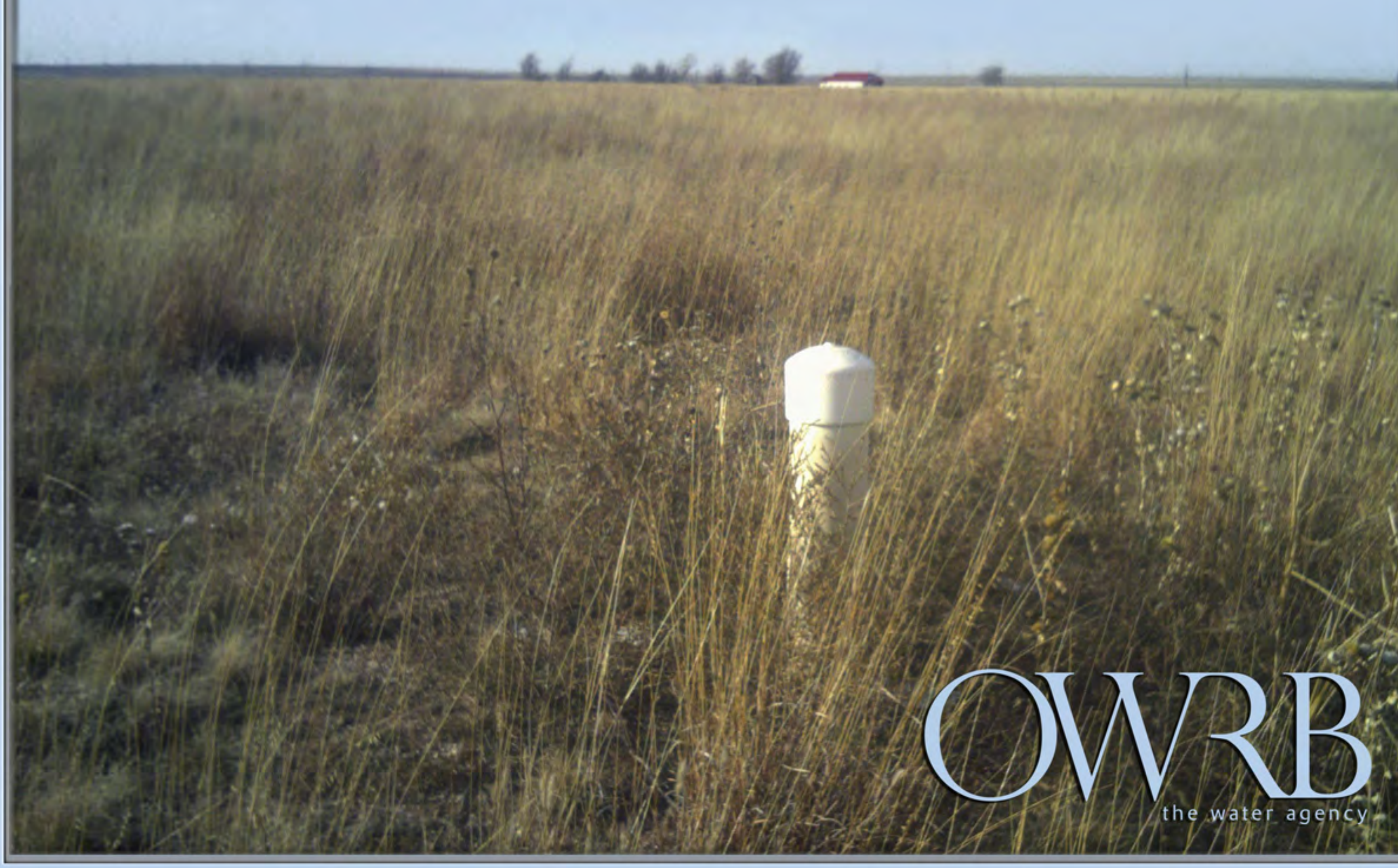
2014

Oklahoma Groundwater Report

Beneficial Use Monitoring Program



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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 and will continue to be phased in over the next 3 years. This baseline period will focus on 4-6 aquifers per year and will assess 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 30-50 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 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 in 2014 with an additional 8. The baseline monitoring will be 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.

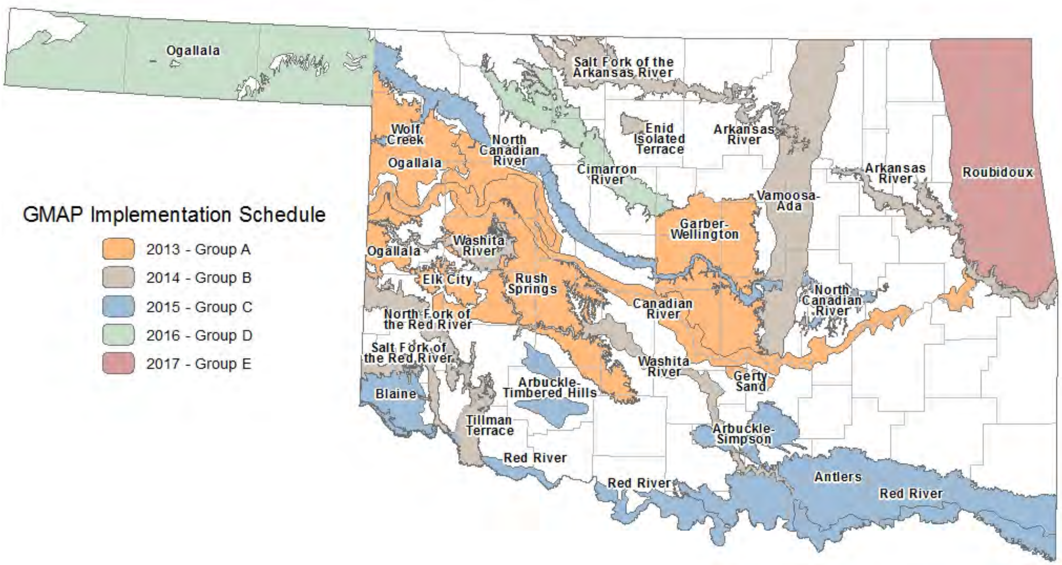

Figure 1. Revised GMAP implementation schedule.

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 2013 (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, 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 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. Additionally, two (2) continuous water level recorders were also installed in Group B aquifers, along with one in another aquifer in the second year of sampling.

Table 2. Baseline characteristics of Group A and B 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	
34	A- CNDN	7.01	394	533	1.19	112	45.9	33.9	99.9	4	8	3	13	4	2	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	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	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	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	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	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	71.9
29	B- ARKS	6.63	255	385	2.42	71	24.8	11.6	26.5	4	10	0	14	0	1	22.5
9	B- ENID	6.75	262	566	11.3	87.5	108	61.2	75.8	3	0	0	6	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	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	15.8
6	B-SFRR	7.06	260	403	9.73	78.2	35.6	<10	37.8	2	3	0	1	0	0	47.6
8	B- TILL	7.12	390	700	13.9	78.7	164	127	103	0	4	3	1	0	0	28.3
31	B- WASH	7.21	1030	990	0.88	127	58.1	31	111	4	11	9	5	1	1	23.9

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. 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. 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 (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	-	-	-	-
Total Dissolved Solids	General Chemistry	SM2540-C	-	500 mg/L	-
Nitrate+Nitrite	Nutrient	353.2	10 mg/L	-	-
Ammonia	Nutrient	350.1	-	-	-
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	-	-
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	-	-
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 two years of the program (Group A, 2013 and Group B, 2014), data was housed in a Microsoft Access 2007 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.).

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.

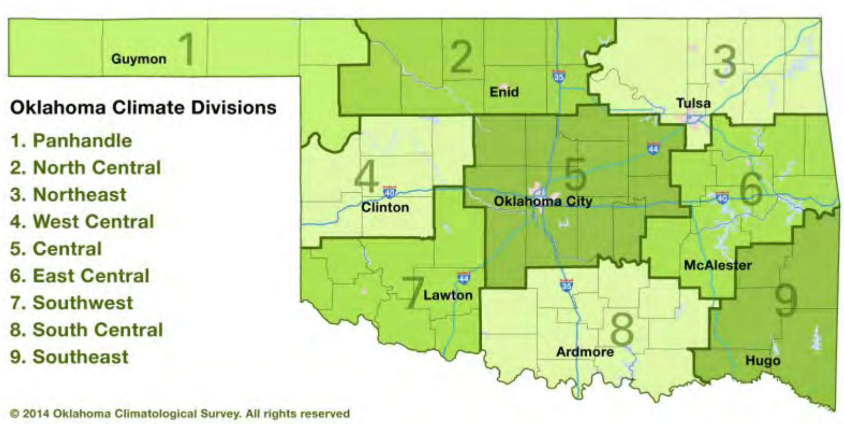

Figure 2. Oklahoma's Climate Divisions as mapped by the OCS.

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 aquifers, investigated in 2013, will include the general character of the resource and review the ongoing collection of water level data. More in depth discussions for water quality in Group A aquifers can be found on the OWRB's website in the 2013 BUMP Report. The aquifer summaries for Group B, investigated in 2014, 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 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.

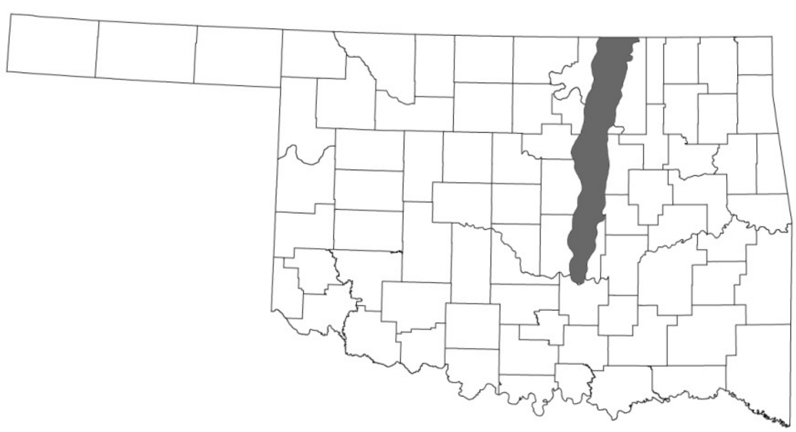

Figure 3. Location and extent of the ADVM.

The aquifer is encompassed by the state's Middle Arkansas, Upper Arkansas, Central, and Eufaula Planning Regions and by Oklahoma's Northeast and Central Climate Divisions. Annual precipitation ranges from 39.24 inches in the north to 34.11 inches in the south, and annual temperatures range from 59.0°F in the north to 60.2°F in the south. Recharge of the aquifer comes mostly from precipitation, with an estimated recharge rate of 0.7-1.4 inches per year. Natural discharge occurs largely through evapotranspiration, along with springs and baseflow to streams. The ADVM has an aerial extent of 6,713 km^2 and stores 14.9 million acre-feet of water. Well yields range from 25-300 gallons per minute; hydraulic conductivity is estimated to be 2-4 feet per day.

Groundwater in this aquifer is mainly utilized for municipal and industrial purposes, along with domestic and stock uses. The OWRB has on file more than 5,110 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 101 active groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 31,545 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 2 acre-feet per acre per year. The Ada-Vamoosa is designated by the OWRB as having a moderate vulnerability level.

Data Collection Results

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).

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

Water Quality

This program found that the ADVM contains water of good quality. Groundwater mineralization is greater, in general, in areas overlain by the Vanoss Formation and Ada Group than in those overlain by the Vamoosa; yet, overall mineral content was low. Groundwater in the aquifer was very hard and moderately alkaline, averaging 221 mg/L and 234 mg/L, respectively. Mean total dissolved solids (TDS) averaged a moderately low 393 mg/L. TDS ranged from 97.5-1120 mg/L with a median concentration of 344 mg/L. Specific conductance and pH were 685 µS/cm and 7.02, respectively. The primary water quality concern in the aquifer is locally elevated total dissolved solids.

The piper plot of ADVM data depicts primarily mixed calcium/magnesium-bicarbonate (34%), calcium/sodium/magnesium-bicarbonate (16%), and sodium-bicarbonate waters (13%). A variety of other water types were also present (Figure 5). The spatial distributions of water types and TDS are shown in Figure 6.

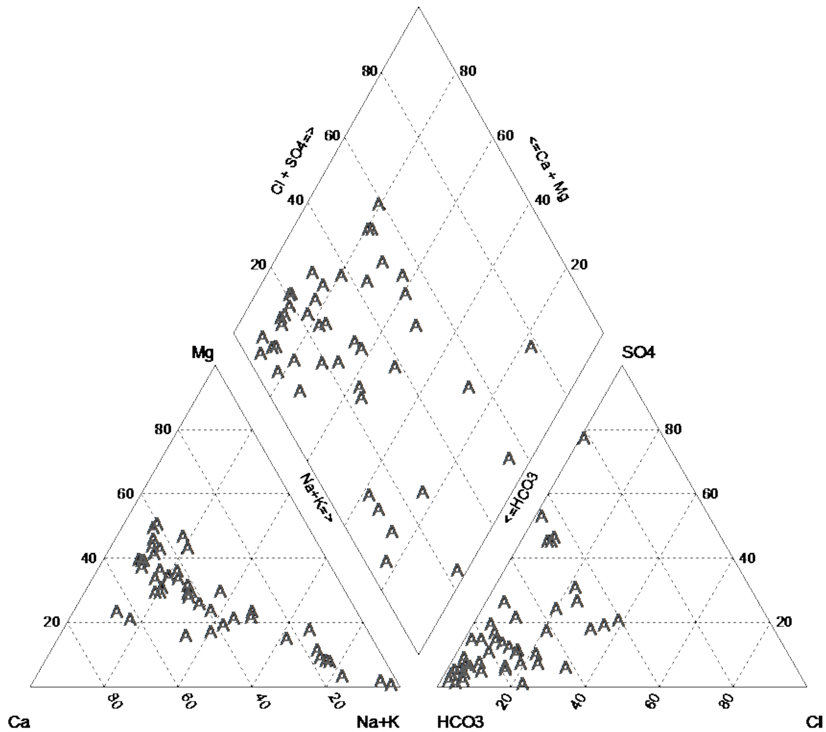

Figure 5. Piper plot diagram of constituents of the ADVM.

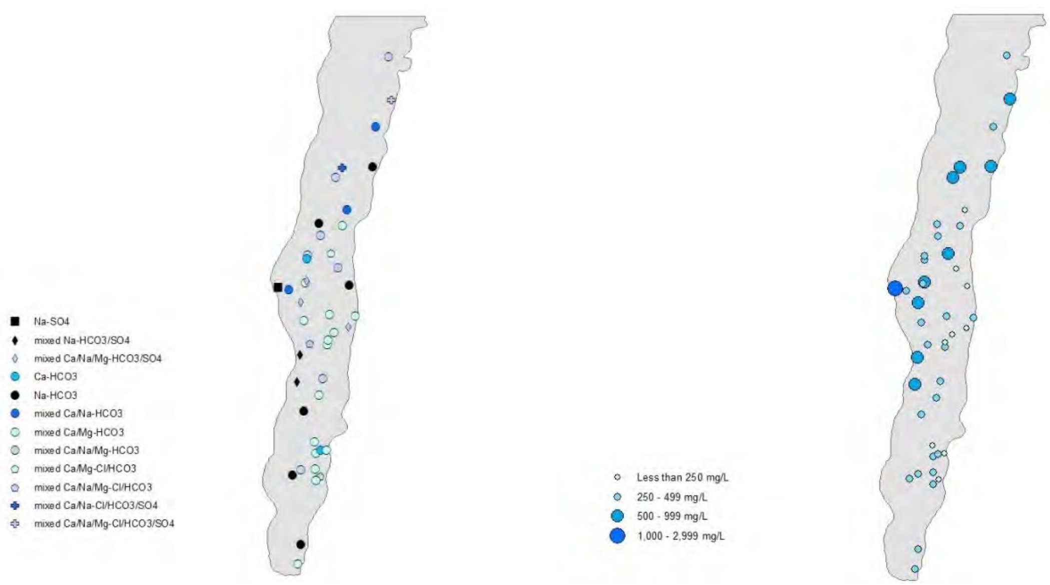

Figure 6. Distribution of water types (left) and TDS concentrations (right) in the ADVM.

Concentrations of bromide, calcium, chloride, potassium, silica were low in the ADVM. Magnesium was moderate, and levels of sodium and sulfate were mostly low with locally elevated levels. Fluoride was rarely detected and was low when present.

Nutrient content in the aquifer was low. Nitrate ranged from <0.05-18.9 mg/L with low mean and median concentrations of 1.48 mg/L and 0.515 mg/L. Ammonia and phosphorus were rarely detected and were mostly at low concentrations when present.

Low levels of metals and trace elements were detected in the ADVM. The following were not detected: aluminum, antimony, beryllium, cadmium, chromium, cobalt, mercury, nickel, selenium, and silver. Mostly low concentrations of arsenic, barium, boron, iron, manganese, vanadium, and zinc were present. Copper, lead, molybdenum, and uranium were rarely detected and were low when present.

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

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	10	--
Nitrate	1	--	--
Sulfate	--	3	--
Iron	--	5	--
Manganese	--	6	1

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 most recent configuration 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. Several of these historical wells were incorporated into the new baseline network to maintain water level sites with long-term records. One of the longest measurement records in this aquifer spans 20 consecutive years (Figure 7).

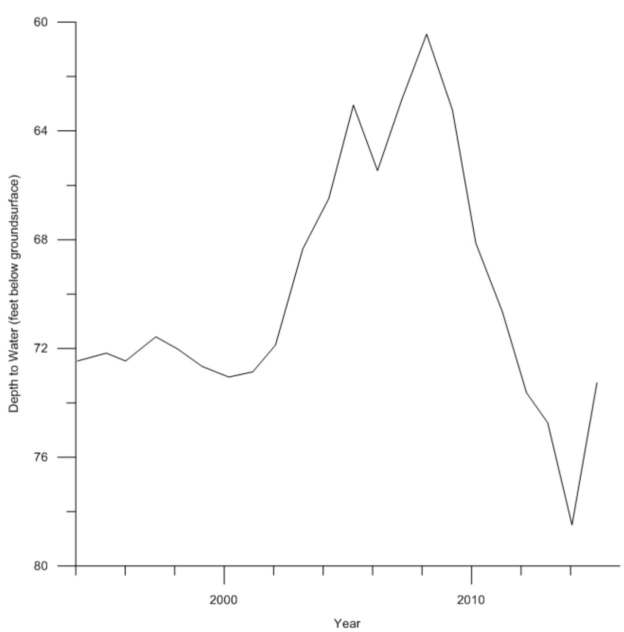

Figure 7. Groundwater level hydrograph of the longest ADVM record, Seminole County (1994-2015).

A baseline groundwater level network composed of 44 wells was implemented in September 2014. The baseline network incorporated 3 wells from the ADVM's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from 11.6-321.1 feet. In unconfined wells this range of depth to water was 11.6-140.3 ft with a mean of 71 ft; total depth for these wells was 72-300 ft with an average 180.9 ft. Depth to water in the five confined wells ranged 22.7-321.2 ft with a mean of 163.9 ft; total depth for these confined wells was 330-850 ft with an average 497.8 ft. Thirty-six (36) of the 50 wells in the baseline network have been incorporated into a trend network, a marked improvement over the historical network. Unconfined conditions are reflected in 32 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 over the last five years; the above hydrograph reflects a decline of 5.13 ft (2010-2015).

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 8).

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.

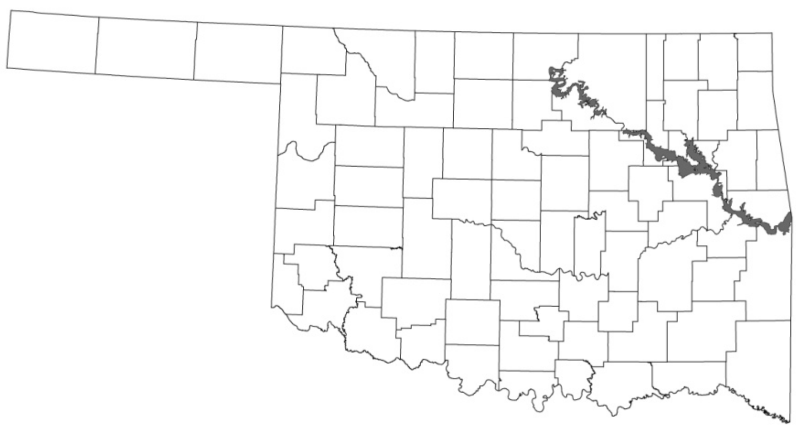

Figure 8. Location and extent of the ARKS.

The aquifer flows through the state's Upper Arkansas, Middle Arkansas, and Lower Arkansas Planning Regions. The northern part of the aquifer is in Oklahoma's Northeast Climate Division with averages of 59.0°F and 39.24 inches of precipitation annually; the southern part is located in the East Central Climate Division with averages of 60.7°F and 42.88 inches. Recharge is mostly a result of infiltration of precipitation, with an estimated recharge rate of 5 inches per year. Natural discharge occurs through evapotranspiration and base flow to streams. The ARKS has an aerial extent of 2,223 km^2 and stores 946 thousand acre-feet of water. Well yields range from 100-500 gallons per minute. The Arkansas is designated by the OWRB as having a very high vulnerability level.

Groundwater in this aquifer is mainly utilized for agriculture, domestic, and public supply purposes. The OWRB has on file more than 2,850 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 131 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 66,487 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 2 acre-feet per acre per year.

Data Collection Results

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 9).

Figure 9. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ARKS in 2014.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content was low-moderate. Groundwater in the ARKS was very hard and moderately alkaline, averaging 264 mg/L and 234 mg/L, respectively. Mean total dissolved solids (TDS) was moderately low at 386.5 mg/L. TDS ranged from 225-848 mg/L with a median concentration of 340 mg/L. Specific conductance and pH were 651 µS/cm and 6.57, respectively. Keystone Lake, at the confluence of the Arkansas and Cimarron Rivers, appears to be a boundary for water quality in this aquifer. Sites above Keystone have much higher hardness, TDS, and overall mineralization of the groundwater. While water below Keystone may still have high concentrations of these parameters, sites are interspersed with water of lower concentrations and there are not obvious areas of delineation. The primary water quality concern in the aquifer is locally elevated iron and manganese.

The piper plot of ARKS data reveals mostly calcium-bicarbonate water (55% - Figure 10). Mixed types of calcium/sodium-bicarbonate and calcium/sodium/magnesium-bicarbonate were also prominent (17%); other types present include sodium-bicarbonate, sodium-chloride, and mixed bicarbonate/chloride waters. The spatial distributions of water types and TDS are shown in Figure 11.

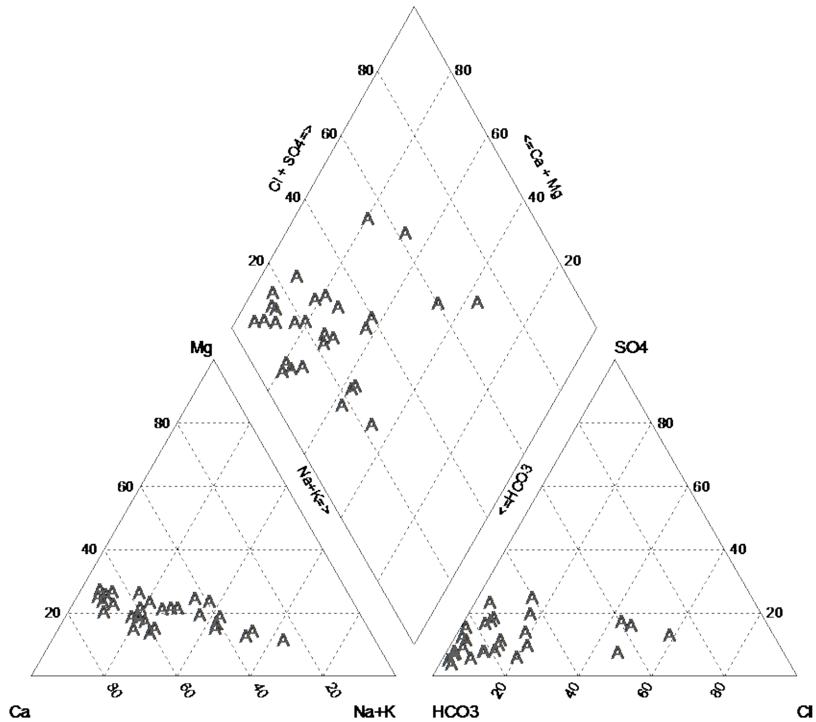

Figure 10. Piper plot diagram of constituents of the ARKS.

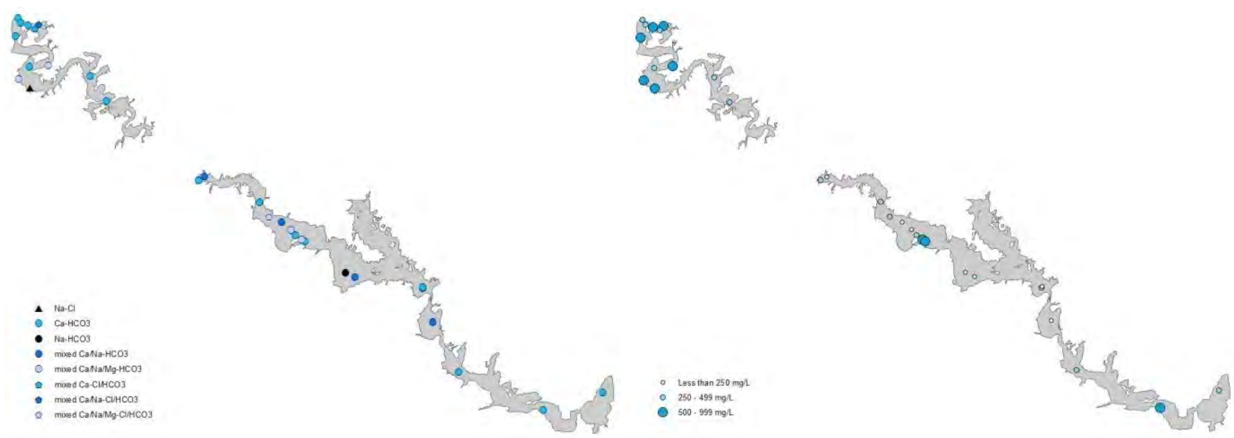

Figure 11. Distribution of water types (left) and TDS concentrations (right) in the ARKS.

Low concentrations of bromide, chloride, fluoride, magnesium, potassium, silica, sodium, and sulfate were present. Calcium was detected at moderate levels averaging 70.7 mg/L.

Nutrients in the aquifer reflect low to moderate levels of nitrate. Nitrate content ranged from <0.05-17.4 mg/L; mean and median concentrations were 3.46 mg/L and 2.42 mg/L which are considered near natural background levels. Moderate levels of phosphorus were present at an average of 0.15 mg/L. Ammonia was rarely detected but concentrations were generally moderate when present.

Few metals and trace elements were present in the ARKS. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, lead, mercury, nickel, selenium, and silver. Arsenic, chromium, copper, molybdenum, uranium, and vanadium were rarely detected. Iron varied widely and was generally found at low concentration, although several values were well over EPA limits. Manganese also varied widely but was generally high when detected with many sites exceeding EPA thresholds. Barium, boron, 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 ARKS had some 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 ARKS water quality, see Appendix B.

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	9	--
Nitrate	1	--	--
Chloride	--	1	--
Iron	--	7	--
Manganese	--	15	13

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 12). The most recent network configuration had 2 wells in the Northeast and 4 wells in the East Central division.

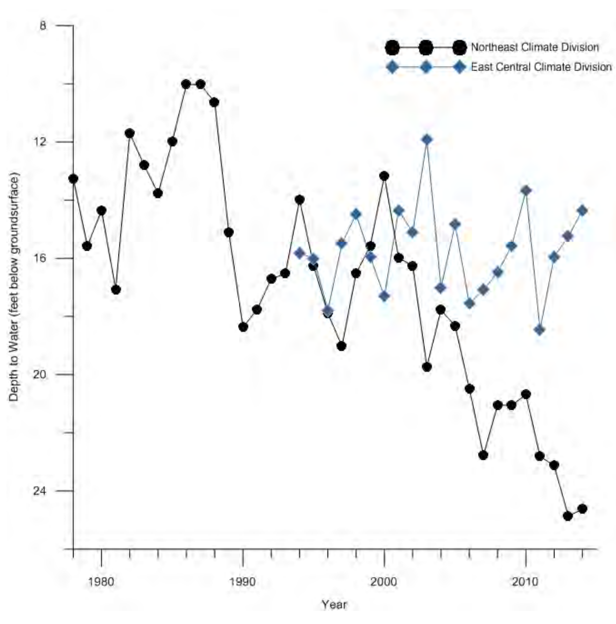

Figure 12. Average ARKS water level over period of record prior to GMAP implementation (1976-2014), divided by climate division.

A baseline groundwater level network for the ARKS was comprised of 22 wells and implemented in September-October 2014. To maintain some wells with long periods of record, the baseline network incorporated 6 wells from the aquifer's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from an artesian flowing well to 60.3 feet below ground surface with a mean of 24.6 ft over the entire aquifer; 28.6 ft in the Northeast and 11.9 ft in the East Central climate divisions. The total depth of wells used in the network ranged from 26-116 feet and averaged 45.4 ft. Twenty-one (21) of the 35 wells in the baseline network have been incorporated into a trend network. Though fluctuation in alluvial and terrace aquifers is normal due to their sensitivity to use and climate, water levels in ARKS wells have dropped 4.15 feet in the last five years (2010-2015), with an average drop of 5.26 ft in the Northeast and 3.6 ft in the East Central climate divisions.

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 13).

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 13. 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 14). 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 C of this report.

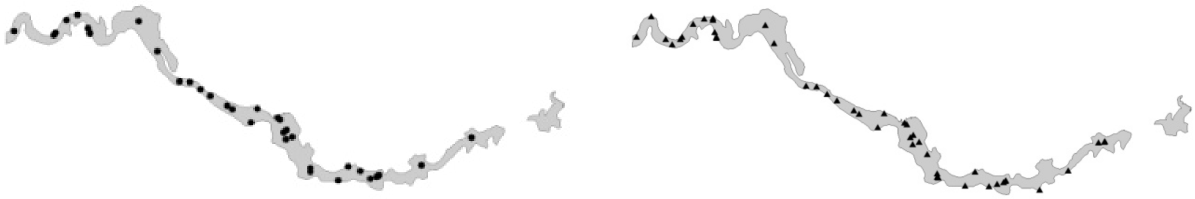

Figure 14. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the CNDN in 2013.

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. 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 15). Several of these wells were incorporated into the new baseline network to maintain water level sites with long-term records.

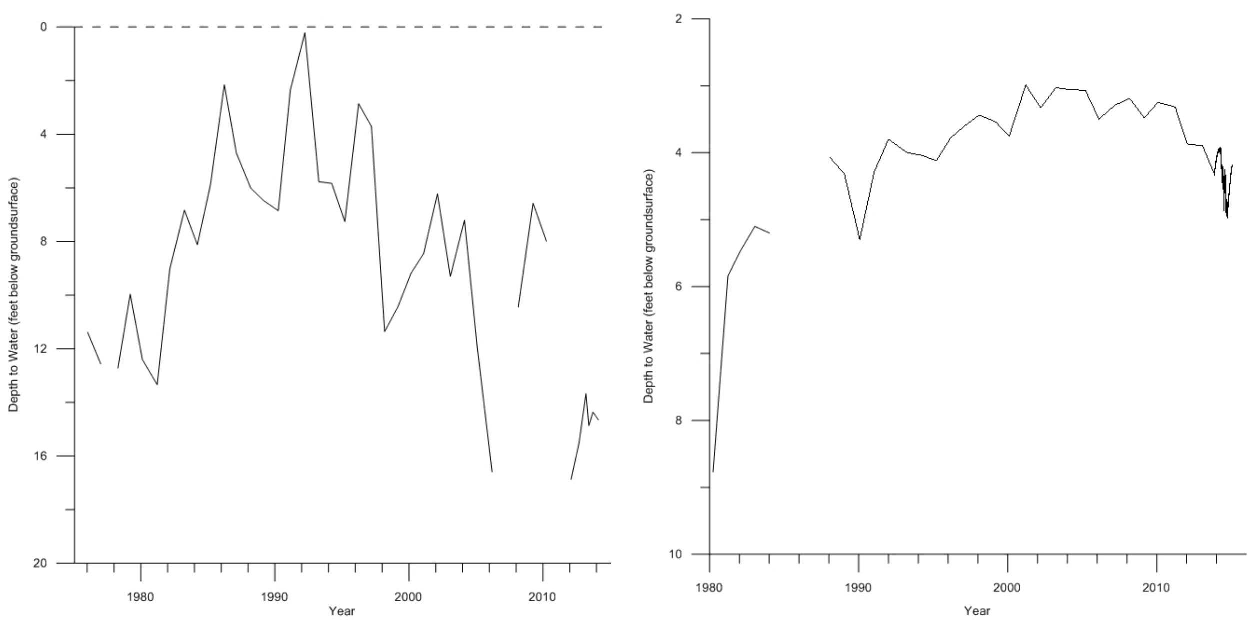

Figure 15. Groundwater level hydrographs for two of the longest CNDN records, McClain County (1977-2015; left) and Roger Mills County (1980-2015; right).

A baseline groundwater level network comprising 46 wells was implemented in August-September 2013. Measurements of depth to water made during baseline water quality sampling in 2013 ranged from 2.68 feet to 54.32; the total depth of wells used in the network ranged from 14 to 112 feet. In western areas of the aquifer (west of Canadian county), depth to water ranged 4.04-51.74 ft with a mean of 20.93 ft; in central areas, depth to water ranged 2.68-54.32 ft with a mean of 21.36 ft; and, in eastern areas (east of Seminole county), depth to water ranged 5.4-47.65 ft with a mean of 20.63ft. A trend network composed of 34 wells from the baseline network was also initiated (13 in west, 17 in central, and 4 wells in eastern areas), with some wells measured three times a year. 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.

The average water level in CNDN wells has dropped 2.3 ft in the west (3 wells), 6.2 ft in the central (2 wells), and 4.5 ft in the eastern areas (4 wells) over the past 5 years (2010-2015). The new GMAP trend network has recorded the average water level dropping in CNDN wells 0.64 ft in the west, 1.45 ft in the central, and 0.13 ft in the eastern areas over the last year (2014-2015). 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 (Figure 16).

