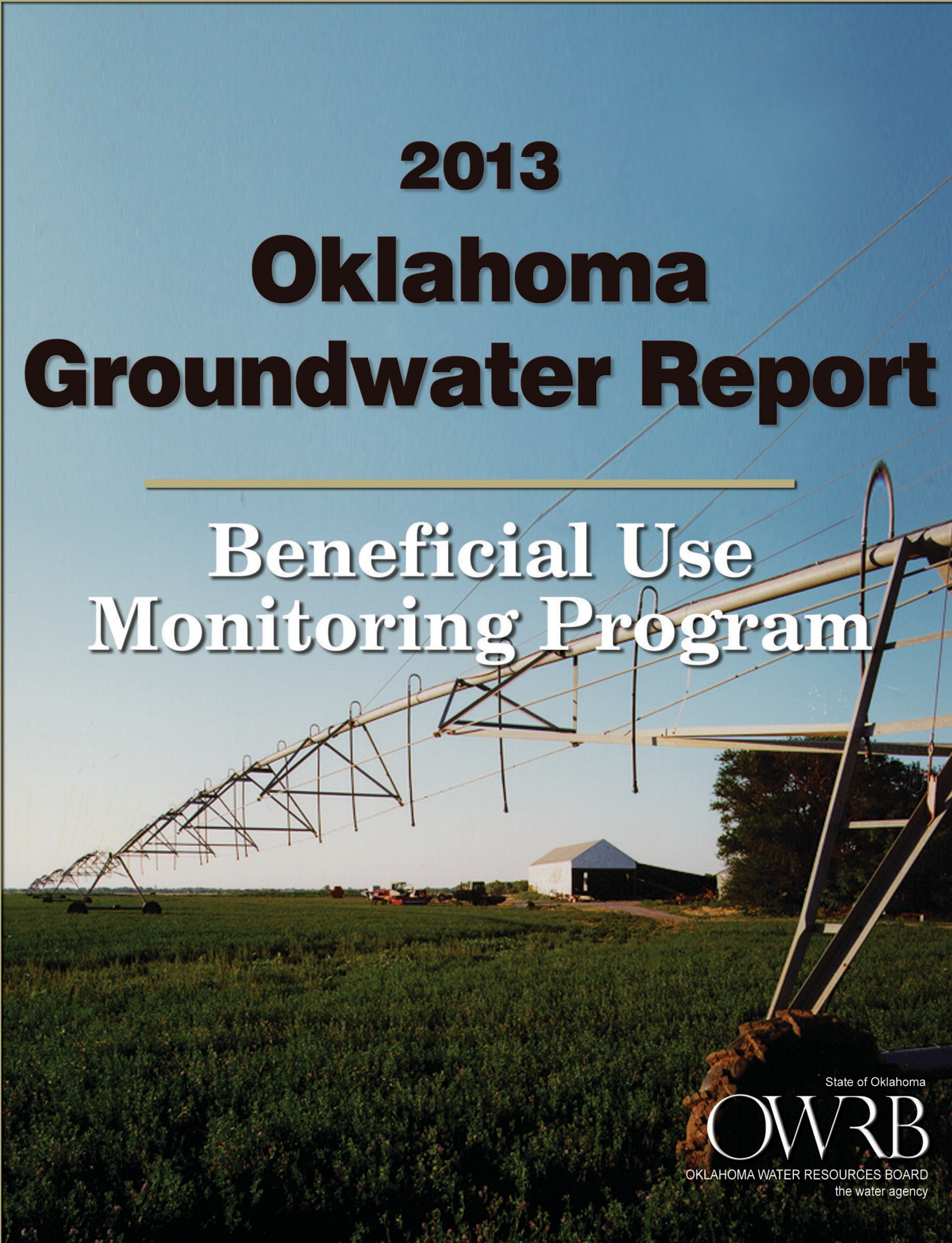
2013 Oklahoma Groundwater Report

Beneficial Use Monitoring Program



State of Oklahoma

OWRB

OKLAHOMA WATER RESOURCES BOARD

the water agency

2013
Oklahoma Groundwater Report

Published by the Oklahoma Water Resources Board's Groundwater Monitoring and Assessment Program (GMAP), a component of the Beneficial Use Monitoring Program (BUMP).

Table of Contents

Table of Figures

Table of Tables

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 toward 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 this Oklahoma Water Resources Board (OWRB) report 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 are 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 OWQS and facilitate the prioritization of pollution control activities. Data collected from the Groundwater Monitoring and Assessment Program 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 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. The data contained in this report is scientifically defensible and 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 Oklahoma Water Quality Standards (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.

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 a $1,500,000 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. Water quality data will be collected from networks of wells on the basis of an aquifer's areal extent. This design feature generated sample populations of at least 30 wells for each of Oklahoma's 15 largest aquifers. Smaller aquifers are represented by fewer wells but proportionally have more sites per areal extent (Table 1).

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

In the first year of sampling, 203 wells in 6 major aquifers were sampled for water quality and 299 wells for water level. 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. Work began on expanding the groundwater level measurement program in January 2014 with the addition of 87 new wells to the program. For one half of the water level network, manual measurements will become tri-annual events. In January 2014 110 wells were added to the tri-annual measurement network. Additionally, over the 4-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. 16 continuous water level recorders were installed in 8 aquifers across the state for this purpose in the first year of sampling.

- **Monitoring Rivers & Streams** - The OWRB is currently monitoring approximately eighty-four (84) stations on a 6-week rotation. Fixed station monitoring is based largely upon the eighty-four (84) planning basins as outlined in the Oklahoma Comprehensive Water Plan (OCWP). In general, at least one (1) sample station was located at the terminal end of each of the planning basins. The OWRB also conducts sampling on 25-30 probabilistic monitoring stations annually.
- **Fixed Station Load Monitoring** - The OWRB is currently working with several partners including the United States Geological Survey (USGS), US Army Corp of Engineers (USACE), Grand River Dam Authority, and other partners to conduct flow monitoring on all of our fixed station sites that are not part of the Oklahoma/USGS Cooperative Gaging Network. This cooperative effort will allow for loadings to be calculated, trends to be assessed statewide, and provide much needed data for the Use Support Assessment process. Along with the USGS cost share program, Oklahoma's 319 program, Oklahoma's 314 program and the 303(d)-process will drive sample site locations associated with this task.
- **Fixed Station Lakes Monitoring** - As part of the Beneficial Use Monitoring Program, the Oklahoma Water Resources Board (OWRB) conducts sampling on lakes and reservoirs across the State of Oklahoma. To accomplish this task, the OWRB has taken a probabilistic survey approach for the lakes monitoring program. This survey design allows the state's objectives to be met as well as ensure various sized waterbodies are represented adequately. The survey population includes all lakes above 50 surface acres, which encompasses approximately 206 different waterbodies. The population is then stratified into two groups – lakes greater than 500 surface acres and those below 500 surface acres. The greater than 500 surface acres group includes 68 lakes, of which approximately one-fifth are monitored annually (quarterly samples) 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 these 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 waterbodies managed by the Corps. Data collected consists primarily of water chemistry, nutrients, and chlorophyll-a information. In general, a minimum of three to five stations per reservoir is 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. Water quality parameters have been added to the lakes sampling effort over the years to enhance program ability to make use support determinations.

- **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. One potential use for the intensive studies envisioned was identified during the data analysis phase of this reporting process. For example, monies could be spent to identify if high turbidity readings in rivers and streams are due to natural processes or due to human activities in the watershed of concern. 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, just to mention a few.

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, randomized (probabilistic) 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 for six (6) of Oklahoma's major aquifers. The baseline monitoring will be phased in over a four year interval (Figure 1). 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 station (trend sites) to observe water quality and water level changes over time.

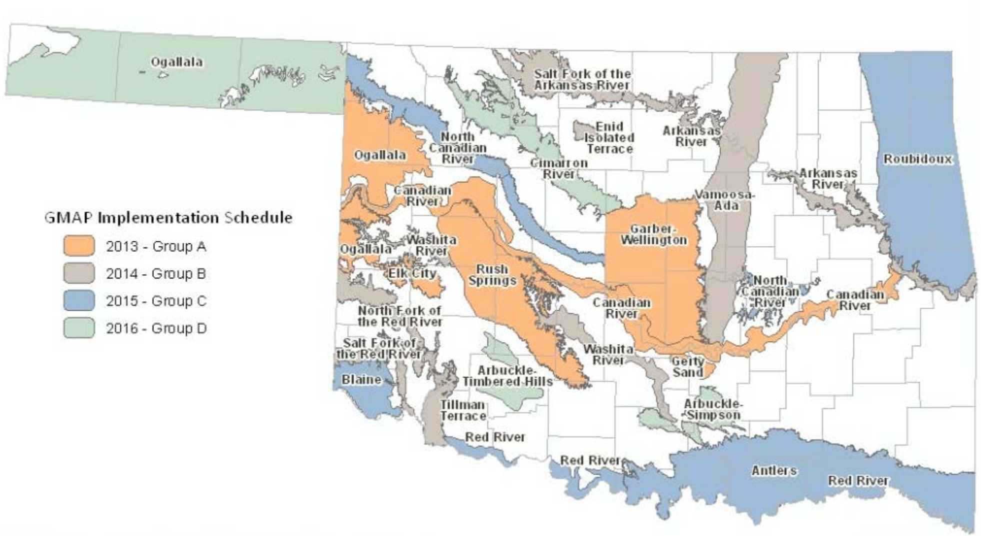


Figure 1. GMAP implementation schedule.

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 two hundred ninety-nine (299) groundwater level measurements were made. Four (4) continuous water level recorders collecting hourly measurements were also installed in the Group A aquifers. Table 2 reflects aquifer-wide median concentrations for a subset of the analytical and physical data collected during the first year along with an enumeration of the number of wells sampled by use category.

Table 2. Baseline Characteristics of Group A Aquifers.

SP	Aquifer	Field Parameters		Analytical Parameters						Well Use Categories						DTW
		pH	Hard	TDS	NO3	Ca	Na	Cl	SO4	P	I	S	D	M	N	
34	CANR-AQ	7.01	394	533	1.19	112	45.9	33.9	99.9	4	8	3	13	4	2	15.1
13	ELKC-AQ	7.26	272	349	6.37	67.2	36.5	10.6	16.5	0	1	5	7	0	0	22.8
47	GBWL-AQ	6.97	261	328	0.89	55.6	31.8	18.8	17.4	0	0	0	47	0	0	69.9
5	GRTY-AQ	6.43	202	306	2.12	50.8	33.4	36.8	13.0	0	0	2	3	0	0	45.5
40	OGNW-AQ	7.12	219	340	6.02	72.2	26.6	14.2	16.0	3	3	6	18	10	0	74.2
64	RSPG-AQ	7.18	302	427	4.46	78.5	25.4	11.8	61.4	6	10	7	37	4	0	58.9

SP–Samples collected, Aquifers: CANR-AQ-Alluvial & Terrace Deposits of the Canadian River, ELKC-AQ-Elk City Sandstone, GBWL-AQ-Garber-Wellington, GRTY-AQ-Gerty Sand Aquifer, OGNW-AQ-Ogallala Northwest, RSPG-AQ-Rush Springs Sandstone. Field parameters: Hard–Hardness, TDS–Total Dissolved Solids, NO3–Nitrate, 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

It is the intent of this Oklahoma Water Resources Board (OWRB) report 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 are 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.

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*, 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.

In addition to our vital groundwater resources, the state's surface waters generate billions of dollars per year for Oklahoma through tourism, outdoor activities, hydroelectric power, and water supply. The National Recreation Lakes Study Commission (NRLSC) estimates recreation in and around our numerous man-made lakes contributes approximately $2.2 billion each year to Oklahoma's economy. Of additional value are the recreational benefits associated with our smaller municipal/watershed projects, Oklahoma Department of Wildlife lakes, and rivers and streams throughout the state, which infuse millions into state coffers through fishing, hunting, camping and related activities.

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 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. State agencies are responsible for implementing the OWQS as outlined by the OWRB through development of Implementation Plans. 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 assess the effectiveness of our diverse water quality management activities.

The OWQS are housed in OAC 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 to water 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 new Groundwater Monitoring and Assessment Program, 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.

All state environmental agencies are currently required to implement Oklahoma's Water Quality Standards within the scope of their jurisdiction through the development of an Implementation Plan specific for their agency. This process, called OWQS Implementation, allows the OWQS to be utilized by other state agencies in the performance of their regulatory (statutory) responsibilities to manage water quality or to facilitate best management practice initiatives.

In the late 1990s, the need for a protocol to determine beneficial use impairment was identified, which would facilitate state agencies in directing their time and money to the areas in most need of protection or remediation. The OWRB working in close concert with other state environmental agencies and other concerned parties developed Use Support Assessment Protocols (USAP) to be used by all parties for assessing if a water body was meeting its assigned beneficial uses. In addition, protocols were developed which could be coupled with a trend monitoring system to detect threatened waters before they become seriously impaired. Data collection efforts connected with protocol development and/or implementation also serves a vital purpose in refining numerical criteria currently included in the OWQS and in developing appropriate numerical and narrative criteria for future OWQS documents. It is essential that our waters meet their assigned uses and that OWQS implementation protocols are appropriate. Please see the OWRB website for the applicable Oklahoma Administrative Code OAC 785:46 related to the USAP. Final approval of the USAP occurred in 2000 and the OWRB has constantly worked to refine the existing protocols and pursue the addition or modification of USAP protocols to further enhance its utility and effectiveness. It is expected that data collected during the Groundwater Monitoring and Assessment Program will be instrumental in developing beneficial use criteria and anti-degradation protocols for the State's groundwater resources.

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. In general, each environmental agency conducts their monitoring programs with either some degree of integration and coordination with other state, municipal, or federal programs, or with no integration at all. 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 very 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). The goal of the BUMP is 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. The goal of the GMAP is to determine a baseline of water quality and quantity against which future changes can be measured, detect and quantify water quality and quantity trends, and apply collected data toward the establishment of beneficial use criteria for the State's groundwater resources as well as strengthen existing beneficial use criteria.

Beneficial Use and Monitoring Program Overview

The overall 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 OWQS, and facilitate the prioritization of pollution control activities. Data collected from the Groundwater Monitoring and Assessment Program will serve to 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.

Beneficial Use Monitoring Program Components

- **Groundwater Monitoring and Assessment Program (GMAP)** – This new program was made possible as result of a $1,500,000 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 be phased in over 4 years. This baseline period will focus on 4-6 aquifers per year and will assess concentrations of nutrients, metals and major ion species. Water quality data will be collected from networks of wells on the basis of an aquifer's areal extent. This design feature generated sample populations of at least 30 wells for each of Oklahoma's 15 largest aquifers. Smaller aquifers are represented by fewer wells but proportionally have more sites per areal extent (Table 1).
- In the first year of sampling, 203 wells in 6 major aquifers were sampled for water quality and 299 wells for water level. 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 1,100 wells) and will be spatially redistributed. Work began on expanding the groundwater level measurement program in January 2014 with the addition of 115 new wells to the program. For one half of the water level network,

manual measurements will become tri-annual events. In January 2014 109 wells were added to the tri-annual measurement network. Additionally, over the 4-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. 16 continuous water level recorders were installed in 8 aquifers across the state for this purpose in the first year of sampling.

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  The OWRB works with other agencies, such as the US Army Corps of Engineers (USACE), for inclusion of additional information on waterbodies managed by the Corps. Data collected consists primarily of water chemistry, nutrients, and chlorophyll-a information. In general, a minimum of three to five stations per reservoir is 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. Water quality parameters have been added to the lakes sampling effort over the years to enhance program ability to make use support determinations.

- **Intensive Investigations** - If beneficial use impairment is identified or suspected, then all appropriate state agencies will be alerted. 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. One potential use for the intensive studies envisioned was identified during the data analysis phase of this reporting process. For example, monies could be spent to identify if high turbidity readings in rivers and streams are due to natural processes or due to human activities in the watershed of concern. 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 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.

Groundwater Monitoring & Assessment Program

The Oklahoma state legislature adopted the 2012 Oklahoma Comprehensive Water Plan (OCWP) Update 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 rock formation that is capable of holding and yielding significant amounts of groundwater. Aquifers in Oklahoma range in geologic age from Cambrian (570 million years) to Quaternary (1.6 million years to present). Older formations, generally referred to as bedrock aquifers, are typically more consolidated (solid), consisting of sandstone, shale, limestone, dolomite, and gypsum. Alluvial aquifers are younger deposits of unconsolidated sand, silt, and clay. The OWRB defines major bedrock aquifers as those yielding an average of at least 50 gallons per minute (gpm) 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 of the Panhandle, some groundwater depths are approaching 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 issuing or 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 Vamoosa-Ada. 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 and will be phased in over the next 4-6 years (Figure 1). This baseline period will focus on 4-6 aquifers per year and will assess 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 4-6 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 aquifers being considered for monitoring. Wells were filtered by aquifer, by well type and use, by depth according to each aquifer's geology, and by construction and lithology details. 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 randomized well selection was chosen to yield data representing the general water quality of each aquifer using an existing network of 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. Once 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%, whichever is greater

Samples are collected, preserved, and stored on ice, and field analyses of alkalinity and hardness were performed using EPA-equivalent Hach field methods.

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

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 aquifer 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. 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.

