2015 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 new groundwater program prioritizes efforts on Oklahoma's 21 major groundwater aquifers with the baseline phase scheduled to be completed at the conclusion of 2016. This 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). When fully implemented, there will be 750 wells in the statewide groundwater quality network statewide. In addition, the OWRB's annual groundwater level measurement program will be doubled in capacity from around 530 to 1100 wells and will be spatially redistributed. Also over the 5-year baseline period, the OWRB plans to install 30-40 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. 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** – The OWRB conducts sampling on lakes and reservoirs across the State of Oklahoma. To accomplish this task, the OWRB has taken a probabilistic survey approach that allows the state's objectives to be met as well as ensure various sized water bodies are represented adequately. The survey population includes all lakes above 50 surface acres, which encompasses approximately 206 different water bodies. 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) on a randomized draw. They are then monitored again during a subsequent year in the 5-year rotation, so that each lake greater than 50 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 lakes. Additionally, ten randomly drawn lakes of less than 500 surface acres are sampled annually (quarterly samples) over the 5 year sample frame. Many of the smaller lakes have not been sampled historically through the BUMP program and include small municipal water supplies. The OWRB also works with the USACE for inclusion of additional information on water bodies managed by the Corps. In general, a minimum of three to five stations per reservoir are sampled depending on the size of the reservoir. Stations are located such that they represent the lacustrine, transitional, and riverine zones of the lake. On many reservoirs, additional sites are monitored, including major arms of the reservoir as appropriate.

- **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 (7 major; 1 minor) in 2014 and 7 (6 major; 1 minor) in 2015.

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.

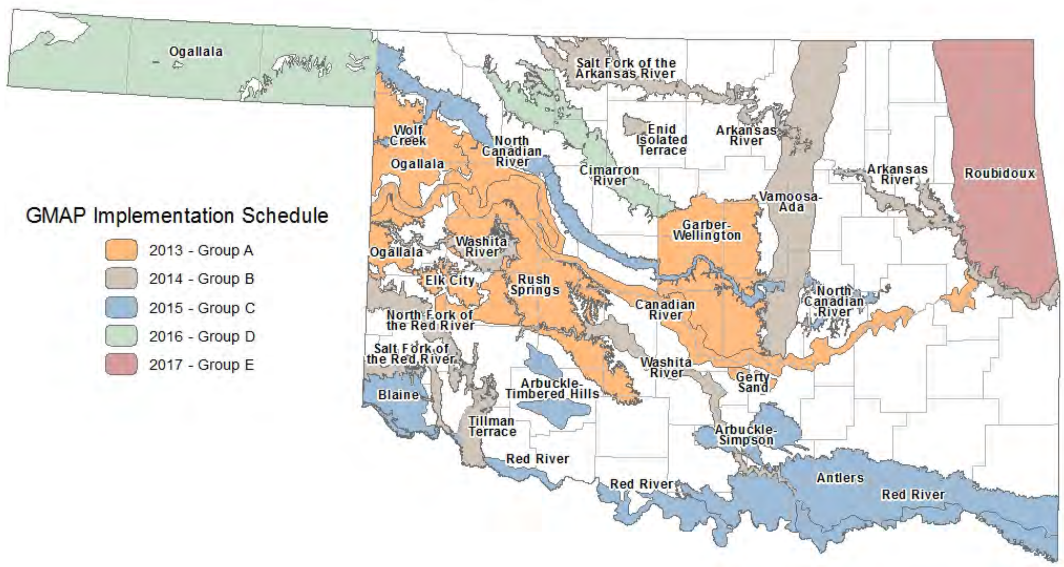

Figure 1. Revised GMAP implementation schedule.

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. Five (5) continuous water level recorders collecting hourly measurements were also installed in the Group A aquifers, along with 11 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, 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. 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. Additionally, two (2) continuous water level recorders were installed in Group C aquifers, during the third year of sampling. Eight (8) continuous water level recorders collecting hourly measurements were installed during the second year, along with 14 throughout the state during the first year of sampling.

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

Sites	Aquifer	Field Parameters		Analytical Parameters						Well Use Categories							DTW
		pH	Hard	TDS	NO3	Ca	Na	Cl	SO4	P	I	S	D	M	N	O	
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

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, ABSMP-Arbuckle-Simpson, ABTMB-Arbuckle-Timbered Hills, BNCR-North Canadian River, RED-Red River, WOLF-Wolf Creek. Parameters: Hard–Hardness, TDS–Total Dissolved Solids, NO3–

Nitrate+Nitrite, 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 21 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 11 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, Washita River, Enid Isolated Terrace, Gerty Sand, and Tillman Terrace. GMAP prioritizes efforts on these 21 major groundwater aquifers, along with some associated minor aquifers, and is being phased in over 5-6 years (Figure 1). This baseline period focuses on 4-6 aquifers per year and assesses concentrations of nutrients, metals and major ion species to characterize regional groundwater quality and groundwater levels. When fully implemented, there will be 750 wells in the groundwater quality network statewide. In addition, the OWRB's annual groundwater level measurement program will be doubled in capacity from around 530 to 1,100 wells and will be spatially redistributed. For one half of the water level network, manual measurements will increase from annual to tri-annual events. Additionally, over the 5-6 year baseline period, the OWRB plans to install 30-50 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 or tri-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) 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, 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. 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 Draft Contaminant Candidate List 4 (manganese, which has a SMCL, is also slated for review). In addition, the EPA has issued health advisories for a few constituents that do not have MCLs. 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, 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	ODEQ 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	Nutrient	353.2	10 mg/L	-	-
Ammonia	Nutrient	350.1	-	-	30 mg/L
Phosphorus	Nutrient	365.3	-	-	-
Sulfate	Mineral	375.4	-	250 mg/L	-
Chloride	Mineral	325.2	-	250 mg/L	-
Bromide	Mineral	4500BrDM	-	-	-
Fluoride	Mineral	300.0	4 mg/L	2 mg/L	-
Aluminum, Dissolved	Metal/Trace Element	200.8	-	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	200.7	2,000 µg/L	-	-
Beryllium, Dissolved	Metal/Trace Element	200.7	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	200.7	100 µg/L	-	-
Cobalt, Dissolved	Metal/Trace Element	200.7	-	-	-
Copper, Dissolved	Metal/Trace Element	200.7	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	-	-
Magnesium, Dissolved	Mineral	200.7	-	-	-
Manganese, Dissolved	Metal/Trace Element	200.7	-	50 µg/L	300 µg/L
Mercury, Dissolved	Metal/Trace Element	200.8	2 µg/L		-
Molybdenum, Dissolved	Metal/Trace Element	200.7	-	-	40 µg/L
Nickel, Dissolved	Metal/Trace Element	200.7	-	-	100 µg/L
Potassium, Dissolved	Mineral	200.7	-	-	-
Selenium, Dissolved	Metal/Trace Element	200.7	50 µg/L	-	-
Silica, Dissolved	Mineral	200.7	-	-	-
Silver, Dissolved	Metal/Trace Element	200.7	-	100 µg/L	100 µg/L
Sodium, Dissolved	Mineral	200.7	-	-	-
Thallium, Dissolved*	Metal/Trace Element	200.8	2 µg/L	-	-
Uranium, Dissolved	Metal/Trace Element	200.8	30 µg/L	-	-
Vanadium, Dissolved	Metal/Trace Element	200.8	-		-
Zinc, Dissolved	Metal/Trace Element	200.7	-	5,000 µg/L	2,000 µg/L

ODEQ- Oklahoma's Dept of Environmental Quality. 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 three years of the program (Group A, 2013; Group B, 2014; and Group C, 2015), data was housed in a Microsoft Access 2002-2003 database. Statistical tests and quality assurance checks were conducted using Microsoft Excel 2007. 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 1.5x 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.). For 2015 sample sites, total dissolved phosphorus data was returned with higher relative percent difference between replicate samples than is typically allowed. However, a subsequent resample of a subset of sites informed the decision to report total dissolved phosphorus values with the above caveat.

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, analysis of statistical outliers, and other groundwater-specific comparisons. 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. 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.

2015 saw Oklahoma's wettest year on record, with a statewide average of 53.88 inches of precipitation, 50 percent higher than the normal average of 36.43 inches. Precipitation in individual climate divisions ranged from 20 percent above normal in the North Central Division to 73 percent above normal in the East Central Division, with the majority of divisions receiving precipitation 40-55 percent above normal.

According to the U.S. Drought Monitor, the unprecedented rainfall reduced Oklahoma's area drought percentage from an April peak of 68 percent, with 40 percent considered extreme or exceptional, to zero percent at the end of the calendar year. The influence of this historic year could be felt across the state's groundwater resources and is reflected in the data presented in this year's report. Response rate and magnitude varied considerably among Oklahoma's aquifers depending on precipitation, aquifer composition, and presence or absence of confining layers, but the majority of aquifers saw at least some recovery of groundwater levels, though many still did not recover to pre-drought levels.

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 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 and in the 2014 BUMP Report for Group B aquifers. The aquifer summaries for Group C, investigated in 2015, 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, 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 3). 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.

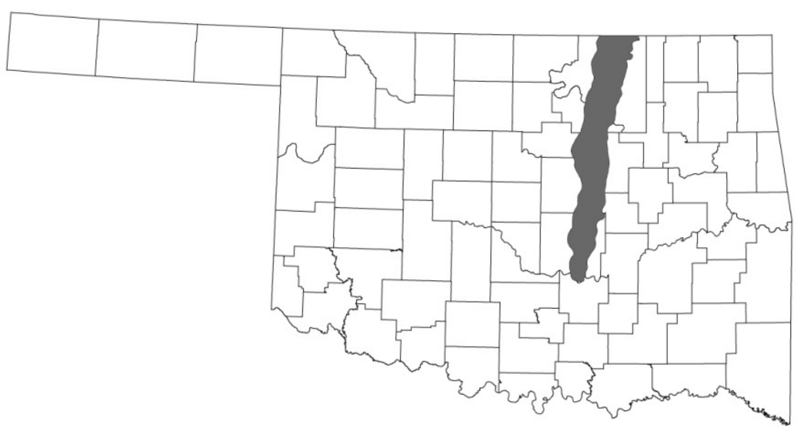

Figure 3. Location and extent of the ADVM.

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

Groundwater Level Measurements

Seven (7) wells, located between the Arkansas River and the Canadian River, had historical depth to water measurements in the ADVM; the configuration prior to GMAP was even smaller at 3-4 wells measured each year. The inadequate number of sites for the size of the aquifer, along with the variable time intervals from which data was collected, prevents the generation of an aquifer-wide composite hydrograph for the period of record. Three of these historical wells were incorporated into the new water level network to maintain sites with long-term records. One of the longest measurement records in this aquifer approaches 20 consecutive years (Figure 5).

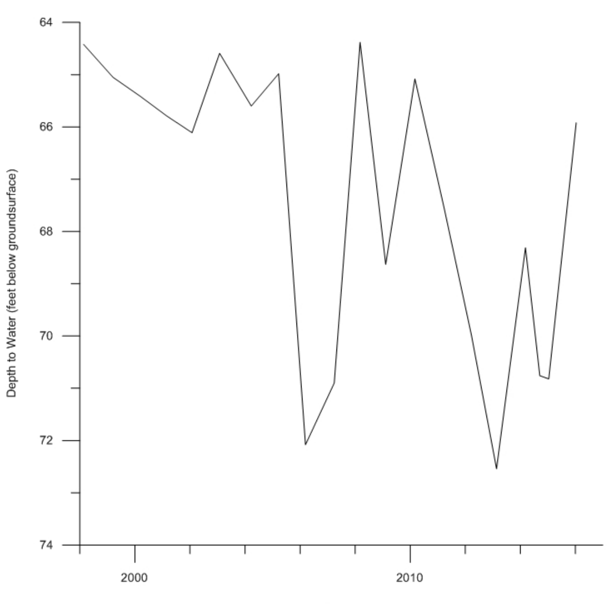

Figure 5. Groundwater level hydrograph of an unconfined ADVM record, Seminole County (1998-2016).

A baseline groundwater level network composed of 44 wells was measured in September 2014. Thirty-five (35) wells are currently in the annual trend network, a marked improvement over the historical network, with 17 of these sites measured seasonally. Unconfined conditions are reflected in 31 wells of the trend network, and 4 are considered to be in the deeper, confined parts of the aquifer.

Water levels have been declining in ADVM wells but 2015 had record rainfalls, during which average annual precipitation over the ADVM measured at 6.01 inches above normal. Over the last five years, the above hydrograph reflects a steady decline in water level prior to these rains and then a sharp increase. Average water levels across the aquifer have increased in unconfined wells by 0.9 ft during that time period (2011-2016). The new GMAP trend network has recorded the average water level increasing in unconfined ADVM wells even more over the last year by an average 3.83 ft in the Northeast and 2.94 ft in the Central areas (2015-2016). Confined wells also responded with a 6.95 ft average increase in water levels (4 wells; 2015-2016).

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 6). 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.

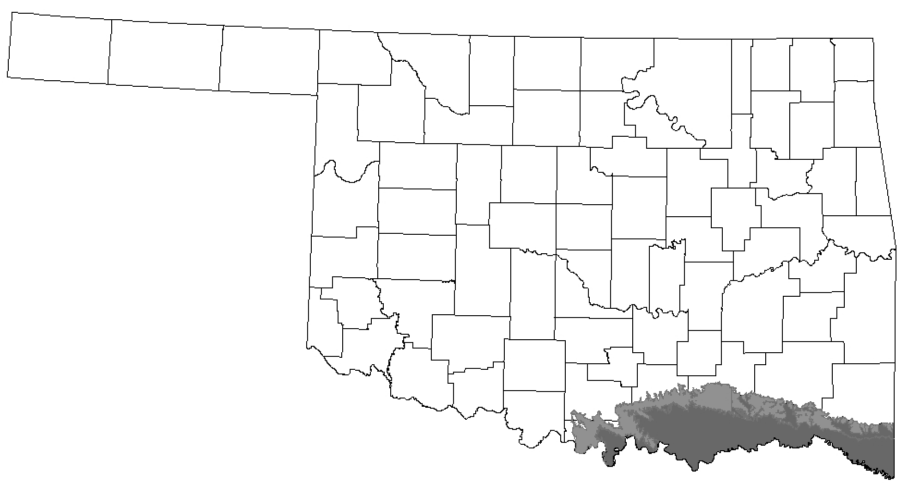

Figure 6. Location and extent of the ALRS (outcrop in light gray).

This aquifer is encompassed by the Lower Washita, Blue-Boggy, and Southeast Watershed Planning Regions. ALRS is divided with the western part in Oklahoma's South Central Climate Division, which averages 62.3°F and 37.77 inches of precipitation annually, and the eastern part in the Southeast Division, which averages 61.1°F and 47.63 inches of precipitation annually. Recharge of the aquifer comes mostly from precipitation on the outcrop areas, along with infiltration from streams and ponds. The estimated recharge rate is 0.3-1.7in/yr. Water is discharged naturally through springs and seeps, evapotranspiration, as baseflow to streams crossing the outcrop, and subsurface flow out of the state to the south and southeast. Antlers has an aerial extent of 1,093 km^2 and stores 53.5 million acre-feet of water. Common well yields are 100-400 gallons/min, and hydraulic conductivity ranges from 0.87-3.75ft/day.

The ALRS supplies water for municipal, irrigation, domestic and industrial uses. The OWRB has on file more than 1,700 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer outcrop area. As of January 2016, 169 active groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 71,560.8 acre-feet of water per year. The maximum withdrawal rate from the aquifer is set at 2.1 acre-feet per acre per year. The Antlers aquifer is designated by the OWRB as having a moderate vulnerability level.

Data Collection Results

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 7). 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 will be discussed separately as a sub-study from the main set of unconfined data (Figure 8).

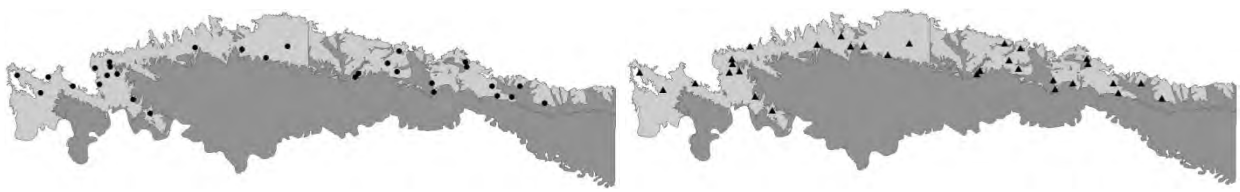

Figure 7. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ALRS outcrop in 2015.

Figure 8. Confined sub-study water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ALRS subcrop in 2015.

Water Quality

Overall, water in the outcrop of ALRS was of good quality. Mineral content was very low. Groundwater was hard with moderately low alkalinity, averaging 147.6 mg/L and 153.1 mg/L, respectively. Mean total dissolved solids (TDS) was moderately low with an average 275 mg/L. TDS ranged 15-694 mg/L with a median of 254 mg/L. Average specific conductance was 511.1 uS/cm and pH was 6.52. Water in the eastern half (east of the Bryan/Choctaw county line) appears to be less mineralized with lower levels of metals. Primary water quality concerns are low pH and locally elevated hardness, iron, and manganese.

The piper plot of ALRS data depicts primarily calcium-bicarbonate water (17%) and mixed calcium/sodium/magnesium-chloride/bicarbonate/sulfate water (13%), along with a variety of other water types (Figure 9). The spatial distributions of water types and TDS are shown in Figure 10.

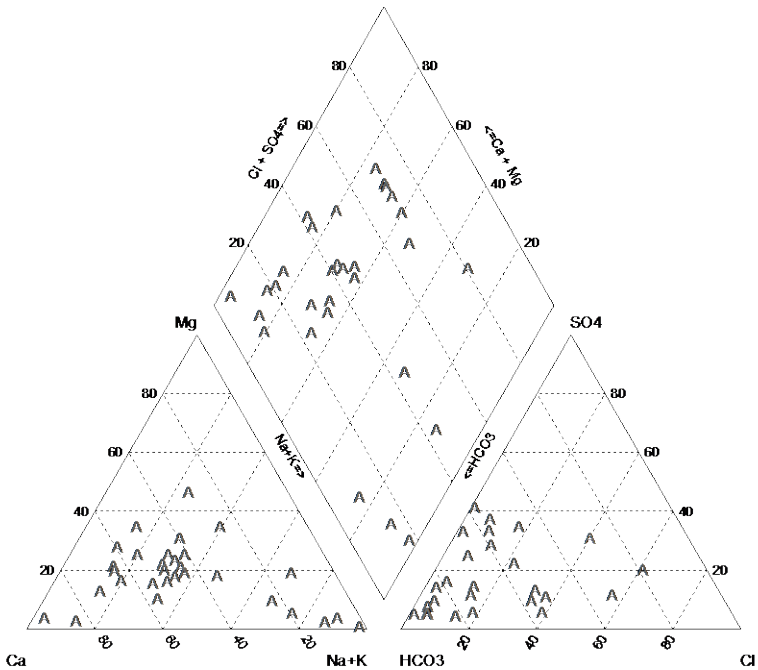

Figure 9. Piper plot diagram of constituents of the ALRS outcrop.

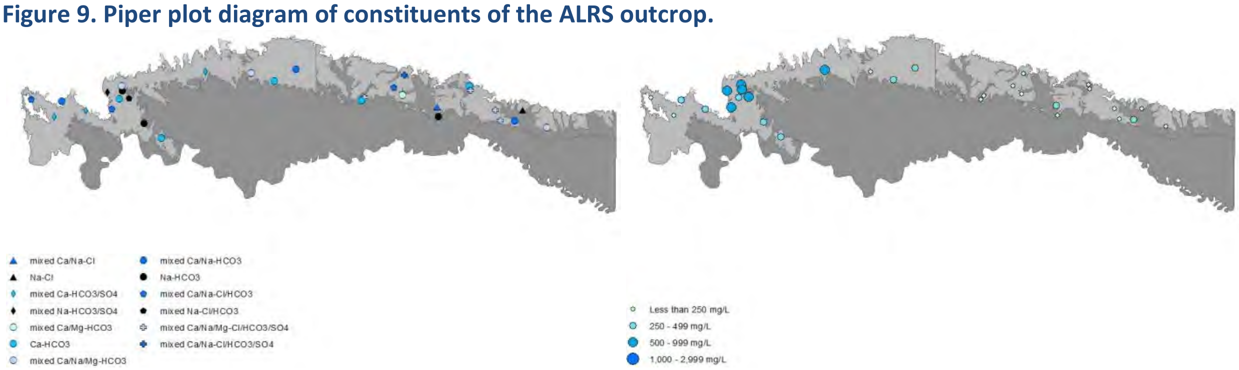

Figure 10. Water type (left) and TDS concentrations in the ALRS.

Concentrations of bromide, calcium, chloride, magnesium, potassium, silica, sodium, and sulfate were low in the ALRS outcrop. Fluoride was not detected.

Nutrient content was low in this aquifer. Nitrate ranged from <0.05-3.43 mg/L with low mean and median concentrations of 0.77 mg/L and 0.15 mg/L. Ammonia was rarely detected but was at moderate concentrations when present. Phosphorus ranged from <0.005-0.157 mg/L with low mean and median concentrations of 0.024 mg/L and 0.014 mg/L.

Mostly low levels of metals and trace elements were present in the ALRS. The following were not detected: antimony, cadmium, mercury, molybdenum, silver, and thallium. Low concentrations of barium, boron, copper, selenium, and zinc were detected. Nickel was detected at low to moderate concentrations. Iron was moderately low and manganese was present at moderate levels. Arsenic, beryllium, uranium, and vanadium were rarely detected and low when present; lead and chromium were rarely detected and moderate when present. Aluminum and cobalt were rarely detected but at high concentrations where present.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The ALRS 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 ALRS water quality, see Appendix B.

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	6	--
pH	--	12 under	--
Aluminum	--	1	--
Iron	--	5	--
Manganese	--	12	2

An additional 8 wells were measured in the confined portions of the aquifer, and this set of data is considered separately from the main set of unconfined data discussed above. Overall, water in the subcrop of ALRS was of fair quality. Groundwater was soft with high alkalinity. Mean total dissolved solids (TDS) was moderately high with an average 657 mg/L, average specific conductance was 1,237 uS/cm, and pH was 8.3. Concentrations of minerals were either low or moderately low, except fluoride and sodium which were present in moderate concentrations. Nitrate was very low with mean and median concentrations of 0.31 mg/L and <0.05 mg/L, but ammonia was detected at moderate levels. Most metals and trace elements were either not detected or present at low levels in the ALRS confined subcrop, although boron and molybdenum were present at moderate levels. The confined ALRS data reveals primarily sodium-bicarbonate water (50%) and mixed sodium-bicarbonate/sulfate water (25%). Primary water quality concerns are fluoride, sodium, high pH, and TDS.

Groundwater Level Measurements

Seven (7) wells located in the outcrop of the Antlers, along with 9 wells in the subcrop, have historic depth to water measurements. Four (4) outcrop and 7 subcrop wells configure the most recent networks (Figure 11).

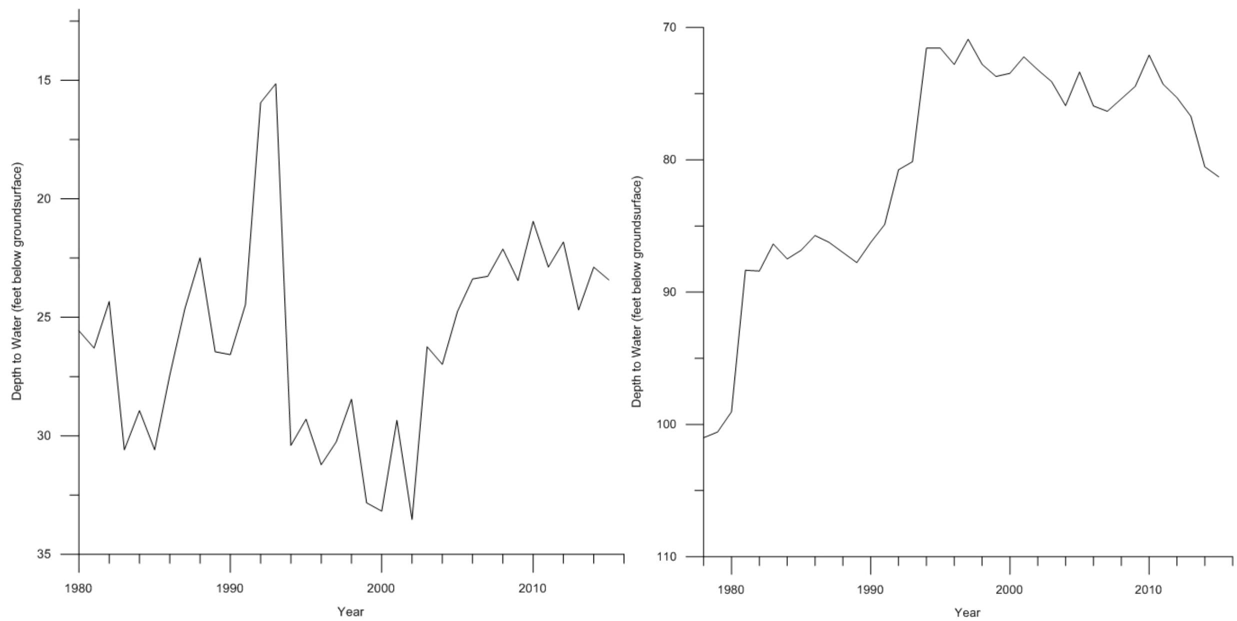

Figure 11. Average water level in the ALRS over period of record prior to GMAP implementation (outcrop, 1980-2015; left) (subcrop, 1978-2015; right).

A baseline groundwater level network of 42 wells was measured in August 2015. Several wells in this aquifer have over 30 years of record, with the longest record spanning nearly 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). In the outcrop, measurements of depth to groundwater made during baseline water quality sampling ranged from a flowing artesian well to 132.12 feet below ground surface with a mean of 54.5 ft; the total depth of wells used in the outcrop network ranged from 20-380 feet and averaged 130 feet. Confined water levels in the subcrop measured from 22.62-203.63 feet below ground surface with a mean of 113.5 ft; the total depth of wells used in the baseline ranged from 140-651 feet and averaged 422.9 feet. Thirty-one (31) wells have been incorporated into a trend network measured annually, with 12 of these measured seasonally. Unconfined conditions of the outcrop are reflected in 22 wells of the water level network, and 9 are considered to be in the confined subcrop of the aquifer.

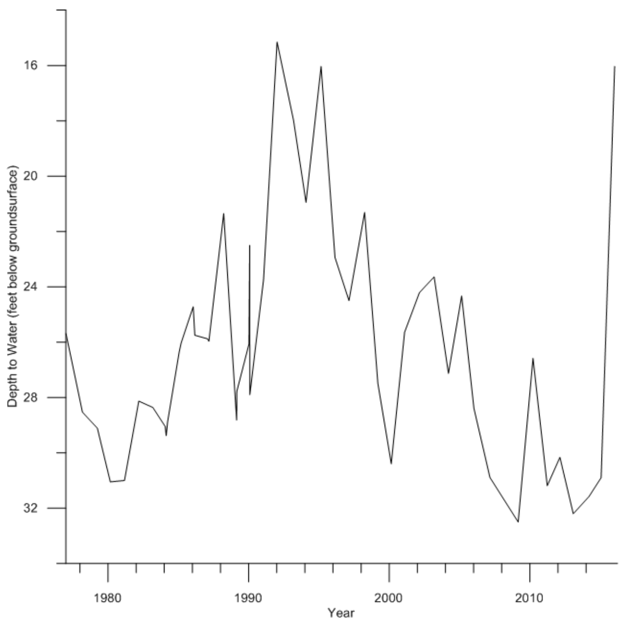

Figure 12. Groundwater level hydrograph of an unconfined ALRS record, Johnston County (1977-2016).

The average water level in both the outcrop and the subcrop has generally been increasing in ALRS wells but recently experienced several years of decline in relation to drought before the record rainfalls in 2015, during which average annual precipitation over the ALRS measured at 31.27 inches above normal. Average water levels across the outcrop of the aquifer have increased by 5.01 ft during the last 5 years, and water levels in the subcrop have increased by 2.14 ft (2011-2016). The average water level has increased even more over the last year by an average 7.98 ft in the South Central and 2.82 ft in the Southeast areas of the outcrop, and by 6.42 ft in the South Central and 2.38 ft in the Southeast areas of the confined subcrop (2015-2016).

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.

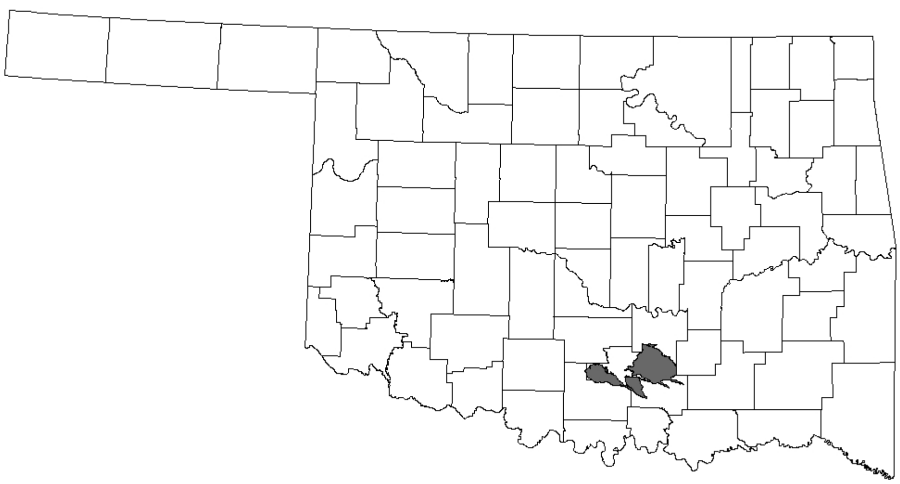

Figure 13. Location and extent of ABSMP.

The aquifer lies in the state's Lower Washita and the Blue-Boggy Watershed Planning Regions; it is within Oklahoma's South Central Climate Division which averages 62.3 °F and 37.77 inches of precipitation annually. Recharge of the aquifer comes mainly from precipitation on higher elevations in the outcrop area, with an estimated 5.6 inches per year. Groundwater naturally discharges to multiple springs and contributes baseflow to several streams. Arbuckle-Simpson has an aerial extent of 1,586 km^2 and stores 9.4 million acre-feet of water. Common well yields vary 100-600 gallons per minute depending on location and depth in the aquifer, and hydraulic conductivity averages 3-4ft/day.

The ABSMP is used to supply municipal, industrial, commercial, recreational, agricultural, and domestic purposes. The OWRB has on file more than 890 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of January 2016, 65 active groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 16,000 acre-feet of water per year. The maximum withdrawal rate from the aquifer has been set at 0.2 acre-feet per acre per year. The Arbuckle-Simpson aquifer is designated by the OWRB as having a high vulnerability level.

Data Collection Results

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).

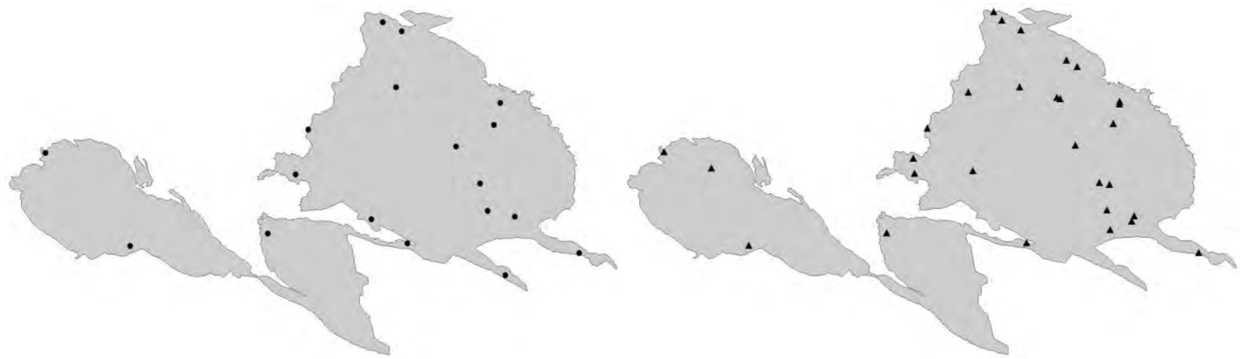

Figure 14. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ABSMP in 2015.

Water Quality

Overall, this aquifer contains water of very good quality. Mineral content was generally low. Groundwater in the ABSMP was very hard with high alkalinity, averaging 341 mg/L and 319 mg/L respectively. Mean total dissolved solids (TDS) was moderately low at 351.7 mg/L. TDS ranged from 218-529 mg/L with a median concentration of 335 mg/L. Specific conductance and pH measured 662.3 uS/cm and 6.88. 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.

The piper plot of ABSMP data reveals either mixed calcium/magnesium-bicarbonate water (72%) or calcium-bicarbonate water (28%) (Figure 15). The spatial distributions of water types and TDS are shown in Figure 16.

