1.3	4.1	MCL: 10; 0 over
dissolved Barium (µg/L)	257	36.0	58.6	124	209	345	885	MCL: 2000; 0 over
dissolved Boron (µg/L)	51.7	8.44	<20	<20	45.7	70.0	232	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <5, except 1 (5.8)							MCL: 100; 0 over
dissolved Copper (µg/L)	5.45	0.980	<5	<5	<5	7.5	26.7	MCL: 1300; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Iron (µg/L)	902	444	<20	<20	20.4	283	12200	SMCL: 300; 7 over
dissolved Manganese (µg/L)	515	156	<5	<5	242	674	3970	SMCL: 50; 15 over HA: 300; 13 over
dissolved Molybdenum (µg/L)	All Values <5, except 1 (5.7)							HA: 40; 0 over
dissolved Uranium (µg/L)	1.66	0.393	<1	<1	<1	2.1	9.2	MCL: 30; 0 over
dissolved Vanadium (µg/L)	5.14	0.721	<5	<5	<5	7.9	15	
dissolved Zinc (µg/L)	45.3	15.5	<5	<5	6.8	37.8	371	SMCL: 5000; 0 over HA: 2000; 0 over

Appendix G– Descriptive Statistics & Selected Maps for Boone Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
September-November 2017	34	42



General		
	Location	runs through Northeast Oklahoma
	Area	7,938 km^2
	Capacity	27 million acre-feet
	Primary Use	Domestic
	Category	Minor Bedrock

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Bromide, Cadmium, Cobalt, Lead, Mercury, Nickel, Silver, and Thallium.

Table G1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	159	11.2	50	100	145	195	410	N = 50
Depth to Water (ft)	43.77	5.58	7.27	18.64	33.89	56.10	181.90	Below ground surface
Temperature (°C)	16.38	0.19	12.93	16.06	16.55	16.94	18.35	
Specific Conductance (µS/cm)	402.94	23.75	154.70	323.98	384.80	449.08	831.70	
Dissolved Oxygen (mg/L)	4.94	0.45	0.26	3.36	5.63	6.94	8.29	
pH (units)	7.09	0.05	6.50	6.85	7.09	7.40	7.63	SMCL: 6.5-8.5; 0 under, 0 over
Field Alkalinity (mg/L)	170	8	77	136	169	205	275	N = 33
Field Hardness (mg/L)	195	10	100	152	195	232	326	N = 33
Field Calculated Bicarbonate (mg/L)	208.0	9.523	93.94	165.3	206.2	250.1	335.5	N = 33
Total Dissolved Solids (mg/L)	236	13.7	122	181	235	267	472	SMCL: 500; 0 sites over

Table G2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All values <0.1, except 6 (0.05, 0.05, 0.06, 0.06, 0.07, 0.08)							
Nitrate+Nitrite as N (mg/L)	1.59	0.366	<0.050	0.271	0.766	2.16	10.7	MCL: 10; 1 over
Phosphorus (mg/L)	0.020	0.002	<0.015	<0.015	0.017	0.021	0.067	

Table G3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Calcium (mg/L)	76.3	4.08	23.8	58.4	78.9	88.9	135	
Chloride (mg/L)	8.77	2.00	<2	2.25	4.95	11.1	56.8	SMCL: 250; 0 over
Fluoride (mg/L)	All values <0.1, except 4 (0.11, 0.11, 0.20, 0.38)							MCL: 4; 0 over SMCL: 2; 0 over
dissolved Magnesium (mg/L)	1.81	0.174	0.58	1.08	1.47	2.43	4.15	
dissolved Potassium (mg/L)	0.87	0.14	<0.50	<0.50	0.68	0.94	4.6	
dissolved Silica (mg/L)	9.93	0.254	8.10	8.71	9.66	11.0	14.2	
dissolved Sodium (mg/L)	6.98	1.66	1.37	2.36	3.33	7.41	50.9	
Sulfate (mg/L)	8.68	1.71	1.21	2.72	4.74	8.03	34.9	SMCL: 250; 0 over

Table G4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All values <1, except 1 (1.16)							MCL: 10; 0 over
dissolved Barium (µg/L)	58.0	9.32	11.8	28.3	37.3	74.0	274	MCL: 2000; 0 over
dissolved Boron (µg/L)	All values <20, except 6 (21.1, 23.2, 31.5, 52.1, 57.2, 73.6)							HA: 6000; 0 over
dissolved Chromium (µg/L)	1.84	0.171	<1.00	1.06	1.92	2.31	4.57	MCL: 100; 0 over
dissolved Copper (µg/L)	3.78	1.14	<1.00	<1.00	2.21	4.18	38.0	MCL: 1300; 0 over

Parameter	Mean ± SEM	Min	25%	Median	75%	Max	Comment
dissolved Iron (µg/L)	All Values <10, except 6 (38.2, 48.3, 51.0, 83.0, 235, 340)						SMCL: 300; 1 over
dissolved Manganese (µg/L)	All values <15, except 2 (17.6, 195)						SMCL: 50; 1 over. HA: 300; 0 over
dissolved Molybdenum (µg/L)	All values <1, except 2 (2.18, 2.40)						HA: 40; 0 over
dissolved Selenium (µg/L)	All values <5, except 7 (1.14, 1.24, 2.05, 2.23, 2.44, 2.95, 5.91)						MCL: 50; 0 over
dissolved Uranium (µg/L)	1.67	0.57	<1.00	<1.00	<1.00	1.54	19.3	MCL: 30; 0 over
dissolved Vanadium (µg/L)	All values <1, except 2 (23.4, 24.8)						
dissolved Zinc (µg/L)	All values <35, except 6, (36.2, 73.8, 84.0, 87.0, 171, 175)						SMCL: 5000; 0 over. HA: 2000; 0 over

Figure G1. Location and extent of the BOON.

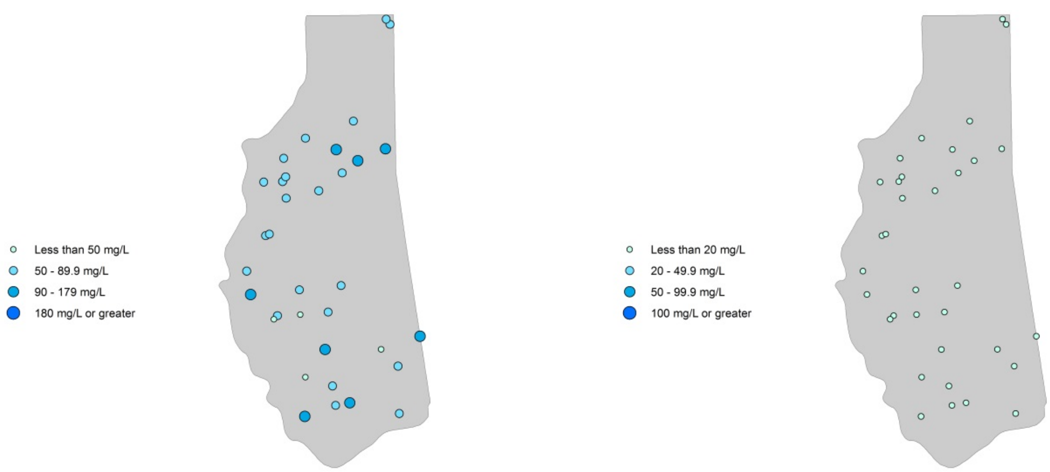


Figure G2. Calcium (left) and magnesium concentrations in the BOON.

Figure G3. Sodium+potassium (left) and bicarbonate concentrations in the BOON.

Figure G4. Chloride (left) and sulfate concentrations in the BOON.

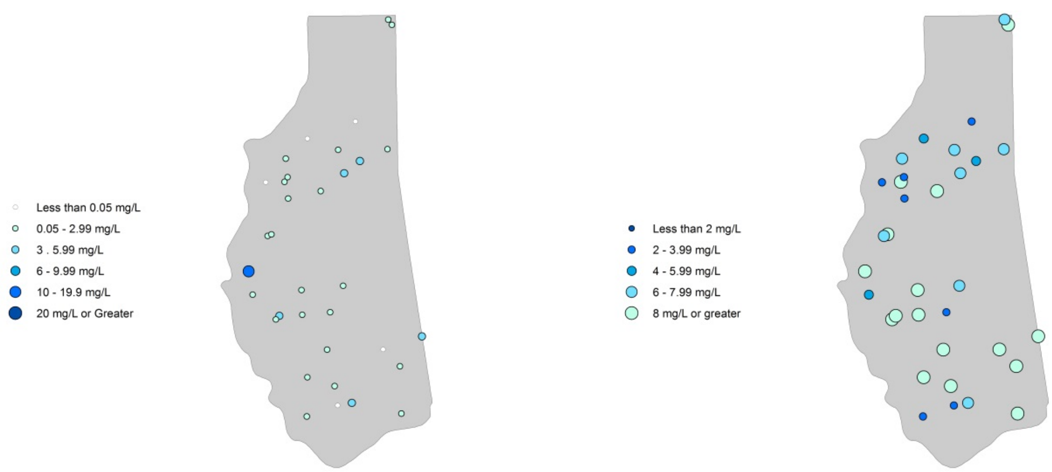


Figure G5. Nitrate+nitrite-N (left) and dissolved oxygen concentrations in the BOON.

Appendix F– Descriptive Statistics for Canadian River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August-September 2013	34	44

General	**Location**	runs through Mid-Oklahoma
	Area	5,544 km^2
	Capacity	5.01 million acre-feet
	Primary Use	Variety
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Lead, Nickel, Silver, & Thallium.

Table F1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	66.5	2.71	14	54	63	80	112	N=49
Depth to Water (ft)	21.32	2.22	2.68	11.00	15.05	32.21	54.32	Below ground surface
Temperature (°C)	19.99	0.229	17.95	18.79	20.16	21.03	22.43	
Specific Conductance (µS/cm)	1370	167	102	724	908	2080	3710	
Dissolved Oxygen (mg/L)	3.75	0.512	0.10	0.83	3.44	6.52	8.88	
pH (units)	6.94	0.051	5.91	6.86	7.01	7.12	7.45	
Field Alkalinity (mg/L)	266	21.7	26.4	187	275	329	537	
Field Hardness (mg/L)	666	97.2	25.8	289	394	1110	2230	
Field calculated Bicarbonate (mg/L)	337	25.5	68.8	246	341	409	661	
Total Dissolved Solids (mg/L)	1040	157	86.3	436	533	1750	3420	SMCL: 500; 23 sites over

Table F2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 8 (0.2, 0.23, 0.24, 0.26, 0.29, 0.35, 0.46, 0.97)							
Nitrate+nitrite as N (mg/L)	3.34	0.739	<0.05	<0.05	1.19	5.27	16.1	MCL: 10; 5 over
Phosphorus (mg/L)	0.060	0.016	<0.005	<0.005	0.035	0.074	0.516	

Table F3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	353	36.9	<100	217	320	449	966	
dissolved Calcium (mg/L)	163	21.2	16.7	77.9	112	223	445	
Chloride (mg/L)	59.2	13.2	<10	14.1	33.9	61.8	380	SMCL: 250; 1 over
Fluoride (mg/L)	0.206	0.024	<0.2	<0.2	<0.2	0.31	0.56	MCL: 4; 0 over
dissolved Magnesium (mg/L)	51.3	7.58	5.3	16.7	39.3	69.5	180	
dissolved Potassium (mg/L)	1.95	0.220	<0.5	0.9	2.0	2.4	5.0	
dissolved Silica (mg/L)	23.4	1.32	11.0	20.1	22.7	25.0	54.2	
dissolved Sodium (mg/L)	77.8	15.2	10.5	22.2	45.9	94.0	430	
Sulfate (mg/L)	463	104	<10	37.7	99.9	943	1860	SMCL: 250; 13 over

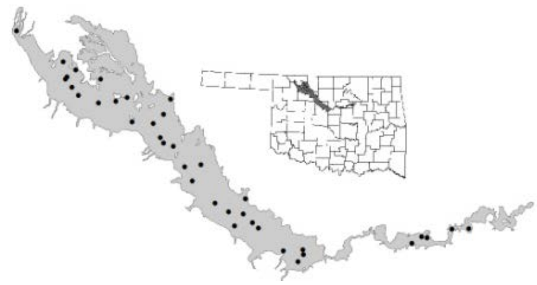
Table F4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All Values <10, except 2 (12.2, 19.9)							MCL: 10; 2 over
dissolved Barium (µg/L)	167	35.8	<10	20.3	81.4	230	987	MCL: 2000; 0 over
dissolved Boron (µg/L)	400	105	<50	77.6	206	421	2970	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <5, except 3 (6.1, 6.4, 9.4)							MCL: 100; 0 over
dissolved Copper (µg/L)	All Values <5, except 2 (6.7, 13.1)							MCL: 1300; 0 over
dissolved Iron (µg/L)	839	244	<50	<50	<50	828	4940	SMCL: 300; 12 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Manganese (µg/L)	210	50.7	<50	<50	<50	376	1090	SMCL: 50; 14 over. HA: 300; 9 over
dissolved Mercury (µg/L)	All Values <0.05, except 1 (0.73)							MCL: 2; 0 over
dissolved Molybdenum (µg/L)	All Values <10, except 3 (14.1, 19, 51.4)							HA: 40; 1 over
dissolved Selenium (µg/L)	All Values <20, except 1 (31.8)							MCL: 50; 0 over
dissolved Uranium (µg/L)	7.68	1.79	<1	<1	3.5	8.8	40.8	MCL: 30; 2 over
dissolved Vanadium (µg/L)	28.6	4.22	<10	6.4	18.8	44.3	94.1	
dissolved Zinc (µg/L)	37.2	13.8	<10	<10	10.5	25.5	424	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix H– Descriptive Statistics & Selected Maps for Cimarron River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July-August 2016	37	60



General	Location	runs through Northwest/North-Central Oklahoma
	Area	4,427 km^2
	Capacity	3.86 million acre-feet
	Primary Use	Public Supply; Domestic; Industrial; Stock; Irrigation
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Boron, Cadmium, Cobalt, Iron, Mercury, Silver, Thallium, Thorium, & Titanium.