The State of Oklahoma designates a domestic beneficial use for groundwater 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 Contaminant Candidate List 3. 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	Reporting limit	USEPA MCL	USEPA SMCL	USEPA Health Advisory
Hardness	General Chemistry		10 mg/L	-	-	-
Alkalinity	General Chemistry		10 mg/L	-	-	-
pH	General Chemistry			-	-	-
Total Dissolved Solids	General Chemistry	SM2540-C	10 mg/L	-	500 mg/L	-
Nitrate+Nitrite	Nutrient	353.2	0.05 mg/L	10 mg/L	-	-
Ammonia	Nutrient	350.1	0.1 mg/L	-	-	-
Phosphorus	Nutrient	365.3	0.005 mg/L	-	-	-
Sulfate	Mineral	375.4	10 mg/L	-	250 mg/L	-

Parameter	Category	ODEQ Analytic method	Reporting limit	USEPA MCL	USEPA SMCL	USEPA Health Advisory
Chloride	Mineral	325.2	10 mg/L	-	250 mg/L	-
Bromide	Mineral	4500BrDM	100 µg/L	-	-	-
Fluoride	Mineral	300.0	0.2 mg/L	4 mg/L	-	-
Aluminum, Dissolved	Metal/Trace Element	200.8	100 µg/L	-	200 µg/L	-
Antimony, Dissolved	Metal/Trace Element	200.8	1 µg/L	6 µg/L	-	-
Arsenic, Dissolved	Metal/Trace Element	200.7	10 µg/L	10 µg/L	-	-
Barium, Dissolved	Metal/Trace Element	200.7	10 µg/L	2,000 µg/L	-	-
Beryllium, Dissolved	Metal/Trace Element	200.8	2 µg/L	4 µg/L	-	-
Boron, Dissolved	Metal/Trace Element	200.7	50 µg/L	-	-	6,000 µg/L
Cadmium, Dissolved	Metal/Trace Element	200.7	5 µg/L	5 µg/L	-	-
Calcium, Dissolved	Mineral	200.7	5 mg/L	-	-	-
Chromium, Dissolved	Metal/Trace Element	200.7	5 µg/L	100 µg/L	-	-
Cobalt, Dissolved	Metal/Trace Element	200.7	10 µg/L	-	-	-
Copper, Dissolved	Metal/Trace Element	200.7	5 µg/L	1,300 µg/L	-	-
Iron, Dissolved	Metal/Trace Element	200.7	50 µg/L	-	300 µg/L	-
Lead, Dissolved	Metal/Trace Element	200.7	10 µg/L	15 µg/L	-	-
Magnesium, Dissolved	Mineral	200.7	5 mg/L	-	-	-
Manganese, Dissolved	Metal/Trace Element	200.7	50 µg/L	-	50 µg/L	300 µg/L
Mercury, Dissolved	Metal/Trace Element	200.8	0.05 µg/L	2 µg/L		-
Molybdenum, Dissolved	Metal/Trace Element	200.7	10 µg/L	-	-	40 µg/L
Nickel, Dissolved	Metal/Trace Element	200.7	10 µg/L	-	-	100 µg/L
Potassium, Dissolved	Mineral	200.7	0.5 mg/L	-	-	-
Selenium, Dissolved	Metal/Trace Element	200.7	20 µg/L	50 µg/L	-	-
Silica, Dissolved	Mineral	200.7	50 µg/L	-	-	-
Silver, Dissolved	Metal/Trace Element	200.7	10 µg/L	-	100 µg/L	100 µg/L
Sodium, Dissolved	Mineral	200.7	5 mg/L	-	-	-
Thallium, Dissolved	Metal/Trace Element	200.8	1 µg/L	2 µg/L	-	-
Uranium, Dissolved	Metal/Trace Element	200.8	1 µg/L	30 µg/L	-	-
Vanadium, Dissolved	Metal/Trace Element	200.7	10 µg/L	-		-
Zinc, Dissolved	Metal/Trace Element	200.7	10 µg/L	-	5,000 µg/L	2,000 µg/L

Group A Sampling

Aquifers sampled in the first year (Group A) include the Canadian River Allluvium, Elk City, Garber-Wellington, Gerty Sand, Ogallala-Northwest, and Rush Springs aquifers (Figure 2). Sampling sites were derived from the OWRB's licensed well drillers' well log database, which houses over 150,000 completion reports of groundwater and monitoring wells constructed within aquifers being considered for the Groundwater Monitoring and Assessment Program. 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 geology (lithology) of the well bore; 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 (i.e., around waste water retention lagoons) would be excluded. The resulting lists of wells were provided to the Western Ecology Division of the US Environmental Protection Agency (EPA) where a spatially balanced, randomized tessellation was run for each aquifer in the program. This randomized well selection was chosen to yield data representing the general water quality of each aquifer. Once landowners gave permission for access, reconnaissance visits to each site were made to further assess the suitability for inclusion into the program based on details such as existing plumbing, current use, and measurement access. When a well was deemed acceptable for GMAP inclusion, a filtered sample was obtained. The Oklahoma Department of Environmental Quality (ODEQ) ran laboratory analyses for all parameters on all samples.

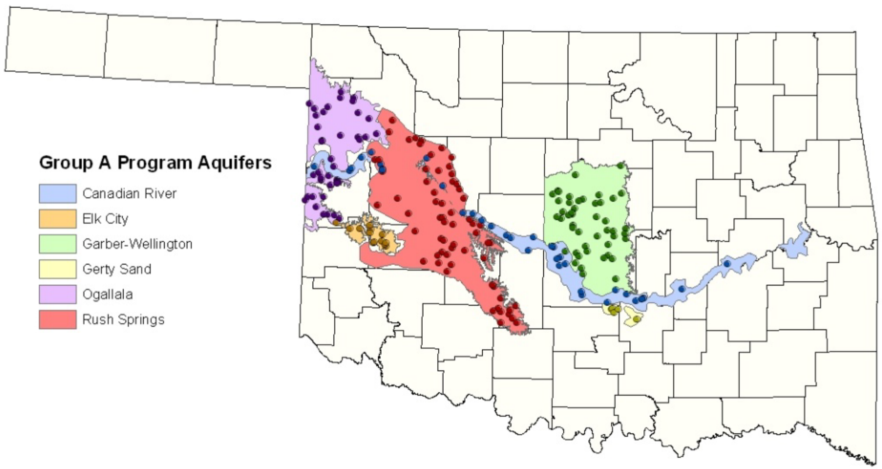

Figure 2. The baseline water quality network of sampling sites within Group A aquifers of GMAP.

Data Protocols

Only descriptive statistics are reported, as the main objective for this data is to summarize ambient water quality conditions in each aquifer and there is currently only one year of data. Full summary tables for each aquifer can be found in appendices at the end of this report. In the first year of the program (Group A, 2013), 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, as the main objective for this data is to summarize ambient water quality conditions in each aquifer. Normality of the data was not taken into consideration; reported statistics included 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.

All parameters were box-plotted using Grapher 10 software. Outliers were identified using 1.5x the parameter's inter-quartile range as the threshold value. For parameters with over 50 percent of wells below reporting limit, identified outliers were investigated but not taken into serious consideration. 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. Outliers were kept unless an acceptable explanation was discovered as to why that data point was unusual (lithology, screen interval, 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, comparisons of field and laboratory methods, 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.

Introduction-Review of the Groundwater Quality 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 well measurements, determined manually with graduated tapes or with down hole pressure transducers, can be shown using time series well hydrographs that plot the time series on the x axis and the depth to water or water level elevation on the y axis. 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. What typically happens, however, is that in order to obtain spatial representativeness within an aquifer, a network of sites provides groundwater level data from areas of the aquifer that reflect ambient conditions as a well as those influenced by groundwater withdrawals. Data from both sites are useful for interpreting groundwater level changes resultant from either natural stressors related to drought or anthropogenic stressors related to groundwater use.

The next section of the report will describe the results of baseline sampling and groundwater level depth determinations by individual aquifer. The descriptions contained in the aquifer summaries 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 are responsible for the groundwater quality characteristics; 3) portray and 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 constituent 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. Lastly, box plots will be used to compare and contrast selected water quality constituents and depth to water among aquifers.

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 (Figure 3).

The Canadian River Alluvial and Terrace Aquifer, hereafter shortened to CANR-AQ, 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 3. Location and extent of CANR-AQ.

The aquifer is encompassed within portions of the state's West-Central, Central, Lower Washita, Blue-Boggy, Eufaula, and Lower Arkansas Watershed Planning Regions and transitions through three different climate divisions. The westernmost part of this aquifer is in Oklahoma's West Central Climate Division, which averages 59.0°F and 26.55 inches of precipitation annually. The middle of this aquifer is in the Central Climate Division, which averages 59.9°F and 34.43 inches of precipitation annually; and the easternmost part of this aquifer is in the East Central Division, which averages 60.5°F and 43.19 inches of precipitation annually. Recharge to the aquifer is estimated to be 2 inches per year, mainly as result of infiltration of precipitation. Natural discharge occurs as base flow to streams and evapotranspiration. The CANR-AQ has an aerial extent of 5548 km^2 and stores 5 million acre-feet of water. Well yields generally range from 50-400 gallons per minute; hydraulic conductivity is estimated to be 134 feet per day. The CANR-AQ is designated by the OWRB as having a very high vulnerability level.

Groundwater in this aquifer is utilized for irrigation, public water supply, mining, industrial, domestic and stock purposes. The OWRB has on file more than 750 well construction reports from Oklahoma's licensed water well drilling firms documenting water well drilling and completion activities in the aquifer. As of December 31, 2013, 330 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 170 thousand acre-feet of water per year from around 600 wells. Permit withdrawal rates for this aquifer are not to exceed 2 acre-feet per acre per year.

Data Collection Results

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 4).

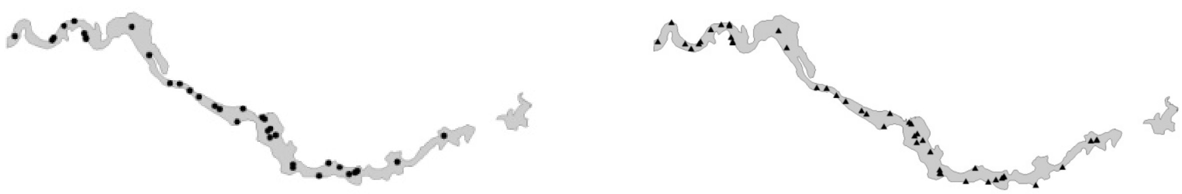

Figure 4. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the CANR-AQ in 2013.

Water Quality

Overall, the water quality of the aquifer is fair-good. Groundwater in the aquifer is extremely hard and moderately alkaline, averaging 666 mg/L and 266 mg/L respectively. Mean total dissolved solids (TDS), specific conductance and pH are 1040 mg/L, 1370 µS/cm and 6.94 respectively. TDS ranged from 86.3 to 3420 mg/L with a median of 533 mg/L.

The piper plot of the CANR-AQ data reflects varied water types. Fifty percent of the sites (17) are calcium–bicarbonate; nine sites are calcium-sulfate water; and the remaining 8 sites exhibit mixed chemistries (Figure 5). In the mixed chemistry sites, sodium along with calcium was generally present at comparable concentrations. The spatial distribution of water types is shown in Figure 6.

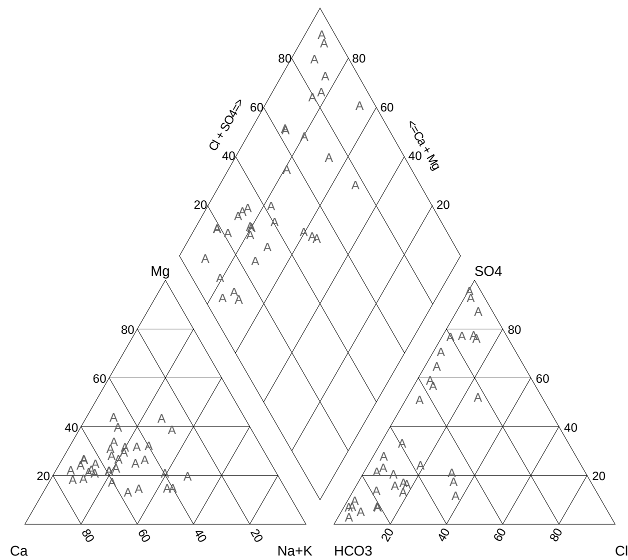

Figure 5. Piper plot diagram of constituents of the CANR-AQ.

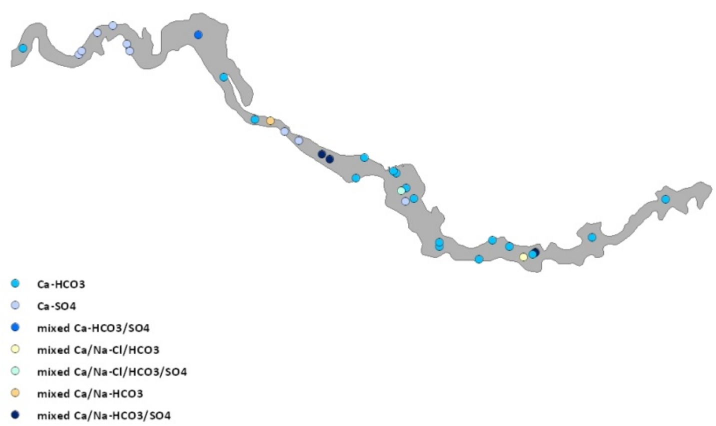

Figure 6. Water types in the CANR-AQ.

The data indicate that water quality across the aquifer is highly variable, but the primary water quality concern in local areas relates to mineralization as reflected by TDS, specific conductance and hardness. Sixty-seven percent of sites exceed the EPA's recommended secondary guideline of 500 mg/L. However, groundwaters with less than 3,000 mg/L TDS are considered by the State of Oklahoma to be suitable for general use with minimal treatment. However, if a potable water supply was the end use, and constituents that affect human health were present above EPA MCLs, treatment costs would be higher. Locally high TDS in the aquifer is attributed to sulfate, calcium and bicarbonate followed in importance by sodium and magnesium. The variability of mineralization exhibited by the test results may reflect differences among bedrock types that underlie the aquifer. The higher mineralized aquifer areas tend to correspond to locations where the underlying bedrock is composed of beds containing gypsum, dolomite and halite (Figure 7). Groundwater quality of this aquifer may be an expression in part of the quality of the underlying bedrock. Locally, this could result from a natural vertical flow gradient where mineralized groundwater from the underlying bedrock mixes with groundwater in the alluvial and terrace aquifer; from pumping wells that induce the mixing of bedrock and alluvial water; or in some instances, it could be an artifact of well construction as a result of partial penetration and screening of the underlying bedrock formation.

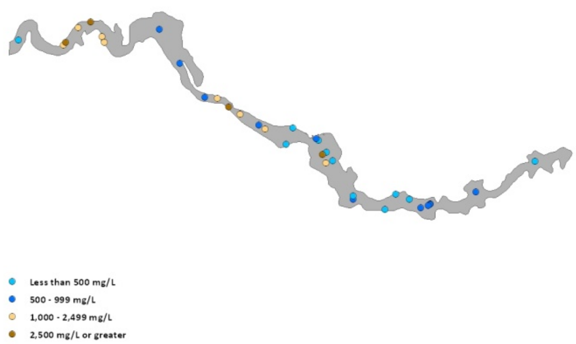

Figure 7. Total dissolved solids (left) and sulfate concentrations across the CANR-AQ.

Nutrients in the CANR-AQ were low. Ammonia and phosphorus were detected at low concentrations, if at all. Nitrate content in the aquifer was variable but was generally low, with mean and median concentrations of 3.34 and 1.19 mg/L, respectively (Figure 8).

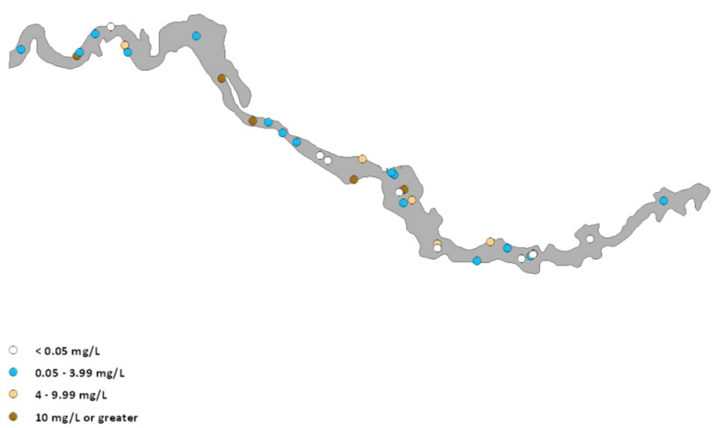

Figure 8. Nitrate concentrations in the CANR-AQ.

The CANR-AQ had several metals and trace elements detected. The following were not found above laboratory reporting limits: aluminum, antimony, beryllium, cadmium, cobalt, lead, nickel, silver, and thallium. Less than 3% of the samples had detections for chromium, copper, selenium, mercury, molybdenum and arsenic (ranging from 1-3 detections per constituent). Manganese, when present, was detected at high concentrations. Uranium were detected in 77% of the samples across a large range of values, but mean and median concentrations were low (Figure 9). Iron was detected in 47% of samples across a large range of values, but median concentrations were below the reporting limit. Other trace elements and metals present in the aquifer include barium, boron, bromide, fluoride, vanadium and zinc; their summary information is included in Appendix A.

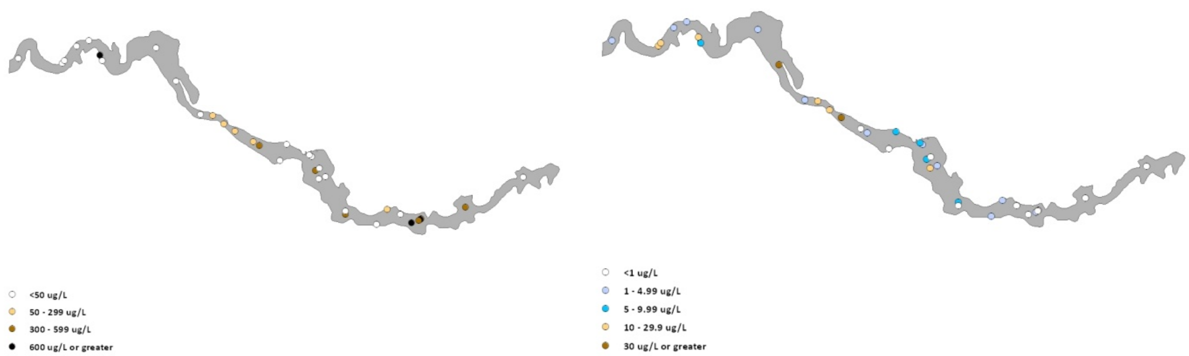

Figure 9. Manganese (left) and uranium concentrations in the CANR-AQ.

Generalized Spatial Patterns or Tendencies of the CANR-AQ Constituents

Increasing from East to West

- Vanadium, sulfate, hardness, TDS, specific conductance

Increasing from West to East

- Barium, manganese

No apparent spatial pattern

- Bicarbonate, calcium, silica, chloride, magnesium, potassium, sodium, nitrate, ammonia, bromide, fluoride, iron, uranium, zinc, alkalinity, dissolved oxygen, pH, alkalinity, groundwater levels

Localized Tendency (relatively higher concentration in specific locations of the aquifer)

- Boron, manganese, sulfate, TDS, specific conductance

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). In the CANR-AQ, several constituents exceeded these thresholds. Table 4 summarizes the parameters and number of occurrences over the EPA standards for drinking water.

Table 4. CANR-AQ Constituents Exceeding EPA Drinking Water Standards – Health Advisories.