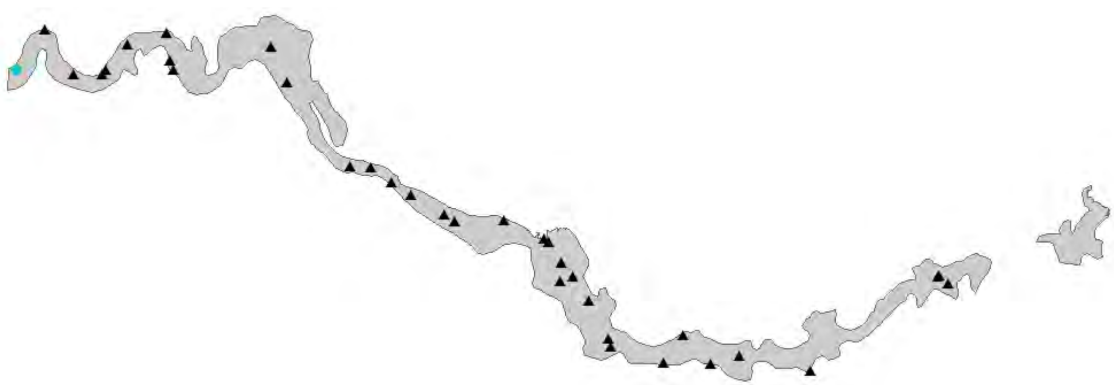

Figure 16. Location of the continuous water level recorder (blue circle) against the entire CNDN water level network.

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 17). 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 17. 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 18). 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 D of this report.

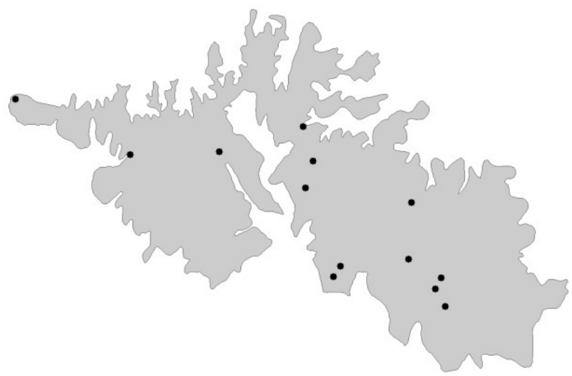

Figure 18. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ELKC in 2013.

Groundwater Level Measurements

The ELKC's historical groundwater level network began measurements on 7 wells in 2010, adding to one well with a 25 year period of record (Figure 19).

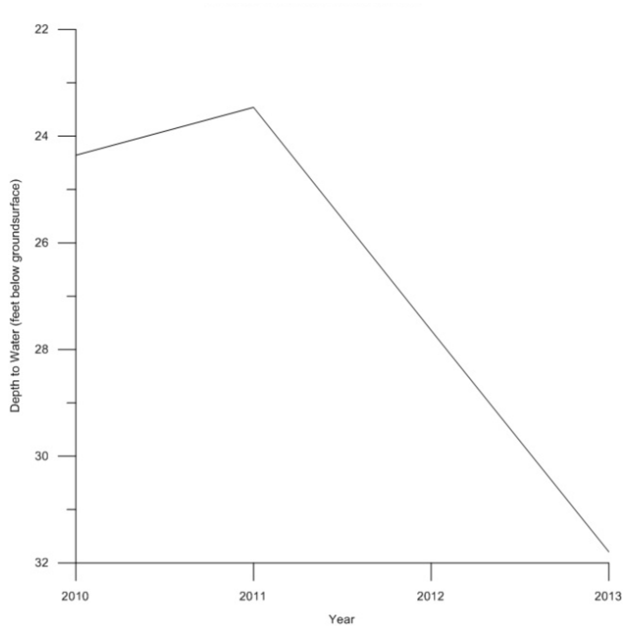

Figure 19. Average ELKC water level over period of record prior to GMAP implementation (2010-2013).

A baseline groundwater level network comprising 25 wells was implemented in July-August 2013. All 8 historical wells were incorporated into the baseline network. Measurements of depth to water made during baseline water quality sampling ranged from 10.95 to 107.8 ft with a mean of 28.98 feet. Twenty-three (23) of the 25 wells in the baseline network have been incorporated into a trend network. Figure 20 is a depth to water hydrograph of the one well with a 25 year period of record.

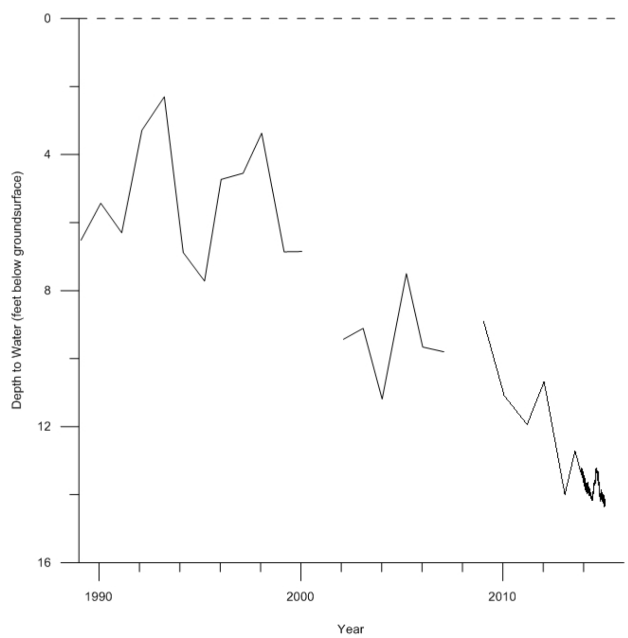

Figure 20. Groundwater level hydrograph of the longest ELKC record, Washita County (1989-2015).

Taped measurements of the well depicted in Figure 20 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 21). These hydrographs reflect an overall decline in water levels in ELKC wells of 8.37 feet over the last five years (2010-2015). The new GMAP trend network has recorded the average water level dropping in ELKC wells 1.06 ft over the last year (2014-2015).

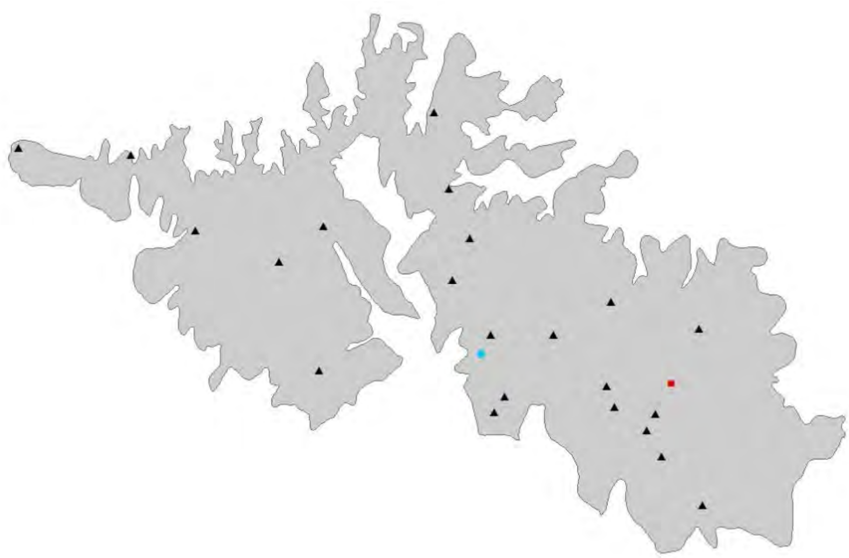

Figure 21. Location of the continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire ELKC water level network.

Enid Isolated Terrace Aquifer

The Enid Isolated Terrace aquifer, located in north central Oklahoma and underlying Garfield County, is an isolated terrace aquifer separated from the Cimarron River by erosion (Figure 22). 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 22. Location and extent of the ENID.

The aquifer lies mainly in the state's Upper Arkansas Planning Region with the far western edge in the Central Region. It is located within Oklahoma's North Central Climate Division, which averages 58.2°F and 28.65 inches of precipitation annually. Recharge of the ENID comes mainly from infiltration of precipitation and return irrigation flow with a minor contribution of subsurface flow from the Cedar Hills Sandstone. Rate of recharge is estimated at 2.3 inches per year. Natural discharge occurs through springs and seeps at overlying streams, along with leaks at the aquifer boundaries. The ENID has an aerial extent of 209.6 km^2 and stores 246 thousand acre-feet of water. Well yields range from 25-300 gallons per minute; hydraulic conductivity is estimated to be 93-133 feet per day.

Groundwater in this aquifer is mainly utilized for irrigation, domestic, municipal, and industrial purposes. The OWRB has on file more than 4,200 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 44 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 5,844 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 0.5 acre-feet per acre per year. The Enid Isolated Terrace is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 23). 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.

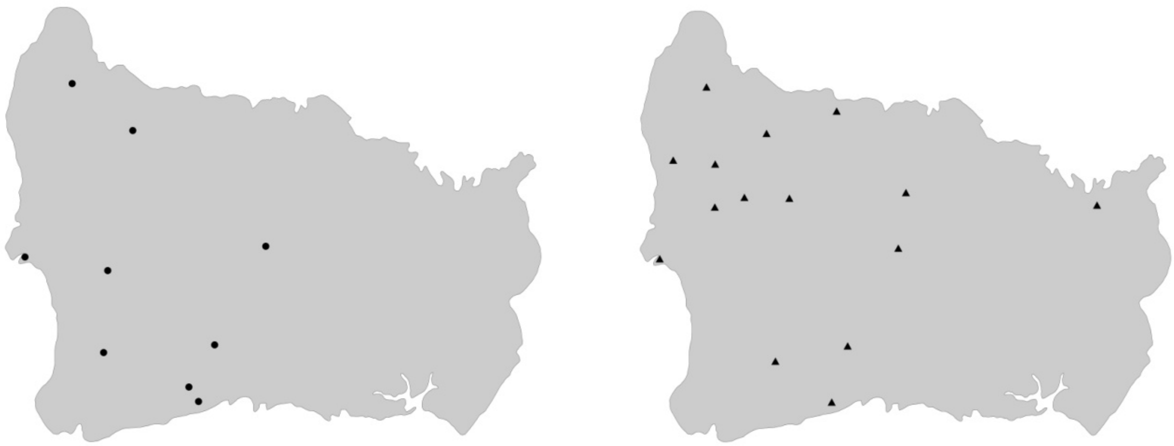

Figure 23. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the ENID in 2014.

Water Quality

Overall, this aquifer contains water of fair quality. Mineral content was at moderate concentrations. Groundwater in the aquifer was very hard and moderately alkaline, averaging 297 mg/L and 270 mg/L, respectively. Mean total dissolved solids (TDS) were moderately high at 610 mg/L, ranging from 170-1050 mg/L with a median concentration of 566 mg/L (Figure 25). Specific conductance and pH were 992 µS/cm and 6.73, respectively. The primary water quality concern in the aquifer is nitrate levels, along with locally elevated concentrations of TDS, sodium, & chloride.

The piper plot of ENID data shows primarily bicarbonate waters with a mix of calcium and sodium cations (Figure 24). Other water types include calcium/sodium/magnesium-bicarbonate, calcium/sodium-chloride/bicarbonate, and calcium/sodium-chloride/bicarbonate/sulfate. The mixed anion types clustered in the southwestern corner (Figure 25).

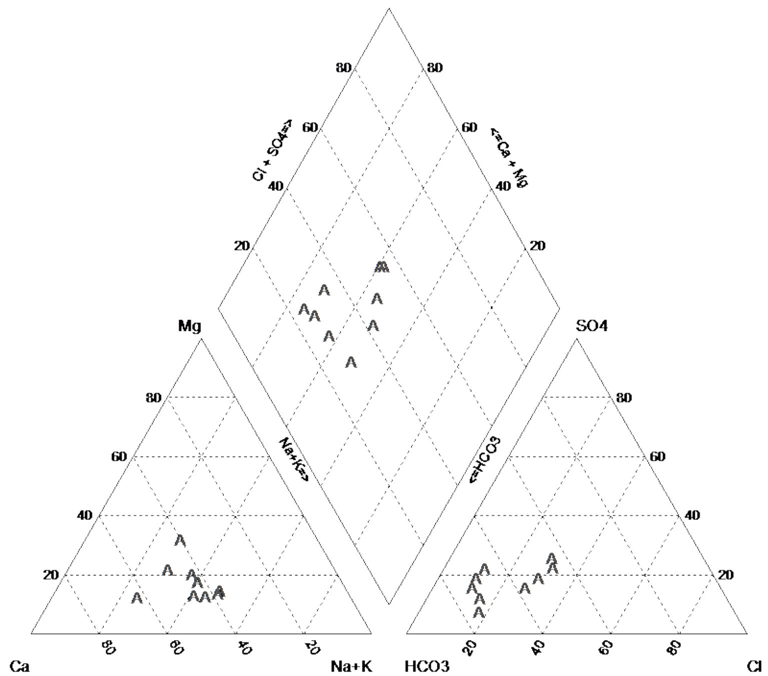

Figure 24. Piper plot diagram of constituents of the ENID.

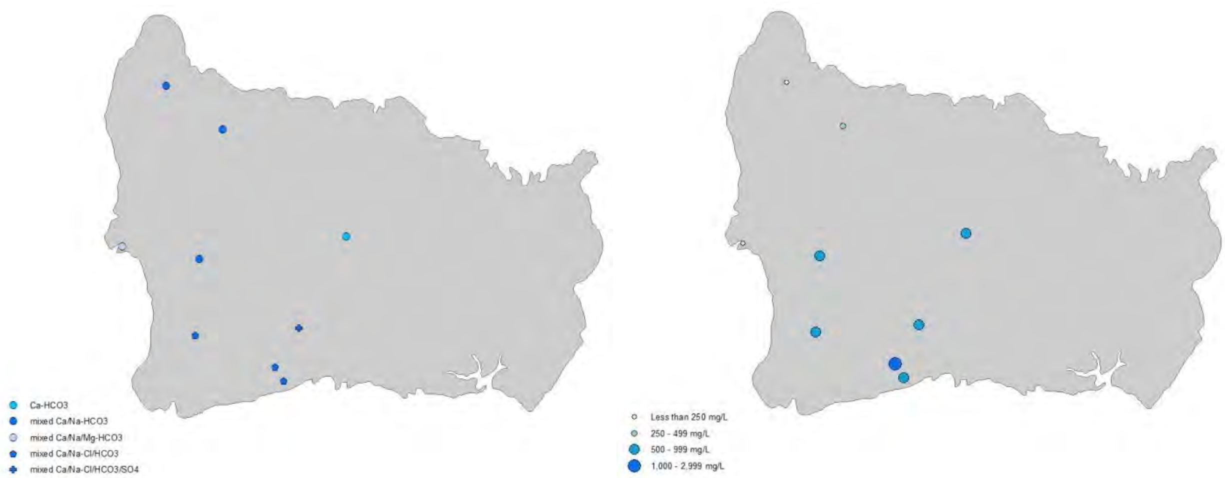

Figure 25. Distribution of water types (left) and TDS concentrations (right) in the ENID.

Bromide, chloride, fluoride, silica, sodium, sulfate, and magnesium were low in the aquifer. Potassium was detected at moderate and calcium was detected at moderately high concentrations in the ENID.

Nutrients in the aquifer reflect high levels of nitrate and moderate levels of phosphorus; ammonia was not detected. Phosphorus concentrations varied but averaged 0.12 mg/L. Nitrate content ranged from 2.45-29 mg/L, with mean and median concentrations of 10.99 mg/L and 11.3 mg/L that are considered elevated above natural background levels.

The ENID had low levels of metals and trace elements detected. The following were not detected: aluminum, beryllium, cadmium, chromium, cobalt, iron, lead, mercury, molybdenum, nickel, selenium, and silver. Antimony, copper, and manganese were rarely detected and were at low concentrations when present. Low levels of arsenic, barium, boron, uranium, vanadium, and zinc were present.

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

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	6	--
Nitrate	5	--	--

Groundwater Level Measurements

Thirteen (13) wells in the ENID had historical measurements, with 9 wells in the most recent network configuration (Figure 26). Two of these wells have had discontinuous measurements since the 1950's.

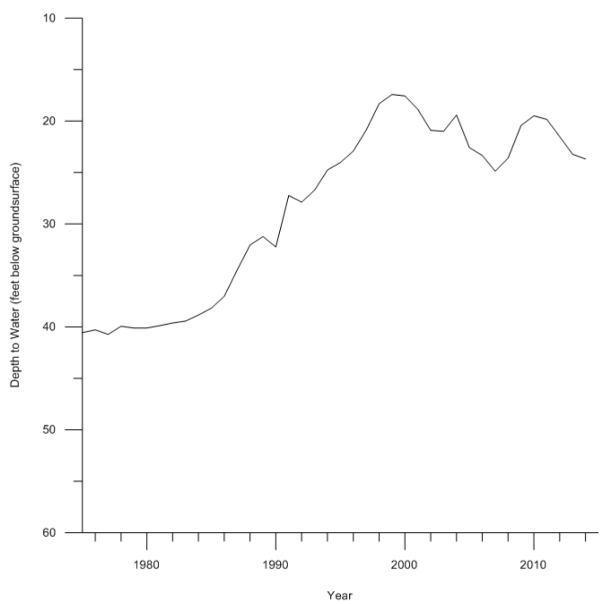

Figure 26. Average ENID water level over the period of record prior to GMAP implementation (1975-2014).

A baseline groundwater level network of 18 wells was implemented in September 2014. The baseline network incorporated the 9 wells from the aquifer's historical groundwater level network to continue long-term records. Measurements of depth to groundwater made during baseline water quality sampling ranged from 7.65-49.51 ft with a mean of 25.48 ft. The total depth of wells used in the network ranged from 32-70 feet and averaged 49.47 feet. Fourteen (14) of the 18 wells in the baseline network have been incorporated into a trend network, along with a few extra sites. Figure 27 is a depth to water hydrograph of one of the two ENID wells that has nearly 50 years of measurements.

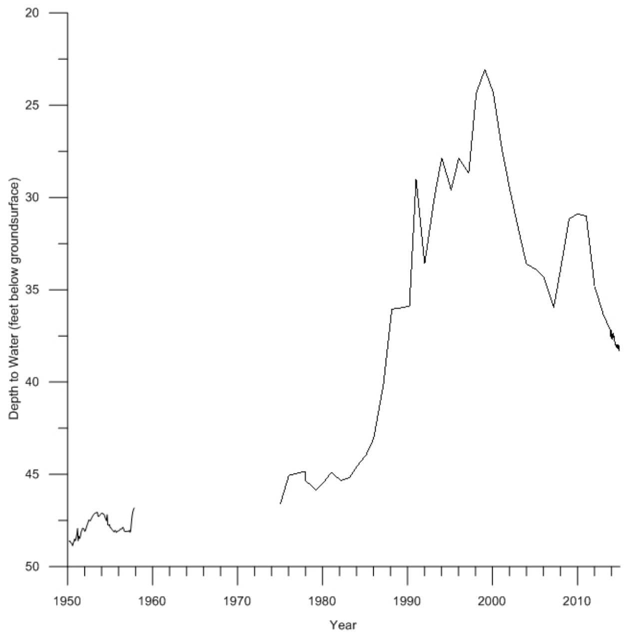

Figure 27. Groundwater level hydrograph of one of the longest ENID records, Garfield County (1950-2015).

Taped measurements of the well depicted in Figure 26 began in 1950, with a hiatus from 1958-1975, and then continued until 2013. A continuous water level recorder was installed in November 2013 and has been collecting hourly depth to water measurements (Figure 28). The second well with a 60 year period of record has a similar measurement history and is still measured manually once a year. The above hydrographs reflect declining water levels with an average drop of 4.85 feet in ENID wells during the last 5 years (2010-2015).

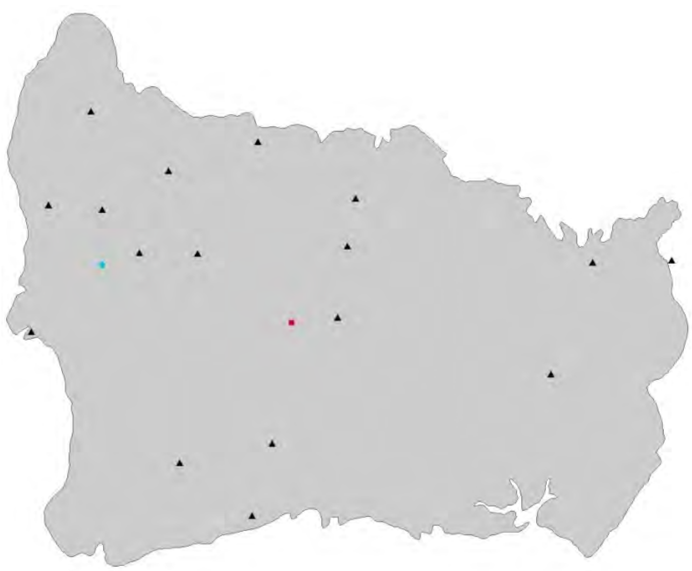

Figure 28. Location of the continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire ENID water level network.

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 29). 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 29. 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 30). 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 F of this report.

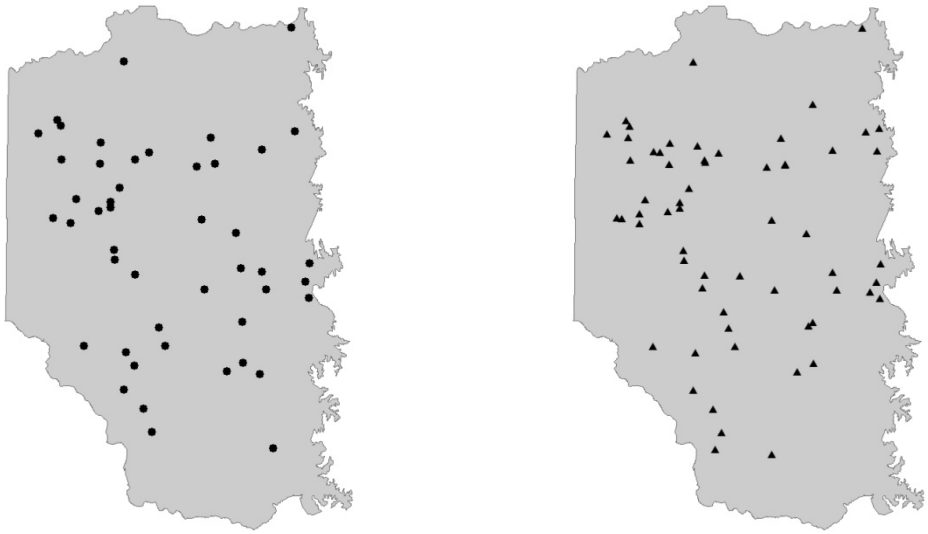

Figure 30. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the GSWF in 2013.

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 most recent network configurations (Figure 31).

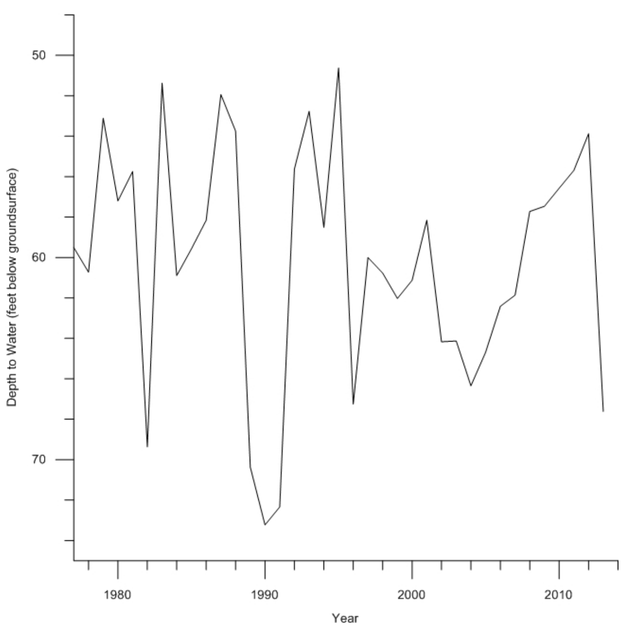

Figure 31. Average water level in unconfined GSWF wells over period of record prior to GMAP implementation (1977-2013).

A baseline groundwater level network comprising 61 wells was implemented in October-November 2013. The baseline incorporated 14 wells from the aquifer's most recent historical network to continue these long-term records. Measurements of depth to water made during baseline water quality sampling in 2013 ranged from 8.45 to 228.1 feet. In unconfined wells, this range of depth to water was 8.45-218.8 ft with a mean of 74.8 ft; the total depth of unconfined wells used in the network ranged 43-300 ft with an average 189.2 ft. In the one confined well, depth to water was 228.1 ft and total depth was 380 ft. Forty-two of the 57 wells in the baseline network have been incorporated into a new trend network, along with a few extra sites. Unconfined conditions are reflected in 42 wells of the trend network, and 7 are considered to be in the deeper, confined parts of the aquifer. Figure 32 is a depth to water hydrograph for an unconfined well with over 30 years of measurements.

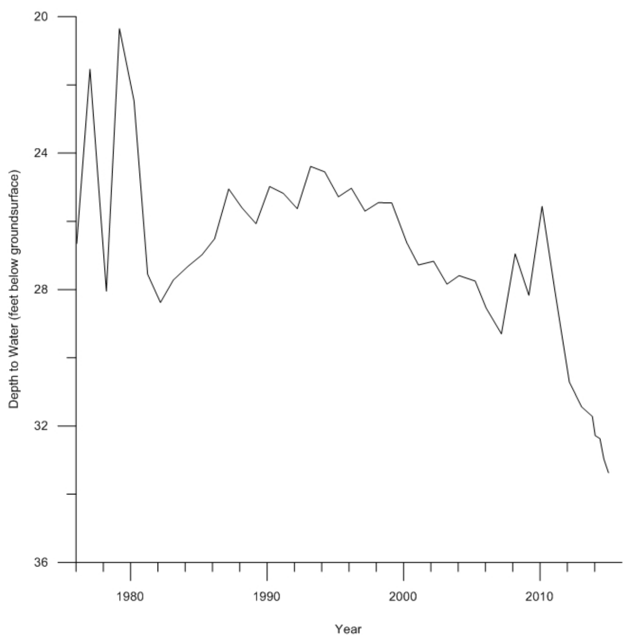

Figure 32. Groundwater level hydrograph of a GSWF well, Oklahoma County (1976-2015).

Taped measurements of the well in Figure 32 have been made annually since 1976 and will continue 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. In the last five years, water levels have dropped in unconfined GSWF wells an average of 7.6 feet (2010-2015). The new GMAP trend network has recorded an average drop of 1.28 ft in GSWF wells over the last year (2014-2015). Hourly measurements of depth to water are being collected from continuous water level recorders installed in Cleveland and Lincoln Counties during summer 2013, along with several others installed for a separate OWRB hydrologic study (Figure 33).

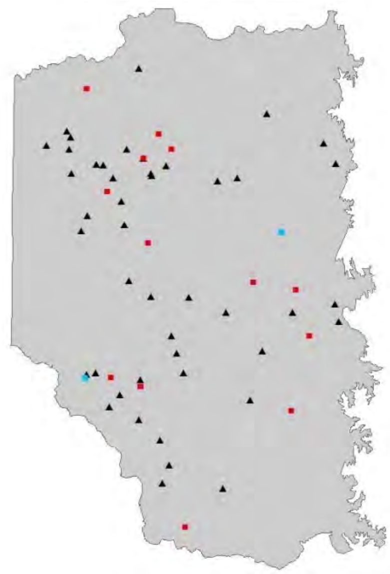

Figure 33. Location of the continuous water level recorders deployed for GMAP long-term seasonal monitoring (blue circles) and for a separate OWRB hydrologic study (red squares) against the entire GSWF water level network.

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 34), 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 34. 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 35). 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 G of this report.

Figure 35. 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 have only been tracked in two wells in the GRTY; only one has been measured in the decade prior to GMAP implementation. Measurements of these wells reflect rising groundwater levels for most of the period of record, and depth to water has not changed in the last five years (2010-2015) (Figure 36).

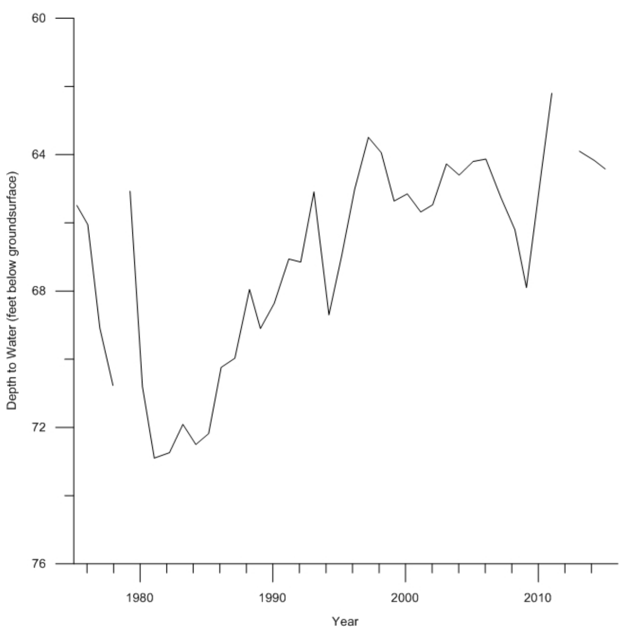

Figure 36. Groundwater level hydrograph of a GRTY well, Garvin County (1975-2015).

The Gerty Sand water level network is a work in progress. The current baseline network was implemented in August 2013 and consists of five new wells. Five (5) additional wells will be added to the eastern lobe of the aquifer and 1-2 wells will be added to the western lobe. Measurements of depth to groundwater made during baseline water quality sampling in 2013 ranged from 15.95 to 58.8 feet, with a mean of 42.23 feet. The total depth of wells used in the network ranged from 45-91 feet, averaging 67 feet. Four of the 5 baseline wells were incorporated into the trend water level network. Water level in the GRTY is currently being monitored by a continuous water level recorder deployed by the OWRB for a separate hydrologic study (Figure 37).

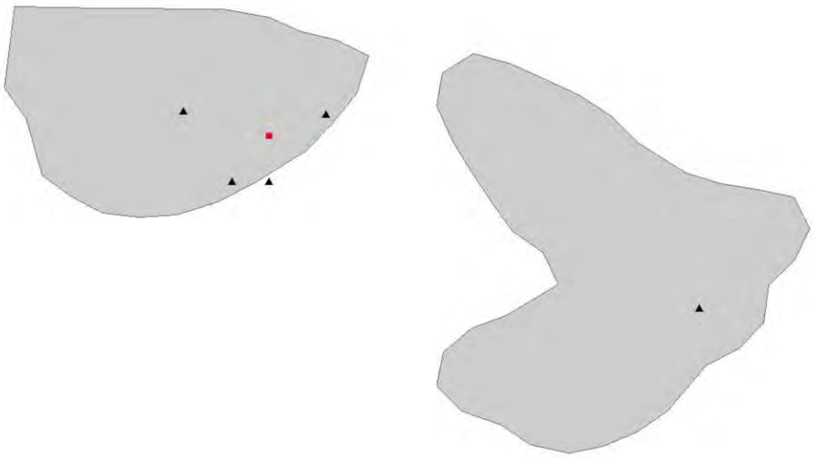

Figure 37. Location of continuous water level recorder (red square) in a current OWRB hydrologic study against the entire GRTY GMAP water level network.

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 38).

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.

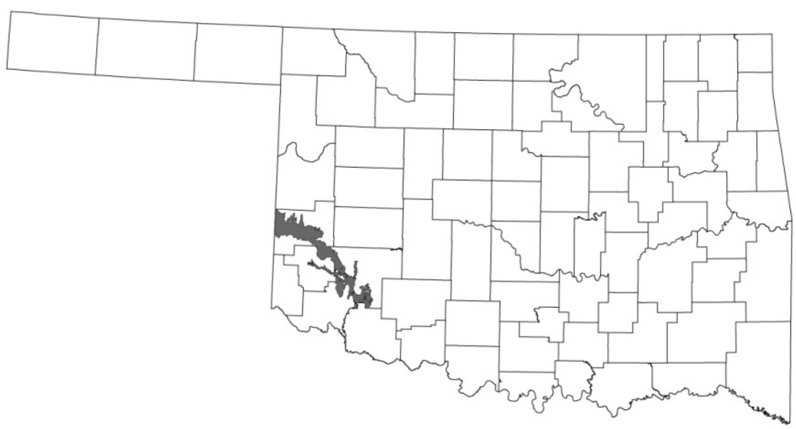

Figure 38. Location and extent of the NFRR.

The aquifer is within the state's Southwest Planning Region. The northern part of this aquifer is located in Oklahoma's West Central Climate Division, which averages 59.0°F and 26.07 inches of precipitation annually; the southern part is in the Southwest Climate Division, with averages of 61.1°F and 27.62 inches annually. Recharge of the aquifer comes mostly from infiltration of precipitation and return flow from irrigation, with an estimated recharge rate of 2.3 inches per year. Natural discharge occurs through evapotranspiration and discharge to streams. The NFRR has an aerial extent of 1,734 km^2 and stores 3.76 million acre-feet of water. Well yields range from 25-300 gallons per minute; hydraulic conductivity is estimated to be 98-132 feet per day.

Groundwater in this aquifer is utilized for public water supply, industrial, domestic, and agricultural purposes. The OWRB has on file more than 2,630 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 402 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 77,941 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 1 acre-foot per acre per year. The North Fork of the Red River is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 39).