Table H1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	58.4	2.05	25.0	44.6	60.0	70.0	100	N = 69
Depth to Water (ft)	19.5	1.43	4.29	11.2	17.3	24.8	52.4	Below ground surface
Temperature (°C)	20.1	0.371	16.9	18.6	19.7	21.3	24.6	N = 36
Specific Conductance (µS/cm)	817	94.1	286	497	712	907	3688	
Dissolved Oxygen (mg/L)	4.47	0.462	0.300	2.13	4.32	6.87	11.4	N = 36
pH (units)	7.08	0.056	6.10	6.86	7.11	7.39	7.53	SMCL: 6.5-8.5; 3 under, 0 over
Field Alkalinity (mg/L)	194	13.3	60.0	125	192	232	402	
Field Hardness (mg/L)	303	38.2	82.0	191	263	344	1541	
Field calculated Bicarbonate (mg/L)	235	16.2	73.0	153	231	283	490	
Total Dissolved Solids (mg/L)	532	77.9	202	336	424	550	3088	SMCL: 500; 13 sites over
d18O isotope (‰)	-5.94	0.079	-6.72	-6.16	-5.91	-5.70	-4.10	
d2H isotope (‰)	-36.4	0.543	-42.6	-37.5	-36.4	-34.6	-25.7	

Table H2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+Nitrite as N (mg/L)	10.8	1.13	1.34	5.59	9.93	13.0	35.9	MCL: 10; 18 over
Phosphorus (mg/L)	0.061	0.007	<0.015	0.031	0.048	0.075	0.195	

Table H3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	240	24.0	<250	<250	<250	343	541	
dissolved Calcium (mg/L)	92.2	11.9	22.8	55.5	75.7	110	478	
Chloride (mg/L)	66.6	12.4	6.96	22.5	33.1	89.0	365	SMCL: 250; 1 over
Fluoride (mg/L)	0.215	0.023	<0.2	<0.2	0.212	0.284	0.619	MCL: 4; 0 over. SMCL: 2; 0 over
dissolved Magnesium (mg/L)	21.5	3.34	6.99	11.3	15.8	22.9	129	
dissolved Potassium (mg/L)	1.73	0.247	0.54	1.08	1.42	1.85	9.62	
dissolved Silica (mg/L)	25.1	0.741	12.9	22.5	25.2	28.4	34.9	
dissolved Sodium (mg/L)	50.2	7.72	6.26	25.5	35.7	56.1	250	
Sulfate (mg/L)	94.1	38.7	5.79	27.3	37.3	64.3	1440	SMCL: 250; 3 over

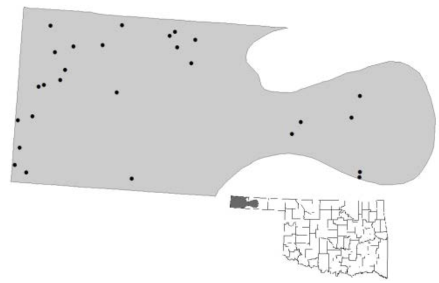
Table H4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM	Min	25%	Median	75%	Max	Comment

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	1.44	0.129	<1	1.08	1.24	1.78	4.05	MCL: 10; 0 over
dissolved Barium (µg/L)	299	39.6	11.3	174	221	413	1360	MCL: 2000; 0 over
dissolved Chromium (µg/L)	All Values <1, except 4 (1.05, 1.23, 1.29, 1.72)							MCL: 100; 0 over
dissolved Copper (µg/L)	3.08	0.749	<1	<1	1.60	3.23	21.1	MCL: 1300; 0 over
dissolved Lead (µg/L)	All Values <1, except 6 (1.01, 1.31, 1.39, 1.57, 1.69, 1.71)							MCL: 15; 0 over
dissolved Lithium (mg/L)	0.020	0.002	<0.02	<0.02	0.020	0.020	0.060	
dissolved Manganese (µg/L)	All Values <1, except 7 (1.1, 1.2, 4.7, 5.14, 20.0, 157, 215)							SMCL: 50; 2 over. HA: 300; 0 over
dissolved Molybdenum (µg/L)	All Values <1, except 5 (1.00, 1.16, 1.52, 1.75, 1.82, 2.44)							HA: 40; 0 over
dissolved Nickel (µg/L)	All Values <1, except 5 (1.01, 1.82, 2.00, 2.03, 2.88)							HA: 100; 0 over
dissolved Selenium (µg/L)	All Values <5, except 3 (13.82, 15.09, 15.57)							MCL: 50; 0 over
dissolved Strontium (mg/L)	0.422	0.075	0.150	0.240	0.301	0.440	2.94	HA: 4; 0 over
dissolved Uranium (µg/L)	2.73	0.498	<1	<1	2.07	3.12	13.9	MCL: 30; 0 over
dissolved Vanadium (µg/L)	4.92	0.426	1.95	3.20	3.83	6.15	13.0	
dissolved Zinc (µg/L)	All values <100, except 2 (105, 367)							SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix I– Descriptive Statistics & Selected Maps for Dakota-Dockum Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August-October 2016	27	13



General	Location	Western Oklahoma Panhandle
	Area	5,817 km^2
	Capacity	not available
	Primary Use	Stock; Domestic; Irrigation
	Category	Bedrock- interbedded sandstone/shale; may also include sandstone, sandstone/ shale/siltstone/conglomerate

The following were sampled for and not found above laboratory reporting limits: Aluminum, Beryllium, Cadmium, Lead, Mercury, Silver, Thallium, & Titanium.

Table I1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	282	18.1	100	206	288	347	530	N = 30
Depth to Water (ft)	158	20.4	33.3	124	170	204	275	Below ground surface
Temperature (°C)	18.3	0.270	15.9	17.3	18.5	18.9	21.9	
Specific Conductance (µS/cm)	833	123	398	489	615	826	3370	
Dissolved Oxygen (mg/L)	5.75	0.630	0.270	3.04	7.24	8.23	11.7	
pH (units)	7.51	0.520	7.07	7.34	7.52	7.71	8.13	SMCL: 6.5-8.5; 0 under, 0 over
Field Alkalinity (mg/L)	243	18.2	73.0	194	206	281	440	
Field Hardness (mg/L)	210	15.4	42.0	181	204	228	388	
Field calculated Bicarbonate (mg/L)	296	21.7	89.0	236	251	343	537	
Total Dissolved Solids (mg/L)	546	89.2	256	300	362	536	2390	SMCL: 500; 8 sites over
d18O isotope (‰)	-8.36	0.162	-10.4	-8.88	-8.16	-7.73	-7.15	
d2H isotope (‰)	-58.4	1.28	-74.7	-63.2	-57.3	-53.2	-48.2	

Table I2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 3 (0.15, 0.33, 0.34)							
Nitrate+Nitrite as N (mg/L)	2.73	0.578	<0.05	0.872	1.88	3.36	13.8	MCL: 10; 1 over
Phosphorus (mg/L)	All Values <0.015, except 4 (0.018, 0.023, 0.023, 0.024)							

Table I3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	179	16.7	<250	<250	<250	264	361	
dissolved Calcium (mg/L)	45.6	4.85	5.50	24.5	40.7	55.8	98.7	
Chloride (mg/L)	16.2	1.60	3.21	10.7	14.9	18.8	38.4	SMCL: 250; 0 over
Fluoride (mg/L)	1.52	0.156	0.300	0.934	1.20	2.08	3.67	MCL: 4; 0 over SMCL: 2; 8 over
dissolved Magnesium (mg/L)	24.1	2.18	5.78	16.0	20.6	30.6	55.7	
dissolved Potassium (mg/L)	4.49	0.387	1.55	3.24	3.82	6.04	10.0	
dissolved Silica (mg/L)	24.5	2.16	7.09	14.5	23.6	33.2	42.9	
dissolved Sodium (mg/L)	106	30.1	9.84	21.0	34.6	154	738	
Sulfate (mg/L)	168	56.3	16.6	28.5	50.0	165	1440	SMCL: 250; 5 over

Table I4. Descriptive statistics on metal constituents.

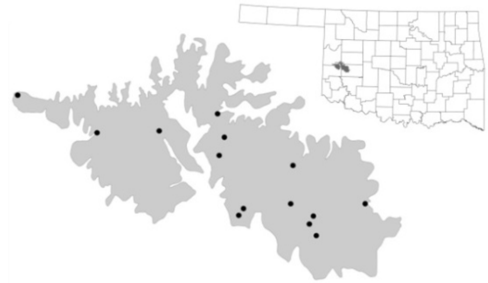
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Antimony (µg/L)	All Values <1, except 1 (1.4)							MCL: 6; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	4.02	1.06	<1	<1	3.01	5.42	29	MCL: 10; 1 over
dissolved Barium (µg/L)	62.3	9.87	12.2	23.4	50.0	85.3	240	MCL: 2000; 0 over
dissolved Boron (µg/L)	All Values <500, except 3 (520, 600, 1000)							HA: 6000; 0 over
dissolved Chromium (µg/L)	1.19	0.239	<1	<1	<1	1.42	5.06	MCL: 100; 0 over
dissolved Cobalt (µg/L)	All Values <1, except 2 (1.62, 20.7)							
dissolved Copper (µg/L)	All Values <1, except 5 (1.9, 1.95, 2.15, 3.06, 5.73)							MCL: 1300; 0 over SMCL: 1000; 0 over
dissolved Iron (µg/L)	All Values <100, except 3 (170, 210, 710)							SMCL: 300; 1 over
dissolved Lithium (mg/L)	0.079	0.014	0.020	0.035	0.070	0.090	0.370	
dissolved Manganese (µg/L)	12.1	8.65	<1	<1	<1	<1	234	SMCL: 50; 1 over. HA: 300; 0 over
dissolved Molybdenum (µg/L)	7.18	1.26	<1	3.18	4.44	11.0	30.7	HA: 40; 0 over
dissolved Nickel (µg/L)	All Values <1, except 2 (1.27, 3.14)							HA: 100; 0 over
dissolved Selenium (µg/L)	4.56	0.683	<5	<5	<5	6.53	14.6	MCL: 50; 0 over
dissolved Strontium (mg/L)	0.893	0.073	0.26	0.685	0.85	1.20	1.74	HA: 4; 0 over
dissolved Thorium (µg/L)	All Values <1, except 1 (2.13)							
dissolved Uranium (µg/L)	8.67	1.24	<1	3.63	8.14	13.1	28.0	MCL: 30; 0 over
dissolved Vanadium (µg/L)	14.6	3.79	<1	<1	12.4	17.3	100	
dissolved Zinc (µg/L)	All Values <100, except 3 (121, 141, 547)							SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix J– Descriptive Statistics for Elk City Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July-August 2013	13	25

General	**Location**	Southwest Oklahoma
	Area	782 km^2
	Capacity	2.2 million acre-feet
	Primary Use	Public Supply; Domestic; Irrigation
	Category	Bedrock - sandstone



The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, & Thallium.

