USGS
science for a changing world

Prepared in cooperation with the Colorado Department of Agriculture

Design and Installation of a Groundwater Monitoring-Well Network in the High Plains Aquifer, Colorado

Data Series 456

U.S. Department of the Interior
U.S. Geological Survey

Design and Installation of a Groundwater Monitoring-Well Network in the High Plains Aquifer, Colorado

By L.R. Arnold, J.L. Flynn, and S.S. Paschke

Prepared in cooperation with the Colorado Department of Agriculture

Data Series 456

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

Suggested citation:
Arnold, L.R., Flynn, J.L., and Paschke, S.S., 2009, Design and installation of a groundwater monitoring-well network in the High Plains aquifer, Colorado: U.S. Geological Survey Data Series 456, 47 p.

Contents

Abstract....1
Introduction....1
Purpose and Scope....1
Network Design....1
Final Site Selection....9
Well Drilling and Installation....9
Well Development....11
Summary....11
References Cited....11
Appendix 1. Lithologic Logs....12
Appendix 2. Well-Construction Diagrams....31
Appendix 3. Well-Development Records....41

Figures

1–7. Maps showing:
1. Location of High Plains aquifer in Colorado....2
2. Extent of irrigated agricultural land overlying the High Plains aquifer, 1999....3
3. Depth to water for the High Plains aquifer, 2000....4
4. Saturated thickness of the High Plains aquifer, 2000....5
5. Area meeting criteria for monitoring-well installation....6
6. Thirty equal-area polygons and three potential groundwater monitoring sites for each polygon generated for the area meeting monitoring criteria....7
7. Locations of 20 groundwater monitoring wells installed in the High Plains aquifer, 2008....8
8. Schematic diagram of High Plains groundwater monitoring-well completions....10

Tables

1. Latitude, longitude, land-surface altitude, installation date, and development date for groundwater monitoring wells installed in the High Plains aquifer, 2008....9
2. Summary of groundwater monitoring-well locations, construction, and depth to water....10

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Design and Installation of a Groundwater Monitoring-Well Network in the High Plains Aquifer, Colorado

By L.R. Arnold, J.L. Flynn, and S.S. Paschke

Abstract

The High Plains aquifer is an important water source for irrigated agriculture and domestic supplies in northeastern Colorado. To address the needs of Colorado's Groundwater Protection Program, the U.S. Geological Survey designed and installed a groundwater monitoring-well network in cooperation with the Colorado Department of Agriculture in 2008 to characterize water quality in the High Plains aquifer underlying areas of irrigated agriculture in eastern Colorado. A 30-well network was designed to provide for statistical representation of water-quality conditions by using a computerized technique to generate randomly distributed potential groundwater sampling sites based on aquifer extent, extent of irrigated agricultural land, depth to water from land surface, and saturated thickness. Twenty of the 30 sites were selected for well installation, and wells were drilled and installed during the period June–September 2008. Lithologic logs and well-construction reports were prepared for each well, and wells were developed after drilling to remove mud and foreign material to provide for good hydraulic connection between the well and aquifer. Documentation of the well-network design, site selection, lithologic logs, well-construction diagrams, and well-development records are presented in this report.

Introduction

The High Plains aquifer underlies about 12,500 mi^2 in eastern Colorado (fig. 1) and is an important source of water for irrigated agriculture and domestic supplies. Within Colorado, the High Plains aquifer consists primarily of the Ogallala Formation, which is composed of an unconsolidated and poorly sorted sequence of gravel, sand, silt, and clay ranging from 0 to about 500 feet thick (Robson and Banta, 1995). Between the South Platte River and Arkansas River, the saturated zone of the Ogallala Formation is as much as 400 feet thick and is used extensively for irrigation. South of the Arkansas River the Ogallala Formation is only partially saturated, and many irrigation wells are completed in the underlying Dakota Sandstone. North of the South Platte River, the High Plains aquifer in Colorado consists primarily of the Brule Formation of Tertiary age, which is composed primarily of siltstone that is relatively impermeable except in those areas where the rock has been extensively fractured (Robson and Banta, 1995).

The Colorado Department of Agriculture (CDA) monitors agricultural chemicals in the High Plains aquifer as part of Colorado's Groundwater Protection Program (GWPP), a cooperative effort of the Colorado Department of Agriculture, Colorado Department of Public Health and Environment, and Colorado State University Cooperative Extension. The goal of the GWPP is to reduce negative effects to groundwater and the environment by improving the management of agricultural chemicals and to ensure that groundwater remains safe for domestic and livestock consumption by preventing contamination. To address the needs of the GWPP, the U.S. Geological Survey designed and installed a groundwater monitoring-well network in cooperation with the CDA in 2008 to characterize water quality in the High Plains aquifer underlying areas of irrigated agriculture in eastern Colorado.

Purpose and Scope

The purpose of this report is to document the design and installation of a groundwater-quality monitoring network for the High Plains aquifer in eastern Colorado. The study objectives were to design a 30-well network and install 20 of the 30 wells to characterize water quality in the High Plains aquifer in areas of irrigated agriculture in Colorado. Specific study tasks were:

1. Design a well network to monitor water quality of recently recharged groundwater near the water table in areas of irrigated agriculture in the saturated parts of the High Plains aquifer of Colorado.
2. Obtain permission from landowners to drill and install wells.
3. Oversee well-drilling operations and document the site geologic materials and well completion.
4. Develop wells after drilling to establish hydraulic communication between the well and the aquifer.

Network Design

Well sites were selected in areas of irrigated agriculture in Colorado where the depth to water in the High Plains aquifer is less than 200 feet and saturated thickness is greater than 50 feet. Areas with depth to water less than 200 feet were used in the site-selection process to enable well installation by hollow-stem-auger drilling methods, which avoid introduction