Parameter	>MCL	>SMCL	>Health Advisory
Nitrate	5		
Chloride		1	
Sulfate		13	

TDS		23	
Arsenic	2		
Manganese		14	9
Molybdenum			1
Uranium	2		

Groundwater Level Measurements

A baseline groundwater level network comprising 46 wells was implemented in August-September 2013. Based on the 46 well completion reports, depth to the Permian "red bed" (base of aquifer) averaged around 60 feet with a maximum depth of 112 feet. Historically, long-term groundwater level monitoring in the CANR-AQ consisted of a small network of 10 wells. This network lacked sufficient numbers and spatial diversity to be able to characterize groundwater levels for the entire aquifer. Several of these wells were incorporated into the new baseline network to maintain water level sites with long-term records. A few of the historical wells have 30-35 years of record on groundwater level changes in the aquifer (Figure 10). The hydrograph reflects groundwater levels varying from less than 1 foot below land surface to more than 18 feet. The difference between the initial depth to water measurement and 2014 measurement is around 2 feet. Generally, the graph shows trending upward water levels through the middle 1990s followed by a general decline (with a few sharp breaks) until the present. Groundwater level response in alluvium and terrace aquifers are more sensitive (respond more rapidly) to drought or wet periods than many types of bedrock aquifers due to proximity of the water table to land surface and their sandy porous overburden.

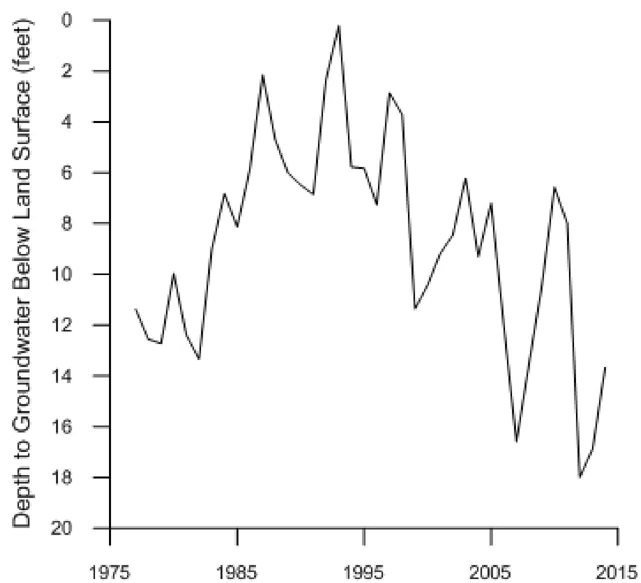

Figure 10. Groundwater level hydrograph of the CANR-AQ (1977-2014), McClain County.

Measurements of depth to water made during baseline implementation ranged from 2.68 feet to 54.32 feet with a mean of 21.32 feet. The total depth of wells used in the network ranged from 14 to 112 feet with an average of 68 feet. A seasonal network composed of 18 wells from the baseline network will be measured three times a year (Jan-Feb, Apr-May, and mid Sept-mid-Nov) in order to characterize seasonal and long-term water level changes.

A continuous water level recorder was installed in Roger Mills County (Figure 11) in November 2013. Depth to water in feet below land surface is being recorded in hourly increments.

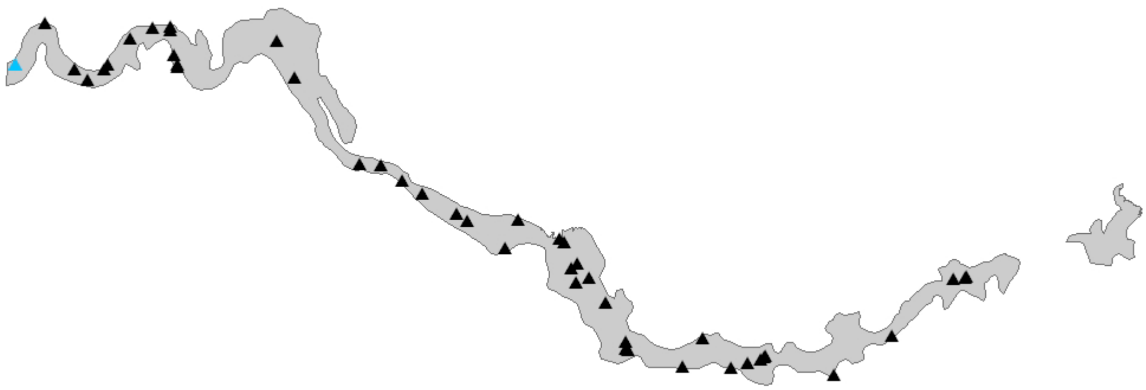

Figure 11. Location of the CANR-AQ continuous water level recorder (blue) against the entire CANR-AQ water level network.

Elk City Aquifer

The Elk City Aquifer, hereafter shortened to ELKC-AQ, located in western Oklahoma and underlying portions of Roger Mills, Beckham and Washita counties, is an unconfined bedrock aquifer (Figure 12). 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-AQ 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 12. Location and extent of the ELKC-AQ.

The aquifer straddles the state's West Central and Southwest Watershed Planning Regions and is located in Oklahoma's West Central Climate Division, which averages 59.0°F and 26.55 inches of precipitation annually. The recharge rate is estimated to be 2.8 inches per year, mainly through precipitation with some return irrigation flow. Natural discharge occurs through evapotranspiration, springs, and seeps. The ELKC-AQ has an aerial extent of 782 km^2 and stores 2.2 million acre-feet of water. Wells commonly yield 10-25 gallons per minute for domestic use and as much as 300 gallons per minute for irrigation and industrial uses; hydraulic conductivity ranges are estimated to be 6.7-100.3 feet per day. The ELKC-AQ is designated by the OWRB as having a high vulnerability level.

Groundwater in this aquifer is mainly utilized for municipal, irrigation, domestic, and industrial use. The OWRB has on file more than 750 well construction reports from Oklahoma's licensed water well drilling firms documenting water well drilling and completion activities in the aquifer. As of December 31, 2013, 106 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 21,000 acre-feet of water per year from 218 wells. Permit withdrawal rates for this aquifer are not to exceed 1 acre-foot per acre per year.

Data Collection Results

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 13).

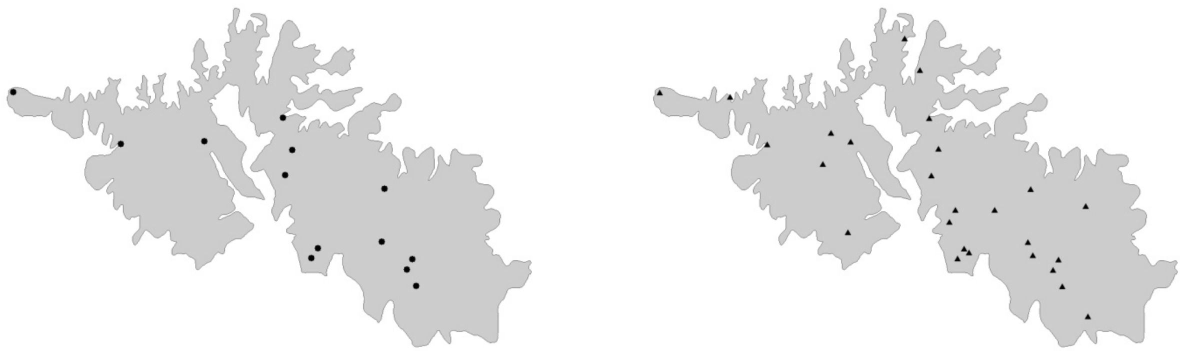

Figure 13. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the ELKC-AQ in 2013.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content of the water is low-moderate. Water in the aquifer is hard and moderately alkaline, averaging 272 and 276 mg/L respectively. Mean total dissolved solids (TDS), electrical conductivity and pH were 360 mg/L, 624 µS/cm and 7.29, respectively. TDS ranged from 254-436 mg/L with a median of 349 mg/L. The piper plot of the data reflects a calcium-bicarbonate water type (Figure 14).

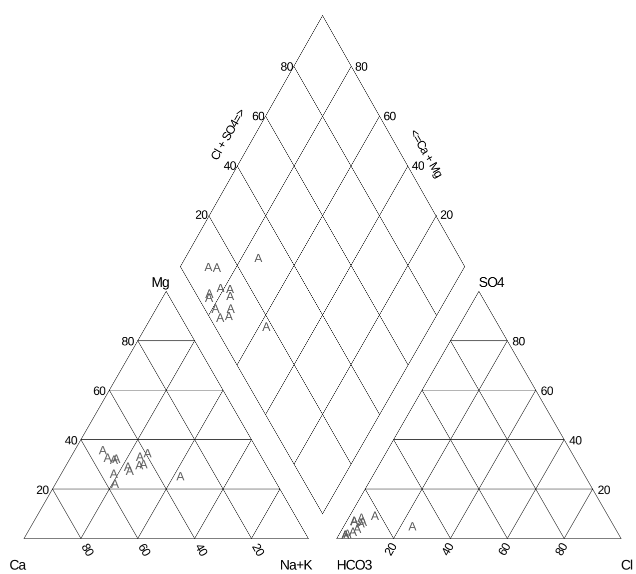

Figure 14. Piper plot diagram of constituents of the ELKC-AQ.

Calcium and magnesium are both responsible for the hard water in the aquifer. Calcium, magnesium and bicarbonate are the primary constituents that account for TDS in the aquifer. Sodium, sulfate and chloride were present at low concentrations.

Nutrients in the ELKC-AQ were detected at low-moderate concentrations. Ammonia was not detected in the aquifer, and phosphorus was detected rarely at very low levels. Nitrate concentrations ranged from 0.09-8.58 mg/L with mean and median concentrations of 5.44 and 6.37 mg/L, respectively (Figure 15).

Figure 15. Nitrate concentrations in the ELKC-AQ.

The ELKC-AQ had very few metals or trace elements present. The following were not detected: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, nickel, selenium, silver, and thallium. The following trace elements and metals were present in the aquifer: barium, boron, bromide, copper, fluoride, uranium, vanadium and zinc; their summary information is included in Appendix B. Iron was found at low concentrations but rarely detected. Boron was found at 43% of sites at low concentrations. Barium, copper, uranium, vanadium, and zinc were present at low levels.

Generalized Spatial Patterns or Tendencies of the Elk City-AQ Constituents

Water quality across the aquifer was relatively uniform; no obvious spatial patterns were observed.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). For the ELKC-AQ, no drinking water based standards were exceeded.

Groundwater Level Measurements

A baseline groundwater level network comprising 25 wells was implemented in July-August 2013. The baseline network incorporated 8 wells from the aquifer's historical groundwater level network. Figure 16 is a depth to water hydrograph of a well with a 25 year period of record. Taped measurements of this well have been made annually since 1989. The hydrographs reflects an overall decline in depth to water of about 7.5 feet over the period of record. This well has subsequently been equipped with a continuous water level recorder that is collecting hourly water level data (Figure 17). Measurements of depth to water made during baseline implementation ranged from 10.95 to 107.8 ft with a mean of 28.98 feet. Eight of the 25 wells in the baseline network have been incorporated into a tri-annual seasonal network.

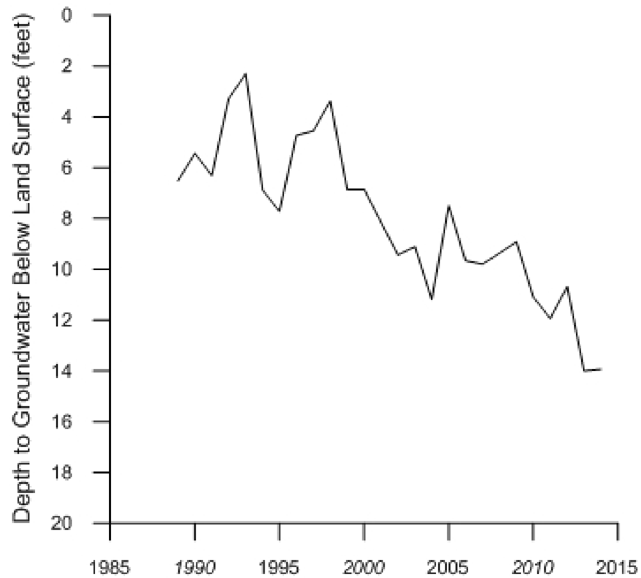

Figure 16. Groundwater level hydrograph of the ELKC-AQ (1989-2014), Washita County.

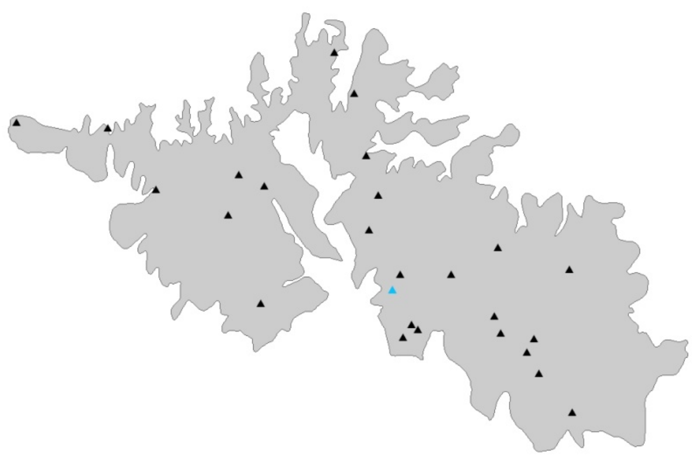

Figure 17. Location of the ELKC-AQ continuous water level recorder (blue) against the entire ELKC-AQ water level network.

Garber-Wellington Aquifer

The Garber-Wellington aquifer, hereafter shortened to GBWL-AQ, 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 18). 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 18. Location and extent of the GBWL-AQ.

The majority of the aquifer is within the state's Central Watershed Planning Region but extends slightly into the Upper Arkansas and Eufaula Regions and is located in Oklahoma's Central Climate Division, which averages 59.9°F and 34.43 inches of precipitation annually. The recharge rate is estimated to be 1.6 inches per year, mostly through precipitation. Groundwater discharge is mainly base flow to streams and from pumping wells. The GBWL-AQ has an aerial extent of 7,493 km^2 and stores 58 million acre-feet of water. Well yields typically range from 25-400 gallons per minute; hydraulic conductivity ranges are estimated to be 0.33-3.3 feet per day. The GBWL-AQ is designated by the OWRB as having a moderate vulnerability level.

Groundwater in this aquifer is a major source for public and domestic water supply, as all of the major communities in central Oklahoma (except Oklahoma City) rely at least partially on this aquifer; it is also utilized for industrial, agricultural and commercial use. The OWRB has on file more than 13,000 well construction reports from Oklahoma's licensed water well drilling firms documenting water well drilling and completion activities in the aquifer. As of December 31, 2013, 532 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 283,000 acre-feet of water per year from around 1,400 wells. The maximum withdrawal rate for permit holders is 2 acre-feet per acre per year. For the GBWL-AQ, the baseline network was established in the unconfined or shallow confined portions of the aquifer. There is a large subset of public water supply and industrial wells completed in the deeper, confined regions of the aquifer. Substantial water quality and geochemical information exists from these deep wells in the aquifer as a result of Safe Drinking Water Compliance Samples submitted to ODEQ from cities and towns and the United States Geological Survey's comprehensive groundwater quality assessments made on the "Central Oklahoma Aquifer" in the 1980s. These assessments identified the localized presence of nitrate, arsenic, chromium, selenium and uranium in different parts of the aquifer. To be considered for inclusion in this network, a depth constraint of 350 feet was designed for wells where the Hennessey Shale is absent and 450 feet where the Hennessey Shale is present on the west side of the aquifer. These well depth restrictions tended to exclude most public supply and industrial wells, which are typically drilled deeper into the Garber-Wellington; the resulting network comprised entirely domestic wells, as the Garber-Wellington underlies urban area and other well uses like stock and irrigation are rare.

Data Collection Results

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 19).

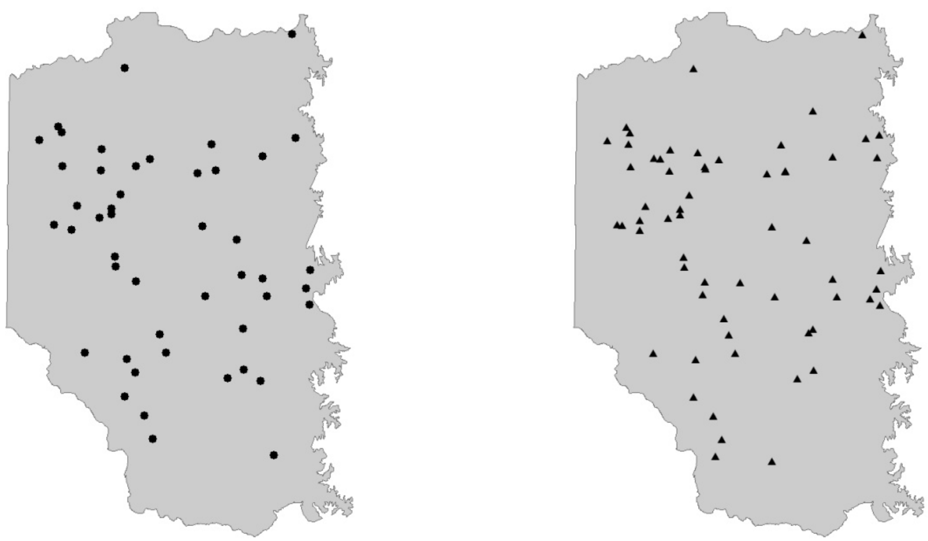

Figure 19. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the GBWL-AQ in 2013.

Water Quality

Overall, this aquifer contains water of good quality although variability exists depending on location within the aquifer. Water is hard and has moderately high alkalinity, averaging 278 mg/L and 268 mg/L, respectively. For the GBWL-AQ, mean total dissolved solids (TDS), specific conductance and pH were 418 mg/L, 728 µS/cm, and 6.95, respectively. TDS ranged from 123-2,150 mg/L, with a median concentration of 328 mg/L.

There are two primary groundwater types identified with this sampling network comprising calcium-magnesium-bicarbonate (60%) and sodium-bicarbonate and/or sodium-calcium-bicarbonate (28%) (Figure 20). Mixed ion chemistries found were of calcium-sulfate, sodium-sulfate and sodium-chloride types. Sodium-bicarbonate and mixed ion chemistries were primarily found where the Hennessey Group overlies the Garber Sandstone in the west and within the Chase, Admire and Council Grove Groups in the east. Higher concentrations of TDS, sulfate and chloride typically occurred within these two areas. Wells completely within the Garber Sandstone or Wellington Formations usually were composed of calcium-bicarbonate water and had lower TDS excepting along the Deep Fork River east of I-35, where sodium and TDS were higher. The spatial distribution of water types is shown in Figure 21.