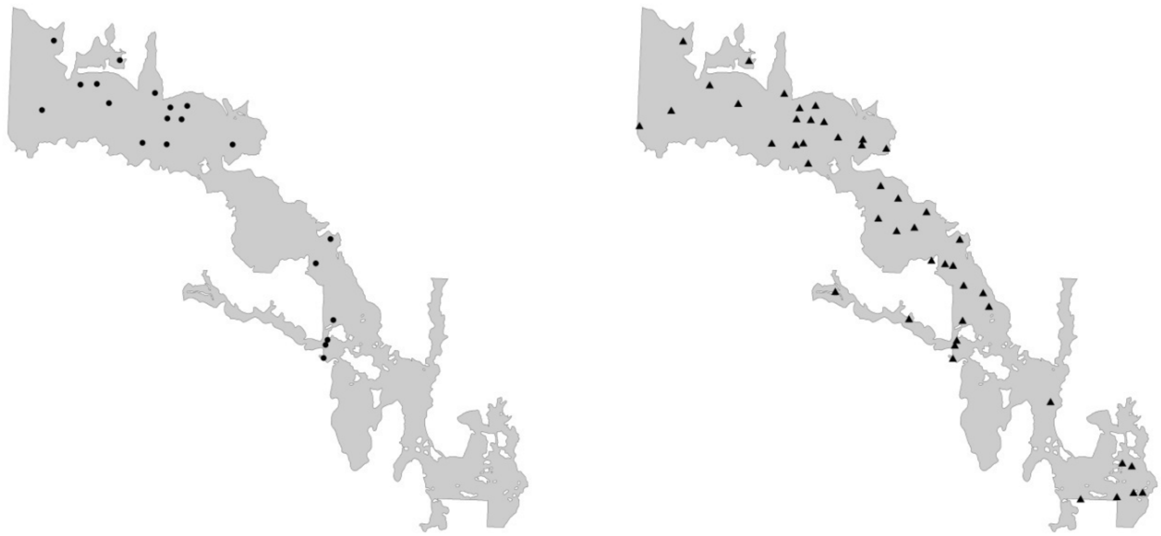

Figure 39. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the NFRR in 2014.

Water Quality

Overall, this aquifer contains water of fair quality. Mineral content was moderately high, and metals were low when detected. Groundwater in the aquifer was very hard and moderately alkaline, averaging 487 mg/L and 225 mg/L, respectively. Mean total dissolved solids (TDS) were moderately high at 895 mg/L, with a range from 295-3520 mg/L and a median of 542 mg/L (Figure 41). Specific conductance averaged 1340 µS/cm, and pH was 7.06. Of note are three wells 1-2 miles upstream of the Elm Fork Tributary's confluence with the NFRR that affected the averages for this aquifer, having the highest specific conductance readings along with the highest levels for several parameters (boron, bromide, chloride, magnesium, potassium, sodium, sulfate, and TDS). These wells were the only sites with chloride prominent in the mixed water type. Salt flats in northern Harmon County originating from the Flower Pot Shale discharge sodium chloride-laden water to the river. The saline river water has infiltrated the alluvial and terrace deposits over time, increasing its mineral content, particularly with respect to aquifer areas downstream from or adjacent to the confluence with the North Fork of the Red River. Though different from most of this aquifer, these data are considered representative of the water in the area where the two rivers merge; thus, they were kept in the general statistics for the entirety of the NFRR. In contrast is a small area to the south of the town of Sayre with water that exhibits lower mineralization than that of the aquifer as a whole. The primary water quality concerns in the aquifer are high nitrate, sulfate, hardness, and TDS concentrations.

The piper plot of NFRR data depicts a range between calcium-bicarbonate water (40% of sites) and calcium-sulfate water (20% of sites) (Figure 40). The majority of other water types present were mixed calcium and/or sodium with bicarbonate and/or sulfate. There was no apparent spatial distribution of water types, other than a cluster of chloride waters at the confluence of the Elm Fork tributary (Figure 41).

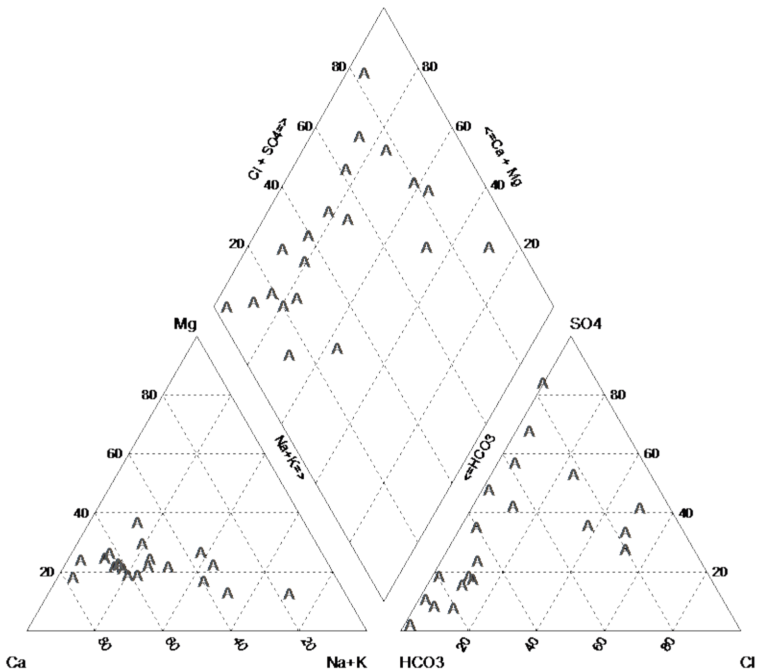

Figure 40. Piper plot diagram of constituents of the NFRR.

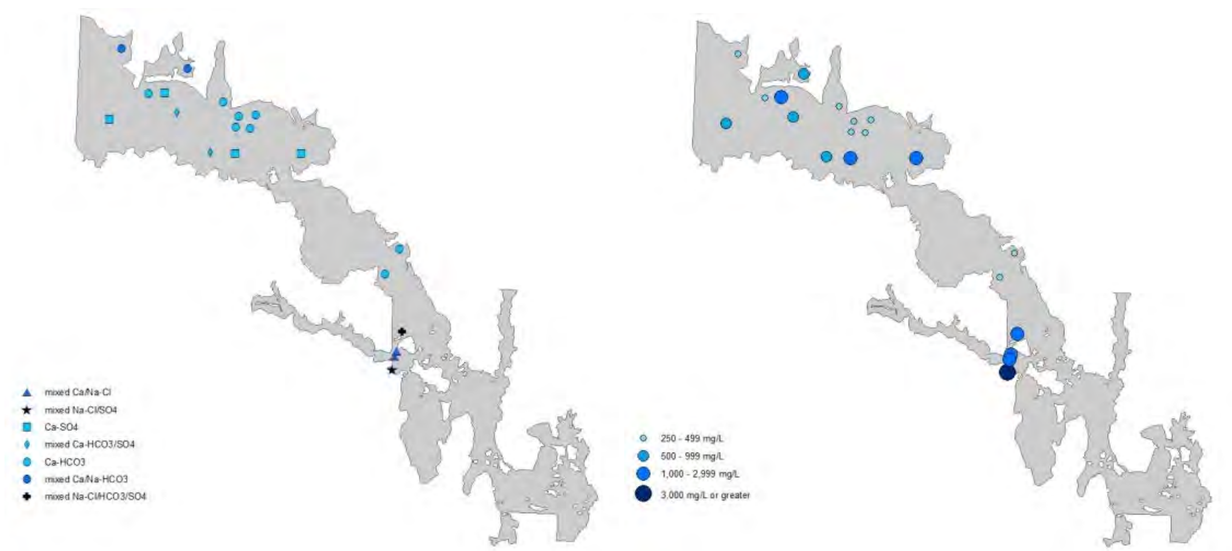

Figure 41. Distribution of water types (left) and TDS concentrations (right) in the NFRR.

Fluoride and silica concentrations were low. Sodium was present at moderately low levels; potassium was present in moderate concentrations. There were moderate levels of bromide, chloride, and magnesium driven by the high levels at sites near the Elm Fork. Calcium and sulfate concentrations were high, due to high levels at sites near the Elm Fork and at some western sites that overlie bedrock with large amounts of mineral salts and gypsum.

Nutrients in the aquifer reflect low levels of phosphorus, no detected ammonia and locally elevated levels of nitrate. Nitrate content ranged from 0.83-19.4 mg/L with mean and median concentrations of 8.29 mg/L and 7.95 mg/L, considered above natural levels.

The NFRR detected low levels of metals and trace elements. The following were not detected: aluminum, antimony, beryllium, cadmium, chromium, cobalt, lead, mercury, nickel, and silver. Copper, iron, manganese, and molybdenum were rarely detected but present at low concentrations when present; selenium was rare but at moderate concentrations when detected. Other trace elements and metals in the aquifer were detected at low concentrations and include arsenic, barium, boron, 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 NFRR had few 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 NFRR water quality, see Appendix H.

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	11	--
Nitrate	7	--	--
Chloride	--	3	--
Sulfate	--	7	--

Groundwater Level Measurements

The historical network had 74 wells with measurements. About 30 wells make up the most recent configurations, some with records dating to 1976 (Figure 42). The baseline network incorporated 26 wells from the NFRR's historical groundwater level network to continue these long-term records.

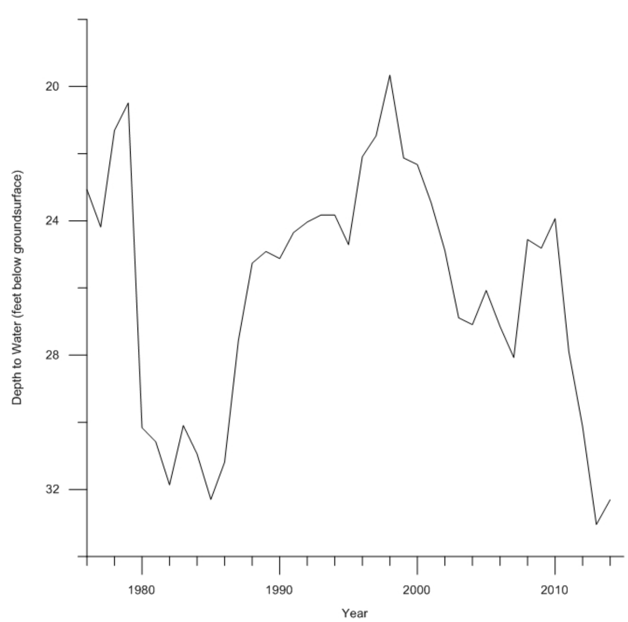

Figure 42. Average NFRR water level over period of record prior to GMAP implementation (1976-2014).

A baseline groundwater level network of 43 wells was implemented in July-August 2014. Measurements of depth to groundwater made during baseline water quality sampling ranged from 10.6-113.2 feet with a mean of 36.64 feet. The total depth of wells used in the network ranged from 29-210ft, averaging 71.91 feet. Thirty-eight (38) of the 43 wells in the NFRR baseline water level network have been incorporated into a trend network. Though fluctuation in alluvial and terrace aquifers is normal due to their sensitivity to use and climate, the sustained drought in the region over the last five years is reflected in water levels that have declined an average 10.45 feet in NFRR wells (2010-2015).

Ogallala-Northwest Aquifer

The Tertiary Ogallala Aquifer is part of the regional High Plains Aquifer 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 43). 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 43. 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 44). 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 I of this report.

Figure 44. 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 most recent network configurations. Many of these have a period of record of more than 30 years (Figure 45).

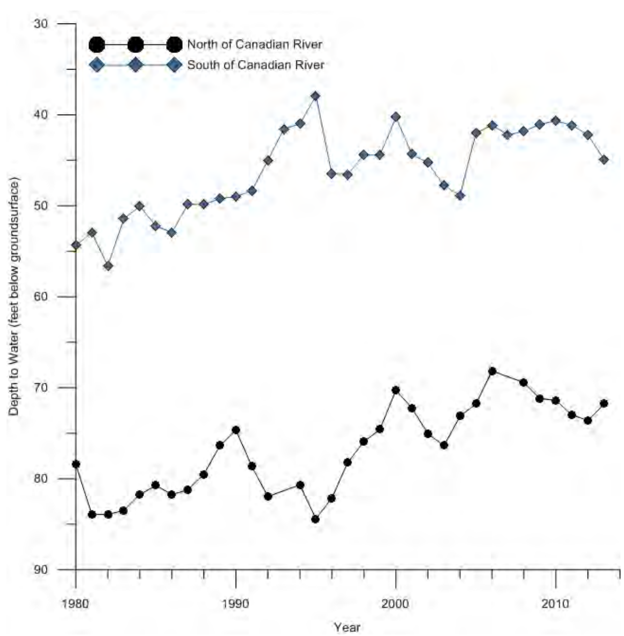

Figure 45. Average OGLL-NW water levels over period of record prior to GMAP implementation (1980-2013).

A baseline groundwater level network comprising 49 wells was implemented in August-September 2013. The baseline network incorporated 12 wells from the aquifer's historical groundwater level network to continue these long-term records. Measurements of depth to groundwater made during baseline water quality sampling in 2013 ranged from 7.91 to 175.2 ft with a mean of 77.02 ft. The total depth of wells used in the network ranged from 30-340 feet averaging 166 feet. Thirty (30) of the 49 wells in the baseline network have been incorporated into the trend network. 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 46). The two periods reflecting rising groundwater levels correspond in part with above average rainfall for the state. Since 2010, the water level has dropped another 3.5 feet at this site.

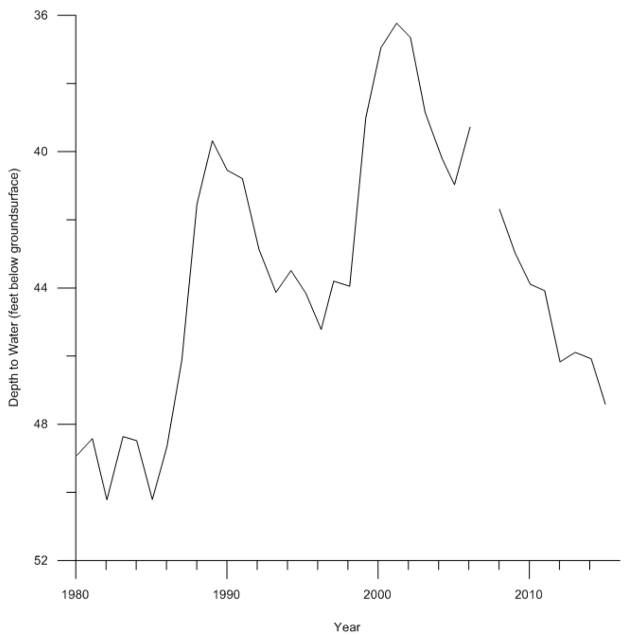

Figure 46. Groundwater level hydrograph of a record in OGLL-NW, Ellis County (1980-2015).

Average water levels in the OGLL-NW wells have dropped 5.15 feet in the last five years (2010-2015); an average 5.09 feet in wells north of the Canadian River and 5.35 feet in wells south. The new GMAP trend network has recorded the wells north of the Canadian River declining an average 0.33 ft and wells south declining an average 0.83 ft over the last year (2014-2015). A continuous water level recorder was installed in an Ellis county well during November 2013 to record hourly depth to water measurements (Figure 47).

Figure 47. Location of the continuous water level recorder (blue circle) against the entire OGLL-NW water level network.

Rush Springs Aquifer

The Rush Springs Aquifer, hereafter shortened to RSPG, located in west-central Oklahoma, underlies portions of Woodward, Dewey, Custer, Blaine, Washita, Caddo, and Grady counties (Figure 48). 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.

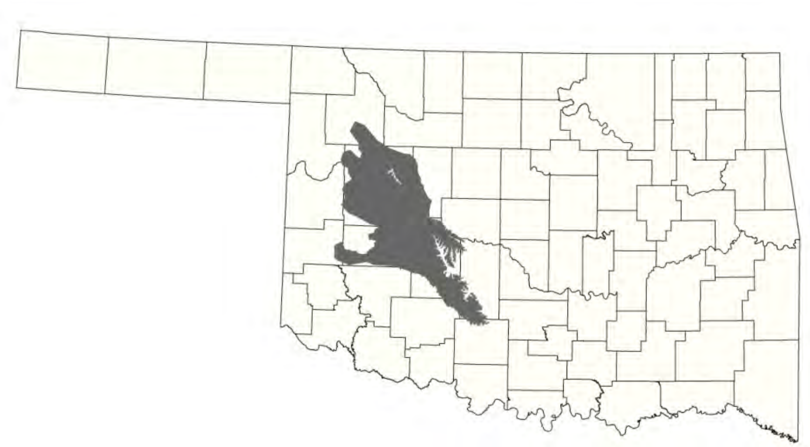

Figure 48. Location and extent of the RSPG.

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 49). 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 J of this report.

Figure 49. 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 more recent network configurations (Figure 50). Many of these older sites have nearly 40 years of record but with unfortunate interruptions in measurement.

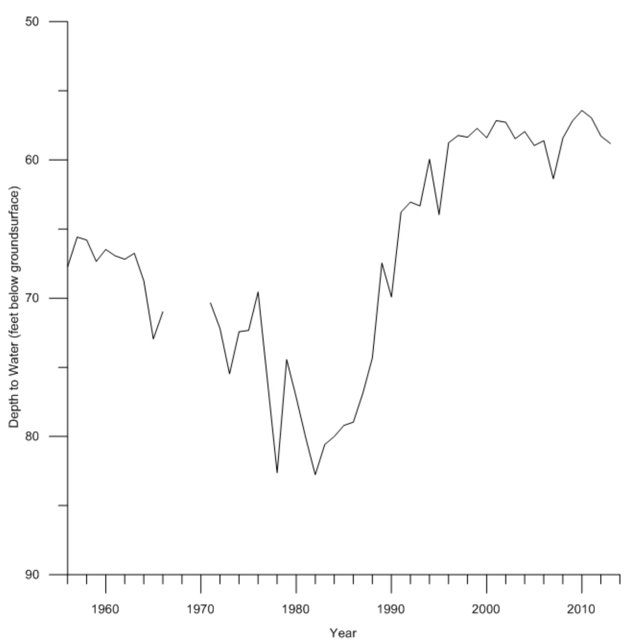

Figure 50. Average RSPG water levels over period of record prior to GMAP implementation (1976-2013).

A baseline groundwater level network comprising 104 wells was implemented in September-October 2013. Some wells have intermittent records spanning 50 years, so 69 historical wells were incorporated in the RSPG's baseline water level network to continue long-term measurement records (Figure 51).

Baseline water level measurements made during 2013 reflected groundwater level depths ranging from 7.75 to 196.6 feet, with a mean depth to water of 62.44 feet. The total depth of wells used in the network ranged from 30-425 feet, averaging 211 feet. Sixty-nine (69) of the 104 wells in the baseline network have been incorporated into the trend network.

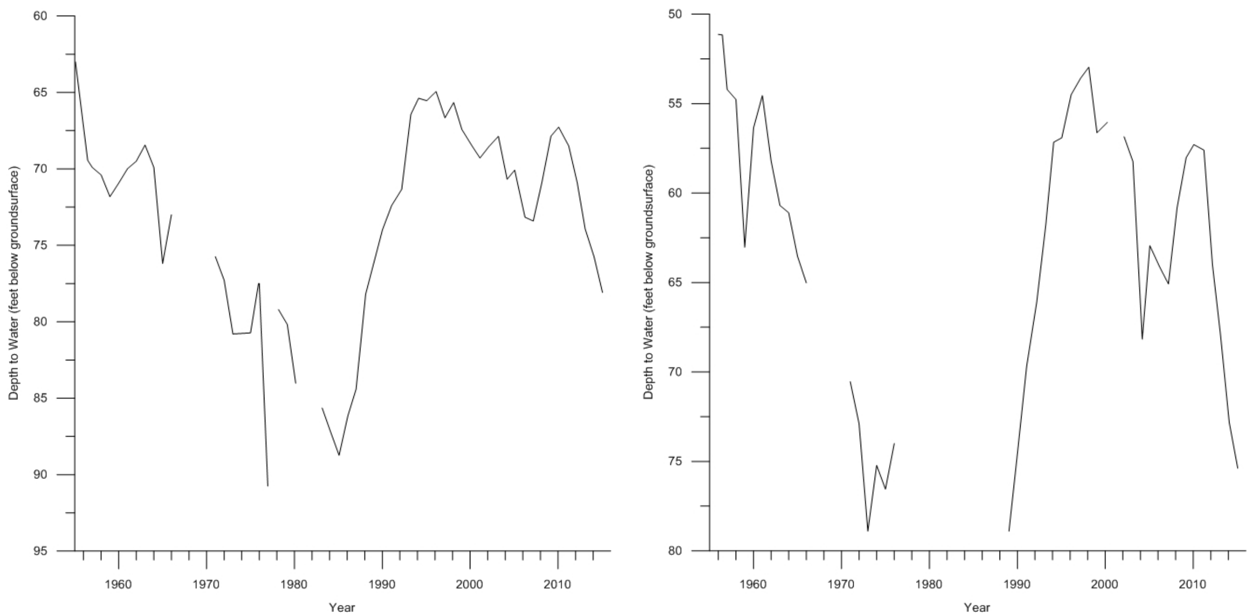

Figure 51. Groundwater level hydrographs for two of the longest RSPG records, Caddo County (1955-2015; left) and Caddo County (1956-2015; right).

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. In contrast, the most recent five year interval shows that water levels have been on the decline in RSPG wells, dropping an average 7.32 feet (2010-2015). The new GMAP trend network has recorded the average water level dropping in RSPG wells by 1.92 ft over the last year (2014-2015). Water levels in the RSPG are currently being monitored by several continuous water level recorders deployed by the OWRB for a separate hydrologic study (Figure 52).

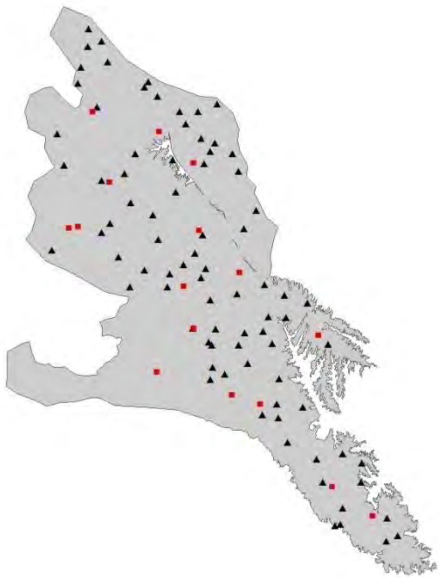

Figure 52. Location of continuous water level recorders (red squares) in a current OWRB hydrologic study against the entire RSPG GMAP water level network.

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 53).

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.

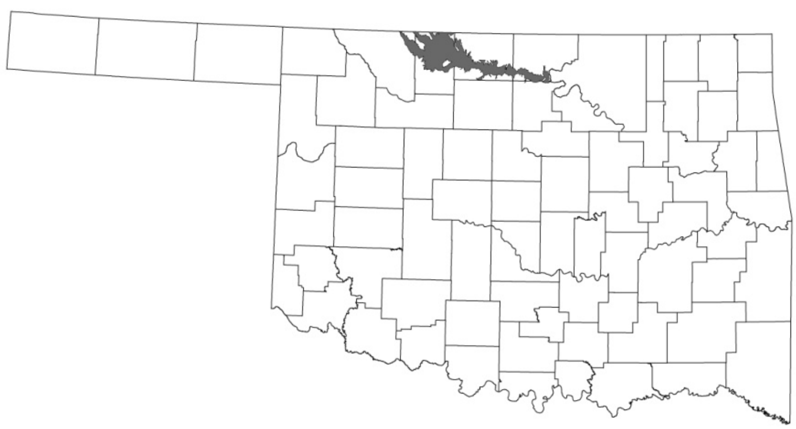

Figure 53. Location and extent of the SFAR.

The aquifer is located within the state's Upper Arkansas Planning Region and Oklahoma's North Central Climate Division, which averages 58.2°F and 28.65 inches of precipitation annually. Recharge of the aquifer is mostly a result of infiltration of precipitation, with an estimated recharge rate of 2.3 inches per year. Groundwater naturally discharges into the river and the Great Salt Plains Lake, as well as through evapotranspiration. The SFAR has an aerial extent of 2,209 km^2 and stores 2.18 million acre-feet of water. Well yields range from 100-500 gallons per minute; hydraulic conductivity is estimated to range from 55-500 feet per day. The Salt Fork of the Arkansas is designated by the OWRB as having a very high vulnerability level.

Groundwater in this aquifer is mainly used for municipal supply and irrigation, along with agricultural and domestic purposes. The OWRB has on file more than 1,930 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 169 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 42,555 acre-feet of water per year. The maximum withdrawal rate from the SFAR is 2 acre-feet per acre per year.

Data Collection Results

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 54).

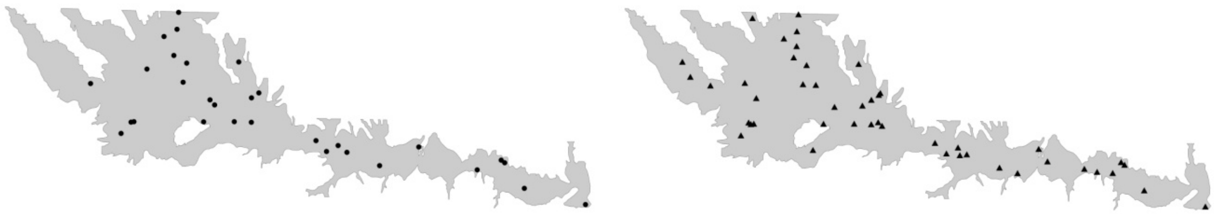

Figure 54. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFAR in 2014.

Water Quality

Overall, this aquifer contains water of fair quality. Mineral content was moderate-high. Groundwater in the aquifer was very hard and had high alkalinity, averaging 370 mg/L and 315 mg/L, respectively. Mean total dissolved solids (TDS) was moderately high at 657 mg/L; it ranged from 86-1470 mg/L with a median concentration of 552 mg/L. Specific conductance averaged 1148 µS/cm and pH was 7.09. Of note is a small area to the northeast of the Salt Plains Reservoir that exhibits lower mineralization than the aquifer as a whole. The primary water quality concern in the aquifer is locally elevated salts due to the natural brines and salt plains in the area.

The piper plot of SFAR data depicts primarily bicarbonate water with a mix of sodium and/or calcium cations (Figure 55). Twenty-six percent (26%) of sites had calcium/sodium-bicarbonate, 16% had calcium-bicarbonate, 13% had sodium-bicarbonate, and 13% had sodium-chloride/bicarbonate water. Various other mixed water types were also present. The spatial distributions of water types and TDS are shown in Figure 56.

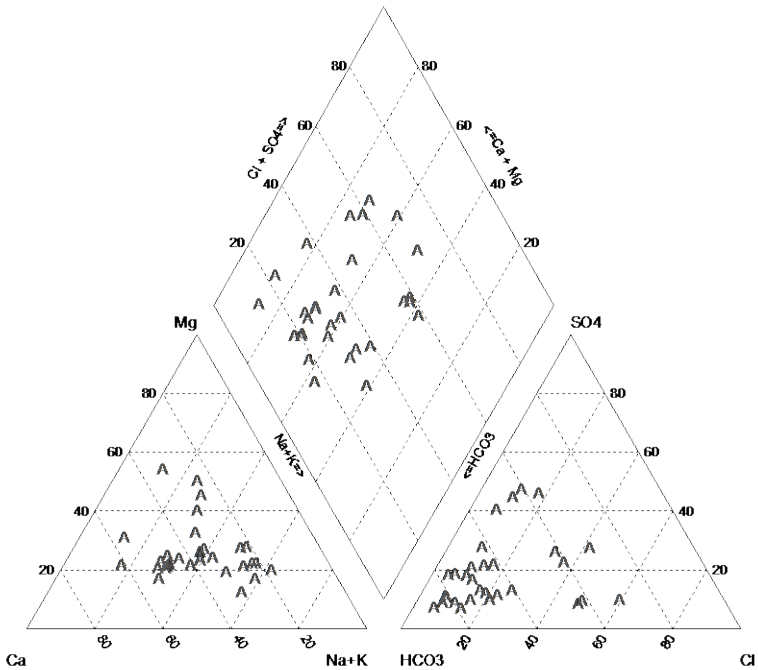

Figure 55. Piper plot diagram of constituents of the SFAR.

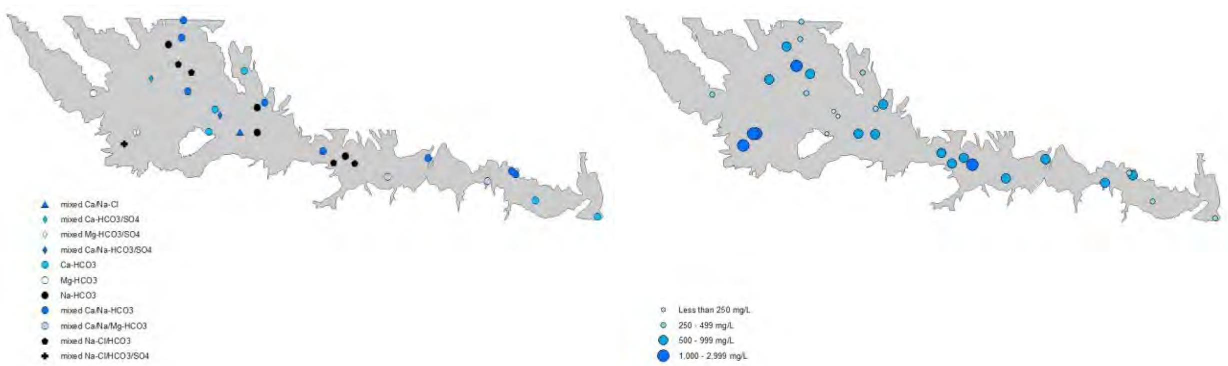

Figure 56. Distribution of water types (left) and TDS concentrations (right) in the SFAR.

Mineral constituents were moderately high. Fluoride and silica concentrations were low in the aquifer. Sodium, bromide, calcium, chloride, potassium, and magnesium were present at moderate levels, and sulfate content was generally low, except for locally elevated levels. Discharge of saline water from the Salt Plains Reservoir along with discharge or river feed from the salt flats (evaporites) to the Salt Fork of the Arkansas are potential sources of the locally moderate to high chloride and bromide content in the SFAR.

Nutrients in the aquifer reflect low levels ammonia and moderate levels of phosphorus, along with locally elevated levels of nitrate. Nitrate content was moderate and ranged from non-detectable to 20 mg/L with mean and median concentrations of 5.03 mg/L and 4.14 mg/L, above what would be considered background levels.

The SFAR had low levels of metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, chromium, cobalt, lead, mercury, nickel, and silver. Copper and molybdenum were present at low concentrations but were rarely detected. Iron and manganese were rarely detected but were at high concentrations when present with a few sites exceeding EPA thresholds. Selenium was rarely detected and was at moderate concentrations when present. Other trace elements and metals detected at low concentrations in the aquifer include arsenic, barium, boron, 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 SFAR had several 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 SFAR water quality, see Appendix K.

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

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	18	--
Nitrate	5	--	--
Chloride	--	5	--
Sulfate	--	4	--
Arsenic	1	--	--
Iron	--	4	--
Manganese	--	6	3
Uranium	1	--	--

Groundwater Level Measurements

The historical network had measurements on 26 wells, with about 20 wells in the most recent network configurations (Figure 57). Several SFAR wells have ten years of recorded measurements.

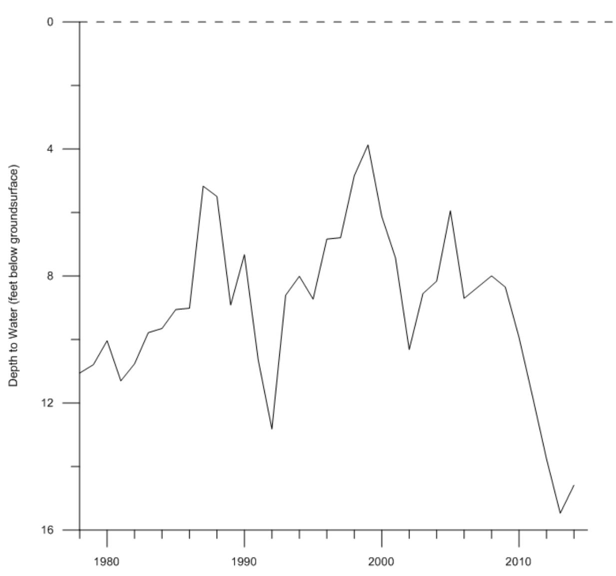

Figure 57. Average SFAR water level over period of record prior to GMAP implementation (1978-2014).

A baseline groundwater level network comprising 46 wells was implemented in July 2014. The baseline network incorporated 18 wells from the aquifer's historical groundwater level network. Measurements of depth to groundwater made during baseline water quality sampling ranged from 0.38 ft above ground surface to 30.2 ft below with a mean of 15.56 ft. The total depth of wells used in the network ranged from 24-97 ft, averaging 44.42 feet. Thirty-five (35) of the 46 wells in the baseline water level network have been incorporated into the trend network. Over the last five years, water levels have declined in SFAR wells an average 4.35 feet (2010-2015). A continuous water level recorder was installed in Grant County (Figure 58) in December 2014 where depth to water in feet below land surface is being recorded in hourly increments.

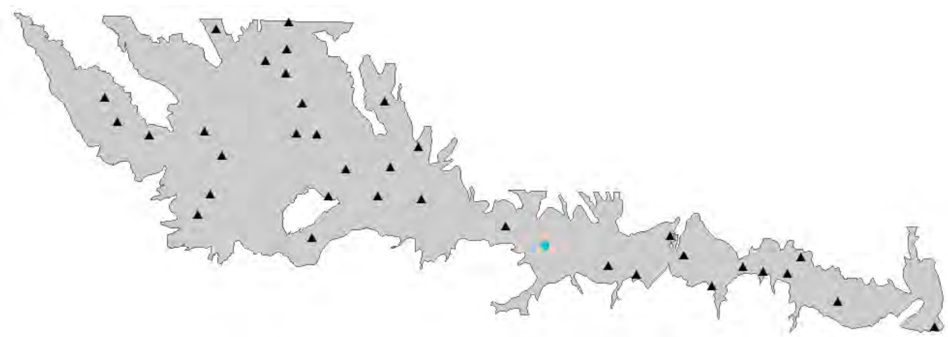

Figure 58. Location of the continuous water level recorder (blue circle) against the entire SFAR water level network.

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 59).

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.

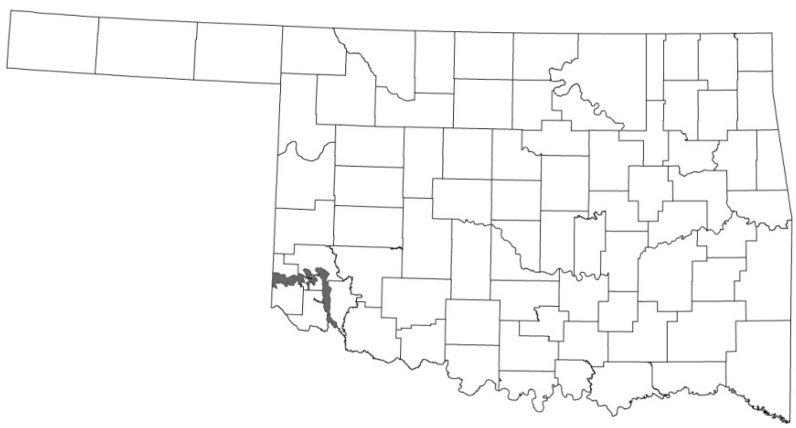

Figure 59. Location and extent of the SFRR.