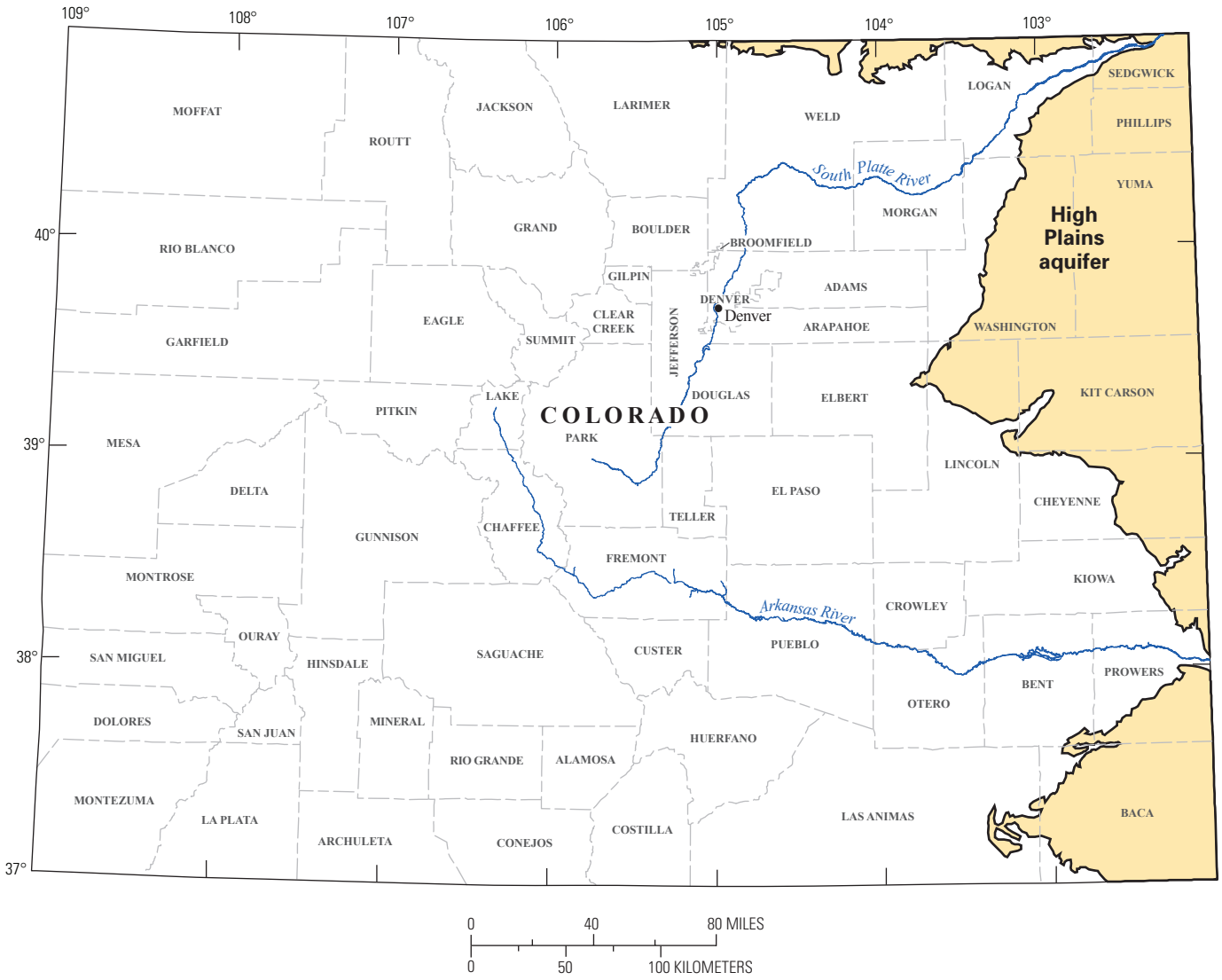


Figure 1. Location of High Plains aquifer in Colorado.

of drilling fluids into the aquifer. Because substantial water-level declines have occurred in many areas of the High Plains aquifer (McGuire, 2007; McMahon and others, 2007), areas of saturated thickness greater than 50 feet were used in the site selection process to provide for potential long-term availability of groundwater at sampling sites.

A network of 30 well locations was created using a computerized technique (Scott, 1990) that generates and selects randomly distributed potential groundwater sampling sites. Digital maps of (1) updated High Plains aquifer extent (Sharon Qi, U.S. Geological Survey, written commun., 2008) (fig. 1); (2) irrigated agricultural land (Bauder and others, 2004) (fig. 2); (3) depth to water from land surface for 2000 (Sharon Qi, U.S. Geological Survey, written commun., 2008; shown in McMahon and others, 2007) (fig. 3); and (4) saturated thickness for 2000 (V.L. McGuire, U.S. Geological Survey, written commun., 2008; shown in McGuire and others, 2003) (fig. 4) were used as input to the site-selection process to determine well locations for areas of irrigated agriculture in Colorado where the depth to water in the High Plains aquifer is less than 200 feet and the saturated thickness is greater than 50 feet (fig. 5). Irrigated land areas were aggregated into larger polygons if they were 6,562 feet (2,000 m) or less in distance from each other (fig. 2). The area meeting monitoring criteria (within irrigated lands, depth to water less than 200 feet, and saturated thickness greater than 50 feet) (fig. 5) was used as input into a program to design random site networks (Scott, 1990). The random site-selection process divided the area meeting monitoring criteria into 30 equal-area polygons (available at *http://water.usgs.gov/lookup/getspatial?ds472_equalareas)* and then generated one to three potential groundwater monitoring sites within each polygon (fig. 6; available at *http://water.usgs.gov/lookup/getspatial?ds472_randomsites)*.

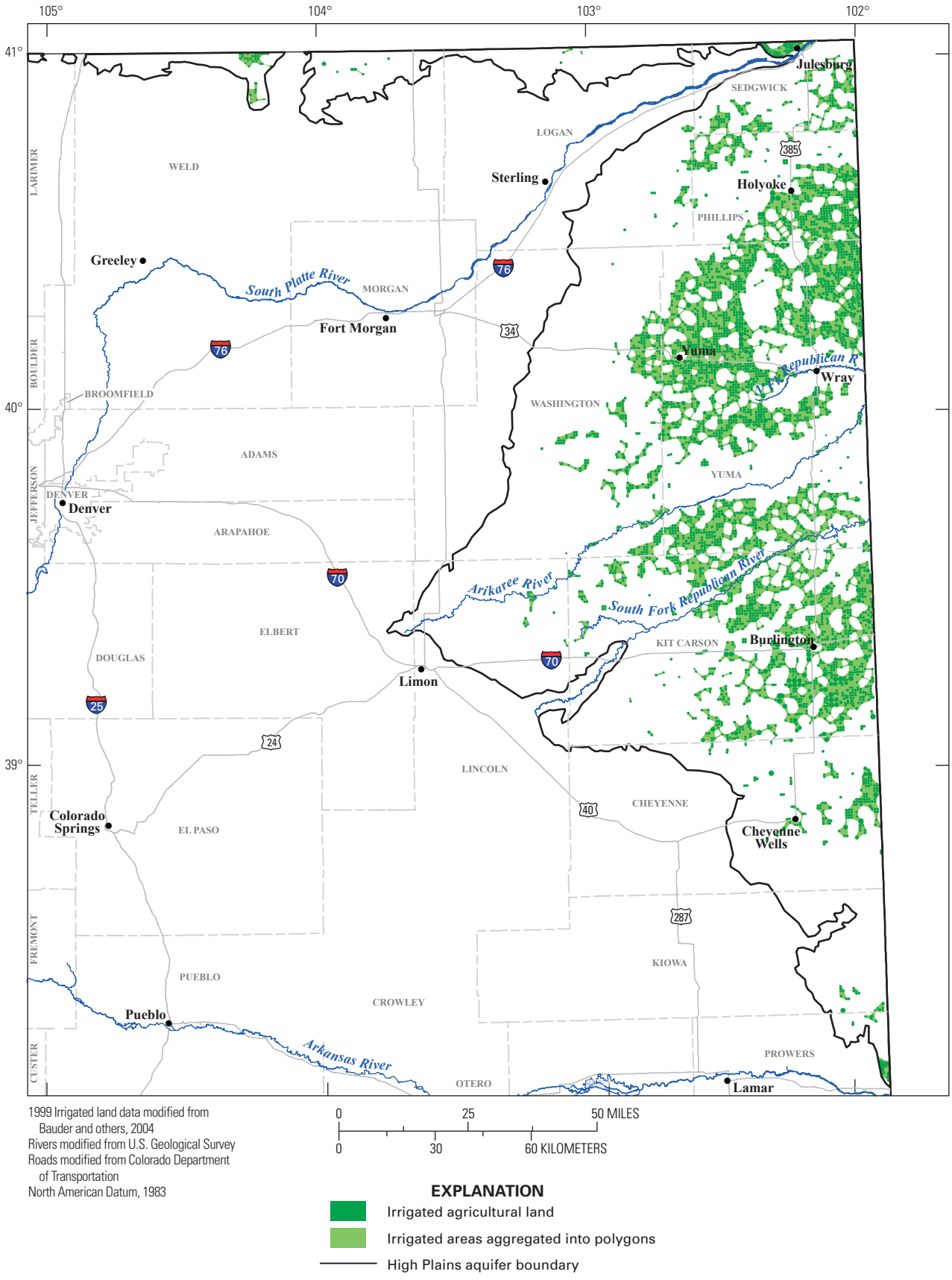


Figure 2. Extent of irrigated agricultural land overlying the High Plains aquifer, 1999.