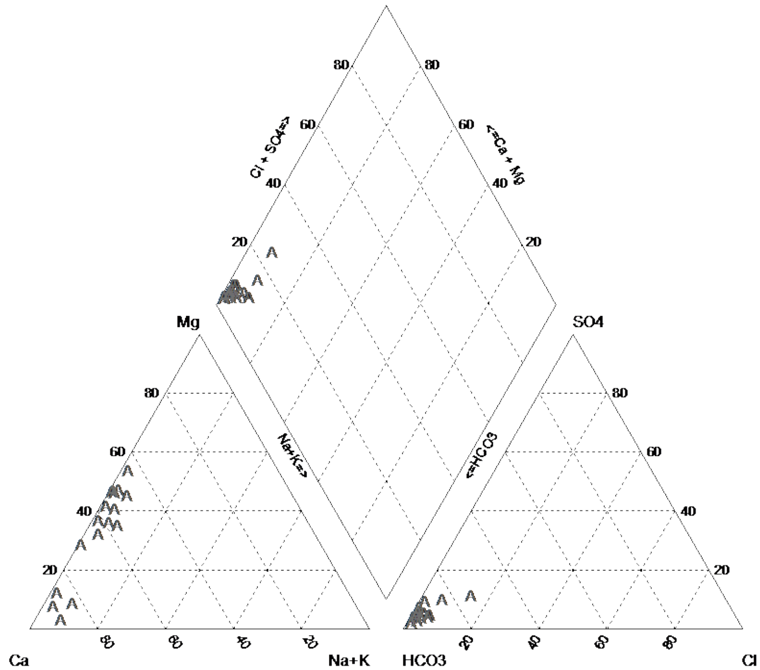

Figure 15. Piper plot diagram of constituents of the ABSMP.

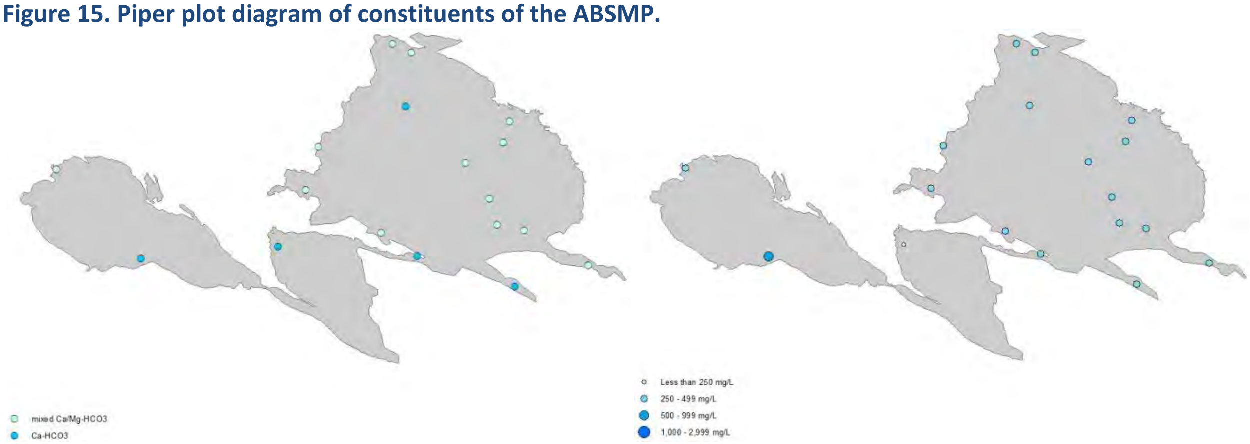

Figure 16. Water type (left) and TDS concentrations in the ABSMP.

Low concentrations of bromide, potassium, silica, sodium, and sulfate were present. Calcium and magnesium were detected at moderate levels. Chloride and fluoride were rarely detected but at low concentrations when present.

Nutrients in the aquifer were very low. Nitrate content ranged from <0.05- 6.86 mg/L; mean and median concentrations were 1.74 mg/L and 0.99 mg/L which are considered natural background levels. Ammonia was not detected. Phosphorus was rarely detected and generally at low levels when present.

Few metals and trace elements were present in the ABSMP. The following were not detected: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, mercury, silver, and thallium. Boron, lead, manganese, molybdenum, nickel, and uranium were rarely detected but low when present;

iron was rare but at moderate concentration when detected. Barium, copper, selenium, and zinc were present in low concentration.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The ABSMP had almost no constituents exceed these thresholds. Table 5 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the ABSMP water quality, see Appendix C.

Table 5. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the ABSMP.

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	1	--
pH	--	1 under	--

Groundwater Level Measurements

Fifteen (15) wells have depth to water measurements through the historical winter measurement program in this aquifer; although, many other wells have also been measured under a special study on the Arbuckle-Simpson. Thirteen (13) wells comprised the most recent network configuration (Figure 17).

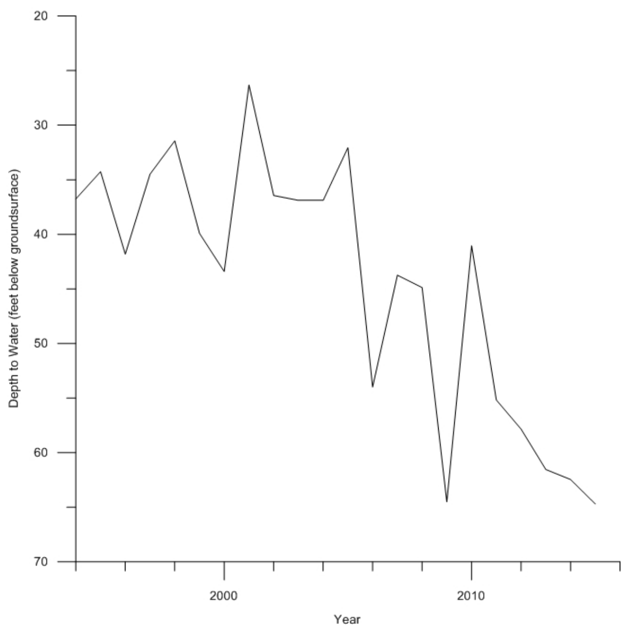

Figure 17. Average ABSMP water level over period of record prior to GMAP implementation (1994-2015).

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 18). To maintain wells with long periods of record, the baseline included 11 wells from the ABSMP's historical network.

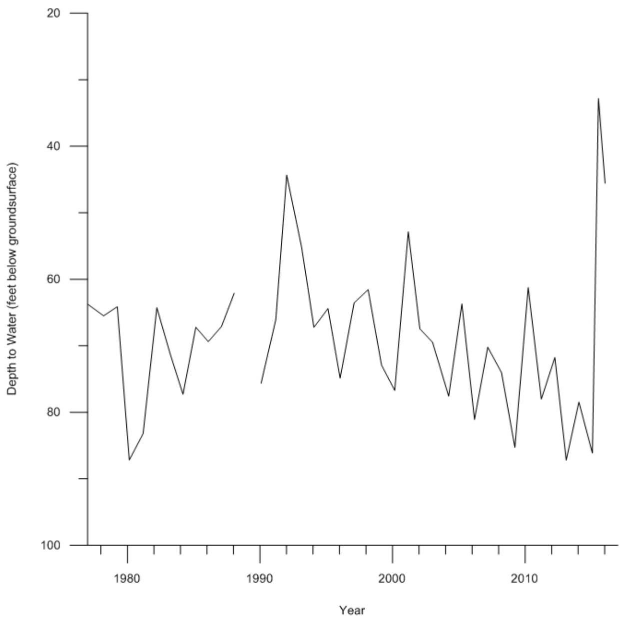

Figure 18. Groundwater level hydrograph for one of the longest ABSMP records, Pontotoc County (1977-2016).

Measurements of depth to groundwater made during baseline water quality sampling ranged from an artesian flowing well to 83.5 feet below ground surface with a mean of 28.5 ft over the entire aquifer. The total depth of wells used in the network ranged from 55-1,116 feet and averaged 260.4 feet. Nineteen (19) wells have been incorporated into the trend groundwater level network measured annually, with 9 of these measured seasonally.

Because of its karst nature, the ABSMP is prone to large fluctuations in water level. As seen in Figure 17, water levels had generally been declining prior to the record rainfalls of 2015, during which average annual precipitation over the ABSMP measured at 34.39 inches above normal. Over the last five years, the above hydrographs show a general decline in water level prior to these rains and then a sharp increase. Average water levels across the aquifer have increased by 24.67 ft over the last five year period (2011-2016). The new GMAP trend network has recorded the average water level increasing in ALRS wells over the last year by an average 29.66 ft (2015-2016). 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 19).

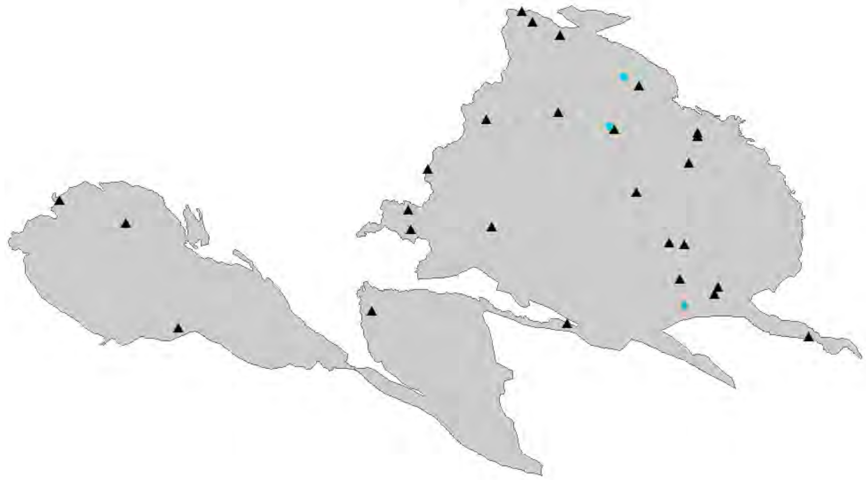

Figure 19. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire ABSMP water level network.

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 20). 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.

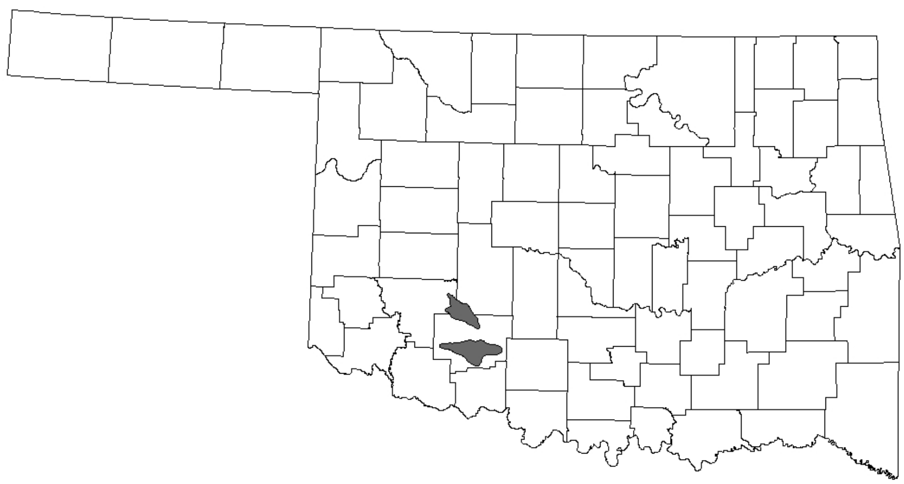

Figure 20. Location and extent of ABTMB.

Most of the aquifer is within the state's Beaver-Cache Planning Region with the northern edge in the West Central Region; the entire aquifer is within Oklahoma's Southwest Climate Division which averages 61.2°F and 27.7 inches of precipitation annually. Recharge of the aquifer comes mostly from precipitation, which is estimated to be 0.3-0.6in/yr. The Arbuckle-Timbered Hills has an aerial extent of 973 km^2 and stores 962 thousand acre-feet of water. Common well yields are 10-600 gallons/min.

The ABTMB is rarely used; most wells supply rural, domestic, and municipal purposes in the northern lobe and industrial uses in the southern lobe. The OWRB has on file more than 1,374 well construction reports from Oklahoma's licensed water well drilling firms within the aquifer's boundaries; however, fewer than 50 actually tap into the ABTMB. As of January 2016, 12 active groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 12,000 acre-feet of water per year. The maximum withdrawal rate from the aquifer is temporarily 2 acre-feet per acre per year. The Arbuckle-Timbered Hills aquifer is designated by the OWRB as having a moderate vulnerability level.

Data Collection Results

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 21).

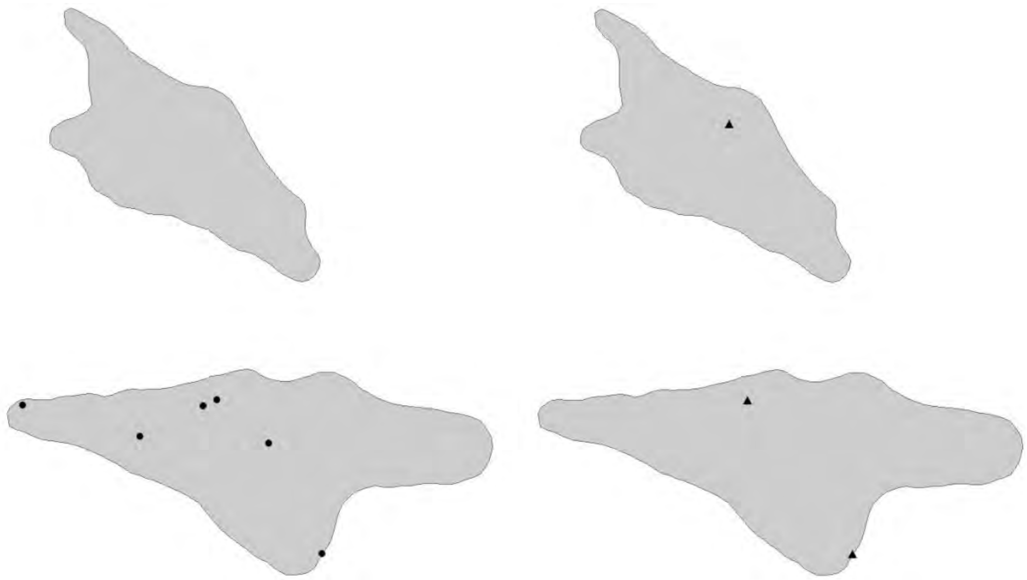

Figure 21. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ABTMB in 2015.

Water Quality

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. Mineral content was moderate. Groundwater in the aquifer was soft with moderately high alkalinity, averaging 23 mg/L and 283 mg/L, respectively. Mean total dissolved solids (TDS) were moderately high at 708 mg/L, ranging from 326-1760 mg/L with a median concentration of 562 mg/L. Specific conductance and pH were 1281 µS/cm and 8.55, respectively. The primary water quality concerns in the aquifer are fluoride, arsenic, pH, and TDS.

The piper plot of ABTMB data shows primarily sodium-bicarbonate waters (67%) with one site exhibiting mixed sodium-chloride/bicarbonate water and one sodium-chloride (Figure 22). The spatial distributions of water types and TDS are shown in Figure 23.

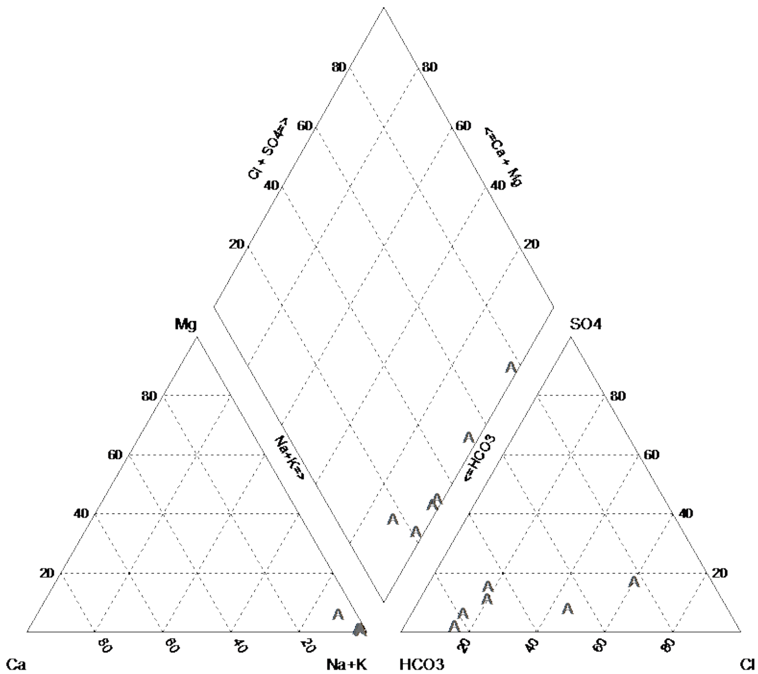

Figure 22. Piper plot diagram of constituents of the ABTMB.

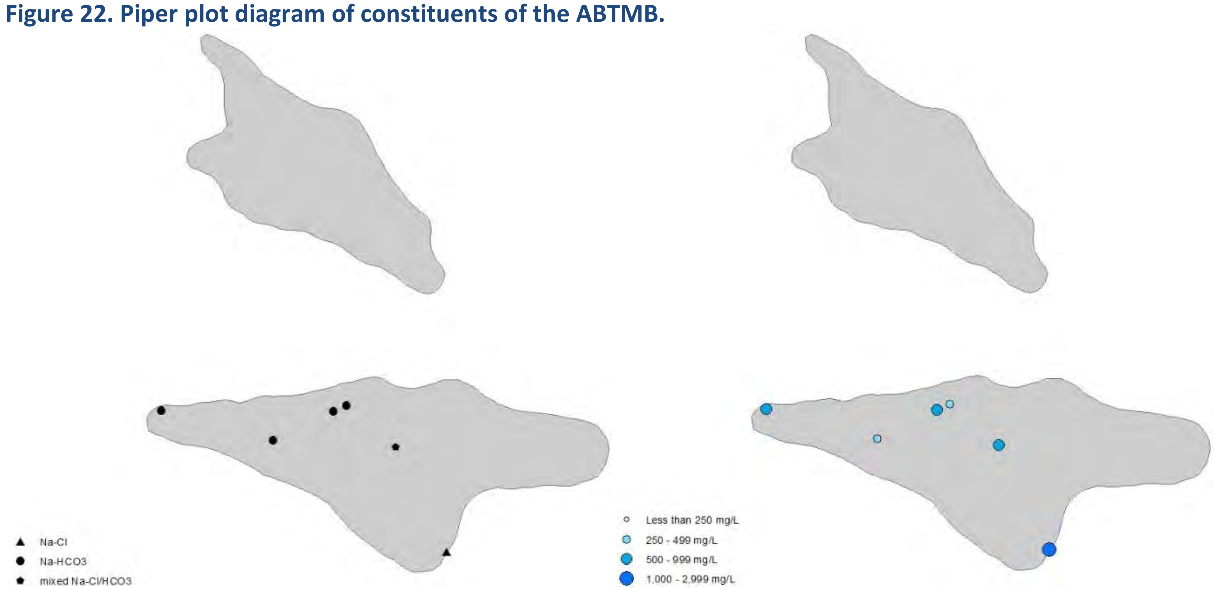

Figure 23. Water type (left) and TDS concentrations in the ABTMB.

Calcium, magnesium, potassium, silica, and sulfate were low in the aquifer. Chloride was detected at moderately low concentrations and sodium was at moderate concentrations. Bromide was present at moderately high levels, ranging 255-2590 mg/L. Fluoride levels were very high, averaging 8.6 mg/L and ranging 3.4-15.9 mg/L.

Nutrients in the aquifer reflect low levels of ammonia, nitrate, and phosphorus. Nitrate and phosphorus were only detected at one site with low concentrations of 0.06 mg/L and 0.013 mg/L, respectively.

The ABTMB had mostly low levels of metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, lead, mercury, nickel, silver, thallium, uranium, and vanadium. Barium and selenium was present at low concentrations; chromium, copper, iron, manganese, and zinc were rarely detected but were low when present. Boron and molybdenum were present at moderate concentrations, and arsenic was detected 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 ABTMB 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 ABTMB water quality, see Appendix D.

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

Parameter	>MCL	>SMCL	>Health Advisory
Arsenic	5	--	--
Chloride	--	1	--
Fluoride	5	--	--
Molybdenum	--	--	1
TDS	--	4	--
pH	--	4 over	--

Groundwater Level Measurements

There are no wells with historical groundwater level measurements in the ABTMB, therefore all wells are new to the program.

In spite of staff's best efforts, only 3 wells were able to be included for the baseline groundwater level network in July 2015. Measurements of depth to groundwater made during baseline quality sampling averaged 109.9 feet. The total depth of wells used in the ABTMB network ranged from 1,100-2,243 ft. These 3 wells have been incorporated into the trend network measured annually, with one of these measured seasonally.

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 24).

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.

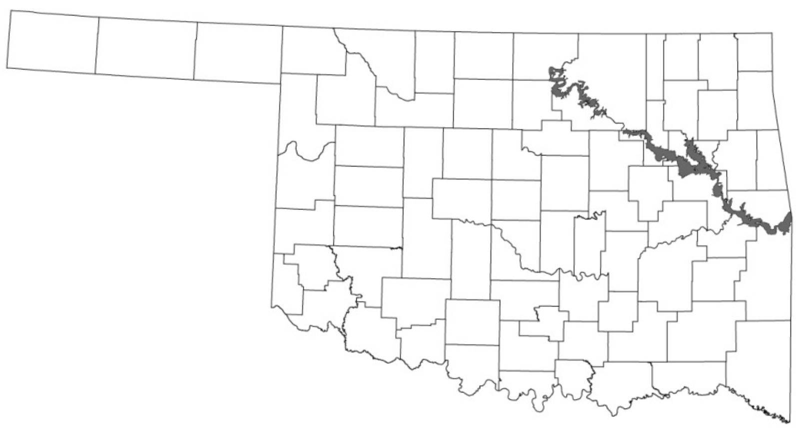

Figure 24. Location and extent of the ARKS.

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

Groundwater Level Measurements

The historical network had measurements on 18 wells, 14 as the river runs through the Northeast climate division and 4 throughout the East Central division (Figure 26). The network configuration prior to GMAP had 2 wells in the Northeast and 4 wells in the East Central division.

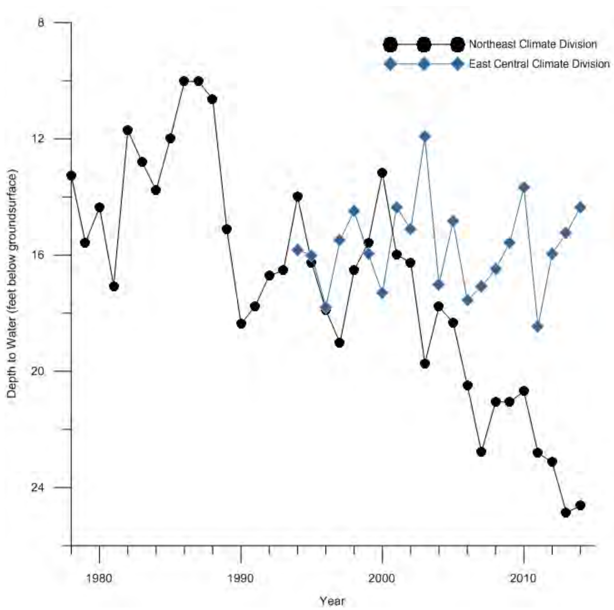

Figure 26. Average ARKS water level over period of record prior to GMAP implementation (1976-2014), divided by climate division.

A baseline groundwater level network for the ARKS of 22 wells was measured in September-October 2014. Twenty (20) wells are currently in the annual trend network, with 9 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 27).

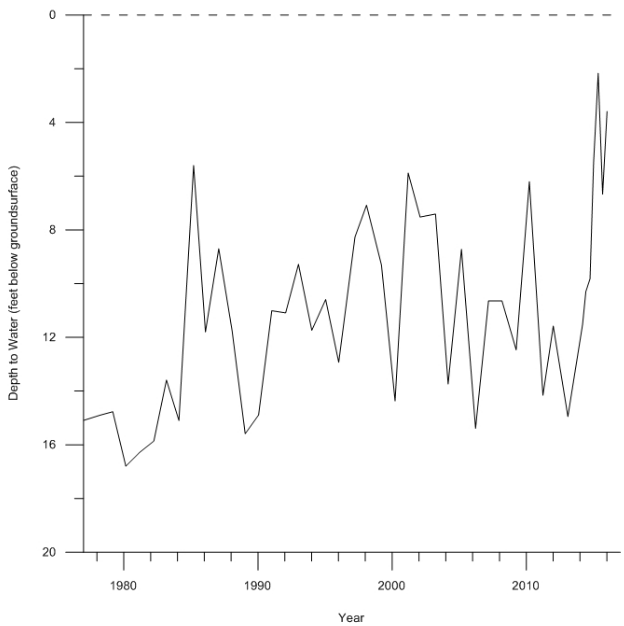

Figure 27. Groundwater level hydrograph of an ARKS well, Sequoyah County (1977-2016).

Fluctuation in alluvial and terrace aquifers is normal due to their sensitivity to use and climate. Over the last five year period, average water levels across the aquifer have increased by 3.89 ft (2011-2016). Water levels had been declining in ARKS wells but 2015 had record rainfalls, during which average annual precipitation over the ARKS measured at 26.71 inches above normal. The new GMAP trend network has recorded the average water level increasing in ARKS wells even more over the last year by an average 3.43 ft in the Northeast and 3.88 ft in the East Central areas (2015-2016).

Blaine Aquifer

The Blaine aquifer in southwestern Oklahoma, hereafter abbreviated DCBG, is a bedrock aquifer underlying portions of Harmon, Greer, and Jackson Counties (Figure 28). 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.

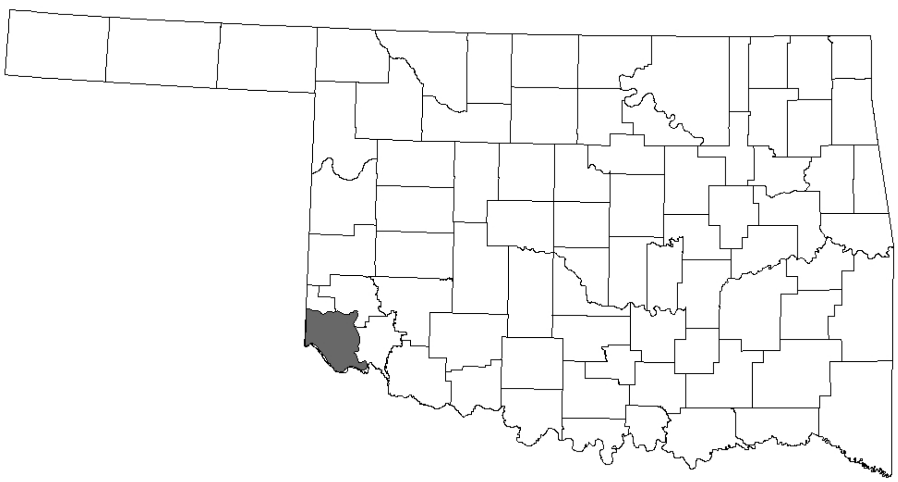

Figure 28. Location and extent of the DCBG.

This aquifer is within Oklahoma's Southwest Watershed Planning Region and Southwest Climate Division, which averages 61.2°F and 27.7 inches of precipitation annually. Recharge of the aquifer comes from infiltration of precipitation along with stream loss from karst openings with an estimated rate of 1.5 inches per year. Groundwater is naturally discharged through springs, seeps, transpiration, and baseflow to streams. DCBG has an estimated aerial extent of 1,884 km^2 and stores 1.4 million acre-feet of water. Common well yields are 100-500 gallons/min.

The Blaine mainly supplies water for agricultural use. The OWRB has on file more than 800 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of January 2016, 547 active groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 121,477 acre-feet of water per year. The maximum withdrawal rate from the aquifer is temporarily 2 acre-feet per acre per year. The Blaine aquifer is designated by the OWRB as having a high vulnerability level.

Data Collection Results

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 29).

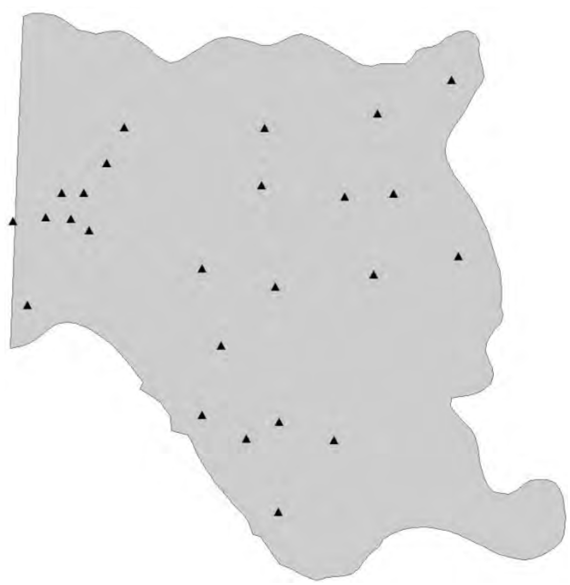

Figure 29. Baseline water level sites (triangles) measured in the DCBG in 2015.

Groundwater Level Measurements

The Blaine Aquifer has a long history of water level monitoring spanning over 60 years (Figure 30). Thirty-three wells (33) have historical depth to water measurements in the DCBG, 20 of which were in the most recent configuration of the groundwater level network.

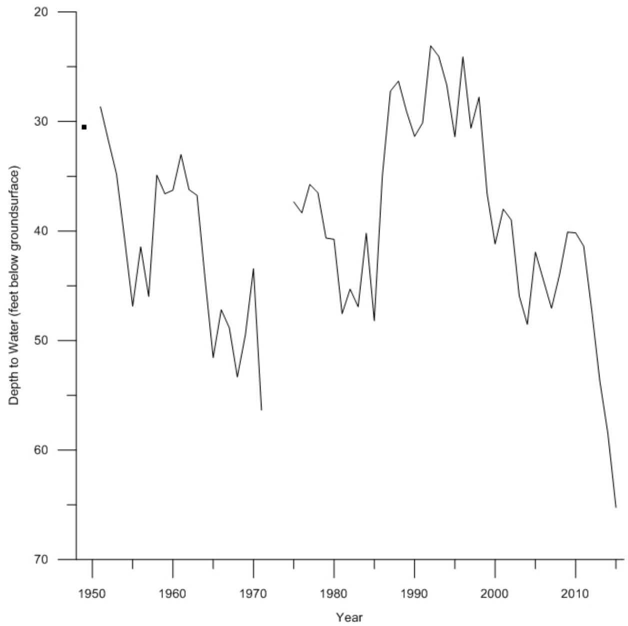

Figure 30. Average DCBG water level over period of record prior to GMAP implementation (1949-2015).

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 31). Measurements of depth to groundwater made during baseline water quality sampling ranged from 9.4 ft below ground surface to 82.7 ft below with a mean of 43.4 feet. The total depth of wells used in the network ranged from 72-320 ft, averaging 149.95 feet. Twenty-four (24) wells have been included in the annual trend water level network.

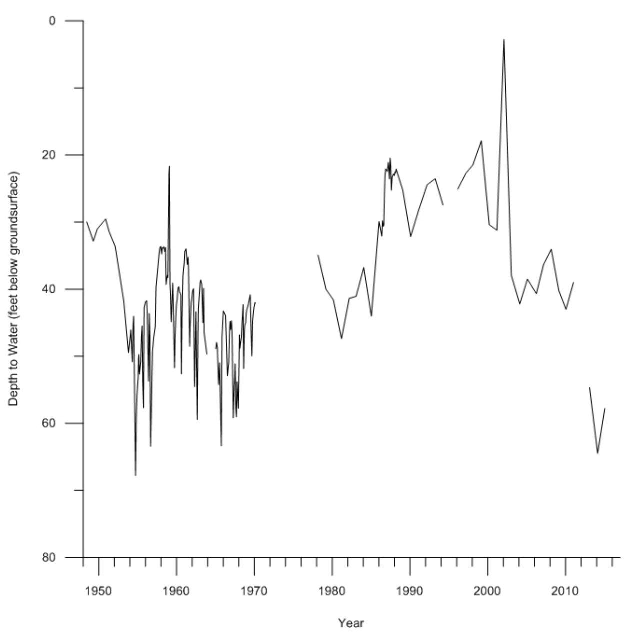

Figure 31. Groundwater level hydrograph for one of the longest DCBG records, Jackson County (1948-2016).

Because of its karst nature, the DCBG is prone to large fluctuations in water level. Water levels had generally been declining prior to the record rainfalls of 2015, during which average annual precipitation over the DCBG measured at 17.87 inches above normal. Over the last five years, the above hydrograph reflects an overall decline in water level prior to these rains and then a sharp increase. Average water levels across the aquifer have increased by 6.64 ft (2011-2016), a notable divergence from the average 27 ft decline recorded over 2010-2015. The new GMAP trend network has recorded the average water level increasing in DCBG wells even more over the last year by an average 33.26 ft (2015-2016). A continuous water level recorder was installed in Harmon County (Figure 32) in March 2015 where depth to water in feet below land surface is being recorded in hourly increments.

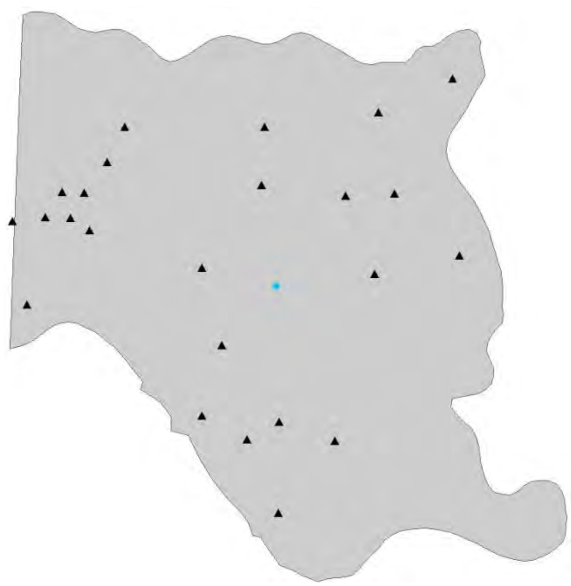

Figure 32. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) against the entire DCBG water level network.