The aquifer is encompassed by the state’s Southwest Planning Region and Southwest Climate Division. Precipitation averages 27.62 inches and temperatures average 61.1°F annually. The SFRR has an aerial extent of 754.3 km^2. Due to the limited number of studies on this minor aquifer, many aspects of storage and yield are unavailable.

Groundwater in this aquifer is mainly utilized for agricultural purposes. The OWRB has on file over 370 well construction reports from Oklahoma’s licensed water well drilling firms, documenting water well drilling and completion activities in the SFRR. As of December 2014, 89 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 23,724 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 2 acre-feet per acre per year. The Salt Fork of the Red River is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 60).

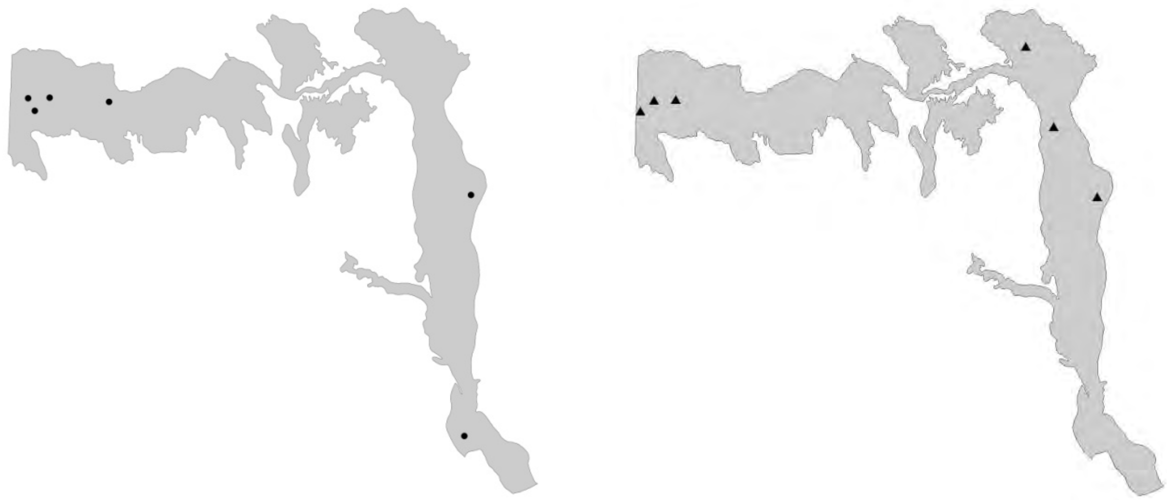

Figure 60. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the SFRR in 2014.

Water Quality

The SFRR is a minor aquifer, and the sample size for the water quality network is small. A limited number of wells in the aquifer, along with difficulties finding suitable wells and acquiring landowner permission, resulted in the uneven spatial distribution. This smaller sample size also resulted in many averages that were much higher than the median concentrations. With this caveat, this aquifer contains water of fair but variable quality. Mineral content was moderate. Groundwater in the aquifer was extremely hard and moderately alkaline, averaging 787 mg/L and 229 mg/L, respectively. Mean total dissolved solids (TDS) was high at 1753 mg/L, although it ranged widely from 303-6080 mg/L and had a more moderate median concentration of 403 mg/L (Figure 62). Specific conductance also varied widely with a very high average of 2340 µS/cm, and pH was 7.03.

The piper plot of SFRR data depicts one cluster of calcium-bicarbonate water and another cluster of mixed sodium-sulfate waters (Figure 61). The spatial distribution of water types shows that these clusters correspond to the upstream and downstream legs of the river (Figure 62).

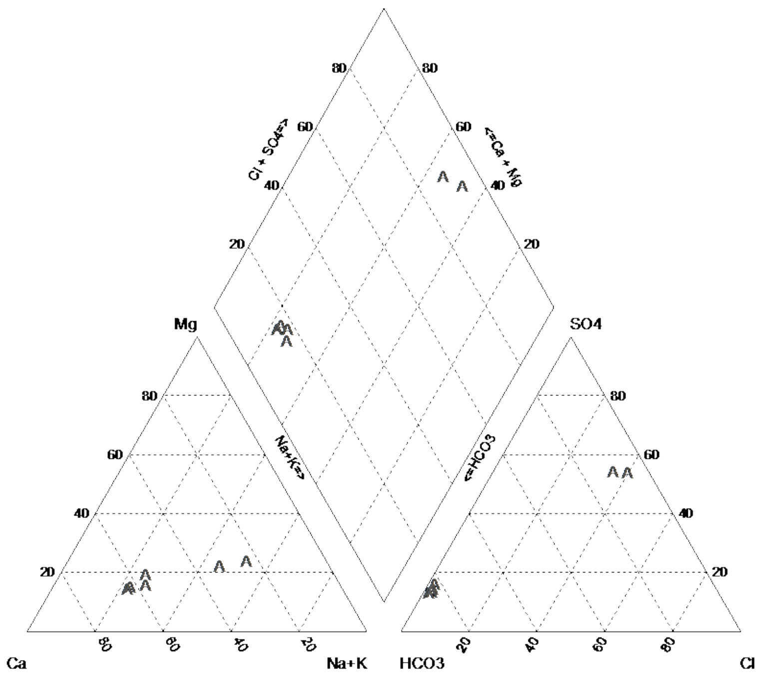

Figure 61. Piper plot diagram of constituents of the SFRR.

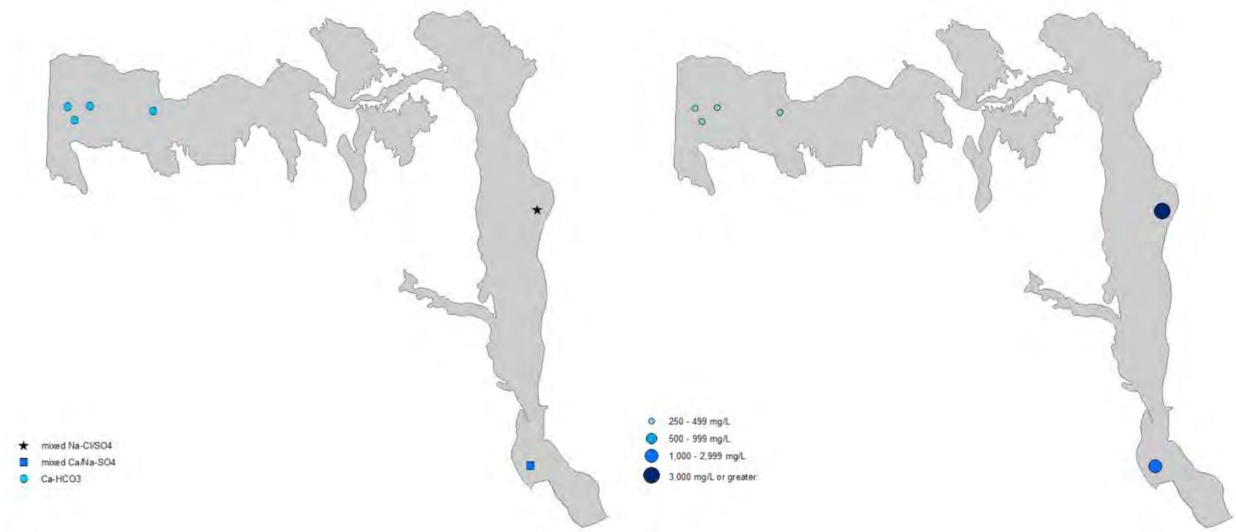

Figure 62. Distribution of water types (left) and TDS concentrations in the SFRR.

Minerals varied depending on what leg of the river the sites were located in. Fluoride and silica were at low levels. Bromide, calcium, potassium, sodium, and magnesium were present in high concentrations in the downstream sites and more moderate to low in the upstream sites. Sulfate and chloride were only detected in the downstream leg of the SFRR and were high when present.

Nutrients in the aquifer reflect low levels of phosphorus, no detected ammonia and elevated levels of nitrate. Nitrate content ranged from 6.26-15.1 mg/L with high mean and median concentrations of 10.14 mg/L and 9.73 mg/L, well above what would be considered natural background levels.

The SFRR had generally low levels of metals and trace elements. The following were not detected: aluminum, antimony, beryllium, cadmium, chromium, cobalt, lead, mercury, nickel, and silver. Copper, molybdenum, and selenium were rarely detected and low when present; iron and manganese were rarely detected but moderately high when present. Other trace elements and metals detected at low levels in the aquifer include arsenic, barium, boron, 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 SFRR had some constituents exceed these thresholds. Table 9 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the SFRR water quality, see Appendix L.

Table 9. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the SFRR.

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	2	--
Nitrate	3	--	--
Chloride	--	2	--
Sulfate	--	2	--
Iron	--	1	--
Manganese	--	2	1
Selenium	1	--	--

Groundwater Level Measurements

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

A baseline groundwater level network comprising 6 wells was implemented in August 2014 for the SFRR. Measurements of depth to groundwater made during baseline quality sampling ranged from 8.15-69.8 ft with a mean of 40.83 ft. The total depth of wells used in the SFRR network ranged from 40-230 ft, averaging 100.4 ft. Five (5) of the 6 wells in the baseline water level network have been incorporated into the trend network, along with one additional for a total of 6.

Tillman Terrace Aquifer

The Tillman Terrace aquifer, underlying part of Tillman County in southwestern Oklahoma, is an alluvial & terrace aquifer (Figure 63). 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 63. Location and extent of the TILL.

The aquifer straddles the state's Southwest and Beaver-Cache Planning Regions and lies within Oklahoma's Southwest Climate Division, which averages 27.62 inches of precipitation and 61.1°F annually. Recharge to the aquifer is estimated to be 2.9 inches per year, mainly as result of infiltration of precipitation although subsurface flow from streams also contributes. Natural discharge occurs as base flow to streams, evapotranspiration, and springs and seeps along the eastern boundary. The TILL has an aerial extent of 751.3 km^2 and stores 1.28 million acre-feet of water. Well yields range from 200-500 gallons per minute; hydraulic conductivity is estimated to be 117 feet per day.

Groundwater in this aquifer is primarily used for irrigation purposes but also supplies water for municipal, mining, agriculture, stock, and domestic purposes. The OWRB has on file more than 1,260 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the TILL. As of December 2014, 422 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 50,936 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 1 acre-foot per acre per year. The Tillman Terrace is designated by the OWRB as having a high vulnerability level.

Data Collection Results

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 64).

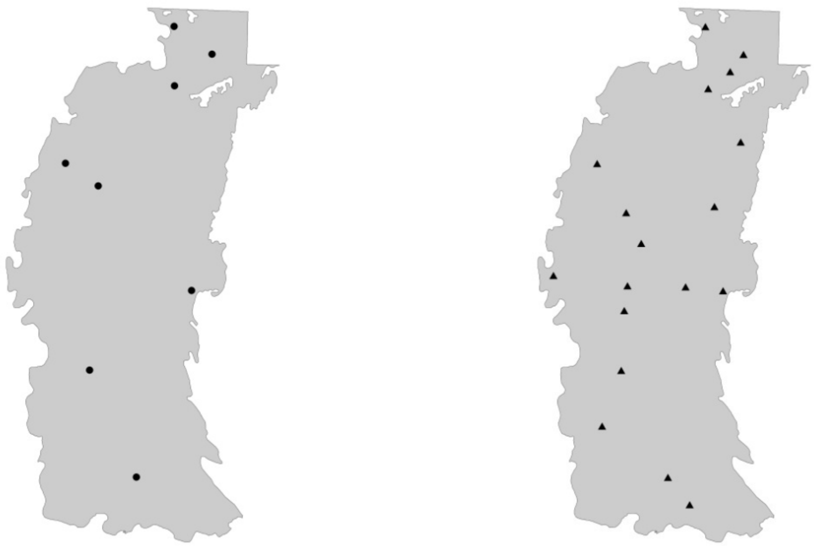

Figure 64. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the TILL in 2014.

Water Quality

Overall, this aquifer contains water of fair-poor quality. Mineral content was high. Groundwater in the aquifer was very hard and highly alkaline, averaging 451 mg/L and 327 mg/L, respectively. Mean total dissolved solids (TDS) were high at 1022 mg/L, with a range of 395-3090 mg/L and a median concentration of 699.5 mg/L. Mean specific conductance was also high at 1709 µS/cm, and pH was 7.09. The primary water quality concerns in the aquifer are nitrate, chloride, sodium, and TDS.

The piper plot of TILL data depicts mixed water types (Figure 65). Forty-three percent (43%) of sites had sodium-chloride/bicarbonate waters. Other water types present were primarily bicarbonate with a mix of calcium, sodium, and/or magnesium. The spatial distributions of water types and TDS are shown in Figure 66.

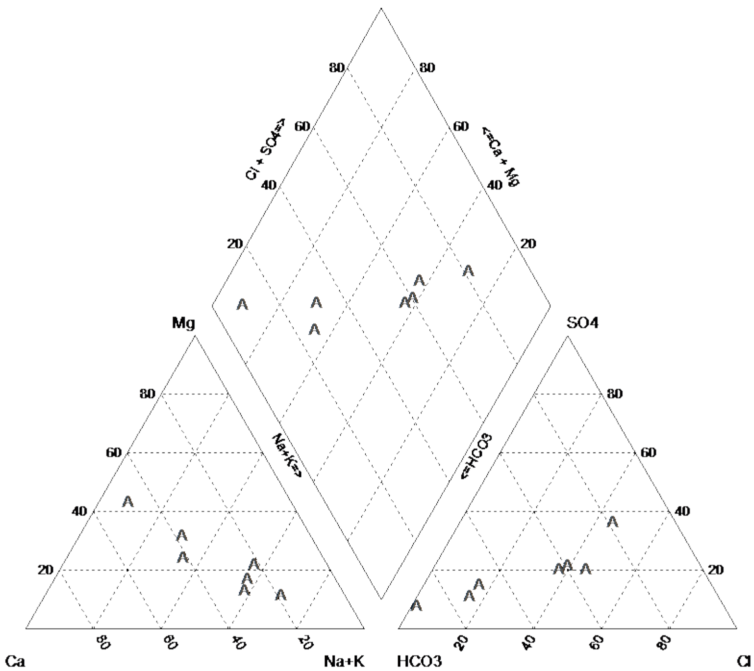

Figure 65. Piper plot diagram of constituents of the TILL.

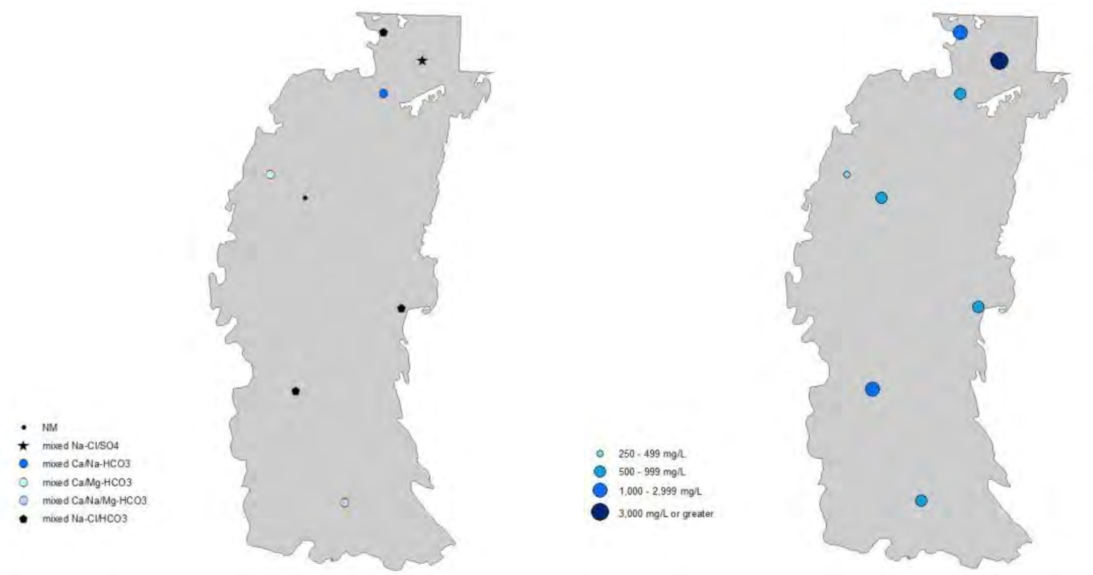

Figure 66. Distribution of water types (left) and TDS concentrations (right) in the TILL.

Low concentrations of fluoride and silica were present in the TILL. Sodium, magnesium, and potassium were detected at moderate concentrations; chloride and sulfate were present in moderately high concentrations; and, bromide and calcium were detected at high concentrations.

Nutrients in the aquifer reflect low levels of phosphorus, no detected ammonia, and elevated levels of nitrate. Nitrate content ranged widely from 0.1-24.5 mg/L with high mean and median concentrations of 13.89 mg/L and 13.85 mg/L that are well above what would be considered background levels.

The TILL had few metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, and silver. Arsenic, barium, boron, uranium, vanadium, and zinc were present in low concentrations. Iron and manganese were rarely detected.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The TILL had few constituents exceed these thresholds. Table 10 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the TILL water quality, see Appendix M.

Table 10. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the TILL.

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	7	--
Nitrate	6	--	--
Chloride	--	3	--
Sulfate	--	1	--
Iron	--	1	--
Manganese	--	1	0

Groundwater Level Measurements

There were 35 measured wells in the historical network, with 12-15 in the most recent network configurations (Figure 67).

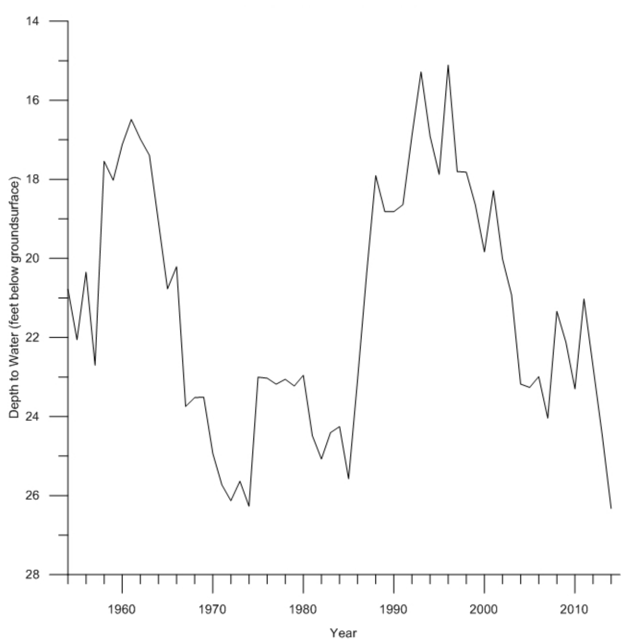

Figure 67. Average TILL water level over period of record prior to GMAP implementation (1955-2014).

A baseline groundwater level network of 17 wells was implemented in the TILL 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 68). Measurements of depth to groundwater made during baseline water quality sampling ranged from 9.43-44.97 ft with a mean of 27.01 ft. The total depth of wells used in the network ranged from 30-70 ft, averaging 50.92 ft. Fifteen (15) of the 17 wells in the baseline water level network have been incorporated into a trend network. The average water level has dropped 4.1 feet in TILL wells over the last 5 years (2010-2015).

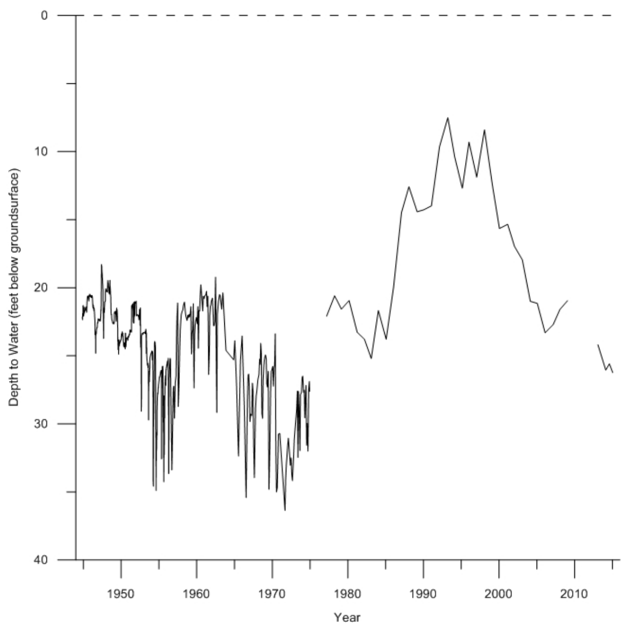

Figure 68. Groundwater level hydrograph for the longest TILL record, Tillman County (1944-2015).

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 69). 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).

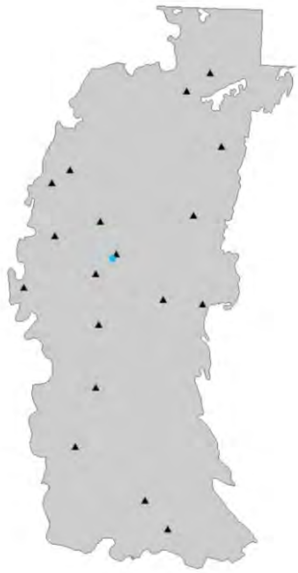

Figure 69. Location of the continuous water level recorder (blue circle) against the entire TILL water level network.

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 70).

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.

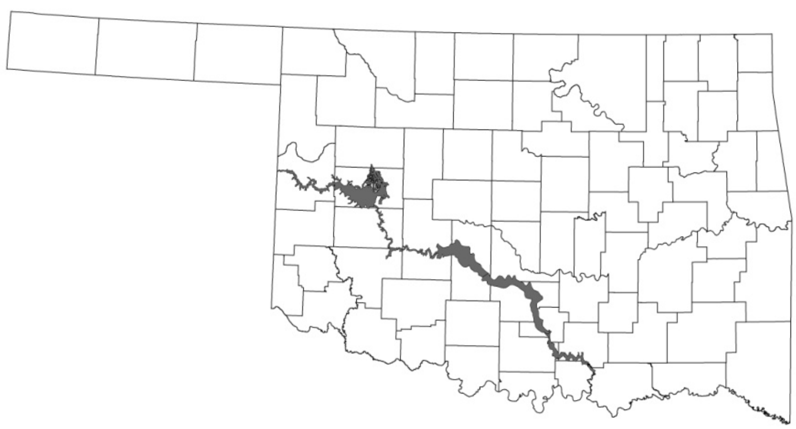

Figure 70. Location and extent of the WASH.

The aquifer is encompassed by the state's West Central and Lower Washita Planning Regions. It flows from Oklahoma's West Central Climate Division (with averages of 59.0°F and 26.07 inches of precipitation annually), through the northern part of the Southwest Division (averages 61.1°F and 27.62 in), through the southern part of the Central Division (averages 60.2°F and 34.11 in), and into the South Central Division (averages 62.2°F and 37.54 in). Recharge of the aquifer comes mostly from precipitation and runoff, with an estimated recharge rate of 2.65-4.41 inches per year. Natural discharge occurs through evapotranspiration and base flow to the river. The WASH has an aerial extent of 2,452 km^2 and stores 4.92 million acre-feet of water. Well yields range from 100-500 gallons per minute; hydraulic conductivity is estimated to be around 100 feet per day.

Groundwater in the WASH is utilized for municipal, industrial, and irrigation purposes. The OWRB has on file more than 3,930 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 2014, 265 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 128,877 acre-feet of water per year. The maximum withdrawal rate from the aquifer is 1-1.5 acre-feet per acre per year, dependent upon which reach the well is located in. The Washita is designated by the OWRB as having a very high vulnerability level.

Data Collection Results

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 71).

Figure 71. Baseline water quality sites sampled (left; circles) and water level sites (right; triangles) measured in the WASH in 2014.

Water Quality

Overall, this aquifer contains water of fair quality with moderately high mineral content. Groundwater in the aquifer was extremely hard and highly alkaline, averaging 1033 mg/L and 298 mg/L, respectively. Mean total dissolved solids (TDS) was high at 1553 mg/L, with a range of 138-3650 mg/L and a high median concentration of 990 mg/L. Mean specific conductance was also high at 1901 µS/cm, and pH was 7.18. 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). Water in the west has higher hardness, TDS, and overall mineralization than water in the rest of the aquifer. Reach 1 of the WASH overlies the Cloud Chief formation which is composed of significant amounts of dolomite and gypsum that may contribute to these higher detections. The primary water quality concern in the aquifer is the overall high mineralization, along with locally elevated iron and manganese (particularly in Roger Mills County and at the intersection of Grady, McClain, and Garvin counties).

The piper plot of the WASH data depicts primarily calcium-sulfate water (35%), calcium-bicarbonate water (16%), and mixed calcium/magnesium-bicarbonate water (16%). Other water types present include magnesium-bicarbonate, sodium-bicarbonate and other mixed water types (Figure 72). The spatial distribution of water types shows that sulfate waters dominate the western reaches of this aquifer, while bicarbonate waters predominate in the central reaches (Figure 73).

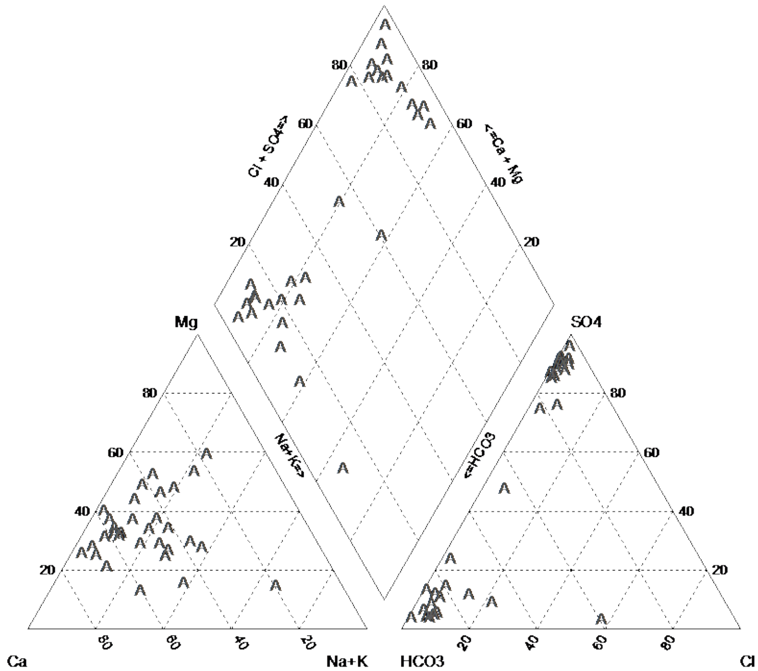

Figure 72. Piper plot diagram of constituents of the WASH.

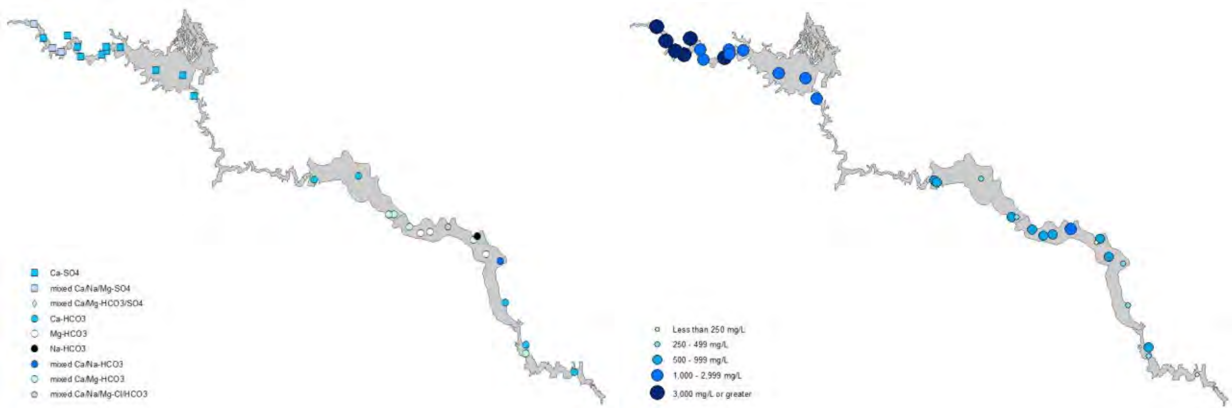

Figure 73. Distribution of water types (left) and TDS concentrations (right) in the WASH.

Low concentrations of chloride, fluoride, potassium, silica, and sodium were detected. Of note is an area of slightly higher sodium and chloride in Roger Mills County. Bromide concentrations were moderate to high in most of the WASH with lower concentrations in Reach 1. Magnesium and calcium were detected in mainly moderate to high concentrations throughout most of the aquifer, but both had very high concentrations in Reach 1. Sulfate was also present at very high levels in Reach 1.

Nutrients in the aquifer reflect low levels of ammonia and nitrate. Nitrate content ranged widely from <0.05-18.7 mg/L with low mean and median concentrations of 2.33 mg/L and 0.88 mg/L, within what would be considered natural background levels. Moderate concentrations of phosphorus were present with an average of 0.082 mg/L.

The WASH had several metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, lead, mercury, nickel, and silver. Arsenic was present in low concentrations. Barium was present in low concentrations in the west with moderate levels in the rest of the aquifer, and boron was present in moderate concentrations in the west with lower levels in the other reaches. Chromium, copper, iron, molybdenum, selenium, uranium, vanadium, and zinc were rarely detected. Manganese and iron were present in moderate concentrations throughout the aquifer.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The WASH had several constituents exceed these thresholds. Table 11 summarizes the parameters and number of occurrences exceeding a drinking water standard. For more detailed statistics and figures on the WASH water quality, see Appendix N.

Table 11. Number of sites exceeding EPA Drinking Water Standards and Health Advisories in the WASH.

Parameter	>MCL	>SMCL	>Health Advisory
TDS	--	24	--
Nitrate	2	--	--
Chloride	--	1	--
Sulfate	--	15	--
Iron	--	10	--
Manganese	--	15	10
Uranium	1	--	--

Groundwater Level Measurements

Twenty (20) wells in this aquifer had historical measurements, with 8 in the most recent network configuration. 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 74). The baseline network incorporated 5 wells from the WASH's historical groundwater level network to continue these long-term monitoring records.

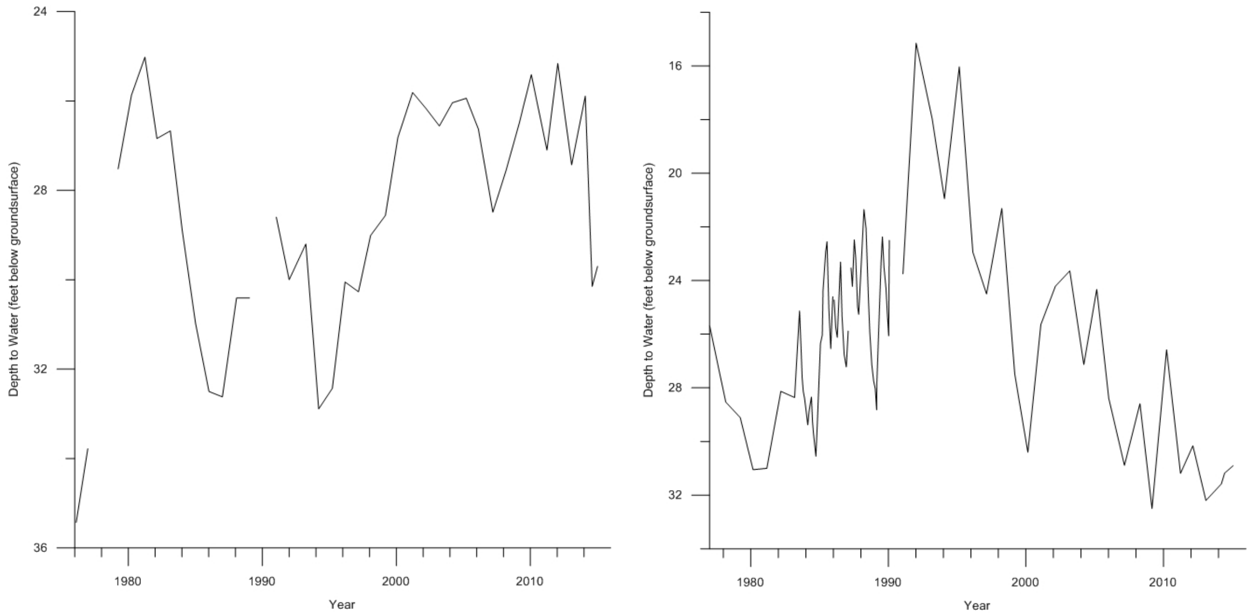

Figure 74. Groundwater level hydrographs for two of the longest WASH records, Roger Mills County (1976-2015; left) and Johnston County (1977-2015; right).

A baseline groundwater level network composed of 31 wells was implemented in July-August 2014. Measurements of depth to groundwater made during baseline water quality sampling ranged from 4.6-67.8 ft in sites located in the West Central and Southwest climate divisions with a mean of 21.16 ft; total depth was 28-190 ft in these western wells with an average 111.6 ft. In sites located in the Central and South Central climate divisions, depth to water ranged 11.31-60.08 ft with a mean of 29.51 ft; total depth was 45-110 ft in these central wells with an average 75.78 ft. Twenty-six (26) of the 31 wells in the baseline network have been incorporated into the trend network. Water levels have been declining over the last five years (2010-2015), as reflected in the above hydrographs. In the West Central climate division, average WASH water levels have dropped 5.39 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 6.27 ft. Water level in the WASH is currently being monitored by a continuous water level recorder deployed by the OWRB for a separate hydrologic study (Figure 75).