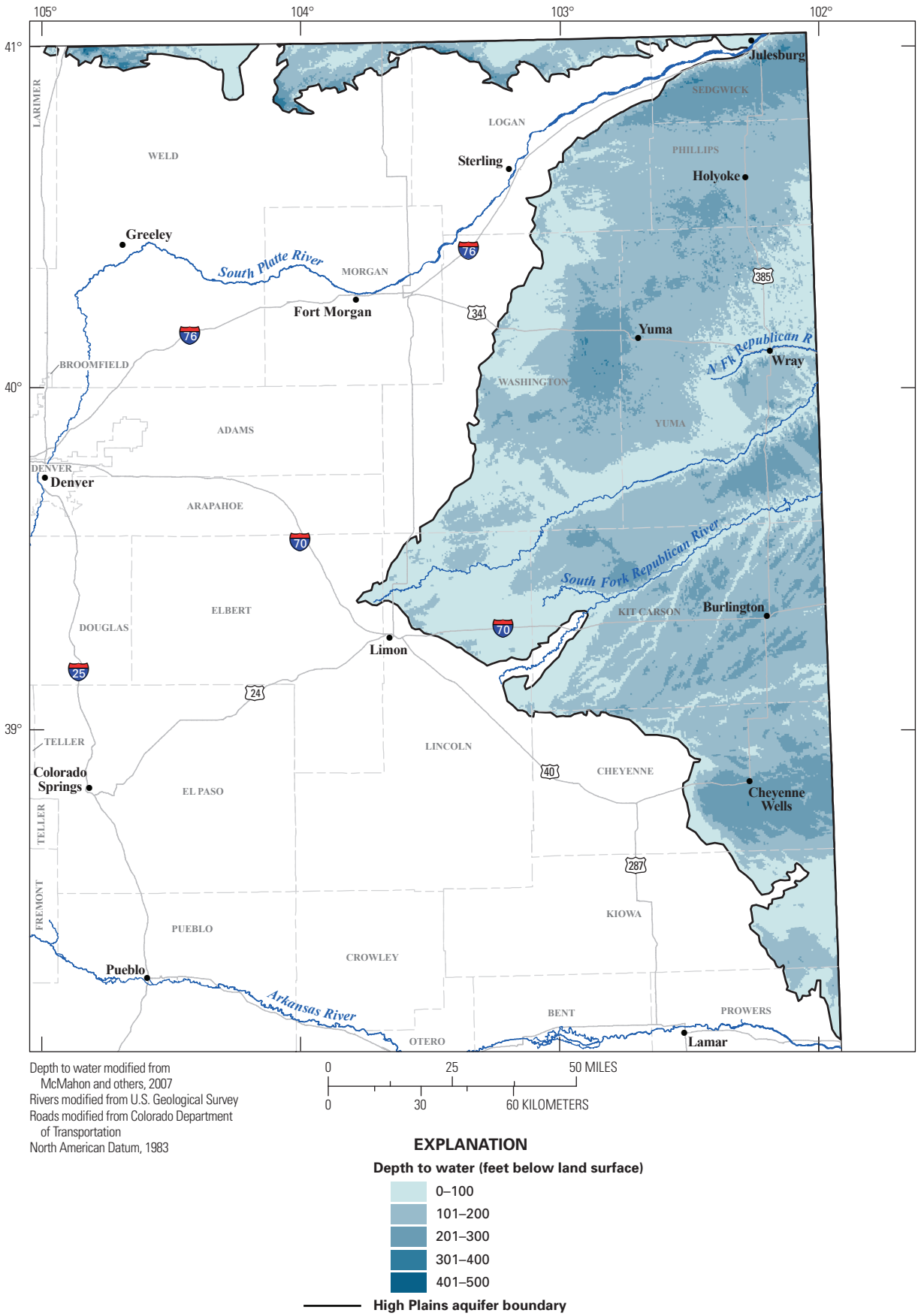


Figure 3. Depth to water for the High Plains aquifer, 2000.

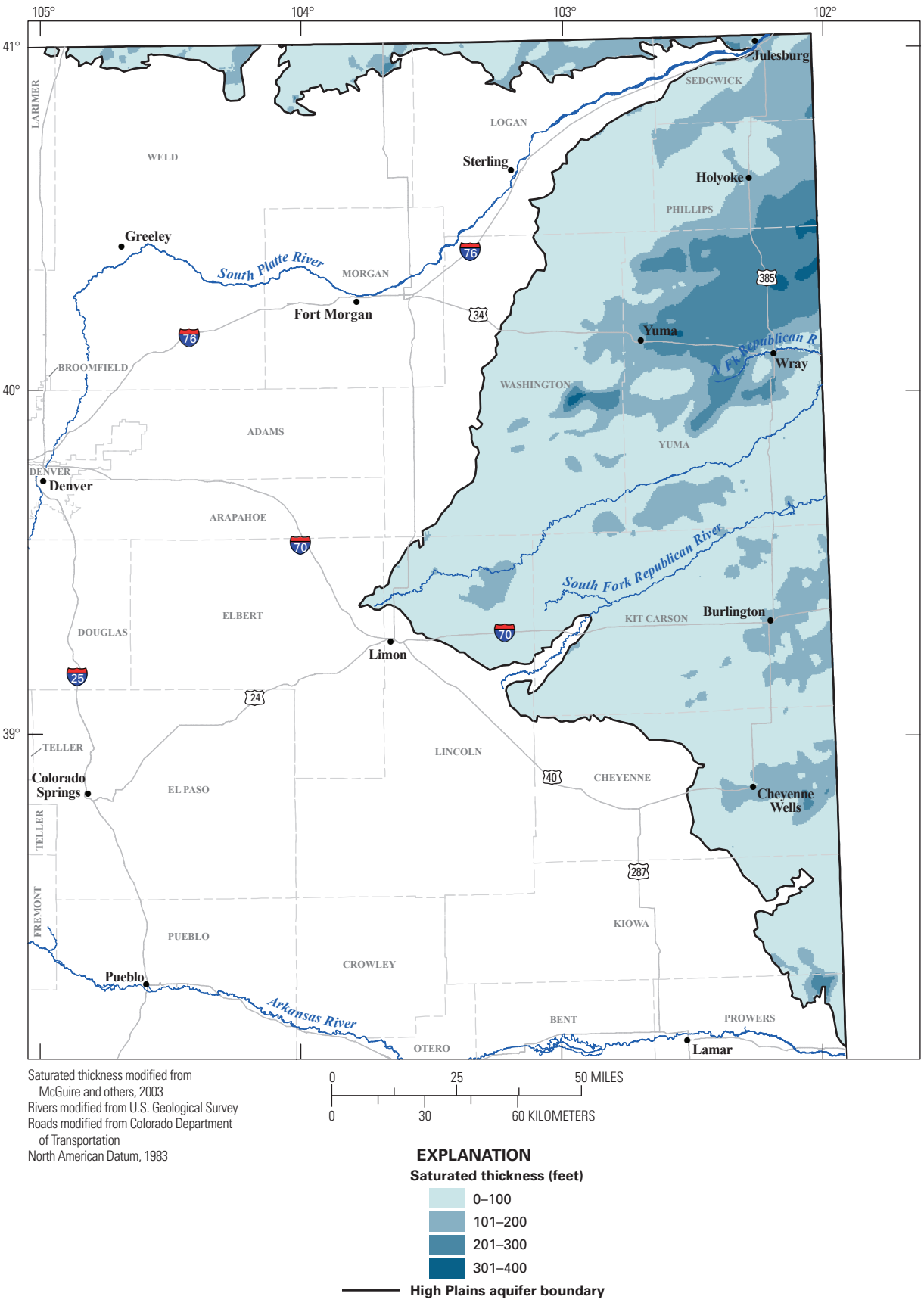


Figure 4. Saturated thickness of the High Plains aquifer, 2000.