Table J1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	119	6.05	42	99	122	140.5	175	N=27
Depth to Water (ft)	28.98	4.85	10.95	15.20	22.80	27.44	107.80	Below ground surface
Temperature (°C)	21.50	0.57	18.36	19.86	21.25	23.56	24.27	
Specific Conductance (µS/cm)	624	27.0	475	576	599	672	822	
Dissolved Oxygen (mg/L)	5.98	0.639	0.65	5.06	6.39	7.92	8.53	
pH (units)	7.29	0.036	7.14	7.21	7.26	7.41	7.53	
Field Alkalinity (mg/L)	276	16.3	215	238	276	288	437	
Field Hardness (mg/L)	272	7.73	232	253	272	289	329	
Field calculated Bicarbonate (mg/L)	340	20.0	265	293	340	354	537	
Total Dissolved Solids (mg/L)	360	15.7	254	335	349	399	436	SMCL: 500; 0 over

Table J2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	5.44	0.808	0.09	3.92	6.37	7.52	8.58	MCL: 10; 0 over
Phosphorus (mg/L)	All Values <0.005, except 3 (0.006, 0.1, 0.011)							

Table J3. Descriptive statistics on mineral constituents.

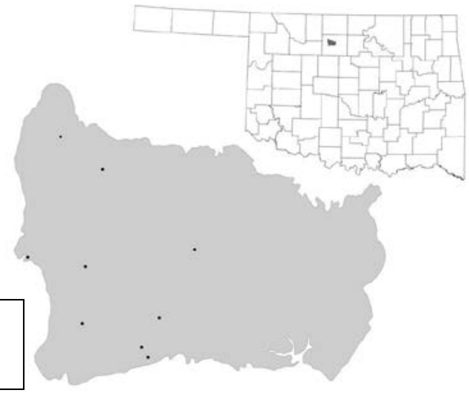
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	375	59.7	232	281	298	336	1090	
dissolved Calcium (mg/L)	65.4	2.90	45.4	59.3	67.2	70.7	81.8	
Chloride (mg/L)	13.1	3.84	<10	<10	10.6	13.6	58.4	SMCL: 250; 0 over
Fluoride (mg/L)	0.345	0.021	0.20	0.30	0.33	0.40	0.48	MCL: 4; 0 over
dissolved Magnesium (mg/L)	25.21	1.19	18.6	21.9	25.8	27.3	32.3	
dissolved Potassium (mg/L)	1.49	0.276	0.5	0.9	1.3	1.6	4.5	
dissolved Silica (mg/L)	25.1	0.372	22.8	24.4	25.1	26.0	27.2	
dissolved Sodium (mg/L)	35.1	4.16	13.3	24.1	36.5	44.3	68.2	
Sulfate (mg/L)	15.0	2.44	<10	<10	16.5	19.4	30.1	SMCL: 250; 0 over

Table J4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	409	50.8	85.9	304	447	550	629	MCL: 2000; 0 over
dissolved Boron (µg/L)	48.3	8.17	<50	<50	<50	68.4	118	HA: 6000; 0 over
dissolved Copper (µg/L)	5.12	1.17	<5	<5	<5	6.3	16.2	MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <50, except 1 (188)							SMCL: 300; 0 over
dissolved Uranium (µg/L)	2.05	0.940	<1	<1	1.4	2.0	10.6	MCL: 30; 0 over
dissolved Vanadium (µg/L)	18.8	1.53	<10	16.5	19.7	22.8	26	
dissolved Zinc (µg/L)	30.0	7.77	<10	<10	19.3	52	83.9	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix K– Descriptive Statistics for Enid Isolated Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
September 2014	9	15



General	Location	North Central Oklahoma
	Area	209.6 km^2
	Capacity	246 thousand acre-feet
	Primary Use	Irrigation; Public Supply; Domestic; Industrial
	Category	Isolated Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Beryllium, Cadmium, Chromium, Cobalt, Iron, Lead, Mercury, Molybdenum, Nickel, Selenium, & Silver.

Table K1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	49.5	2.76	32	40	50	60	70	N=17
Depth to Water (ft)	25.48	3.30	7.65	16.14	20.22	35.37	49.51	Below ground surface
Temperature (°C)	20.06	0.938	17.61	18.59	19.27	20.28	27.20	
Specific Conductance (µS/cm)	992	150	329	793	980	1340	1650	
Dissolved Oxygen (mg/L)	3.83	0.819	0.61	2.47	3.04	6.16	7.43	
pH (units)	6.73	0.054	6.43	6.64	6.75	6.85	6.97	
Oxidation Reduction Potential (mV)	412	3.34	400	409	416	416	418	N=5
Field Alkalinity (mg/L)	270	37.6	90.0	197	305	348	390	
Field Hardness (mg/L)	297	50.7	109	189	262	393	540	
Field calculated Bicarbonate (mg/L)	332	46.2	111	243	376	429	480	
Total Dissolved Solids (mg/L)	610	104	170	486	566	851	1050	SMCL: 500; 6 over

Table K2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	11.0	2.70	2.45	5.11	11.3	12.3	29.0	MCL: 10; 5 over
Phosphorus (mg/L)	0.120	0.029	<0.005	0.038	0.164	0.192	0.214	

Table K3. Descriptive statistics on mineral constituents.

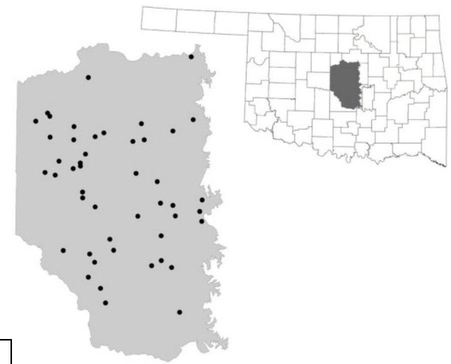
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	425	77.0	110	313	398	632	766	
dissolved Calcium (mg/L)	91.6	15.6	25.2	66.7	87.5	124	150	
Chloride (mg/L)	87.3	24.2	12.4	32.3	61.2	150	201	SMCL: 250; 0 over
Fluoride (mg/L)	0.171	0.023	<0.2	<0.2	0.21	0.22	0.27	MCL: 4; 0 over
dissolved Magnesium (mg/L)	19.1	2.81	8.1	13.5	18.8	22.1	36.7	
dissolved Potassium (mg/L)	2.72	0.179	1.6	2.7	2.9	3.1	3.2	
dissolved Silica (mg/L)	24.1	1.15	17.1	23.6	24.5	26.1	29.2	
dissolved Sodium (mg/L)	97.2	19.4	18.9	54.7	108	153	165	
Sulfate (mg/L)	85.4	22.5	20.5	30.8	75.8	125	193	SMCL: 250; 0 over

Table K4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Antimony (µg/L)	All Values <1, except 1 (1.1)							MCL: 6; 0 over
dissolved Arsenic (µg/L)	2.54	0.67	<1	1.3	2.4	2.5	7.8	MCL: 10; 0 over
dissolved Barium (µg/L)	225	48.0	64.7	90.2	249	287	496	MCL: 2000; 0 over
dissolved Boron (µg/L)	96.3	28.9	30.2	53.6	63.8	92.6	310	HA: 6000; 0 over
dissolved Copper (µg/L)	5.47	1.53	<5	<5	<5	8.8	13.2	MCL: 1300; 0 over
dissolved Manganese (µg/L)	All Values <5, except 2 (5.3, 17.8)							SMCL:50; 0 over.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								HA:300; 0 over.
dissolved Uranium (µg/L)	4.41	1.77	<1	1.2	2	6.1	16.9	MCL: 30; 0 over
dissolved Vanadium (µg/L)	8.29	1.33	<5	6.9	7.7	9	16.5	
dissolved Zinc (µg/L)	61.3	35.8	<5	<5	7.1	56.4	324	SMCL:5000; 0 over. HA:2000; 0 over

Appendix L– Descriptive Statistics for Garber-Wellington Aquifer



Baseline Sample Period	Sampling Sites	Water Level Sites
August-September 2013	47	61

General		
	Location	Central Oklahoma
	Area	5,544 km^2
	Capacity	5.01 million acre-feet
	Primary Use	Public Supply; Domestic; Industrial
	Category	Bedrock- inter-bedded sandstone/shale

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Cadmium, Cobalt, Mercury, Molybdenum, Nickel, Silver, & Thallium.

Table L1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	192	7.60	43	155	200	220	380	N=65
Depth to Water (ft)	77.30	5.53	20.19	50.51	69.94	89.78	228.1	Below ground surface
Temperature (°C)	17.39	0.229	13.61	16.33	17.25	18.89	20.07	
Specific Conductance (µS/cm)	728	73.0	233	472	617	821	2550	
Dissolved Oxygen (mg/L)	4.89	0.337	0.30	3.25	4.91	6.92	8.58	
pH (units)	6.95	0.075	5.82	6.81	6.97	7.16	8.85	
Field Alkalinity (mg/L)	268	14.8	44.0	214	284	326	450	
Field Hardness (mg/L)	278	30.1	31	137	261	326	1270	N=46
Field calculated Bicarbonate (mg/L)	322	18.2	54.3	263	350	400	554	
Total Dissolved Solids (mg/L)	419	53.0	123	244	328	447	2150	SMCL: 500; 9 over

Table L2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	1.84	0.399	<0.05	0.42	0.89	2.17	14.8	MCL: 10; 1 over
Phosphorus (mg/L)	0.019	0.005	<0.005	<0.005	<0.005	0.021	0.156	

Table L3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	425	42.9	139	272	335	486	1820	
dissolved Calcium (mg/L)	60.8	8.84	<5	26.4	55.6	73.7	409	
Chloride (mg/L)	47.0	11.8	<10	11.4	18.8	46.8	448	SMCL: 250; 2 over
Fluoride (mg/L)	0.194	0.028	<0.2	<0.2	<0.2	0.23	0.99	MCL: 4; 0 over
dissolved Magnesium (mg/L)	28.6	2.62	<5	13.3	27.9	34.8	79.1	
dissolved Potassium (mg/L)	1.52	0.106	<0.5	1.0	1.2	2.1	3.6	
dissolved Silica (mg/L)	18.6	0.632	10.1	16.0	17.8	21.4	30.3	
dissolved Sodium (mg/L)	63.5	10.0	7.2	15.1	31.8	85.7	318	
Sulfate (mg/L)	59.3	24.7	<10	7.9	17.4	26.5	1090	SMCL: 250; 2 over

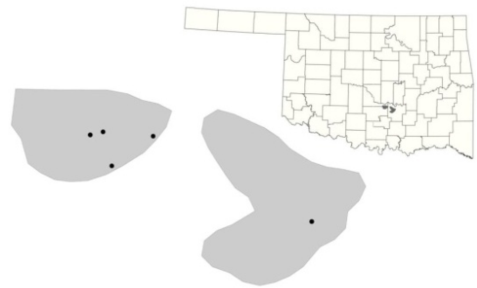
Table L4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All Values <10, except 1 (11.8)							MCL: 10; 1 over
dissolved Barium (µg/L)	302	32.6	<10	119	242	457	923	MCL: 2000; 0 over
dissolved Boron (µg/L)	253	65.7	<50	55.6	88.0	158	2450	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <5, except 3 (16.3, 16.5, 24.4)							MCL: 100; 0 over
dissolved Copper (µg/L)	11.0	2.19	<5	<5	<5	12.0	75.6	MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <50, except 5 (69.4, 81.1, 93, 109, 136)							SMCL: 300; 0 over
dissolved Lead (µg/L)	All Values <10, except 1 (12.7)							MCL: 15; 0 over
dissolved Manganese (µg/L)	All Values <50, except 1 (405)							SMCL: 50; 1 over. HA:

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								300; 1 over
dissolved Selenium (µg/L)	All Values <20, except 2 (28.4, 30.8)							MCL: 50; 0 over
dissolved Uranium (µg/L)	5.20	1.45	<1	<1	1.5	4.3	57	MCL: 30; 1 over
dissolved Vanadium (µg/L)	50.7	7.38	<10	13.6	52.6	65.9	296	
dissolved Zinc (µg/L)	27.7	5.48	<10	<10	<10	34.3	184	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix M– Descriptive Statistics for Gerty Sand Isolated Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August 2013	5	5



General	**Location**	South Central Oklahoma
	Area	284 km^2
	Capacity	224 thousand acre-feet
	Primary Use	Public Supply; Domestic; Irrigation
	Category	Isolated Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Arsenic, Beryllium, Boron, Cadmium, Chromium, Cobalt, Fluoride, Iron, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, & Thallium.

