

F I N A L

OGALLALA AQUIFER BASELINE STUDY REPORT

Prepared for

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List of Acronyms

ft bgs	feet below ground surface
BTEX	benzene, toluene, ethylbenzene, xylenes
CDPHE	Colorado Department of Public Health and Environment
COC	chain of custody
COGCC	Colorado Oil and Gas Conservation Commission
DWR	Division of Water Resources
EDBMS	environmental database management system
EDDs	data deliverables
GIS	geographic information system
GPS	global positioning system
LCS	laboratory control sample
MDL	method detection limit
mg/l	milligrams per liter
MS	matrix spike
MSD	matrix spike duplicate
MW	monitoring well
QA/QC	quality assurance/quality control
RFP	request for proposal
RL	reporting limit
RPD	relative percent difference
SEO	State Engineer's Office
TDS	total dissolved solids
URS	URS Corporation
USEPA	United States Environmental Protection Agency
µg/l	micrograms per liter

This report presents the results of the Ogallala Aquifer Baseline Study conducted by URS Corporation (URS) on behalf of the Colorado Oil and Gas Conservation Commission (COGCC). The study was designed in response to increased oil and gas drilling activity in Washington and Yuma Counties, Colorado. The study consisted of sampling 75 selected domestic water wells; one from each selected township across the study area (Figure 1-1). The report is divided into the following sections:

- Introduction
- Field Program
- Laboratory Analysis
- Data Review
- Results and Conclusions

URS met with COGCC representatives on April 4, 2007 to discuss field program logistics. The meeting allowed COGCC to describe any criteria that they were considering for the selection of the domestic water wells to be sampled within each township. Information for all 75 townships was provided to URS for help in the selection process as discussed in Section 2.1.

2.1 Domestic Water Well Selection

A multi-phased approach was used to identify representative and accessible/available permitted Ogallala water wells within the study area. URS used Geographic Information System (GIS) and database management as tools to combine recent high resolution aerial photography and recent county assessor's data into a map that was used to identify current landowner locations and addresses within the study area. URS searched the State Engineer's Office (SEO) database of permitted domestic, stock, and irrigation water wells for Yuma and Washington counties to obtain the most accurate list of permitted SEO water wells in the Ogallala aquifer in the baseline study area. The well locations were plotted on a high resolution aerial photograph (Figure 1-1).

Only domestic wells with SEO permit numbers and well depth information in the database were shown. Additional filtering of the database to locate newer wells was also completed, with the purpose of obtaining more recent address and ownership information. Starting with well locations within section numbers nearest the center of each of the 75 townships, URS selected a primary, secondary, and tertiary well location for each township. This allowed the COGCC the ability to review the proposed well selections before URS went in the field, and gave the URS field teams additional known locations to contact for access and to sample should an access issue arise with the primary selection. A map and a list of these wells and permit completion information were submitted to COGCC on April 12, 2007 for approval. Following COGCC approval, URS obtained the permit data in electronic format for all wells from the SEO files, specifically the drillers completion report/lithologic log, well construction details, and pump installation and well yield testing report. Concurrently with the well selection process, URS prepared the template for the landowner sampling access permission request letter. The letter template was submitted to COGCC for review and was approved prior to generating individual homeowner letters.

Following revisions and approval of proposed wells by COGCC on April 17, 2007, URS contacted landowners of primary well locations via telephone. No more than three attempts over a five-day period to contact an individual landowner were performed. After three attempts, the secondary selected well in the township was contacted. The purpose of the telephone interview was to confirm the well permit and landowner information, and determine if the landowner was willing to sign the access agreement, or at least agree to have their water well included in the study. Following the telephone contact, URS sent permission letters to 76 of the 77 landowners who had agreed to review the agreement. Due to water quality data obtained during a 2006 complaint investigation, no sampling was required in township 3 south, range 50 west as per COGCC instructions..