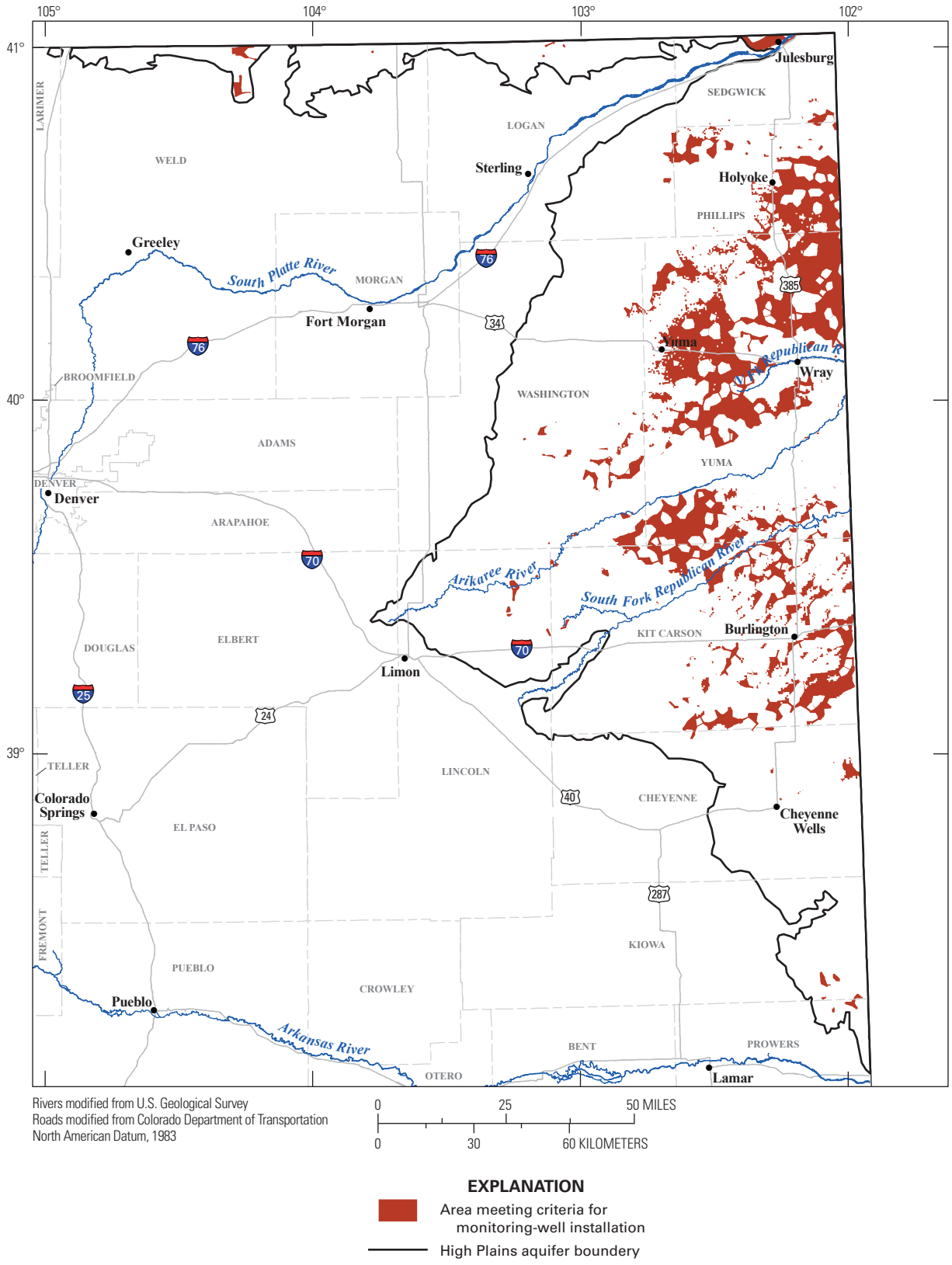


Figure 5. Area meeting criteria for monitoring-well installation.

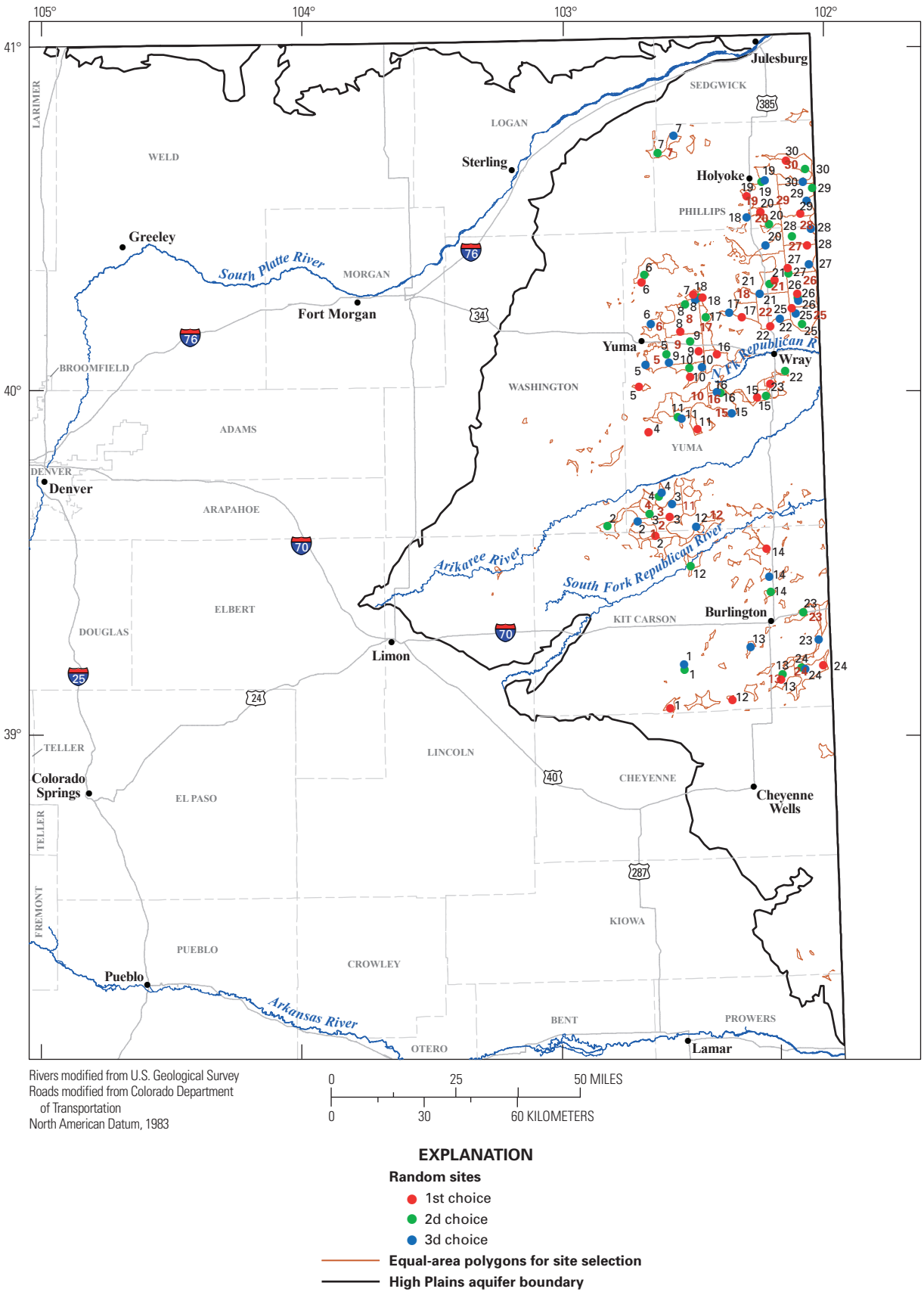


Figure 6. Thirty equal-area polygons and three potential groundwater monitoring sites for each polygon generated for the area meeting monitoring criteria.