Table M1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	67.2	8.14	45	60	60	80	91	N=5
Depth to Water (ft)	42.23	7.07	15.95	44.30	45.53	46.55	58.80	Below ground surface
Temperature (°C)	22.35	1.56	19.38	20.19	20.8	23.37	27.99	
Specific Conductance (µS/cm)	550	56.0	433	456	492	684	687	
Dissolved Oxygen (mg/L)	3.49	1.15	0.69	0.95	4.25	5.11	6.48	
pH (units)	6.49	0.158	6.03	6.36	6.43	6.70	6.96	
Field Alkalinity (mg/L)	209	37.5	80.0	193	204	273	293	
Field Hardness (mg/L)	198	23.4	125	179	202	216	268	
Field calculated Bicarbonate (mg/L)	257	46.1	98.7	238	251	336	361	
Total Dissolved Solids (mg/L)	316	26.1	255	268	306	368	385	SMCL: 500; 0 over

Table M2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	2.81	0.786	0.62	2.08	2.12	4.57	4.67	MCL: 10; 0 over
Phosphorus (mg/L)	0.122	0.052	<0.005	0.038	0.133	0.136	0.301	

Table M3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	473	91.9	254	276	493	631	711	
dissolved Calcium (mg/L)	54.0	7.60	34.6	50.6	50.8	52.7	81.5	
Chloride (mg/L)	35.5	11.9	11.3	14.5	36.8	37.3	77.8	SMCL: 250; 0 over
dissolved Magnesium (mg/L)	14.9	2.24	9.1	10.8	16.5	16.8	21.5	
dissolved Potassium (mg/L)	1.88	0.389	1.2	1.5	1.6	1.7	3.4	
dissolved Silica (mg/L)	37.9	3.66	30.7	31.0	34.4	45.7	47.7	
dissolved Sodium (mg/L)	37.2	7.54	24.5	27.1	33.4	34.4	66.4	
Sulfate (mg/L)	13.7	1.34	10.1	12.8	13.0	14.3	18.3	SMCL: 250; 0 over

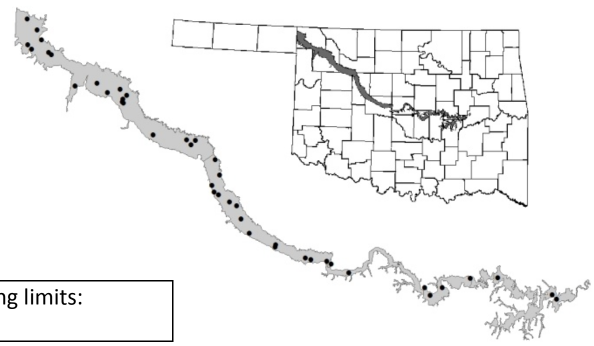
Table M4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	237	44.1	69.6	249	262	275	330	MCL: 2000; 0 over
dissolved Copper (µg/L)	14.1	5.36	<5	6	10.5	18.9	32.5	MCL: 1300; 0 over
dissolved Uranium (µg/L)	All Values <1, except 1 (2.2)							MCL: 30; 0 over
dissolved Vanadium (µg/L)	All Values <10, except 1 (10.7)							
dissolved Zinc (µg/L)	69.8	37.8	11.5	16.3	22.0	89.0	210	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix N– Descriptive Statistics for North Canadian River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August-September 2015	41	67

General	Location	runs Northwest through Central Oklahoma
	Area	4,427 km^2
	Capacity	8.21 million acre-feet
	Primary Use	Public Supply; Irrigation
	Category	Alluvial & Terrace



The following were sampled for and not found above laboratory reporting limits:
Aluminum, Antimony, Cadmium, Cobalt, Silver, & Thallium.

Table N1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	64.4	3.07	7.9	46.5	56	80	130	N=71
Depth to Water (ft)	22.47	1.69	6.59	11.88	17.98	32.34	59.83	Below ground surface
Temperature (°C)	19.55	0.321	16.62	18.36	18.99	20.23	25.95	
Specific Conductance (µS/cm)	835	84.8	183	437	684	1010	2620	
Dissolved Oxygen (mg/L)	5.22	0.504	0.09	2.29	6.28	7.75	9.33	N=40
pH (units)	6.84	0.052	6.17	6.68	6.88	7.12	7.28	SMCL: 6.5-8.5; 9 under
Oxidation Reduction Potential (mV)	314	18.7	53.2	284	345	394	504	N=40
Field Alkalinity (mg/L)	238	23.4	49.0	126	210	328	635	N=40
Field Hardness (mg/L)	329	31.8	48.0	171	283	444	930	
Field calculated Bicarbonate (mg/L)	290	28.5	60.0	153.8	256.5	400.3	775	N=40
Total Dissolved Solids (mg/L)	509	54.3	118	264	396	574	1670	SMCL: 500; 14 over

Table N2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 6 (0.22, 0.36, 0.37, 0.4, 0.55, 0.67)							
Nitrate+nitrite as N (mg/L)	6.27	0.792	<0.05	1.87	6.56	10.0	20.8	MCL: 10; 10 over
Phosphorus (mg/L)	0.113	0.014	0.025	0.061	0.095	0.136	0.433	

Table N3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	320	30.3	<100	199	278	380	759	
dissolved Calcium (mg/L)	85.7	7.21	10.4	59.9	80.7	108	212	
Chloride (mg/L)	46.7	8.70	<10	14.8	25.5	60.4	281	SMCL: 250; 1 over
Fluoride (mg/L)	0.247	0.038	<0.2	<0.2	<0.2	0.32	1.29	MCL: 4; 0 over
dissolved Magnesium (mg/L)	23.9	3.17	3.6	9.9	16.5	31.6	91.0	
dissolved Potassium (mg/L)	2.56	0.375	0.9	1.3	1.9	2.7	12.5	
dissolved Silica (mg/L)	29.1	1.03	21.7	24.9	27.7	30.3	54.9	
dissolved Sodium (mg/L)	51.1	9.54	9.1	20.7	27.9	47.2	276	
Sulfate (mg/L)	101	18.1	<10	23.9	48.5	147	454	SMCL: 250; 5 over

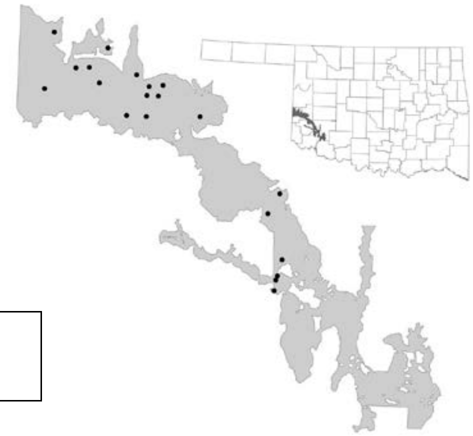
Table N4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.68	0.377	<1	<1	1.8	3.8	9.8	MCL: 10; 0 over
dissolved Barium (µg/L)	181	19.8	34.6	104	150	227	690	MCL: 2000; 0 over
dissolved Beryllium (µg/L)	All Values <1, except 1 (1.2)							MCL: 4; 0 over
dissolved Boron (µg/L)	109	19.7	<20	34.3	61.7	113	586	HA: 6000; 0 over
dissolved Chromium (µg/L)	11.2	2.03	<1	<1	5.4	17.7	45.1	MCL: 100; 0 over
dissolved Copper (µg/L)	5.45	1.83	<1	<1	1.6	4.2	59.9	MCL: 1300; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Iron (µg/L)	322	137	<20	<20	<20	29.4	5040	SMCL: 300; 8 over
dissolved Lead (µg/L)	All Values <0.5, except 10 (0.5, 0.6, 0.7, 0.7, 0.8, 0.8, 0.8, 1, 1.1, 1.4)							MCL: 15; 0 over
dissolved Manganese (µg/L)	139	53.8	<5	<5	<5	24.5	1850	SMCL:50; 10 over. HA:300; 7 over.
dissolved Mercury (µg/L)	All Values <0.05, except 1 (0.07)							MCL: 2; 0 over
dissolved Molybdenum (µg/L)	All Values <5, except 7 (5.6, 6.3, 7.5, 7.6, 7.7, 8.4, 9.5)							HA: 40; 0 over
dissolved Nickel (µg/L)	1.66	0.331	<1	<1	<1	1.8	8.7	HA: 100; 0 over
dissolved Selenium (µg/L)	3.39	0.924	<1	1.2	2.4	3.1	37.9	MCL: 50; 0 over.
dissolved Uranium (µg/L)	4.20	0.884	<1	<1	2.7	5.2	26.2	MCL: 30; 0 over
dissolved Vanadium (µg/L)	11.2	1.14	<5	6.3	8.4	15.9	28	
dissolved Zinc (µg/L)	27.0	8.40	<5	<5	7.5	25.5	252	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix O– Descriptive Statistics for North Fork of the Red River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July-August 2014	20	43



General	**Location**	runs through Southwestern Oklahoma
	Area	1,734 km^2
	Capacity	3.76 million acre-feet
	Primary Use	Public Supply; Domestic; Industrial; Irrigation
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Lead Mercury, Nickel, & Silver.

Table O1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	71.9	5.69	29	48	67	79	210	N=46
Depth to Water (ft)	36.6	3.23	10.60	20.19	33.09	44.19	113.20	Below ground surface
Temperature (°C)	21.5	0.548	18.94	20.14	21.12	22.17	30.64	
Specific Conductance (µS/cm)	1340	247	508	631	862	1840	4830	
Dissolved Oxygen (mg/L)	5.62	0.562	0.89	4.16	6.41	7.35	9.50	
pH (units)	7.06	0.026	6.85	6.99	7.06	7.16	7.26	
Oxidation Reduction Potential (mV)	419	10.4	316	393	426	447	502	
Field Alkalinity (mg/L)	225	10.5	134	199	232	252	331	
Field Hardness (mg/L)	487	68.6	187	265	342	794	1180	
Field calculated Bicarbonate (mg/L)	277	12.9	165	244	286	310	408	
Total Dissolved Solids (mg/L)	895	179	295	379	543	1230	3520	SMCL: 500; 11 over

Table O2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	8.29	1.06	0.83	5.58	7.95	10.73	19.4	MCL: 10; 7 over
Phosphorus (mg/L)	0.029	0.005	<0.005	0.015	0.023	0.042	0.103	

Table O3. Descriptive statistics on mineral constituents.

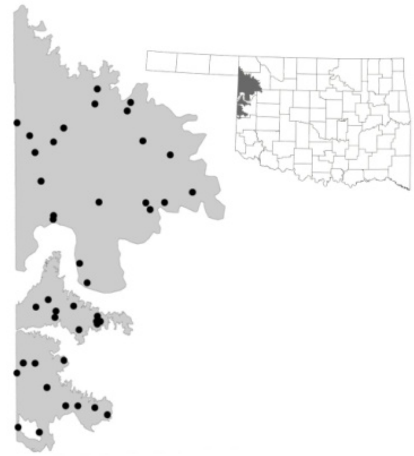
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	593	124	208	265	329	613	1960	
dissolved Calcium (mg/L)	121	15.0	53.2	71.8	94.9	172	312	
Chloride (mg/L)	138	57.5	<10	11.6	24.8	79.8	981	SMCL: 250; 3 over
Fluoride (mg/L)	0.295	0.043	<0.2	<0.2	0.28	0.42	0.74	MCL: 4; 0 over
dissolved Magnesium (mg/L)	34.6	5.73	10.3	17.0	23	46.9	81.6	
dissolved Potassium (mg/L)	2.56	0.429	<0.5	1.5	2.1	3.2	9.3	
dissolved Silica (mg/L)	23.2	2.15	9.95	13.9	24.9	27.4	43.7	
dissolved Sodium (mg/L)	114	45.6	4.4	23.9	37.4	102	905	
Sulfate (mg/L)	268	69.8	<10	38.4	142	383	1090	SMCL: 250; 7 over

Table O4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	1.92	0.393	<1	<1	1.6	2.6	7.6	MCL: 10; 0 over
dissolved Barium (µg/L)	131	30.1	10.8	38.6	89.0	173	577	MCL: 2000; 0 over
dissolved Boron (µg/L)	193	70.0	32.6	57.2	97.6	178	1460	HA: 6000; 0 over
dissolved Copper (µg/L)	All Values <5, except 3 (7.6, 27.7, 51.7)							MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <20, except 1 (32.9)							SMCL: 300; 0 over
dissolved Manganese (µg/L)	3.63	0.403	<5	<5	<5	5.5	7.6	SMCL: 50; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								HA: 300; 0 over
dissolved Molybdenum (µg/L)	All Values <5, except 1 (12.8)							HA: 40; 0 over
dissolved Selenium (µg/L)	All Values <10, except 2 (11.3, 19.9)							MCL: 50; 0 over
dissolved Uranium (µg/L)	4.07	0.782	<1	1.63	3.4	5.1	12.9	MCL: 30; 0 over
dissolved Vanadium (µg/L)	9.76	1.69	<5	<5	7.9	14.2	29.3	
dissolved Zinc (µg/L)	15.5	5.16	<5	<5	4.3	16.2	91.7	SMCL: 5000; 0 over HA: 2000; 0 over

Appendix P– Descriptive Statistics for Ogallala-Northwest Aquifer



Baseline Sample Period	Sampling Sites	Water Level Sites
August-September 2013	40	49

General	**Location**	Western Oklahoma
	Area	4,764 km^2 (includes Ogallala-Panhandle)
	Capacity	90.6 million acre-feet (includes Ogallala-Panhandle)
	Primary Use	Public Supply; Agriculture; Irrigation; Mining
	Category	Bedrock- semi-consolidated sand, gravel, clay

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, & Thallium.