2.2 Sample Collection

URS mobilized two field sampling teams consisting of one person per team on April 24, 2007. Each team was equipped with a complete set of sampling equipment. The two teams worked in the same portion of the project area and were in communication with each other by cellular telephones, as necessary. The sampling was completed by May 4, 2007. A summary of the water well sampling effort is presented in Tables 1-1. Water quality samples were collected from 44 primary locations, 13 secondary locations, 5 tertiary locations, and 13 other locations that were selected by field crews when the first three choices were exhausted. URS used owner information and well information from the original database to contact landowners or went directly to residences in each township to inquire about access and permission to sample wells. Although access and permission was obtained for township 3 south, range 46 west, no sample was collected because all wells within the township were either not operating and/or were not available for sampling. Therefore, a total of 75 groundwater samples were collected.

Whenever possible, URS coordinated the sampling schedule with each landowner in advance. Upon arrival at each site, URS met with the landowner, if available, and confirmed their agreement to have their well sampled. The landowner was questioned briefly regarding their opinion of the water quality, well yield, daily water use, history of the well and any problems with the well or well yield noted, if any. The landowner was asked to direct the field crew to the well and the sampling location closest to the water well. URS observed and noted on field forms the land use in the area located immediately around the well, and the condition of the well head. Field forms with attached photographs are contained in Appendix

A. Water quality samples were collected following the procedures described in the Request for Proposal (RFP). Groundwater samples for dissolved gases were collected in a submerged fashion using the COGCC preferred methodology. Additionally, groundwater samples were collected after purging and stabilization of field parameters, to the extent practicable per COGCC guidance. The field temperature purging stabilization criteria of less than 0.2 ° Celsius variation between the final three consecutive readings was not met at 31 sample locations, although the criteria was met for the last two consecutive readings at 12 of these 31 locations. However, the temperature variation at these 31 locations was typically within 0.5° Celsius. The field pH purging stabilization criteria of less than 0.1 pH unit variation for three consecutive readings was not met at 3 locations, but was close to the criteria. For specific conductance, the criterion was met at all but two locations. At these two locations, the criterion was met for the last two consecutive readings, but not the last 3 consecutive readings.

All information related to sample collection was recorded on field data sheets to facilitate data entry in the database. Digital photographs of the wellhead and the actual sampling location were taken (Appendix A), and the photo identification number recorded on the field sheet. Each water quality sample was assigned a unique sample identification number. This number contains the township number, range number, and date (in MMDDYYYY format). For example T2NR45W-04252007, was used for the sample obtained from township 2 north, range 45 west, on April 25, 2007.

Water quality samples were placed in coolers chilled to 4° Celsius. A chain-of-custody (COC) form was filled out following sample collection at each residence. Samples were shipped daily under strict COC protocol to Southern Petroleum Laboratories (SPL), Inc., located in Houston, Texas. Copies of the COC forms are contained in Appendix C. Quality Assurance/Quality Control (QA/QC) samples consisted of four (4) field duplicates (1 per 20 primary samples), and one (1) matrix spike and matrix spike duplicate sample (MS/MSD).

2.3 Global Positioning System Measurements

A Trimble staff-mounted Global Positioning System (GPS) unit capable of meeting COGCC Rule 215 was utilized for this project. The GPS unit was placed on or adjacent to the wellhead and allowed to lock into the current position. Both the GPS unit and the external antenna were attached to a carbon-fiber, 2-meter field staff. The Trimble® GPS was coupled with a Trimble Recon® field data-logger utilizing Terrasync field acquisition software. Data

were differentially corrected using Pathfinder[®] Office, immediately following the field sampling effort to provide the most up-to-date correction values. This data were then exported to an ESRI shapefile for spatial analysis and plotting. The locations of all the wells sampled are shown on Figure 1-1.