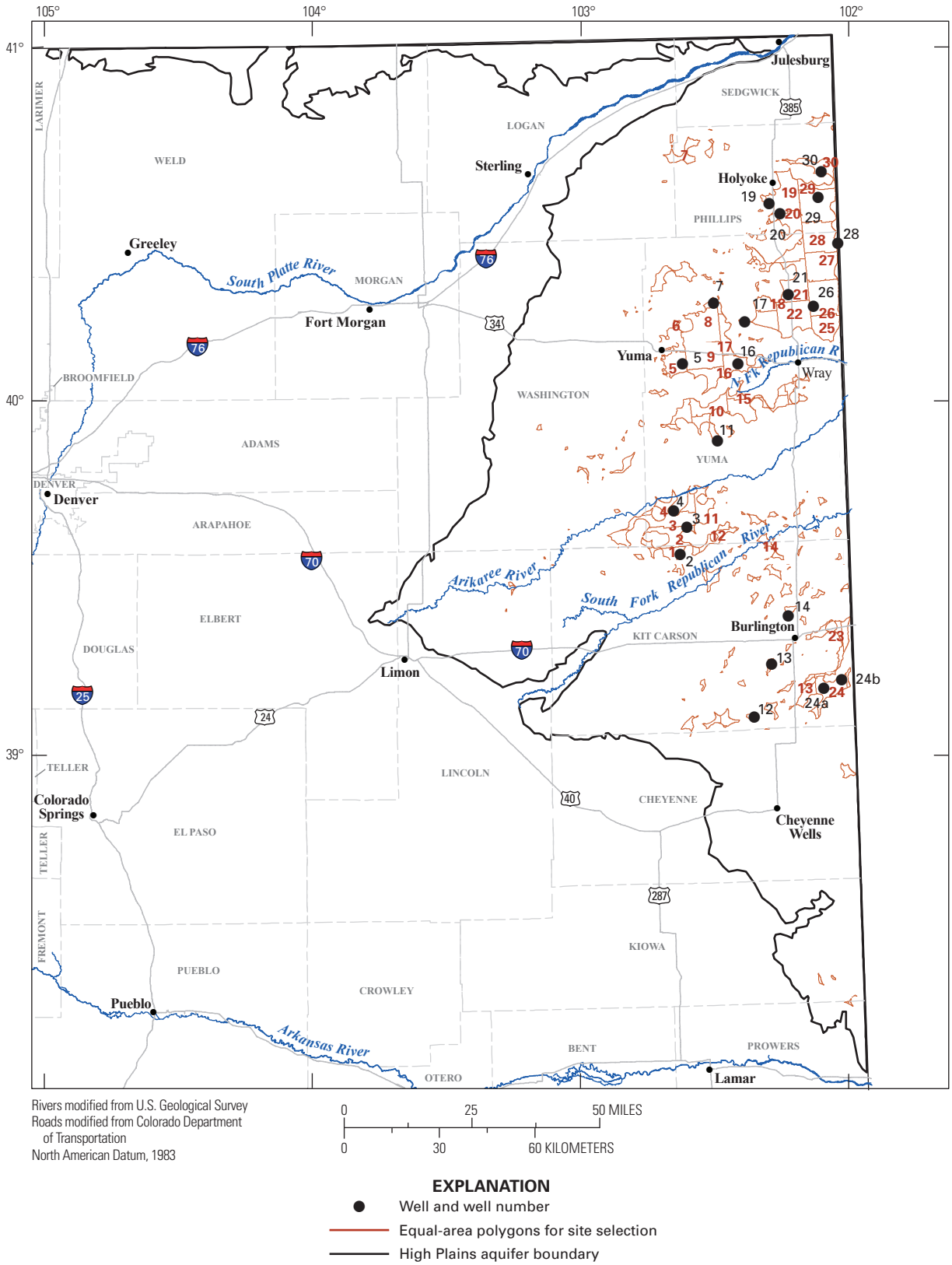


Figure 7. Locations of 20 groundwater monitoring wells installed in the High Plains aquifer, 2008.

Final Site Selection

Twenty of the 30 randomly determined locations were selected for well installation (fig. 7; available at *http://water.usgs.gov/lookup/getspatial?ds472_welldata*). The initial 20-well network was selected in consultation with the CDA so as to provide a wide distribution of wells across the study area south of the South Platte River and north of the Arkansas River. Final well locations also ultimately depended on landowner permission for access. Land ownership of potential drilling sites was obtained from county tax assessor records, and landowners were contacted by the USGS to request permission to drill and install wells as close as possible to the computer-generated sites. Final well locations were established based on landowner permission and site access (table 1).

Well Drilling and Installation

Well drilling and installation occurred June 23, 2008, through September 3, 2008 (table 1). Drilling services were provided by Drilling Engineers, Inc., of Fort Collins, Colorado. Well drilling and installation were overseen by an onsite USGS geologist, who was responsible for documenting daily drilling operations, logging and packaging geologic materials from drill holes, overseeing well installation, and preparing well-construction reports. The CDA was responsible for contracting drilling services and obtaining permits required by the State of Colorado for well drilling.

Boreholes for monitoring wells were drilled with a truck-mounted CME75 drilling rig. Boreholes were advanced with 4.25-inch inside diameter (ID) hollow-stem augers, and split spoon samples of geologic materials were collected as needed to properly identify formation intervals for well installation. Lithologic logs were developed on the basis of visual inspection of split spoon samples and auger cuttings (Appendix 1). Lithologic descriptions are based on the Unified Soil Classification System (American Society for Testing and Materials, 1990).

Figure 8 presents a schematic diagram of monitoring-well completions for the High Plains monitoring wells. Individual well-construction diagrams for the High Plains wells are presented in Appendix 2, and well-completion details are summarized in table 2. Well depths range from 84.4 to 204.6 feet below land surface, and water depths in wells ranged from 62.7 to 184.5 feet below land surface at the time of drilling. Wells are constructed of 2-inch nominal diameter, Schedule 40, threaded and flush-jointed polyvinyl chloride (PVC) well casing. Well screens are 10 feet long with the top of the screen interval generally about 5 feet below the water table at the time of drilling. The screened interval of all wells consists of 0.01-inch slotted PVC. A 5-foot sump was installed below the screen in most wells with a threaded end cap at the bottom of each well. Where not precluded by borehole caving, the annular space adjacent to the screened interval was backfilled with 10–20 mesh silica sand to a minimum height of about 2 feet above the screened interval. The annular space

Table 1. Latitude, longitude, land-surface altitude, installation date, and development date for groundwater monitoring wells installed in the High Plains aquifer, 2008.