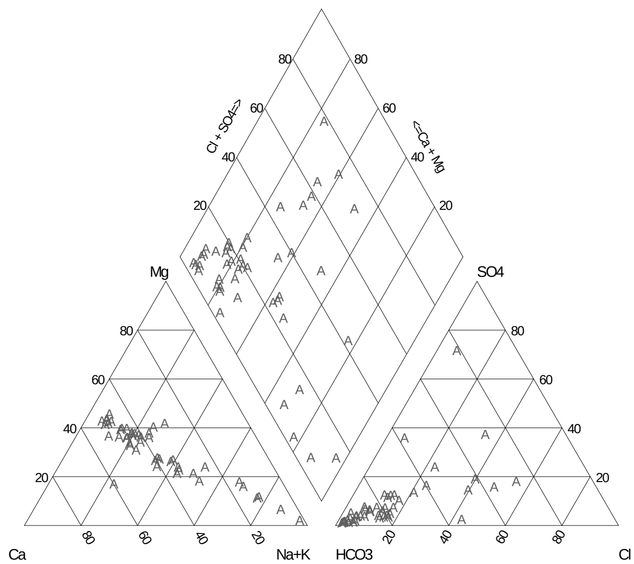

Figure 20. Piper plot diagram of constituents of the GBWL-AQ.

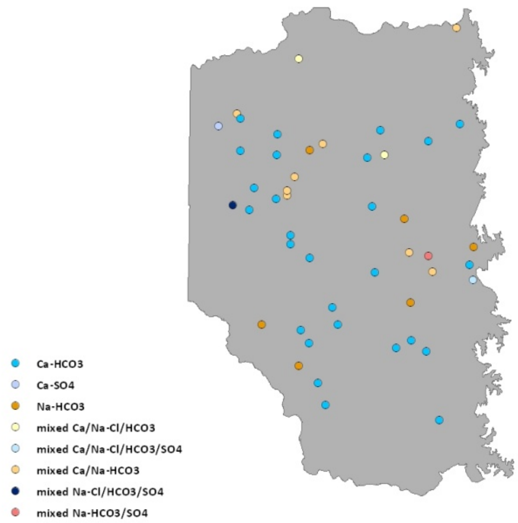

Figure 21. Water types in the GBWL-AQ.

Concentrations of sodium, sulfate and chloride were typically less than 50 mg/L. Higher concentrations of sodium were found locally west of or near the Hennessey-Garber Sandstone contact on the west side of the aquifer, within the Admire, Chase and Council Grove Formations on the east side of the aquifer and along the Deep Fork River in central Oklahoma County. Sites where TDS exceeded its SMCL were usually associated with higher concentrations of sodium, and in a few instances sulfate and chloride. (Figure 22).

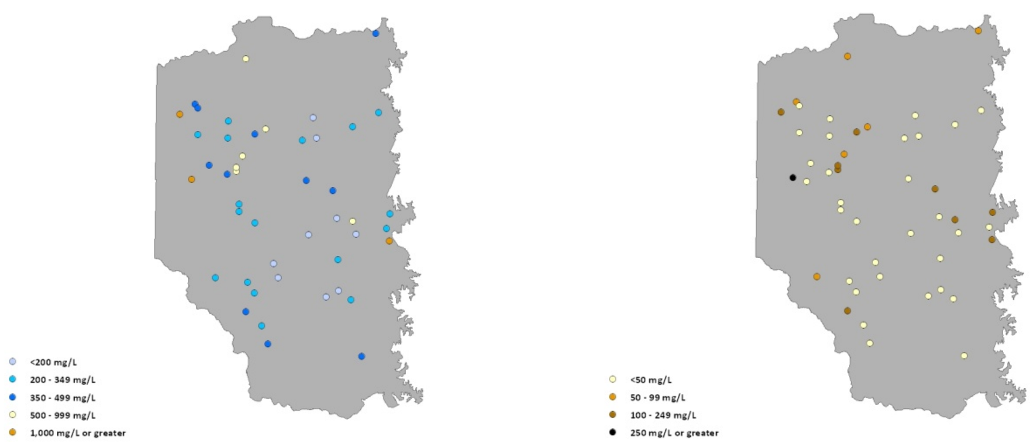

Figure 22. Total dissolved solids (left) and sodium concentrations in the GBWL-AQ.

Nutrients in the GBWL-AQ were low. Ammonia was not detected, and phosphorus was found at very low concentrations. Nitrate levels were typically low, with mean and median concentrations of 1.84 and 0.89 mg/L, respectively (Figure 23).

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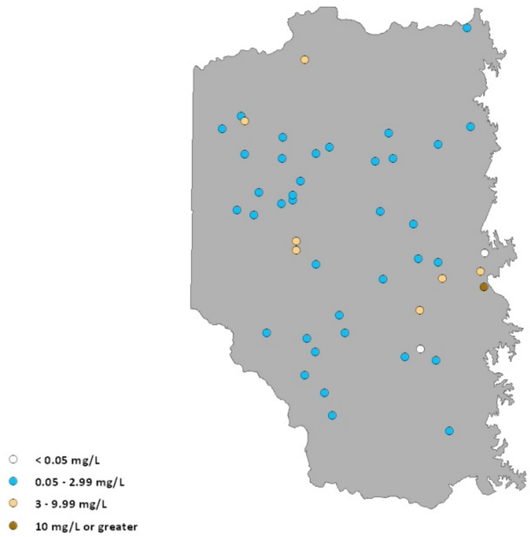

Figure 23. Nitrate concentrations in the GBWL-AQ.

The following metals were not detected in the aquifer: aluminum, antimony, beryllium, cadmium, cobalt, mercury, molybdenum, nickel, silver, and thallium. Arsenic was detected in one well at an elevated concentration. Lead and manganese were detected in single instances at moderately high concentrations. Chromium and selenium were present (3 times each) at low concentrations. Uranium was detected in 62% of the sites at low concentrations excepting two sites (Figure 24). Iron was present at low concentrations but was rarely detected. Boron was detected at 81% of sites at low concentrations. Other trace elements and metals present in the aquifer include barium, bromide, copper, fluoride and vanadium; their data are summarized in Appendix C.

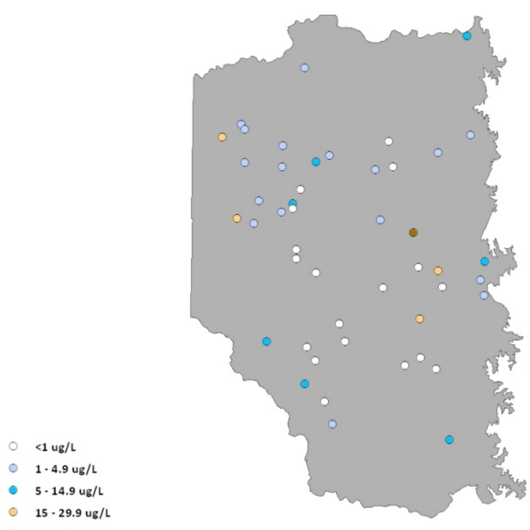

Figure 24. Uranium concentrations in the GBWL-AQ.

Generalized Water Quality Spatial Patterns or Tendencies of the GBWL-AQ

Increasing Content South-North

- Bromide, chloride, hardness

Increasing Content from East to West

- Alkalinity, calcium, magnesium, vanadium

No apparent spatial pattern

- Bicarbonate, potassium, silica, sulfate, nitrate, ammonia, barium, boron, copper, fluoride, uranium, vanadium, zinc, pH, dissolved oxygen, specific conductance, groundwater levels

Localized Tendency (relatively higher concentration in specific locations of the aquifer)

- Sodium, TDS

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). In the GBWL-AQ, in a small number of instances, constituents exceeded these thresholds. Table 5 summarizes the parameters and number of occurrences over the EPA standards for drinking water.

Table 5. GBWL-AQ Constituents Exceeding EPA Drinking Water Standards – Health Advisories.

Parameter	>MCL	>SMCL	>Health Advisory
Nitrate	1		
Chloride		2	
Sulfate		2	
TDS		9	
Arsenic	1		
Manganese		1	1
Uranium	1		

Groundwater Level Measurements

A baseline groundwater level network comprising 61 wells was implemented in October-November 2013. The baseline network incorporated 14 wells from the aquifer's historical groundwater level network. Figure 25 is a depth to water hydrograph for a well with a 31 year period of record. Taped measurements of this well have been made annually since 1983. The hydrograph reflects an overall increase in water levels through 1995 and overall decrease in water levels for the remainder of the period. For the entire period of record, the depth to water increased (water level dropped) by 2.25 feet. Measurements of depth to water made during baseline implementation ranged from 8.45 to 228.1 ft with a mean of 75.68 feet. The total depth of wells used in the network ranged from 100-380 feet averaging 199 feet. 23 of the 57 wells in the baseline network have been incorporated into a tri-annual seasonal network. Hourly measurements of depth to water are being collected from continuous water level recorders in Cleveland and Lincoln Counties (Figure 26).

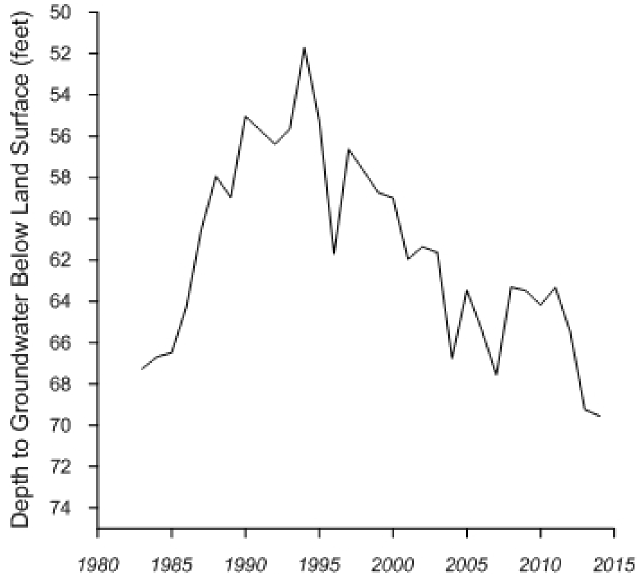

Figure 25. Groundwater level hydrograph of the GBWL-AQ (1983-2014), Oklahoma County.

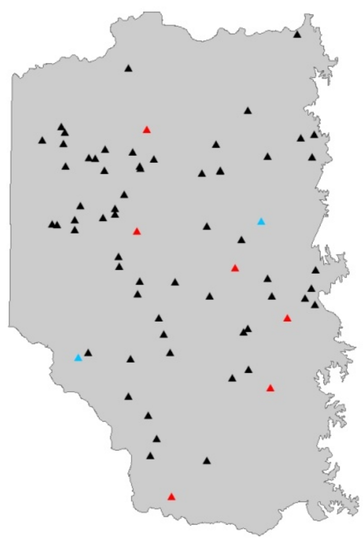

Figure 26. Location of the GBWL-AQ continuous water level recorders deployed for long-term seasonal monitoring (blue) and for a separate OWRB hydrologic study (red) against the entire GBWL-AQ water level network.

Gerty Sand

The Gerty Sand aquifer, hereafter shortened to GRTY-AQ, located in south central Oklahoma and underlying portions of Garvin, McClain, and Pontotoc counties (Figure 27), 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 27. Location and extent of the GRTY-AQ.

The aquifer is encompassed within the state's Central and Lower Washita Watershed Planning Regions and South Central Climate Division, which averages 61.9°F and 37.5 inches of precipitation annually. Natural discharge occurs through evapotranspiration, springs and base flow to small streams and creeks in the area. Other sources of discharge include groundwater withdrawals for irrigation and public water supply. Recharge to the aquifer is estimated to be 1 inch per year by infiltration of precipitation. The GRTY-AQ has an aerial extent of 284 km^2 and stores 224,000 acre-feet of water. Well yields range from 15 gallons per minute for domestic use to around 300 gallons per minute for some irrigation wells; hydraulic conductivity has been estimated to be 15 feet per day.

Groundwater in this aquifer is mainly utilized for irrigation, domestic and municipal supply. The OWRB has on file more than 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 31, 2013, 35 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 4,700 acre-feet of water per year from 35 wells. Permit withdrawal rates for this aquifer are not to exceed 0.70 acre-foot per acre per year. The GRTY-AQ is designated by the OWRB as having a high vulnerability level.

Data Collection Results

The Groundwater Monitoring and Assessment Program sampled 5 wells to assess the baseline water quality of the GRTY-AQ and concurrently measured 5 wells to assess the baseline water level (Figure 28).

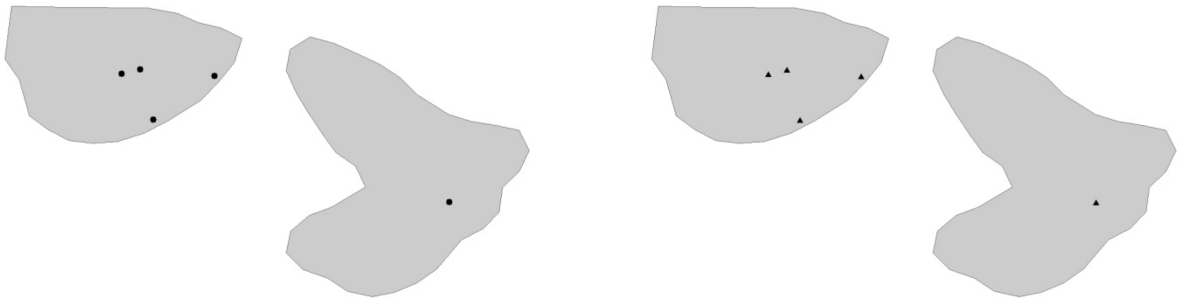

Figure 28. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the GRTY-AQ in 2013.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content is low. Groundwater in the aquifer is hard and moderately alkaline, averaging 198 mg/L and 209 mg/L, respectively. Mean total dissolved solids (TDS), specific conductance and pH are 316 mg/L, 550 µS/cm and 6.49, respectively. TDS ranged from 255-385 mg/L with a median concentration of 306 mg/L. Water type in the GRTY-AQ is composed of calcium- and sodium-bicarbonate waters (Figure 29).

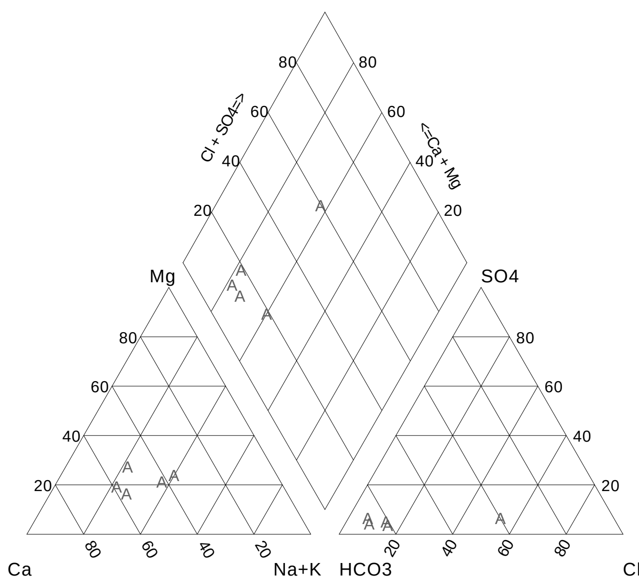

Figure 29. Piper plot diagram of constituents of the GRTY-AQ.

The Gerty Sand network was designed with a small sample size compared to the other GMAP aquifers due to its limited areal extent. Finding suitable wells (in terms of well construction) and acquiring landowner permission proved difficult and is partly responsible for the uneven distribution for this small network. As a consequence, no discussion of spatial patterns of the data is provided. Hardness, electrical conductivity and pH as well as overall mineralization were lower for the Gerty Sand compared to the other aquifers. Sulfate and chloride content were low. Fluoride was not detected above laboratory reporting limits.

Nutrients in the GRTY-AQ were low. Ammonia was not detected. Nitrate mean and median concentrations were 2.81 and 2.08 mg/L. Total dissolved phosphorus was detected at 4 of 5 sites with concentrations ranging from 0.04-0.3 mg/L.

The GRTY-AQ had very few metals and trace elements detected. The following were not detected: aluminum, antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, and thallium. Uranium was detected in one sample at a low concentration. Other metals and trace elements detected included barium, bromide copper, vanadium and zinc; their information is summarized in Appendix D. Iron and potassium data are currently under review and are not included in this report; data will be uploaded to the OWRB web page as it becomes available.

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). In the GRTY-AQ, there were no primary MCL, SMCL, or health advisories exceeded for any constituents.

Groundwater Level Measurements

The Gerty Sand water level network is a work in progress. Five additional wells will be added to the eastern lobe of the aquifer and 1-2 wells will be added to the western lobe. The current baseline network was implemented in August 2013 and consists of five new wells. Historically, groundwater levels have only been tracked in a single well in the GRTY-AQ (Figure 30). The hydrograph of the well reflects rising groundwater levels for most of the period of record. Groundwater levels have decreased slightly over the last three years. Overall, depth to groundwater reflected by this well hydrograph has decreased (groundwater levels have risen) by 6.5 feet over its period of record. Although this well was not incorporated into the baseline study, it will be retained as part of the permanent water level network. Measurements of depth to groundwater made during baseline implementation 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. At least fifty percent of the final configured baseline water level network will be incorporated into a tri-annual seasonal network.

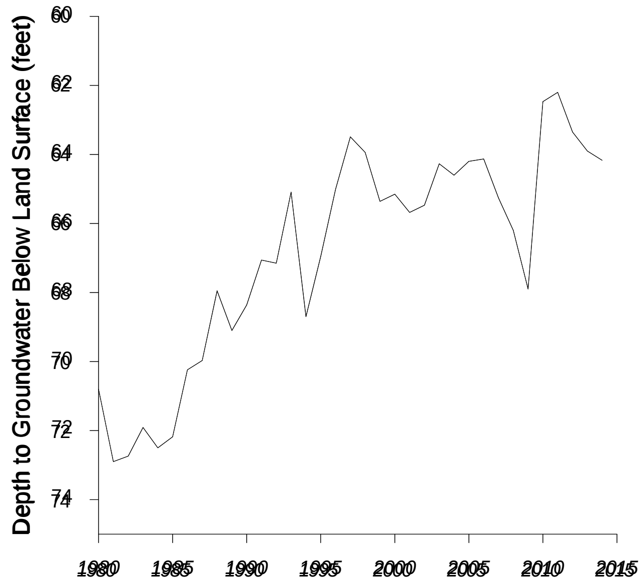

Figure 30. Groundwater level hydrograph in the GRTY-AQ (1980-2014), Garvin County.

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 31). It is composed of semi-consolidated layers of sand, gravel, silt, and clay that is light gray, tan or white in color with intermittent zones cemented by calcium carbonate. The maximum thickness of the Ogallala-Northwest Aquifer (hereafter referred to as OGNW-AQ) 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 31. Location and extent of the OGNW-AQ.

The aquifer is encompassed by the state's Panhandle and West Central Planning Regions and Panhandle and North-Central Climate Divisions. Annual precipitation ranges from 19.86 inches in the north to 28.89 inches in the south and annual temperatures range from 56.2°F in the north to 58.6°F in the south. Recharge to the aquifer is estimated to range from 0.5-0.9 inch per year, mainly through precipitation and return irrigation flow. Natural discharge occurs through evapotranspiration, springs and locally as base flow to rivers (North Canadian, Canadian, Washita and North Fork of the Red) and streams (like Wolf Creek). The OGNW-AQ has an aerial extent of 4,764 km^2 and stores 90.6 million acre-feet of water. Well yields range from 50-600 gallons per minute; hydraulic conductivity is estimated to be 61 feet per day.