Table P1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	169	10.2	30	120	155	213	340	N=52
Depth to Water (ft)	77.02	6.45	7.91	40.97	74.16	105.90	175.20	Below ground surface
Temperature (°C)	20.32	0.459	17.04	18.55	19.03	21.49	29.97	
Specific Conductance (µS/cm)	630	35.6	355	505	581	660	1680	
Dissolved Oxygen (mg/L)	7.22	0.250	1.44	6.82	7.68	8.00	9.86	
pH (units)	7.10	0.026	6.74	7.00	7.12	7.19	7.47	
Field Alkalinity (mg/L)	208	5.52	141	188	204	224	322	
Field Hardness (mg/L)	234	10.2	150	200	219	252	455	
Field calculated Bicarbonate (mg/L)	256	6.82	173	231	251	276	397	
Total Dissolved Solids (mg/L)	370	19.9	225	294	340	407	848	SMCL: 500; 6 over

Table P2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	7.85	1.03	0.92	3.45	6.02	9.94	26.8	MCL: 10; 10 over
Phosphorus (mg/L)	0.018	0.006	<0.005	<0.005	<0.005	0.016	0.240	

Table P3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	288	40.8	106	180	243	327	1770	
dissolved Calcium (mg/L)	75.2	3.11	38.7	62.7	72.2	83.1	139	
Chloride (mg/L)	25.8	6.09	<10	<10	14.2	29.7	207	SMCL: 250; 0 over
Fluoride (mg/L)	0.265	0.032	<0.2	<0.2	0.23	0.31	0.89	MCL: 4; 0 over
dissolved Magnesium (mg/L)	10.9	1.07	<5	7.2	9.3	13.4	10.3	
dissolved Potassium (mg/L)	2.54	0.267	0.8	1.6	2.1	2.5	8.7	
dissolved Silica (mg/L)	30.7	1.22	20.1	25.6	28.3	32.3	54.9	
dissolved Sodium (mg/L)	34.1	4.81	6.5	18.0	26.6	34.8	140	
Sulfate (mg/L)	23.7	4.12	<10	13.4	16.0	23.9	138	SMCL: 250; 0 over

Table P4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	337	25.5	57.6	216	316	427	750	MCL: 2000; 0 over
dissolved Boron (µg/L)	All Values <50, except 8 (50.1, 58.3, 59.5, 60.7, 61.7, 76.9, 83.5, 88.8)							HA: 6000; 0 over
dissolved Copper (µg/L)	All Values <5, except 7 (5.3, 6.3, 8.5, 9.1, 9.6, 10.9, 44.6)							MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <50, except 1 (61.2)							SMCL: 300; 0 over
dissolved Uranium (µg/L)	2.55	0.286	<1	1.4	2.0	3.0	8.6	MCL: 30; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Vanadium (µg/L)	15.8	1.39	<10	11.2	14.4	18.2	41.9	
dissolved Zinc (µg/L)	28.4	5.05	<10	<10	14.55	50.3	147	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix Q– Descriptive Statistics & Selected Maps for Ogallala-Panhandle Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July-October 2016	88	114

General	**Location**	Oklahoma Panhandle
	Area	18,034 km^2 (includes Ogallala-Northwest)
	Capacity	90.6 million acre-feet (includes Ogallala-Northwest)
	Primary Use	Crop Irrigation
	Category	Bedrock- semi-consolidated sand, gravel, clay

The following were sampled for and not found above laboratory reporting limits: Antimony, Beryllium, Boron, Cadmium, Cobalt, Iron, Mercury, Silver, Thallium, Thorium, & Titanium.

Table Q1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	328	10.8	60.0	240	320	400	696	N = 154
Depth to Water (ft)	175	7.72	6.20	115	181	236	355	Below ground surface
Temperature (°C)	19.5	0.190	15.6	18.2	19.2	20.3	24.9	
Specific Conductance (µS/cm)	642	21.7	336	510	591	690	1530	
Dissolved Oxygen (mg/L)	7.69	0.190	2.11	6.90	8.08	8.63	13.2	N = 87
pH (units)	7.30	0.032	6.39	7.19	7.38	7.51	7.97	SMCL: 6.5-8.5; 2 under, 0 over
Field Alkalinity (mg/L)	185	4.07	123	157	177	206	297	N= 87
Field Hardness (mg/L)	244	6.26	76.0	206	240	273	457	N= 87
Field calculated Bicarbonate (mg/L)	225	4.97	150	191	216	251	362	N=87
Total Dissolved Solids (mg/L)	399	14.5	170	324	377	435	996	SMCL: 500; 15 sites over
d18O isotope (‰)	-7.58	0.057	-9.06	-7.92	-7.58	-7.28	-6.33	
d2H isotope (‰)	-51.7	0.446	-63.9	-54.9	-51.4	-49.3	-38.4	

Table Q2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 1 (0.1)							
Nitrate+Nitrite as N (mg/L)	3.50	0.168	0.912	2.45	3.21	4.23	9.07	MCL: 10; 0 over
Phosphorus (mg/L)	All Values <0.015, except 8 (0.018, 0.026, 0.03, 0.031, 0.032, 0.032, 0.036, 0.116)							

Table Q3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	211	12.5	<250	<250	<250	291	553	
dissolved Calcium (mg/L)	53.4	1.94	8.78	39.2	51.1	63.9	118	
Chloride (mg/L)	36.2	5.00	2.66	13.7	19.8	41.6	318	SMCL: 250; 2 over
Fluoride (mg/L)	1.18	0.063	<0.2	0.71	1.21	1.59	2.52	MCL: 4; 0 over SMCL: 2; 8 over
dissolved Magnesium (mg/L)	26.3	0.968	7.09	21.8	26.2	31.1	58.6	
dissolved Potassium (mg/L)	4.09	0.109	1.12	3.39	4.11	4.69	7.63	
dissolved Silica (mg/L)	35.7	0.961	14.3	29.5	34.0	39.9	63.5	
dissolved Sodium (mg/L)	38.5	3.53	7.51	20.9	26.1	43.1	199	
Sulfate (mg/L)	75.3	6.05	7.90	34.1	56.5	104	309	SMCL: 250; 1 over

Table Q4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Aluminum (µg/L)	All Values <5, except 1 (5.21)							SMCL: 200; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	3.83	0.170	1.23	2.50	3.52	5.22	7.79	MCL: 10; 0 over
dissolved Barium (µg/L)	91.5	11.6	7.51	32.7	57.9	102	810	MCL: 2000; 0 over
dissolved Chromium (µg/L)	1.56	0.126	<1	<1	1.23	2.14	5.04	MCL: 100; 0 over
dissolved Copper (µg/L)	1.17	0.112	<1	<1	<1	1.54	5.39	MCL: 1300; 0 over SMCL: 1000; 0 over
dissolved Lead (µg/L)	All Values <1, except 1 (1.01)							MCL: 15; 0 over
dissolved Lithium (mg/L)	0.065	0.003	<0.02	0.040	0.060	0.090	0.170	
dissolved Manganese (µg/L)	All Values <1, except 10 (1.04, 1.1, 1.11, 1.19, 2.27, 2.78, 3.18, 3.42, 3.47, 5.98)							SMCL: 50; 0 over. HA: 300; 0 over
dissolved Molybdenum (µg/L)	4.79	0.339	<1	2.42	4.62	3.62	16.8	HA: 40; 0 over
dissolved Nickel (µg/L)	All Values <1, except 2 (2.06, 2.59)							HA: 100; 0 over
dissolved Selenium (µg/L)	4.95	0.374	<5	<5	<5	6.37	21.1	MCL: 50; 0 over
dissolved Strontium (mg/L)	1.28	0.060	0.26	1.01	1.20	1.45	3.58	HA: 4; 0 over
dissolved Uranium (µg/L)	8.19	0.499	1.48	5.29	7.52	9.59	31.0	MCL: 30; 1 over
dissolved Vanadium (µg/L)	16.6	0.881	2.64	10.5	15.5	22.8	43.0	
dissolved Zinc (µg/L)	All values <100, except 9 (123, 139, 149, 150, 219, 224, 225, 267, 282)							SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix R– Descriptive Statistics for Red River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August 2015	36	38

General		
	Location	runs along the southern Oklahoma state line
	Area	3,794 km^2
	Capacity	2.58 million acre-feet
	Primary Use	Public Supply; Domestic; Agricultural; Irrigation; Industrial
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Mercury, Molybdenum, Silver, & Thallium.

Table R1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	63.8	3.92	28.5	46	55	78	142	N=45
Depth to Water (ft)	27.54	2.63	4.50	14.21	24.42	40.64	57.99	Below ground surface
Temperature (°C)	20.88	0.298	18.61	19.46	20.08	22.16	25.65	
Specific Conductance (µS/cm)	610	75.6	73.8	286	498	856	2200	
Dissolved Oxygen (mg/L)	4.36	0.484	0.22	1.68	4.34	6.90	9.57	
pH (units)	6.61	0.099	5.05	6.12	6.72	7.01	7.53	SMCL: 6.5-8.5; 12 under
Oxidation Reduction Potential (mV)	327	14.8	80.9	313	344	380	499	
Field Alkalinity (mg/L)	159	23.3	12.0	54.7	106	258	521	N=35
Field Hardness (mg/L)	184	22.0	33.0	79.8	156	240	539	
Field calculated Bicarbonate (mg/L)	194	28.4	15.0	66.5	129	315	636	N=35
Total Dissolved Solids (mg/L)	360	41.8	65.0	174	296	486	1200	SMCL: 500; 9 over

Table R2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 1 (0.3)							
Nitrate+nitrite as N (mg/L)	8.70	1.19	<0.05	1.27	8.52	14.9	22.3	MCL: 10; 14 over
Phosphorus (mg/L)	0.058	0.008	<0.005	0.030	0.046	0.074	0.252	

Table R3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	399	65.9	<100	180	271	467	2180	
dissolved Calcium (mg/L)	45.7	4.97	5.6	19.6	41.8	67.7	106	
Chloride (mg/L)	45.8	12.1	<10	<10	18.1	35.4	318	SMCL: 250; 1 over
Fluoride (mg/L)	All Values <0.2, except 7 (0.26, 0.27, 0.33, 0.44, 0.73, 0.87, 1.59)							MCL: 4; 0 over
dissolved Magnesium (mg/L)	15.5	2.29	1.4	5.4	11.9	22.4	60.8	
dissolved Potassium (mg/L)	1.18	0.09	<0.5	0.9	1.1	1.6	2.2	
dissolved Silica (mg/L)	25.3	1.49	11.6	19.5	24.3	28.6	60.3	
dissolved Sodium (mg/L)	54.9	12.9	2.7	13.2	21.9	50.6	349	
Sulfate (mg/L)	31.0	5.43	<10	11.7	18.1	39.2	128	SMCL: 250; 0 over