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 33).

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 33. 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 34). 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 F of this report.

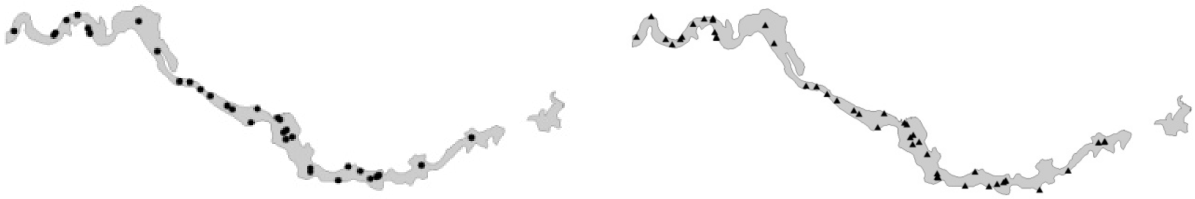

Figure 34. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the CNDN in 2013.

Groundwater Level Measurements

Fifty-six (56) wells had been measured in the aquifer; however, the CNDN generally consisted of a small network of 10 wells prior to GMAP. The number and location of these sites as well as the variable time intervals from which data was collected prevents creation of an aquifer-wide composite hydrograph. A few of the historical wells have 30-35 years of record on groundwater level changes in the aquifer (Figure 35). Several of these wells were incorporated into the new baseline network to maintain water level sites with long-term records.

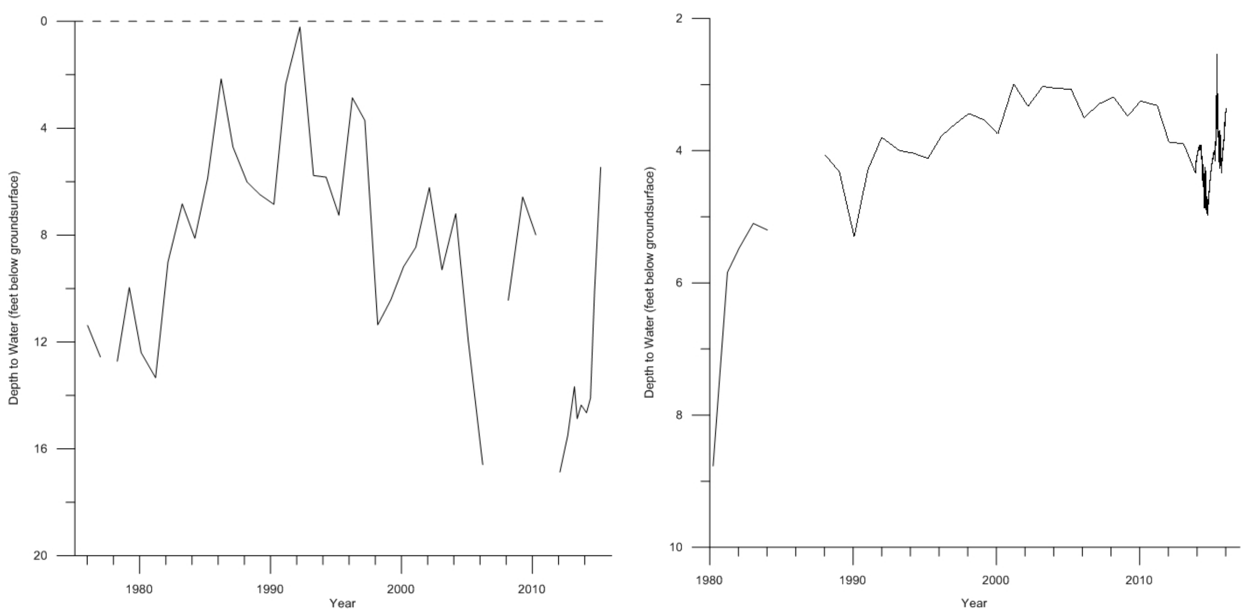

Figure 35. Groundwater level hydrographs for two of the longest CNDN records, McClain County (1977-2016; left) and Roger Mills County (1980-2016; right).

A baseline groundwater level network comprising 46 wells was measured in August-September 2013. The annual trend network is currently composed of 34 wells, with 18 of these sites measured three times a year (Figure 36). 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.

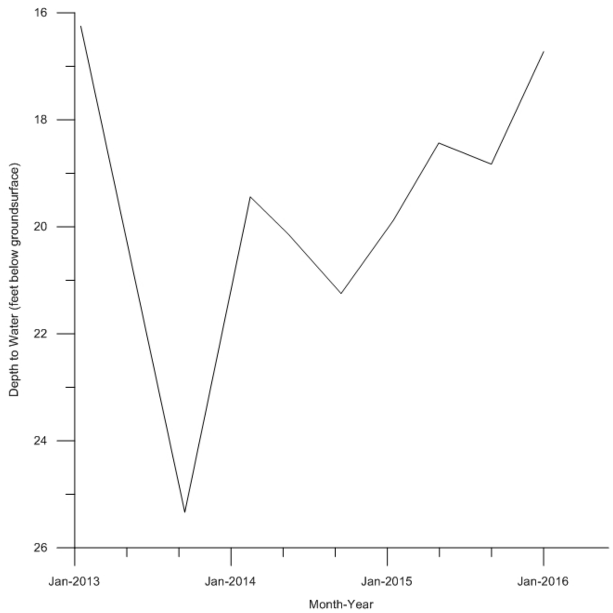

Figure 36. Average Water Level in the GMAP trend water level network for CNDN (2013-2016).

Water levels have been declining in CNDN wells but 2015 had record rainfalls, during which average annual precipitation over the CNDN measured at 28.43 inches above normal. Over the last five years, the above hydrographs reflect a steady decline in water level prior to these rains and then a noticeable increase. Average water levels across the aquifer have increased by 0.52 ft over this period (2011-2016). The new GMAP trend network has recorded the average water level increasing in CNDN wells even more over the last year by an average 1.62 ft in the West Central, 6.64 ft in the Central, and 2.94 ft in the East Central areas (2015-2016). 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 April 2016 (Figure 37).

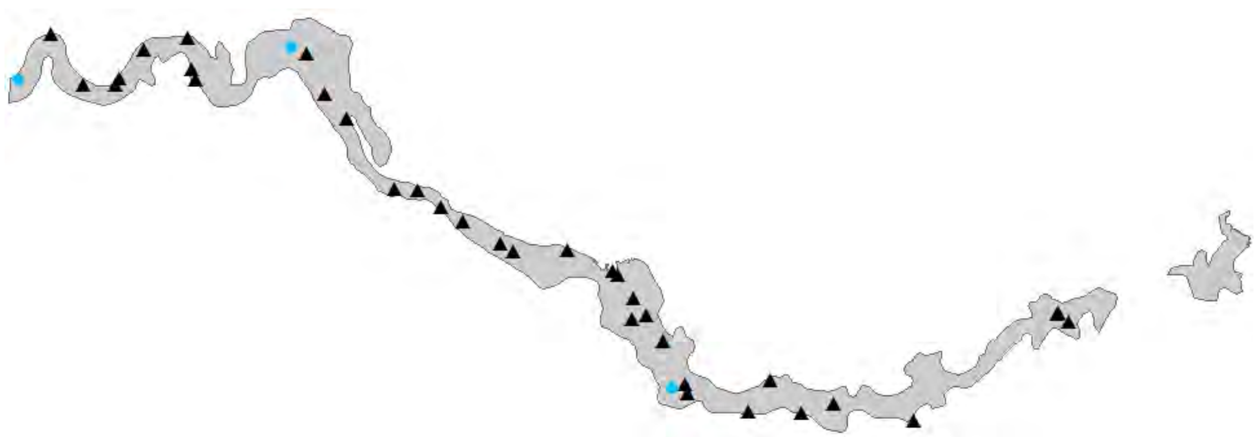

Figure 37. Location of continuous water level recorders (blue circles) against the entire CNDN water level network.

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 38). 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 38. 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 39). 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 G of this report.

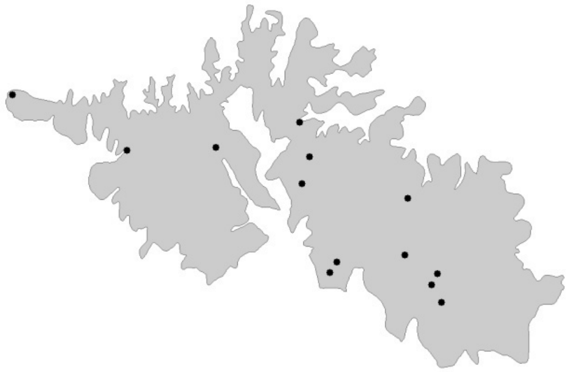

Figure 39. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ELKC in 2013.

Groundwater Level Measurements

The ELKC's historical groundwater level network prior to GMAP began measurements on 7 wells in 2010, adding to one well with a 25 year period of record (Figure 40). All 8 historical wells were incorporated into the new water level network.

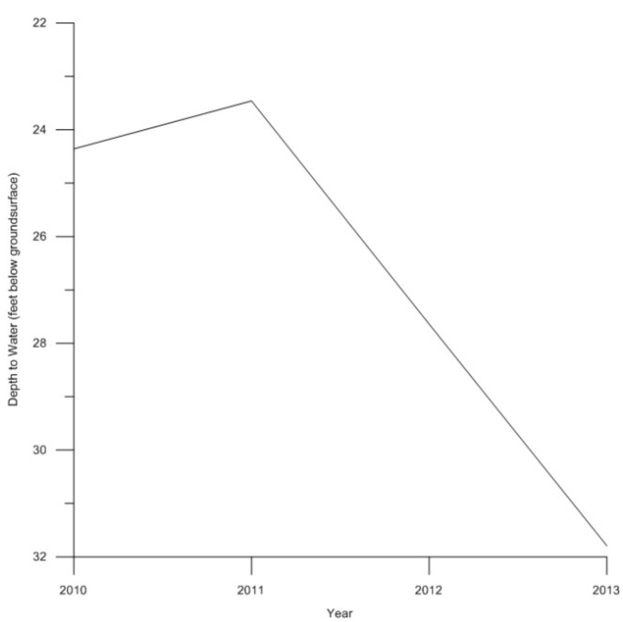

Figure 40. Average ELKC water level over period of record prior to GMAP implementation (2010-2013).

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 8 of these sites measured seasonally (Figure 41).

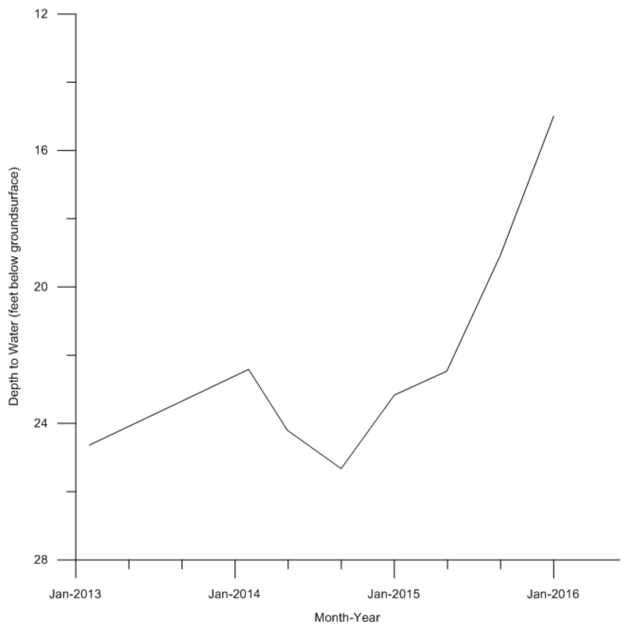

Figure 41. Average Water Level in the GMAP trend water level network for ELKC (2013-2016).

Figure 42 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 42 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 43).

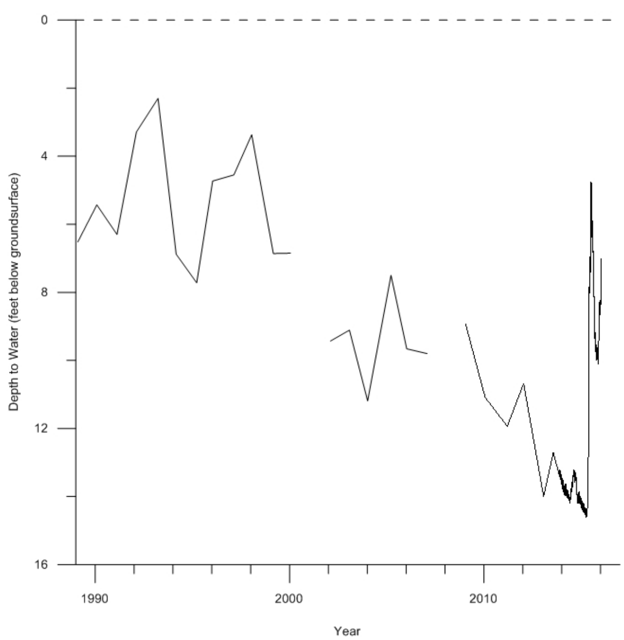

Figure 42. Groundwater level hydrograph of the longest ELKC record, Washita County (1989-2016).

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 ELKC water level network.

Water levels have had an overall decline in ELKC wells of 1.33 feet over the last five years (2011-2016), but 2015 had record rainfalls, during which average annual precipitation over the ELKC measured at 11.3 inches above normal. Over the last five years, the above hydrograph reflects a steady decline in water level prior to these rains and then a sharp increase. The new GMAP trend network has recorded the average water level increasing in ELKC wells 5.42 ft over the last year (2015-2016; Figure 41).

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 44). 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 44. 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 45). 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 H of this report.

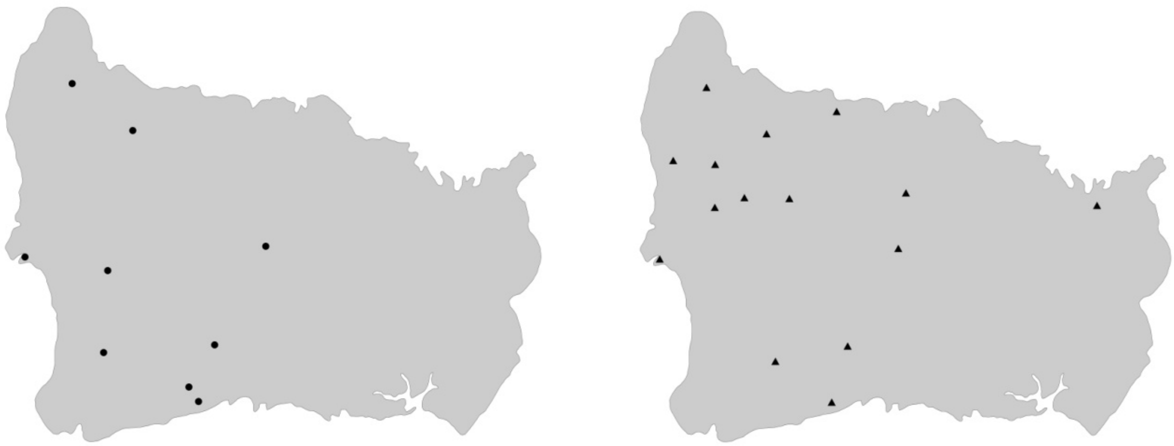

Figure 45. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ENID in 2014.

Groundwater Level Measurements

Thirteen (13) wells in the ENID had historical measurements, with 9 wells in the network configuration prior to GMAP (Figure 46). Two of these wells have had discontinuous measurements since the 1950's.

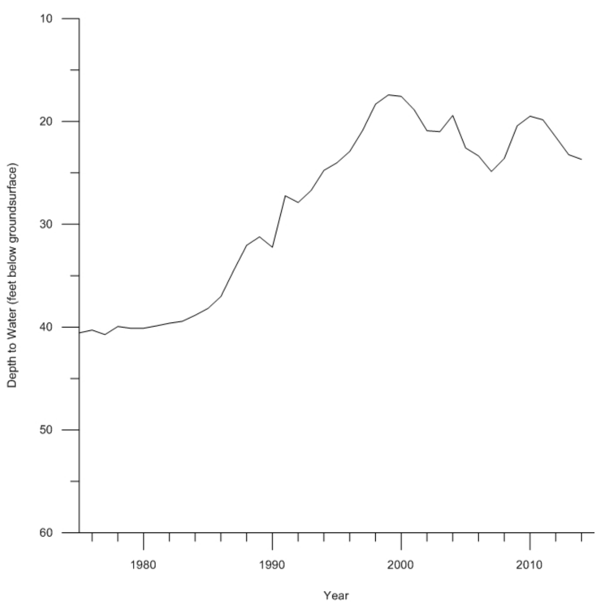

Figure 46. Average ENID water level over the period of record prior to GMAP implementation (1975-2014).

A baseline groundwater level network of 18 wells was measured in September 2014. Eighteen (18) wells are currently in the network measured annually, with 9 of these sites measured seasonally. The network includes 9 wells from the aquifer's historical groundwater level network to continue long-term records. Figure 47 is a depth to water hydrograph of one of the two ENID wells that has nearly 70 years of measurements.

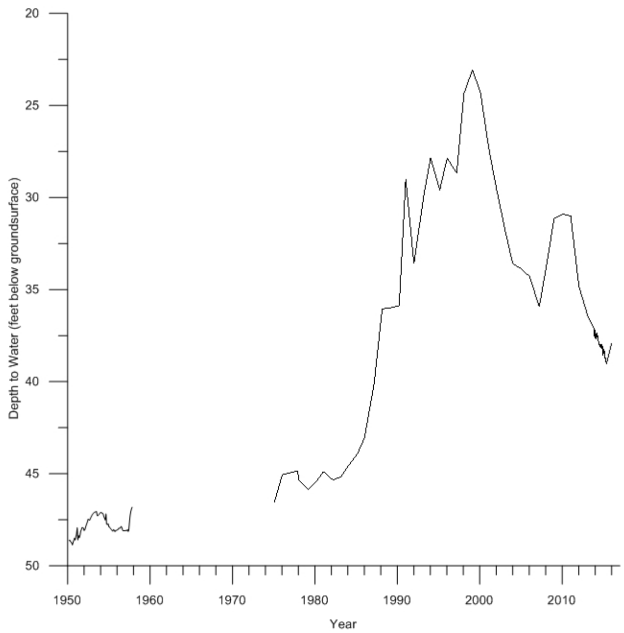

Figure 47. Groundwater level hydrograph of one of the longest ENID records, Garfield County (1950-2016).

Taped measurements of the well depicted in Figure 47 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.

The above hydrographs reflect declining water levels with an average drop of 3.31 feet in ENID wells during the last 5 years (2011-2016). Water levels had been declining more sharply in ENID wells but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the ENID measured at 2.1 inches above normal. The new GMAP trend network has recorded the average water level increasing in ENID wells by an average 1.94 ft over the last year (2015-2016).

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 48). 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 48. 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 49). 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 I of this report.

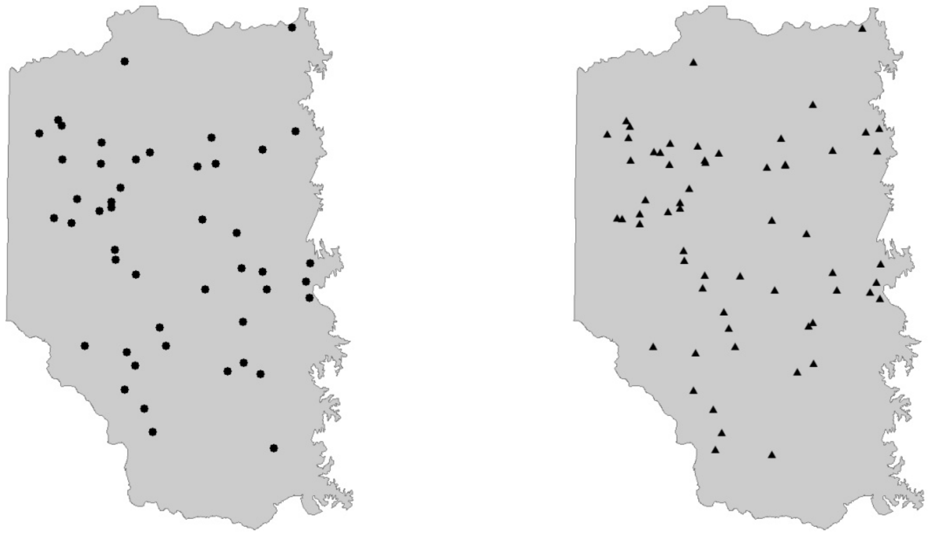

Figure 49. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the GSWF in 2013.

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. Eighty (80) wells in the unconfined portions of the GSWF had historical depth to water measurements, with about 15 unconfined wells in the network prior to GMAP (Figure 50).

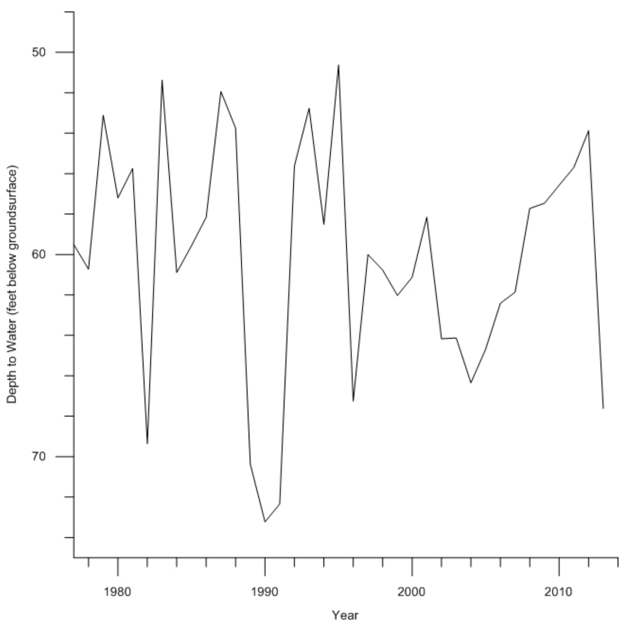

Figure 50. Average water level in unconfined GSWF wells over period of record prior to GMAP implementation (1977-2013).

A baseline groundwater level network comprising 61 wells was measured during October-November 2013. Forty-seven (47) wells are currently in the network measured annually, with 24 measured seasonally (Figure 51). To continue long-term records, the trend network included 20 wells from the aquifer's most recent historical network. Unconfined conditions are reflected in 41 wells of the water level network, and 6 are considered to be in the deeper, confined parts of the aquifer.

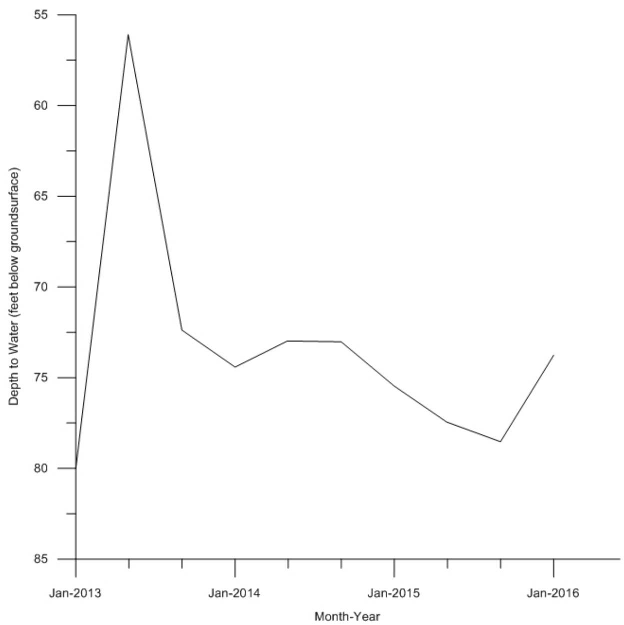

Figure 51. Average Water Level in the unconfined GMAP trend water level network for GSWF (2013-2016).

Figure 52 is a depth to water hydrograph for an unconfined well with over 30 years of measurements. Taped measurements of the well in Figure 52 have been made annually since 1976 and have continued in the GMAP water level network. This hydrograph reflects rising groundwater levels during a generally wet climatic period in Oklahoma (mid 1980s through the late 1990s); groundwater levels declined from 1999-2006 and then rose again following above normal rain fall in 2006 and 2008.

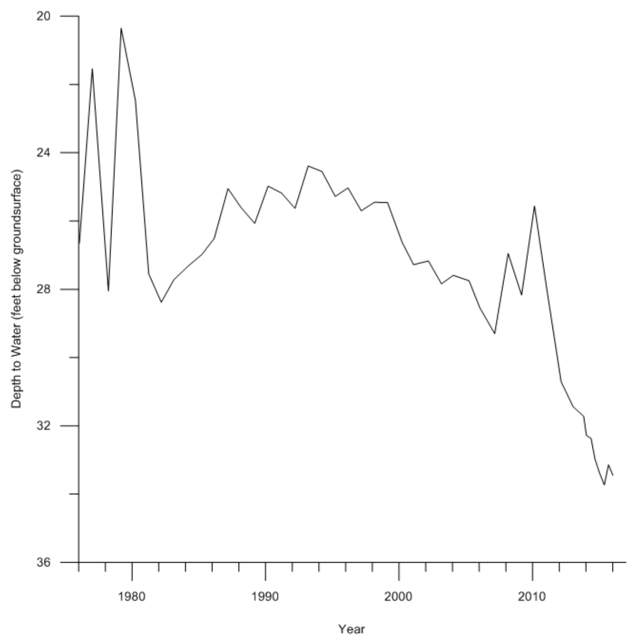

Figure 52. Groundwater level hydrograph of a GSWF well, Oklahoma County (1976-2016).

In the last five years, water levels dropped in unconfined GSWF wells an average of 5.06 feet (2011-2016). Water levels had been declining more steeply in GSWF wells but 2015 had record rainfalls, during which average annual precipitation over the area measured at 16.3 inches above normal. The new GMAP trend network has recorded an average increase of 3.61 ft in unconfined GSWF wells over the last year (2015-2016). Confined wells also responded with a 3.64 ft increase (7 wells; 2015-2016). 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 53).

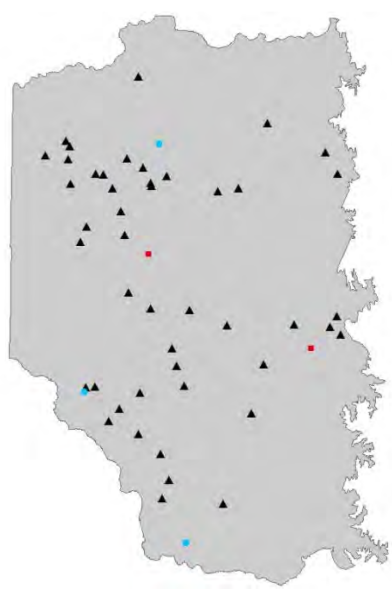

Figure 53. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for Oklahoma Mesonet (red squares) against the entire GSWF water level network.

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 54), 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 54. 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 55). 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 J of this report.

Figure 55. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the GRTY in 2013.

Groundwater Level Measurements

Historically, groundwater levels had only been tracked in two wells in the GRTY; only one had been measured in the decade prior to GMAP implementation. Measurements of these wells reflect rising groundwater levels for most of the period of record (Figure 56).

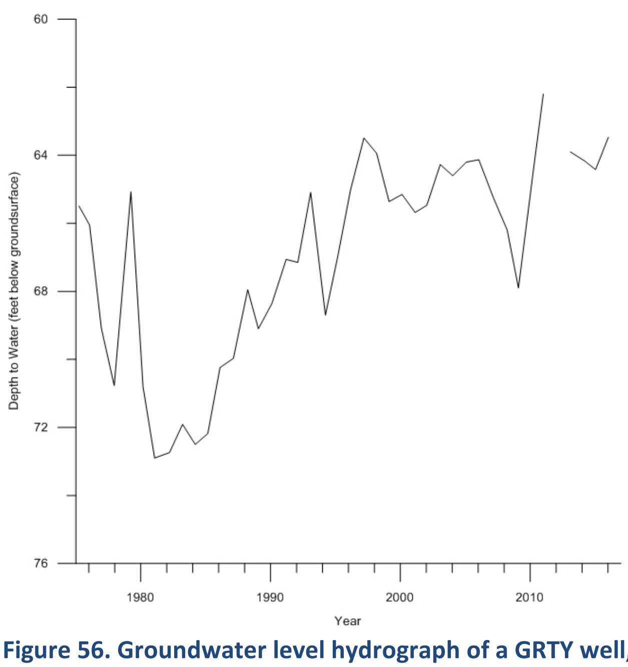

Figure 56. Groundwater level hydrograph of a GRTY well, Garvin County (1975-2016).

A baseline network of 5 wells was measured in August 2013. The Gerty Sand water level network is a work in progress. Five (5) wells are currently in the water level network measured annually, with 3 of these sites measured seasonally (Figure 57). As many as nine new groundwater level sites will be implemented during the 2016 May trend measurement period to enhance this network.

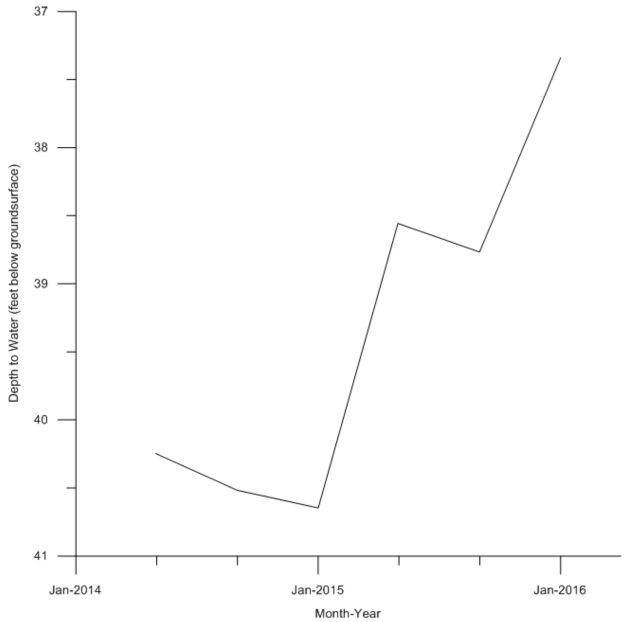

Figure 57. Average Water Level in the GMAP trend water level network for GRTY (2014-2016).

Depth to water has dropped 1.27 feet in the one well measured over the last five years (2011-2016). Water levels have been rising in GRTY wells and 2015 had record rainfalls, during which average annual precipitation over the area measured at 24.7 inches above normal. The new GMAP trend network has recorded an average increase of 2.77 ft in GRTY wells over the last year (2015-2016). Water level in the GRTY is currently being monitored by continuous water level recorders deployed by the OWRB for a separate hydrologic study (Figure 58).

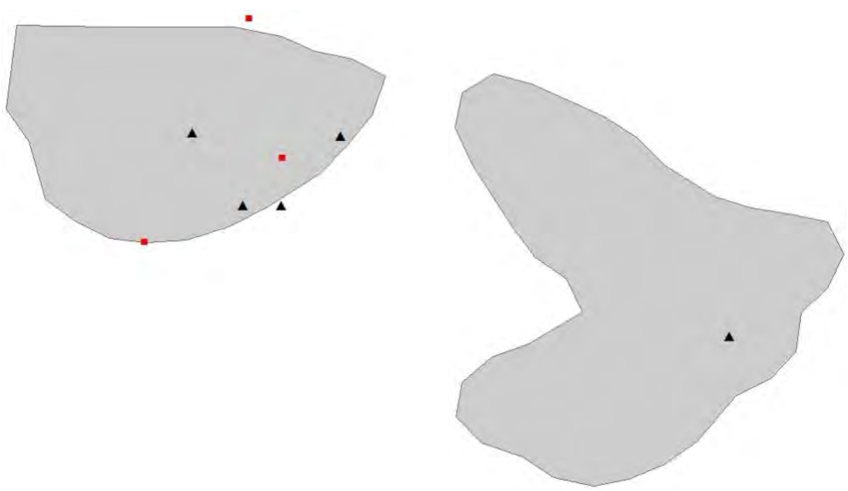

Figure 58. Location of continuous water level recorders (red square) in a current OWRB hydrologic study against the entire GRTY GMAP water level network.

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 59).

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.

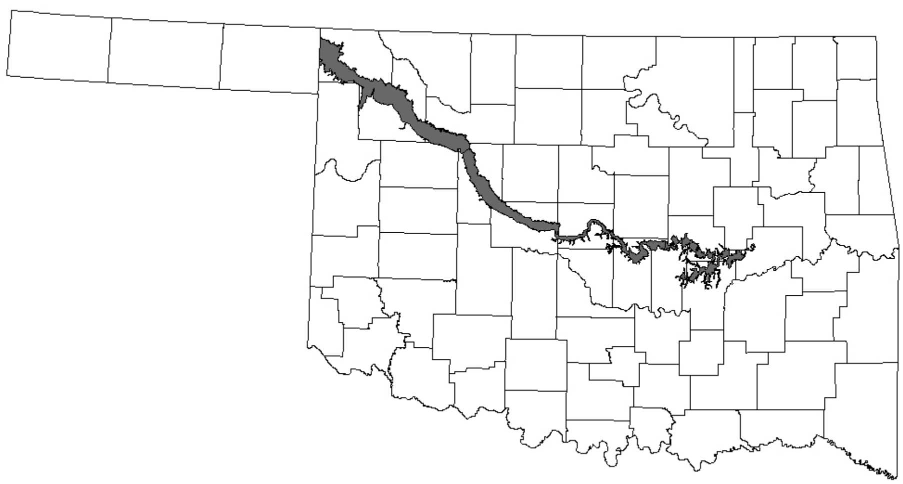

Figure 59. Location and extent of BNCR.