Groundwater in this aquifer is utilized for irrigation, public water supply, mining and domestic purposes. The OWRB has on file more than 3,000 well construction reports from Oklahoma's licensed water well drilling firms, documenting water well drilling and completion activities in the aquifer. As of December 31, 2013, 272 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 131,000 acre-feet of water per year from 467 wells. The maximum withdrawal rate from the aquifer is 1.4 acre-feet per acre per year. The OGNW-AQ is designated by the OWRB as having a low vulnerability level.

Data Collection Results

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 32).

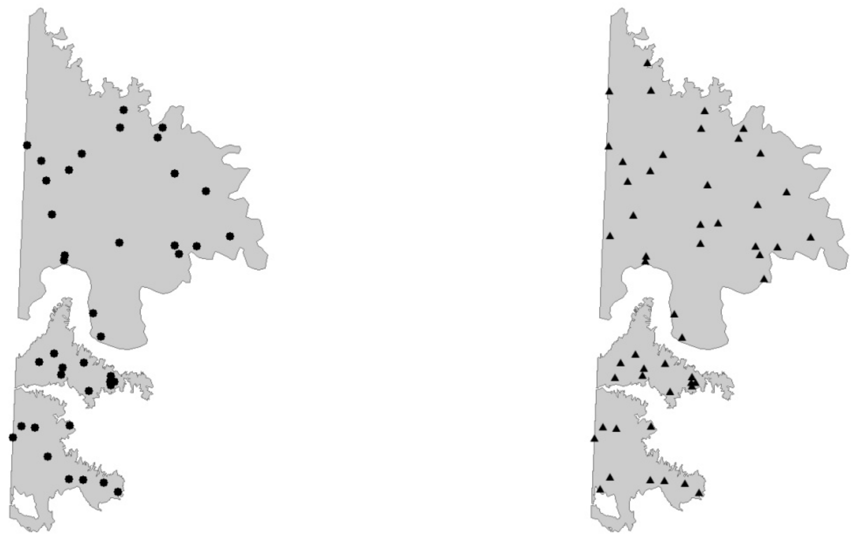

Figure 32. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the OGNW-AQ in 2013.

Water Quality

Overall, this aquifer contains water of good quality. Mineral content is low-moderate. Groundwater in the aquifer is hard and moderately alkaline, averaging 234 mg/L and 208 mg/L, respectively. Mean total dissolved solids (TDS), specific conductance and pH are 370 mg/L, 630 µS/cm and 7.10, respectively. TDS ranged from 225-848 mg/L with a median concentration of 340 mg/L.

The piper plot of OGNW-AQ data depicts primarily calcium-bicarbonate water (75%). Other water types present include sodium bicarbonate and mixed types composed of sodium and/or calcium in combination with bicarbonate, chloride and sulfate (Figure 33). The spatial distribution of water types is shown in Figure 34.

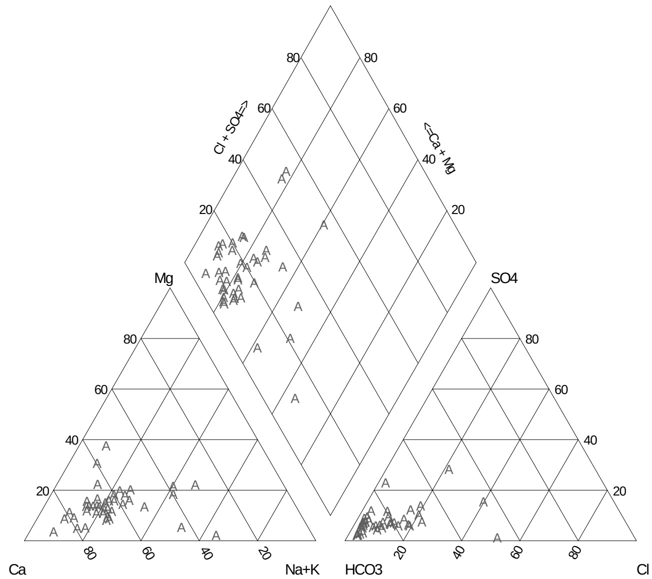

Figure 33. Piper plot diagram of constituents of the OGNW-AQ.

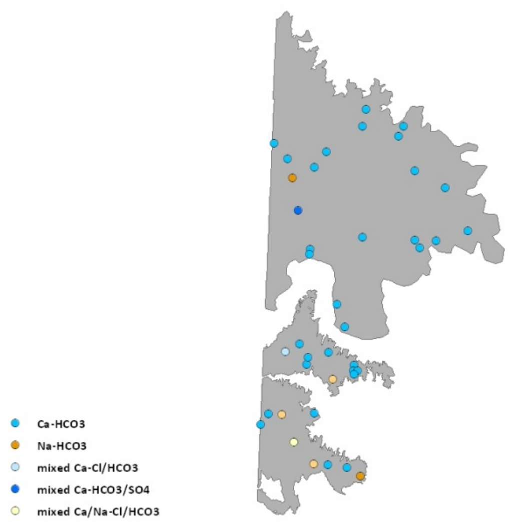

Figure 34. Water types in the OGNW-AQ.

The primary water quality concern in the aquifer is the presence of nitrate, locally at elevated levels. Sulfate, chloride and magnesium concentrations are low in the aquifer. Sodium content is generally low except locally. TDS and sodium content are shown in Figure 35.

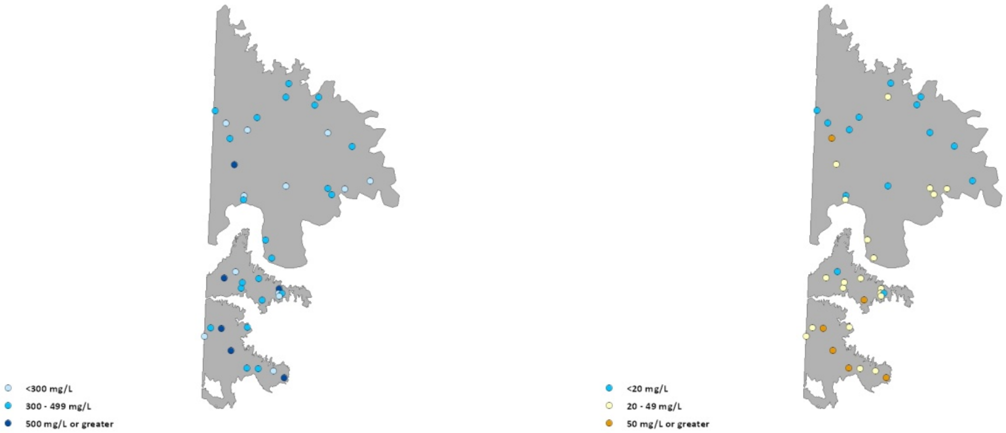

Figure 35. Total dissolved solids (left) and sodium concentrations in the OGNW-AQ.

Nutrients in the aquifer reflect low levels of phosphorus, no detected ammonia and locally elevated levels of nitrate. Nitrate content ranged from 0.92-26.8 mg/L with mean and median concentrations of 7.85 mg/L and 6.02 mg/L (Figure 36).

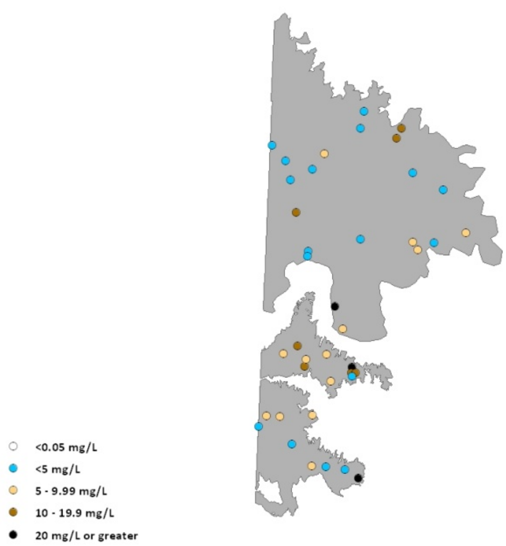

Figure 36. Nitrate concentrations in the OGNW-AQ.

The OGNW-AQ had very few metals and trace elements detected. The following were not detected: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, nickel, selenium, silver, and thallium. Uranium (Figure 37) was frequently detected at low concentrations. Boron and iron were present at low concentrations but were rarely detected. Other trace elements and metals detected in the aquifer include: barium, bromide, copper, fluoride, vanadium and zinc. It's been reported that the primary source of uranium, barium, vanadium and zinc in the aquifer results from the dissolution of volcanic ash deposits.

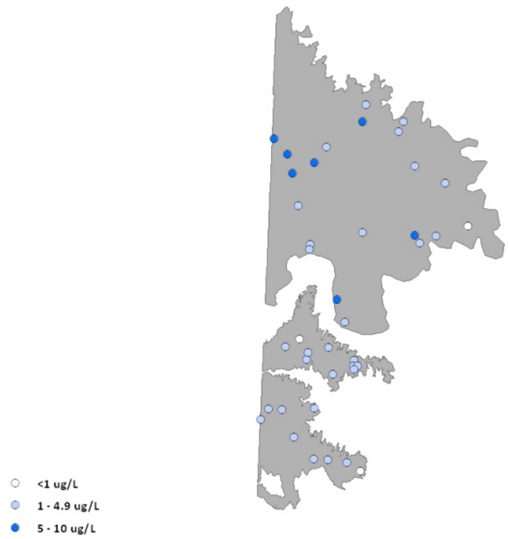

Figure 37. Uranium concentrations in the OGNW-AQ.

Generalized Spatial Patterns or Tendencies of the OGNW-AQ

Increasing Content South-North

- Silica, potassium

Increasing Content North-South

- Sodium, zinc, TDS, specific conductance

No apparent spatial pattern

- Bicarbonate, sulfate, chloride, calcium, barium, copper, magnesium, nitrate, phosphorus, fluoride, bromide, uranium, vanadium, hardness, alkalinity, dissolved oxygen, pH, groundwater levels

Localized Tendency (relatively higher concentration in specific locations of the aquifer)

- None

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). The OGNW-AQ had very few constituents exceed these thresholds. Table 6 summarizes the parameters and number of occurrences exceeding a standard.

Table 6. OGNW-AQ Constituents Exceeding EPA Drinking Water Standards – Health Advisories.

Parameter	>MCL	>SMCL	>Health Advisory
Nitrate	10		
TDS		6	

Groundwater Level Measurements

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. The historical network was composed of 40 wells, many with a period of record of more than 30 years.

In Figure 38, two hydrographs are shown that reflect similar patterns of groundwater level fluctuations of the OGNW-AQ spanning 35 years. Annual water level measurements in both wells were made more or less contemporaneously (within the same week or two) over the period of record. Not surprisingly, annual groundwater level response (rise or fall) to natural, variable climate conditions are more pronounced or rapid in the well hydrograph on the left because of its shallower depth to water; response is more muted and delayed for the well with deeper groundwater depth. Both hydrographs are representative of aquifer water level patterns, the differences explained by response time to variable weather based on depth to water below land surface.

Measurements of depth to groundwater made during baseline implementation 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. 22 of the 49 wells in the baseline network have been incorporated into a tri-annual seasonal network.

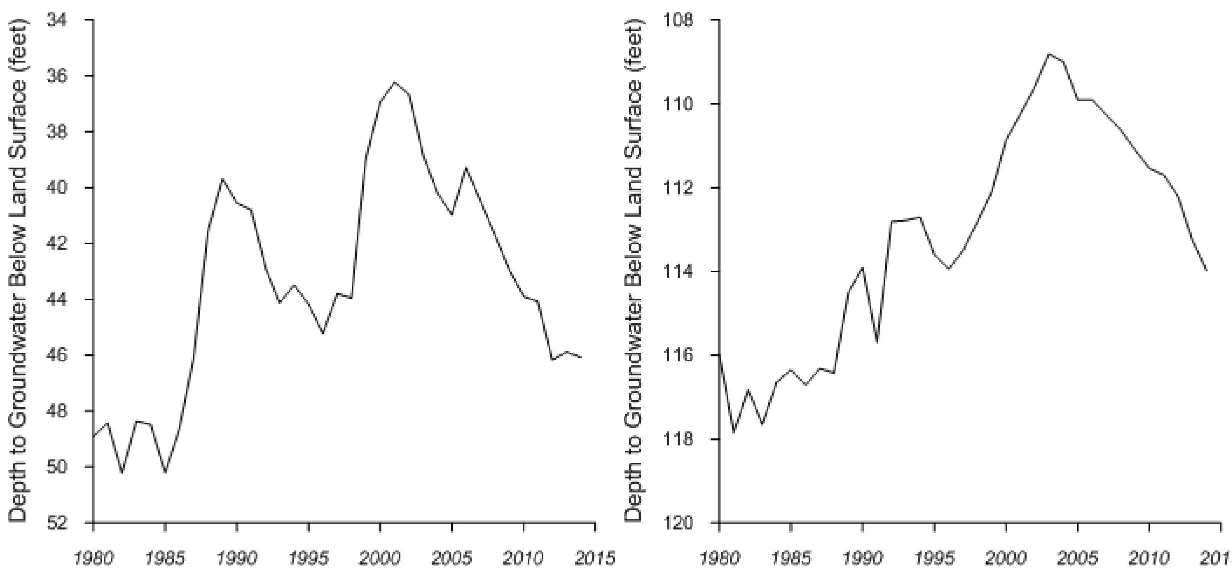

Figure 38. Groundwater level hydrographs of the OGNW-AQ (1980-2014), Ellis County.

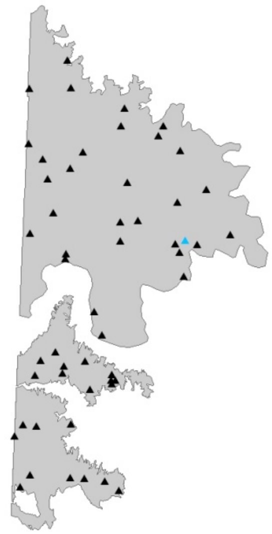

Figure 39. Location of the OGNW-AQ continuous water level recorder (blue) against the entire OGNW-AQ water level network.

Rush Springs Aquifer

The Rush Springs Aquifer, hereafter shortened to RSPG-AQ, located in west-central Oklahoma, underlies portions of Woodward, Dewey, Custer, Blaine, Washita, Caddo, and Grady counties (Figure 40). 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 Rush Springs. 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 is highly mineralized. Water in the Rush Springs 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 40. Location and extent of the RSPG-AQ.

The aquifer is mostly in the state's West Central Watershed Planning Region but extends south and eastward into the Beaver-Cache, Lower Washita, and Central Regions. The northern part of the aquifer is located in Oklahoma's West Central Climate Division, which averages 59.0°F and 26.55 inches of precipitation annually. The southern part is in the Southwest Climate Division, with averages of 61.0°F and 27.87 inches of precipitation annually, and extends into the Central Climate Division, which averages 59.9°F and 34.43 inches of precipitation annually. The recharge rate is estimated to be 1.8 inches per year, mainly through infiltration of precipitation and irrigation return flow. Natural discharge occurs through evapotranspiration, springs and as base flow to rivers and streams. The RSPG-AQ has an aerial extent of 6,297 km^2 and stores 80 million acre-feet of water. Well yields range from 25-1,000 gallons per minute but average around 400 gallons per minute. Mean hydraulic conductivity is estimated to be 8 feet per day.

Groundwater in this aquifer is utilized primarily for irrigation but is also used to supply municipal, livestock, domestic and industrial needs. The majority of the groundwater withdrawals from the aquifer occur in Caddo County. As of December 31, 2013, 1,780 groundwater permits have been issued by the OWRB to property owners authorizing the withdrawal of 387,000 acre-feet of water per year from around 2,467 wells. Permit withdrawal rates for this aquifer are not to exceed 2 acre-feet per acre per year. The RSPG-AQ is designated by the OWRB as having a moderate vulnerability level.

Data Collection Results

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 41).

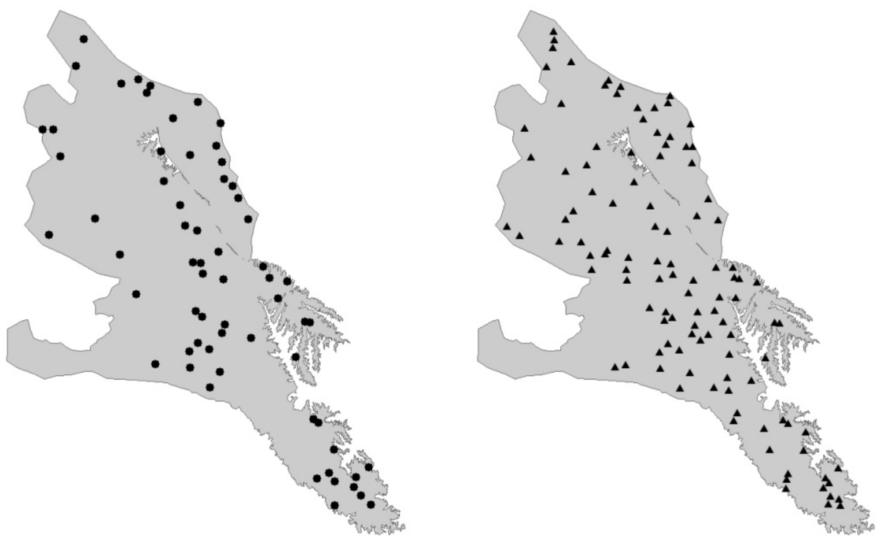

Figure 41. Baseline water quality sites sampled (left; circles) and water level sites (triangles) measured in the RSPG-AQ in 2013.

Water Quality

Overall, this aquifer contains water that ranges from fair to good quality. Groundwater in the aquifer is very hard and moderately alkaline, averaging 558 mg/L and 188 mg/L, respectively. Mean total dissolved solids (TDS), specific conductance and pH are 866 mg/L, 1,070 µS/cm and 7.19, respectively. TDS ranged from 178-4,680 mg/L with a median concentration of 427 mg/L.

The piper plot (Figure 42) for the Rush Springs data reflects calcium-bicarbonate (56% of sites), calcium-sulfate (28% of sites) and mixed chemistry (16% of sites) water types. The spatial distribution of the water types is shown in Figure 43.