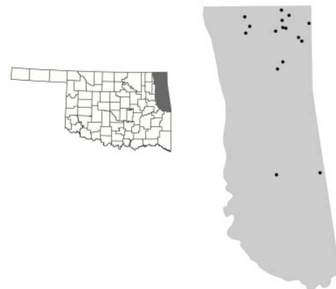
Table R4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	0.972	0.145	<1	<1	<1	1.2	4.1	MCL: 10; 0 over
dissolved Barium (µg/L)	172	20.5	13.4	96.5	147	218	575	MCL: 2000; 0 over
dissolved Boron (µg/L)	107	47.6	<20	<20	32.7	57.5	1700	HA: 6000; 0 over
dissolved Chromium (µg/L)	3.59	1.12	<1	<1	<1	2.4	31	MCL: 100; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Copper (µg/L)	14.7	6.34	<1	1.2	2.9	7.4	211	MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <20, except 8 (22.5, 23.5, 50.8, 82, 108, 671, 1000, 3880)							SMCL: 300; 3 over
dissolved Lead (µg/L)	All Values <0.5, except 8 (0.64, 1, 1, 1.3, 1.7, 1.7, 2.3, 2.5)							MCL: 15; 0 over
dissolved Manganese (µg/L)	61.6	30.8	<5	<5	<5	10.5	956	SMCL: 50; 4 over. HA:300; 2 over.
dissolved Nickel (µg/L)	0.914	0.138	<1	<1	<1	1.03	4.2	HA: 100; 0 over
dissolved Selenium (µg/L)	3.38	0.632	<1	1.7	2.4	3.3	21.3	MCL: 50; 0 over.
dissolved Uranium (µg/L)	1.87	0.424	<1	<1	<1	2.6	10.1	MCL: 30; 0 over
dissolved Vanadium (µg/L)	All Values <5, except 7 (5.2, 8.4, 8.4, 9.3, 14, 20.2, 20.7)							
dissolved Zinc (µg/L)	38.2	16.8	<5	<5	11.1	30.7	606	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix S– Descriptive Statistics & Selected Maps for Roubidoux Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
September-November 2017	17	9



General	**Location**	runs through Northeast Oklahoma
	Area	11,655 km^2
	Capacity	43 million acre-feet
	Primary Use	Public Supply
	Category	Bedrock

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Manganese, Mercury, Nickel, Silver, Thallium, & Uranium

Table S1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	1137	56	600	1011	1145	1328	1526	N = 20
Depth to Water (ft)	240.40	29.46	127.92	169.05	216.39	318.66	392.50	Below ground surface N = 9
Temperature (°C)	20.30	0.59	16.17	19.20	19.84	21.34	25.55	
Specific Conductance (µS/cm)	873.76	167.50	277.70	298.80	553.30	1328.95	2337.00	
Dissolved Oxygen (mg/L)	2.06	0.82	0.20	0.40	0.55	1.83	12.20	
pH (units)	7.72	0.10	7.09	7.47	7.72	7.92	8.91	SMCL: 6.5-8.5; 0 under, 1 over
Field Alkalinity (mg/L)	157	19	81	109	138	187	390	
Field Hardness (mg/L)	159	22	38	118	141	201	435	
Field Calculated Bicarbonate (mg/L)	182	24	22	129	150	222	476	
Total Dissolved Solids (mg/L)	474	89	136	173	330	680	1281	SMCL: 500; 8 sites over

Table S2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	0.14	0.04	<0.05	<0.05	0.07	0.21	0.48	HA: 30; 0 over
Nitrate+Nitrite as N (mg/L)	All values <0.05, except 1 (0.10)							MCL: 10; 0 over
Phosphorus (mg/L)	All values <0.015, except 1 (0.029)							

Table S3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	0.57	0.11	<0.50	<0.50	<0.50	0.90	1.5	
dissolved Calcium (mg/L)	39.8	5.83	11.0	28.2	29.4	51.1	100	
Chloride (mg/L)	148	46.1	5.73	10.9	27.4	258	605	SMCL: 250; 1 over
Fluoride (mg/L)	1.3	0.39	<0.10	0.21	0.42	1.9	5.4	MCL: 4; 0 over. SMCL: 2; 0 over
dissolved Magnesium (mg/L)	13.6	2.10	1.52	8.86	13.1	14.3	41.2	
dissolved Potassium (mg/L)	3.66	0.680	0.660	1.51	2.32	4.93	10.0	
dissolved Silica (mg/L)	9.73	0.170	8.33	9.44	9.60	10.2	11.1	
dissolved Sodium (mg/L)	122	37.0	6.36	10.4	25.0	220	447	
Sulfate (mg/L)	23.3	12.8	1.99	8.57	12.4	13.8	227	SMCL: 250; 0 over

Table S4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	1.05	0.24	<1.00	<1.00	<1.00	1.59	3.76	MCL: 10; 0 over
dissolved Barium (µg/L)	75.7	30.2	9.55	13.4	33.4	65.1	498	MCL: 2000; 0 over
dissolved Boron (µg/L)	339	110	10.0	45.6	90.1	617	1370	HA: 6000; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Chromium (µg/L)	4.18	1.08	<1.00	1.08	2.20	7.17	16.4	MCL: 100; 0 over
dissolved Chromium VI (µg/L)	All values <0.1, except 1 (0.69)							
dissolved Copper (µg/L)	All values <1, except 2 (1.05, 2.42)							MCL: 1300; 0 over SMCL: 1000; 0 over
dissolved Iron (µg/L)	78.8	35.3	<20.0	<20.0	36.3	74.1	614	SMCL: 300; 1 over
dissolved Lead (µg/L)	All values <1, except 2 (1.34, 1.48)							MCL: 15; 0 over
dissolved Molybdenum (µg/L)	1.42	0.480	<1.00	<1.00	<1.00	<1.00	2.54	HA: 40; 0 over
dissolved Radium-226 & Radium-228 (combined) (pCi/L)	2.5	0.57	<0.50	<0.50	1.4	4.1	8.3	MCL: 5 pCi/L; 3 over ±1
dissolved Vanadium (µg/L)	1.50	0.440	<1.00	<1.00	<1.00	2.06	7.04	
dissolved Zinc (µg/L)	All values <35, except 2 (110, 165)							SMCL: 5000; 0 over. HA: 2000; 0 over

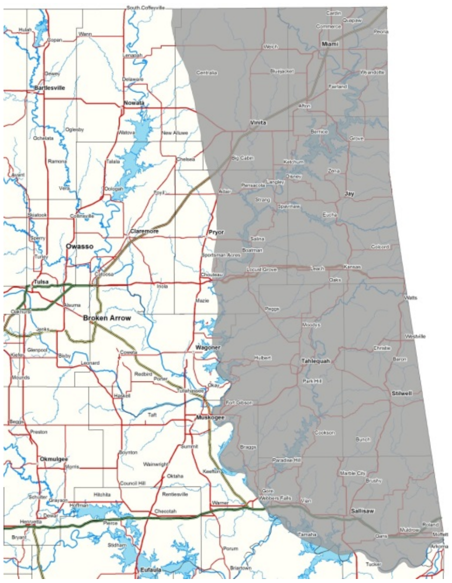


Figure S1. Location and extent of the RBDX.

Figure S2. Calcium (left) and magnesium concentrations in the RBDX.

Figure S3. Sodium+potassium (left) and bicarbonate concentrations in the RBDX.

Figure S4. Chloride (left) and sulfate concentrations in the RBDX.

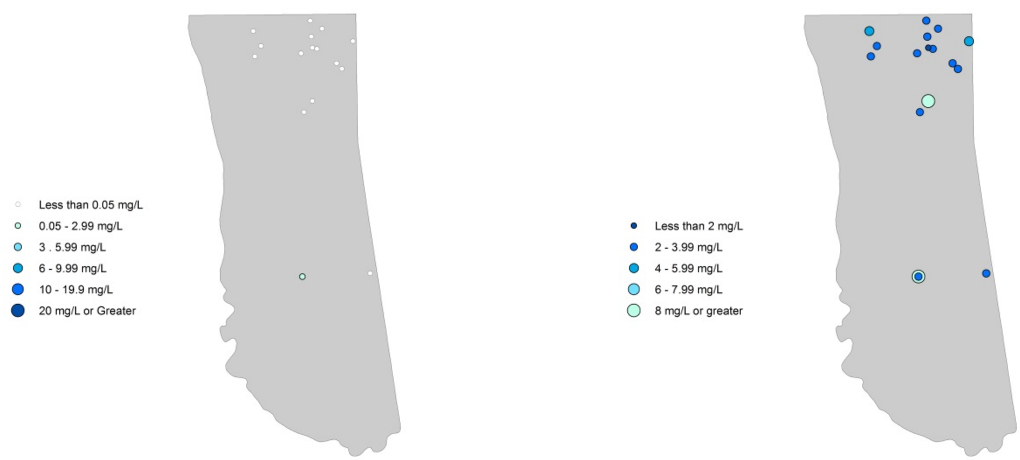


Figure S5. Nitrate+nitrite-N (left) and dissolved oxygen concentrations in the RBDX.

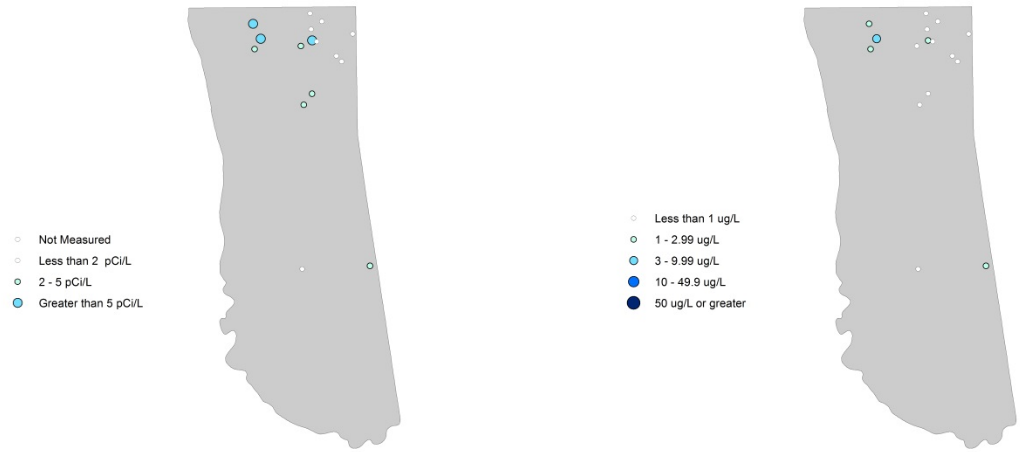
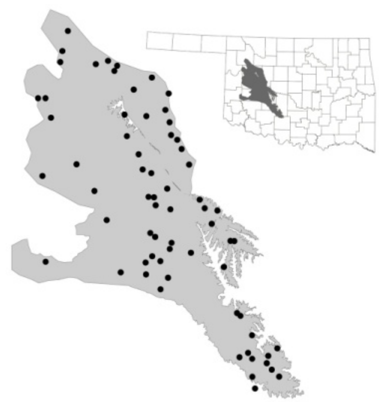


Figure S6. Combined radium (226+228) (left) and arsenic concentrations in the RBDX.

Appendix T– Descriptive Statistics for Rush Springs Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
September-October 2013	64	107



General	Location	Southwestern Oklahoma
	Area	6297 km^2
	Capacity	80 million acre-feet
	Primary Use	Public Supply; Domestic; Irrigation; Industrial
	Category	Bedrock- sandstone

The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Manganese, Mercury, Nickel, Selenium, Silver, & Thallium.