[DDMMSS.S, degrees, minutes, decimal seconds; land-surface altitude in feet]

Well count	Well number	Latitude[1] (DDMMSS.S)	Longitude[1] (DDMMSS.S)	Land-surface altitude[2]	Date well completed	Date well development completed
1	2	393229.7	1024002.5	4,310	08/20/2008	10/07/2008
2	3	393704.7	1023823.4	4,249	07/29/2008	10/08/2008
3	4	393948.5	1024118.2	4,277	07/27/2008	10/09/2008
4	5	400451.0	1023831.5	4,063	09/03/2008	09/11/2008
5	7	401502.1	1023109.3	3,909	07/15/2008	09/04/2008
6	11	395138.1	1023110.7	4,067	07/25/2008	09/12/2008
7	12	390421.5	1022446.1	4,301	08/12/2008	10/14/2008
8	13	391318.4	1022035.1	4,180	08/21/2008	10/09/2008
9	14	392131.9	1021639.2	4,060	08/26/2008	10/09/2008
10	16	400435.3	1022609.5	3,860	07/13/2008	10/16/2008
11	17	401141.4	1022419.9	3,841	07/09/2008	09/04/2008
12	19	403143.6	1021806.7	3,750	06/28/2008	10/02/2008
13	20	402954.4	1021546.7	3,715	07/01/2008	10/01/2008
14	21	401613.1	1021429.8	3,711	07/11/2008	10/03/2008
15	24a	391018.4	1020523.9	4,013	08/23/2008	10/15/2008
16	24b	390900.3	1020923.3	4,073	08/24/2008	10/16/2008
17	26	401359.6	1020902.1	3,659	07/02/2008	10/06/2008
18	28	402439.4	1020309.4	3,558	07/08/2008	10/02/2008
19	29	403230.3	1020717.6	3,601	06/26/2008	09/30/2008
20	30	403650.7	1020618.5	3,618	06/25/2008	09/29/2008

[1]Latitude and longitude determined by Global Positioning System. North American Datum of 1983.

[2]Land-surface altitude estimated from U.S. Geological Survey 1:24,000-scale topographic maps with a contour interval of 10 feet. North American Vertical Datum of 1929.

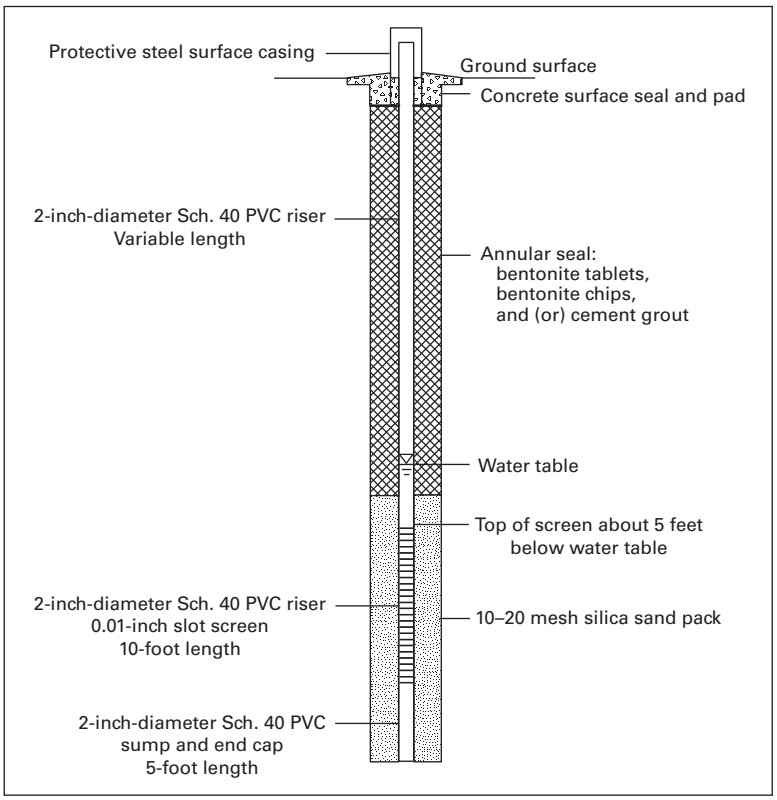


Figure 8. Schematic diagram of High Plains groundwater monitoring-well completions.

Table 2. Summary of groundwater monitoring-well locations, construction, and depth to water.

[DDMMSS.S, degrees, minutes, decimal seconds; land-surface altitude in feet; stick-up height in feet above land surface; all depths in feet below land surface]

Well number	Latitude[1] (DDMMSS.S)	Longitude[1] (DDMMSS.S)	Land-surface altitude[2]	Depth to water[3]	Stick-up height	Depth to top of screen	Depth to bottom of screen	Depth to top of annular seal	Depth to top of sand pack	Total well depth
2	393229.7	1024002.5	4,310	184.5	2.5	192.3	201.7	2.0	184.5	204.6
3	393704.7	1023823.4	4,249	155.3	3.1	159.9	169.3	1.5	157.0	174.9
4	393948.5	1024118.2	4,277	142.8	2.9	144.8	154.2	1.0	140.0	159.8
5	400451.0	1023831.5	4,063	170.4	–0.3	174.2	183.6	1.0	171.5	189.2
7	401502.1	1023109.3	3,909	152.3	3.0	159.2	168.6	2.0	155.0	174.2
11	395138.1	1023110.7	4,067	115.4	2.9	124.7	134.1	1.5	117.5	139.7
12	390421.5	1022446.1	4,301	115.6	3.0	119.4	128.8	2.0	111.0	134.4
13	391318.4	1022035.1	4,180	139.6	2.0	144.7	154.0	1.5	142.0	159.7
14	392131.9	1021639.2	4,060	152.2	2.9	159.1	168.2	1.5	153.0	173.8
16	400435.3	1022609.5	3,860	101.2	3.0	113.8	123.2	2.0	100.0	128.8
17	401141.4	1022419.9	3,841	115.1	3.2	124.6	134.0	2.0	119.0	139.6
19	403143.6	1021806.7	3,750	180.2	3.1	184.5	193.9	2.0	183.0	199.5
20	402954.4	1021546.7	3,715	151.0	2.9	152.1	161.5	1.5	150.5	167.1
21	401613.1	1021429.8	3,711	95.5	2.9	100.0	109.4	1.5	96.0	115.0
24a	391018.4	1020523.9	4,013	158.2	3.0	160.7	169.8	2.0	157.0	175.4
24b	390900.3	1020923.3	4,073	155.6	2.8	165.0	174.4	2.0	161.0	180.0
26	401359.6	1020902.1	3,659	87.8	2.8	97.5	106.9	2.0	93.0	112.5
28	402439.4	1020309.4	3,558	62.7	3.0	69.4	78.8	1.5	53.0	84.4
29	403230.3	1020717.6	3,601	99.8	3.1	105.7	115.1	2.0	102.5	120.7
30	403650.7	1020618.5	3,618	133.4	3.2	140.2	149.6	1.5	138.0	155.2

[1]Latitude and longitude determined by Global Positioning System. North American Datum of 1983.

[2]Land-surface altitude estimated from U.S. Geological Survey 1:24,000-scale topographic maps with a contour interval of 10 feet. North American Vertical Datum of 1929.

[3]Measured at time of drilling.

above the sand pack was backfilled with bentonite tablets, bentonite chips, and (or) cement grout to within about 2 feet of land surface. The surface seal consisted of about 2 feet of concrete in the annular space and a 4-foot-diameter concrete pad surrounding the well. With one exception, an above-ground protective steel casing with a locking cover was placed over the top of the well casing and secured by the concrete surface seal. One well (Well 5) was completed with a flush-mount protective metal casing at ground level. Well construction was in accordance with USGS specifications for water-quality wells (Lapham and others, 1997) and Colorado State regulations *(http:// water.state.co.us/boe/rulesregs.asp*, accessed January 17, 2008).

Well Development

Well development was completed September 4, 2008, through October 16, 2008 (table 1). Wells were developed after drilling to remove mud and foreign material from the well and to establish good hydraulic connection between the well and aquifer. Well development was accomplished using a combination of pumping and mechanical surging until well water was clear and parameters such as turbidity, specific conductance, and pH had stabilized, or for a maximum of 8 hours. Wells were developed by using a Waterra Hydrolift 2 inertial pump system with high-density polyethylene tubing and surge block. Well-development details for each well are provided in Appendix 3.