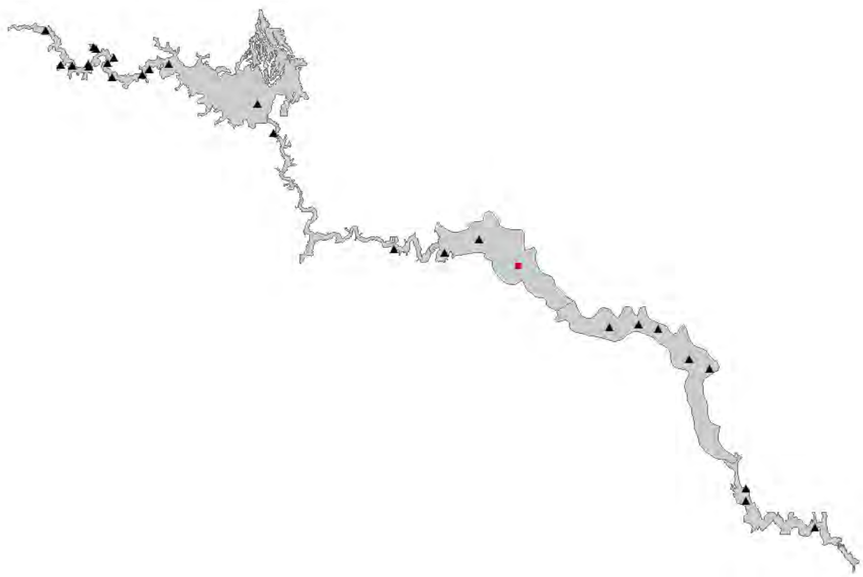

Figure 75. Location of continuous water level recorder (red square) in a current OWRB hydrologic study against the entire WASH GMAP water level network.

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 76). 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.

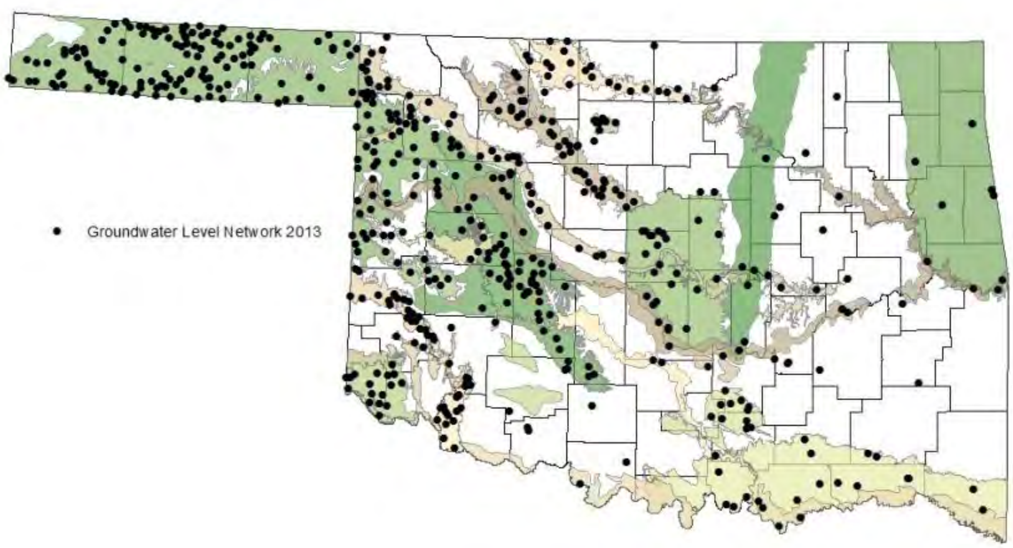

Figure 76. Historical groundwater level measurement sites in Oklahoma prior to the implementation of GMAP.

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. In the first two years of GMAP, 299 wells were measured for water level in the Group A aquifers and 224 wells were measured in the Group B aquifers.

Four hundred fifty-nine (459) of these Group A & B wells have been incorporated into the annual water level monitoring network, 248 of which are new additions to these aquifers that provide significantly improved spatial representativeness (Figure 77). Two hundred two (202) of the 459 wells have been placed into the seasonal trend network (measured tri-annually). An additional 258 wells were measured for water level across the state in aquifers not yet incorporated into GMAP, measurements for which are summarized below.

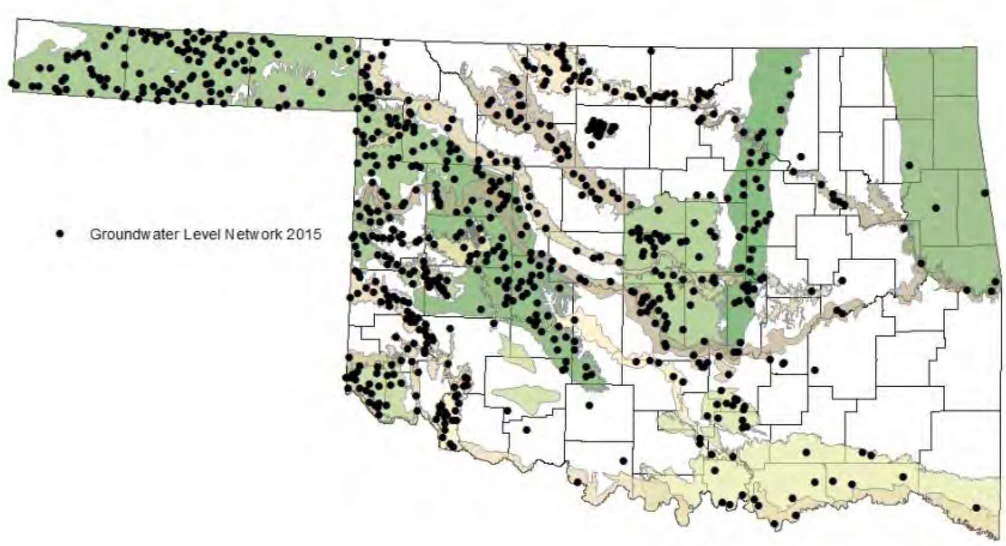

Figure 77. Groundwater level measurement sites after two years of GMAP implementation.

Water Level Measurement in the outcrop of the Antlers Aquifer

A baseline groundwater level network is scheduled for implementation in 2015. Seven (7) wells located in the outcrop of the Antlers, which is the major source of water for this aquifer, have depth to water measurements; four wells configure the most recent network. The average water level in wells located in the outcrop has been generally increasing through 2010, but water levels have declined 3.59 feet in the last five years (2010-2015; Figure 78).

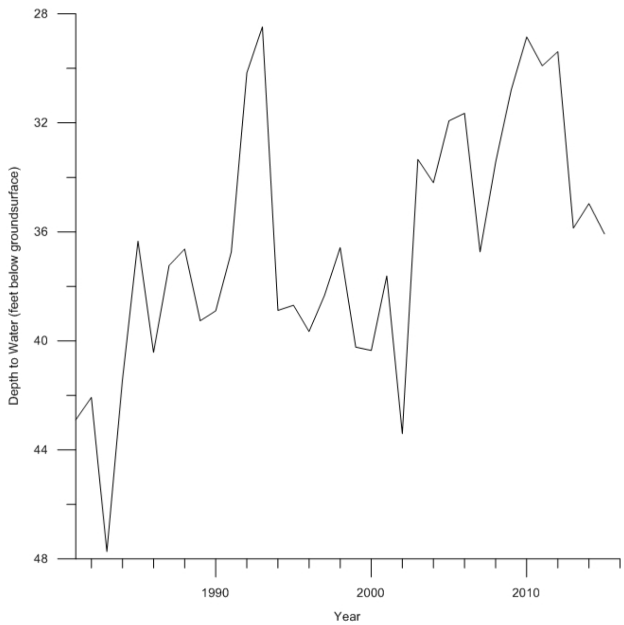

Figure 78. Average water level in the outcrop of the Antlers over period of record (1981-2015).

Water Level Measurement in the Arbuckle-Simpson Aquifer

A baseline groundwater level network is planned for implementation in 2015. Twelve (12) wells have depth to water measurements in this aquifer; ten (10) wells compose the most recent network configuration (Figure 79). The average water level in Arbuckle-Simpson wells has declined 19.48 feet during the last five years (2010-2015).

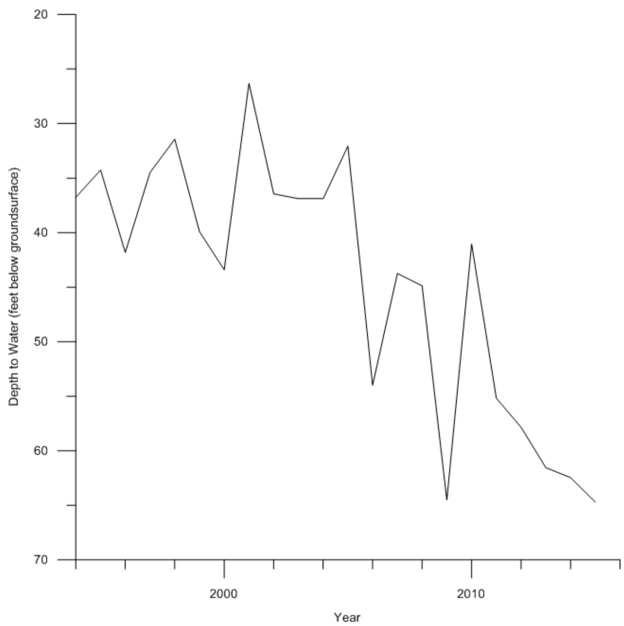

Figure 79. Average Arbuckle-Simpson water level over period of record (1994-2015).

Several wells in this aquifer have over 20 years of record, and one has over 30 years (Figure 80). The Arbuckle-Simpson Aquifer has three GMAP recorders that were installed January 2014, two in Pontotoc and one in Johnston County.

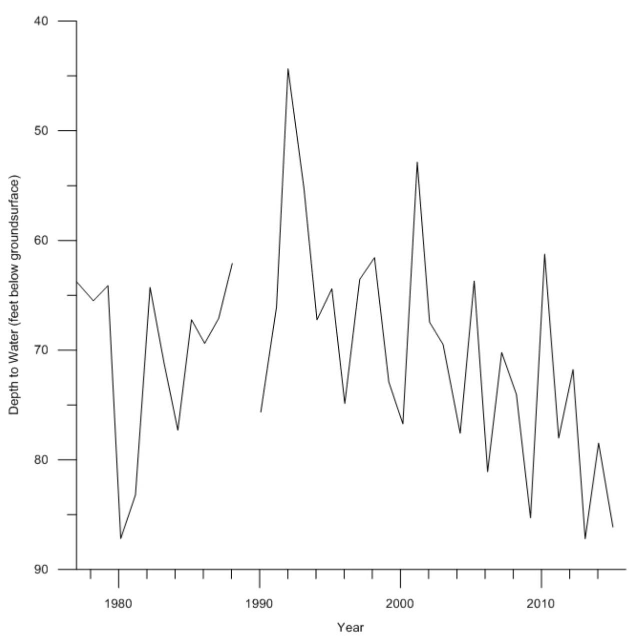

Figure 80. Groundwater level hydrographs for one of the longest Arbuckle-Simpson records, Pontotoc County (1977-2015).

Water Level Measurement in the Arbuckle-Timbered Hills Aquifer

A baseline groundwater level network is slated for implementation in 2015. No sites from the historical groundwater level network are located in this aquifer. Therefore, there are no wells with groundwater level measurements currently in the Arbuckle-Timbered Hills aquifer and all additions will be new to the program.

Water Level Measurement in the Beaver-North Canadian River Alluvial & Terrace Aquifer

A baseline groundwater level network is scheduled for implementation in 2015. Seventy-four wells (74) have depth to water measurements in this aquifer, with 31 wells in the most recent network configuration (Figure 81). The average water level in North Canadian River wells has dropped 4.8 ft over the last 5 years (2010-2015).This aquifer had two GMAP recorders installed in Okfuskee and Woodward counties during winter 2013.

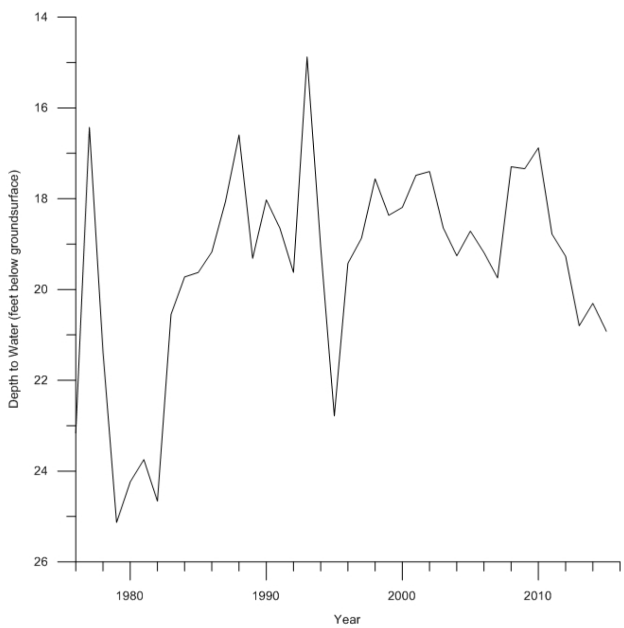

Figure 81. Average North Canadian water level over period of record (1976-2015).

Water Level Measurement in the Blaine Aquifer

A baseline groundwater level network is slated for implementation in 2015. Thirty-three wells (33) have depth to water measurements in the Blaine Aquifer, 20 of which were in the most recent configuration of the groundwater level network. The average water level in these wells has declined 27.04 feet in the past 5 years (2010-2015; Figure 82). This aquifer had a GMAP recorder installed during winter 2014.

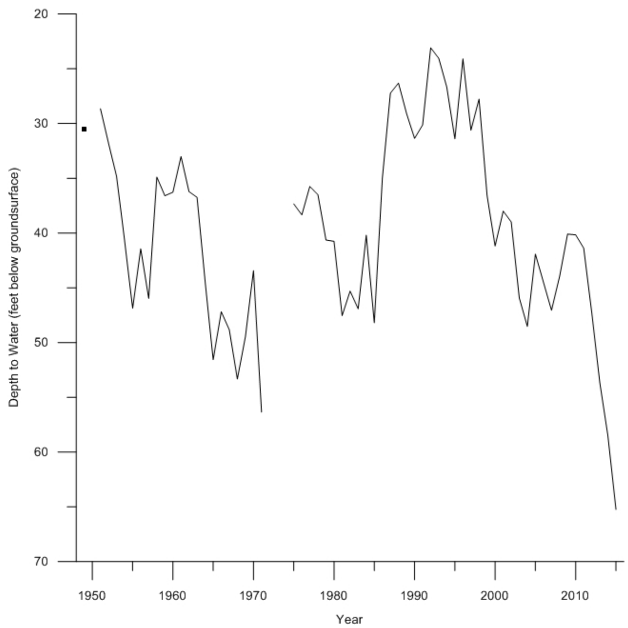

Figure 82. Average Blaine water level over period of record (1949-2015).

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 30 wells (Figure 83). Several wells in this aquifer have over 30 years of measurements.

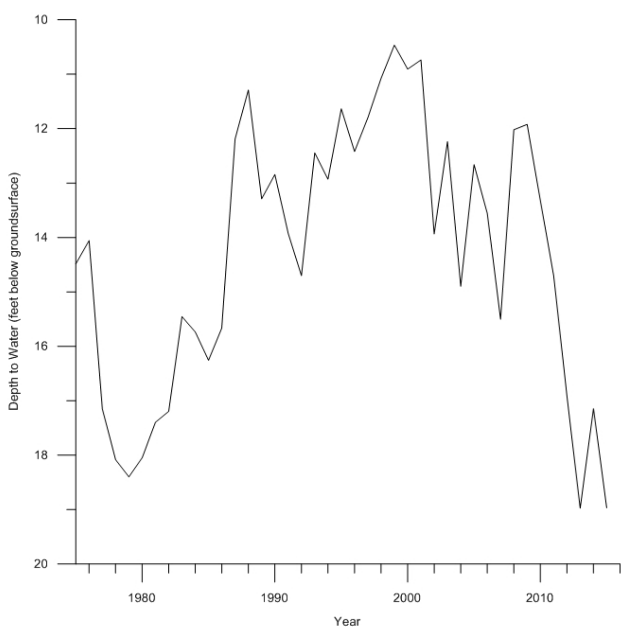

Figure 83. Average Cimarron River water level over period of record (1975-2015).

As depicted in the hydrograph, the average water level in Cimarron wells has declined an average 5.84 feet over the last five years (2010-2015). The Cimarron River Alluvial & Terrace Aquifer has two GMAP recorders in Woods and Logan counties, installed during December 2013.

Water Level Measurement in the Ogallala-Panhandle Aquifer

A baseline groundwater level network is planned for implementation in 2016. Four hundred wells (400) have depth to water measurements in this aquifer. The most recent network configuration consisted of 101 wells (23 in Cimarron Co, 58 in Texas Co, and 20 in Beaver Co). Figure 84 is a hydrograph of average water level depths for Texas and Cimarron Counties; due to variation in the Beaver County network of wells over time, a period of record hydrograph was not included.

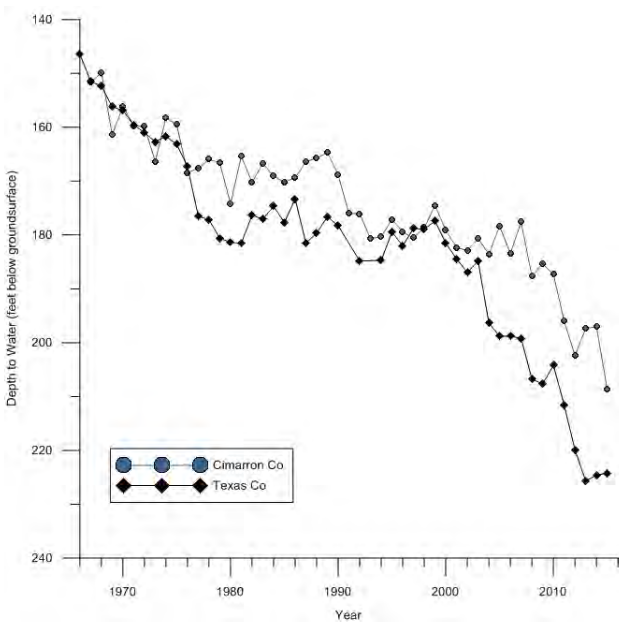

Figure 84. Average Ogallala-Panhandle water level over period of record, split by county (1966-2015).

Many wells measured in this aquifer, including a few in Beaver County, have a period of record that spans over 40 years (Figure 85). As depicted in these figures, the water level in the Ogallala-Panhandle has declined an average of 9.16 feet in Cimarron County, 13.17 feet in Texas County, and 4.3 feet in Beaver County wells over the last five years (2010-2015). The Ogallala-Panhandle Aquifer has three GMAP recorders, one each in Beaver, Texas, and Cimarron counties, installed in January 2014.

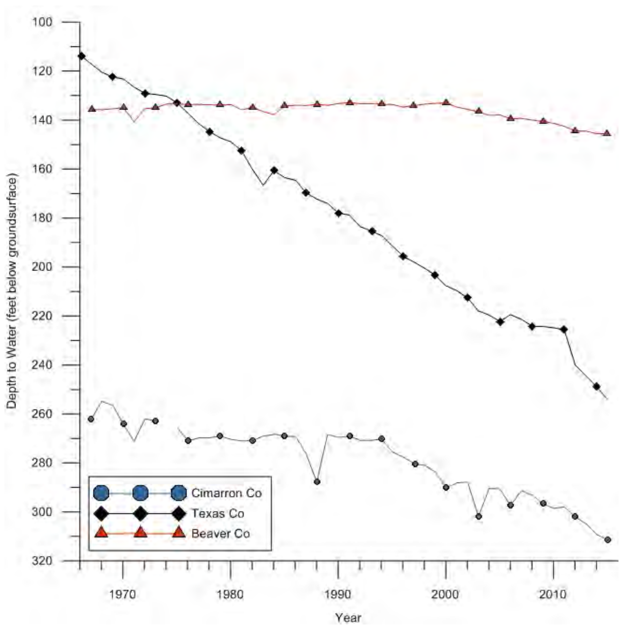

Figure 85. Groundwater level hydrographs for three of the longest Ogallala-Panhandle records, one in each county (1966-2015).

Water Level Measurement in the Red River Alluvial & Terrace Aquifer

A baseline groundwater level network is scheduled for implementation in 2015. 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 86). The average water level in the South Central reaches of the Red River has dropped 3.22 feet in the last 5 years (2010-2015).

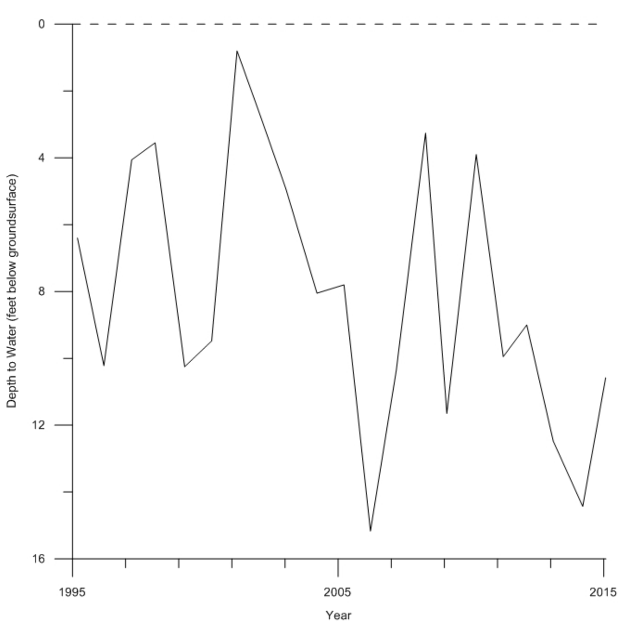

Figure 86. Groundwater level hydrograph for one of the longest current Red River records, Bryan County (South Central climate division; 1995-2015).

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 majority of the state's water levels have fluctuated by less than three feet (2014-2015, Figure 87).

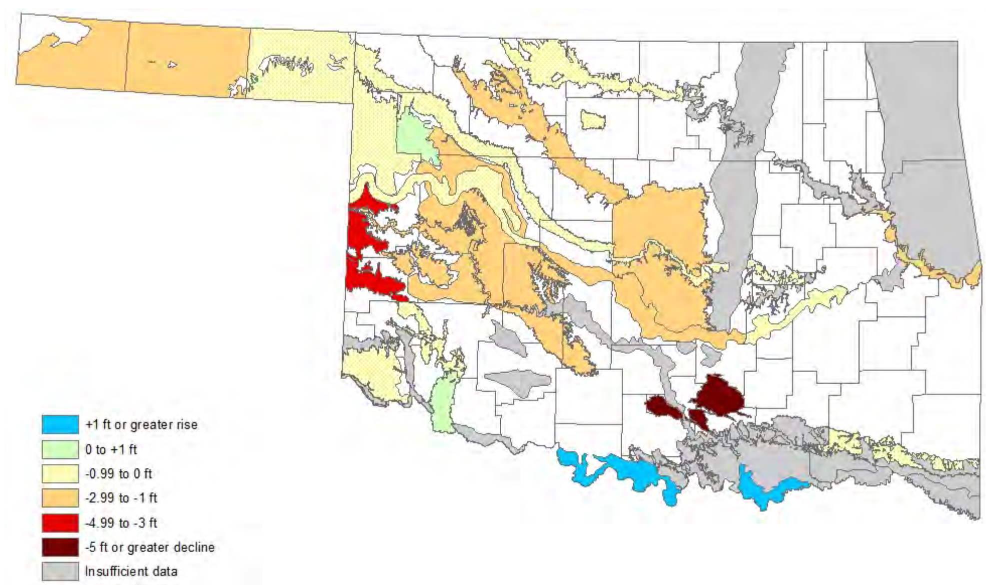

Figure 87. Average one-year water level change, by major aquifer and climate division (2014-2015).

Over the last five years, average water levels have dropped across the state by varying degrees (2010-2015; Figure 88). The largest groundwater declines were observed in Texas County, the section of the North Fork of the Red River located in the West Central climate division, the Arbuckle-Simpson, and the Blaine aquifers. Overall, groundwater levels have declined by more than 6 feet in many of the state's aquifers. Corresponding to these observed drops, state-wide average precipitation has been below normal in 4 of the 5 years preceding the 2015 measurements with 2011 and 2012 being two of the driest and hottest years on record for the state.

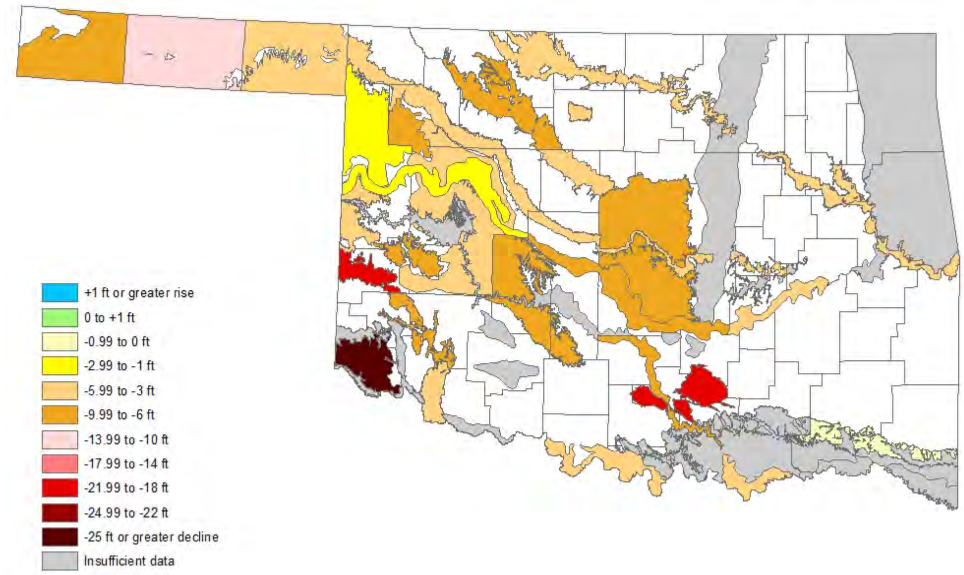

Figure 88. Average five-year water level change, by major aquifer and climate division (2010-2015).

Over the past ten years, average water levels in the state have declined by varying degrees (2005-2015; Figure 89). The largest average declines were detected in the Ogallala-Panhandle in Texas and Cimarron counties, the section of the North Fork of the Red River located in the West Central climate division, the Arbuckle-Simpson, and the Blaine aquifers. The magnitude of groundwater level declines over the latest 10 year period of record are less than the previously discussed 5-year period (excepting the Panhandle), as a result of recharge that occurred in many of Oklahoma's aquifers between 2008-2010 due to above normal precipitation for the state.

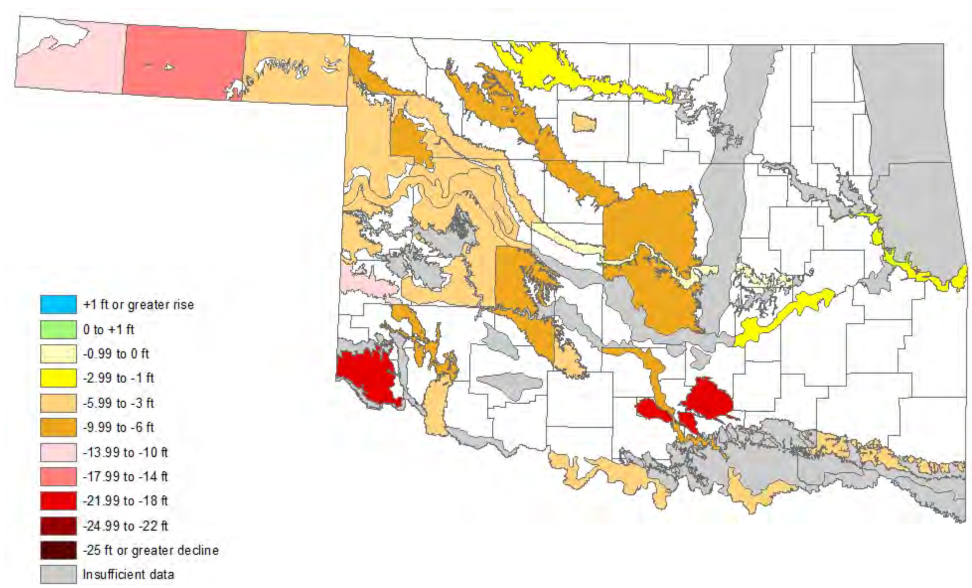

Figure 89. Average ten-year water level change, by major aquifer and climate division (2005-2015).

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 ten aquifers, nine (9) recorders were installed in 2013 and an additional 8 were installed in 2014. 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 90).

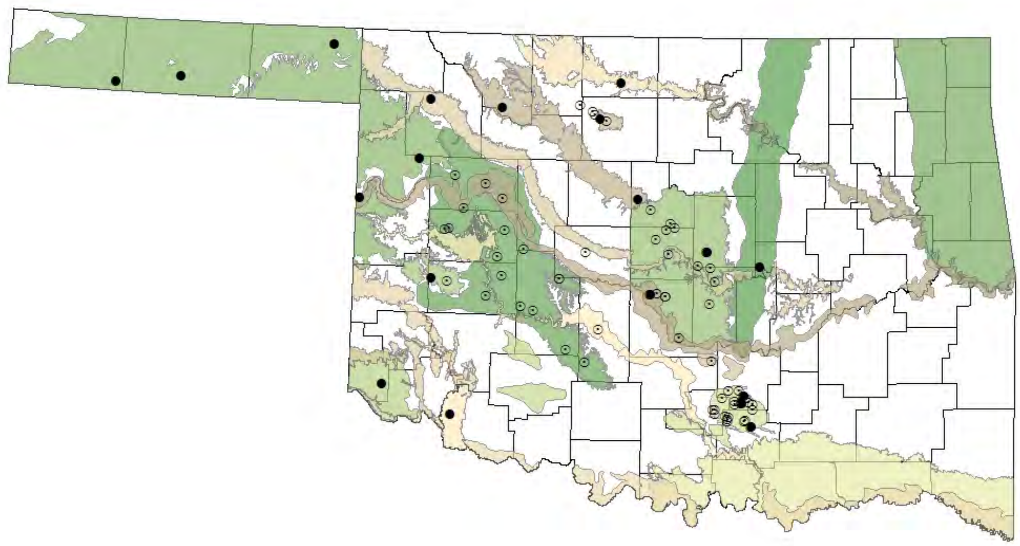

Figure 90. Sites with OWRB continuous water level recorders installed (closed circles indicate those in the GMAP program).

Details on installed recorders can be found in those aquifers' specific sections of this report. There are currently recorders in: the Arbuckle-Simpson, the Beaver-North Canadian River, the Blaine, the Canadian River, the Cimarron River, the Elk City, the Enid Isolated Terrace, the Garber-Wellington, the Ogallala-Northwest, the Ogallala-Panhandle, 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 7 Oklahoma Mesonet Stations (Figure 91). Groundwater observation wells are equipped with down-hole continuous recorders for hourly depth to water measurements. 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. In early 2014, a new well was completed at the Weatherford Mesonet station.

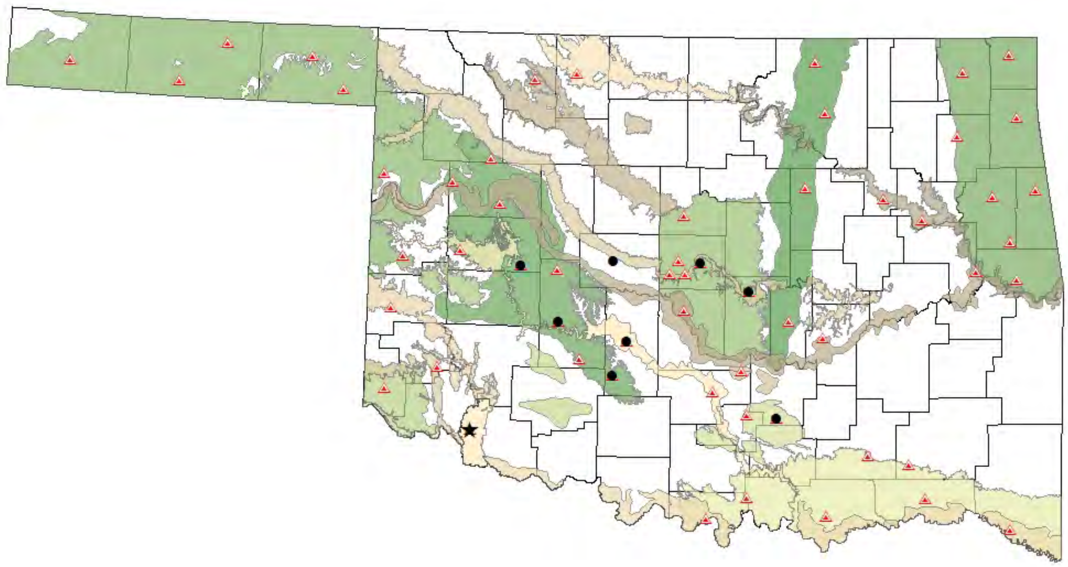

Figure 91. Continuous water level recorders (circles) deployed at Mesonet stations (triangles) in major aquifers across the state. The most recent addition (star) was drilled in 2014, and data collected is expected to go live 2015.

The OWRB is also currently working with Oklahoma State University, the University of Oklahoma, the Oklahoma Climatological Survey, and private landowners to drill additional wells within major aquifers at Mesonet stations. A new observation well near the Tipton Mesonet Station was drilled in December 2014, and real-time data collection viewing should be available from the OCS web site in the next couple of months (Figure 91).