Table T1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	221	10.6	30	137.5	200	292	800	N=123
Depth to Water (ft)	62.4	3.43	7.75	37.00	58.88	82.64	196.6	Below ground surface
Temperature (°C)	19.6	0.182	15.22	18.79	19.56	20.32	23.87	
Specific Conductance (µS/cm)	1080	121	102	457	660	1450	5870	
Dissolved Oxygen (mg/L)	6.91	0.289	0.17	6.09	7.55	8.34	10.77	
pH (units)	7.19	0.028	6.46	7.05	7.18	7.30	7.72	
Field Alkalinity (mg/L)	188	8.34	25.0	150	183	219	384	
Field Hardness (mg/L)	558	68.9	139	201	302	625	2000	N=63
Field calculated Bicarbonate (mg/L)	231	10.3	30.5	185	225	270	473	
Total Dissolved Solids (mg/L)	866	115	178	274	427	1130	4680	SMCL: 500; 26 over

Table T2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All Values <0.1, except 1 (0.17)							
Nitrate+nitrite as N (mg/L)	7.17	1.21	0.24	1.79	4.46	8.23	59.2	MCL: 10; 12 over
Phosphorus (mg/L)	0.015	0.004	<0.005	<0.005	<0.005	0.009	0.217	

Table T3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	288	20.6	121	196	249	320	1200	
dissolved Calcium (mg/L)	173	22.1	31.2	53.1	78.5	232	556	
Chloride (mg/L)	31.6	12.7	<10	<10	11.8	25.8	812	SMCL: 250; 1 over
Fluoride (mg/L)	0.211	0.016	<0.2	<0.2	0.22	0.26	0.52	MCL: 4; 0 over
dissolved Magnesium (mg/L)	29.1	3.29	<5	13.3	18.6	29.1	128	
dissolved Potassium (mg/L)	1.49	0.122	<0.5	0.9	1.3	1.6	6.0	
dissolved Silica (mg/L)	27.9	0.760	11.4	25.2	27.5	30.2	48.4	
dissolved Sodium (mg/L)	44.6	13.7	8.4	18.6	25.4	35.5	890	
Sulfate (mg/L)	401	75.7	<10	16.6	61.4	627	2300	SMCL: 250; 20 over

Table T4. Descriptive statistics on metal constituents.

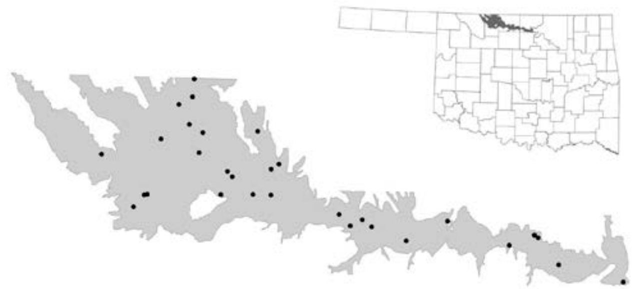
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All Values <10, except 4 (10.7,12.8,13.1,16.5)							MCL: 10; 4 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	150	21.9	<10	16.5	105	189	859	MCL: 2000; 0 over
dissolved Boron (µg/L)	120	28.1	<50	<50	53.9	129	1710	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <5, except 8 (11.8, 23.7, 5.2,5.5,6.2,16.1,5.5,5.8)							MCL: 100; 0 over
dissolved Copper (µg/L)	All Values <5, except 7 (6.3, 5.3, 15.5, 9.5,8.3,8.1,15.1)							MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <50, except 6 (84.2, 111, 117, 126, 298, 435)							SMCL: 300; 1 over
dissolved Lead (µg/L)	All Values <10, except 1 (19.7)							MCL: 15; 1 over
dissolved Molybdenum (µg/L)	All Values <10, except 1 (26)							HA: 40; 0 over
dissolved Uranium (µg/L)	4.47	0.660	<1	1.2	2.6	5.8	27.2	MCL: 30; 0 over
dissolved Vanadium (µg/L)	14.4	1.11	<10	<10	13.4	17.7	40.2	
dissolved Zinc (µg/L)	21.2	5.15	<10	<10	<10	17.6	299	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix U– Descriptive Statistics for Salt Fork of the Arkansas River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July 2014	30	46

General	Location	runs through North Central Oklahoma
	Area	2,209 km^2
	Capacity	2.18 million acre-feet
	Primary Use	Public Supply; Domestic; Agriculture
	Category	Alluvial & Terrace



The following were sampled for and not found above laboratory reporting limits: Aluminum, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Lead, Mercury, Nickel, & Silver.

Table U1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	44.4	1.66	24	36.8	42.5	50	97	N=51
Depth to Water (ft)	15.56	0.857	-0.38	12.36	15.80	19.54	30.20	Below ground surface
Temperature (°C)	20.76	0.391	17.68	19.29	20.51	21.49	26.96	
Specific Conductance (µS/cm)	1150	109	107	783	1040	1530	2290	
Dissolved Oxygen (mg/L)	2.34	0.403	0.18	0.44	1.44	3.92	7.45	
pH (units)	7.09	0.046	6.30	7.01	7.13	7.25	7.40	
Oxidation Reduction Potential (mV)	242	22.1	45.0	213	260	280	359	N=14
Field Alkalinity (mg/L)	315	22.6	28.0	224	332	414	492	
Field Hardness (mg/L)	370	34.9	41.0	234	348	466	872	
Field calculated Bicarbonate (mg/L)	388	32.5	34.5	275	408	509	605	
Total Dissolved Solids (mg/L)	657	66.8	86.3	426	552	843	1470	SMCL: 500; 18 over

Table U2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	All values <0.1, except 2 (0.14, 0.2)							
Nitrate+nitrite as N (mg/L)	5.03	0.968	<0.05	0.91	4.14	6.89	20.0	MCL: 10; 5 over
Phosphorus (mg/L)	0.096	0.014	<0.005	0.048	0.066	0.127	0.311	

Table U3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	477	64.5	<100	263	419	603	1720	
dissolved Calcium (mg/L)	75.4	5.21	10.4	55.6	76.1	98.6	117	
Chloride (mg/L)	98.9	20.6	<10	23.7	55.3	96.7	398	SMCL: 250; 5 over
Fluoride (mg/L)	0.413	0.050	<0.2	0.26	0.31	0.54	1.37	MCL: 4; 0 over
dissolved Magnesium (mg/L)	40.0	5.83	2.0	20.4	31.0	53.3	138	
dissolved Potassium (mg/L)	2.24	0.475	<0.5	1.2	1.4	2.3	14.9	
dissolved Silica (mg/L)	18.1	0.771	12.2	15.5	17.7	19.8	34.0	
dissolved Sodium (mg/L)	113	15.9	6.6	49.8	94.2	147	307	
Sulfate (mg/L)	115	23.4	<10	38.3	66.1	129	508	SMCL: 250; 4 over

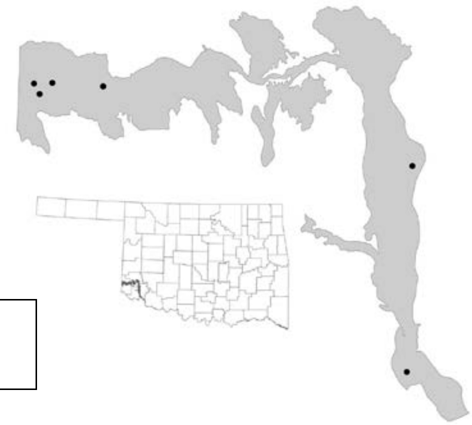
Table U4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.72	0.433	<1	1.23	2	3.28	10.3	MCL: 10; 1 over
dissolved Barium (µg/L)	144	18.1	23.5	71.6	125	183	387	MCL: 2000; 0 over
dissolved Boron (µg/L)	144	16.7	<20	71.2	121	200	377	HA: 6000; 0 over
dissolved Copper (µg/L)	All Values <5, except 4 (5.1, 5.5, 11.7, 16.5)							MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <20, except 5 (58.3, 316, 575, 1720, 2510)							SMCL: 300; 4 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Manganese (µg/L)	74.1	33.8	<5	<5	<5	11.0	811	SMCL: 50; 6 over HA: 300; 3 over
dissolved Molybdenum (µg/L)	All Values <5, except 6 (5.1, 5.2, 5.7, 5.9, 6.7, 7.1)							HA:40; 0 over
dissolved Selenium (µg/L)	All Values <10, except 5 (12.2, 22.3, 36.2, 43.9, 49.1)							MCL: 50; 0 over
dissolved Uranium (µg/L)	8.24	1.54	<1	1.9	4.7	14.5	30.9	MCL: 30; 1 over
dissolved Vanadium (µg/L)	5.99	0.768	<5	<5	5.9	7.4	18.3	
dissolved Zinc (µg/L)	28.0	6.81	<5	<5	7.1	36.6	125	SMCL: 5000; 0 over HA: 2000; 0 over

Appendix V– Descriptive Statistics for Salt Fork of the Red River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August 2014	6	6



General	Location	runs through Southwestern Oklahoma
	Area	754.3 km^2
	Capacity	not available
	Primary Use	Agriculture
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Lead, Mercury, Nickel, & Silver.

Table V1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	100	22.7	40	55	80	98	230	N=9
Depth to Water (ft)	40.83	10.6	8.15	18.65	47.62	58.99	69.80	Below ground surface
Temperature (°C)	21.2	0.775	18.36	20.09	21.90	21.97	23.54	
Specific Conductance (µS/cm)	2340	1260	488	532	635	3300	7960	
Dissolved Oxygen (mg/L)	5.77	1.27	0.17	5.28	6.49	7.03	9.40	
pH (units)	7.03	0.096	6.67	6.89	7.06	7.22	7.27	
Oxidation Reduction Potential (mV)	370	42.5	189	332	420	425	463	
Field Alkalinity (mg/L)	229	14.2	183	210	228	244	284	
Field Hardness (mg/L)	787	369	182	233	260	1163	2330	
Field calculated Bicarbonate (mg/L)	282	17.6	225	259	281	300	350	
Total Dissolved Solids (mg/L)	1750	966	303	352	403	2350	6080	SMCL: 500; 2 over

Table V2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	10.1	1.23	6.26	8.71	9.73	11.2	15.1	MCL: 10; 3 over
Phosphorus (mg/L)	0.034	0.010	<0.005	0.013	0.044	0.050	0.059	

Table V3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	1480	949	265	295	302	1280	6100	
dissolved Calcium (mg/L)	161	58.7	56.6	72.3	78.2	237	394	
Chloride (mg/L)	340	235	<10	<10	<10	466	1400	SMCL: 250; 2 over
Fluoride (mg/L)	0.330	0.059	<0.2	0.26	0.35	0.45	0.48	MCL: 4; 0 over
dissolved Magnesium (mg/L)	68.2	39.1	9.2	10.5	13.3	94.7	242	
dissolved Potassium (mg/L)	3.73	0.881	2.0	2.2	2.7	5.3	6.9	
dissolved Silica (mg/L)	19.2	4.00	7.12	11.6	19.7	26.3	31.3	
dissolved Sodium (mg/L)	275	169	29.7	30.9	36.0	368	1040	
Sulfate (mg/L)	648	420	27.2	34.6	37.8	948	2500	SMCL: 250; 2 over

Table V4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.97	0.983	1.3	1.5	1.8	3.6	7.4	MCL: 10; 0 over
dissolved Barium (µg/L)	104	31.6	10.1	33.0	130	165	178	MCL: 2000; 0 over
dissolved Boron (µg/L)	360	188	48.1	80.7	94.4	537	1160	HA: 6000; 0 over
dissolved Copper (µg/L)	All values <5, except 1 (10)							MCL: 1300; 0 over
dissolved Iron (µg/L)	All values < 20, except 1 (304)							SMCL: 300; 1 over
dissolved Manganese (µg/L)	113	52.6	<5	<5	<5	125	504	SMCL: 50; 2 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								HA: 300; 1 over
dissolved Molybdenum (µg/L)	All values <5, except 1 (6)							HA: 40; 0 over
dissolved Selenium (µg/L)	15.3	9.23	<10	<10	<10	9.1	61.2	MCL: 50; 1 over
dissolved Uranium (µg/L)	9.15	4.52	<1	1.9	4.2	13.0	28.9	MCL: 30; 0 over
dissolved Vanadium (µg/L)	21.3	11.4	5.2	6.6	7.0	21.3	76.1	
dissolved Zinc (µg/L)	14.1	4.66	<5	<5	12.0	23.2	28.8	SMCL: 5000; 0 over HA: 2000; 0 over

Appendix W– Descriptive Statistics for Tillman Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
August 2014	8	17

General	**Location**	Southwestern Oklahoma
	Area	751.3 km^2
	Capacity	1.28 million acre-feet
	Primary Use	Irrigation; Public Supply; Domestic
	Category	Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, & Silver.