Water quality samples were analyzed at SPL for the following parameters using the analytical methods indicated in parentheses:

- Dissolved methane (RSK 175);
- Benzene, toluene, ethylbenzene, and xylenes (BTEX) (EPA 8021B);
- Total metals (Na, K, Ca, Mg, Fe, Se) (EPA 200.7);
- Dissolved metals (As, Ba, Cd, Ch, Pb, Mn) (SW 6010B)
- Alkalinity (CO₃, HCO₃), Br, Cl, F, SO₄(EPA 310.1, 300.0);
- Total dissolved solids (TDS) (EPA 160.1);
- pH, specific conductance (EPA 150.1, 120.1); and
- Nitrite nitrogen as N (NO₂) and nitrate nitrogen as N (NO₃) (EPA 353.2).

Water quality results were submitted to URS by the laboratory in both hardcopy format and electronic data deliverables (EDDs). Analytical results are discussed in Section 4.

Field QA/QC:

All MS/MSD results were acceptable with the exception of the nitrate and nitrite results analyzed by EPA Method 353.2. These nitrate and nitrite results were recovered below the acceptance range of 90-110% and were qualified as estimated. The relative percent difference (RPD) between the parent sample result and the field duplicate result were within the evaluation criteria of 30% and data qualification was not required.

Laboratory QA/QC:

Samples which had detections in the associated method blank above five times the detected value or the method detection level (MDL) were qualified as nondetect at the higher of the reporting limit (RL) or the detected value. All of the laboratory control standards (LCS) were within laboratory criteria and data qualification was not required.

Sample Handling and Shipping:

Nitrate, nitrite, and pH exceeded holding time on various occasions; the associated samples were qualified as estimated. All of the cooler temperatures were within the acceptable range.

This section presents the results of the well data review and the water quality analysis. Prior to data review, the field data (sample location ID, sample ID, field-measured water quality parameters, sample location description, and GPS locations) was input into the environmental database management system (EDBMS) established for this project. The EDBMS runs on a Microsoft Access program, and was developed at URS. The laboratory EDDs were imported electronically into the EDBMS.

4.1 Well Data

URS obtained the water well permits from the SEO for the wells sampled in this study. The drillers log was reviewed to obtain information on well completions for wells sampled in the area. Figures 4-1 through 4-5 are histograms of well information discussed as follows. In Washington and Yuma Counties, Colorado, a total of 75 domestic water wells were sampled.

Total depths of the sampled wells ranged from 55 to 400 feet, with the majority between 200 to 300 feet below ground surface (ft. bgs) (Figure 4-1). On average, the total well depth was 237 ft bgs. The mean top and bottom of screen interval were 202 ft and 237 ft, respectively (Figure 4-2). The top of the well screen ranged from 25 to 335 ft bgs, and screen bottoms ranged from 55 to 400 ft bgs. The average total screen length in each well sampled was 35 ft and ranged from 17 to 125 ft.

All wells sampled had an installed pump (Figure 4-3). Of these, three wells have turbine pumps, and the remaining wells use electric submersible pumps. The majority of wells sampled were installed with pumps in the late 1990s and early 2000s. The earliest pump installation was in June 1964 and the most recent in July 2006. Static water levels were measured at the time of pump installation, covering approximately 42 years in the sample well dataset. Initial static water levels measured after installation ranged from 13 feet below ground surface (ft bgs) to 282 ft bgs (Figure 4-4). The majority of measurements were between 50 to 200 ft and had an average of 145 ft bgs.

The type of well casing used in the sampled wells is primarily PVC. A total of 54 wells used PVC exclusively for casing. Seven wells were completed with steel, one of which used galvanized steel. A hybrid combination of steel and PVC was used in the completion of the other 14 sampled wells. These generally had two different casing sizes used in the completion. The casing size used was primarily between five and six inches in diameter,

although it ranged from four to sixteen inches in diameter for wells sampled in the area (Figure 4-5).