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Table of Appendices

Appendix A– Descriptive Statistics & Selected Maps 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)	216.3	18.3	72	141.3	180	253.8	850	N=50
Depth to Water (ft)	79.29	8.01	11.65	43.33	71.99	104.7	321.2	Below ground surface
Temperature (°C)	19.76	0.188	17.47	18.59	19.67	20.71	23	
Specific Conductance (µS/cm)	684.9	49.54	170.3	466.4	626.9	839	1678	
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)	315.4	18.37	-28	252.1	343.1	391.3	493.3	N=43
Field Alkalinity (mg/L)	234.2	12.78	55	179	249.5	293.3	391	
Field Hardness (mg/L)	220.6	17.58	11.8	122.5	224	280.3	499	
Field calculated Bicarbonate (mg/L)	288	15.7	67.8	220.5	307.5	361.3	482	
Total Dissolved Solids (mg/L)	393.2	32.35	97.5	254.5	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	0.02	<0.1	<0.1	<0.1	0.143	0.54	
Nitrate+nitrite (mg/L)	1.48	0.467	<0.05	<0.05	0.515	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)	335.6	24.13	102	230.3	310	407.3	695	
dissolved Calcium (mg/L)	49.36	3.81	3	29.8	48.3	62.3	105	
Chloride (mg/L)	31.58	4.49	<10	11.65	17.65	41.15	117	SMCL: 250; 0 over
Fluoride (mg/L)	0.28	0.062	<0.2	<0.2	<0.2	0.27	2.29	MCL: 4; 0 over
dissolved Magnesium (mg/L)	21.84	1.93	1	11.7	23.55	29.4	62.1	
dissolved Potassium (mg/L)	1.96	0.13	0.7	1.3	1.9	2.63	4.3	
dissolved Silica (mg/L)	14.38	0.623	7.8	11.45	14.35	16.83	29.4	
dissolved Sodium (mg/L)	67.92	12.42	5.9	14.68	36.6	80.9	351	
Sulfate (mg/L)	75.4	19.58	<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	1.53	4.1	MCL: 10; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	91.22	12.52	8.6	36.45	64.5	111.3	348	MCL: 2000; 0 over
dissolved Boron (µg/L)	507.2	145.4	<20	44.98	99.1	502.3	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)	107.9	42.07	<20	<20	21.35	44.65	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)	34.25	11.25	<5	<5	7.35	19.05	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	8.15	13.48	22.3	
dissolved Zinc (µg/L)	18.84	5.08	<5	<5	6.1	14.25	164	SMCL: 5000; 0 over. HA: 2000; 0 over

Figure A.92. Location and extent of the ADVM.

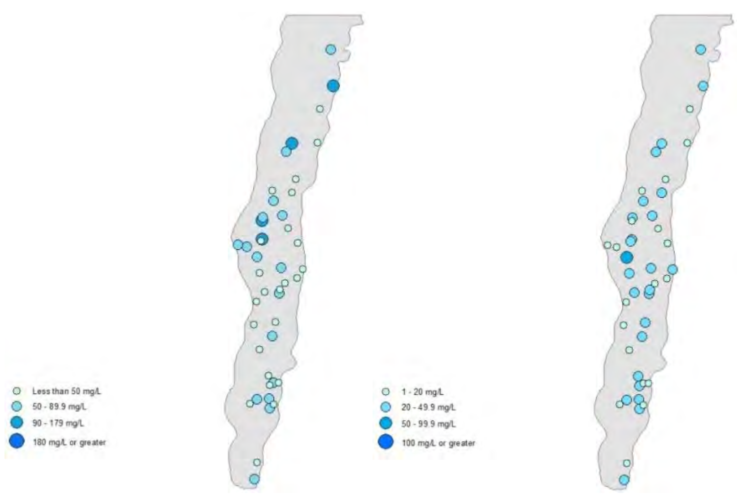


Figure A.93. Calcium (left) and magnesium concentrations in the ADVM.

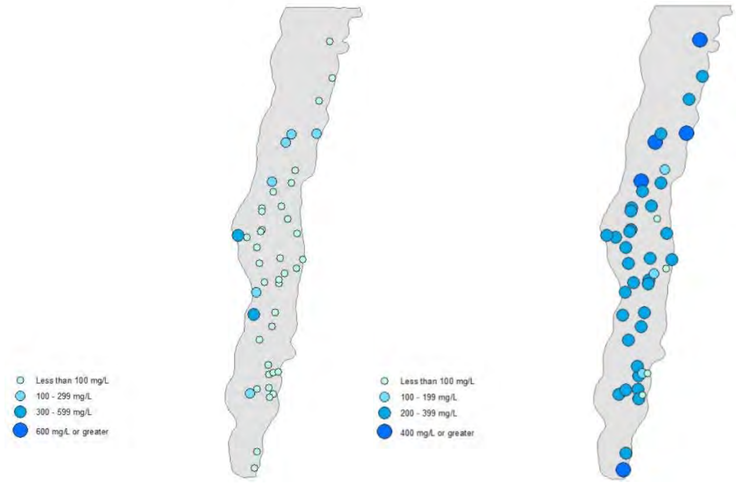


Figure A.94. Sodium+potassium (left) and bicarbonate concentrations in the ADVM.

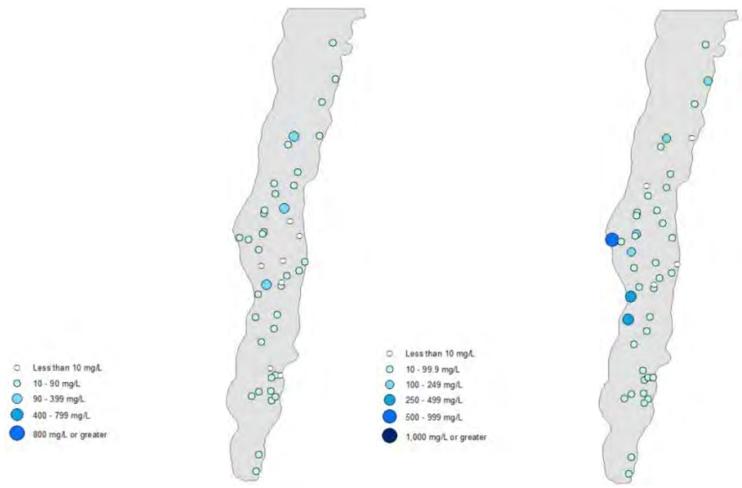


Figure A.95. Chloride (left) and sulfate concentrations in the ADVM.

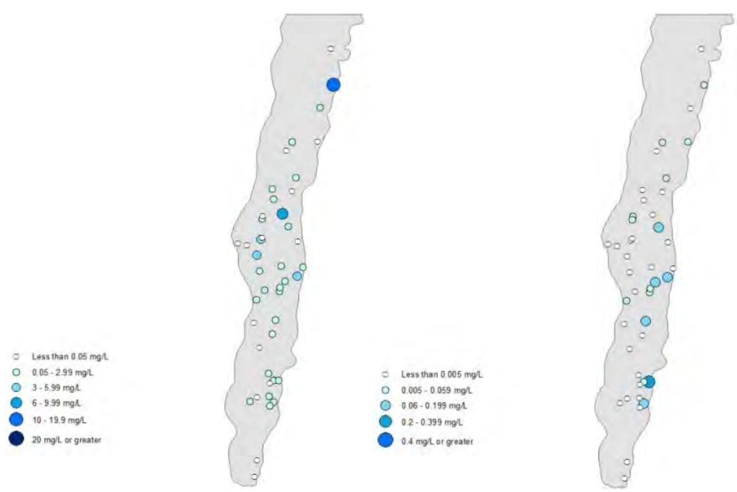


Figure A.96. Nitrate+nitrite (left) and total dissolved phosphorus concentrations in the ADVM.

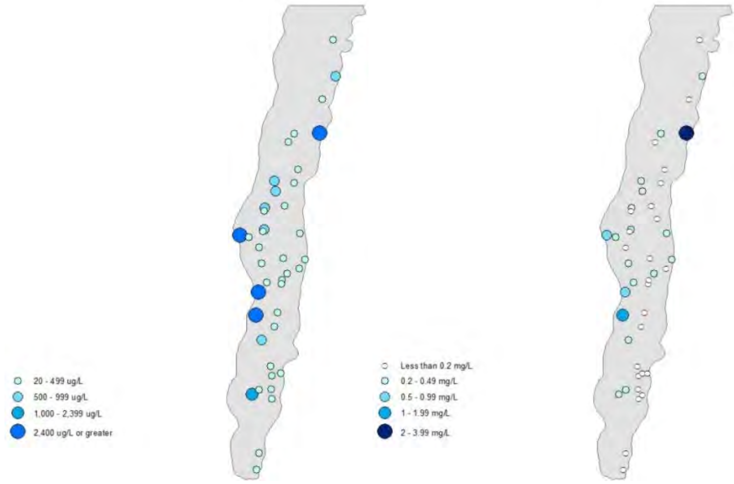


Figure A.97. Boron (left) and fluoride concentrations in the ADVM.

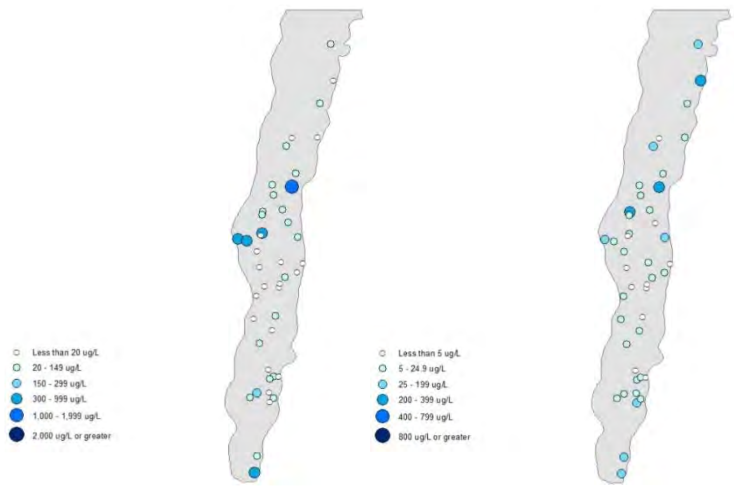
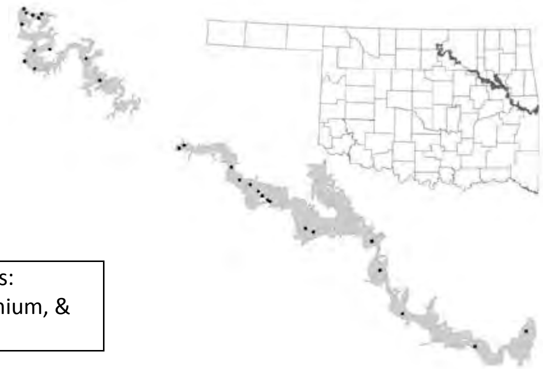


Figure A.98. Iron (left) and manganese concentrations in the ADVM.

Appendix B– Descriptive Statistics & Selected Maps 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 B1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	45.41	3.07	26	35.25	40	49.5	116	N=34
Depth to Water (ft)	24.63	2.97	0	16.28	22.51	27.23	60.31	Below ground surface
Temperature (°C)	19.39	0.402	16.49	17.92	18.98	19.7	27.25	
Specific Conductance (µS/cm)	650.6	68.0	122.5	428	641	916.5	1688	
Dissolved Oxygen (mg/L)	3.89	0.491	0.24	1.28	3.89	5.81	8.7	
pH (units)	6.57	0.072	5.69	6.37	6.63	6.83	7.25	
Oxidation Reduction Potential (mV)	304.1	22.27	48.6	263.5	370.3	378.4	560.6	
Field Alkalinity (mg/L)	233.8	25.52	39	124	224	333	489	
Field Hardness (mg/L)	263.7	26.75	27	179	255	404	484	
Field calculated Bicarbonate (mg/L)	283.2	31.54	48	153	269	410	597	
Total Dissolved Solids (mg/L)	386.5	36.31	88.8	279	385	515	914	SMCL: 500; 9 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 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	5.5	17.4	MCL: 10; 1 over
Phosphorus (mg/L)	0.148	0.041	0.025	0.063	0.1	0.125	1.17	

Table B3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	361.5	44.88	<100	212	291	481	1080	
dissolved Calcium (mg/L)	70.65	7.06	7.6	49.4	71	104	133	
Chloride (mg/L)	41.37	12.69	<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	0.4	MCL: 4; 0 over
dissolved Magnesium (mg/L)	15.95	1.74	1.9	11	14.6	20.6	36.8	
dissolved Potassium (mg/L)	1.96	0.248	0.5	1.1	1.6	2.3	5.7	
dissolved Silica (mg/L)	26.02	1.93	7.82	19.4	22.2	33.1	45.2	
dissolved Sodium (mg/L)	38.83	8.8	7.8	14.1	24.8	40.1	240	
Sulfate (mg/L)	37.01	5.75	<10	16.5	26.5	51.4	125	SMCL: 250; 0 over

Table B4. 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)	257.1	36.04	58.6	124	209	345	885	MCL: 2000; 0 over
dissolved Boron (µg/L)	51.74	8.44	<20	<20	45.7	70	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	0.98	<5	<5	<5	7.5	26.7	MCL: 1300; 0 over
dissolved Iron (µg/L)	901.6	443.9	<20	<20	20.4	283	12200	SMCL: 300; 7 over
dissolved Manganese (µg/L)	514.9	156.3	<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	15.49	<5	<5	6.8	37.8	371	SMCL: 5000; 0 over HA: 2000; 0 over

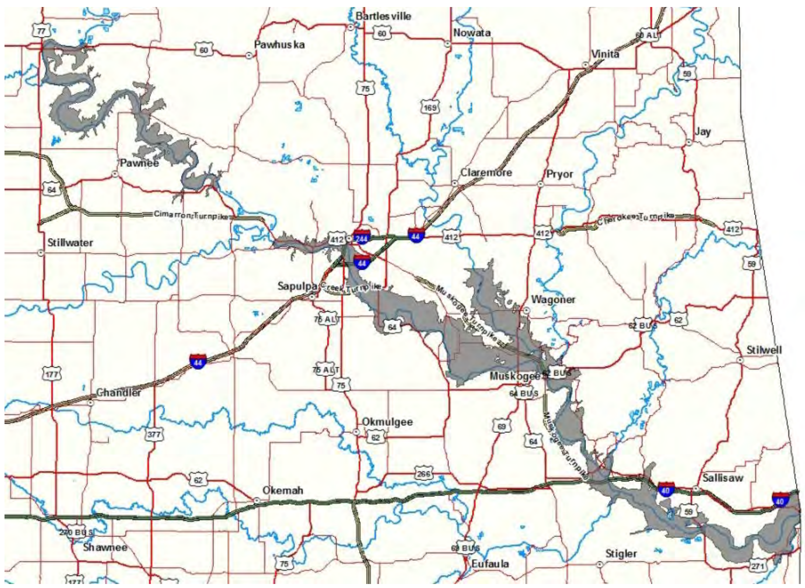


Figure B.1. Location and extent of the ARKS.

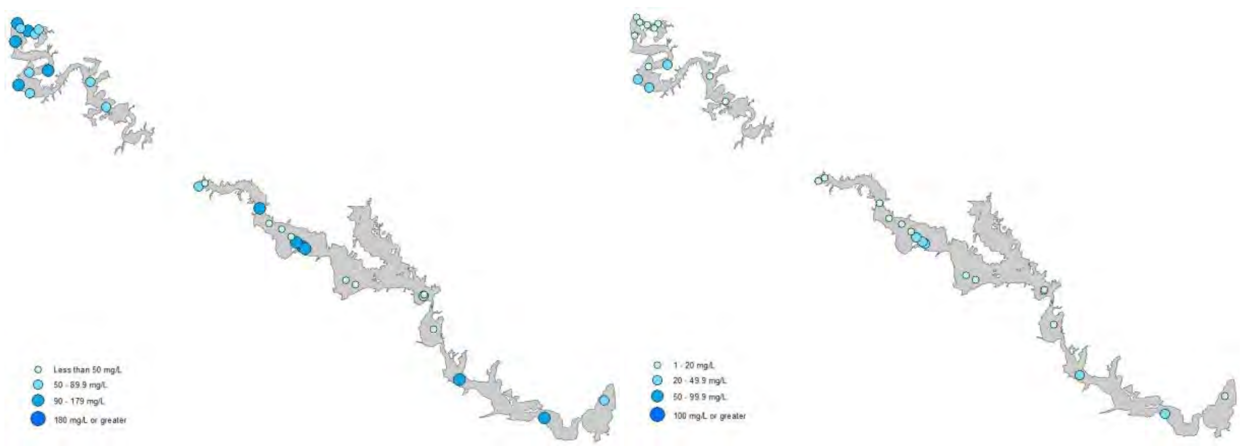


Figure B.2. Calcium (left) and magnesium concentrations in the ARKS.

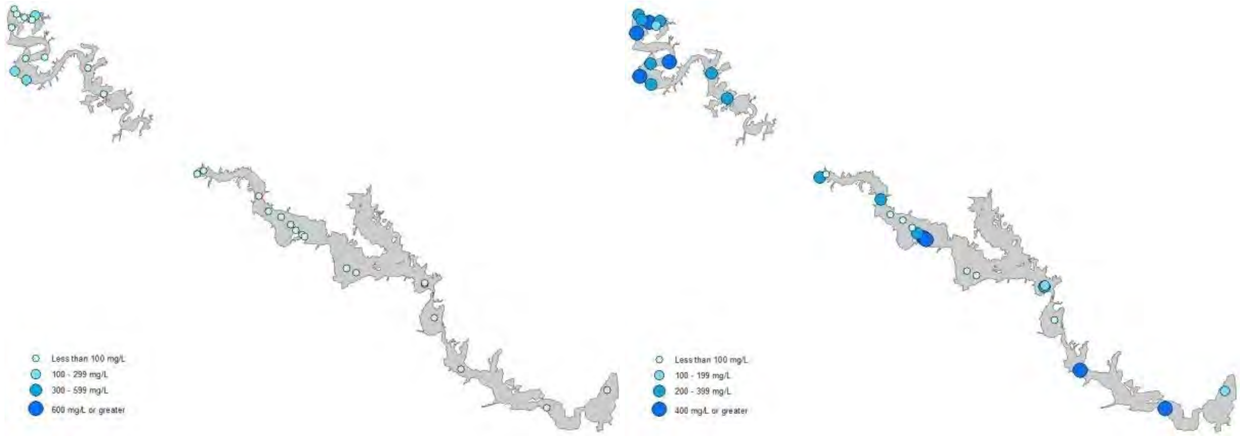


Figure B.3. Sodium+potassium (left) and bicarbonate concentrations in the ARKS.

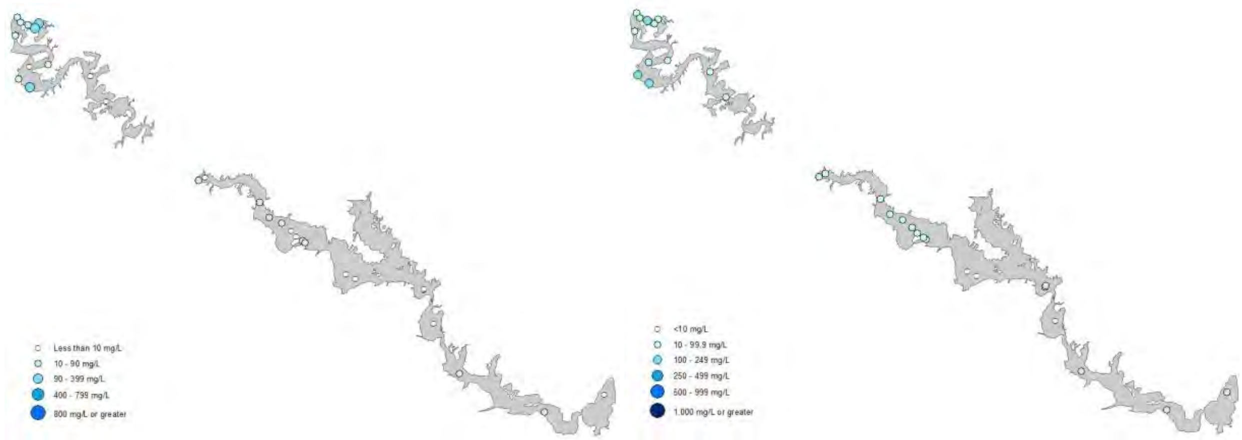


Figure B.4. Chloride (left) and sulfate concentrations in the ARKS.

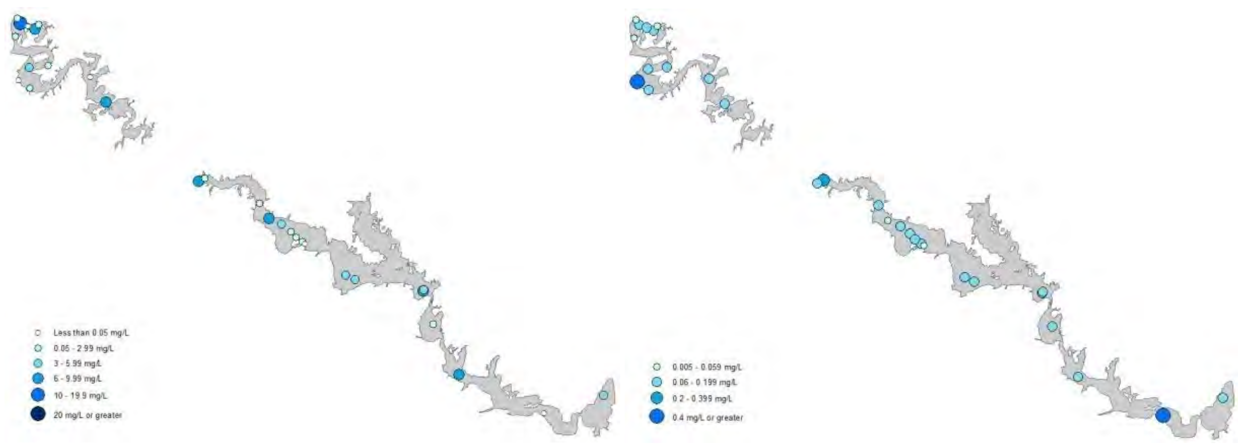


Figure B.5. Nitrate+nitrite (left) and total dissolved phosphorus concentrations in the ARKS.

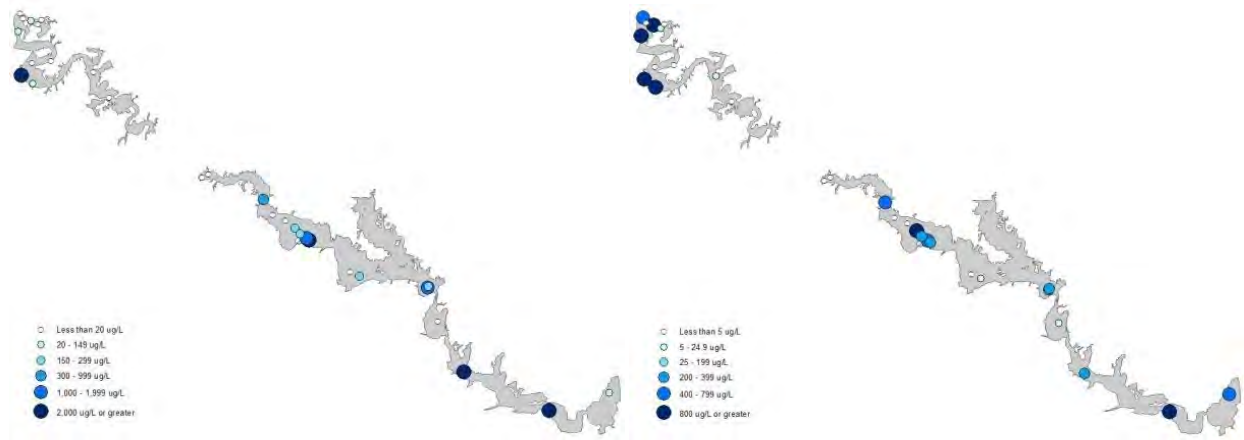


Figure B.6. Iron (left) and manganese concentrations in the ARKS.

Appendix C– 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 C1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	66.45	2.71	14	54	63	80	112	N=49
Depth to Water (ft)	21.32	2.22	2.68	11	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)	1374	166.8	102.1	723.9	907.9	2082	3710	
Dissolved Oxygen (mg/L)	3.75	0.512	0.1	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)	266.1	21.65	26.4	186.5	275	328.8	537	
Field Hardness (mg/L)	666.3	97.23	25.8	289.3	393.5	1113	2233	
Field calculated Bicarbonate (mg/L)	336.6	25.52	68.8	246	341	409	661	
Total Dissolved Solids (mg/L)	1042	157.2	86.3	435.5	533	1748	3420	SMCL: 500; 23 sites over

Table C2. 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)	0.0603	0.016	<0.005	<0.005	0.035	0.074	0.516	

Table C3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	353.4	36.85	<100	217	320	448.8	966	
dissolved Calcium (mg/L)	162.9	21.17	16.7	77.9	111.5	223	445	
Chloride (mg/L)	59.19	13.24	<10	14.1	33.9	61.83	380	SMCL: 250; 1 over
Fluoride (mg/L)	0.206	0.024	<0.2	<0.2	<0.2	0.305	0.56	MCL: 4; 0 over
dissolved Magnesium (mg/L)	51.32	7.58	5.3	16.73	39.25	69.5	180	
dissolved Potassium (mg/L)	1.95	0.220	<0.5	0.85	1.95	2.4	5	
dissolved Silica (mg/L)	23.42	1.32	11	20.13	22.65	25.03	54.2	
dissolved Sodium (mg/L)	77.79	15.18	10.5	22.15	45.9	93.95	430	
Sulfate (mg/L)	462.9	103.8	<10	37.73	99.85	942.5	1860	SMCL: 250; 13 over

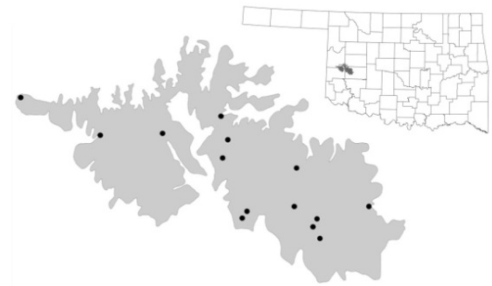
Table C4. Descriptive statistics on metal constituents.

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)	166.8	35.78	<10	20.28	81.35	229.8	987	MCL: 2000; 0 over
dissolved Boron (µg/L)	399.9	104.6	<50	77.6	205.5	420.8	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)	838.9	243.8	<50	<50	<50	828	4940	SMCL: 300; 12 over
dissolved Manganese (µg/L)	210.3	50.66	<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	3.45	8.75	40.8	MCL: 30; 2 over
dissolved Vanadium (µg/L)	28.62	4.22	<10	6.4	18.75	44.28	94.1	
dissolved Zinc (µg/L)	37.21	13.79	<10	<10	10.45	25.53	424	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix D– 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 D1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	118.8	6.05	42	99	122	140.5	175	N=27
Depth to Water (ft)	28.98	4.85	10.95	15.2	22.8	27.44	107.8	Below ground surface
Temperature (°C)	21.50	0.565	18.36	19.86	21.25	23.56	24.27	
Specific Conductance (µS/cm)	623.9	27.02	475.3	576.2	599.4	671.8	821.9	
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)	276.1	16.26	215	238	276	288	437	
Field Hardness (mg/L)	271.9	7.73	232	253	272	289	329	
Field calculated Bicarbonate (mg/L)	339.7	19.98	265	293	340	354	537	
Total Dissolved Solids (mg/L)	360.2	15.71	254	335	349	399	436	SMCL: 500; 0 over

Table D2. 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 D3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	374.7	59.67	232	281	298	336	1090	
dissolved Calcium (mg/L)	65.35	2.90	45.4	59.3	67.2	70.7	81.8	
Chloride (mg/L)	13.08	3.84	<10	<10	10.6	13.6	58.4	SMCL: 250; 0 over
Fluoride (mg/L)	0.345	0.021	0.2	0.3	0.33	0.4	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)	35.06	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 D4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	408.9	50.84	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	0.94	<1	<1	1.4	2	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)	29.95	7.77	<10	<10	19.3	52	83.9	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix E– Descriptive Statistics & Selected Maps 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 E1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	49.47	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	27.2	
Specific Conductance (µS/cm)	991.9	150.1	329	793	980.1	1337	1654	
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)	411.8	3.34	400	408.8	416	416	418.1	N=5
Field Alkalinity (mg/L)	269.6	37.55	90	197	305	348	390	
Field Hardness (mg/L)	296.7	50.71	109	189	262	393	540	
Field calculated Bicarbonate (mg/L)	332.1	46.19	111	243	376	429	480	
Total Dissolved Solids (mg/L)	610.4	104.1	170	486	566	851	1050	SMCL: 500; 6 over

Table E2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (mg/L)	10.99	2.7	2.45	5.11	11.3	12.3	29	MCL: 10; 5 over
Phosphorus (mg/L)	0.12	0.029	<0.005	0.038	0.164	0.192	0.214	

Table E3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	424.8	77.04	110	313	398	632	766	
dissolved Calcium (mg/L)	91.6	15.58	25.2	66.7	87.5	124	150	
Chloride (mg/L)	87.33	24.17	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)	19.11	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)	24.07	1.15	17.1	23.6	24.5	26.1	29.2	
dissolved Sodium (mg/L)	97.23	19.43	18.9	54.7	108	153	165	
Sulfate (mg/L)	85.38	22.52	20.5	30.8	75.8	125	193	SMCL: 250; 0 over

Table E4. 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)	224.7	47.99	64.7	90.2	249	287	496	MCL: 2000; 0 over
dissolved Boron (µg/L)	96.31	28.88	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)	61.33	35.83	<5	<5	7.1	56.4	324	SMCL:5000; 0 over. HA:2000; 0 over

Figure E.1. Location and extent of the ENID.

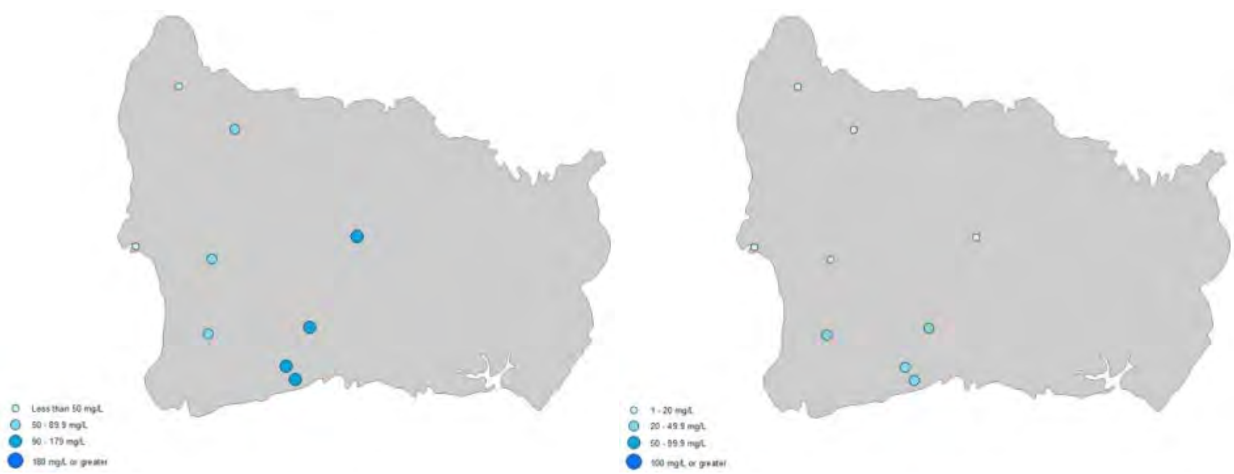


Figure E.2. Calcium (left), magnesium (center), and potassium concentrations in the ENID.

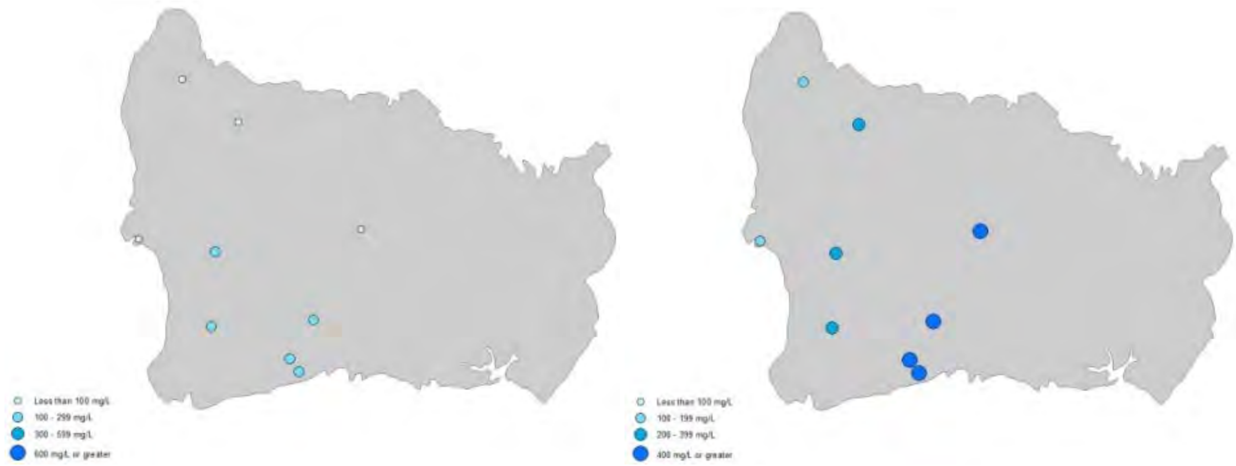


Figure E.3. Sodium+potassium (left) and bicarbonate concentrations in the ENID.

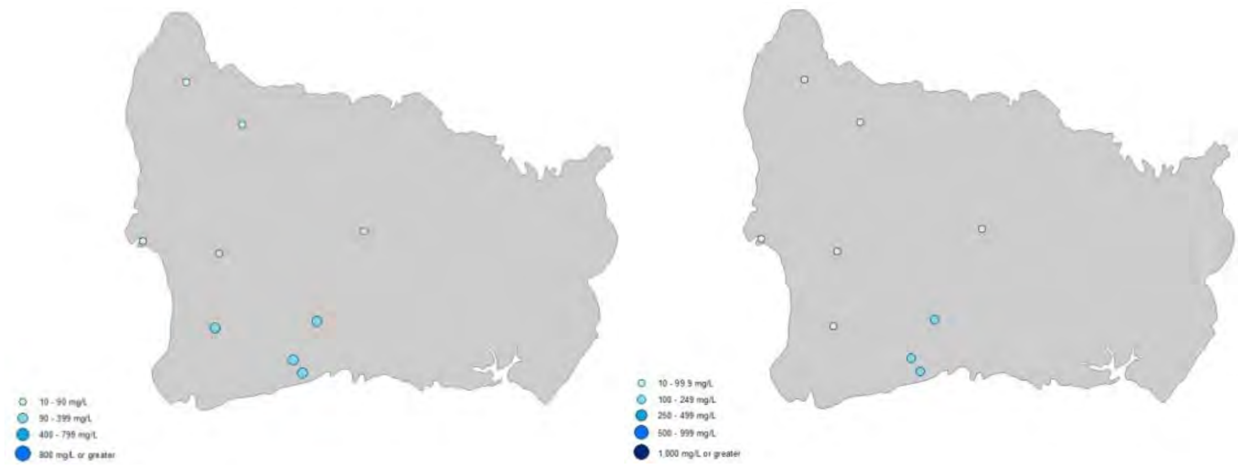


Figure E.4. Chloride (left) and sulfate concentrations in the ENID.