The aquifer is encompassed by the Panhandle, Central, and Eufaula Planning Regions. This aquifer begins in Oklahoma's Panhandle Climate Division with averages of 56.4°F and 19.63 inches of precipitation annually. It flows southeast through the North Central Climate Division with averages of 58.3°F and 28.69 inches of precipitation annually. It continues through the West Central Climate Division, which averages 59.1°F and 26.15 inches of precipitation annually, and into the Central Climate Division, which averages 60.3°F and 34.22 inches of precipitation annually. The eastern most part of this aquifer lies in the East Central Division with averages of 60.8°F and 43.08 inches of precipitation annually. Recharge of the BNCR comes mostly from precipitation with additional sources such as infiltration of runoff, streams that cross the deposits, and induced from streams when groundwater pumpage reduces the water table. The estimated rate of recharge is 1-5 inches per year, depending on the river reach. Natural discharge occurs mainly through base flow contribution to the river, along with evapotranspiration. In some areas, the BNCR overlies bedrock aquifers where the alluvial deposits and the bedrock aquifer are considered hydraulically continuous. The BNCR, as sampled by GMAP, has an estimated aerial extent of 4,427 km^2 and stores 8.21 million acre-feet of water. Well yields vary but may be as much as 1,000 gallons per minute, and the hydraulic conductivity values range up to 160 feet per day with an average of 59.

Groundwater in this aquifer supplies water for municipal and irrigation use. The OWRB has on file more than 6,600 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of January 2016, 663 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 170,130 acre-feet of water per year. The maximum withdrawal rate from the aquifer varies from 0.8 to 1.3 acre-feet per acre per year, dependent on what reach the well is located in. The North Canadian River is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 60).

Figure 60. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the BNCR in 2015.

Water Quality

Overall, this aquifer contains water of fair quality. Mineral content was mostly low. Groundwater in the aquifer was very hard and had moderate alkalinity, averaging 329 mg/L and 238 mg/L, respectively. Mean total dissolved solids (TDS) was moderate at 509 mg/L; it ranged from 118-1670 mg/L with a median concentration of 396 mg/L. Specific conductance averaged 835 µS/cm and pH was 6.84. 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. The primary water quality concerns in the aquifer are nitrate, iron, manganese, sulfate, and TDS.

The piper plot of BNCR data depicts mostly calcium-bicarbonate water (34% - Figure 61). The majority of other water types present were mixed calcium/sodium-bicarbonate (15%) and mixed calcium/sodium/magnesium-chloride/bicarbonate/sulfate (12%) waters, with a variety of other mixed water types present as well. The spatial distributions of water types and TDS are shown in Figure 62.

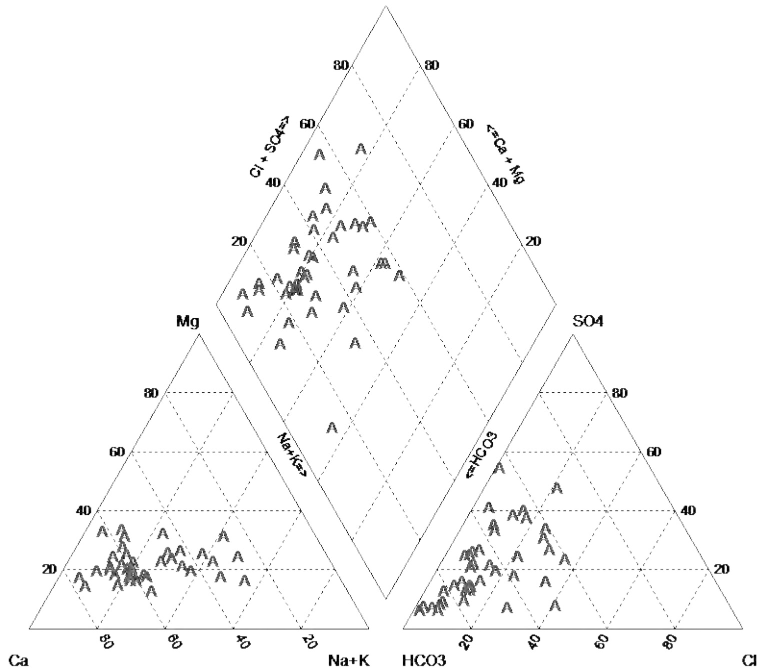

Figure 61. Piper plot diagram of constituents of the BNCR.

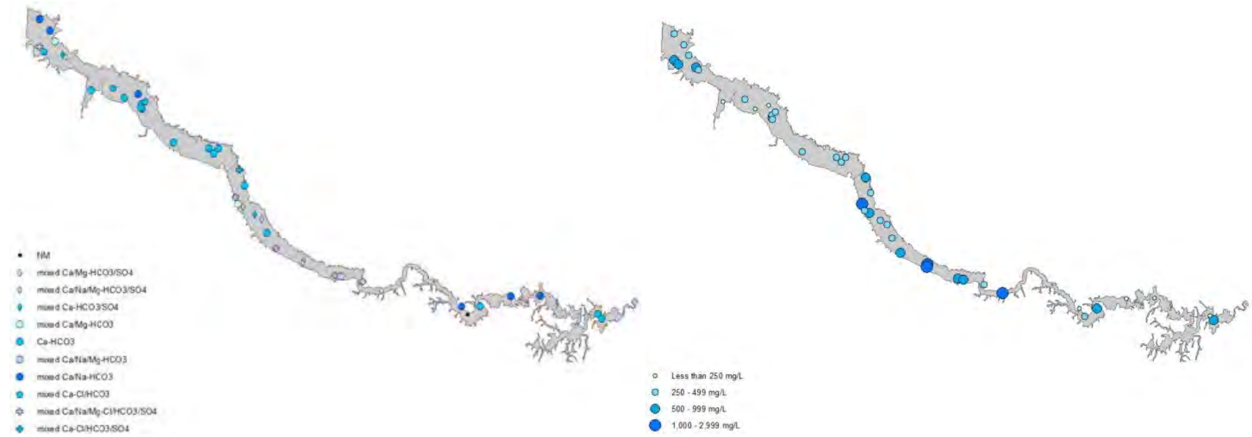

Figure 62. Water type (left) and TDS concentrations in the BNCR.

Mineral constituents were mostly low. Bromide, chloride, silica, sodium, and sulfate concentrations were low in the aquifer. Magnesium was detected at moderately low levels, and calcium and potassium were present at moderate levels. Fluoride was rare but at mostly low concentrations when present.

Nutrients in the aquifer were moderately high. Ammonia was rarely detected but at moderate levels when present. Nitrate content was moderately high and ranged from non-detectable to 20.8 mg/L with mean and median concentrations of 6.27 mg/L and 6.56 mg/L, above what would be considered background levels. Phosphorus was generally moderate and locally high, ranging from <0.005-0.433 mg/L, with mean and median concentrations of 0.113 mg/L and 0.095 mg/L.

The BNCR had mostly low levels of metals and trace elements detected. The following were not detected: aluminum, antimony, cadmium, cobalt, silver, and thallium. Beryllium, lead, mercury, and molybdenum were rarely detected but low when present. Nickel was rarely detected at low to moderate concentrations. Manganese and iron were also rarely detected but at moderate and moderately high levels when present, respectively. Chromium was detected at moderate concentrations. Other trace elements and metals detected at low concentrations in the aquifer include arsenic, barium, boron, copper, selenium, uranium, vanadium, and zinc.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The BNCR had several constituents exceed these thresholds. Table 7 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the BNCR water quality, see Appendix K.

Table 7. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the BNCR.

Parameter	>MCL	>SMCL	>Health Advisory
Chloride	--	1	--
Iron	--	8	--
Manganese	--	10	7
Nitrate	10	--	--
Sulfate	--	5	--
TDS	--	14	--
pH	--	9 under	--

Groundwater Level Measurements

Seventy-four wells (74) have historical depth to water measurements in this aquifer, with 31 wells in the most recent network configuration (Figure 63).

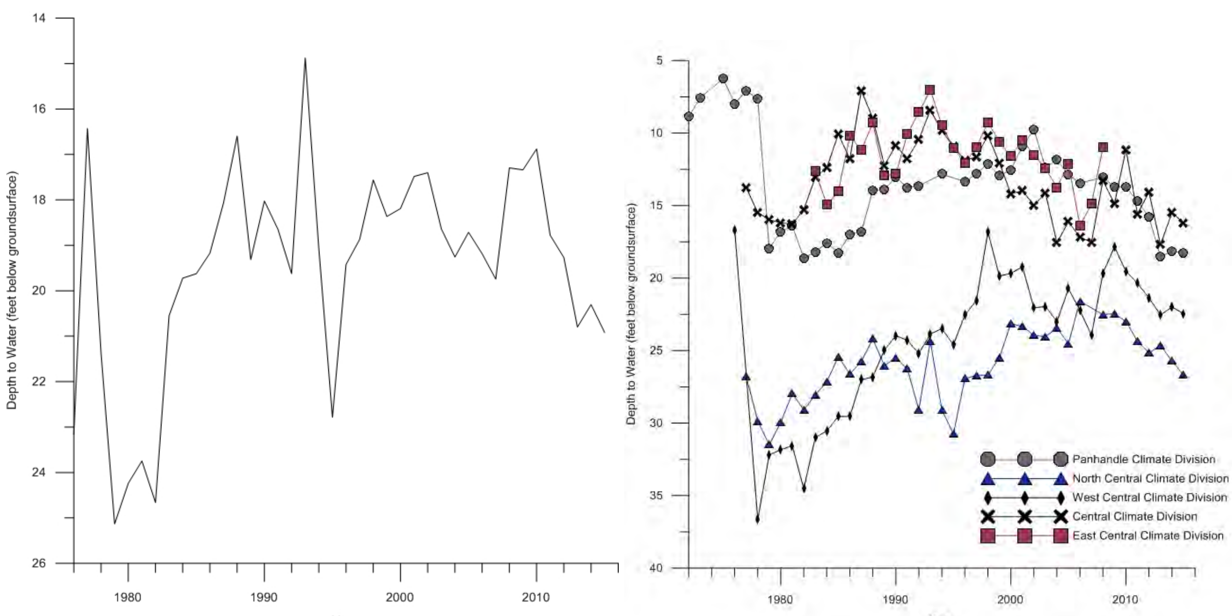

Figure 63. Average water level over period of record prior to GMAP implementation across the entire BNCR (left; 1976-2015) and split by climate division (right; 1976-2015).

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. Measurements of depth to groundwater made during baseline water quality sampling ranged from 6.59-59.83 feet below ground surface with a mean of 22.47 ft over the entire aquifer; averages were 23.3 ft in the Panhandle, 28.11 ft in the North Central, 26.4 ft in the West Central, 14.7 ft in the Central, and 10.6 ft (only 1 well) in the East Central climate divisions. The total depth of wells used in the network ranged from 7.9-130 feet and averaged 64.4 ft. Fifty-four (54) wells have been incorporated into a trend network measured annually, with 19 of these measured seasonally.

Alluvial and terrace aquifers are sensitive to use and climate which can lead to large fluctuations in water levels. The average water level in North Canadian River wells has dropped 0.71 ft over the last 5 years (2011-2016), with an average drop of 3.26 ft in the Panhandle, drop of 2.04 ft in the North Central, drop of 1.58 ft in the West Central, rise of 3.39 ft in the Central, and rise of 4.86 ft (only 1 well) in the East Central climate divisions. Water levels had been declining more sharply in BNCR wells but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the BNCR measured at 16.6 inches above normal. This aquifer had two GMAP recorders installed in Okfuskee and Woodward counties during winter 2013 (Figure 64).

Figure 64. 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 65).

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.

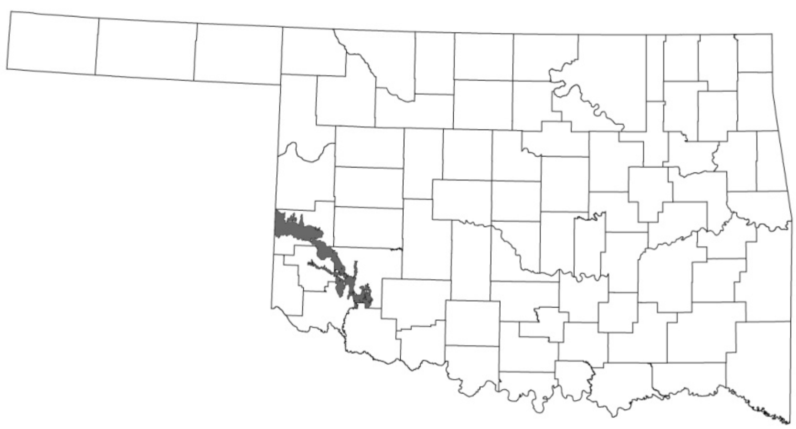

Figure 65. Location and extent of the NFRR.

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 66). 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 L of this report.

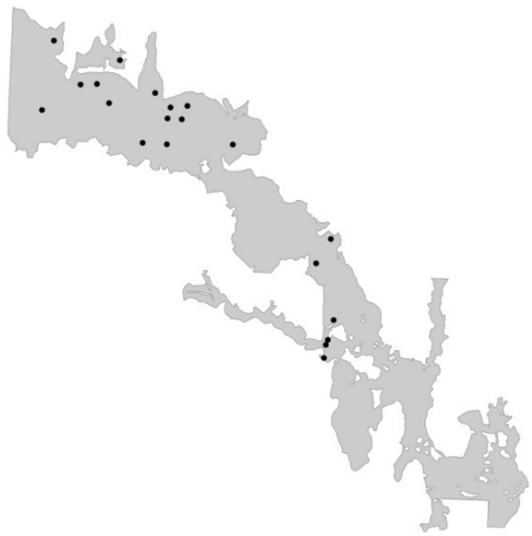

Figure 66. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the NFRR in 2014.

Groundwater Level Measurements

The historical network had 74 wells with measurements. About 30 wells made up the configurations prior to GMAP, some with records dating to 1976 (Figure 67).

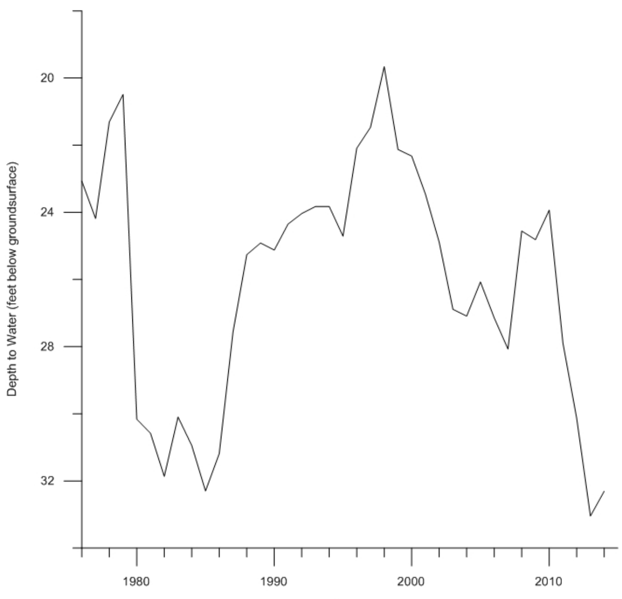

Figure 67. Average NFRR water level over period of record prior to GMAP implementation (1976-2014).

A baseline groundwater level network of 43 wells was measured in July-August 2014. Thirty-seven (37) wells have been incorporated into the network measured annually, with 15 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 68).

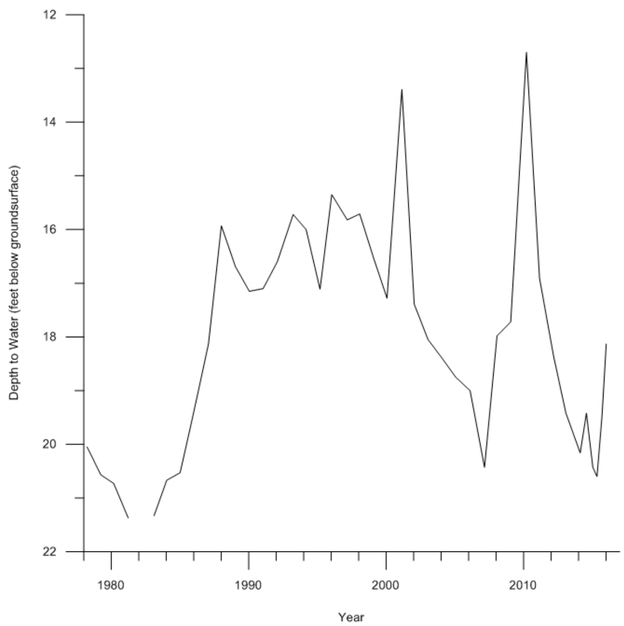

Figure 68. Groundwater level hydrograph of an NFRR record, Kiowa County (1978-2016).

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. The sustained drought in the region over the last five years is reflected in water levels that have declined an average 2.4 feet in NFRR wells (2011-2016). Water levels had been declining more sharply in NFRR wells but this has been attenuated by record rainfall in 2015, during which average annual precipitation in the area measured at 15.8 inches above normal. The new GMAP trend network has recorded the average water level increasing in NFRR wells by 4.82 ft in the west central and by 4.21 ft in the southwest areas over the last year (2015-2016). 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 69).

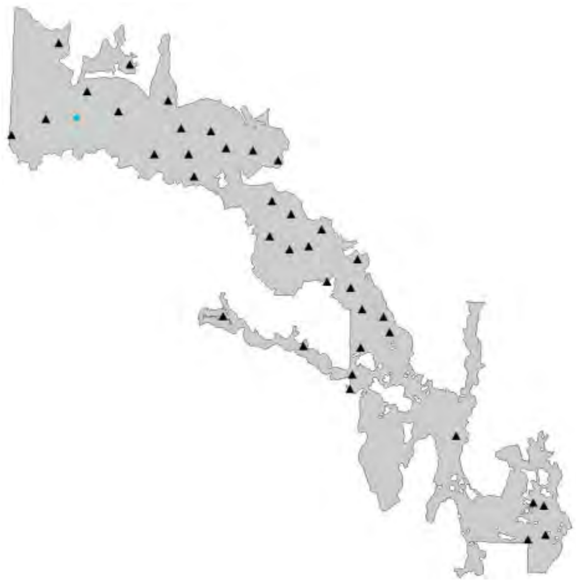

Figure 69. Location of continuous water level recorder deployed for GMAP long-term seasonal monitoring (blue circle) against the entire NFRR water level network.

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 70). 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 OGLL-NW) 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.

Figure 70. Location and extent of the OGLL-NW.

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 71). 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 OGLL-NW can also be found in Appendix M of this report.

Figure 71. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the OGLL-NW in 2013.

Groundwater Level Measurements

One hundred eighty wells (180) have historical depth to water measurements, and about 50 wells were in the network configurations prior to GMAP. Many of these have a period of record of more than 30 years (Figure 72).

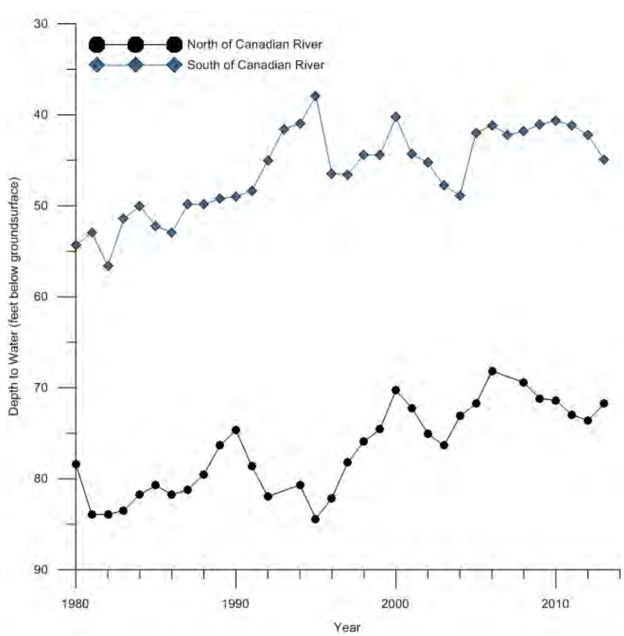

Figure 72. Average OGLL-NW water levels over period of record prior to GMAP implementation (1980-2013).

A baseline groundwater level network comprising 49 wells was measured in August-September 2013. Fifty-eight (58) wells are currently in the network measured annually, with 22 of these sites measured seasonally (Figure 73). Many wells from the aquifer’s historical groundwater level network were included in the water level network to continue these long-term records.

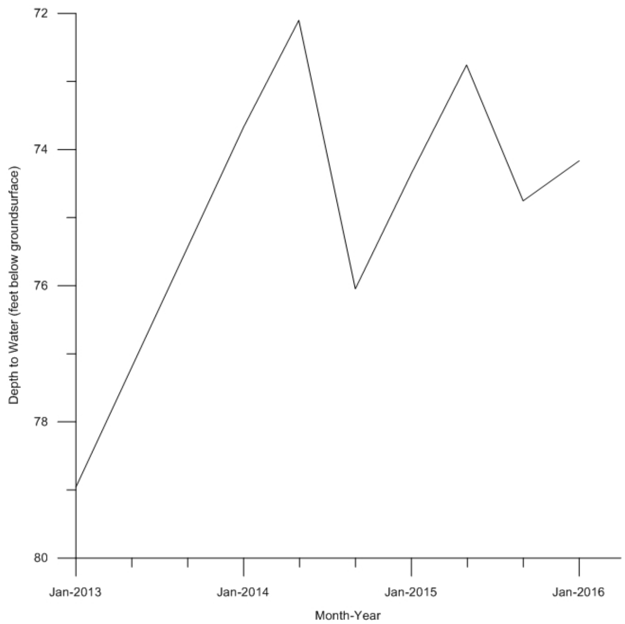

Figure 73. Average Water Level in the GMAP trend water level network for OGLL-NW (2013-2016).

The hydrograph below of an OGLL-NW well reflects three periods of generally increasing depth to water (1980-1985; 1989-1996; 2002-present) and two periods of decreasing depth to water (1985-1989 and 1996-2002) (Figure 74). The two periods reflecting rising groundwater levels correspond in part with above average rainfall for the state. Since 2011, the water level has dropped another 2.69 feet at this site.

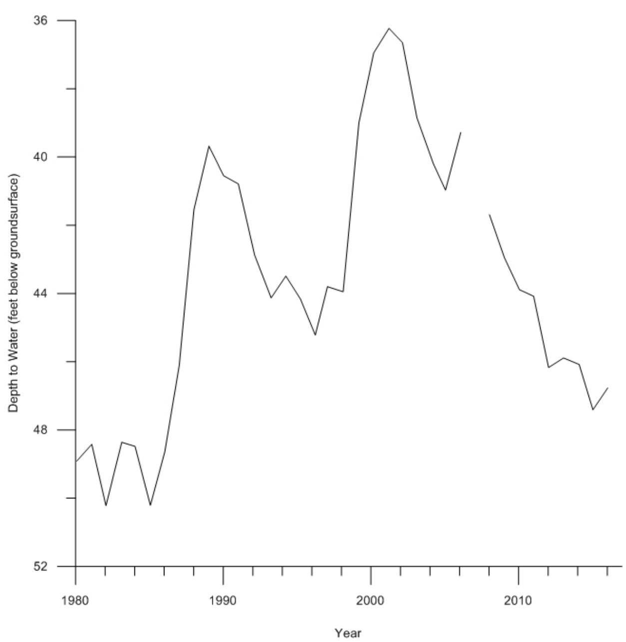

Figure 74. Groundwater level hydrograph of a record in OGLL-NW, Ellis County (1980-2016).

Average water levels in the OGLL-NW wells have dropped 3.06 feet in the last five years (2011-2016); an average 3.31 feet in wells north of the Canadian River and 2.37 feet in wells south. Water levels had been declining more in OGLL-NW wells but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the area measured at 12.99 inches above normal. The new GMAP trend network has recorded the wells north of the Canadian River increasing an average of 0.52 ft and wells south increasing an average 1.63 ft over the last year (2015-2016). A continuous water level recorder was installed in an Ellis county well during November 2013 to record hourly depth to water measurements (Figure 75).

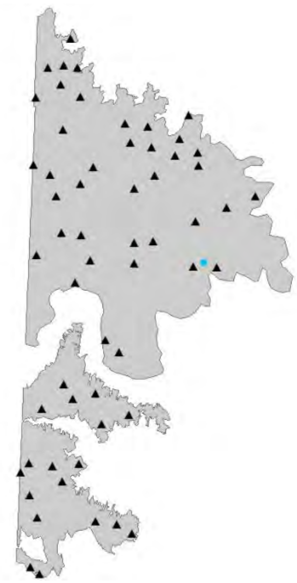

Figure 75. Location of continuous water level recorder (blue circle) against the entire OGLL-NW water level network.

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 76).

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.

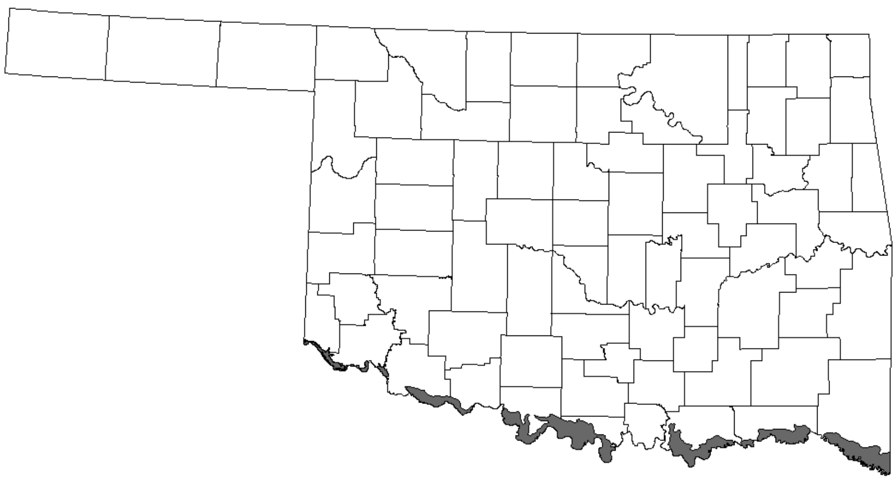

Figure 76. Location and extent of the RED.

The aquifer flows through the state's Southwest, Beaver-Cache, Lower Washita, Blue Boggy, and Southeast Planning Regions. The western most part of this aquifer, which is in Oklahoma's Southwest Climate Division, averages of 61.2°F and 27.7 inches of precipitation annually. The middle of this aquifer is in the South Central Climate Division with averages of 62.3°F and 37.77 inches of precipitation annually. The eastern most part of this aquifer is in the Southeast Division and averages 61.1°F and 47.63 inches of precipitation annually. Recharge of the aquifer comes mostly from precipitation. Additional recharge comes from infiltration of runoff, from streams that cross the deposits, and induced from streams when groundwater pumpage reduces the water table. The estimated recharge rate for the RED is 2.5 inches per year. Natural discharge occurs through evapotranspiration and base flow to streams. The RED, as sampled in GMAP, has an estimated aerial extent of 3,794 km^2 and stores 2.58 million acre-feet of water. Well yields vary but may be up to 500 gallons per minute.

Groundwater is mainly utilized for municipal, irrigation, industrial, rural, domestic, and agricultural use. The OWRB has on file more than 900 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of January 2016, 107 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 30,057.6 acre-feet of water per year. The maximum withdrawal rate from the aquifer is temporarily 2 acre-feet per acre per year. The Red River is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 77).

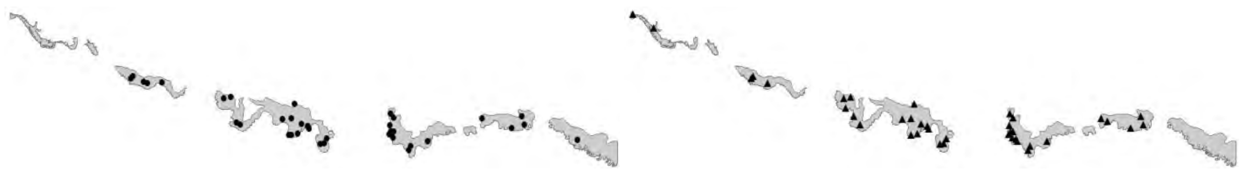

Figure 77. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the RED in 2015.

Water Quality

Overall, this aquifer contains water of fair to good quality. Mineral content was very low. Groundwater in the aquifer was hard with moderately low alkalinity, averaging 184 mg/L and 159 mg/L, respectively. Mean total dissolved solids (TDS) were moderately low at 360 mg/L, with a range of 65-1200 mg/L and a median concentration of 295.5 mg/L. Mean specific conductance averaged 610 µS/cm, and pH was 6.61. The primary water quality concerns are nitrate, low pH, locally elevated manganese, and TDS.

The piper plot of RED data depicts primarily bicarbonate water with calcium and/or mixed cation waters (Figure 78). Twenty-two percent (22%) of sites had calcium/sodium-bicarbonate, 14% had calcium/sodium/magnesium-bicarbonate, 11% had calcium-bicarbonate, and 11% had calcium/magnesium-bicarbonate water. Various other mixed water types were also present. The spatial distributions of water types and TDS are shown in Figure 79.

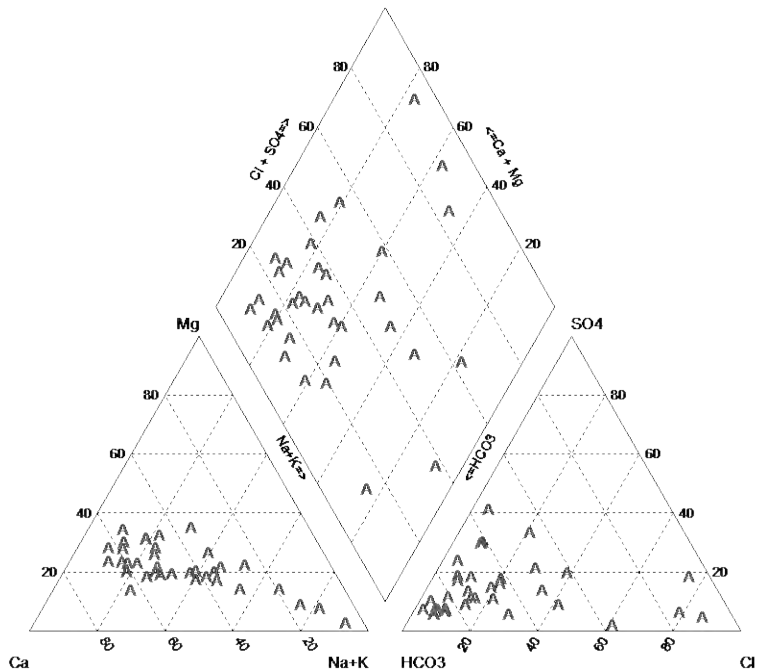

Figure 78. Piper plot diagram of constituents of the RED.

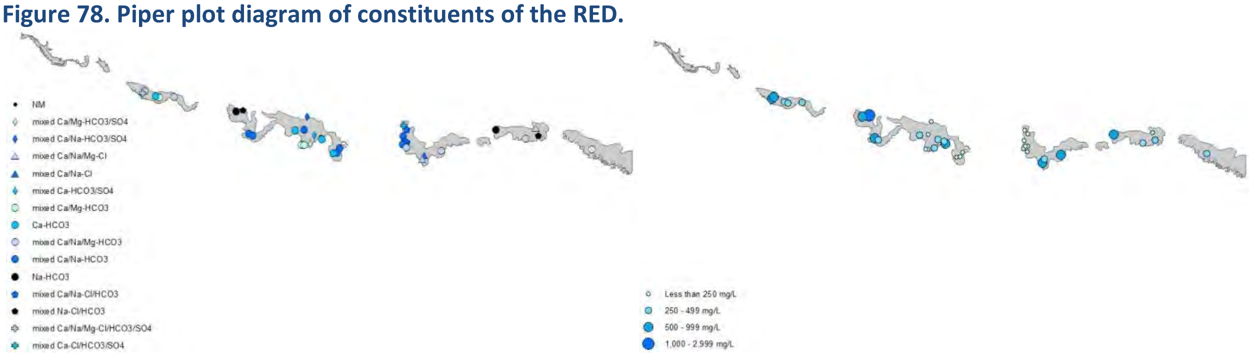

Figure 79. Water type (left) and TDS concentrations in the RED.

Low concentrations of bromide, calcium, chloride, magnesium, potassium, silica, sodium, and sulfate were present in the RED. Fluoride was rarely detected but at moderately low concentrations when present.

Nutrients in the aquifer were at moderate levels. Ammonia was only detected at one site with a moderate concentration. Nitrate content was moderately high with a wide range from non-detectable to 22.3 mg/L and with mean and median concentrations of 8.7 mg/L and 8.52 mg/L that are above what would be considered background levels. Phosphorus was moderately low with a wide range of <0.005-0.252 mg/L and mean and median concentrations of 0.058 mg/L and 0.046 mg/L.

The RED had few metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, mercury, molybdenum, silver, and thallium. Barium, boron, copper, selenium, and zinc were present in low concentrations. Arsenic, nickel, uranium, and vanadium were rarely detected but at low concentrations when present; chromium, lead, and manganese were rarely detected but at moderate concentrations. Iron was also rarely detected and mostly low when present with the exception of a few sites with high concentrations.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The RED had some constituents exceed these thresholds. Table 8 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the RED water quality, see Appendix N.