The data indicate that the primary water quality issues in the aquifer are nitrates (locally), TDS, sulfate and hardness. Whereas elevated nitrate concentrations appear to occur without spatial pattern, excessive mineral content occurs mainly in areas where rock formations with high sulfate content overlie, underlie or abut the Rush Springs Sandstone. Within its outcrop area (excepting areas south of the Washita River), mineralization is much lower. Primary sulfate sources that the mineralized water is derived from include the Cloud Chief, Marlow and El Reno Group. Table 7 shows the median, mean and range of concentrations for sulfate, TDS and hardness for the entire data set (64 sites), Rush Springs Sandstone outcrop (47 sites) and sulfate source areas (17 sites). Figure 44 shows the distribution of TDS and sulfate in the aquifer.

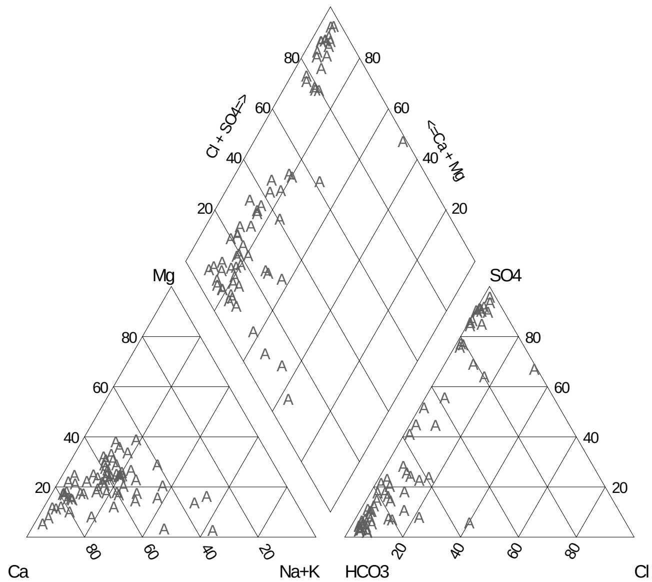

Figure 42. Piper plot diagram of constituents of the RSPG-AQ.

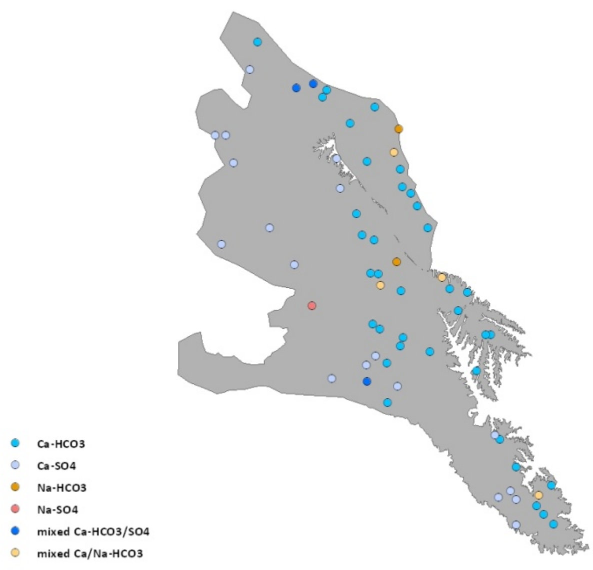

Figure 43. Water types of the RSPG-AQ.

Table 7. Comparisons of Sulfate, TDS and Hardness Data for the RSPG-AQ.

	Complete Data Set (64 samples)			Rush Springs Outcrop (47 samples)			*Sulfate Source Rock Areas (17 samples)		
Parameter	Median	Mean	Range	Median	Mean	Range	Median	Mean	Range
Sulfate	61	401	<5 – 2300	26	156	<5 - 1530	1310	1080	70-2300
TDS	427	865	178-4680	339	518	178-2520	2150	1820	349-4680
Hardness	302	558	139-1998	243	364	139-1827	1320	1130	287-1998

*Includes the Cloud Chief Formation, Marlow Formation and El Reno Group; Median, Mean and Range Concentrations (mg/L)

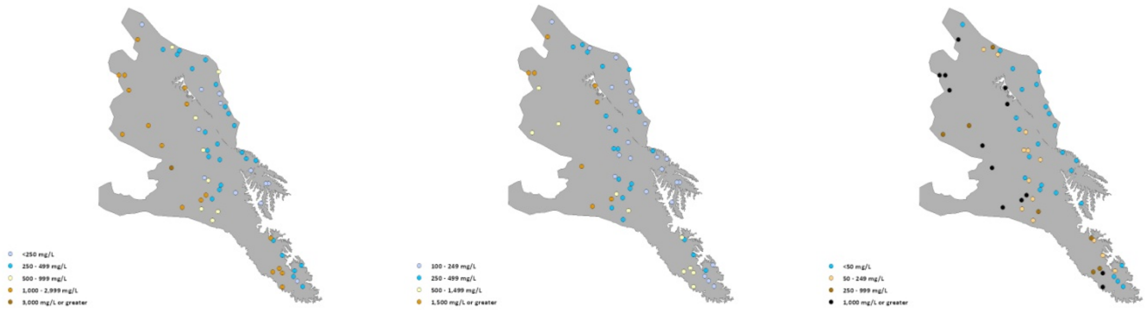

Figure 44. Total dissolved solids (left), hardness (center) and sulfate concentrations in the RSPG-AQ.

Nitrate was detected in all wells, ranging from 0.24- 59.2 mg/L, with mean and median concentrations of 7.17 and 4.46 mg/L, respectively (Figure 45). Other nutrients in the RSPG-AQ were low; ammonia was not detected and phosphorus was present in 13 wells with a maximum concentration of 0.027 mg/L.

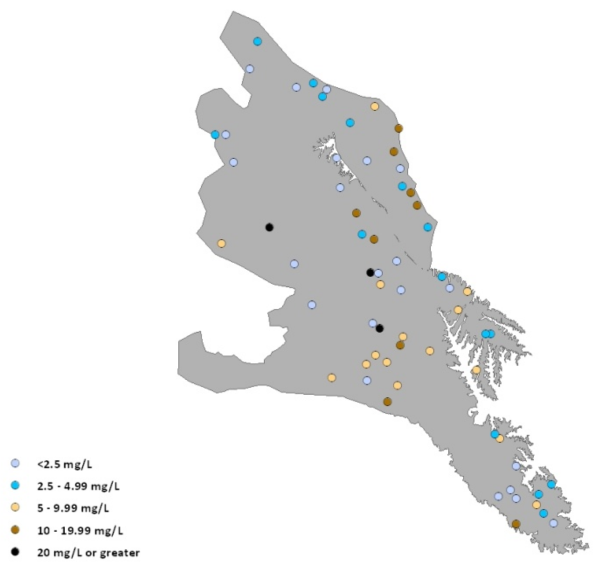

Figure 45. Nitrate concentrations in the RSPG-AQ.

The RSPG-AQ had relatively few metals and trace elements detected. The following were not detected: aluminum, antimony, beryllium, cadmium, cobalt, manganese, mercury, nickel, selenium, silver, and thallium. Arsenic (4 occurrences) and lead (1 occurrence) were detected at high concentrations. Chromium was present only in the western and northern part of the aquifer at low concentrations; uranium was detected in 65% of the samples; generally at low concentrations (Figure 46). Iron was present at low concentrations but was rarely detected. Boron was detected at low concentrations of 53% of samples. Other metals and trace elements that were detected in the aquifer include: barium, bromide, copper, fluoride, molybdenum, vanadium and zinc; their data are summarized in Appendix F.

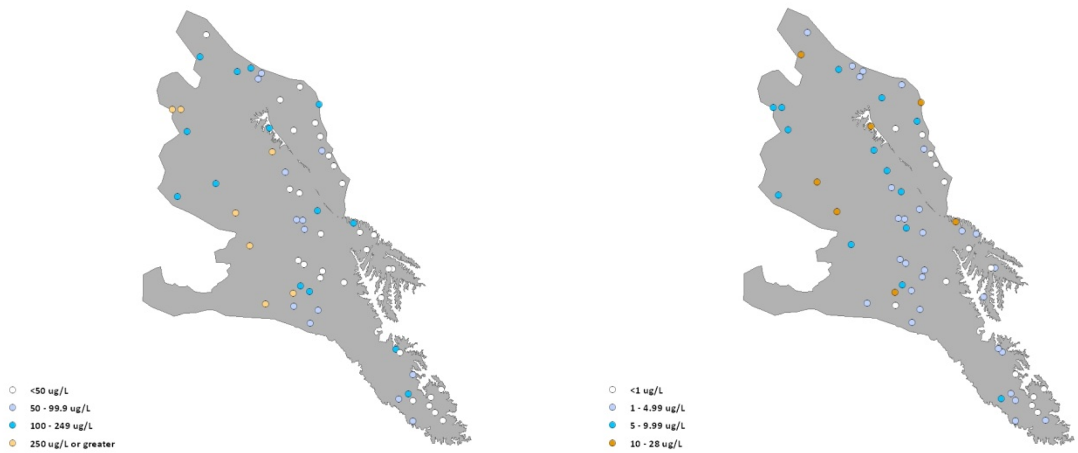

Figure 46. Boron (left) and uranium concentrations in the RSPG-AQ.

General Spatial Patterns of Rush Springs Constituent Concentrations

Increasing Concentration from East to West

- TDS, calcium, potassium, sulfate, hardness, specific conductance, magnesium, boron

Increasing Concentration from West to East

- Barium

No Apparent Spatial Pattern

- Sodium, chloride, calcium, bicarbonate, nitrate, bromide, copper, uranium, vanadium, zinc, alkalinity, dissolved oxygen, pH, water level

Localized Tendency (relatively higher concentration in specific locations of the aquifer)

- TDS, specific conductance, sulfate, hardness, chromium

EPA regulation of drinking water includes primary and secondary standards, along with health advisories, for some parameters measured in GMAP (Table 3). In the RSPG-AQ, several constituents exceeded these thresholds. Table 8 summarizes the parameters and number of occurrences over the EPA standards for drinking water.

Table 8. RSPG-AQ Constituents Exceeding EPA Drinking Water Standards – Health Advisories.

Parameter	>MCL	>SMCL	>Health Advisory
Nitrate	12		
Chloride		1	
Sulfate		20	
TDS		26	
Arsenic	4		
Lead	1		

Groundwater Level Measurements

A baseline groundwater level network comprising 104 wells was implemented in September-October 2013. 69 of the 104 wells were incorporated from the aquifer's historical water level network. Many of these older sites have nearly 40 years of record but with unfortunate interruptions in measurement. The most recent five year interval reflects that water levels have been on the decline (Table 9).

Table 9. Recent Mean Aquifer-wide Groundwater Level Changes in the RSPG-AQ.

2010	2011	2012	2013	2014
-0.09 feet	-1.42 feet	-2.18	-1.59	-1.07

The largest single year decline (2012) ensued after the historically hot and dry 2011 calendar year. The drought extended into 2012 and groundwater levels declined again. Although certain areas of the state received appreciable rainfall in 2013, many areas did not, and groundwater level declines occurred once again but to a lesser magnitude. An examination of a longer view of groundwater levels is shown in Figure 47. In contrast to the last 5 years, 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 hydrograph reflect rising groundwater levels. In spite of the recent trend, the groundwater depth to water has still decreased by about 6 feet as compared to the initial measurement. Depth to groundwater reflected in this hydrograph in the Rush Springs generally reflects those wetter times. As the network is now currently constituted, baseline water level measurements made during September-October of 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. 34 of the 104 wells in the baseline network have been incorporated into a tri-annual seasonal network.

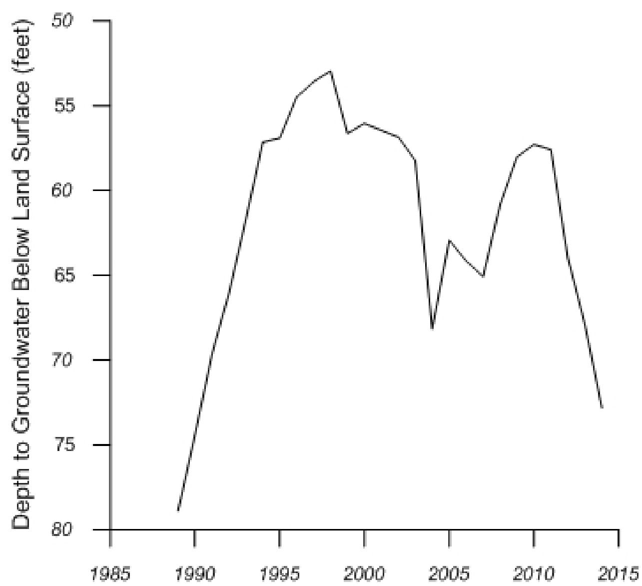

Figure 47. Groundwater level hydrograph, RSPG-AQ (1989-2014), Caddo County.

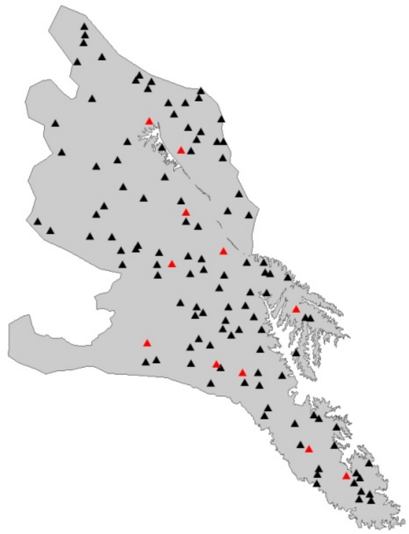

Figure 48. Location of the RUSH-AQ continuous water level recorders (red) deployed for a separate OWRB hydrologic study against the entire RUSH-AQ water level network.

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 (a few sites in the state have records that date to the 1940s). The water level network at one time (mid-late 1980s) was composed of over 1,000 observation wells, and all of the state's major aquifers (excepting 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. Currently the network is composed of about 530 wells unevenly distributed throughout the major aquifers (Figure 49). The data are 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 modeling groundwater systems; and mapping areas of water level change in the High Plains aquifer.

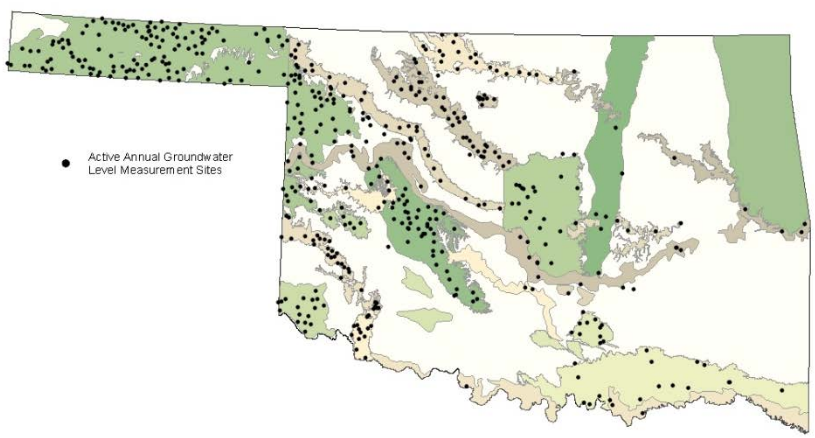

Figure 49. Historical groundwater level measurement sites in Oklahoma's major aquifers.

The mass measurement well network is composed of private wells where landowner authorization has already been granted to access the property to measure the wells. While the existing network has 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 (examples shown in Figure 50). Given the long term data available from some of the network wells and landowners already participating in the current mass measurement program, some of these wells will intentionally be included in the new Groundwater Monitoring and Assessment Program's (GMAP) network (Figure 51).

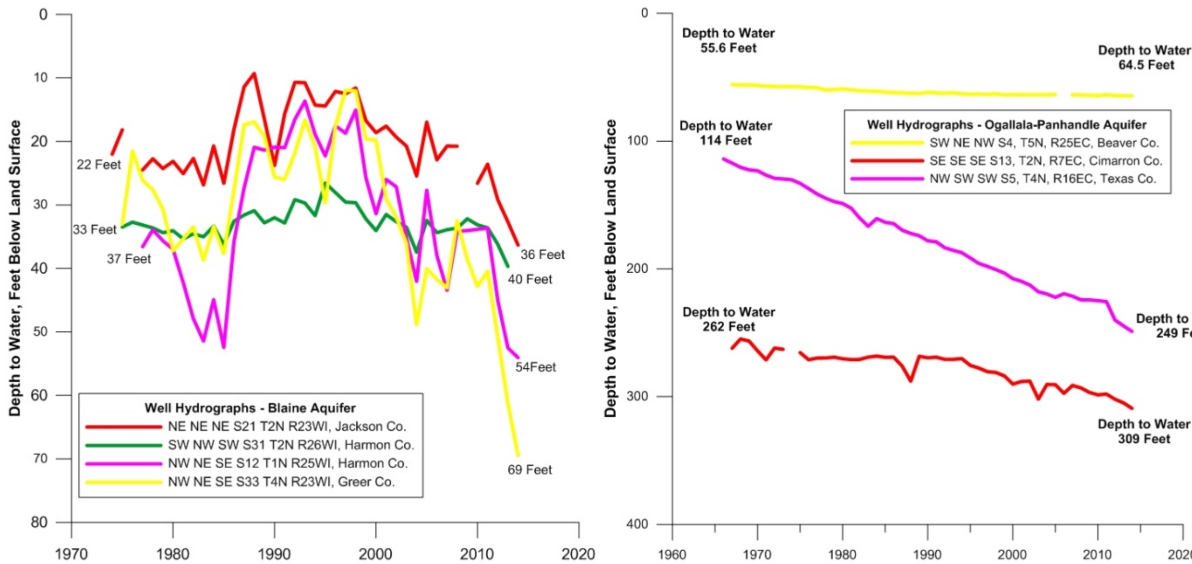

Figure 50. Groundwater level hydrographs of selected wells of the mass measurement program.

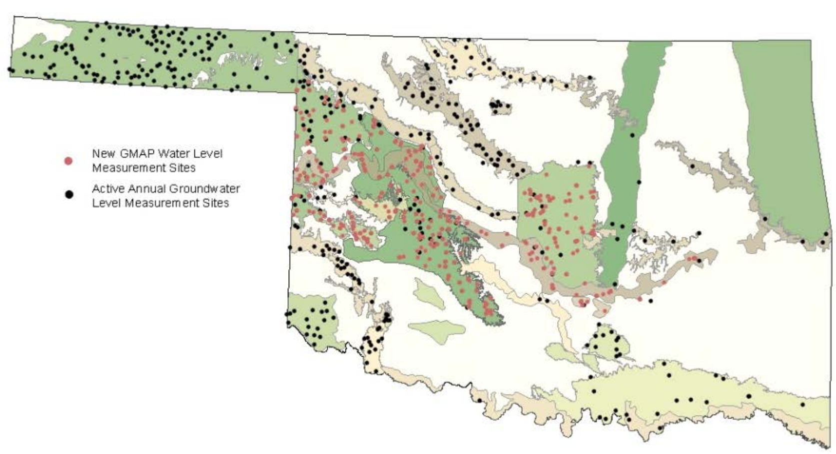

Figure 51. GMAP groundwater level measurement sites incorporated into the historical network.