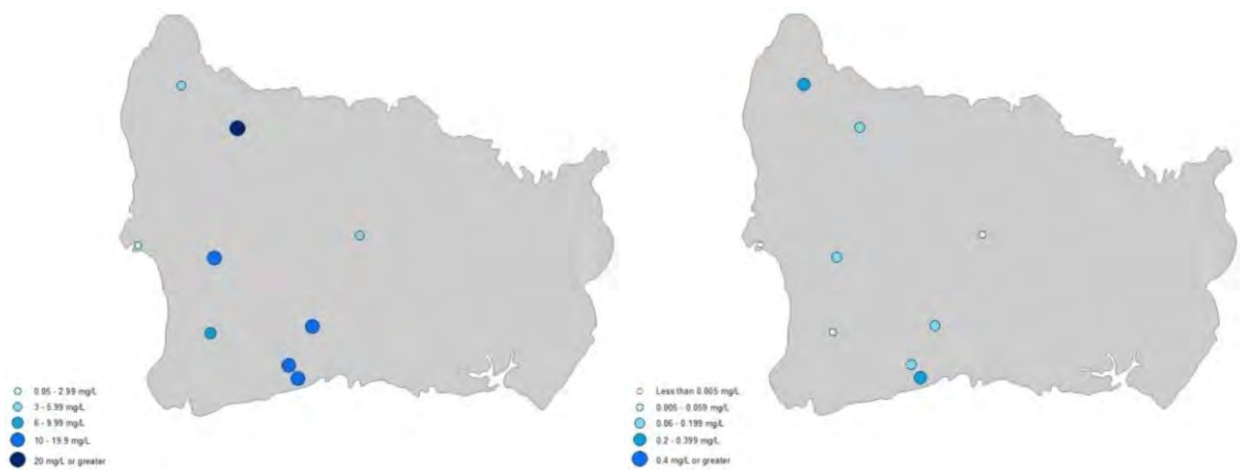
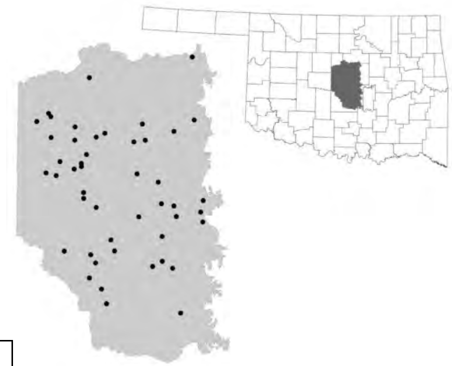


Figure E.5. Nitrate+nitrite (left) and total dissolved phosphorus concentrations in the ENID.

Appendix F– 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 F1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	192.1	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)	728.1	73.04	233.0	472.3	616.6	821.1	2552	
Dissolved Oxygen (mg/L)	4.89	0.337	0.3	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)	268.2	14.83	44.0	213.5	284	326	450.0	
Field Hardness (mg/L)	277.5	30.14	31	136.5	260.5	325.8	1273	N=46
Field calculated Bicarbonate (mg/L)	322.3	18.20	54.3	262.5	350	399.5	554	
Total Dissolved Solids (mg/L)	418.8	52.96	123	243.5	328	446.5	2150	SMCL: 500; 9 over

Table F2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (mg/L)	1.84	0.399	<0.05	0.415	0.89	2.17	14.8	MCL: 10; 1 over
Phosphorus (mg/L)	0.019	0.0049	<0.005	<0.005	<0.005	0.021	0.156	

Table F3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	425	42.92	139	272	335	486	1820	
dissolved Calcium (mg/L)	60.81	8.84	<5	26.4	55.6	73.7	409	
Chloride (mg/L)	46.99	11.77	<10	11.4	18.8	46.75	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)	28.58	2.62	<5	13.25	27.9	34.8	79.1	
dissolved Potassium (mg/L)	1.52	0.106	<0.5	1	1.2	2.05	3.6	
dissolved Silica (mg/L)	18.60	0.632	10.1	16.0	17.8	21.35	30.3	
dissolved Sodium (mg/L)	63.52	10.04	7.2	15.05	31.8	85.7	318	
Sulfate (mg/L)	59.28	24.67	<10	7.85	17.4	26.45	1090	SMCL: 250; 2 over

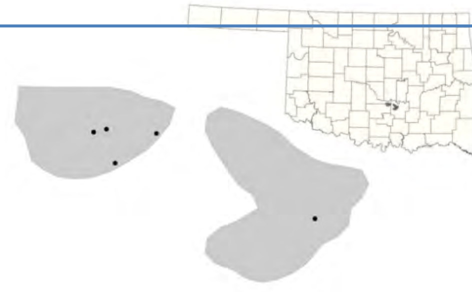
Table F4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	All Values <10, except 1 (11.8)							MCL: 10; 1 over
dissolved Barium (µg/L)	301.5	32.63	<10	118.5	242	457	923	MCL: 2000; 0 over
dissolved Boron (µg/L)	253.1	65.7	<50	55.6	88	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)	10.96	2.19	<5	<5	<5	12	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)	50.67	7.38	<10	13.6	52.6	65.85	296	
dissolved Zinc (µg/L)	27.67	5.48	<10	<10	<10	34.3	184	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix G– 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 G1. 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	44.3	45.53	46.55	58.8	Below ground surface
Temperature (°C)	22.35	1.56	19.38	20.19	20.8	23.37	27.99	
Specific Conductance (µS/cm)	550.3	55.97	433.1	455.5	492	684.1	686.8	
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	6.7	6.96	
Field Alkalinity (mg/L)	208.6	37.47	80	193	204	273	293	
Field Hardness (mg/L)	198	23.38	125	179	202	216	268	
Field calculated Bicarbonate (mg/L)	256.9	46.10	98.7	238	251	336	361	
Total Dissolved Solids (mg/L)	316.4	26.07	255	268	306	368	385	SMCL: 500; 0 over

Table G2. 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 G3. Descriptive statistics on mineral constituents.

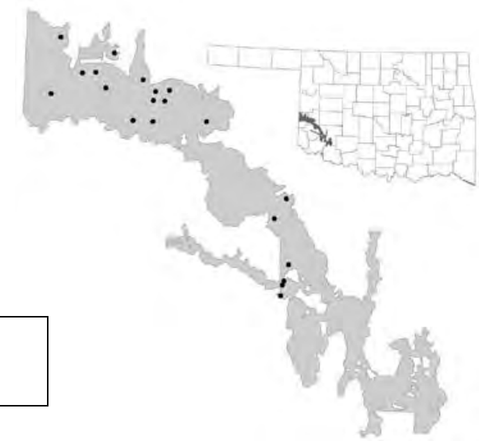
Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	473	91.86	254	276	493	631	711	
dissolved Calcium (mg/L)	54.04	7.60	34.6	50.6	50.8	52.7	81.5	
Chloride (mg/L)	35.54	11.88	11.3	14.5	36.8	37.3	77.8	SMCL: 250; 0 over
dissolved Magnesium (mg/L)	14.94	2.24	9.1	10.8	16.5	16.8	21.5	
dissolved 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	34.4	45.7	47.7	
dissolved Sodium (mg/L)	37.16	7.54	24.5	27.1	33.4	34.4	66.4	
Sulfate (mg/L)	13.7	1.34	10.1	12.8	13	14.3	18.3	SMCL: 250; 0 over

Table G4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	237.1	44.09	69.6	249	262	275	330	MCL: 2000; 0 over
dissolved Copper (µg/L)	14.08	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)	69.76	37.8	11.5	16.3	22	89	210	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix H– Descriptive Statistics & Selected Maps 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 H1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	71.91	5.69	29	48	67	79	210	N=46
Depth to Water (ft)	36.64	3.23	10.6	20.19	33.09	44.19	113.2	Below ground surface
Temperature (°C)	21.53	0.548	18.94	20.14	21.12	22.17	30.64	
Specific Conductance (µS/cm)	1341	247.0	508	630.5	862	1840	4834	
Dissolved Oxygen (mg/L)	5.62	0.562	0.89	4.16	6.41	7.35	9.5	
pH (units)	7.06	0.026	6.85	6.99	7.06	7.16	7.26	
Oxidation Reduction Potential (mV)	418.8	10.38	315.6	392.7	425.9	447	501.7	
Field Alkalinity (mg/L)	224.9	10.49	134	198.5	232	252	331	
Field Hardness (mg/L)	487.1	68.55	187	264.5	342	793.8	1178	
Field calculated Bicarbonate (mg/L)	276.8	12.93	165	244	285.5	310.3	408	
Total Dissolved Solids (mg/L)	895.1	178.7	295	379	542.5	1228	3520	SMCL: 500; 11 over

Table H2. 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 H3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	592.5	124.3	208	264.8	329	613.3	1960	
dissolved Calcium (mg/L)	121.1	14.97	53.2	71.8	94.9	172	312	
Chloride (mg/L)	137.9	57.45	<10	11.55	24.75	79.78	981	SMCL: 250; 3 over
Fluoride (mg/L)	0.295	0.043	<0.2	<0.2	0.28	0.415	0.74	MCL: 4; 0 over
dissolved Magnesium (mg/L)	34.6	5.73	10.3	17.03	23	46.93	81.6	
dissolved Potassium (mg/L)	2.56	0.429	<0.5	1.45	2.1	3.23	9.3	
dissolved Silica (mg/L)	23.22	2.15	9.95	13.88	24.85	27.35	43.7	
dissolved Sodium (mg/L)	114.2	45.58	4.4	23.9	37.35	102	905	
Sulfate (mg/L)	268.4	69.77	<10	38.35	142	383.3	1090	SMCL: 250; 7 over

Table H4. 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	2.55	7.6	MCL: 10; 0 over
dissolved Barium (µg/L)	131.4	30.14	10.8	38.55	89	173	577	MCL: 2000; 0 over
dissolved Boron (µg/L)	192.9	69.98	32.6	57.18	97.55	177.8	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	5.53	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	7.85	14.18	29.3	
dissolved Zinc (µg/L)	15.51	5.16	<5	<5	4.25	16.2	91.7	SMCL: 5000; 0 over HA: 2000; 0 over

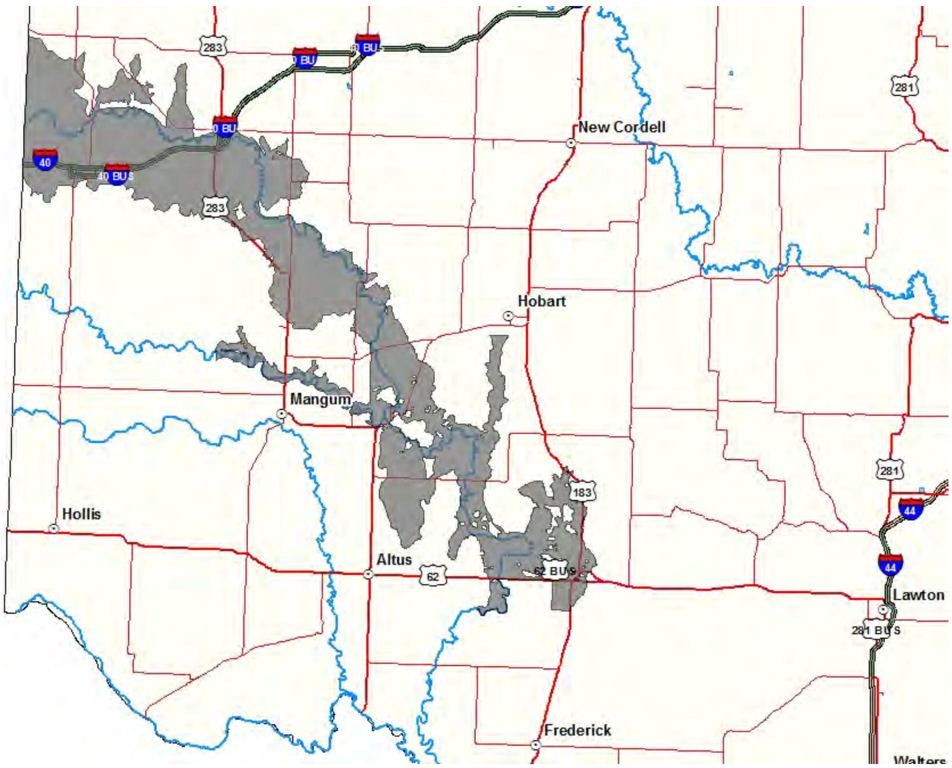


Figure H.1. Location and extent of the NFRR.

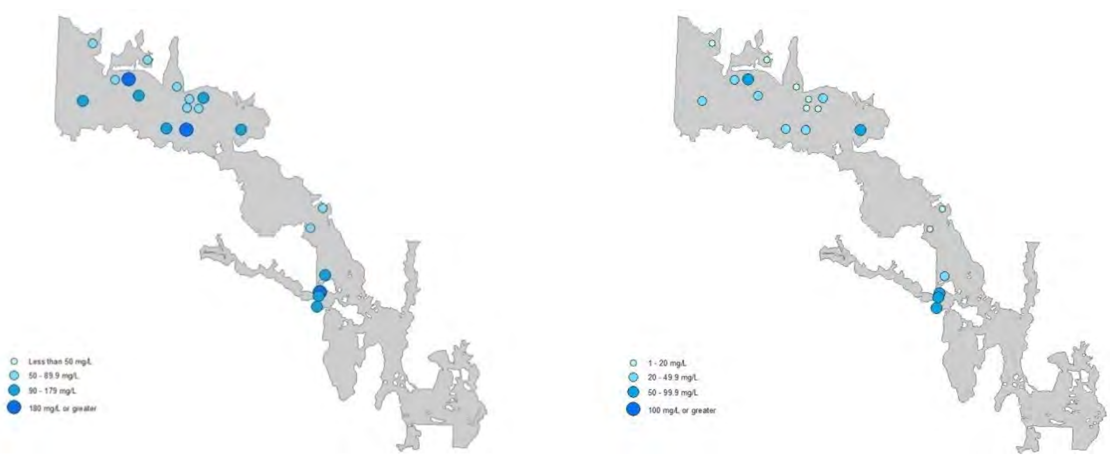


Figure H.2. Calcium (left) and magnesium concentrations in the NFRR.

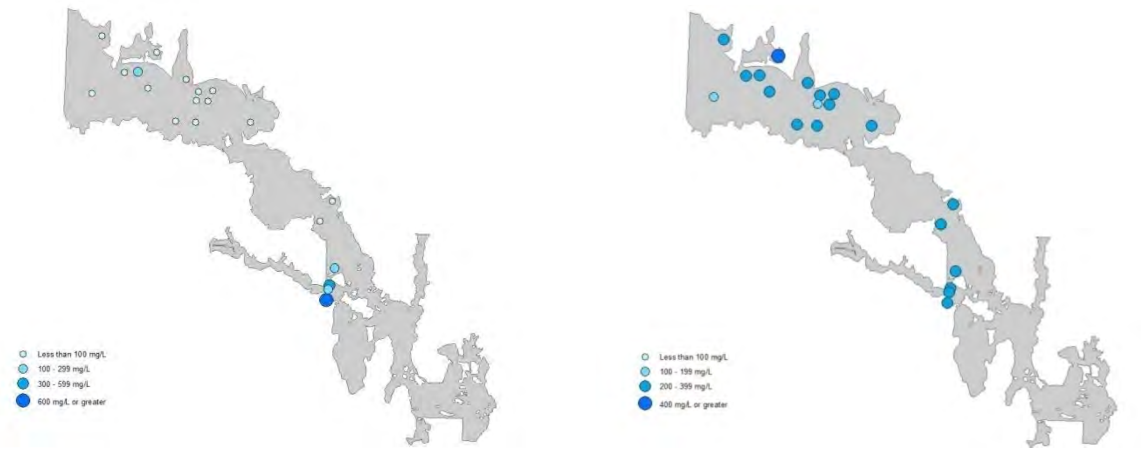


Figure H.3. Sodium+potassium (left) and bicarbonate concentrations in the NFRR.

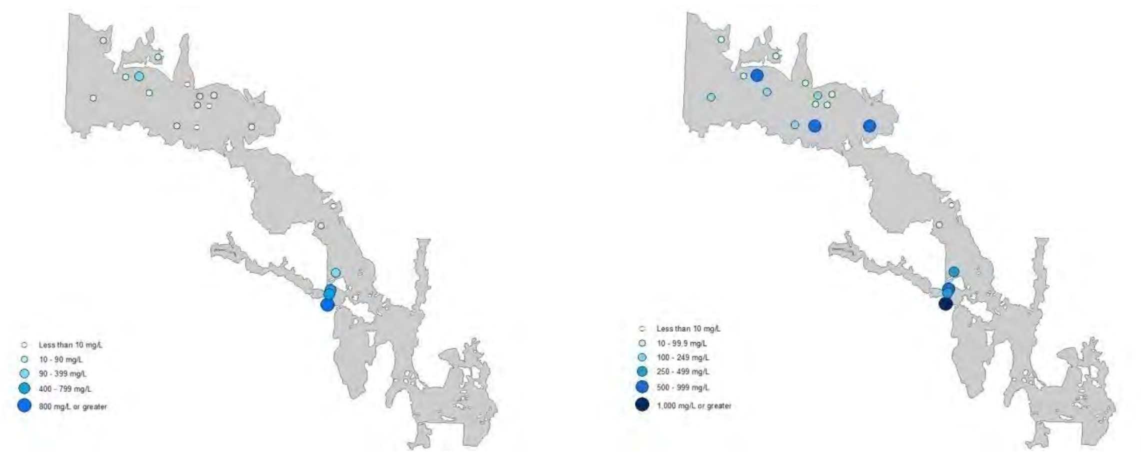


Figure H.4. Chloride (left) and sulfate concentrations in the NFRR.

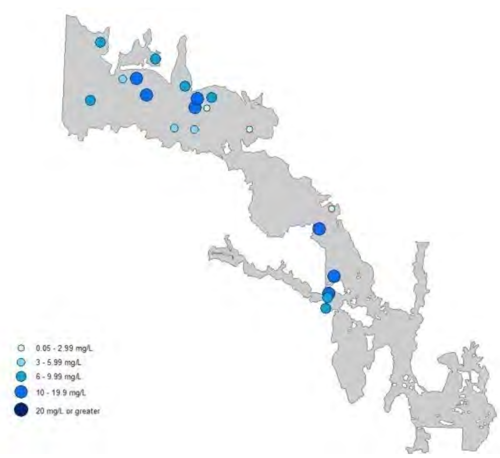
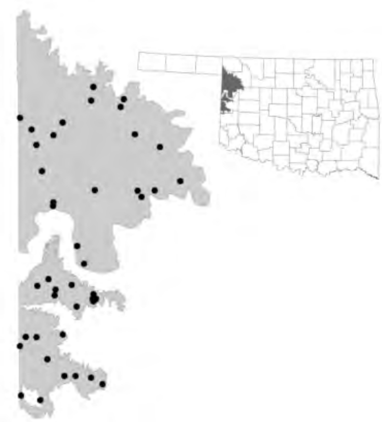


Figure H.5. Nitrate+nitrite concentrations in the NFRR.

Appendix I– 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 I1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	168.5	10.17	30	120	155	212.5	340	N=52
Depth to Water (ft)	77.02	6.45	7.91	40.97	74.16	105.9	175.2	Below ground surface
Temperature (°C)	20.32	0.459	17.04	18.55	19.03	21.49	29.97	
Specific Conductance (µS/cm)	630.3	35.64	355	504.9	581.4	659.6	1680	
Dissolved Oxygen (mg/L)	7.22	0.25	1.44	6.82	7.68	8	9.86	
pH (units)	7.10	0.026	6.74	7	7.12	7.19	7.47	
Field Alkalinity (mg/L)	207.7	5.52	141	187.5	204	224	322	
Field Hardness (mg/L)	233.9	10.21	150	199.8	218.5	252	455	
Field calculated Bicarbonate (mg/L)	255.6	6.82	173	230.5	251	276	397	
Total Dissolved Solids (mg/L)	369.6	19.89	225	294	340	406.5	848	SMCL: 500; 6 over

Table I2. 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	0.24	

Table I3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	288.3	40.82	106	180.3	243	326.8	1770	
dissolved Calcium (mg/L)	75.24	3.11	38.7	62.73	72.2	83.1	139	
Chloride (mg/L)	25.75	6.09	<10	<10	14.15	29.73	207	SMCL: 250; 0 over
Fluoride (mg/L)	0.265	0.032	<0.2	<0.2	0.225	0.31	0.89	MCL: 4; 0 over
dissolved Magnesium (mg/L)	10.85	1.07	<5	7.2	9.25	13.4	10.3	
dissolved Potassium (mg/L)	2.54	0.267	0.8	1.6	2.05	2.53	8.7	
dissolved Silica (mg/L)	30.69	1.22	20.1	25.6	28.3	32.3	54.9	
dissolved Sodium (mg/L)	34.09	4.81	6.5	18	26.6	34.83	140	
Sulfate (mg/L)	23.73	4.12	<10	13.35	16	23.85	138	SMCL: 250; 0 over

Table I4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Barium (µg/L)	336.9	25.46	57.6	216.3	316	426.8	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	1.38	2	2.98	8.6	MCL: 30; 0 over
dissolved Vanadium (µg/L)	15.84	1.39	<10	11.23	14.4	18.18	41.9	
dissolved Zinc (µg/L)	28.41	5.05	<10	<10	14.55	50.3	147	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix J– 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 J1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	220.6	10.61	30	137.5	200	292	800	N=123
Depth to Water (ft)	62.44	3.43	7.75	37	58.88	82.64	196.6	Below ground surface
Temperature (°C)	19.64	0.182	15.22	18.79	19.56	20.32	23.87	
Specific Conductance (µS/cm)	1075	121.2	102.3	456.7	659.7	1453	5866	
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)	187.5	8.34	25	150	182.5	219.3	384	
Field Hardness (mg/L)	558.1	68.85	139	201	302	625	1998	N=63
Field calculated Bicarbonate (mg/L)	230.7	10.29	30.5	184.8	224.5	270	473	
Total Dissolved Solids (mg/L)	865.7	114.7	178	273.8	426.5	1133	4680	SMCL: 500; 26 over

Table J2. 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 J3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	287.8	20.62	121	195.5	248.5	320.3	1200	
dissolved Calcium (mg/L)	173.2	22.12	31.2	53.05	78.45	231.8	556	
Chloride (mg/L)	31.64	12.67	<10	<10	11.8	25.78	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)	29.08	3.29	<5	13.25	18.64	29.08	128	
dissolved Potassium (mg/L)	1.49	0.122	<0.5	0.9	1.25	1.6	6	
dissolved Silica (mg/L)	27.86	0.76	11.4	25.15	27.45	30.2	48.4	
dissolved Sodium (mg/L)	44.62	13.66	8.4	18.58	25.35	35.53	890	
Sulfate (mg/L)	400.7	75.65	<10	16.6	61.35	627	2300	SMCL: 250; 20 over

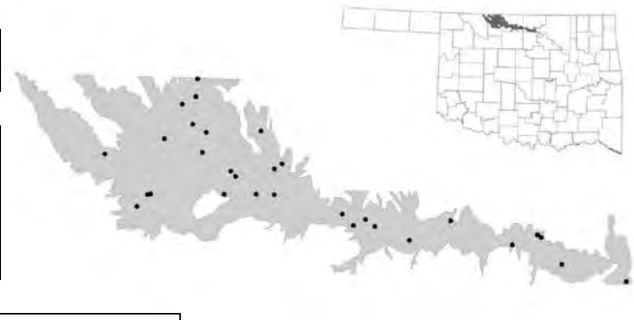
Table J4. Descriptive statistics on metal constituents.

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)	150.0	21.88	<10	16.5	104.5	189	859	MCL: 2000; 0 over
dissolved Boron (µg/L)	119.7	28.1	<50	<50	53.9	128.5	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	0.66	<1	1.18	2.6	5.83	27.2	MCL: 30; 0 over
dissolved Vanadium (μg/L)	14.44	1.11	<10	<10	13.4	17.65	40.2	
dissolved Zinc (μg/L)	21.16	5.15	<10	<10	<10	17.63	299	SMCL: 5000; 0 over. HA: 2000; 0 over

Appendix K– Descriptive Statistics & Selected Maps for Salt Fork of the Arkansas River Alluvial and Terrace Aquifer

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



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

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	44.42	1.66	24	36.75	42.5	50	97	N=51
Depth to Water (ft)	15.56	0.857	-0.38	12.36	15.8	19.54	30.2	Below ground surface
Temperature (°C)	20.76	0.391	17.68	19.29	20.51	21.49	26.96	
Specific Conductance (µS/cm)	1148	108.6	107	783.3	1042	1534	2291	
Dissolved Oxygen (mg/L)	2.34	0.403	0.18	0.435	1.44	3.92	7.45	
pH (units)	7.09	0.046	6.3	7.01	7.13	7.25	7.4	
Oxidation Reduction Potential (mV)	241.7	22.09	45	213	259.6	279.6	358.9	N=14
Field Alkalinity (mg/L)	315.1	22.62	28	223.5	331.5	414	492	
Field Hardness (mg/L)	369.8	34.93	41	233.8	347.5	465.5	872	
Field calculated Bicarbonate (mg/L)	387.6	32.5	34.5	275	408	508.8	605	
Total Dissolved Solids (mg/L)	657.1	66.8	86.3	426	552	842.5	1470	SMCL: 500; 18 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 2 (0.14, 0.2)							
Nitrate+nitrite (mg/L)	5.03	0.968	<0.05	0.913	4.14	6.89	20	MCL: 10; 5 over
Phosphorus (mg/L)	0.096	0.014	<0.005	0.048	0.066	0.127	0.311	

Table K3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	477.4	64.5	<100	262.8	419	602.8	1720	
dissolved Calcium (mg/L)	75.38	5.21	10.4	55.63	76.1	98.6	117	
Chloride (mg/L)	98.94	20.56	<10	23.7	55.25	96.65	398	SMCL: 250; 5 over
Fluoride (mg/L)	0.413	0.050	<0.2	0.255	0.31	0.535	1.37	MCL: 4; 0 over
dissolved Magnesium (mg/L)	39.98	5.83	2	20.38	31	53.33	138	
dissolved Potassium (mg/L)	2.24	0.475	<0.5	1.2	1.4	2.33	14.9	
dissolved Silica (mg/L)	18.12	0.771	12.2	15.53	17.65	19.78	34	
dissolved Sodium (mg/L)	113.2	15.92	6.6	49.83	94.15	147	307	
Sulfate (mg/L)	114.8	23.38	<10	38.28	66.1	129.3	508	SMCL: 250; 4 over

Table K4. 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)	144.4	18.1	23.5	71.58	125	183.3	387	MCL: 2000; 0 over
dissolved Boron (µg/L)	143.6	16.95	<20	71.15	120.5	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)	74.07	33.84	<5	<5	<5	10.98	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	1.93	4.65	14.48	30.9	MCL: 30; 1 over
dissolved Vanadium (µg/L)	5.99	0.768	<5	<5	5.85	7.38	18.3	
dissolved Zinc (µg/L)	28.03	6.81	<5	<5	7.1	36.55	125	SMCL: 5000; 0 over HA: 2000; 0 over

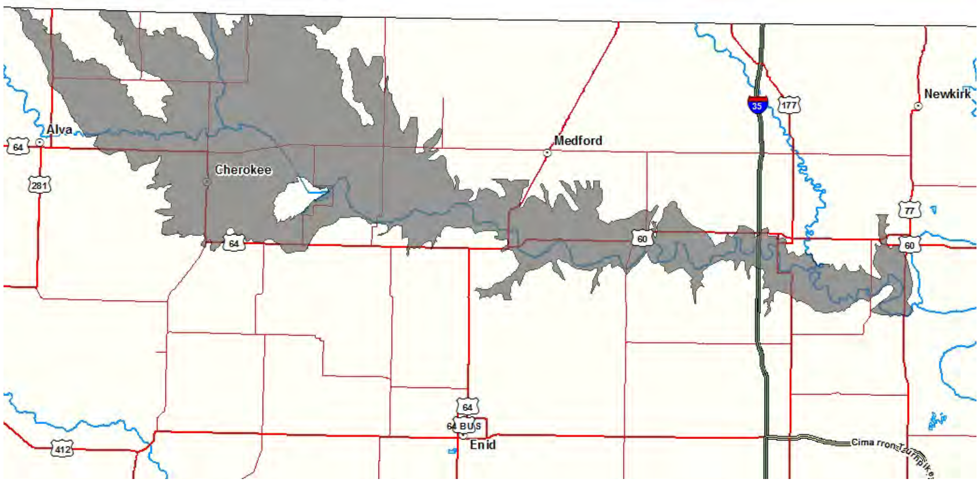


Figure K.1. Location and extent of the SFAR.

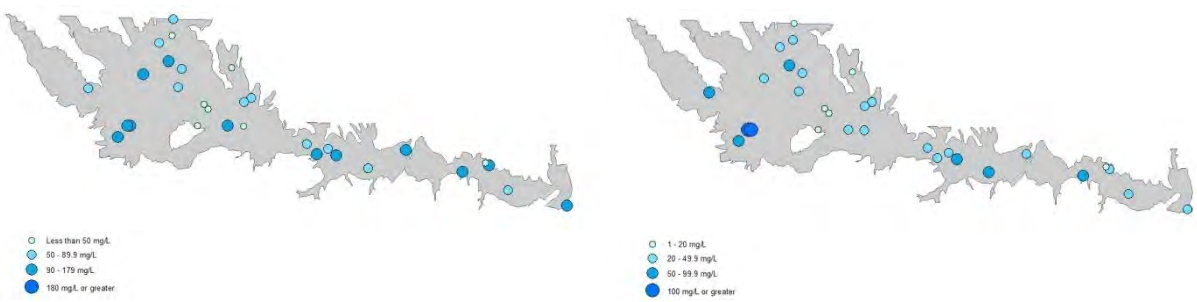


Figure K.2. Calcium (left) and magnesium concentrations in the SFAR.

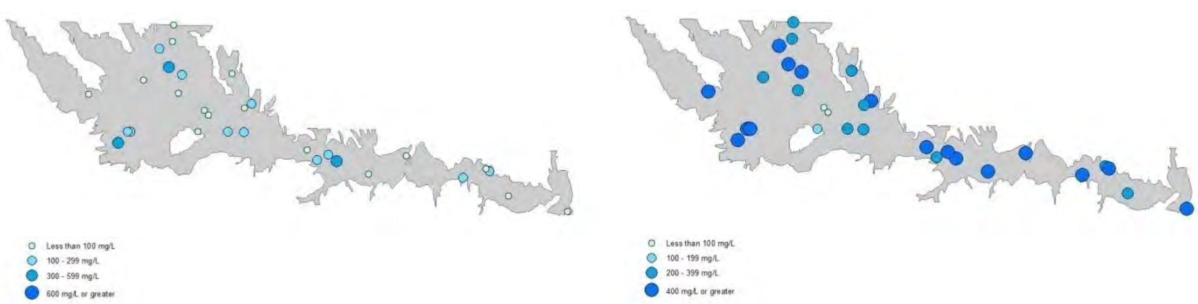


Figure K.3. Sodium+potassium (left) and bicarbonate concentrations in the SFAR.

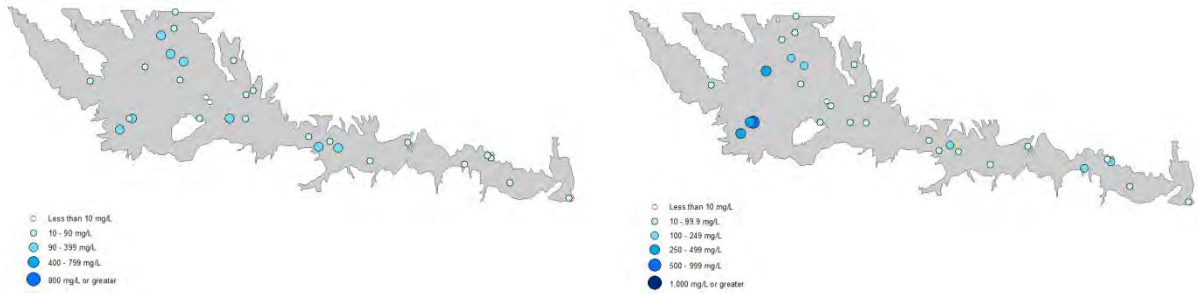


Figure K.4. Chloride (left) and sulfate concentrations in the SFAR.

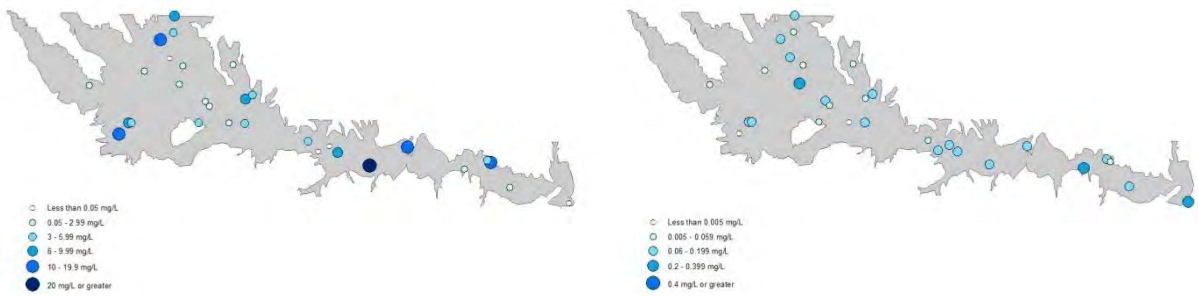


Figure K.5. Nitrate+nitrite (left) and total dissolved phosphorus concentrations in the SFAR.