Table 8. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the RED.

Parameter	>MCL	>SMCL	>Health Advisory
Chloride	--	1	--
Iron	--	3	--
Manganese	--	4	2
Nitrate	14	--	--
TDS	--	9	--
pH	--	12 under	--

Groundwater Level Measurements

Eight (8) wells in this aquifer have depth to water measurements, with only 4 wells in the South Central climate division comprising the most recent network. The number and location of these sites as well as the variable time intervals from which data was collected prevents creation of an aquifer-wide composite hydrograph for the Red River. Several wells have 10-20 years of measurements, although periods of record are not consistent (Figure 80). Several of these wells were incorporated into the new baseline network to maintain water level sites with long-term records.

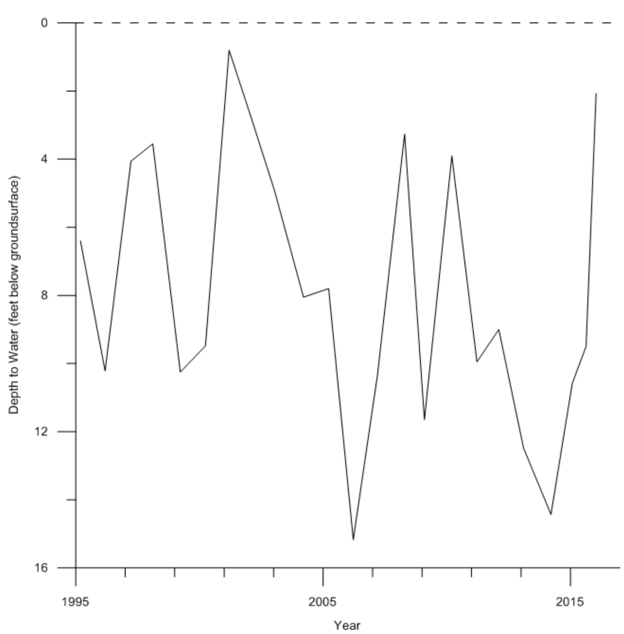

Figure 80. Groundwater level hydrograph for one of the longest current Red River records, Bryan County (South Central climate division; 1995-2016).

A baseline groundwater level network comprising 38 wells was implemented in August 2015. Measurements of depth to water made during baseline water quality sampling in 2015 ranged from 4.5 to 57.99 feet with an average 27.54 ft across the RED; the total depth of wells used in the network ranged from 28.5 to 142 feet. A trend network composed of 32 wells was also initiated (5 in west, 22 in central, and 5 wells in eastern areas) to be measured annually, with 13 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. Over the last five years, water levels have been declining in RED wells but 2015 had record rainfalls, during which average annual precipitation over the aquifer measured at 27.5 inches above normal. This is reflected in a rise of average water level in the South Central reaches of the Red River by 2.71 feet in the last 5 years (2011-2016).

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 81). 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.

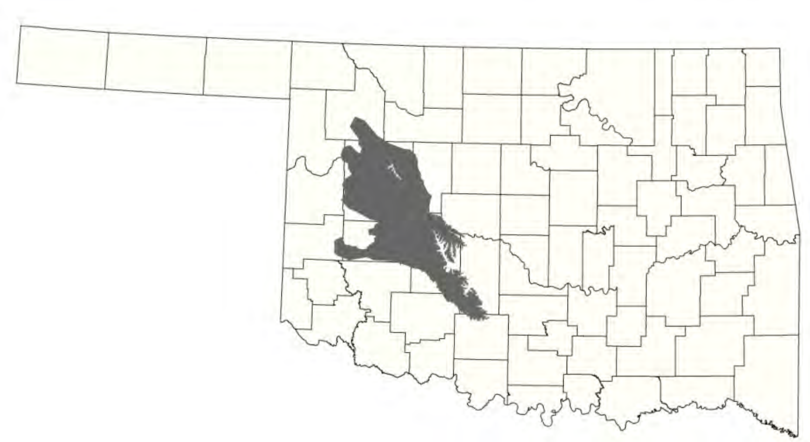

Figure 81. Location and extent of the RSPG.

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 82). 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 O of this report.

Figure 82. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the RSPG in 2013.

Groundwater Level Measurements

One hundred forty wells (140) in the aquifer have historical depth to water measurements, with 60-75 wells in the network configurations prior to GMAP (Figure 83). Many of these older sites have nearly 40 years of record but with unfortunate interruptions in measurement.

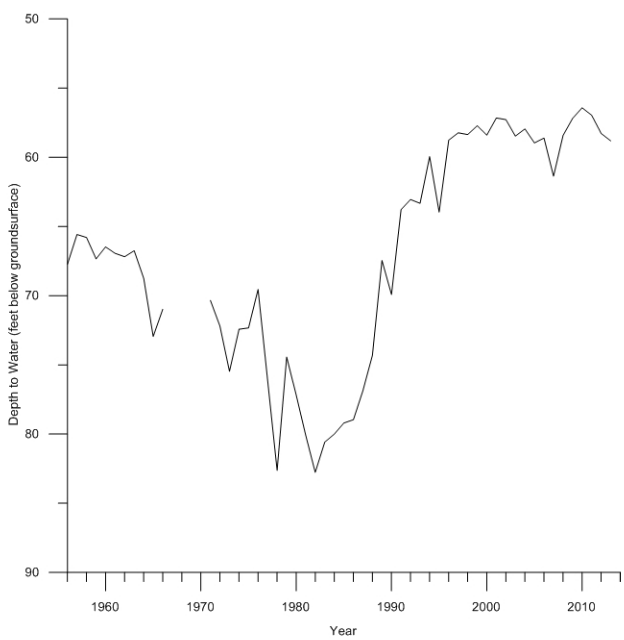

Figure 83. Average RSPG water levels over period of record prior to GMAP implementation (1976-2013).

A baseline groundwater level network comprising 104 wells was measured during September-October 2013. Eighty-two (82) wells have been incorporated into the water level network measured annually, with 32 of these sites measured seasonally (Figure 84).

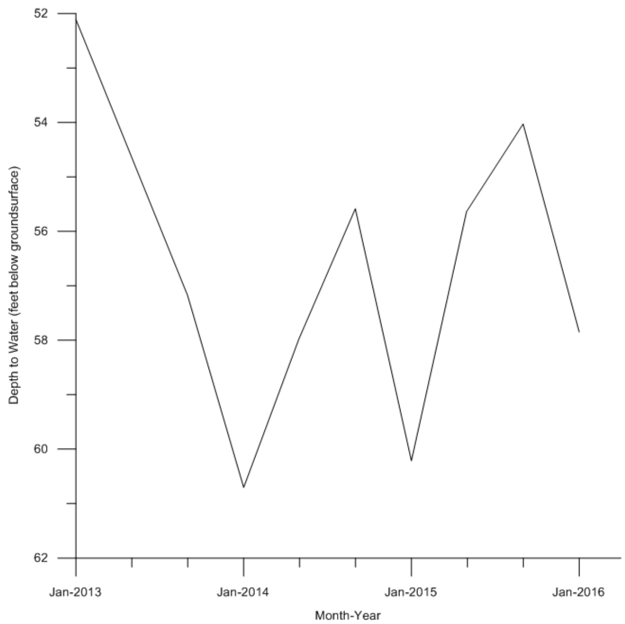

Figure 84. Average Water Level in the GMAP trend water level network for RSPG (2013-2016).

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 85). During most of the 1980s and 1990s, many areas of the state received near normal or above normal precipitation, and groundwater levels as depicted by the well hydrographs reflect rising groundwater levels.

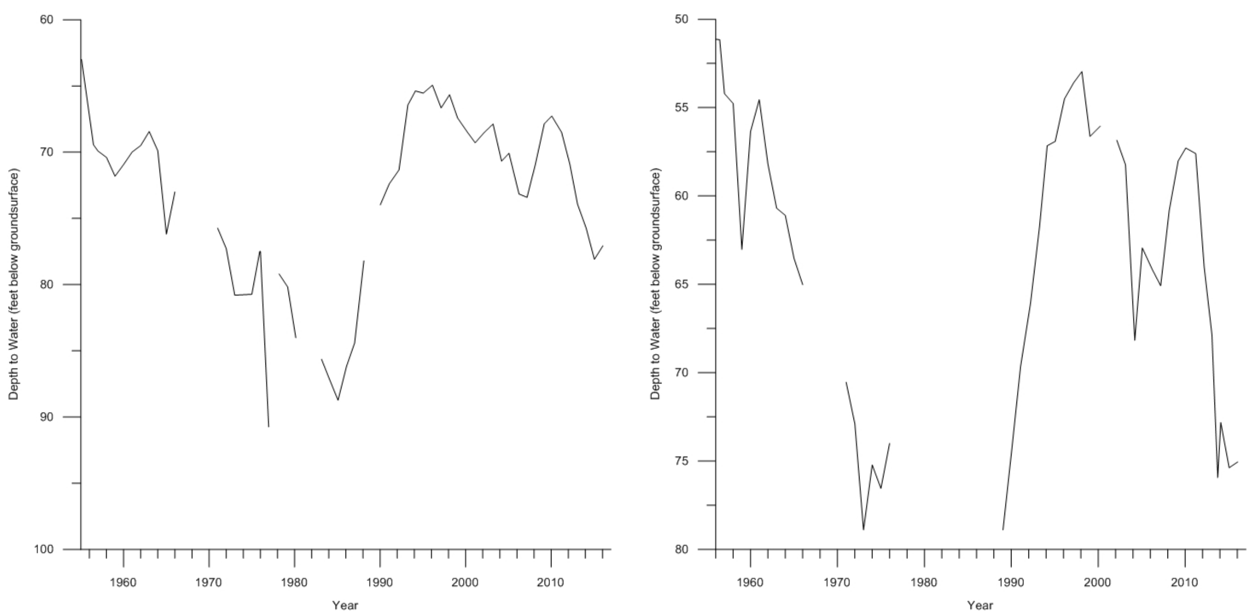

Figure 85. Groundwater level hydrographs for two of the longest RSPG records, Caddo County (1955-2016; left) and Caddo County (1956-2016; right).

In contrast, the most recent five year interval shows that water levels have been on the decline in RSPG wells, dropping an average 4.65 feet (2011-2016). Water levels had been declining more sharply but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the RSPG measured at 11.87 inches above normal. The new GMAP trend network has recorded the average water level increasing in RSPG wells by 2.19 ft over the last year (2015-2016). 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 86).

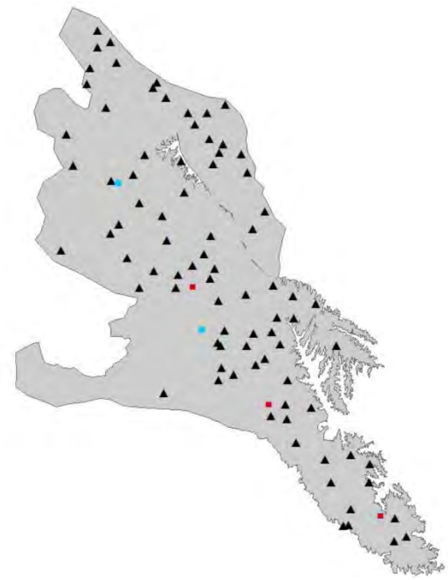

Figure 86. Location of continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for the Oklahoma Mesonet (red squares) against the entire RSPG water level network.

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 87).

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.

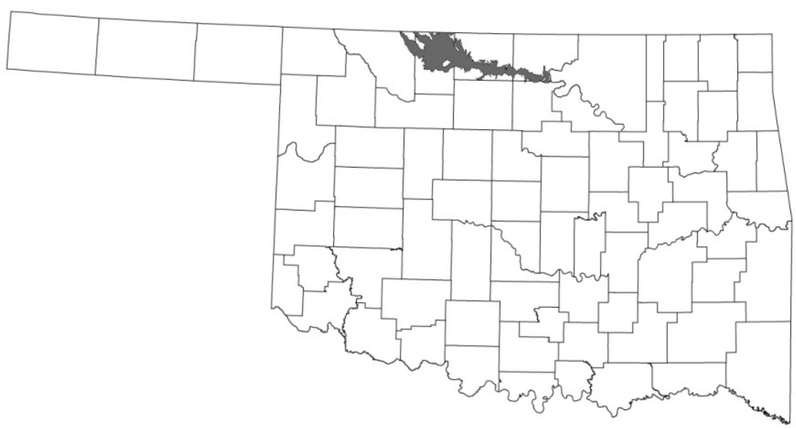

Figure 87. Location and extent of the SFAR.

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 88). 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 P of this report.

Figure 88. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFAR in 2014.

Groundwater Level Measurements

The historical network had measurements on 26 wells, with about 20 wells in the network configurations prior to GMAP (Figure 89). Several SFAR wells have ten years or more of recorded measurements.

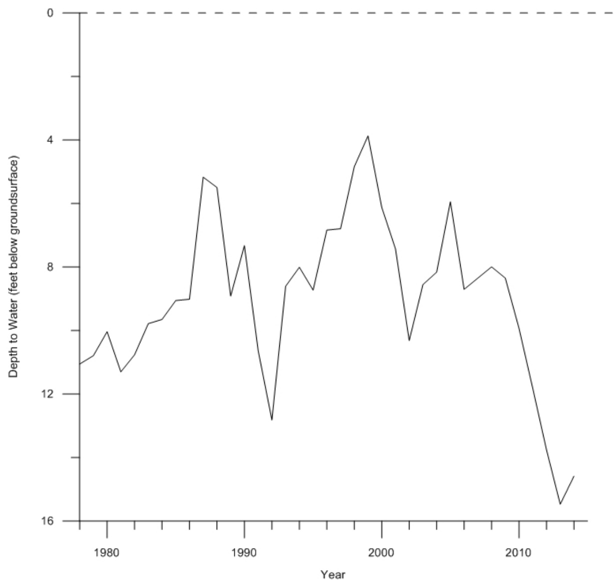

Figure 89. Average SFAR water level over period of record prior to GMAP implementation (1978-2014).

A baseline groundwater level network comprising 46 wells was measured in July 2014. Thirty-five (35) wells have been incorporated into the water level network measured annually, with 17 of these sites measured seasonally. Some historical wells were included in the new network to maintain long-term records (Figure 90).

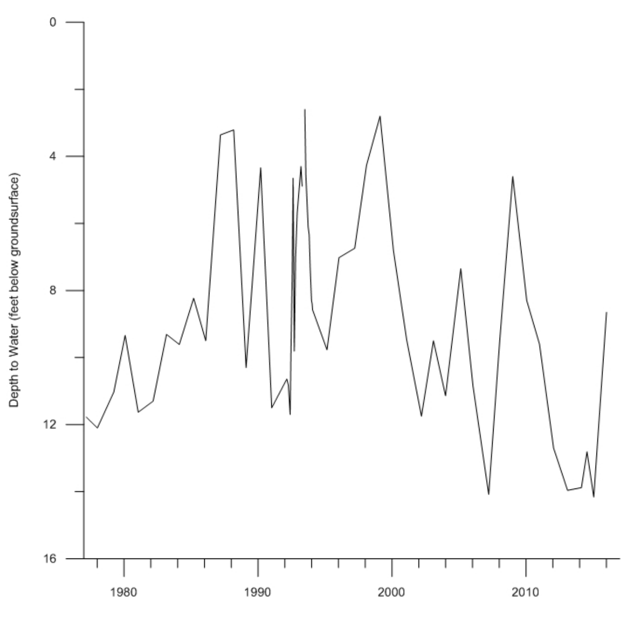

Figure 90. Groundwater level hydrographs for a SFAR record, Grant County (1977-2016).

Over the last five years, water levels had been declining in SFAR wells but 2015 had record rainfalls, during which average annual precipitation over the aquifer measured at 4.7 inches above normal. Water levels have risen in SFAR wells an average 0.44 feet during this period (2011-2016), and the new GMAP trend network has recorded the average water level increasing in SFAR wells by 3.78 ft over the last year (2015-2016). A continuous water level recorder was installed in Grant County (Figure 91) in December 2014 where depth to water in feet below land surface is being recorded in hourly increments.

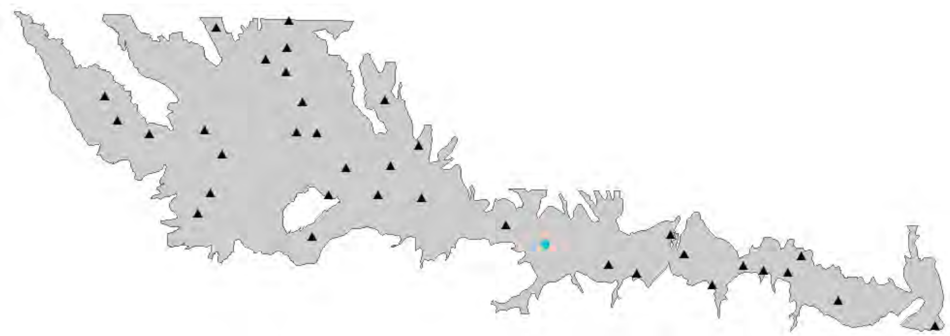

Figure 91. Location of continuous water level recorder (blue circle) against the entire SFAR water level network.

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 92).

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.

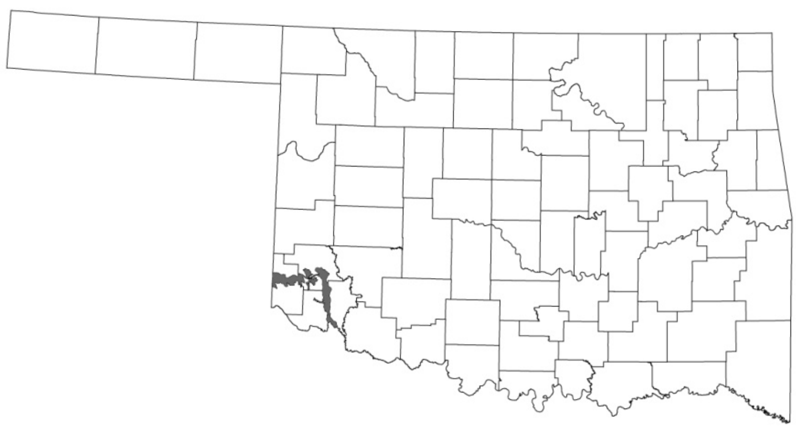

Figure 92. Location and extent of the SFRR.

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 93). 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 Q of this report.

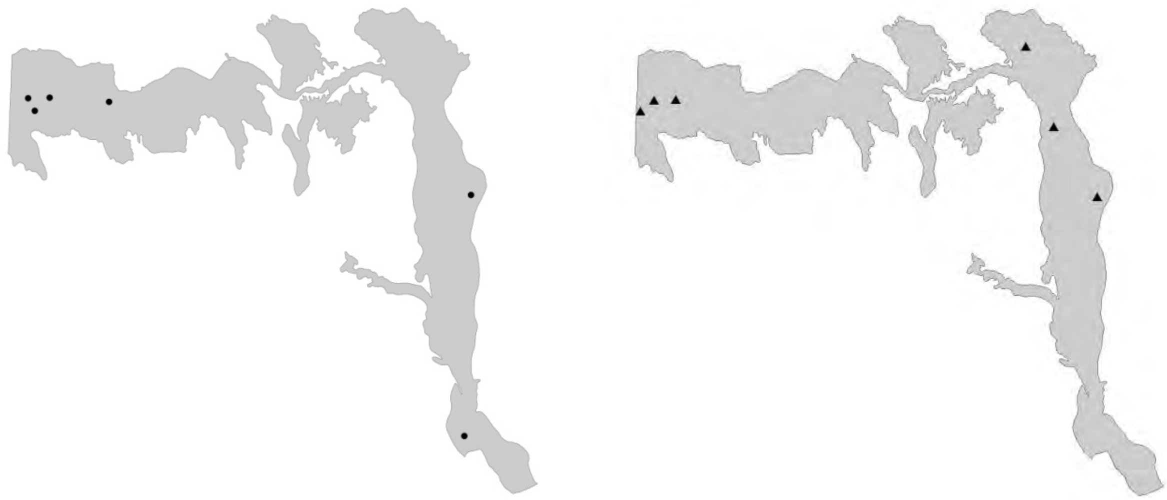

Figure 93. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFRR in 2014.

Groundwater Level Measurements

There are no wells with historical groundwater level measurements 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. The new GMAP network has recorded the average water level increasing in SFRR wells by 2.02 ft over the last year (2015-2016). The state saw record rainfalls during 2015, during which average annual precipitation over the SFRR measured at 13.2 inches above normal.

Tillman Terrace Aquifer

The Tillman Terrace aquifer, underlying part of Tillman County in southwestern Oklahoma, is an alluvial & terrace aquifer (Figure 94). 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 94. 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 95). 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 R of this report.

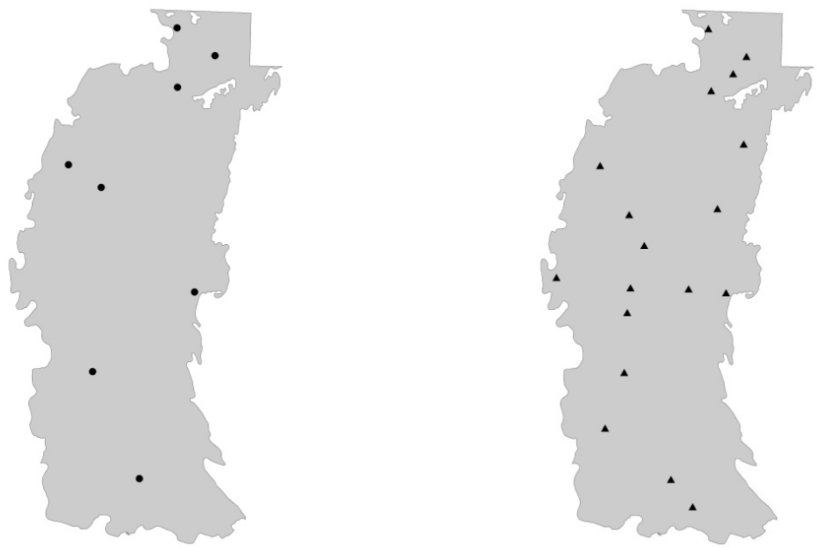

Figure 95. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the TILL in 2014.

Groundwater Level Measurements

There were 35 measured wells in the historical network, with 12-15 in the network configurations prior to GMAP (Figure 96).

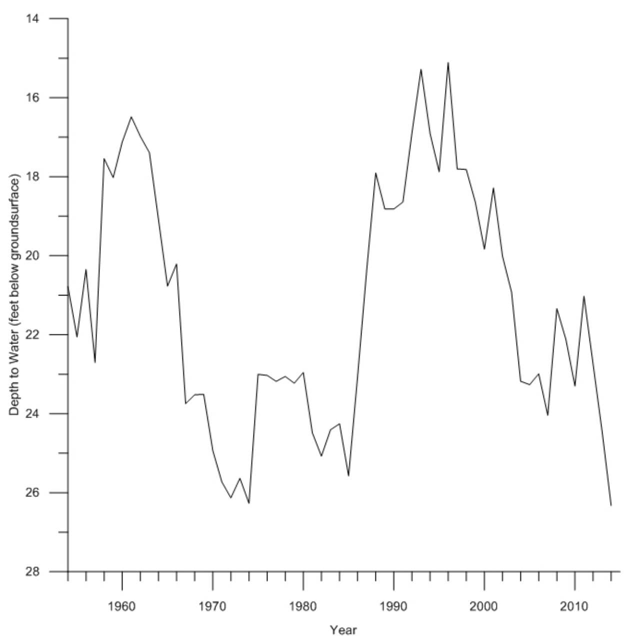

Figure 96. Average TILL water level over period of record prior to GMAP implementation (1955-2014).

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 (Figure 97). Eighteen (18) wells are currently in the network measured annually, with 10 of these sites measured seasonally.

The above hydrographs reflect declining water levels with an average drop of 1.25 feet in TILL wells over the last 5 years (2011-2016). Water levels had been declining more sharply in TILL wells but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the area measured at 9.6 inches above normal. The new GMAP water level network has recorded the average water level increasing in TILL wells by 3.07 ft over the last year (2015-2016).

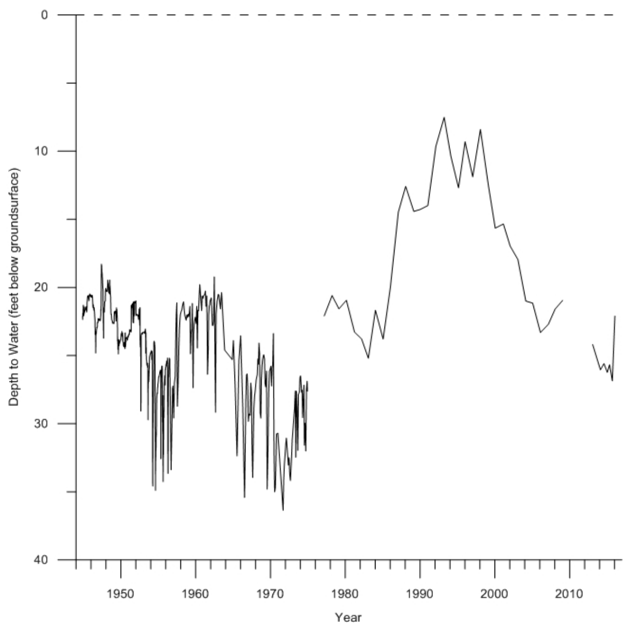

Figure 97. Groundwater level hydrograph for the longest TILL record, Tillman County (1944-2016).

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 98). 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).

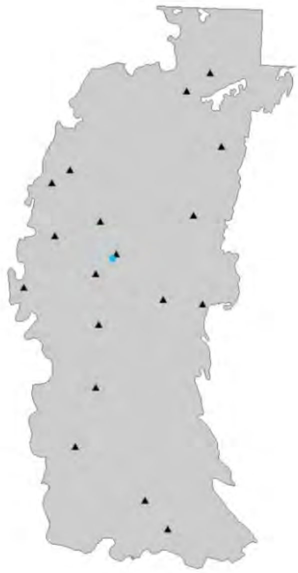

Figure 98. Location of continuous water level recorder (blue circle) at an Oklahoma Mesonet station against the entire TILL water level network.

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 99).

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.

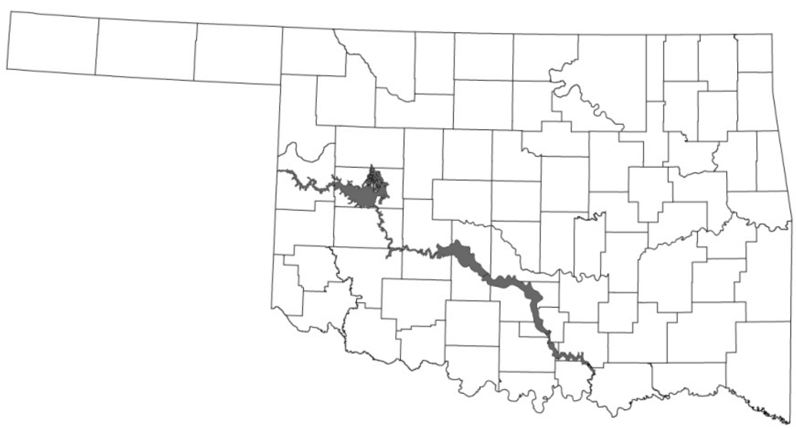

Figure 99. Location and extent of the WASH.

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 100). 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 S of this report.

Figure 100. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the WASH in 2014.

Groundwater Level Measurements

Twenty (20) wells in this aquifer had historical measurements, with 8 in the network configuration prior to GMAP. The number and location of these sites in the WASH prevents creation of an aquifer-wide composite hydrograph. Several historical wells have a period of record that spans over 30 years (Figure 101). The baseline network incorporated 5 wells from the WASH's historical groundwater level network to continue these long-term monitoring records.

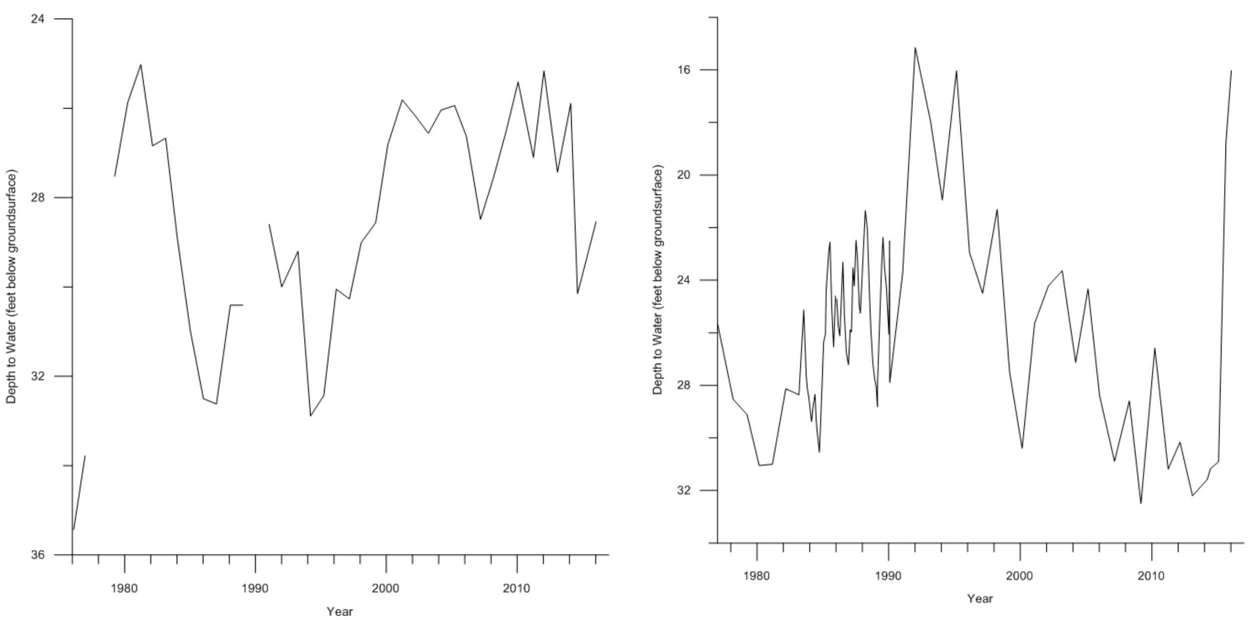

Figure 101. Groundwater level hydrographs for two of the longest WASH records, Roger Mills County (1976-2016; left) and Johnston County (1977-2016; right).

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 13 of those sites measured seasonally.

Alluvial and terrace aquifers are sensitive to use and climate which can lead to large fluctuations in water levels. Water levels have been declining in WASH wells but 2015 had record rainfalls, during which average annual precipitation over the aquifer measured at 18.1 inches above normal. Over the last five years, the above hydrographs reflect a steady decline in water level prior to these rains and then a noticeable increase. In the West Central climate division, average WASH water levels have risen 1.37 ft; there is no data for this time period in the Southwest or Central divisions; and in the South Central division, average water levels have declined by 0.3 ft. The new GMAP trend network has recorded the average water level increasing in WASH wells by 3.74 ft in the West Central, 5.18 ft in the Southwest, 6.2 ft in the Central, and by 8.68 ft in the South Central areas over the last year (2015-2016). 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 102).

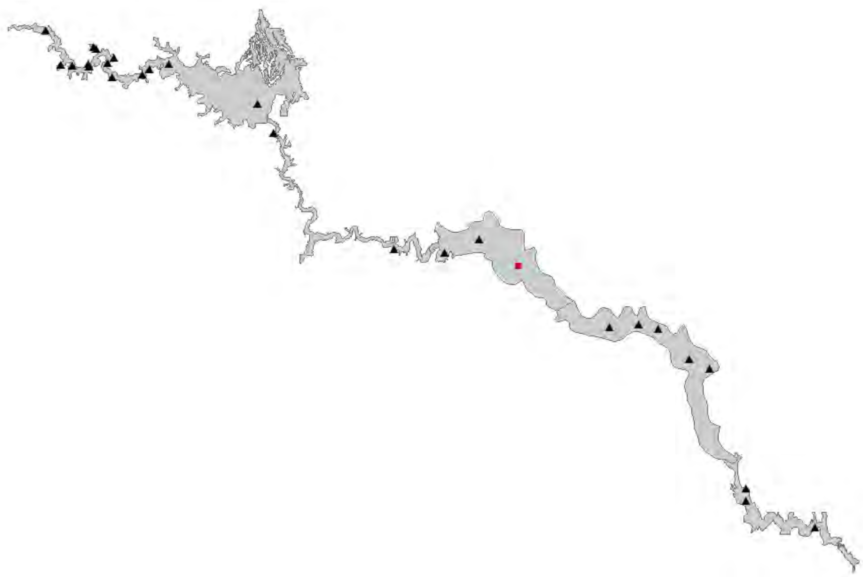

Figure 102. Location of continuous water level recorder (red square) at an Oklahoma Mesonet station against the entire WASH GMAP water level network.

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 103).

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.