Groundwater level measurements combined with land surface elevation (determined by GPS) and base of aquifer depths (determined through well log analysis) can be used for point determinations of aquifer subsurface water level elevation and saturated thickness. In combination with a spatially distributed network of wells, mapping of aquifer saturated thickness, potentiometric surface (water table), groundwater flow direction and gradient can be generated. A groundwater level monitoring network also can be used to track changes in groundwater levels over time related to drought, seasonal variation and groundwater usage. With an expanded, spatially distributed network of wells, assessments of aquifer wide groundwater level changes will be possible. GMAP's new groundwater level network design will provide data that more comprehensively reflect 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. 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 precise water level data across the state. For those wells that are in an aquifer that has not yet been phased into GMAP, the annual winter water level measurement will continue.

In the first year of GMAP, 299 wells were measured for water level in the Group A aquifers (Figure 52, Figure 53). 247 of the 299 wells have been retained in the permanent Group A water level monitoring network, representing an overall increase of 87 wells in these aquifers while providing significantly improved spatial representativeness. 111 of the 247 wells have been incorporated into the Group A seasonal water level network. An additional 335 wells were measured across the state in aquifers not yet incorporated into GMAP, with an additional 5 wells converted to continuous water level monitoring sites.

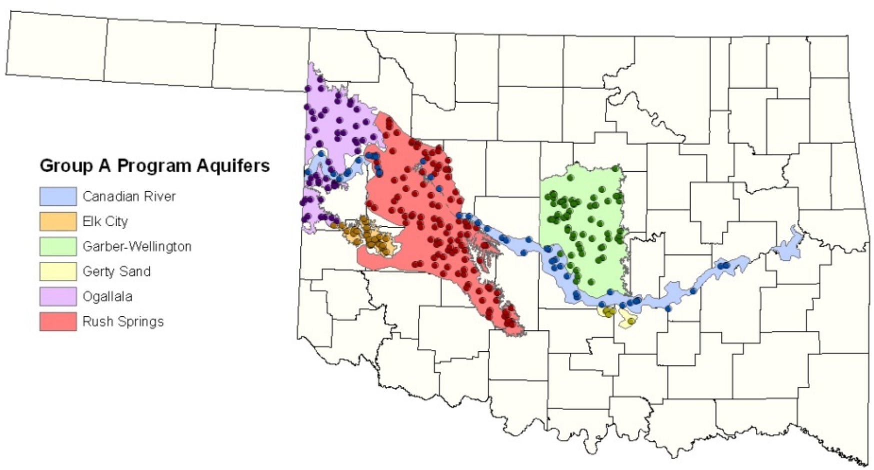

Figure 52. The baseline water level network in Group A aquifers of GMAP.

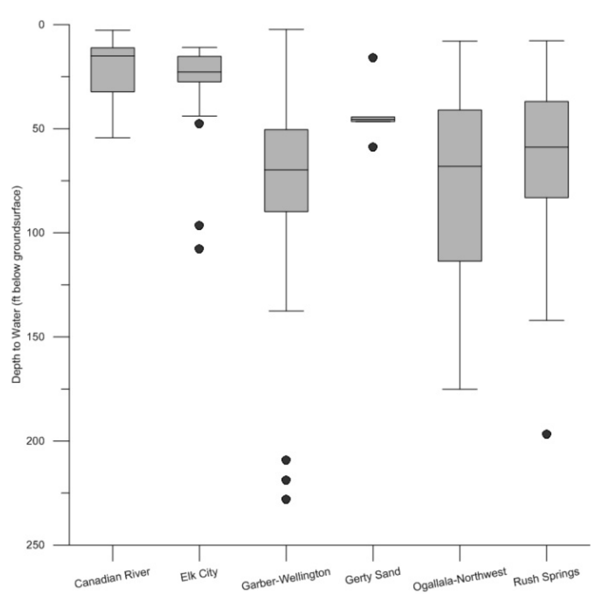

Figure 53. Boxplot of 2013 water levels in the Group A aquifers.

Along with the annual measurements, a select number of dedicated wells in each aquifer will be equipped with water level data loggers to monitor changes on a scale of weeks or days. Sixteen continuous water level meters in six different aquifers were installed in 2013, in addition to the continuous water level meters already in place for separate, single-aquifer hydrologic studies being conducted by the OWRB (Figure 54). Since 2004 the OWRB has collaborated with the Oklahoma Climatological Survey to drill groundwater level observation wells at 7 Oklahoma Mesonet Stations. The most recent collaboration and completion of a new well occurred this winter at the Weatherford Mesonet station. Groundwater observation wells are equipped with down-hole pressure transducers recording 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. The OWRB is currently working with Oklahoma State University, the University of Oklahoma, the Oklahoma Climatological Survey-Mesonet and landowners to drill additional wells at Mesonet stations (within major aquifers) located near Cherokee, Pauls Valley, Porter, Idabel, and Tipton during 2014.

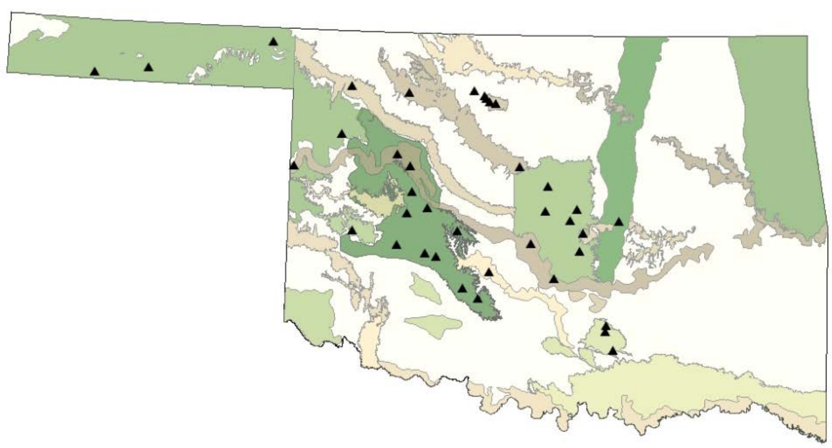

Figure 54. Sites with OWRB continuous water level recorders installed.

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Table of Appendices

Appendix A – Descriptive Statistics and Selected Maps 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	5544 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 A.1. 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)	1373.9	166.8	102.1	723.9	907.9	2081.9	3709.6	
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)	1041.5	157.2	86.3	435.5	533	1747.5	3420	SMCL: 500; 23 sites over

Table A.2. Descriptive statistics on nutrient constituents.

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
Ammonia (mg/L)	All Values <0.1, except 8 (0.46,0.29,0.2,0.97,0.35,0.24,0.26,0.23)							
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 A.3. 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 A.4. 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)	166.75	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
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

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

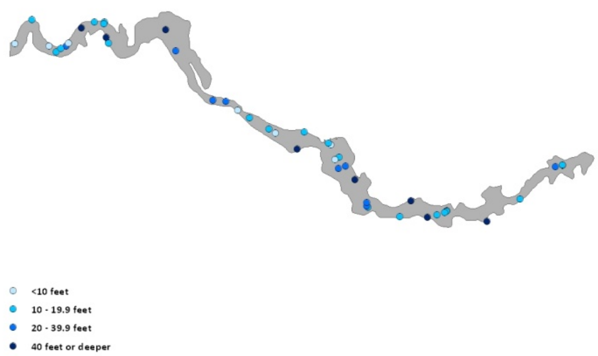


Figure A.1. Water level in the CANR-AQ.

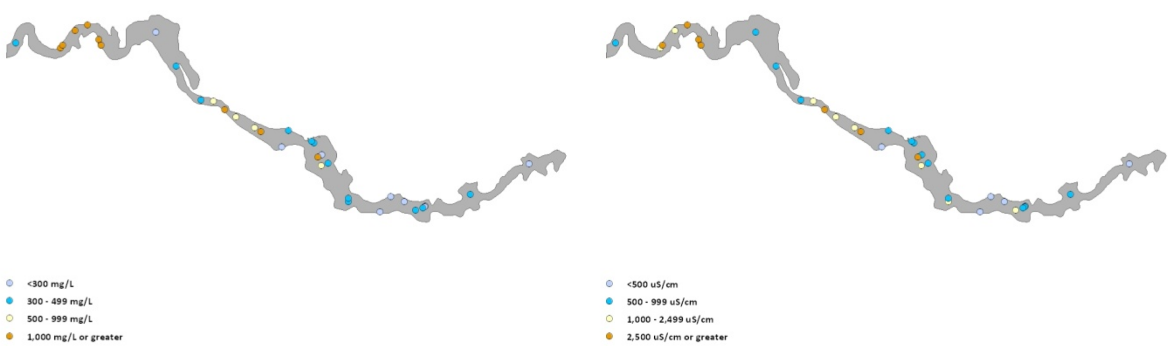


Figure A.2. Hardness (left) and specific conductance concentrations in the CANR-AQ.

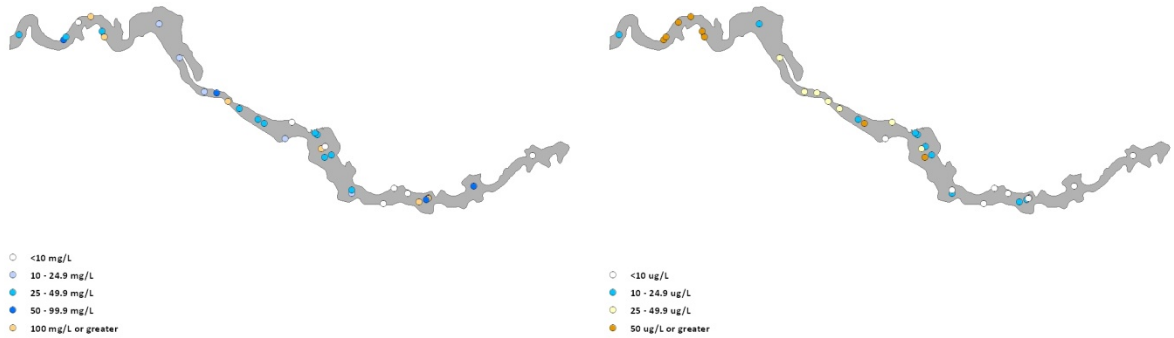


Figure A.3. Chloride (left) and vanadium concentrations in the CANR-AQ.

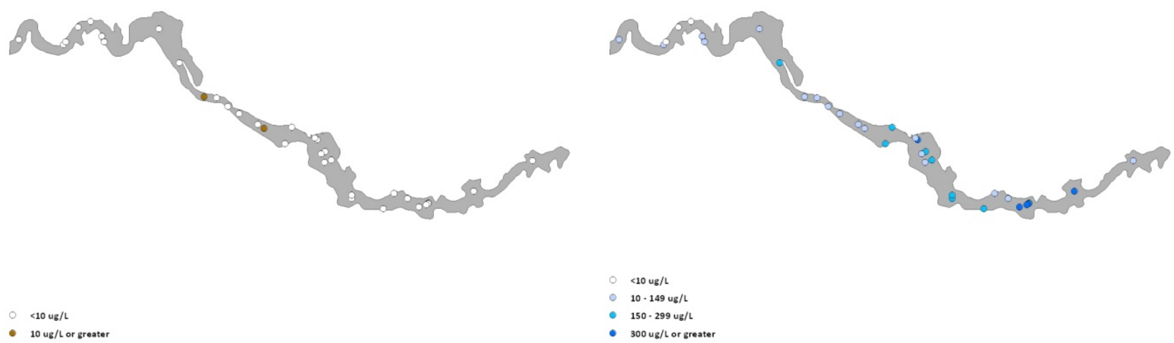


Figure A.4. Arsenic (left) and barium concentrations in the CANR-AQ.

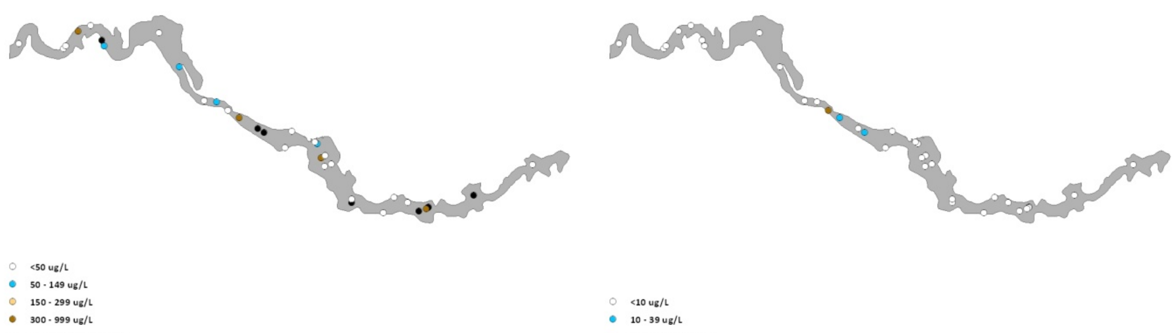
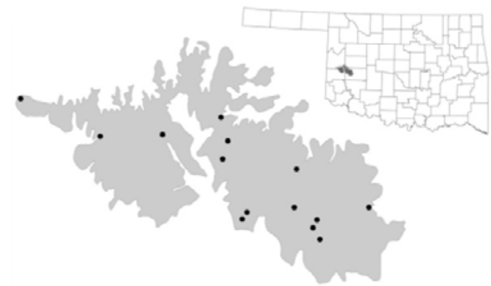


Figure A.5. Iron (left) and molybdenum concentrations in the CANR-AQ.

Appendix B – Descriptive Statistics and Selected Maps 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	Municipal & Domestic Supply; Irrigation
	Category	Bedrock - Sandstone

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

Table 1. 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)	276.08	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 2. 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 3. 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	2.44	<10	<10	16.5	19.4	30.1	SMCL: 250; 0 over

Table 4. 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

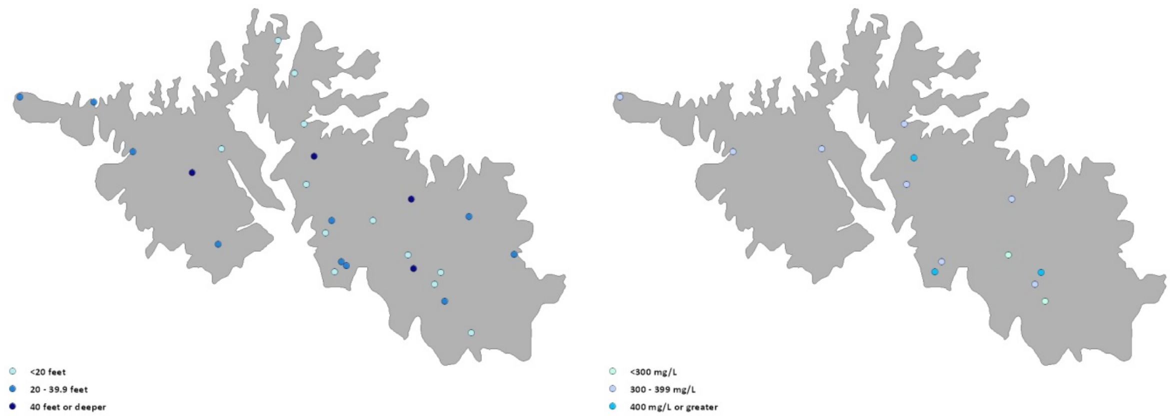
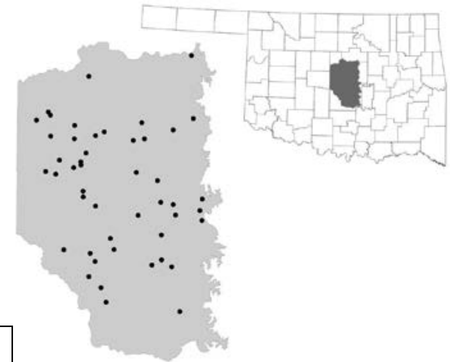


Figure B.1. Water level (left) and TDS concentrations in the ELKC-AQ.

Appendix C – Descriptive Statistics and Selected Maps for Garber-Wellington Aquifer



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

General		
	Location	runs through Mid-Oklahoma
	Area	5544 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, Ammonia, Antimony, Beryllium, Cadmium, Cobalt, Mercury, Molybdenum, Nickel, Silver, & Thallium.

Table 1. 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	2552.2	
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	325.75	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 2. 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	0.0205	0.156	

Table 3. 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 4. 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 Beryllium (µg/L)	All Values <2							MCL: 4; 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

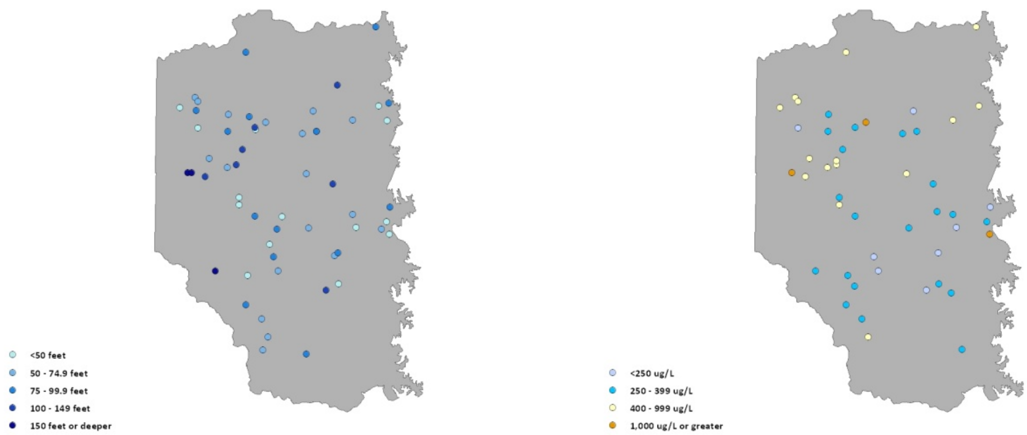


Figure C.1. Water level (left) and bromide concentrations in the GBWL-AQ.