Summary

To address the needs of Colorado's Groundwater Protection Program, the U.S. Geological Survey designed and installed a network of groundwater monitoring wells in cooperation with the Colorado Department of Agriculture in 2008 to characterize water quality in the High Plains aquifer underlying areas of irrigated agriculture in eastern Colorado. A network of 30 wells was designed to provide for statistical representation of water-quality conditions by using a computerized technique to generate randomly distributed potential groundwater sampling sites. Digital maps of aquifer extent, irrigated agricultural land, depth to water from land surface, and saturated thickness were used as input in the site-selection process to determine locations where areas of irrigated agriculture coincide with areas of the High Plains aquifer having depth to water less than 200 feet and saturated thickness greater than 50 feet.

Wells were installed at 20 of the 30 randomly determined locations on the basis of site access and landowner permission and to provide a wide distribution of wells across the study area. Twenty wells were drilled and installed during the period June–September 2008. Well depths range from 84.4 to 204.6 feet below land surface, and water depths in wells ranged from 62.7 to 184.5 feet below land surface at the time of drilling. Wells were constructed using 2-inch nominal diameter, Schedule 40, threaded and flush-jointed polyvinyl chloride (PVC) well casing with 10-foot-long well screens. The top of well screens generally were installed about 5 feet below the water table at the time of drilling. Lithologic logs and well-construction reports were prepared for each well at the time of drilling. A combination of pumping and mechanical surging was used to develop wells after drilling to remove mud and foreign material from the well and to establish good hydraulic connection between the well and aquifer. Well development was performed until well water was clear and parameters such as turbidity, specific conductance, and pH had stabilized, or for a maximum of 8 hours.

References Cited

American Society for Testing and Materials, 1990, D 2487–90, Classification of soils for engineering purposes: Annual Book of ASTM Standards, v. 04.08, p. 326–336.

Bauder, Troy, Cipra, Jan, Waskom, Reagan, and Gossenauer, Michael, 2004, Center pivot irrigation in Colorado as mapped by LANDSAT imagery: Fort Collins, Colorado State University Agricultural Experiment Station Technical Bulletin TB04–04.

Geological Society of America, 1995, Rock-color chart with genuine Munsell color chips (8th printing): U.S.A., Munsell Color, 10 p.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard procedures for studies of ground-water quality—Selection and installation of wells, and supporting documentation: U.S. Geological Survey Water-Resources Investigations Report 96–4233, 110 p.

McGuire, V.L., 2007, Changes in water levels and storage in the High Plains aquifer, predevelopment to 2005: U.S. Geological Survey Fact Sheet 2007–3029, 2 p.

McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M., 2003, Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243, 51 p.

McMahon, P.B., Dennehy, K.F., Bruce, B.W., Gurdak, J.J., and Qi, S.L., 2007, Water-quality assessment of the High Plains aquifer, 1999–2004: U.S. Geological Survey Professional Paper 1749, 136 p.

Robson, S.G., and Banta, E.R., 1995, Ground-water atlas of the United States, segment 2: U.S. Geological Survey Hydrologic Investigations Atlas HA 730–C, 32 p.

Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of a ground-water-quality sampling network: U.S. Geological Survey Water Resources Investigations Report 90–4101, 109 p.

Appendix 1. Lithologic Logs

Well 2

Latitude/longitude: 39° 32'29.7"/102° 40'02.5", North American Datum of 1983
Land surface altitude: 4,310 feet, North American Vertical Datum of 1929
Date well completed: 8/20/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–24	cuttings	Sand, slightly silty (±10%), fine to medium grained with ±10% coarse, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, loose, pale yellowish brown (10YR 6/2) to dark yellowish brown (10YR 6/6), dry to damp, eolian sand.
24–35	cuttings	Sand, slightly gravelly to gravelly (10–20%), fine to coarse grained, gravel up to 22 mm in size, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, medium dense, dark yellowish orange (10YR 6/6), damp, Ogallala Formation.
35–47	cuttings	Gravel, sandy (±30%), sand is fine to coarse grained, gravel up to 25 mm in size, subangular to subrounded, ±45% quartz, ±50% feldspar, ±5% lithics, medium dense, dark yellowish orange (10YR 6/6), damp, Ogallala Formation.
47–88	cuttings	Clayey sand, ±30% clay, fine to coarse grained, more coarse grained and slightly gravelly (5–10%) below 67 ft, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, low plasticity, dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
88–157	cuttings and on bit	Sandy clay, ±40% sand, sand is fine to coarse grained, with minor (<5%) gravel up to 10 mm in size, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics (dark and $CaCO_3$), low plasticity, hard, pale yellowish brown (10YR 6/2), moist, Ogallala Formation.
157–168	split spoon[1] 160–161 ft blows: 26/60	Sand, slightly gravelly (10–15%), fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, very dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.
168–186	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, minor gravel (<5%) up to 7 mm in size, subangular to subrounded, ±65% quartz, ±25% feldspar, ±10% lithics (dark and $CaCO_3$), low plasticity, dense to very dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
186–189	none	Hard drilling and minor chatter. Probably gravel with clay.
189–205	split spoon[1] 190–191 ft blows: 21/16	Silty clay, slightly sandy (±10%), sand is fine grained, low plasticity, mottled with caliche, contains thin (a few inches) gravel layers, hard, moderate yellow (5Y 7/6) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 3

Latitude/longitude: 39° 37′04.7″/102° 38′23.4″, North American Datum of 1983
Land surface altitude: 4,249 feet, North American Vertical Datum of 1929
Date well completed: 7/29/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–2	cuttings	Sandy clay, ±20% sand, sand is fine to coarse grained, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, low plasticity, stiff, dark yellowish brown (10YR 4/2), dry, surface soil.
2–5	cuttings	Silty clay, slightly sandy (±10%), sand is fine to coarse grained, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics ($CaCO_3$), contains small caliche nodules, low plasticity, stiff, very pale orange (10YR 8/2), dry, Ogallala Formation.
5–9	cuttings	Clay, slightly sandy (±10%), sand is fine to medium grained with minor (±5%) coarse, subangular to subrounded, ±70% quartz, ±30% feldspar, low plasticity, very stiff, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
9–15	cuttings	Sand, fine to coarse grained, minor (<5%) gravel up to 8 mm in size, subangular to subrounded, ±70% quartz, ±30% feldspar, slightly clayey (±10%) below 13 ft, medium dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), dry, Ogallala Formation.
15–72	cuttings	Clay, slightly sandy to sandy (10–30%), sand is fine to coarse grained, minor (<5%) gravel up to 6 mm in size from 15 to 19 ft, subangular to subrounded, ±60% quartz, ±30% feldspar, ±10% lithics (dark and $CaCO_3$), caliche mottling in zones, low plasticity, very stiff to hard, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
72–88	cuttings	Sand, gravelly (30–40%), fine to coarse grained, gravel up to 17 mm in size, slightly clayey in zones, subangular to subrounded, ±50% quartz, ±50% feldspar, dense to very dense, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
88–100	cuttings	Sandy clay, ±40% sand, sand is fine to coarse grained, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, very stiff to hard, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
100–114	cuttings	Sand, slightly clayey to clayey (10–20%), fine to coarse grained, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, nonplastic to very low plasticity, dense to very dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
114–130	cuttings	Gravelly clay, ±30% gravel, sandy (±15%), sand is medium to coarse grained with minor fine, gravel up to 7 mm in size, subangular to subrounded, ±40% quartz, ±50% feldspar, ±10 % lithics, low plasticity, hard, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
130–150	cuttings and on bit at 140 ft	Sandy clay, ±20% sand, slightly gravelly (±10%), sand is fine to coarse grained, gravel up to 13 mm in size, subangular to subrounded, ±50% quartz, ±45% feldspar, ±5% lithics, low plasticity, hard, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
150–170	split spoon[1] 160–161.5 ft blows: 6/12/20	Silty clayey sand, 30–40% fines, fine to medium grained with ±10% coarse, subangular to subrounded, ±45% quartz, ±10% feldspar, ±45% lithics (dark and $CaCO_3$), mottled with caliche, low plasticity, dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), wet to saturated, Ogallala Formation.
170–175	on bit @ 175’	Clay, slightly sand to sandy (10–20%), similar to 130–150 ft but no gravel