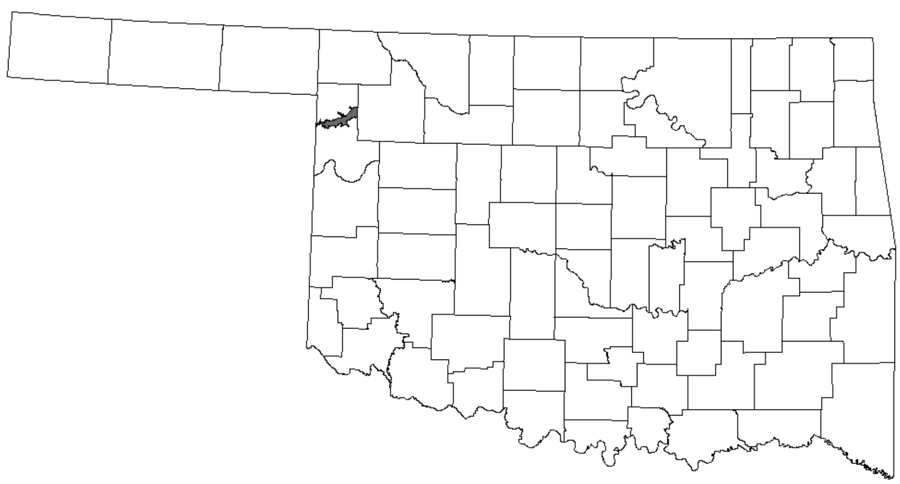

Figure 103. Location and extent of the WOLF.

The aquifer flows through the state's Panhandle Planning Region and is located in Oklahoma's Panhandle Climate Division, with averages of 56.4°F and 19.63 inches of precipitation annually. The WOLF has an estimated aerial extent of 211 km^2. Due to limited studies on this minor aquifer, many aspects of storage and yield are unavailable. Generally, minor aquifers yield less than 50 gpm per well.

Groundwater in this aquifer is mainly utilized for low volume domestic and stock use. The OWRB has on file more than 170 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of January 2016, 20 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 6,934.6 acre-feet of water per year. The maximum withdrawal rate from the aquifer is temporarily set at 2 acre-feet per acre per year. The Wolf Creek is designated by the OWRB as having a high to very high vulnerability level.

Data Collection Results

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 104). 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.

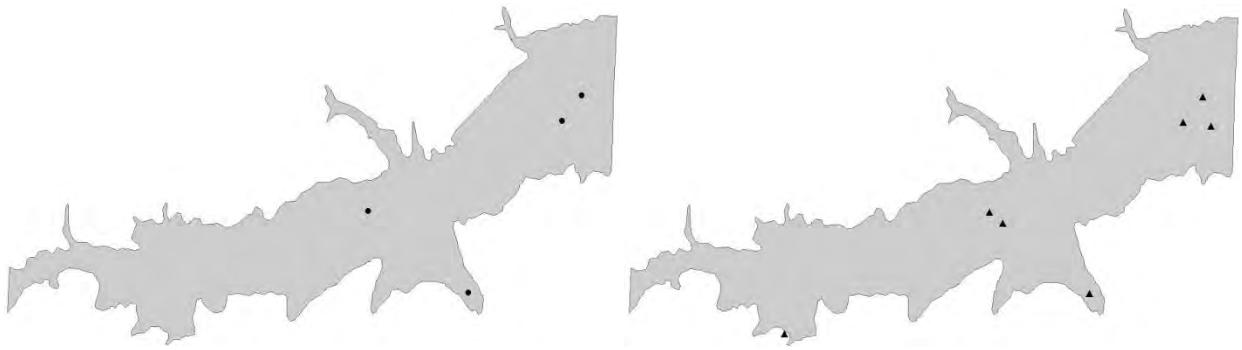

Figure 104. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the WOLF in 2015.

Water Quality

With the above caveat of sample size, this aquifer contains water of good quality. Mineral content was low. Groundwater was very hard and moderately alkaline, averaging 261.8 mg/L and 192.3 mg/L, respectively. Mean total dissolved solids (TDS) was moderately low with an average 411.8 mg/L. TDS ranged 316-601 mg/L with a median of 365 mg/L. Average specific conductance was 670.8 uS/cm and pH was 7.27. With the small number of sampling sites in mind, there are no gross water quality concerns apparent in this data set.

The piper plot of WOLF data depicts calcium-bicarbonate water (50%) and mixed water types (Figure 105). The spatial distributions of water types and TDS are shown in Figure 106.

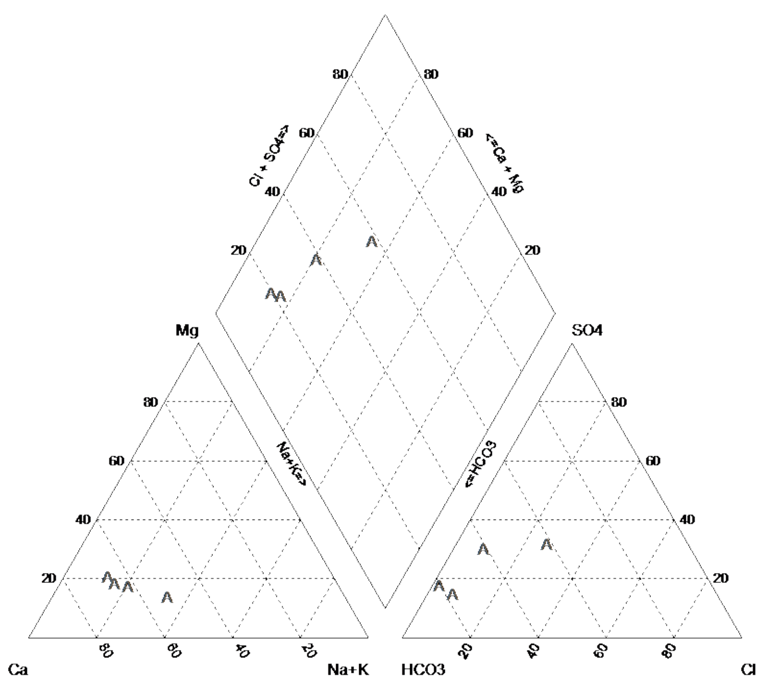

Figure 105. Piper plot diagram of constituents of the WOLF.

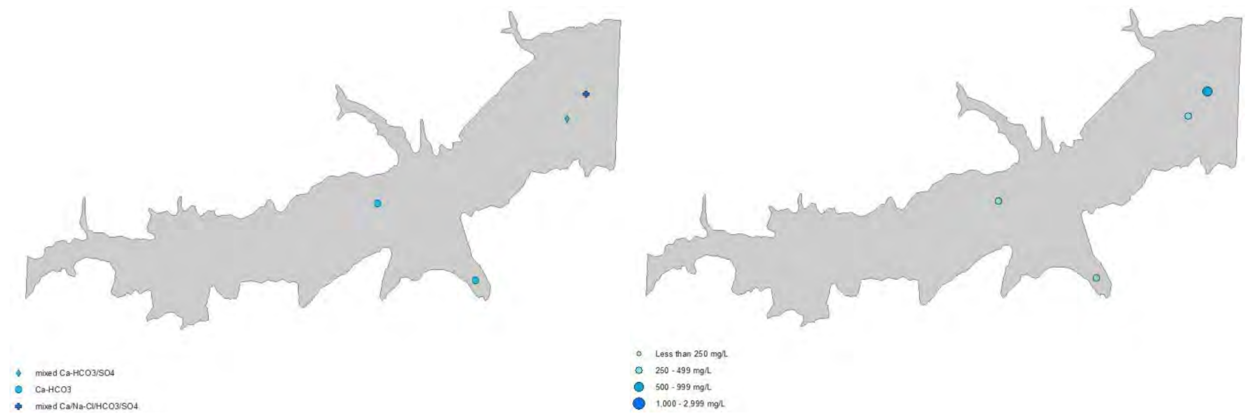

Figure 106. Water type (left) and TDS concentrations in the WOLF.

Low concentrations of bromide, chloride, magnesium, potassium, sodium, and sulfate were detected. Silica was at moderately low levels, and calcium was at moderate levels in the aquifer. Fluoride was not detected.

Nutrients were mostly low in the WOLF. Ammonia was not detected. Nitrate content ranged from 2.63-4.26 mg/L with moderately low mean and median concentrations of 3.38 mg/L and 3.32 mg/L. Phosphorus was present at low levels with mean and median concentrations of 0.023 mg/L and 0.019 mg/L.

The WOLF had low amounts of metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, iron, manganese, mercury, molybdenum, nickel, silver, and thallium. Barium, boron, selenium, uranium, and vanadium were present in low concentrations. Arsenic was detected at moderately low levels and chromium was present at moderate levels. Copper, lead, and zinc were rare but low when detected.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The WOLF only had one site exceed the SMCL for TDS with no other constituents exceeding their set thresholds. For more detailed statistics and figures on the WOLF water quality, see Appendix T.

Groundwater Level Measurements

Eight (8) wells in this aquifer had historical measurements. A network of around 8 wells was measured during the 1980's, one well was measured during the 1990's, and no wells have been measured since 2000 (Figure 107). None of these historic wells were incorporated into the WOLF baseline network, either due to lack of construction information or inability to locate and access.

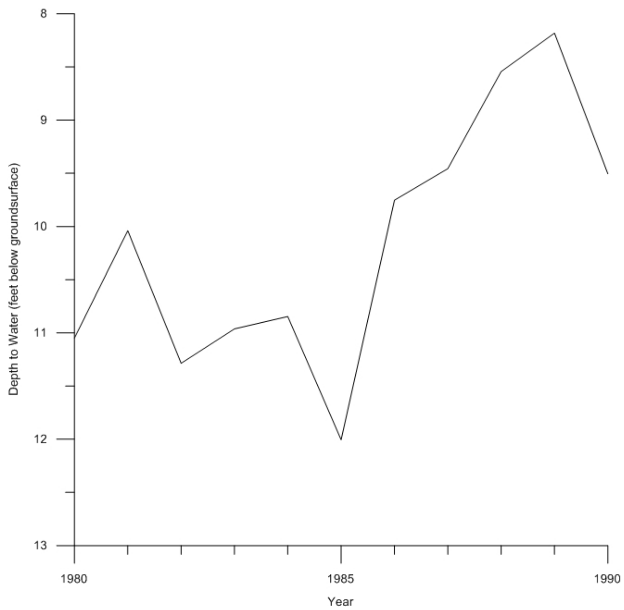

Figure 107. Average WOLF water level over period of record prior to GMAP implementation (1980-1990).

A baseline groundwater level network composed of 7 wells was measured during GMAP sampling in September 2015. Measurements of depth to groundwater made during baseline water quality sampling ranged from 19.11-41.74 feet with a mean of 26.8 feet. The total depth of wells used in the network ranged from 70-149 ft, averaging 107 feet. Six (6) wells have been incorporated into a trend water level network measured annually, with 2 of these measured seasonally.

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 108). 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.

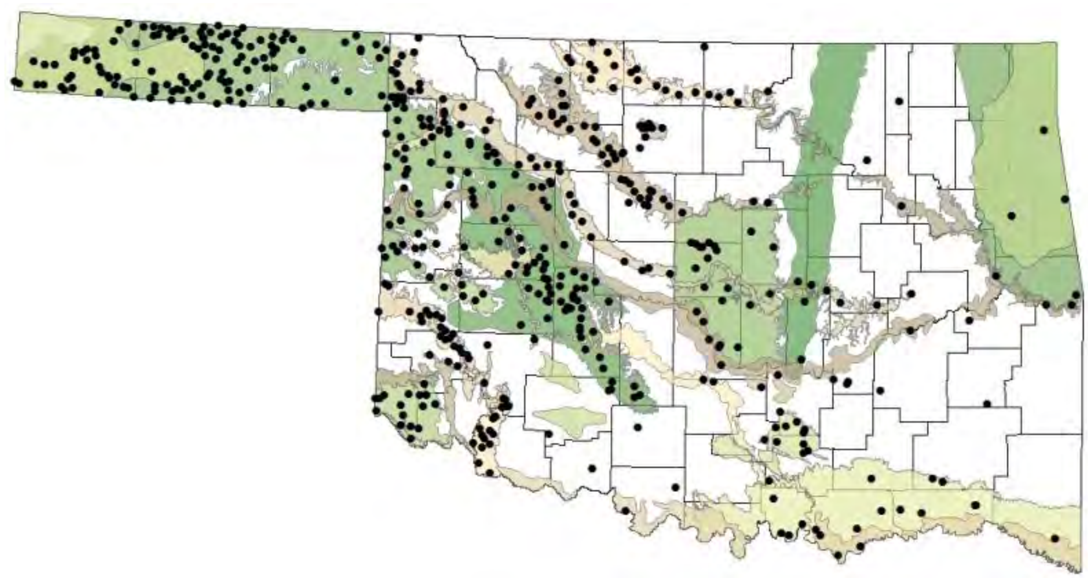

Figure 108. Historical groundwater level measurement sites in Oklahoma prior to the implementation of GMAP (2013).

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, the response patterns to variable precipitation, and the 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 have been and will be intentionally included in the Groundwater Monitoring and Assessment Program's (GMAP) new network for each aquifer.

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 will be possible, in addition to how those changes over time are related to drought, seasonal variation and groundwater usage. GMAP's new groundwater level network design will provide 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 are phased into the GMAP program, existing mass measurement wells are included in the water level baseline network. These wells, along with additional water level sites, increase the number of wells and improve the distribution in each aquifer, allowing for more complete water level data across the state. The annual water level measurement will continue in the improved network after the GMAP Baseline study is complete for an aquifer. For those wells that are in an aquifer that has not yet been phased into GMAP, the annual winter measurement will continue without changes to the network. 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.

Six hundred twelve (612) wells in Group A, B, & C aquifers have been incorporated into the annual water level monitoring network, 335 of which are new additions to these aquifers that provide significantly improved spatial representativeness (Figure 109). Two hundred fifty-four (254) of the 612 wells have been placed into the seasonal trend network (measured tri-annually). An additional 169 wells were measured for water level across the state in aquifers not yet incorporated into GMAP, measurements for which are summarized below.

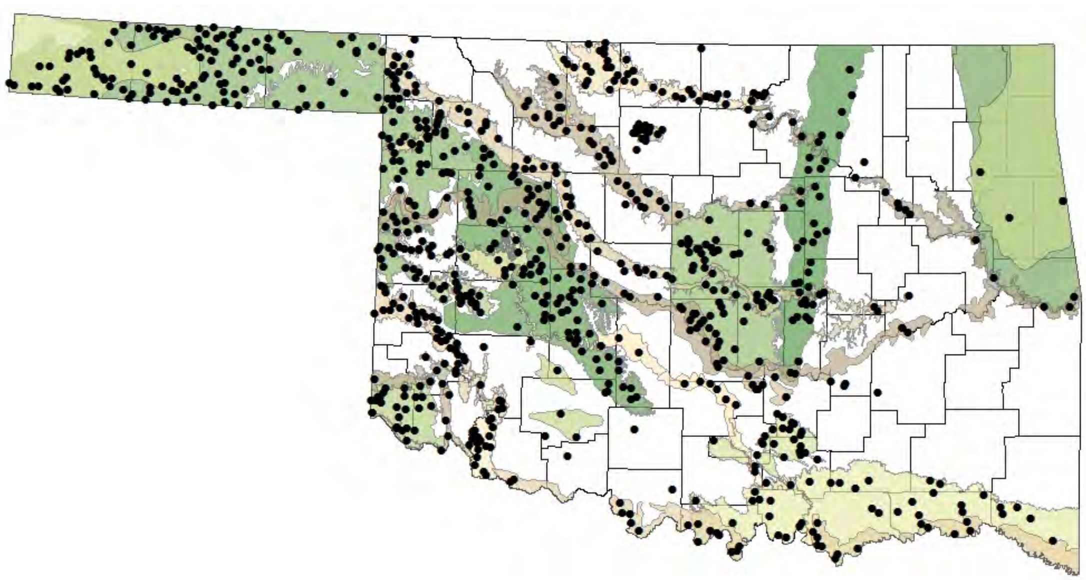

Figure 109. Groundwater level measurement sites after three years of GMAP implementation (2016).

Water Level Measurement in the Boone Aquifer

The Boone is classified as a minor aquifer due to well yields, but a baseline groundwater level network is projected for implementation in 2017 due to its high use in the state. Nineteen wells (19) have depth to water measurements in this aquifer, and the most recent water level network configuration was 3 wells. The inadequate number of sites for the size of the aquifer prevent the generation of an aquifer-wide composite hydrograph for the period of record. Several wells in this aquifer have over 25 years of measurements, and the longest measurement record in this aquifer spans 34 consecutive years (Figure 110).

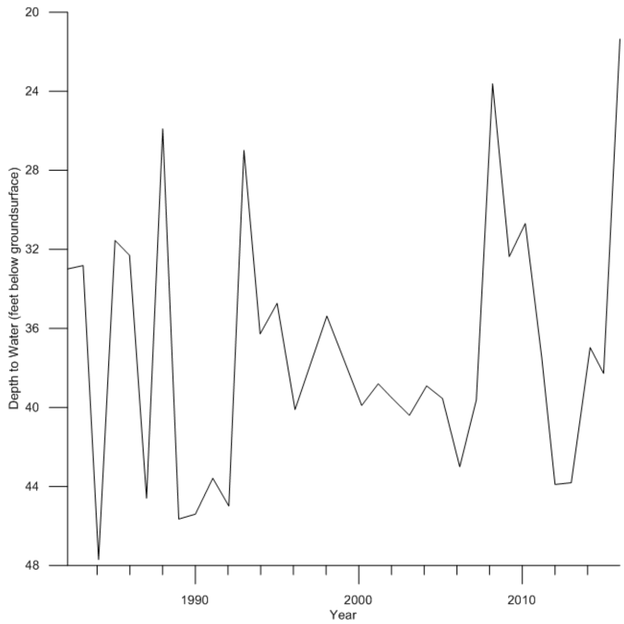

Figure 110. Groundwater level hydrograph of the longest Boone record, Adair County (1982-2016).

The state saw record rainfalls in 2015, during which average annual precipitation over the Boone measured at 26.1 inches above normal. The average water level in Boone wells has increased 11.3 feet over the last five years (2 wells; 2011-2016).

Water Level Measurement in the Cimarron River Alluvial & Terrace Aquifer

A baseline groundwater level network is projected for implementation in 2016. Seventy wells (70) have depth to water measurements in this aquifer, and the most recent water level network configuration was 33 wells (Figure 111). Several wells in this aquifer have over 30 years of measurements.

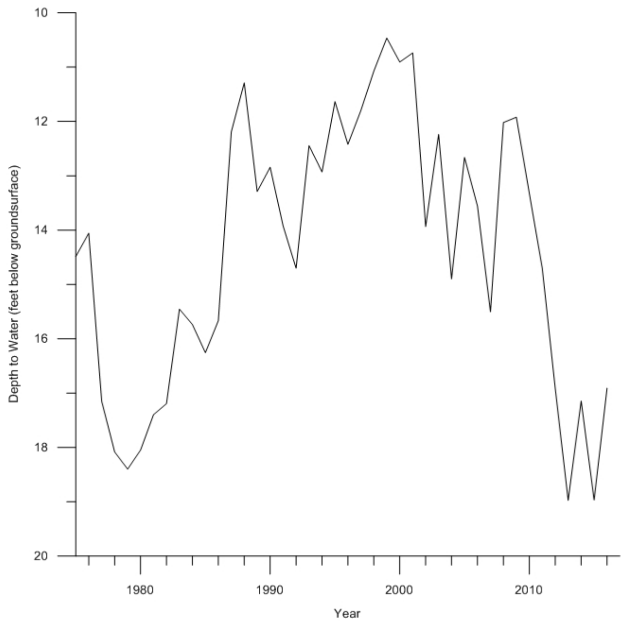

Figure 111. Average Cimarron River water level over period of record (1975-2016).

As reflected in the hydrograph, the average water level in Cimarron wells has declined by 2.56 feet over the last five years (2011-2016). Water levels had been declining more sharply but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the aquifer measured at 6.2 inches above normal. The Cimarron River Alluvial & Terrace Aquifer has two GMAP recorders in Woods and Logan counties, installed during December 2013.

Water Level Measurement in the Dakota-Dockum Aquifer

The Dakota-Dockum is classified as a minor aquifer due to well yields, but a baseline groundwater level network is projected for implementation in 2016 due to its high use in the state. Twenty-four wells (24) have depth to water measurements in this aquifer, 20 of which were part of a historical network that was discontinued in 2003. The most recent water level network configuration was established in 2011 and consists of 3 wells (Figure 112).

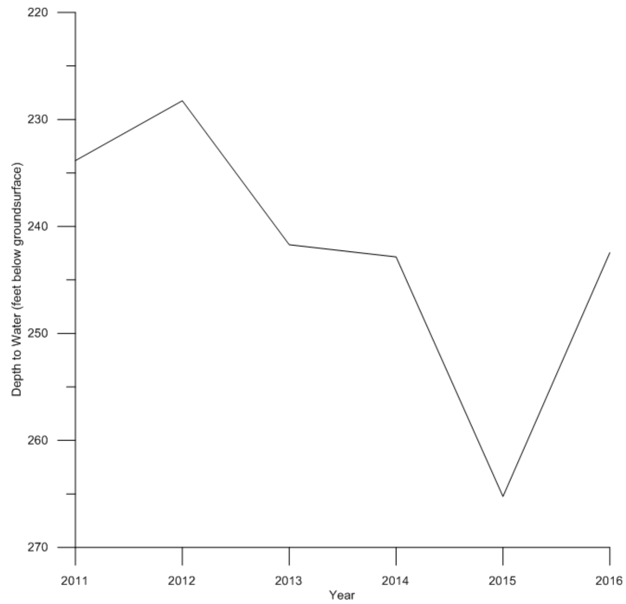

Figure 112. Average Dakota-Dockum water level over most recent continuous period of record (2011-2016).

As depicted in the hydrograph, the average water level in Dakota-Dockum wells has declined an average 21.9 feet over the last five years (2011-2016). Water levels had been declining more sharply in the aquifer but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the area measured at 8.3 inches above normal.

Water Level Measurement in the Ogallala-Panhandle Aquifer

A baseline groundwater level network is planned for implementation in 2016. Over four hundred wells (400) have depth to water measurements in this aquifer. The most recent network configuration consisted of 105 wells (27 in Cimarron Co, 60 in Texas Co, and 18 in Beaver Co). Figure 113 is a hydrograph of average water level depths for Texas and Cimarron Counties; due to large variation in the Beaver County network of wells over time, a period of record hydrograph was not included.

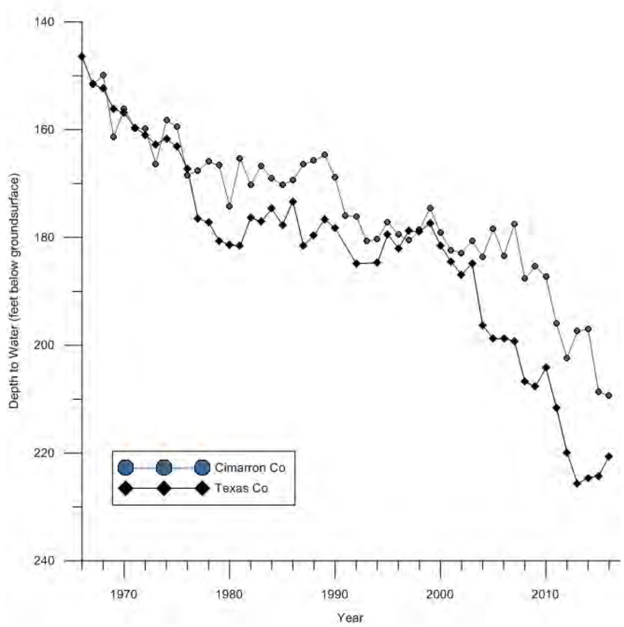

Figure 113. Average Ogallala-Panhandle water level over period of record, split by county (1966-2016).

Many wells measured in this aquifer, including a few in Beaver County, have a period of record that spans over 40 years (Figure 114). As depicted in these figures, the water level in the Ogallala-Panhandle has declined an average of 8.34 feet in Cimarron County, declined 11.13 feet in Texas County, and risen 2.6 feet in Beaver County wells over the last five years (2011-2016). Water levels had been declining more sharply but this has been attenuated by record rainfall in 2015, during which average annual precipitation over the aquifer measured at 11.5 inches above normal. This slowing in the rate of decline is most likely attributed to less water being withdrawn for irrigation as opposed to recharge of the aquifer. The Ogallala-Panhandle Aquifer has three GMAP recorders, one each in Beaver, Texas, and Cimarron counties, installed in January 2014.

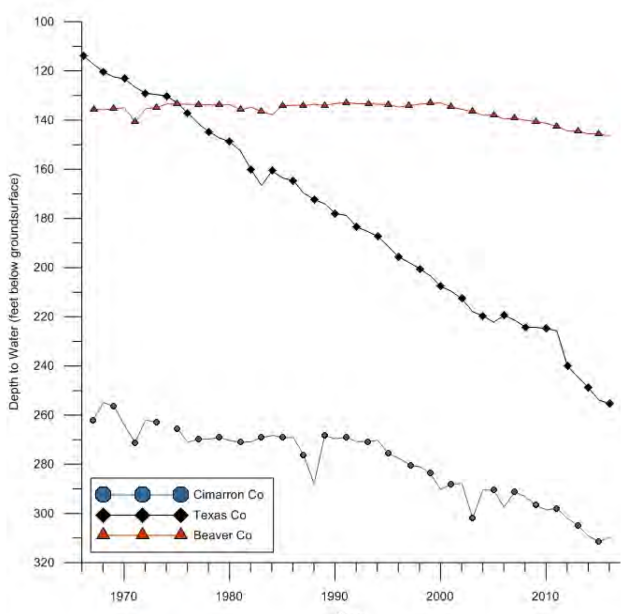

Figure 114. Groundwater level hydrographs for three of the longest Ogallala-Panhandle records, one in each county (1966-2016).

Water Level Measurement in the Roubidoux Aquifer

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 Roubidoux Aquifer and all additions will be new to the program.

Statewide Water Level Changes

The previous sections discuss water levels in the context of individual aquifers; however, it is also useful to compare them from the statewide perspective. 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. In the last year, the state's water levels have shown increases or only slight decreases (2015-2016, Figure 115). Water levels have been declining but 2015 had record rainfalls, during which the statewide average of 53.88 inches of precipitation was 50 percent higher than normal. Response rate and magnitude varied among Oklahoma's aquifers but the majority saw at least some recovery of groundwater levels, though many still did not recover to pre-drought levels.

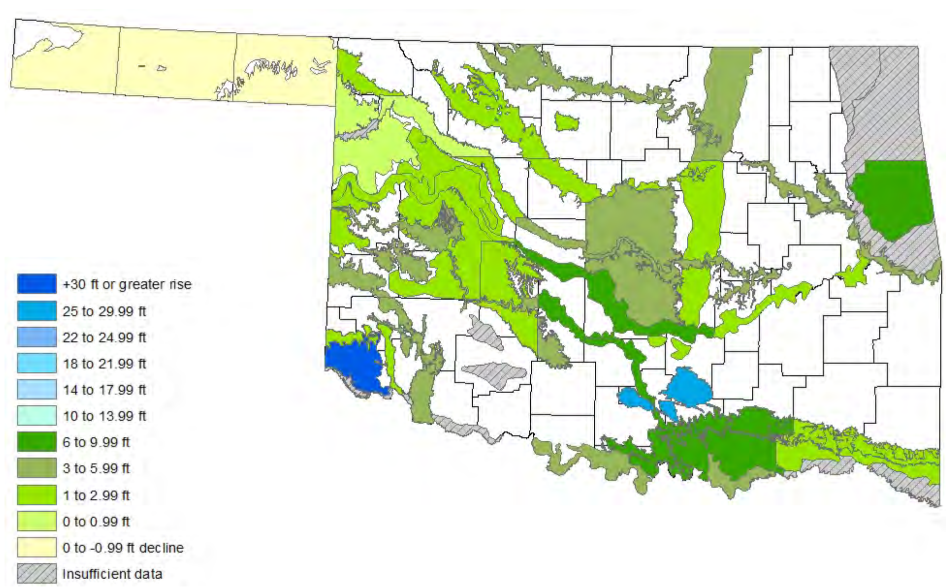

Figure 115. Average one-year water level change, by major aquifer and climate division (2015-2016).

Over the last five years, average water levels have exhibited a range of responses across the state (2011-2016; Figure 116). The largest groundwater increases were observed in the karst bedrock aquifers: Arbuckle-Simpson, Boone, and Blaine. The largest declines were observed in Texas and Cimarron Counties. Overall, groundwater levels have either increased or decelerated in their declines across the state's aquifers, reflective of the 2015 record rainfall events. State-wide average precipitation had been below normal in the years preceding.

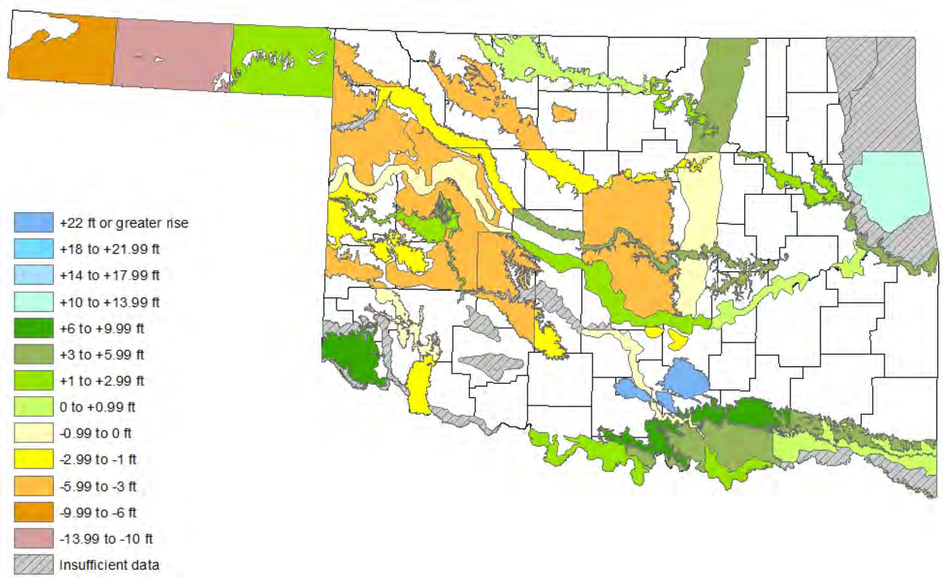

Figure 116. Average five-year water level change, by major aquifer and climate division (2011-2016).

Over the past ten years, average water levels in the state have increased and decreased by varying degrees (2006-2016; Figure 117). The largest average declines were detected in the Ogallala-Panhandle in Texas and Cimarron counties and the section of the North Fork of the Red River located in the West Central climate division. The largest groundwater increases were observed in the karst bedrock aquifers: Arbuckle-Simpson, Boone, and Blaine.

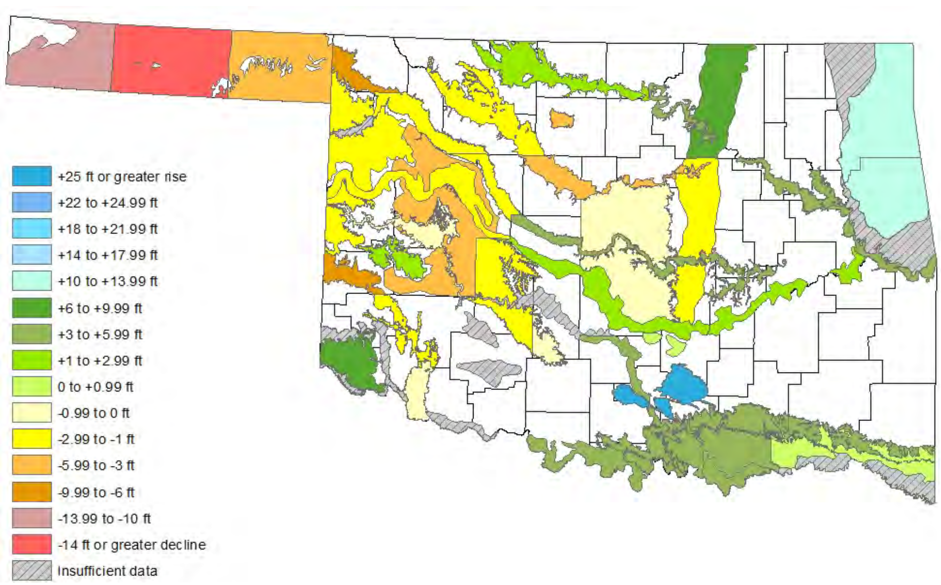

Figure 117. Average ten-year water level change, by major aquifer and climate division (2006-2016).

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 thirteen aquifers, twenty-four (24) 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 118, open circles).

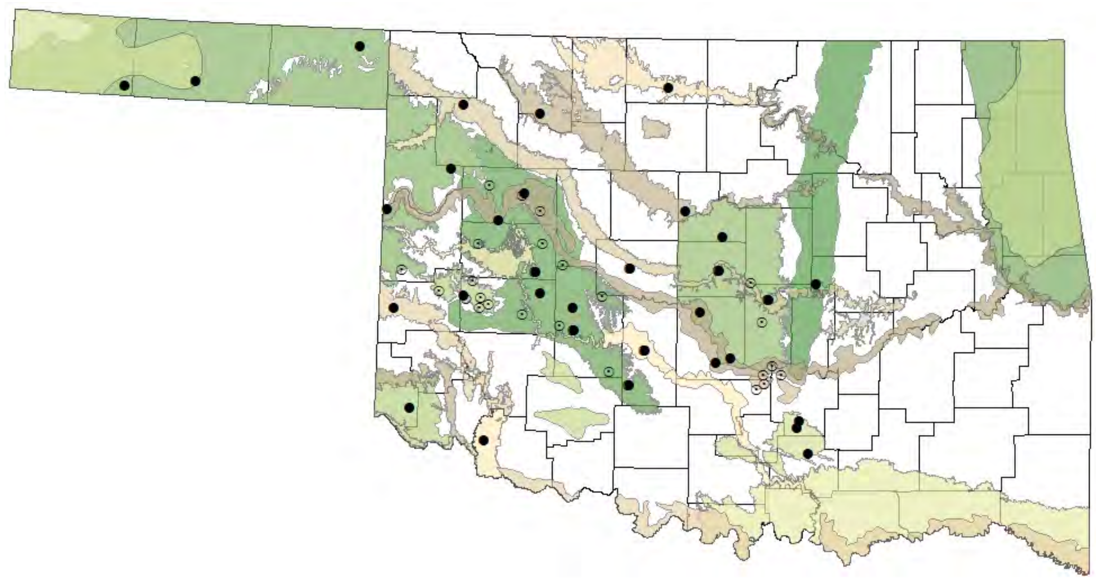

Figure 118. Sites with OWRB continuous water level recorders installed (closed circles indicate those in the GMAP program).