4.2 Groundwater Quality Data

This section discusses the geochemical methods and data used to assess water quality in the study area. Figure 1-1 is a well location map that shows groundwater sampling locations selected for discussions of major ion chemistry. Sampled wells are highlighted and referenced by permit number, and gas wells in the study area are also shown for reference. Regional groundwater flow is assumed to mimic ground surface topography, and flow towards the east.

Groundwater quality was evaluated from the analytical data on a site-wide basis. Data evaluation consisted of identification of water-types and construction of geochemical plots of major ion chemistry using commercially available software (AquaChem, v5.0). Data were also compared to state and federal water quality standards, evaluated in terms of simple descriptive statistics, and mapped in ArcGIS using graduated symbol maps of analyte concentrations.

A summary of constituents found in water quality samples from the 75 wells sampled is shown on Table 4-1. The applicable regulatory standards (Colorado Basic Standards for Groundwater and U.S. Environmental Protection Agency (EPA) Primary and Secondary Drinking Water Standards) are also included for comparison. Samples with an exceedance of a standard are shown in bold. Historical water quality provided by the COGCC for wells in the area sampled previously by the COGCC and U.S. Geological Survey (UGGS) are also provided for reference.

4.1.1 Water Types and Major Ion Chemistry of Groundwater

The charge balance for the major cations and anions was calculated to evaluate the accuracy of the data. The average charge balance error for the 75 samples was 9 percent, with only 5 samples exceeding a charge balance error of more than 12 percent. The lowest error was -35 percent, and the highest was 16 percent. AquaChem version 5 software was used for identifying the water-types of groundwater samples. (Software brands are mentioned in this report for information only. URS does not endorse any particular company or software

brand). AquaChem, in conjunction with ArcGIS, was used to produce a variety of geochemical plots including Stiff plots and graduated pie charts from the major ion results.

The predominant water chemistry type (water type) in the study area is calcium-magnesium-bicarbonate type (Ca-Mg-HCO₃). In all but one of the 75 water samples collected for this baseline study, the dominant cation is calcium. Bicarbonate is the dominant anion in 73 of the 75 samples. Sulfate is the dominant ion in one of the other samples, and chloride is the dominant ion in the other sample.

Figure 4-6 is a histogram of TDS concentrations from the 75 wells sampled in the baseline study. TDS concentrations ranged from 80 to 4,350 milligrams per liter (mg/L). The mean (average) TDS concentration is 379 mg/L, which is biased high due to the occurrence of two relatively high sample concentrations. The median (middle) TDS concentration is 274 mg/L, and 245 mg/L is the mode. The median and mode values perhaps more accurately reflect the average background TDS value for the Ogallala aquifer in the study area. Seventy percent, or 53 samples, had TDS concentrations between 200 and 300 mg/L.

Eight wells exceeded the EPA Secondary Drinking Water Standard of 500 mg/L standard as shown on Table 4-1 and Figure 4-6. The TDS concentrations at these locations ranged from 513-4,350 mg/L. Figures 4-7 and 4-8 are isopleth contour and graduated symbol maps of TDS concentrations for comparison. Two locations, 194080-A and 213107-A, had TDS concentrations of 2,210 mg/L and 4,350 mg/L respectively. The higher concentrations of TDS generally occur in the western, southwestern, and southeastern portions of the study area. Although the highest TDS location (213107-A) is located in an area with many producing oil and gas wells, there are other water wells sampled in producing areas that did not have elevated TDS concentrations.

The concentrations of major ions in the samples were converted to milliequivalents per liter (meq/L) using AquaChem. Figure 4-9 is a graduated pie chart of cations and anions in groundwater. The size of the pie diameter is based on the TDS concentration at each location. The proportion of each ion's "slice" is based on the relative percentage of the milliequivalents of each ion. For contrast, cations are shown in blue-green colors, and anions are displayed in red-orange colors in Figure 4-9. Two water sample locations are obviously different than other wells. Locations 213107-A (T2S R43W) and 194080-A (T2N R51W) have the largest diameter circles, reflecting high TDS concentrations, and also display unique major ion proportions. The chloride ion proportion, shown in bright red, is apparent in all of

the wells with elevated TDS concentrations, and is generally more noticeable in samples collected from water wells in the southwest portion of the study area.