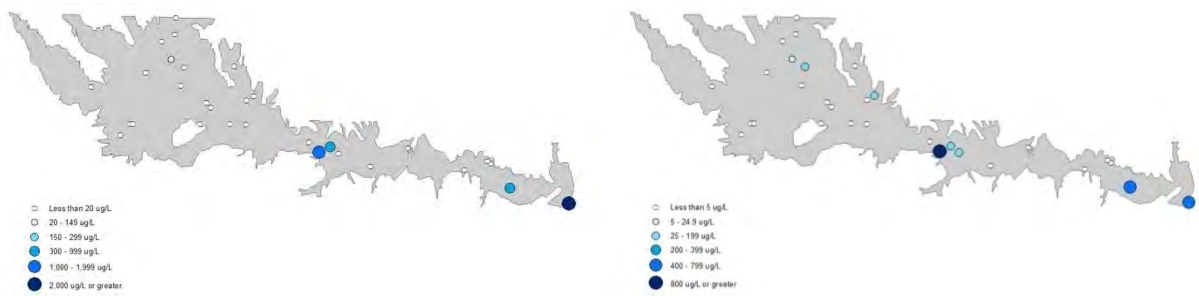


Figure K.6. Iron (left) and manganese concentrations in the SFAR.

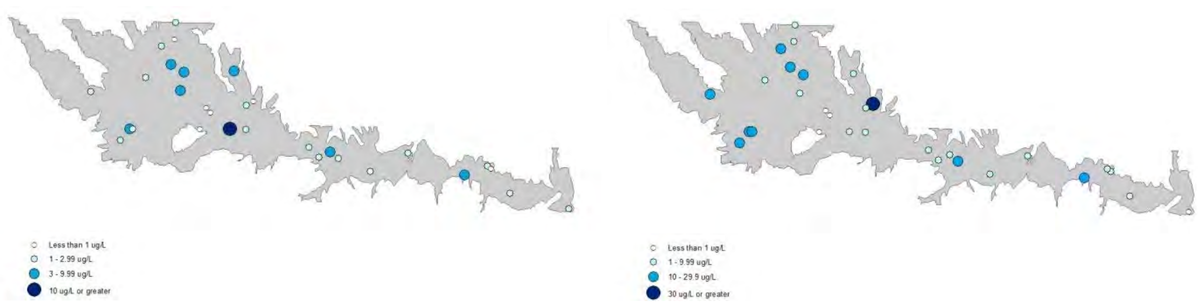
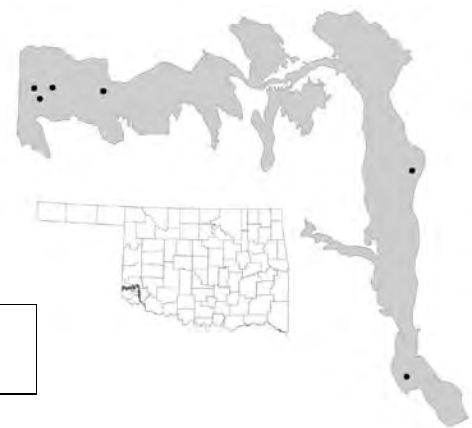


Figure K.7. Arsenic (left) and uranium concentrations in the SFAR.

Appendix L– Descriptive Statistics & Selected Maps 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 L1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	100.4	22.69	40	55	80	98	230	N=9
Depth to Water (ft)	40.83	10.59	8.15	18.65	47.62	58.99	69.8	Below ground surface
Temperature (°C)	21.19	0.775	18.36	20.09	21.9	21.97	23.54	
Specific Conductance (µS/cm)	2340	1257	488	532	634.7	3298	7957	
Dissolved Oxygen (mg/L)	5.77	1.27	0.17	5.28	6.49	7.03	9.4	
pH (units)	7.03	0.096	6.67	6.89	7.06	7.22	7.27	
Oxidation Reduction Potential (mV)	370.1	42.45	188.8	331.5	420.3	425.1	462.5	
Field Alkalinity (mg/L)	229.3	14.24	183	210.3	228	243.5	284	
Field Hardness (mg/L)	787.3	369.2	182	233.3	259.5	1163	2334	
Field calculated Bicarbonate (mg/L)	282.3	17.62	225	258.8	280.5	300	350	
Total Dissolved Solids (mg/L)	1754	965.9	303	352	402.5	2349	6080	SMCL: 500; 2 over

Table L2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (mg/L)	10.14	1.23	6.26	8.71	9.73	11.18	15.1	MCL: 10; 3 over
Phosphorus (mg/L)	0.034	0.010	<0.005	0.013	0.044	0.05	0.059	

Table L3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	1477	949.0	265	295	301.5	1276	6100	
dissolved Calcium (mg/L)	161.2	58.69	56.6	72.28	78.2	237.1	394	
Chloride (mg/L)	340	234.6	<10	<10	<10	466.3	1400	SMCL: 250; 2 over
Fluoride (mg/L)	0.33	0.059	<0.2	0.26	0.345	0.445	0.48	MCL: 4; 0 over
dissolved Magnesium (mg/L)	68.18	39.10	9.2	10.45	13.3	94.68	242	
dissolved Potassium (mg/L)	3.73	0.881	2	2.2	2.65	5.28	6.9	
dissolved Silica (mg/L)	19.19	4.0	7.12	11.58	19.7	26.25	31.3	
dissolved Sodium (mg/L)	274.8	169.4	29.7	30.85	35.95	367.6	1040	
Sulfate (mg/L)	647.8	420.3	27.2	34.6	37.8	947.5	2500	SMCL: 250; 2 over

Table L4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.97	0.983	1.3	1.45	1.8	3.58	7.4	MCL: 10; 0 over
dissolved Barium (µg/L)	104.1	31.64	10.1	32.95	129.5	165	178	MCL: 2000; 0 over
dissolved Boron (µg/L)	359.5	188.0	48.1	80.65	94.35	536.8	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)	113.3	52.57	<5	<5	<5	125.1	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)	15.27	9.23	<10	<10	<10	9.05	61.2	MCL: 50; 1 over
dissolved Uranium (µg/L)	9.15	4.52	<1	1.93	4.2	13	28.9	MCL: 30; 0 over
dissolved Vanadium (µg/L)	21.3	11.42	5.2	6.63	6.95	21.3	76.1	
dissolved Zinc (µg/L)	14.07	4.66	<5	<5	12	23.2	28.8	SMCL: 5000; 0 over HA: 2000; 0 over

Figure L.1. Location and extent of the SFRR.

Figure L.2. Calcium (left) and magnesium concentrations in the SFRR.

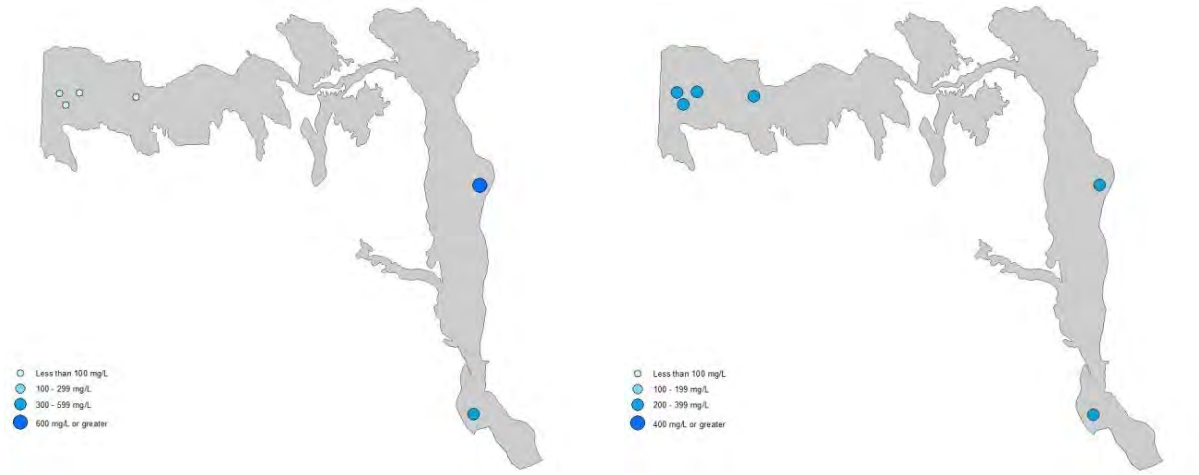


Figure L.3. Sodium+potassium (left) and bicarbonate concentrations in the SFRR.

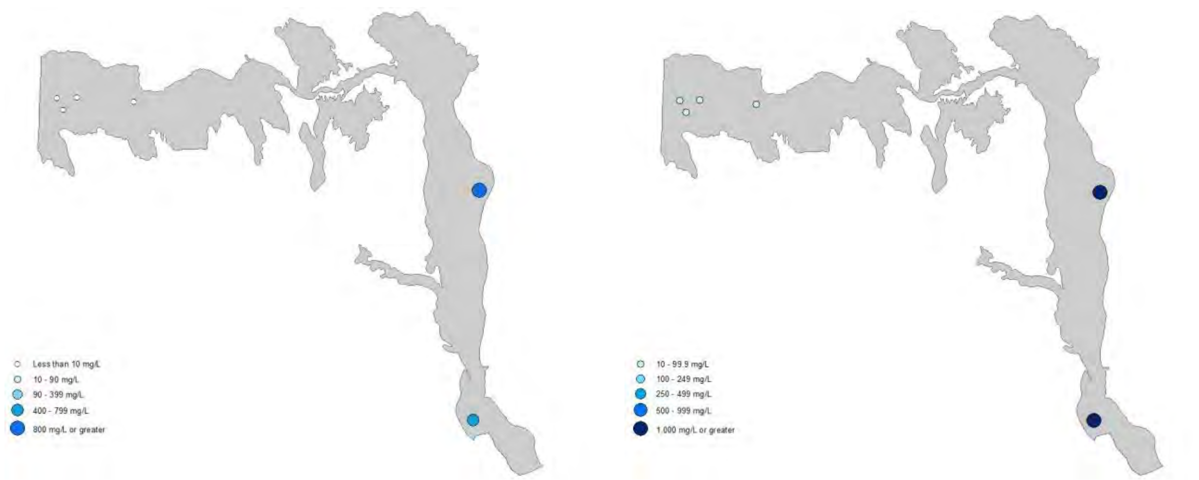
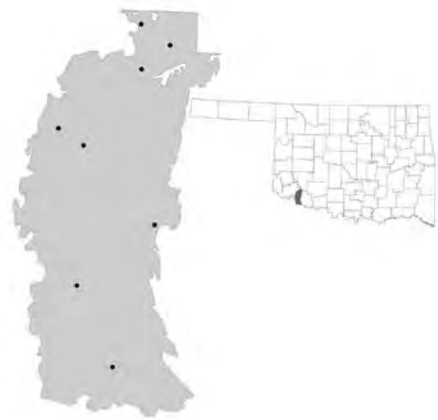


Figure L.4. Chloride (left) and sulfate concentrations in the SFRR.

Figure L.5. Nitrate+nitrite concentrations in the SFRR.

Appendix M– Descriptive Statistics & Selected Maps 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 M1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	50.92	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	0.64	20.9	21.68	22.59	23.81	26.06	
Specific Conductance (µS/cm)	1710	472.1	729	939.8	1225	1885	4812	
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)	339.9	31.01	162	300.9	361.2	402.0	430.5	
Field Alkalinity (mg/L)	326.9	29.84	267	274.5	286	361	464	N=7
Field Hardness (mg/L)	451.1	77.64	300	333.5	390	453	895	N=7
Field calculated Bicarbonate (mg/L)	402.3	36.67	329	338	352	444	571	N=7
Total Dissolved Solids (mg/L)	1022	310.3	395	545.5	699.5	1110	3090	SMCL: 500; 7 over

Table M2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Nitrate+nitrite (mg/L)	13.89	3.05	0.1	9.56	13.85	20.35	24.5	MCL: 10; 6 over
Phosphorus (mg/L)	0.018	0.009	<0.005	<0.005	0.009	0.018	0.076	

Table M3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	1024	334.1	355	534	625	1160	3210	
dissolved Calcium (mg/L)	91.81	14.69	57.7	71.88	78.7	90.83	190	
Chloride (mg/L)	216.3	98.24	<10	41.5	127	268	849	SMCL: 250; 3 over
Fluoride (mg/L)	0.505	0.111	<0.2	0.265	0.5	0.673	1.05	MCL: 4; 0 over
dissolved Magnesium (mg/L)	39.64	5.64	23.4	27.05	37.95	43.05	70.2	
dissolved Potassium (mg/L)	2.59	0.538	0.9	1.58	2.15	3.35	5.6	
dissolved Silica (mg/L)	18.86	1.01	14.8	16.9	19	20.98	22.8	
dissolved Sodium (mg/L)	229.2	91.72	15.1	70.03	164	255.5	830	
Sulfate (mg/L)	199.4	104.2	25.8	52.03	103.2	171.5	912	SMCL: 250; 1 over

Table M4. 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	2.05	2.4	4	MCL: 10; 0 over
dissolved Barium (µg/L)	109.1	26.37	31.3	61.08	90.2	142	256	MCL: 2000; 0 over
dissolved Boron (µg/L)	256.5	41.14	108	127	320	348.3	359	HA: 6000; 0 over

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Iron (µg/L)	All Values <20, except 2 (21.7, 421)							SMCL: 300; 1 over
dissolved Manganese (µg/L)	All Values <5, except 2 (23.8, 281)							SMCL: 50; 1 over HA: 300; 0 over
dissolved Uranium (µg/L)	9.73	2.31	1.8	6.18	9.2	11.85	22.5	MCL: 30; 0 over
dissolved Vanadium (µg/L)	8.4	1.44	<5	6.05	7.25	11.4	15	
dissolved Zinc (µg/L)	24.54	8.70	<5	<5	15.2	47.88	62.1	SMCL: 5000; 0 over HA: 2000; 0 over

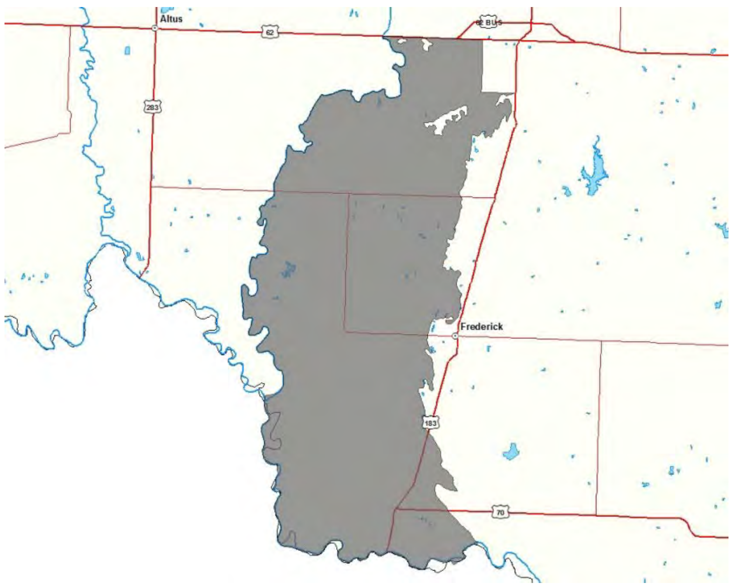


Figure M.1. Location and extent of the TILL.

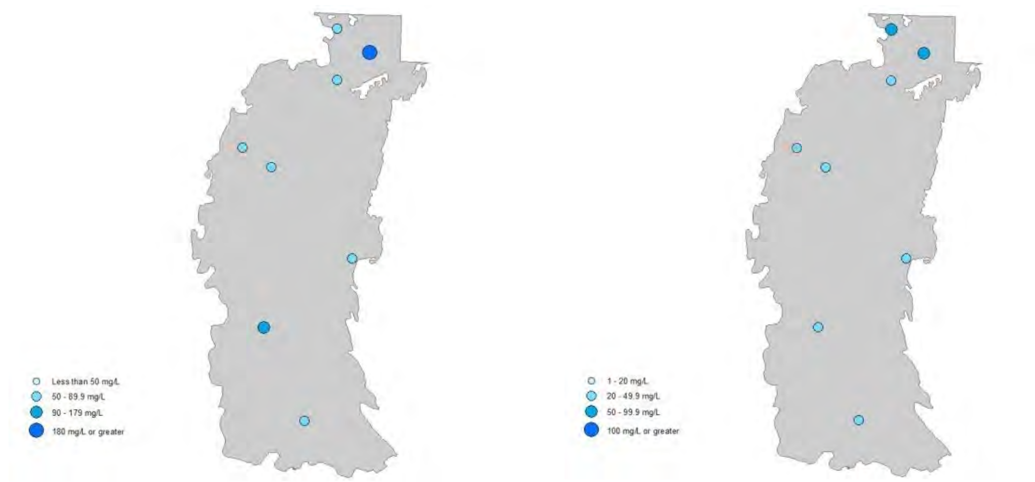


Figure M.2. Calcium (left) and magnesium concentrations in the TILL.

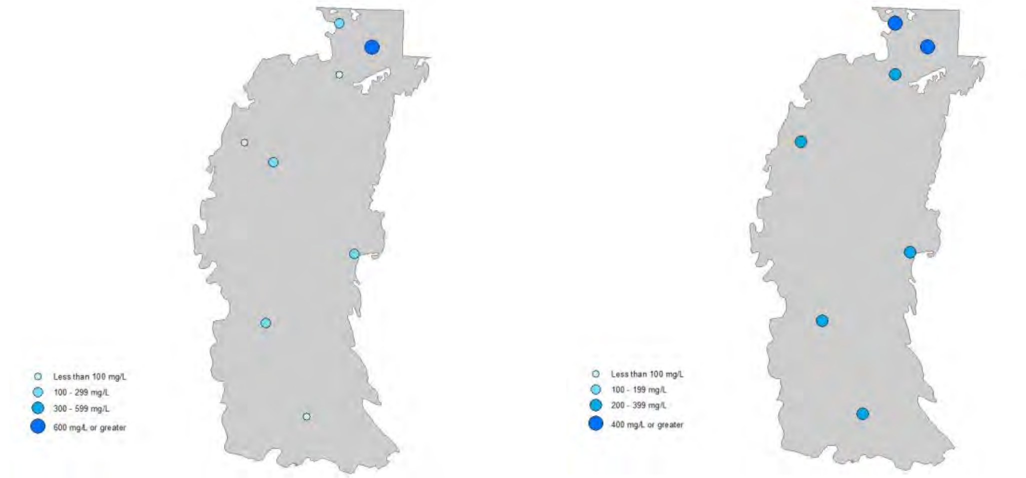


Figure M.3. Sodium+potassium (left) and bicarbonate concentrations in the TILL.

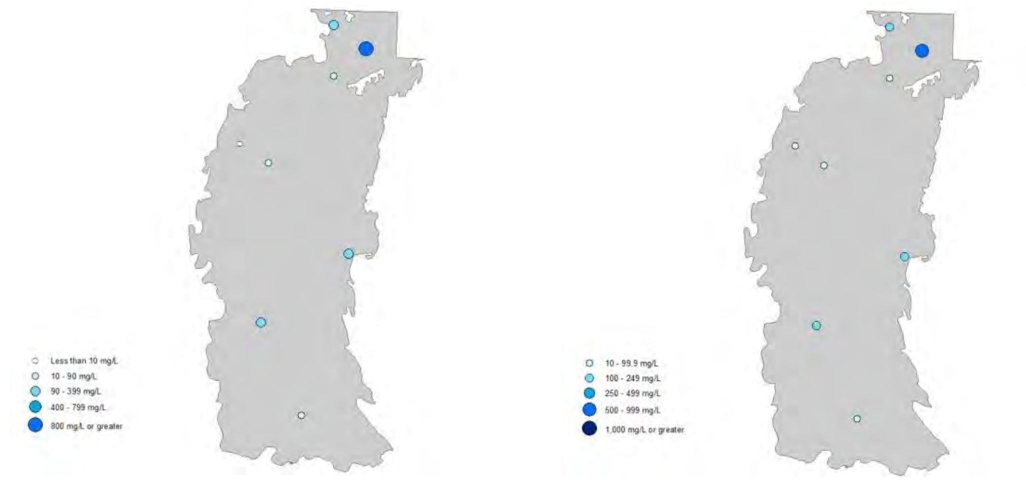


Figure M.4. Chloride (left) and sulfate concentrations in the TILL.

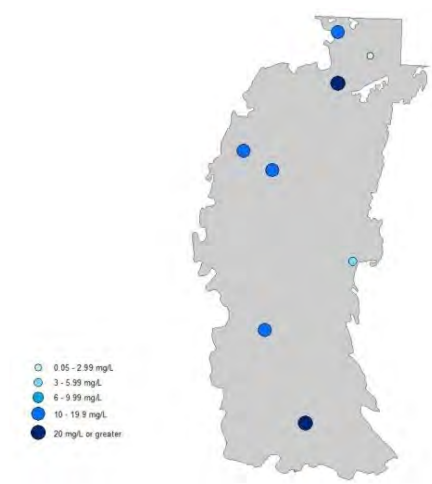
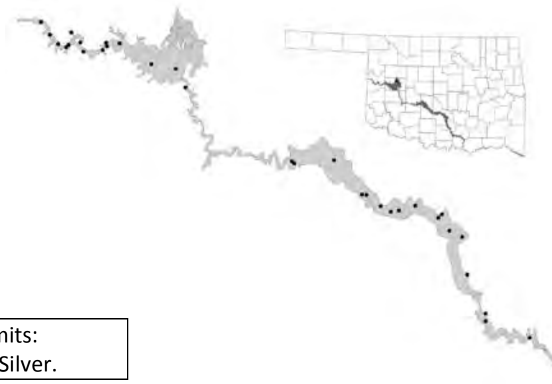


Figure M.5. Nitrate+nitrite concentrations in the TILL.

Appendix N– Descriptive Statistics & Selected Maps 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 N1. Descriptive statistics on general parameters taken in the field.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Well Depth (ft)	95.85	6.27	28	70	85	111	190	N=42
Depth to Water (ft)	24.78	2.77	4.6	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	25.4	
Specific Conductance (µS/cm)	1902	204.8	231.9	893.5	1736	2866	4073	
Dissolved Oxygen (mg/L)	2.06	0.365	0.25	0.455	0.82	3.68	7.5	
pH (units)	7.18	0.043	6.52	7	7.21	7.37	7.57	
Oxidation Reduction Potential (mV)	241.9	22.15	202.4	223.5	244.5	261.8	279	N=3
Field Alkalinity (mg/L)	297.9	30.76	35.4	175.5	264	410.5	720	
Field Hardness (mg/L)	1034	116.9	142	447	1030	1663	1916	
Field calculated Bicarbonate (mg/L)	366.4	37.86	43.4	215.5	325	505	886	
Total Dissolved Solids (mg/L)	1554	214.2	138	509.5	990	2740	3650	SMCL: 500; 24 over

Table N2. 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	0.135	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	0.04	0.093	0.382	

Table N3. Descriptive statistics on mineral constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Bromide (µg/L)	537.6	97.06	124	293.5	363	465.5	2570	
dissolved Calcium (mg/L)	209.2	27.01	24.5	81.4	127	363.5	534	
Chloride (mg/L)	49.99	13.57	<10	17.1	31	47.35	412	SMCL: 250; 1 over
Fluoride (mg/L)	0.231	0.027	<0.2	<0.2	0.23	0.275	0.7	MCL: 4; 0 over
dissolved Magnesium (mg/L)	85.53	8.97	5.3	43.75	85.6	127	172	
dissolved Potassium (mg/L)	2.08	0.169	<0.5	1.55	2	2.4	4	
dissolved Silica (mg/L)	22.28	1.39	8.92	18.35	21.3	35.25	41.6	
dissolved Sodium (mg/L)	89.78	16.03	5.3	29.05	58.1	108	365	
Sulfate (mg/L)	803.6	157.7	<10	28.85	111	1760	2300	SMCL: 250; 15 over

Table N4. Descriptive statistics on metal constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Arsenic (µg/L)	2.68	0.339	<1	1.15	2.5	4.1	8.7	MCL: 10; 0 over
dissolved Barium (µg/L)	142.2	30.93	<5	11.1	82.4	210	524	MCL: 2000; 0 over
dissolved Boron (µg/L)	508.8	99.29	30.6	122	332	617.5	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)	364.5	91.94	<20	<20	27.2	688	1580	SMCL: 300; 10 over
dissolved Manganese (µg/L)	202.0	48.02	<5	7.3	34	353.5	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)	10.45	1.82	<5	<5	8	14.15	37.6	
dissolved Zinc (µg/L)	27.93	15.0	<5	<5	<5	9.95	460	SMCL: 5000; 0 over. HA: 2000; 0 over

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

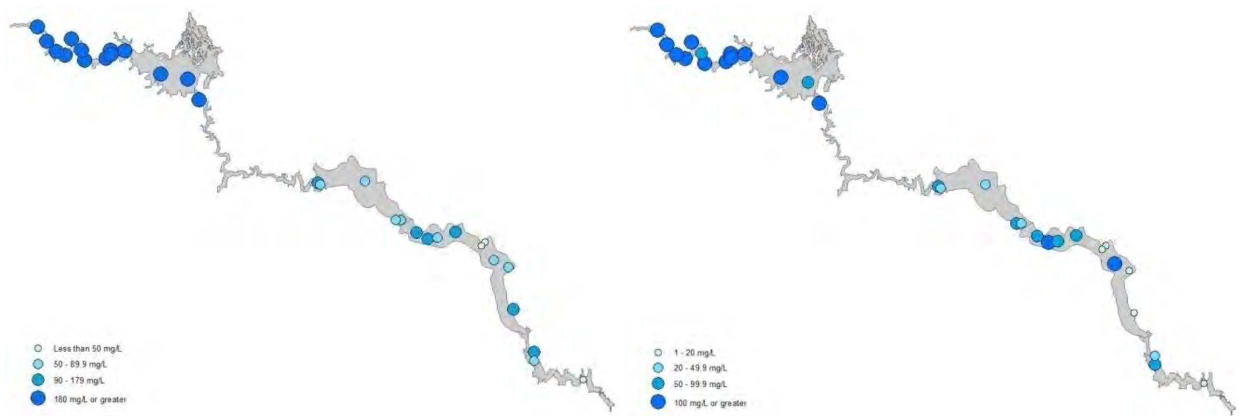


Figure N.2. Calcium (left) and magnesium concentrations in the WASH.

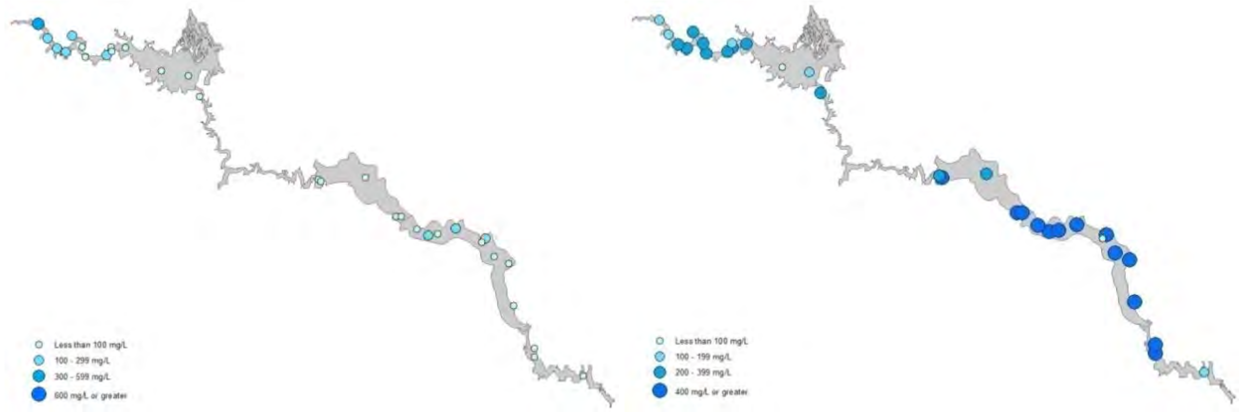


Figure N.3. Sodium+potassium (left) and bicarbonate concentrations in the WASH.

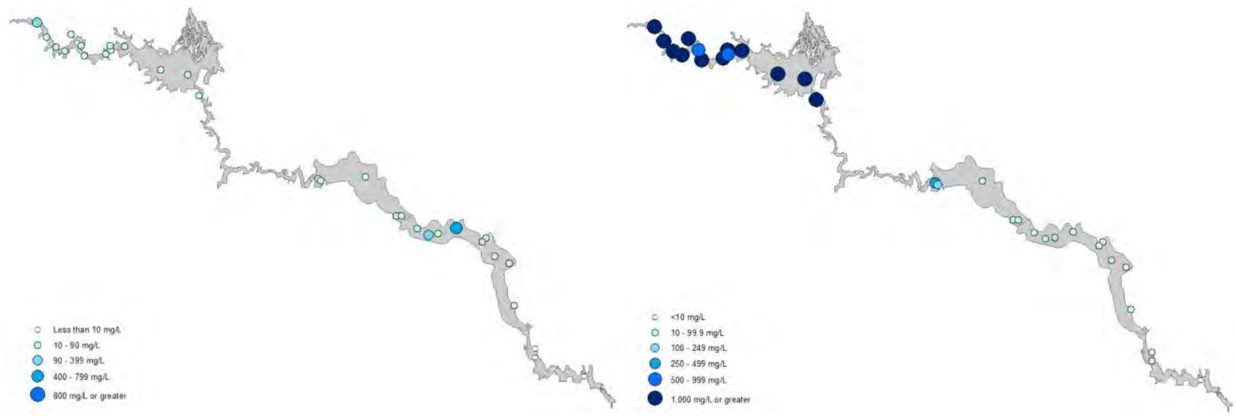


Figure N.4. Chloride (left) and sulfate concentrations in the WASH.

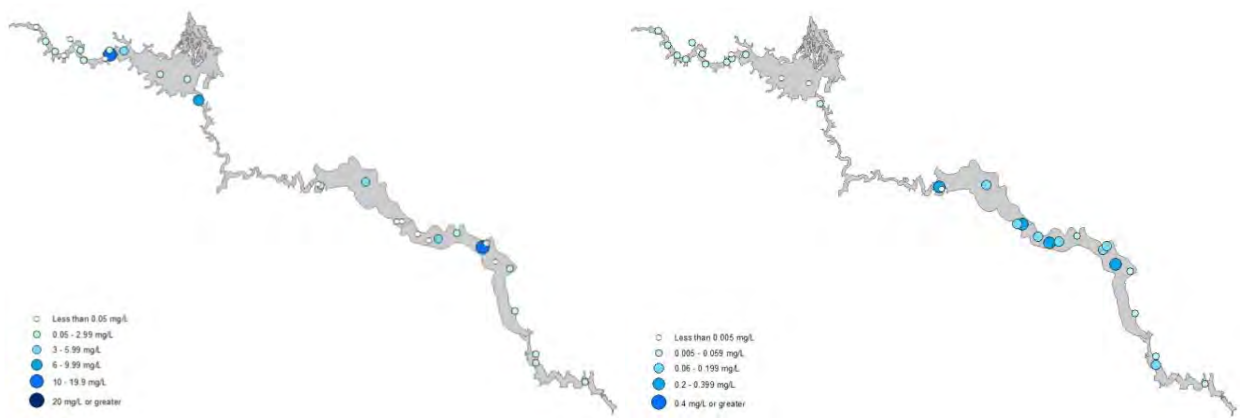


Figure N.5. Nitrate+nitrite (left) and total dissolved phosphorus concentrations in the WASH.

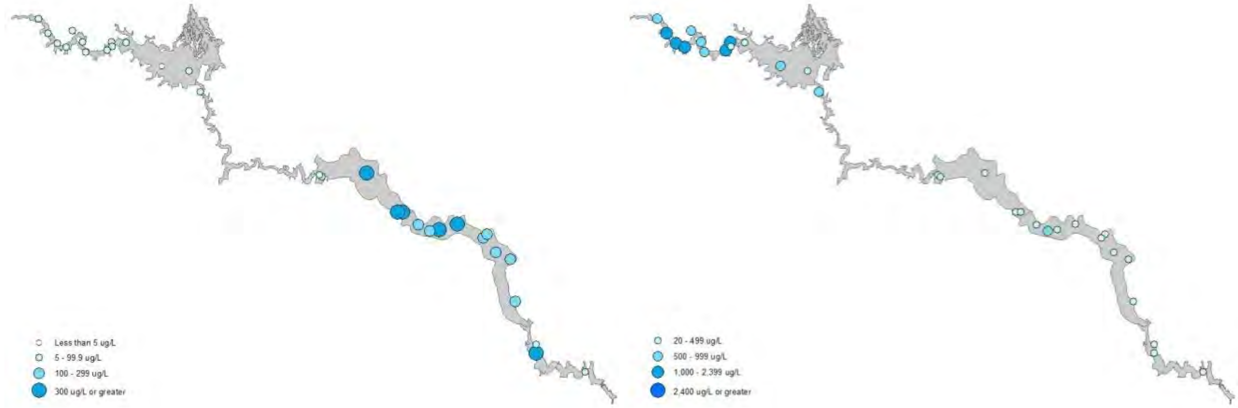


Figure N.6. Barium (left) and boron concentrations in the WASH.

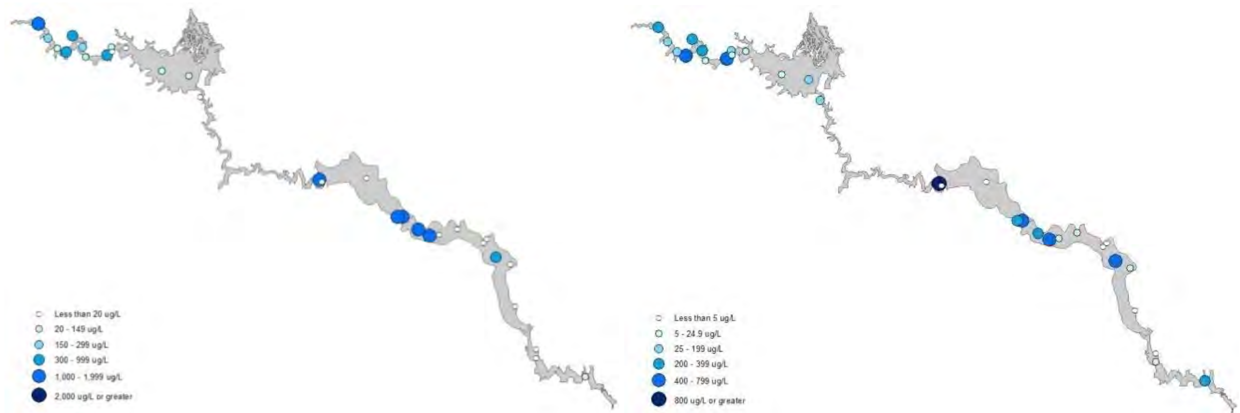


Figure N.7. Iron (left) and manganese concentrations in the WASH.

Figure N.8. Uranium concentrations in the WASH.