Details on installed recorders can be found in those aquifers' specific sections of this report. There are currently recorders in: the Arbuckle-Simpson, the Blaine, the Canadian River, the Cimarron River, the Elk City, the Garber-Wellington, the North Canadian River, the North Fork of the Red River, the Ogallala-Northwest, the Ogallala-Panhandle, the Rush Springs, the Salt Fork of the Arkansas River, and the Tillman Terrace 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 119). 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.

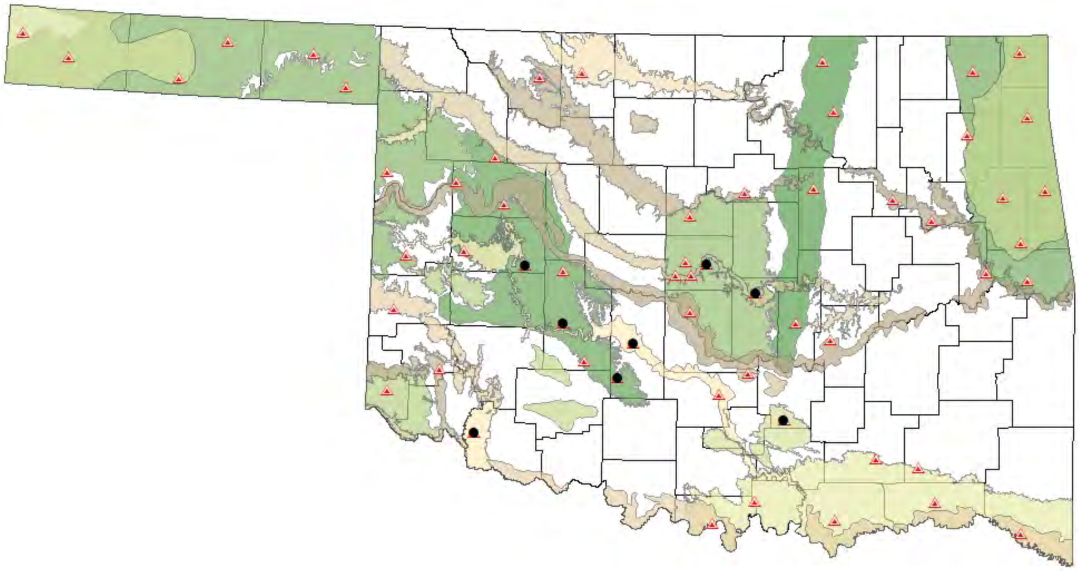

Figure 119. Continuous water level recorders (circles) deployed at Mesonet stations (triangles) in major aquifers across the state.

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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 (mg/L)	0.124	0.020	<0.1	<0.1	<0.1	0.14	0.54	
Nitrate+nitrite (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

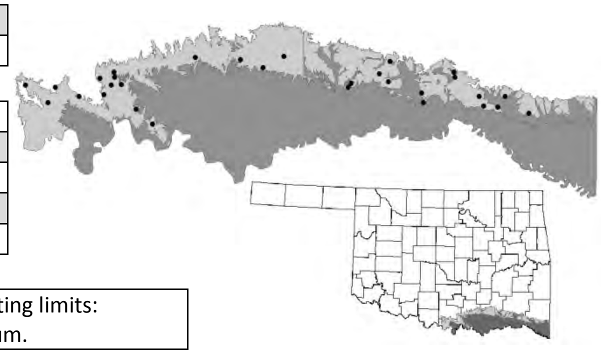
Table A4. Descriptive statistics on metal constituents.

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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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
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 & Selected Maps 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 (mg/L)	All Values <0.1, except 6 (0.14, 0.25, 0.26, 0.26, 0.28, 0.56)							
Nitrate+nitrite (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

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

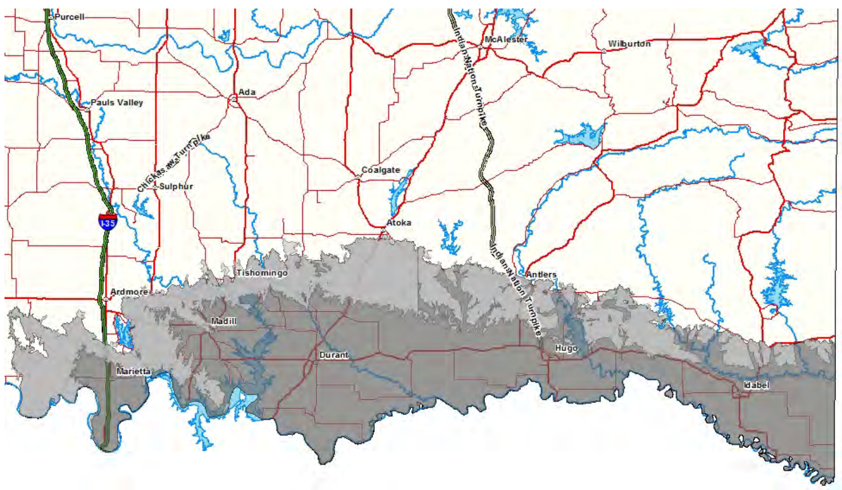


Figure B.120. Location and extent of the ALRS.

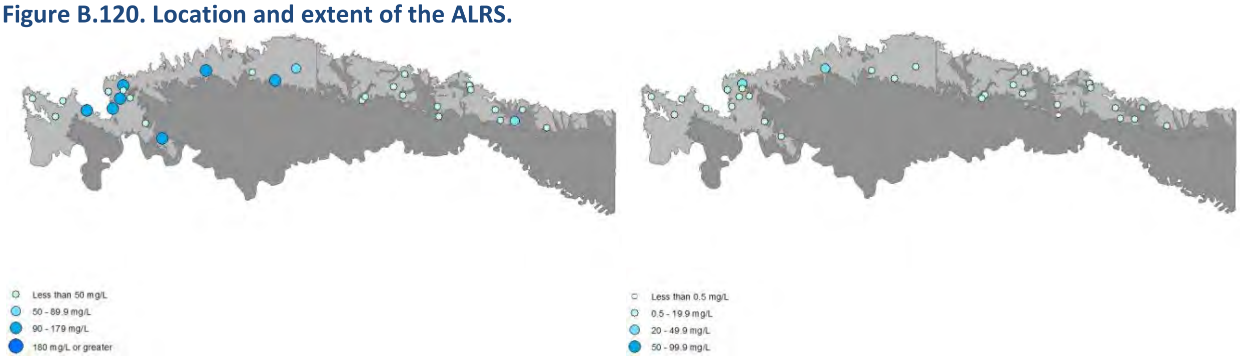


Figure B.121. Calcium (left) and magnesium concentrations in the ALRS.

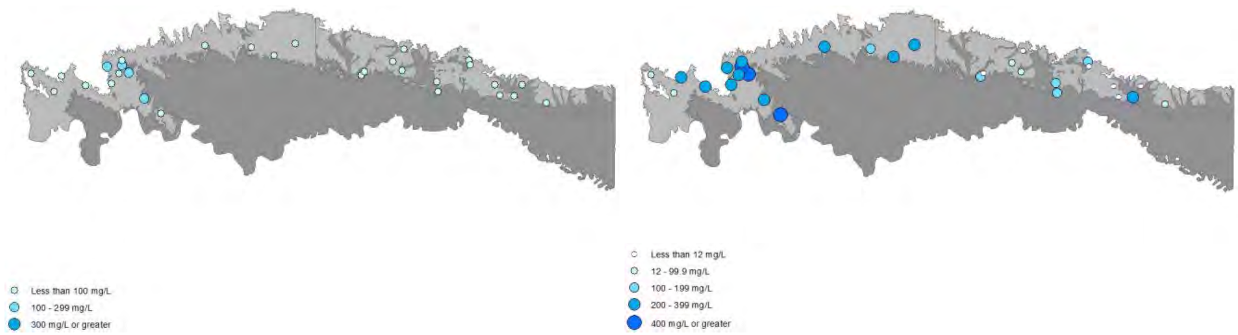


Figure B.122. Sodium+potassium (left) and bicarbonate concentrations in the ALRS.

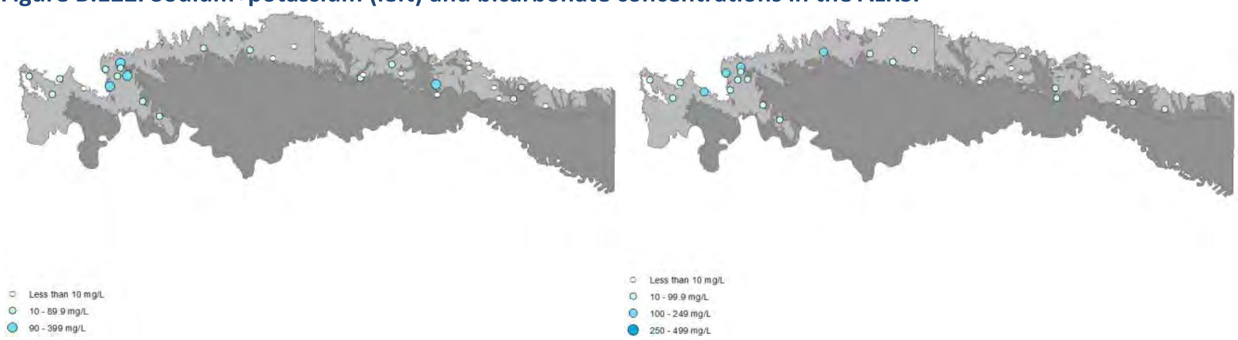


Figure B.123. Chloride (left) and sulfate concentrations in the ALRS.

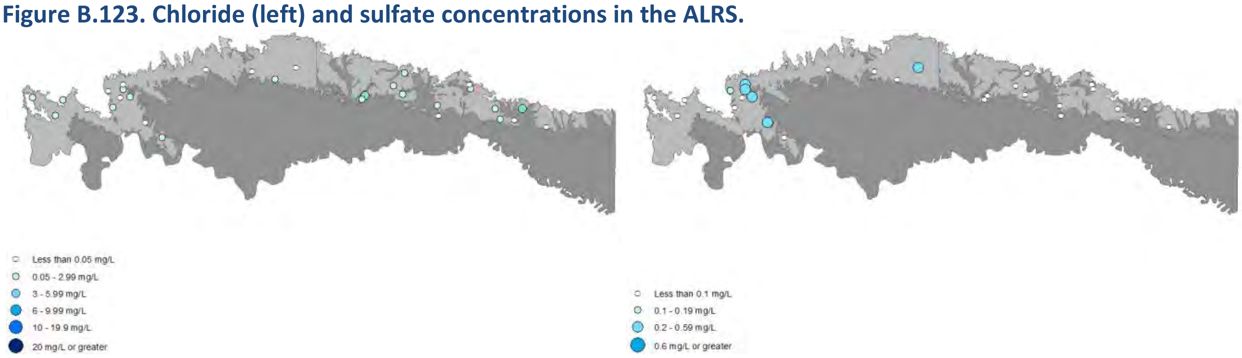


Figure B.124. Nitrate+nitrite (left) and ammonia concentrations in the ALRS.

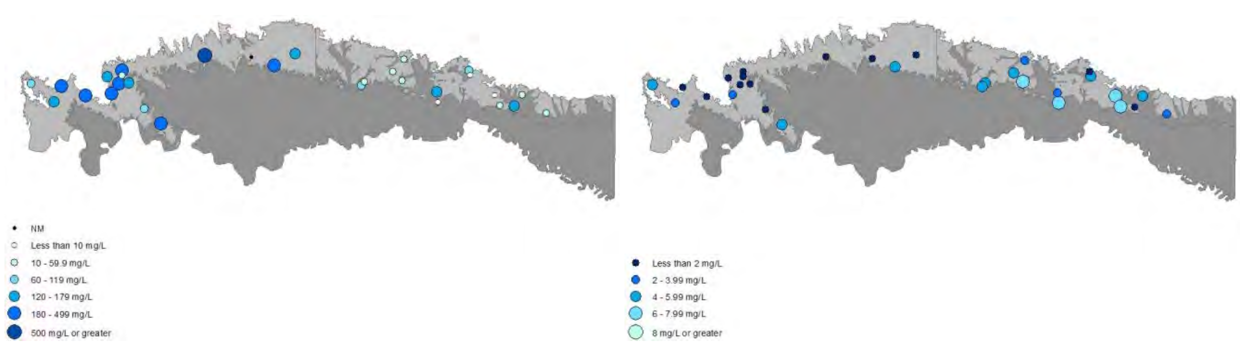


Figure B.125. Hardness (left) and dissolved oxygen concentrations in the ALRS.

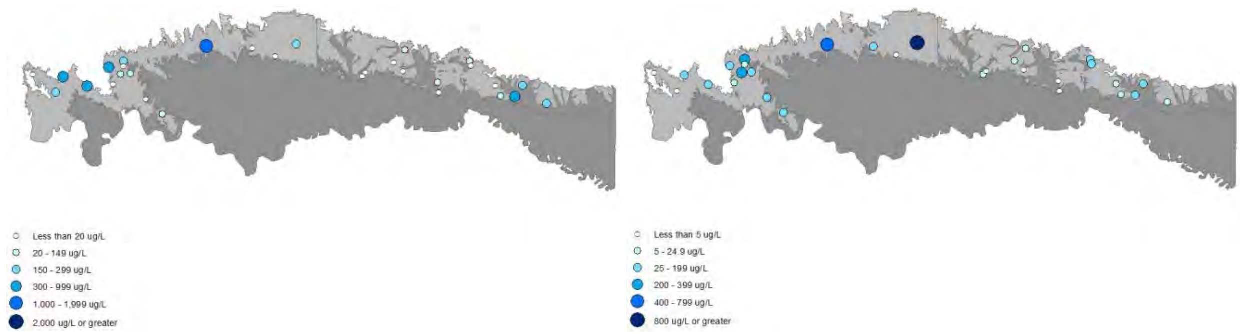
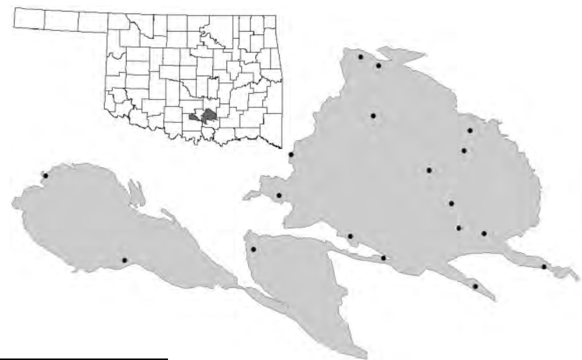


Figure B.126. Iron (left) and manganese concentrations in the ALRS.

Appendix C– Descriptive Statistics & Selected Maps 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, 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 (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

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

Figure C.1. Location and extent of the ABSMP.

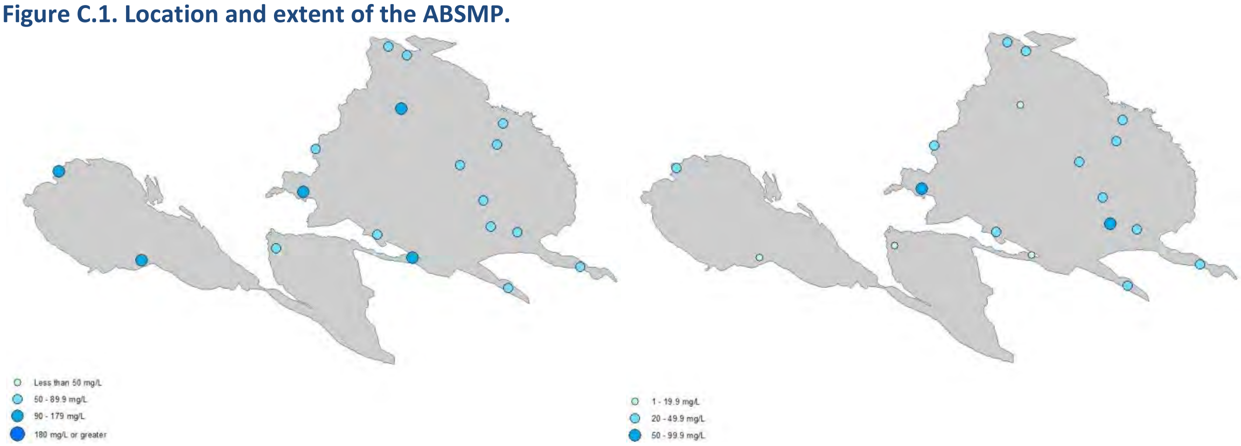


Figure C.2. Calcium (left) and magnesium concentrations in the ABSMP.

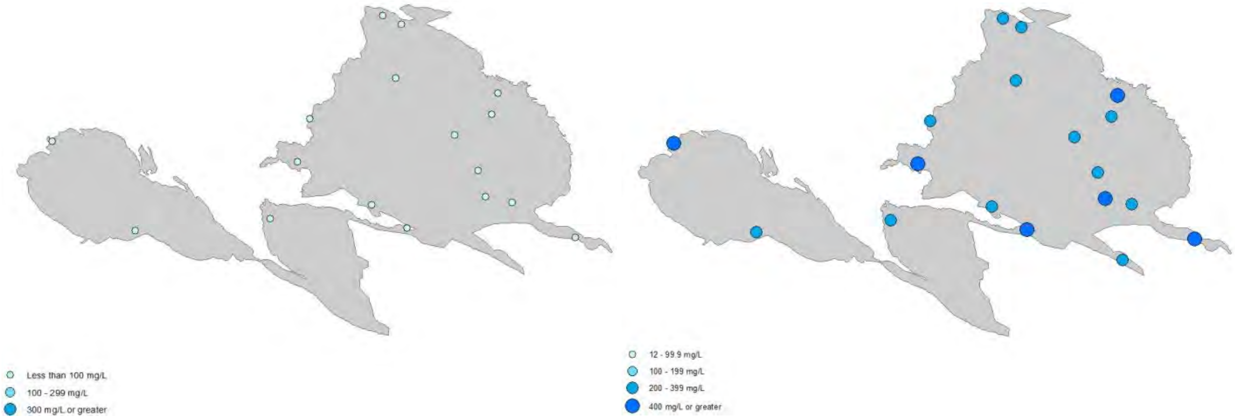


Figure C.3. Sodium+potassium (left) and bicarbonate concentrations in the ABSMP.

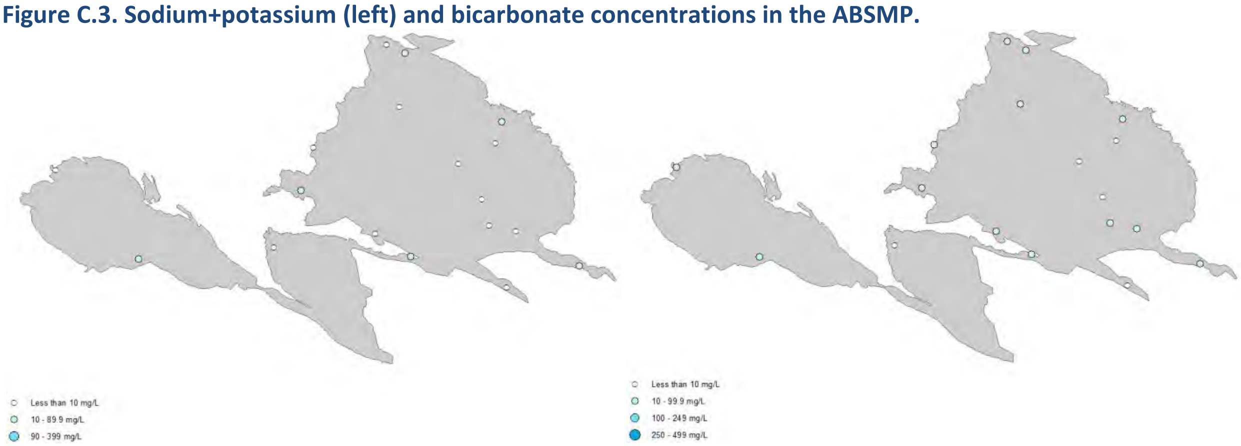


Figure C.4. Chloride (left) and sulfate concentrations in the ABSMP.

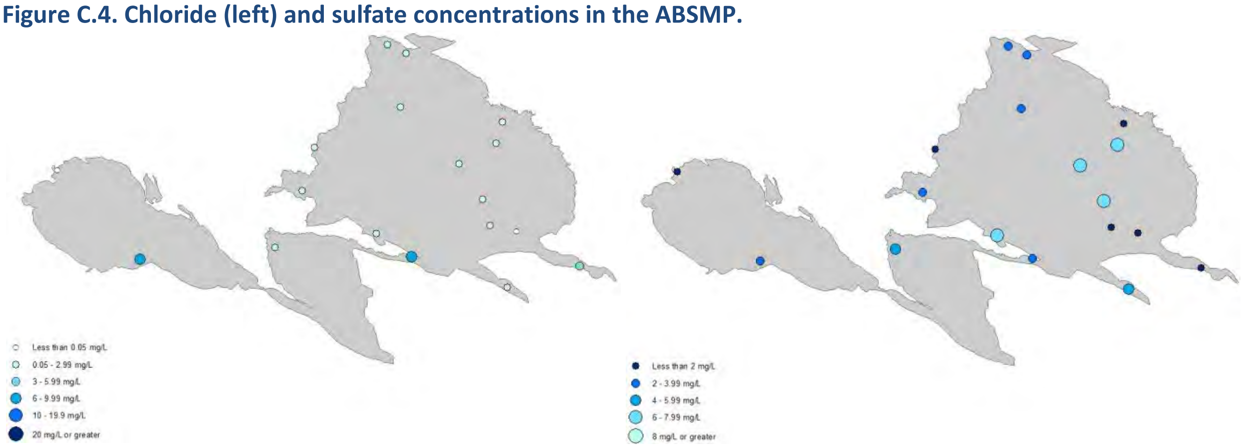
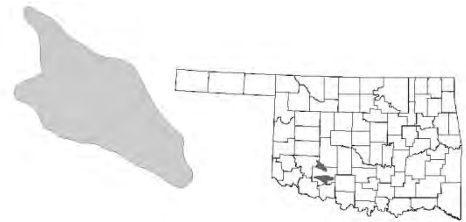


Figure C.5. Nitrate+nitrite (left) and dissolved oxygen concentrations in the ABSMP.

Appendix D– Descriptive Statistics & Selected Maps 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 (mg/L)	0.147	0.023	<0.1	--	0.17	--	0.20	
Nitrate+nitrite (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

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

Figure D.1. Location and extent of the ABTMB.

Figure D.2. Calcium (left) and magnesium concentrations in the ABTMB.

Figure D.3. Sodium+potassium (left) and bicarbonate concentrations in the ABTMB.

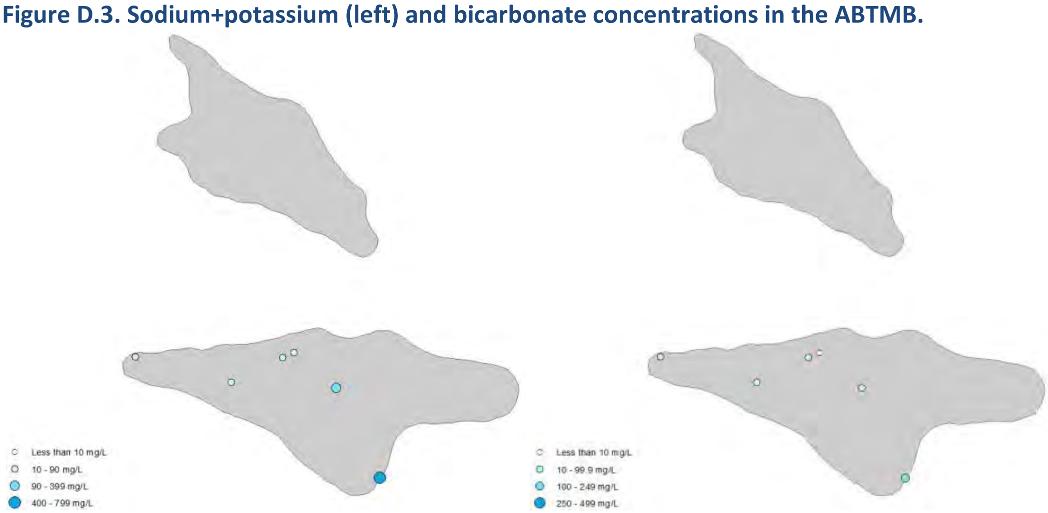


Figure D.4. Chloride (left) and sulfate concentrations in the ABTMB.

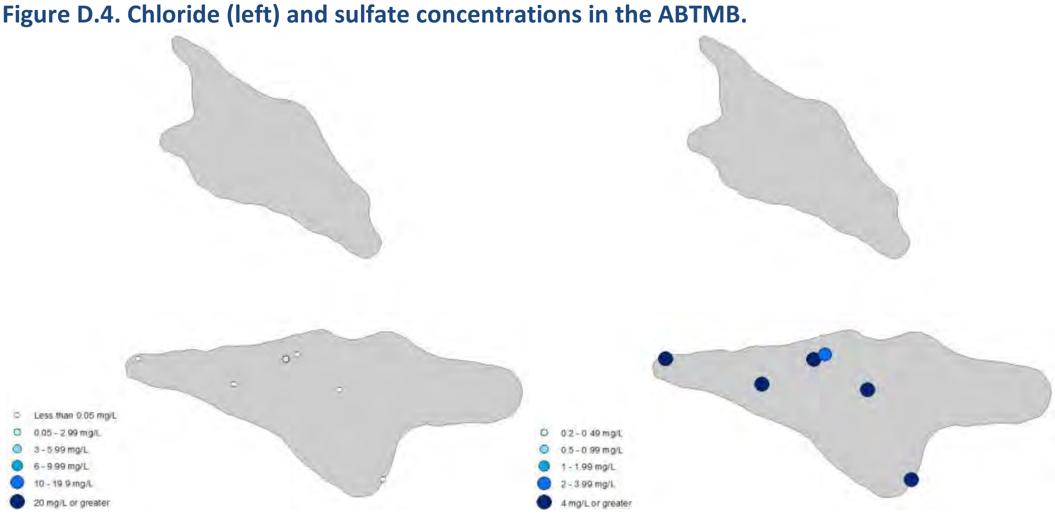


Figure D.5. Nitrate+nitrite (left) and fluoride concentrations in the ABTMB.

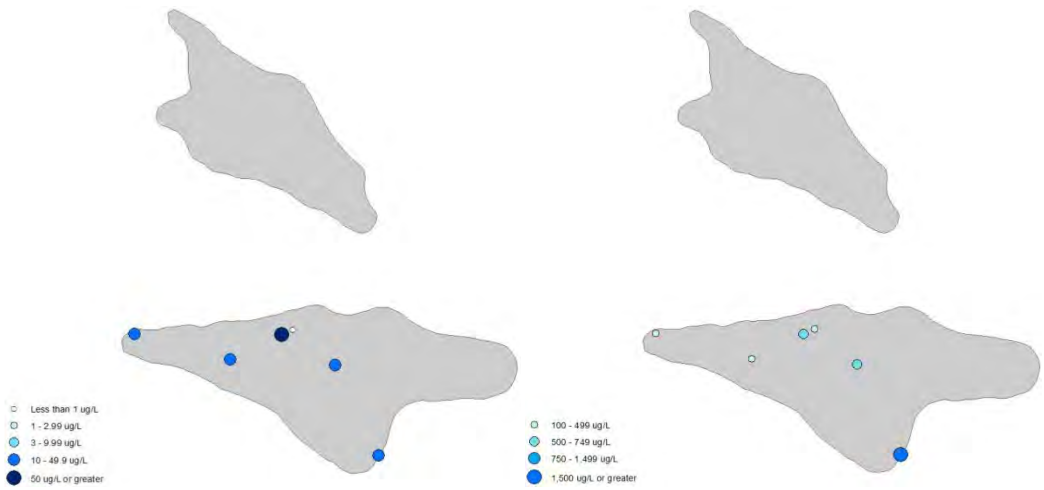
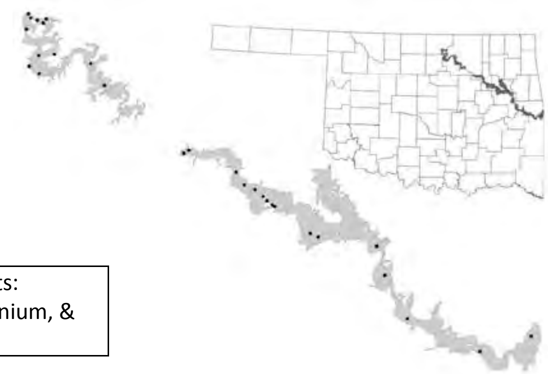


Figure D.6. Arsenic (left) and bromide concentrations in the ABTMB.

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 (mg/L)	All Values <0.1, except 5 (0.15, 0.17, 0.18, 0.21, 0.91)							
Nitrate+nitrite (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

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

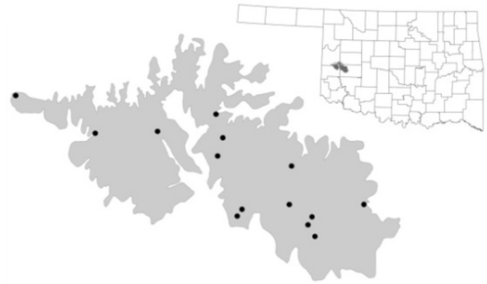
Table F4. Descriptive statistics on metal constituents.

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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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
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 G– 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, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, & Thallium.

Table G1. 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 G2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 G3. 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 G4. 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 H– 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, Beryllium, Cadmium, Chromium, Cobalt, Iron, Lead, Mercury, Molybdenum, Nickel, Selenium, & Silver.

Table H1. 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 H2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 H3. Descriptive statistics on mineral constituents.

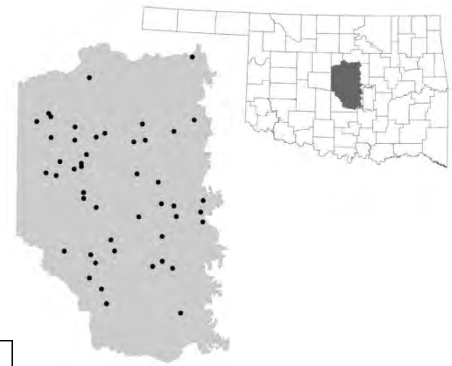
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	425	77.0	110	313	398	632	766	
dissolved Calcium (mg/L)	91.6	15.6	25.2	66.7	87.5	124	150	
Chloride (mg/L)	87.3	24.2	12.4	32.3	61.2	150	201	SMCL: 250; 0 over
Fluoride (mg/L)	0.171	0.023	<0.2	<0.2	0.21	0.22	0.27	MCL: 4; 0 over
dissolved 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 H4. 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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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. 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 I– 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, Antimony, Beryllium, Cadmium, Cobalt, Mercury, Molybdenum, Nickel, Silver, & Thallium.

Table I1. 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 I2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 I3. 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 I4. Descriptive statistics on metal constituents.

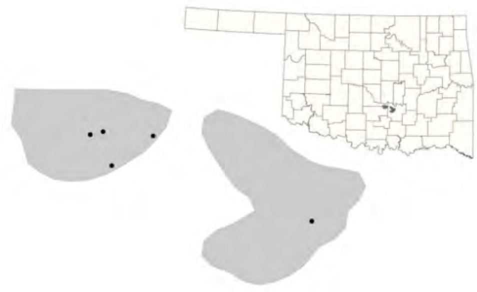
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All Values <10, except 1 (11.8)							MCL: 10; 1 over
dissolved Barium (µg/L)	302	32.6	<10	119	242	457	923	MCL: 2000; 0 over
dissolved Boron (µg/L)	253	65.7	<50	55.6	88.0	158	2450	HA: 6000; 0 over
dissolved Chromium (µg/L)	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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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: 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 J– 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, Antimony, Arsenic, Beryllium, Boron, Cadmium, Chromium, Cobalt, Fluoride, Iron, 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)	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 J2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 J3. Descriptive statistics on mineral constituents.

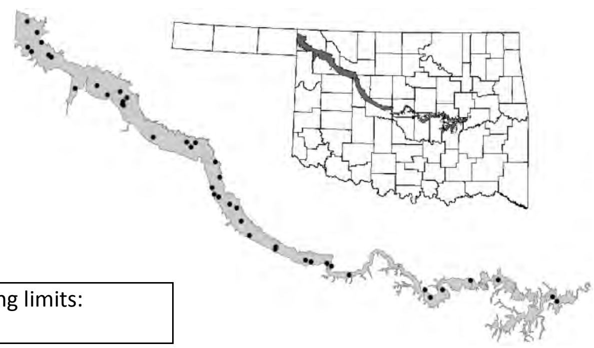
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	473	91.9	254	276	493	631	711	
dissolved Calcium (mg/L)	54.0	7.60	34.6	50.6	50.8	52.7	81.5	
Chloride (mg/L)	35.5	11.9	11.3	14.5	36.8	37.3	77.8	SMCL: 250; 0 over
dissolved Magnesium (mg/L)	14.9	2.24	9.1	10.8	16.5	16.8	21.5	
dissolved Potassium (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 J4. 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 K– Descriptive Statistics & Selected Maps 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 K1. 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 K2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	All Values <0.1, except 6 (0.22, 0.36, 0.37, 0.4, 0.55, 0.67)							
Nitrate+nitrite (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 K3. 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 K4. 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

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

Figure K.1. Location and extent of the BNCR.