Figure 4-10 shows Stiff plots of the major ions in groundwater for wells sampled in the study area. TDS is represented by the width of individual plots, with wider plots having higher ion and TDS concentrations. The Stiff plots show visually that at the 75 locations sampled the most frequent water type is the calcium-magnesium-bicarbonate type. Again, the two wells with the highest TDS concentrations have distinctive Stiff plots, reflecting the unique major ion chemistry at these two sample locations.

The occurrence of petroleum hydrocarbons as reflected by detections of BTEX compounds and dissolved methane were quite limited. Toluene was the only petroleum hydrocarbon detected, and it was only found in two locations and at very low levels. The two locations are permit 198791 in T5S R45W and permit 238071 in T4S R48W.

Nitrate was detected in 74 of the 75 water wells samples (Figure 4-11). Concentrations ranged from less than one to 147 mg/L. The location with the highest nitrate concentration also had the highest TDS concentration (4,350 mg/L). This sample is from permit 213107-A in T2S R43W, located in Yuma County, on the eastern edge of the study area.

Arsenic was found above the reporting limit of 16.7 micrograms per liter ($\mu\text{g/L}$) in 17 samples. The reporting limit is above the revised drinking water standard of 10 $\mu\text{g/L}$. Concentrations ranged from 17 to 33.9 $\mu\text{g/L}$.

Other constituents that were present in one or more water samples at concentrations exceeding a relevant drinking water standard are:

- ◆ Sulfate exceeded the secondary drinking water standard of 250 mg/L in one sample (1,750 mg/L at permit location 213107-A in T2S R43W).
- ◆ Chloride exceeded the secondary drinking water standard of 250 mg/L in one sample (571 mg/L in permit location 194080-A in T2N R51W).
- ◆ Fluoride exceeded the primary drinking water standard of 4 mg/L in one sample (4.76 mg/L at permit location 213107-A in T2S R43W).

- ◆ Manganese exceeded the secondary drinking water standard of 50 µg/L in two samples (1,500 µg/L at permit location 213107-A in T2S R43W, and 65 µg/L at permit location 36998-A in T3S R44W).

Seventy-five domestic water wells were sampled by URS in Washington and Yuma Counties, Colorado for the Ogallala Aquifer Baseline Study. The conclusions from this study are presented below:

- The mean TDS concentration for the 75 water wells sampled in the study area is 274 mg/L.
- TDS concentrations in the study area were below the secondary drinking water standard (500 mg/L) at 67 of the 75 wells sampled. Locations 213107-A (T2S R43W) and 194080-A (T2N R51W) had the highest TDS concentrations, 4,350 mg/L and 2,210 mg/L, respectively, and are located on the east and west sides of the study area, respectively.
- The primary water chemistry type for the Ogallala Aquifer in the study area is a calcium-magnesium-bicarbonate type.
- Toluene was the only petroleum hydrocarbon constituent detected in the 75 groundwater samples collected. Two water wells had toluene concentrations of 0.77 µg/L, which is below the drinking water standard. Benzene, ethylbenzene, xylenes, and methane were not detected in any of the 75 samples.
- Nitrate was detected in all but one of the 75 samples. The highest concentration was at location 213107-A at 147 mg/L, which is the only water sample that exceeded the groundwater standard of 10 mg/L.
- Arsenic was detected in 17 samples above the 2006 drinking water standard of 10 µg/L.
- Sulfate exceeded the secondary drinking water standard of 250 mg/L in one sample.
- Chloride exceeded the secondary drinking water standard of 250 mg/L in one sample.
- Fluoride exceeded the secondary drinking water standard of 4 mg/L in one sample.
- Manganese exceeded the secondary drinking water standard of 50 µg/L in two samples.