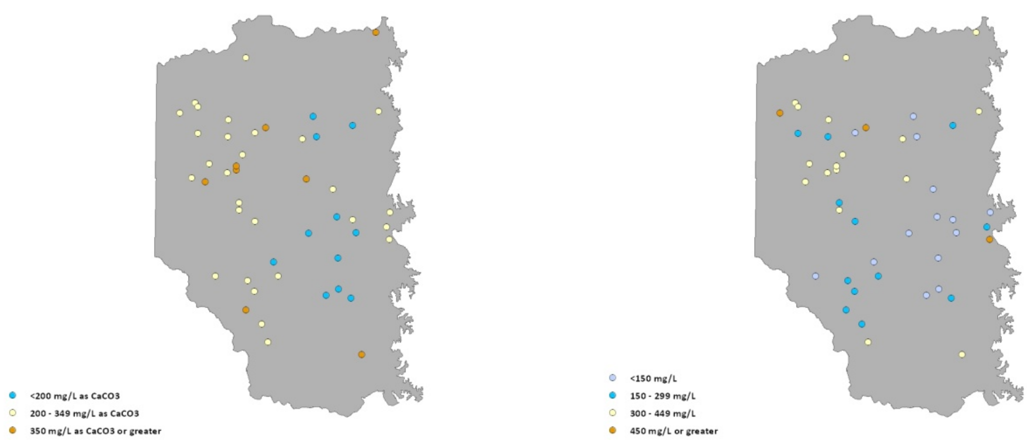


Figure C.2. Alkalinity (left) and hardness concentrations in the GBWL-AQ.

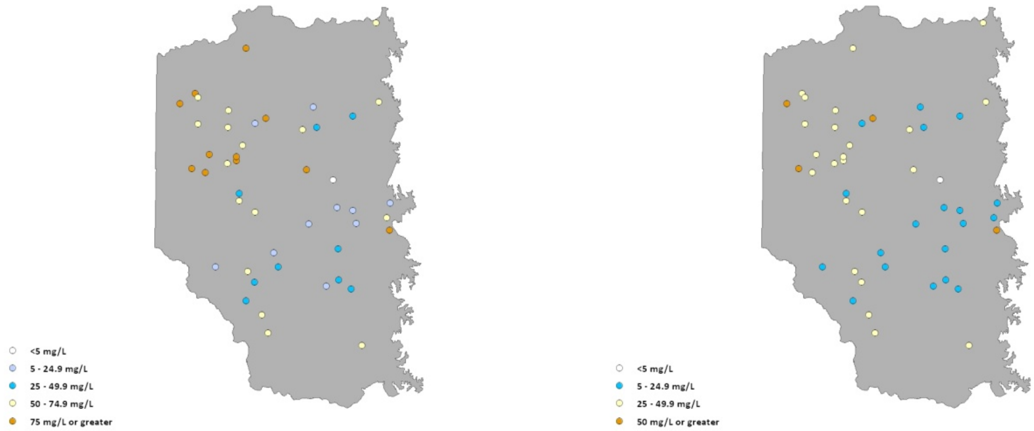


Figure C.3. Calcium (left) and magnesium concentrations in the GBWL-AQ.

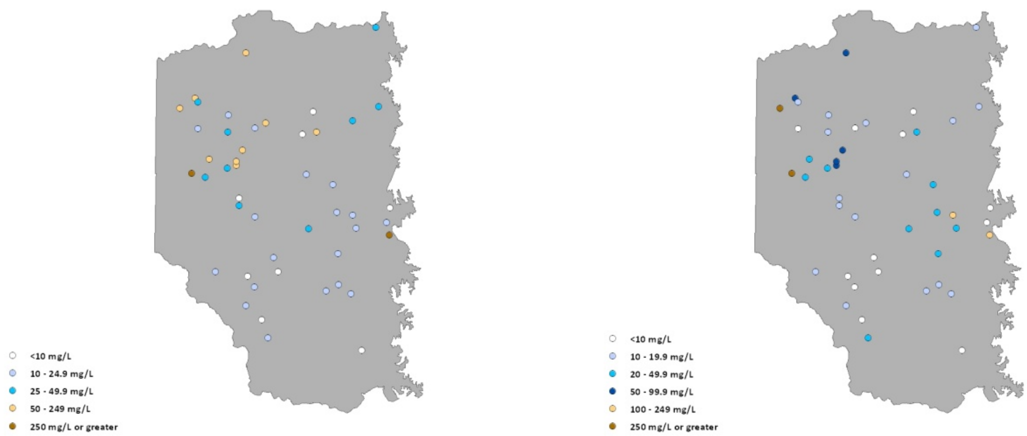
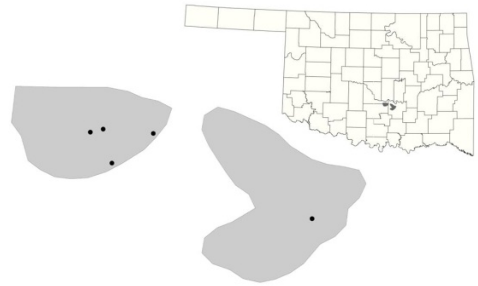


Figure C.4. Chloride (left) and sulfate concentrations in the GBWL-AQ.

Appendix D – 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	Municipal & Domestic Supply; 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 1. . 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 2. 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	

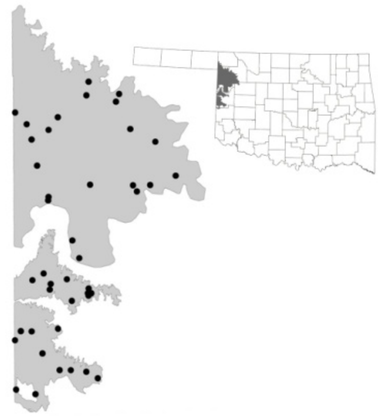
Table 3. Descriptive statistics on mineral constituents.

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 4. 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 Boron (µg/L)	All Values <50							HA: 6000; 0 over
dissolved Copper (µg/L)	14.08	5.36	<5	6	10.5	18.9	32.5	MCL: 1300; 0 over
dissolved Iron (µg/L)	All Values <50							SMCL: 300; 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 E – Descriptive Statistics and Selected Maps 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	Agriculture & Irrigation
	Category	Bedrock

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

Table 1. 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	1680.2	
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)	207.67	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 2. 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 3. 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 4. 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
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	

Parameter	Mean ± SEM		Min	25%	Median	75%	Max	Comment
dissolved Zinc (µg/L)	28.41	5.05	<10	<10	14.55	50.3	147	SMCL: 5000; 0 over. HA: 2000; 0 over

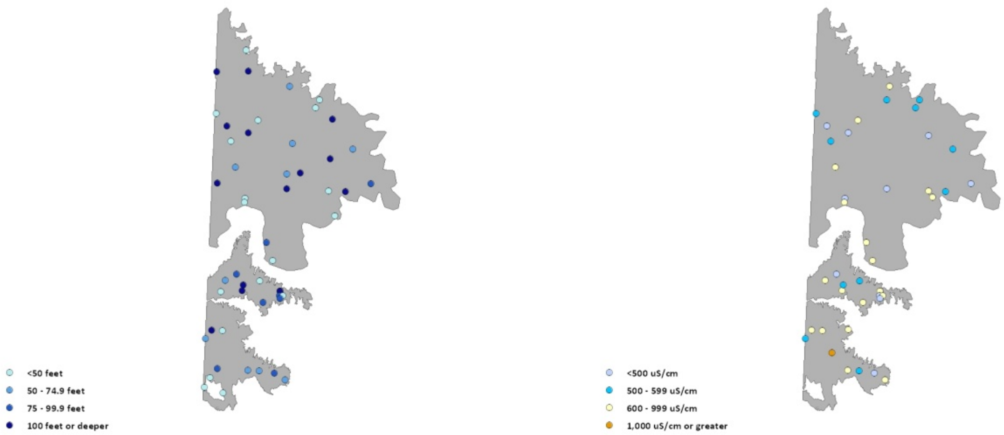


Figure E.1. Water level (left) and specific conductance in the OGNW-AQ.

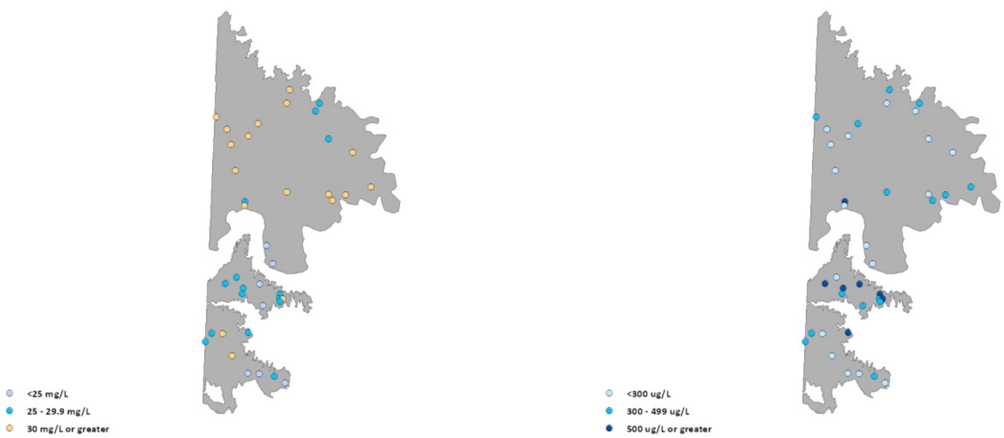
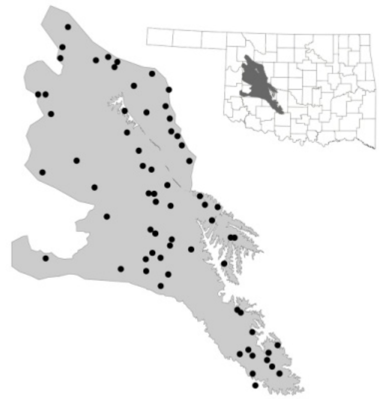


Figure E.2. Silica (left) and barium concentrations in the OGNW-AQ.

Appendix F – Descriptive Statistics and Selected Maps 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	Municipal & Domestic Supply; Irrigation
	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 1. 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)	1074.6	121.2	102.3	456.7	659.7	1453.3	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	184.75	224.5	270	473	
Total Dissolved Solids (mg/L)	865.7	114.7	178	273.8	426.5	1132.5	4680	SMCL: 500; 26 over

Table 2. 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	0.0044	<0.005	<0.005	<0.005	0.0093	0.217	

Table 3. 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)	400.73	75.65	<10	16.6	61.35	627	2300	SMCL: 250; 20 over

Table 4. 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

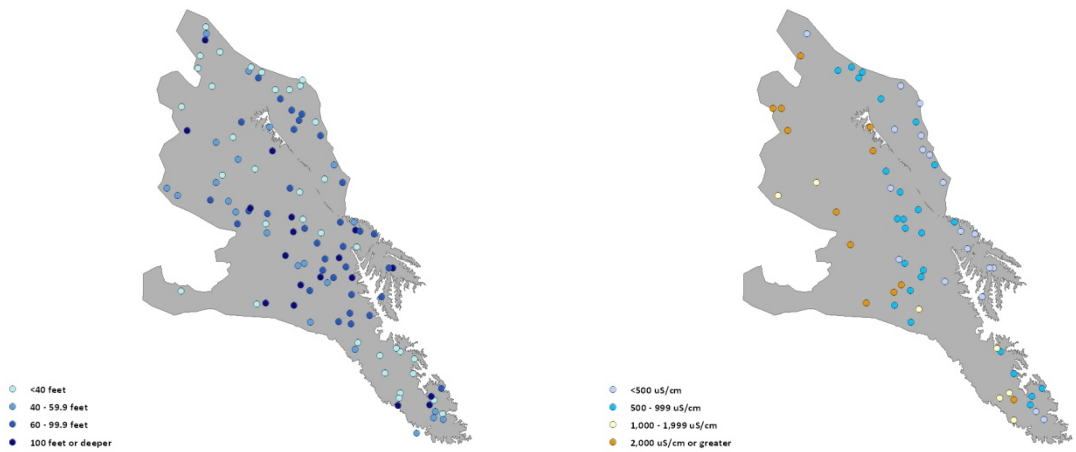


Figure F.1. Water level (left) and specific conductance in the RUSH-AQ.

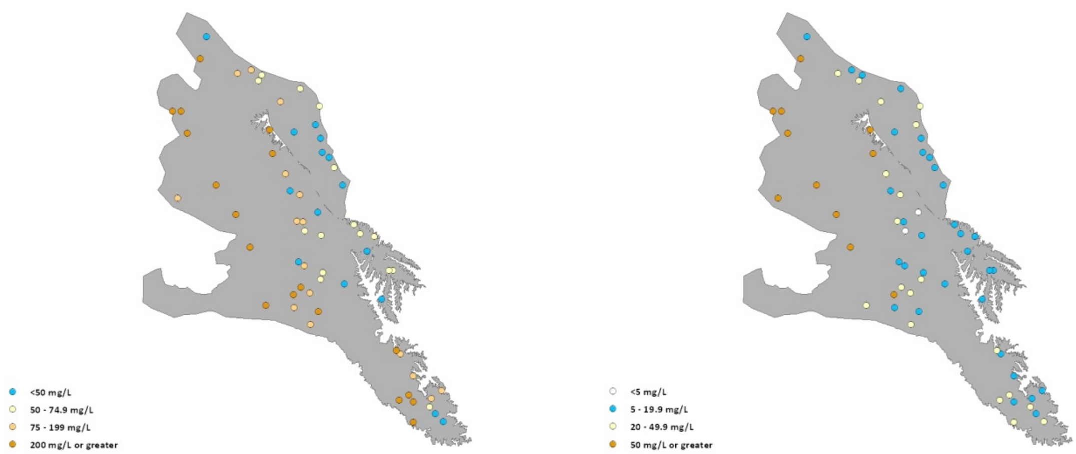


Figure F.2. Calcium (left) and magnesium concentrations in the RUSH-AQ.

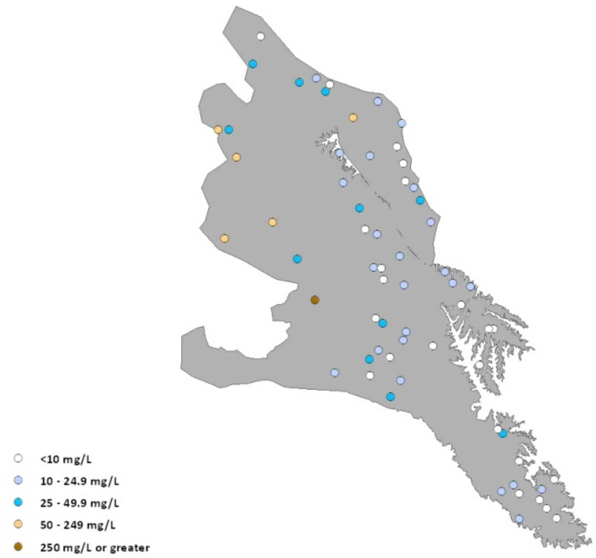


Figure F.3. Chloride concentrations in the RUSH-AQ.

Appendix G – Note on Reported Zinc Values

While quality assurance checks generally showed data to be of high quality, it should be noted that twenty percent of blank samples presented zinc concentrations above the reporting limit. Of the aquifers sampled, only the Canadian River, Ogallala-Northwest, and Rush Springs aquifers coincided with said blanks (Figure G.1). The presence of blank values above the reporting limit for zinc does not necessarily indicate that cross-contamination is occurring. Any possible influence is unlikely to be of concern to drinking water quality, as reported blank and environmental sample levels are far below the EPA SMCL (Figure G.2). The OWRB is currently investigating causes of and solutions to this issue. Zinc numbers are presented as reported pending a decision by the OWRB.

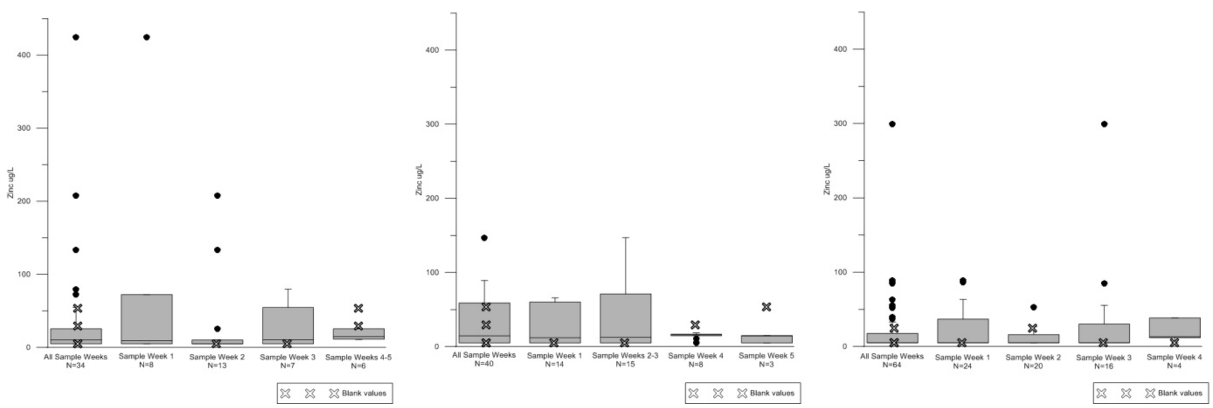


Figure G.1. Zinc values, by week and overall, compared with blank values for (left to right) the CANR-AQ, OGNW-AQ, and RSPG-AQ.

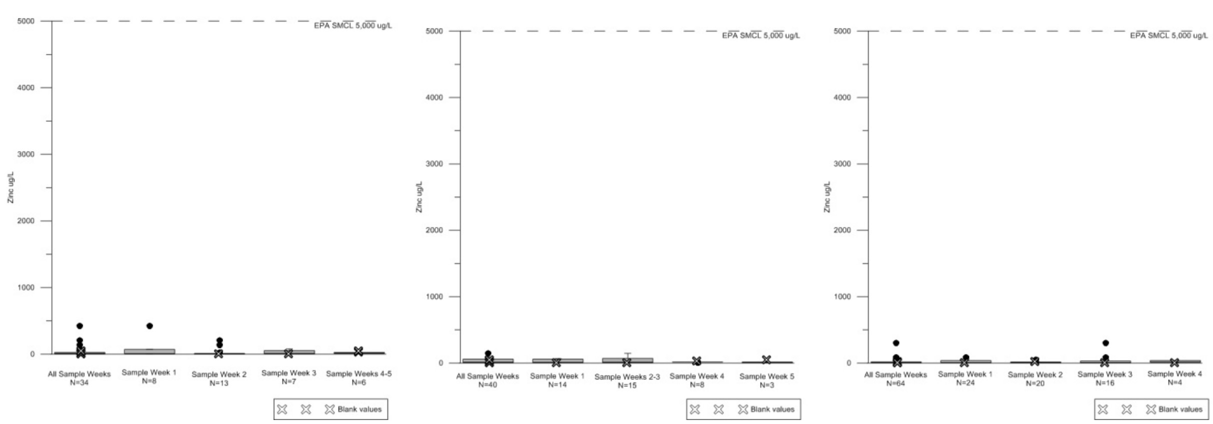


Figure G.2. Zinc values, by week and overall, compared with blank values for (left to right) the CANR-AQ, OGNW-AQ, and RSPG-AQ, with the EPA SMCL for zinc drawn for comparison.