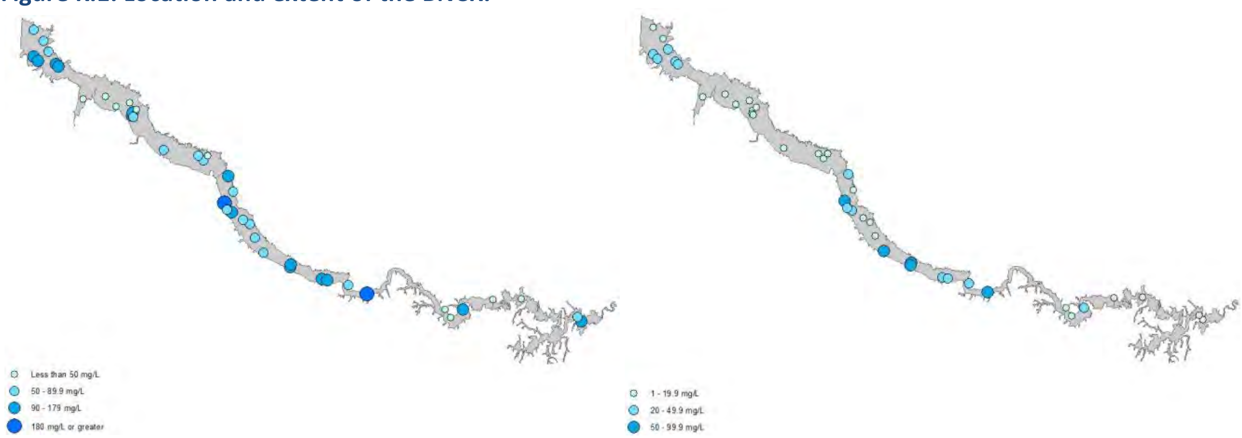


Figure K.2. Calcium (left) and magnesium concentrations in the BNCR.

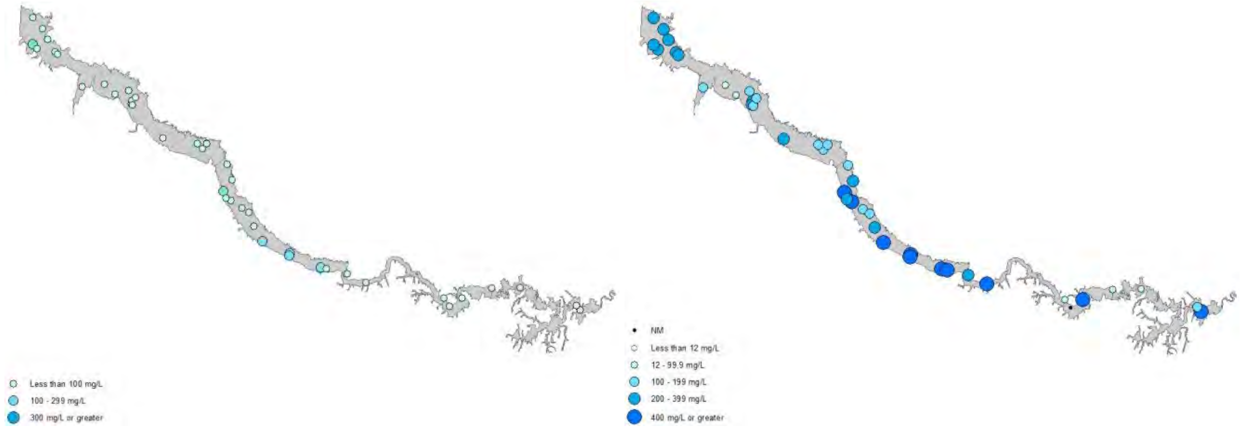


Figure K.3. Sodium+potassium (left) and bicarbonate concentrations in the BNCR.

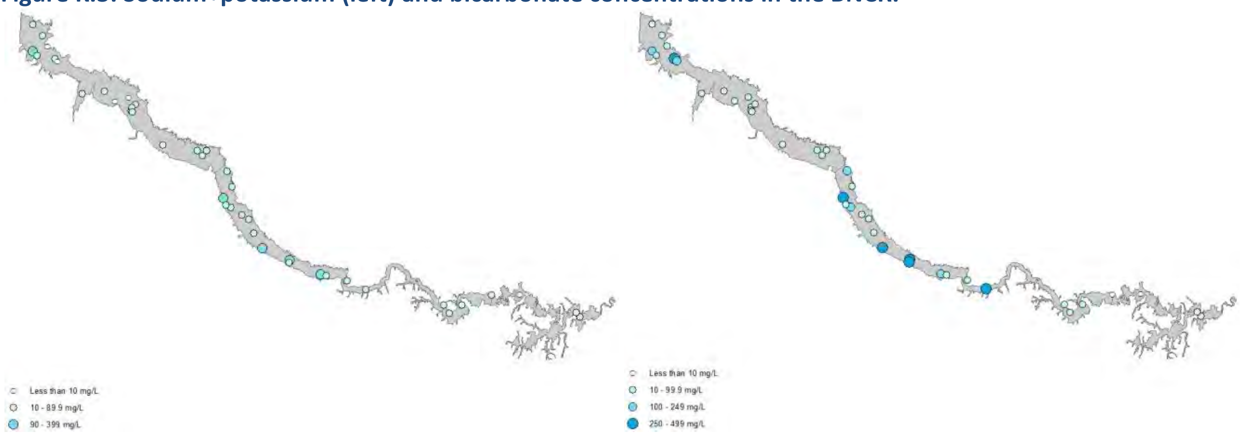


Figure K.4. Chloride (left) and sulfate concentrations in the BNCR.

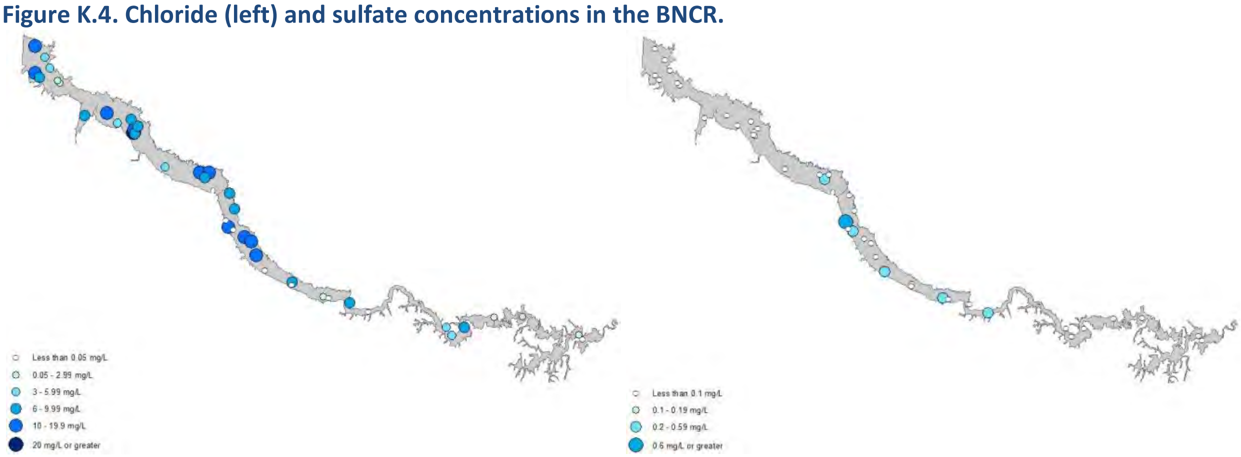


Figure K.5. Nitrate+nitrite (left) and ammonia concentrations in the BNCR.

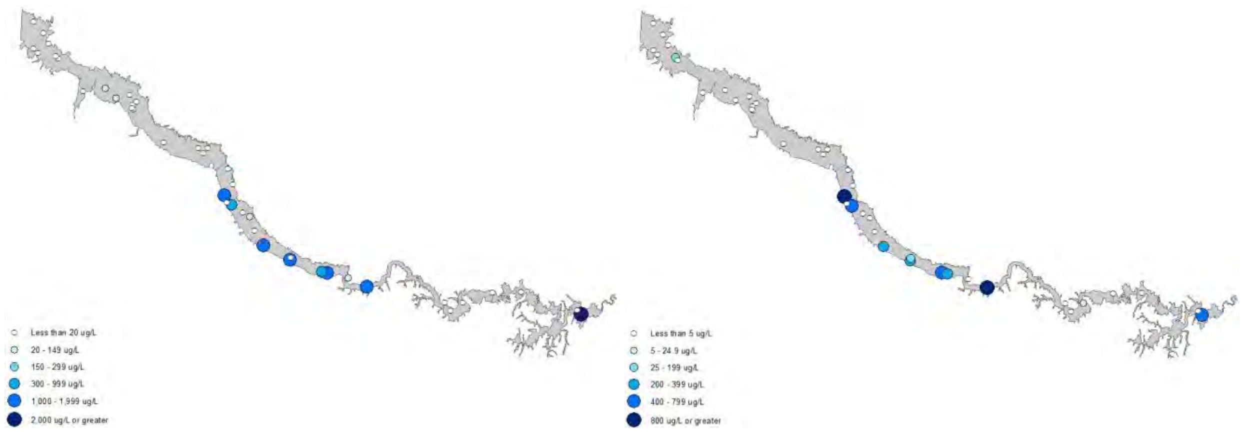


Figure K.6. Iron (left) and manganese concentrations in the BNCR.

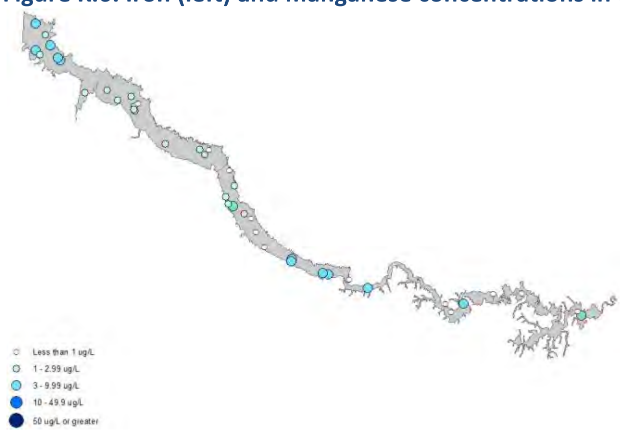
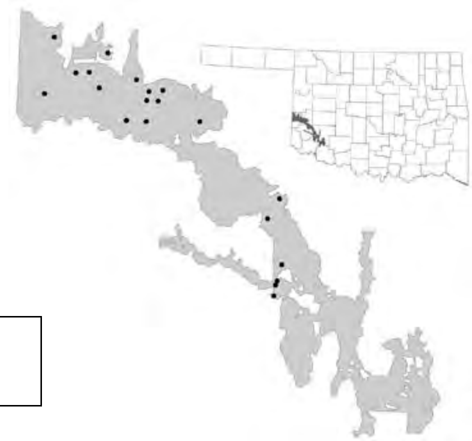


Figure K.7. Arsenic concentrations in the BNCR.

Appendix L– 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, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Lead Mercury, Nickel, & Silver.

Table L1. 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 L2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 L3. Descriptive statistics on mineral constituents.

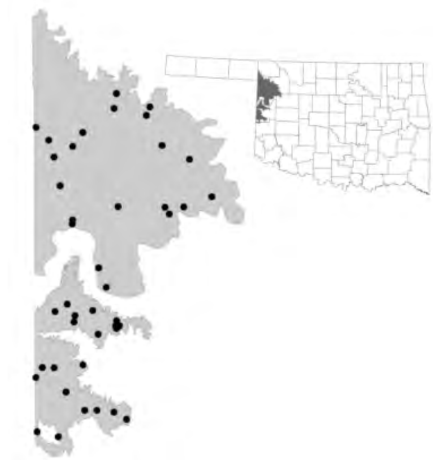
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	593	124	208	265	329	613	1960	
dissolved Calcium (mg/L)	121	15.0	53.2	71.8	94.9	172	312	
Chloride (mg/L)	138	57.5	<10	11.6	24.8	79.8	981	SMCL: 250; 3 over
Fluoride (mg/L)	0.295	0.043	<0.2	<0.2	0.28	0.42	0.74	MCL: 4; 0 over
dissolved Magnesium (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 L4. 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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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 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 M– Descriptive Statistics for Ogallala-Northwest Aquifer



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

General		
	Location	Western Oklahoma
	Area	4764 km^2
	Capacity	90.6 million acre-feet
	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, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, 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)	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 M2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 M3. Descriptive statistics on mineral constituents.

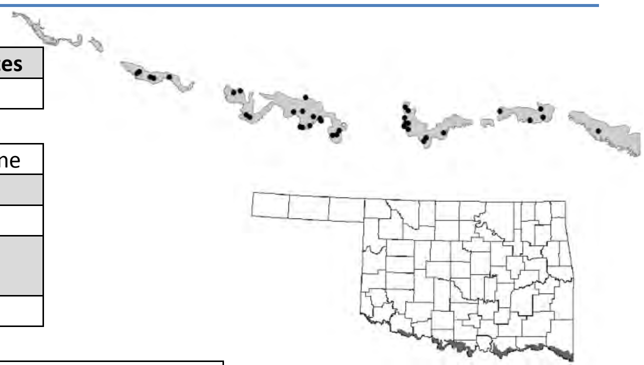
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	288	40.8	106	180	243	327	1770	
dissolved Calcium (mg/L)	75.2	3.11	38.7	62.7	72.2	83.1	139	
Chloride (mg/L)	25.8	6.09	<10	<10	14.2	29.7	207	SMCL: 250; 0 over
Fluoride (mg/L)	0.265	0.032	<0.2	<0.2	0.23	0.31	0.89	MCL: 4; 0 over
dissolved 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 M4. 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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Uranium (µg/L)	2.55	0.286	<1	1.4	2.0	3.0	8.6	MCL: 30; 0 over
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 N– Descriptive Statistics & Selected Maps 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 N1. 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 N2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	All Values <0.1, except 1 (0.3)							
Nitrate+nitrite (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 N3. 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 N4. 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

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

Figure N.1. Location and extent of the RED.

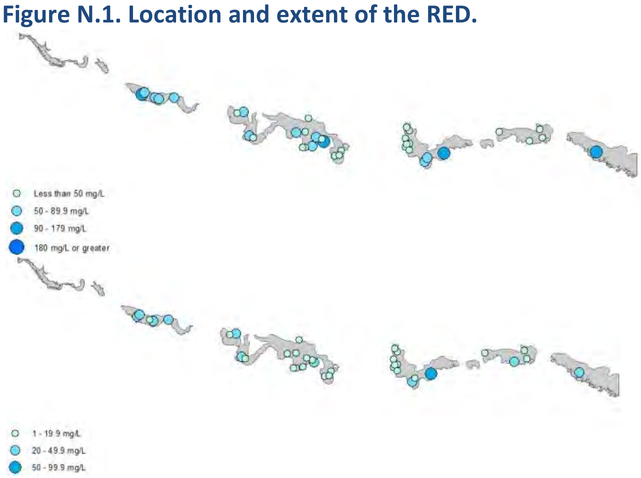


Figure N.2. Calcium (left) and magnesium concentrations in the RED.

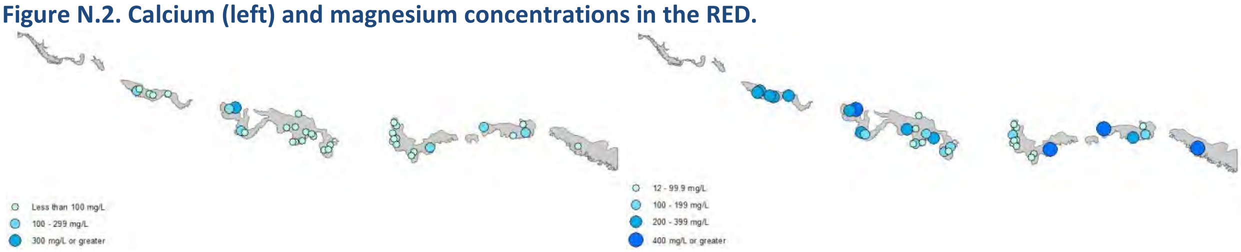


Figure N.3. Sodium+potassium (left) and bicarbonate concentrations in the RED.

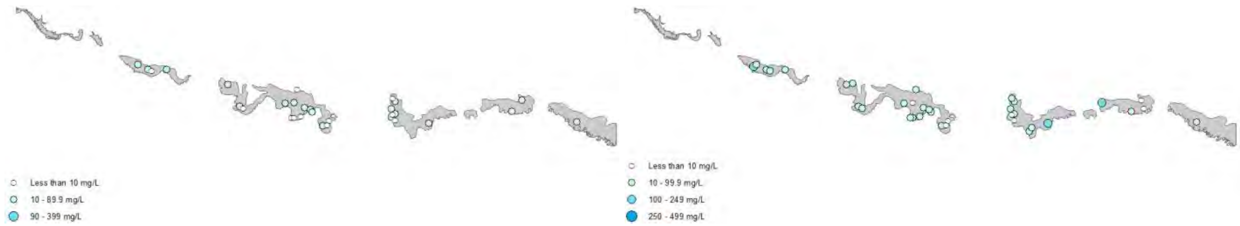


Figure N.4. Chloride (left) and sulfate concentrations in the RED.

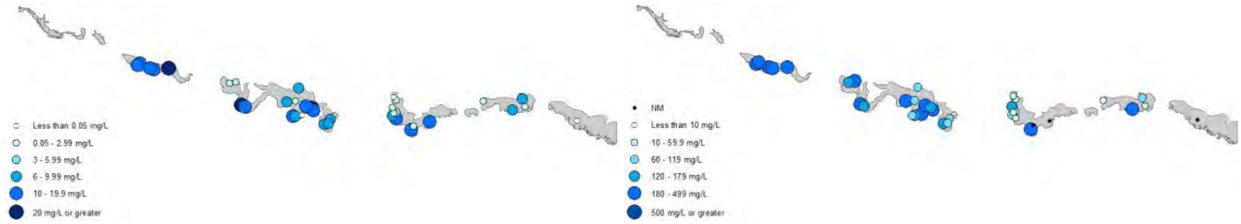


Figure N.5. Nitrate+nitrite (left) and hardness concentrations in the RED.

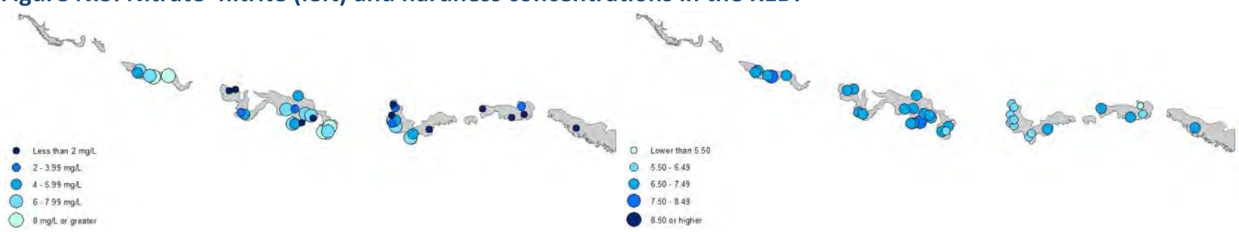


Figure N.6. Dissolved oxygen concentrations (left) and pH values in the RED.

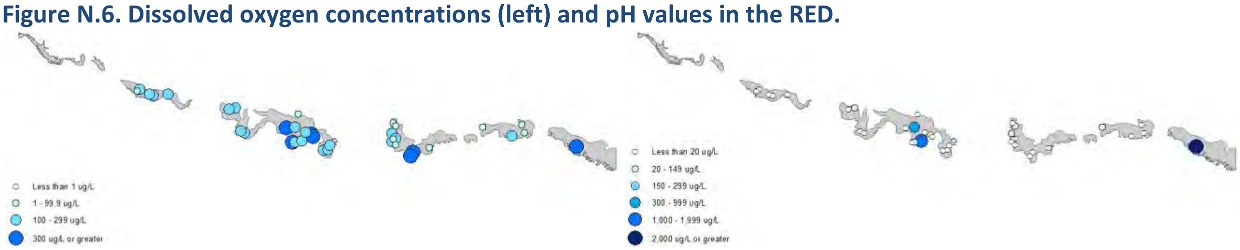


Figure N.7. Barium (left) and iron concentrations in the RED.

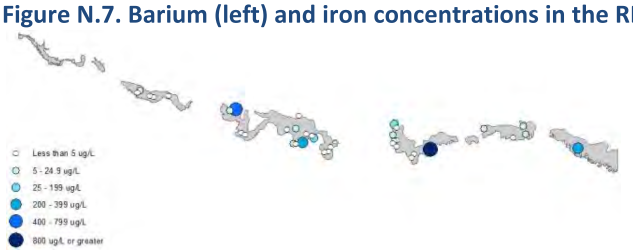


Figure N.8. Manganese concentrations in the RED.

Appendix O– 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 O1. 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 O2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	All Values <0.1, except 1 (0.17)							
Nitrate+nitrite (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 O3. 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

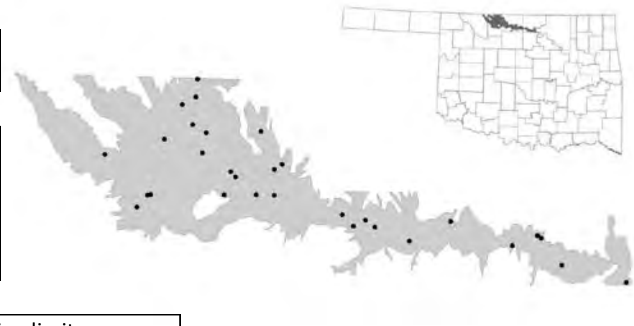
Table O4. Descriptive statistics on metal constituents.

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
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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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 P– 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 P1. 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 P2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	All values <0.1, except 2 (0.14, 0.2)							
Nitrate+nitrite (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 P3. 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

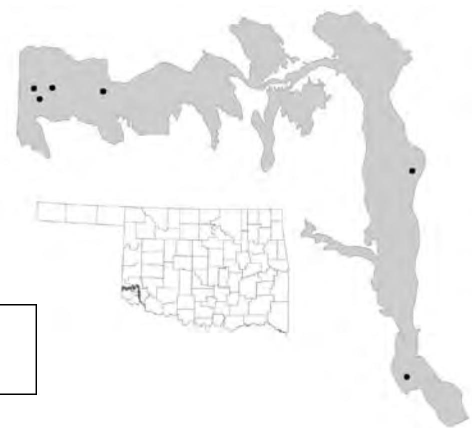
Table P4. Descriptive statistics on metal constituents.

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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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
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 Q– 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, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Lead, Mercury, Nickel, & Silver.

Table Q1. 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 Q2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 Q3. 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 Q4. 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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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 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 R– 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, Antimony, Beryllium, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, & Silver.

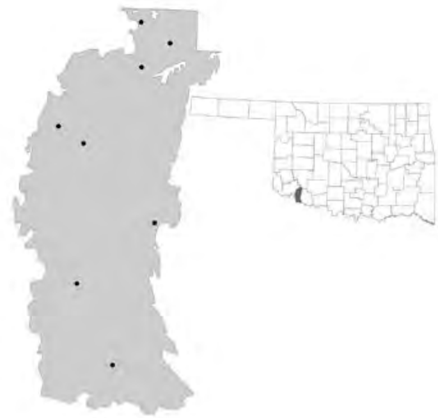


Table R1. Descriptive statistics on general parameters taken in the field.

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 R2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 R3. 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

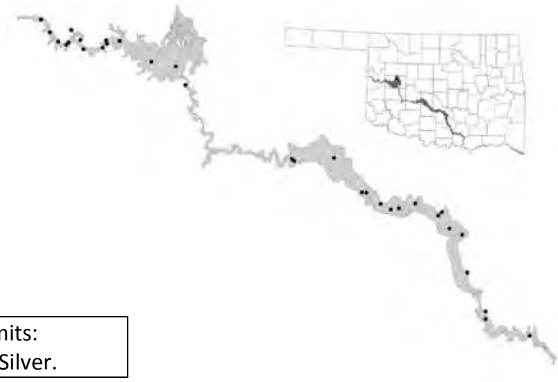
Table R4. Descriptive statistics on metal constituents.

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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
								HA: 300; 0 over
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 S– 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 S1. 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 S2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	0.154	0.036	<0.1	<0.1	<0.1	0.14	0.74	
Nitrate+nitrite (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 S3. 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

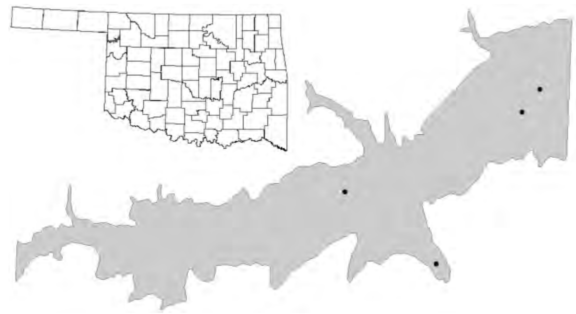
Table S4. Descriptive statistics on metal constituents.

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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
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
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 T– Descriptive Statistics & Selected Maps 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, Antimony, Beryllium, Cadmium, Cobalt, Fluoride, Iron, Manganese, Mercury, Molybdenum, Nickel, 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)	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 T2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (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 T3. 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 T4. 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

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

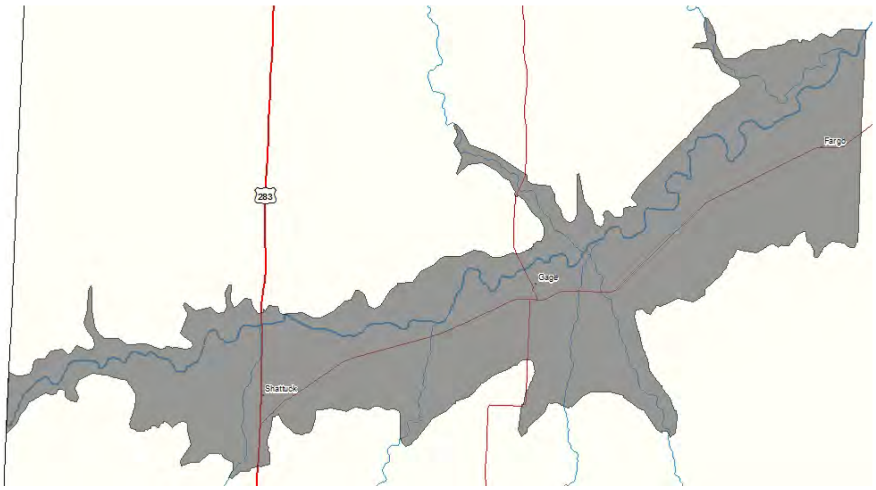


Figure T.1. Location and extent of the WOLF.

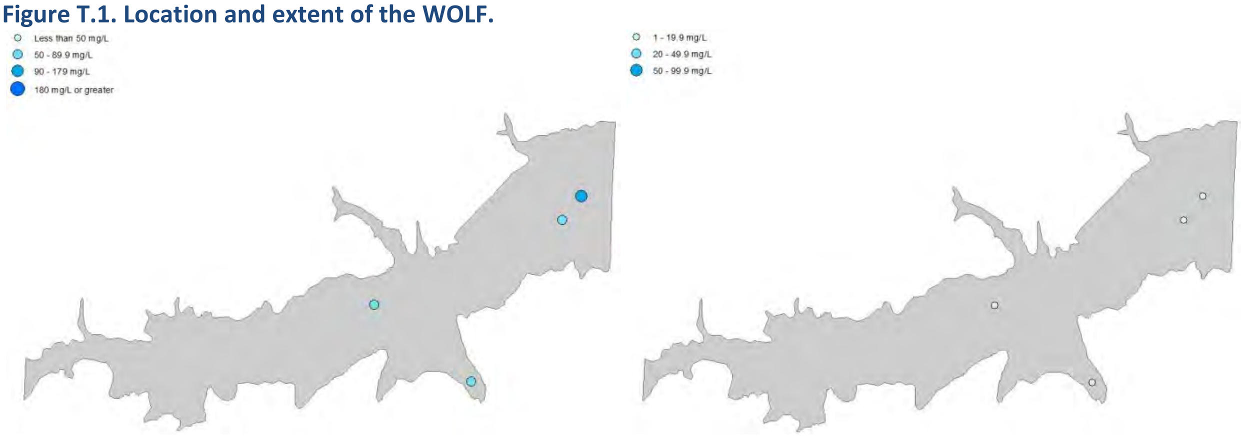


Figure T.2. Calcium(left) and magnesium concentrations in the WOLF.

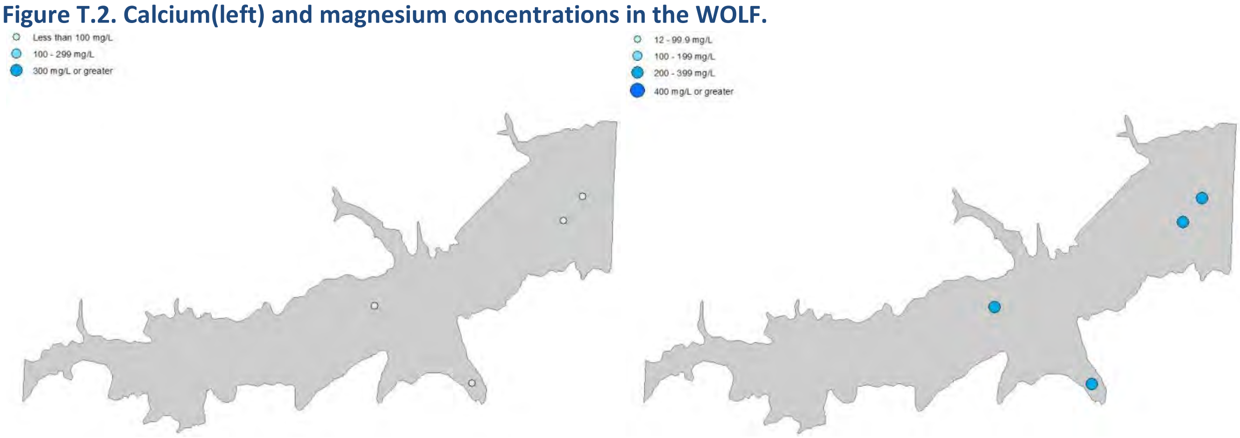


Figure T.3. Sodium+potassium (left) and bicarbonate concentrations in the WOLF.

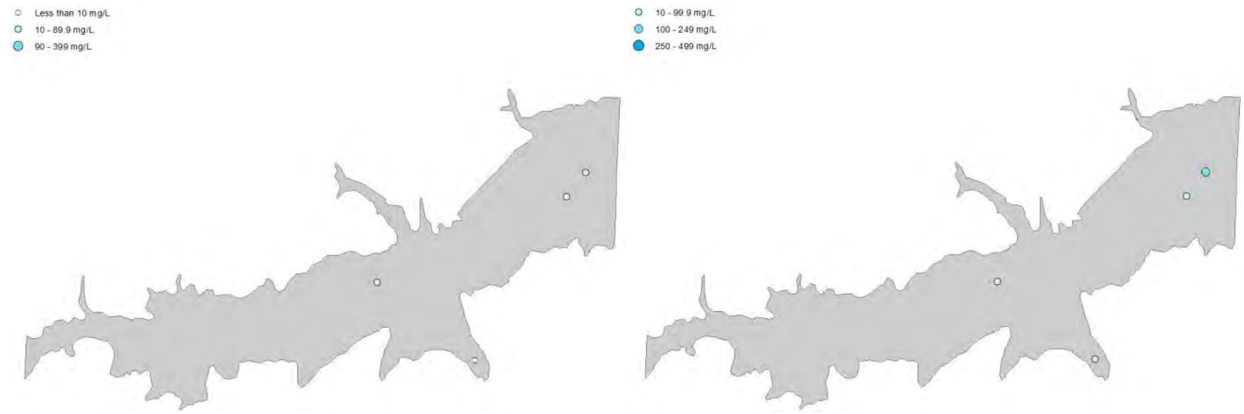


Figure T.4. Chloride (left) and sulfate concentrations in the WOLF.

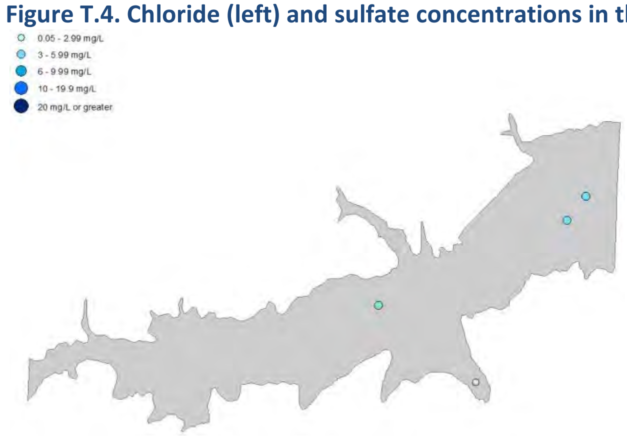


Figure T.5. Nitrate+nitrite concentrations in the WOLF.