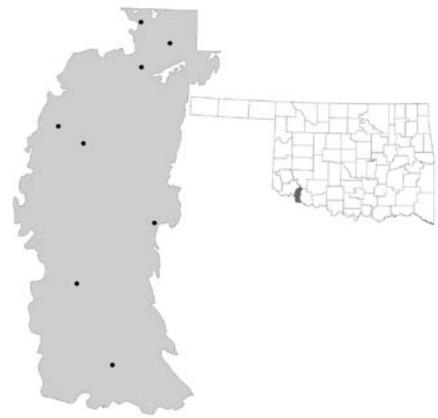


Table W1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	50.9	2.90	30	41	52	60	70	N=19
Depth to Water (ft)	27.01	2.48	9.43	18.58	28.31	31.19	44.97	Below ground surface
Temperature (°C)	22.98	0.640	20.90	21.68	22.59	23.81	26.06	
Specific Conductance (µS/cm)	1710	472	729	940	1230	1890	4810	
Dissolved Oxygen (mg/L)	4.89	1.07	0.23	3.64	5.96	7.15	7.45	
pH (units)	7.09	0.027	6.99	7.02	7.12	7.16	7.17	
Oxidation Reduction Potential (mV)	340	31.0	162	301	361	402	431	
Field Alkalinity (mg/L)	327	29.8	267	275	286	361	464	N=7
Field Hardness (mg/L)	451	77.6	300	334	390	453	895	N=7
Field calculated Bicarbonate (mg/L)	402	36.7	329	338	352	444	571	N=7
Total Dissolved Solids (mg/L)	1020	310	395	546	700	1110	3090	SMCL: 500; 7 over

Table W2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	13.9	3.05	0.10	9.56	13.9	20.4	24.5	MCL: 10; 6 over
Phosphorus (mg/L)	0.018	0.009	<0.005	<0.005	0.009	0.018	0.076	

Table W3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	1020	334	355	534	625	1160	3210	
dissolved Calcium (mg/L)	91.8	14.7	57.7	71.9	78.7	90.8	190	
Chloride (mg/L)	216	98.24	<10	41.5	127	268	849	SMCL: 250; 3 over
Fluoride (mg/L)	0.505	0.111	<0.2	0.27	0.50	0.67	1.05	MCL: 4; 0 over
dissolved Magnesium (mg/L)	39.6	5.64	23.4	27.1	38.0	43.1	70.2	
dissolved Potassium (mg/L)	2.59	0.538	0.9	1.6	2.2	3.4	5.6	
dissolved Silica (mg/L)	18.9	1.01	14.8	16.9	19.0	21.0	22.8	
dissolved Sodium (mg/L)	229	91.7	15.1	70.0	164	256	830	
Sulfate (mg/L)	199	104	25.8	52.0	103	172	912	SMCL: 250; 1 over

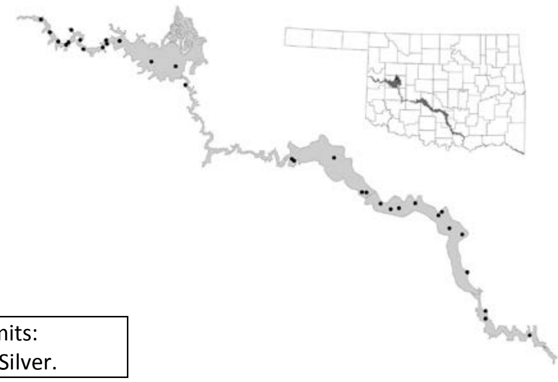
Table W4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.15	0.306	1.3	1.5	2.1	2.4	4.0	MCL: 10; 0 over
dissolved Barium (µg/L)	109	26.4	31.3	61.1	90.2	142	256	MCL: 2000; 0 over
dissolved Boron (µg/L)	257	41.1	108	127	320	348	359	HA: 6000; 0 over
dissolved Iron (µg/L)	All Values <20, except 2 (21.7, 421)							SMCL: 300; 1 over
dissolved Manganese (µg/L)	All Values <5, except 2 (23.8, 281)							SMCL: 50; 1 over HA: 300; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Uranium (µg/L)	9.73	2.31	1.8	6.2	9.2	11.9	22.5	MCL: 30; 0 over
dissolved Vanadium (µg/L)	8.40	1.44	<5	6.1	7.3	11.4	15.0	
dissolved Zinc (µg/L)	24.5	8.70	<5	<5	15.2	47.9	62.1	SMCL: 5000; 0 over HA: 2000; 0 over

Appendix X– Descriptive Statistics for Washita River Alluvial and Terrace Aquifer

Baseline Sample Period	Sampling Sites	Water Level Sites
July-August 2014	31	30



General	Location	runs West Central - South Central Oklahoma
	Area	2,452 km^2
	Capacity	4.92 million acre-feet
	Primary Use	Public Supply; Domestic; Irrigation; Industrial
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits:
Aluminum, Antimony, Beryllium, Cadmium, Cobalt, Lead, Mercury, Nickel, & Silver.

Table X1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	95.9	6.27	28	70	85	111	190	N=42
Depth to Water (ft)	24.78	2.77	4.60	13.26	23.99	30.07	67.75	Below ground surface
Temperature (°C)	19.86	0.325	17.48	18.68	19.35	20.55	25.40	
Specific Conductance (µS/cm)	1900	205	232	894	1740	2870	4070	
Dissolved Oxygen (mg/L)	2.06	0.365	0.25	0.46	0.82	3.68	7.50	
pH (units)	7.18	0.043	6.52	7.00	7.21	7.37	7.57	
Oxidation Reduction Potential (mV)	242	22.2	202	224	245	262	279	N=3
Field Alkalinity (mg/L)	298	30.8	35.4	176	264	411	720	
Field Hardness (mg/L)	1030	117	142	447	1030	1660	1920	
Field calculated Bicarbonate (mg/L)	366	37.9	43.4	216	325	505	886	
Total Dissolved Solids (mg/L)	1550	214	138	510	990	2740	3650	SMCL: 500; 24 over

Table X2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia as N (mg/L)	0.154	0.036	<0.1	<0.1	<0.1	0.14	0.74	
Nitrate+nitrite as N (mg/L)	2.33	0.719	<0.05	<0.05	0.88	2.79	18.7	MCL: 10; 2 over
Phosphorus (mg/L)	0.082	0.019	<0.005	0.014	0.040	0.093	0.382	

Table X3. Descriptive statistics on mineral constituents.

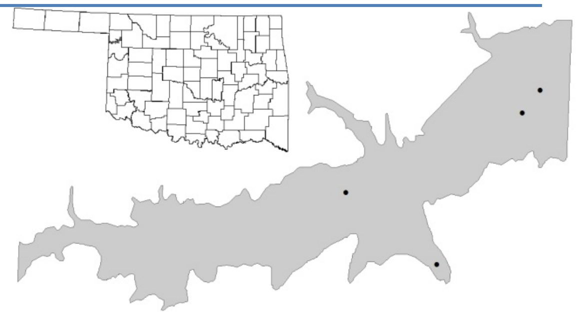
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	538	97.1	124	294	363	466	2570	
dissolved Calcium (mg/L)	209	27.0	24.5	81.4	127	364	534	
Chloride (mg/L)	50.0	13.6	<10	17.1	31.0	47.4	412	SMCL: 250; 1 over
Fluoride (mg/L)	0.231	0.027	<0.2	<0.2	0.23	0.28	0.7	MCL: 4; 0 over
dissolved Magnesium (mg/L)	85.5	8.97	5.3	43.8	85.6	127	172	
dissolved Potassium (mg/L)	2.08	0.169	<0.5	1.6	2.0	2.4	4.0	
dissolved Silica (mg/L)	22.3	1.39	8.92	18.4	21.3	35.3	41.6	
dissolved Sodium (mg/L)	89.8	16.0	5.3	29.1	58.1	108	365	
Sulfate (mg/L)	804	158	<10	28.9	111	1760	2300	SMCL: 250; 15 over

Table X4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.68	0.339	<1	1.2	2.5	4.1	8.7	MCL: 10; 0 over
dissolved Barium (µg/L)	142	30.9	<5	11.1	82.4	210	524	MCL: 2000; 0 over
dissolved Boron (µg/L)	509	99.3	30.6	122	332	618	2070	HA: 6000; 0 over
dissolved Chromium (µg/L)	All Values <5, except 1 (18)							MCL: 100; 0 over
dissolved Copper (µg/L)	All Values <5, except 4 (5.6, 6, 7.1, 8.4)							MCL: 1300; 0 over
dissolved Iron (µg/L)	365	91.9	<20	<20	27.2	688	1580	SMCL: 300; 10 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Manganese (µg/L)	202	48.0	<5	7.3	34.0	354	1070	SMCL: 50, 15 over. HA:300; 10 over
dissolved Molybdenum (µg/L)	4.62	0.661	<5	<5	<5	5.8	15.8	HA: 40; 0 over
dissolved Selenium (µg/L)	All Values <10, except 1 (10)							MCL: 50; 0 over
dissolved Uranium (µg/L)	6.31	1.43	<1	<1	4.6	8.2	40.7	MCL: 30; 1 over
dissolved Vanadium (µg/L)	10.5	1.82	<5	<5	8.0	14.2	37.6	
dissolved Zinc (µg/L)	27.9	15.0	<5	<5	<5	10.0	460	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix Y– Descriptive Statistics for Wolf Creek Alluvial and Terrace Aquifer



Baseline Sample Period	Sampling Sites	Water Level Sites
September 2015	4	7

General		
	Location	Northwest Oklahoma
	Area	211 km^2
	Capacity	not available
	Primary Use	Domestic; Agriculture
	Category	Alluvial & Terrace

The following were sampled for and not found above laboratory reporting limits: Aluminum, Ammonia-N, Antimony, Beryllium, Cadmium, Cobalt, Fluoride, Iron, Manganese, Mercury, Molybdenum, Nickel, Silver, & Thallium.

Table Y1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	107	10.1	70	90	110	120	149	N=7
Depth to Water (ft)	26.83	4.05	13.84	19.11	24.52	34.76	41.74	Below ground surface
Temperature (°C)	21.16	0.781	19.12	--	21.29	--	22.93	
Specific Conductance (µS/cm)	671	95.4	532	--	601	--	949	
Dissolved Oxygen (mg/L)	6.73	0.173	6.28	--	6.77	--	7.12	
pH (units)	7.27	0.046	7.16	--	7.27	--	7.36	SMCL: 6.5-8.5; 0
Oxidation Reduction Potential (mV)	463	59.8	377	--	418	--	639	
Field Alkalinity (mg/L)	192	2.81	186	--	193	--	197	
Field Hardness (mg/L)	262	15.2	233	--	260	--	294	
Field calculated Bicarbonate (mg/L)	235	3.28	227	--	234	--	240	
Total Dissolved Solids (mg/L)	412	66.6	316	--	365	--	601	SMCL: 500; 1 over

Table Y2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite as N (mg/L)	3.38	0.335	2.63	--	3.32	--	4.26	MCL: 10; 0 over
Phosphorus (mg/L)	0.023	0.006	0.014	--	0.019	--	0.040	

Table Y3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	210	14.1	187	--	201	--	251	
dissolved Calcium (mg/L)	82.2	6.51	70.9	--	79.0	--	99.7	
Chloride (mg/L)	32.0	18.9	<10	--	17.6	--	87.7	SMCL: 250; 0 over
dissolved Magnesium (mg/L)	13.8	0.698	12.3	--	13.6	--	15.6	
dissolved Potassium (mg/L)	1.85	0.087	1.6	--	1.9	--	2.0	
dissolved Silica (mg/L)	31.8	0.799	29.9	--	31.8	--	33.8	
dissolved Sodium (mg/L)	36.1	13.6	15.7	--	26.6	--	75.6	
Sulfate (mg/L)	75.0	23.4	35.3	--	64.8	--	135	SMCL: 250; 0 over

Table Y4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	3.53	0.752	2.0	--	3.3	--	5.6	MCL: 10; 0 over
dissolved Barium (µg/L)	98.2	32.0	24.8	--	94.0	--	180	MCL: 2000; 0 over
dissolved Boron (µg/L)	65.3	6.99	53.3	--	62.6	--	82.8	HA: 6000; 0 over
dissolved Chromium (µg/L)	3.03	0.620	1.2	--	3.6	--	3.8	MCL: 100; 0 over
dissolved Copper (µg/L)	All Values <1, except 1 (1.6)							MCL: 1300; 0 over
dissolved Lead (µg/L)	All Values <0.5, except 2 (0.5., 0.8)							MCL: 15; 0 over
dissolved Selenium (µg/L)	1.34	0.18	1.1	--	1.3	--	1.9	MCL: 50; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Uranium (µg/L)	3.00	0.349	2.4	-	3.0	--	3.7	MCL: 30; 0 over
dissolved Vanadium (µg/L)	15.3	1.72	11.6	--	14.8	--	19.9	
dissolved Zinc (µg/L)	All Values <5, except 2 (8.5, 53.5)							SMCL: 5000; 0 over. HA: 2000; 0 over