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 4

Latitude/longitude: 39° 39'48.5"/102°41'18.2", North American Datum of 1983
Land surface altitude: 4,277 feet, North American Vertical Datum of 1929
Date well completed: 07/27/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–2	cuttings	Silty clay, slightly sandy to sandy (10–20%), sand is fine to coarse grained, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, organic rich, low plasticity, loose, dark yellowish brown (10YR 4/2), dry, top soil.
2–7	cuttings	Silty clay, slightly sand to sandy (10–20%) slightly gravelly (±10%), sand is fine to coarse grained, gravel up to 10 mm in size, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, contains caliche nodules, low plasticity, stiff, grayish orange (10YR 7/4), dry, Ogallala Formation.
7–12	cuttings	Clayey sand, ±15% clay, gravelly (±30%), fine to coarse grained, gravel up to 12 mm in size, subangular to subrounded, ±65% quartz, ±35% feldspar, very low plasticity, medium dense, light brown (5YR 6/4–5YR 5/6), damp, Ogallala Formation.
12–16	cuttings	Sandy silty clay, ±20% sand, sand is fine to coarse grained with minor (<5%) gravel up to 8 mm in size, subangular to subrounded, ±70% quartz, ±30% feldspar, low plasticity, very stiff, grayish orange (10YR 7/4), damp to moist, Ogallala Formation.
16–26	cuttings	Sand, slightly clayey to clayey (10–20%), slightly gravelly (±10%), fine to coarse grained, gravel up to 10 mm in size, subangular to subrounded, ±65% quartz, ±30% feldspar, ±5% lithics, very low plasticity, medium dense to dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
26–32	cuttings	Sandy silty clay (same as 12–16 ft), Ogallala Formation.
32–135	cuttings and split spoon[1] 100–100.5 ft blows: 45	Clay, slightly sandy to sandy (10–20%), sand is fine to coarse grained, subangular to rounded, ±70% quartz, ±30% feldspar, low plasticity, very stiff, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.
135–160	split spoon[1] 150–151.5 ft blows: 7/42/42	Clayey sand, 30–40% clay, fine to coarse grained with minor (±5%) gravel up to 30 mm in size, subangular to subrounded, ±50% quartz, ±25% feldspar, ±25% lithics (dark and $CaCO_3$), minor caliche mottling, contains thin (a few inches) sand layers with less clay, very low plasticity, very dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), wet to saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 5

Latitude/longitude: 40°04'51.0"/102°38'31.5", North American Datum of 1983
Land surface altitude: 4,063 feet, North American Vertical Datum of 1929
Date well completed: 9/03/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty sand, slightly clayey, (±20% fines), fine to medium grained, with minor coarse, subangular to rounded, ±85% quartz, ±10% feldspar, ±5% lithics, very low plasticity, medium soft, dark yellowish brown (10YR 4/2), organic rich, moist, top soil.
2–10	cuttings	Silty clay, low plasticity, stiff, grayish orange (10YR 7/4), dry, Ogallala Formation
10–15	cuttings	Silty sand, slightly clayey, ±20% fines, fine to medium grained with ±10% coarse, subangular to rounded, ±85% quartz, ±10% feldspar, ±5% lithics, very low plasticity, medium dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), dry, Ogallala Formation.
15–23	cuttings	Clayey sand, 20–30% clay, fine to coarse grained, slightly gravelly (±10%) below 18 ft, gravel up to 12 mm in size, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
23–30	cuttings	Sandy clay, 30–40% sand, sand is fine to coarse grained, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, low plasticity, very stiff to hard, grayish orange (10YR 7/4), damp, Ogallala Formation.
30–172	cuttings	Clayey sand (similar to 15–23 ft), more fine grained below 60 ft with more clay (up to 40%) and minor (<5%) gravel, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), Ogallala Formation.
172–184	on bit and augers	Silty sand, slightly clayey from 172–180 ft, ±20% silt, ±75% quartz, ±20% feldspar, ±5% lithics, non-plastic, medium dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), saturated, Ogallala Formation.
184–190	on bit and augers	Clay, low to high plasticity, hard, dark yellowish orange (10YR 6/6), moist, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 7

Latitude/longitude: 40°15′02.1″/102°31′09.3″, North American Datum of 1983
Land surface altitude: 3,909 feet, North American Vertical Datum of 1929
Date well completed: 7/15/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–3	cuttings	Silty sand, 10–20% silt, fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, nonplastic, loose, dark yellowish brown (10YR 4/2) moist, surface soil.
3–12	cuttings	Sandy clay, ±20% sand, sand is fine to coarse grained, minor (<5%) gravel up to 10 mm in size, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, infrequent caliche mottling, low plasticity, medium soft to stiff, grayish orange (10YR 7/4), moist, Ogallala Formation.
12–20	cuttings	Sand, fine to coarse grained, ±10% gravel up to 15 mm in size, ±60% quartz, ±30% feldspar, ±10% lithics, medium dense, dark yellowish orange (10YR 6/6), moist, Ogallala Formation.
20–35	cuttings	Clayey sand, ±20% clay, coarse grained with ±15% fine to medium, gravelly (±30%), gravel up to 8 mm in size, subangular to subrounded, ±55% quartz, ±35% feldspar, ±10% lithics, very low plasticity, medium dense, light brown (5YR 5/6), moist, Ogallala Formation.
35–41	cuttings	Sandy clay, ±40% sand, sand is fine to coarse grained, subangular to subrounded, ±60% quartz, ±30% feldspar, ±10% lithics, low plasticity, stiff, moderate yellowish brown (10YR 5/4), moist to wet, Ogallala Formation.
41–65	cuttings	Clayey sand, ±30% clay, fine to coarse grained, minor (<5%) gravel up to 9 mm in size, ±55% quartz, ±35% feldspar, ±10% lithics, low plasticity, medium dense, light brown (5YR 5/6), moist, Ogallala Formation.
65–77	cuttings	Sandy clay, ±40% sand, sand is fine to coarse grained, minor (<5%) gravel up to 12 mm in size, subangular to subrounded, low plasticity, ±60% quartz, ±30% feldspar, ±10% lithics, pale yellowish brown (10YR6/2), moist to wet, Ogallala Formation.
77–83	split spoon[1] 80–81 ft blows: 16/21	Sand, slightly silty (±10%), slightly gravelly (±15%), fine to coarse grained, gravel up to 15 mm in size, subangular to subrounded, ±40% quartz, ±50% feldspar, ±10% lithics, dense, light brown (5YR 5/6) to moderate yellowish brown (10YR 5/4), moist with wet lenses, Ogallala Formation.
83–107	cuttings	Clayey sand, ±30–40% clay, slightly gravelly to gravelly (10–20%), fine to coarse grained, gravel up to 18 mm in size, subangular to subrounded, ±40% quartz, ±50% feldspar, ±10% lithics, low plasticity, dense, Ogallala Formation.
107–112	split spoon[1] 110–110.5 ft, blows: 25	Gravelly sand, ±25% gravel, fine to coarse grained, gravel up to 10 mm in size, subangular to subrounded, ±55% quartz, ±30% feldspar, ±15% lithics, dense to very dense, dark yellowish orange (10YR 6/6), damp to moist, Ogallala Formation.
112–153	cuttings	Clayey sand (same as 83–107 ft), Ogallala Formation.
153–156	split spoon[1] 155–156 ft, blows: 11/20	Sand, fine to medium grained with ±10% coarse, subangular to subrounded, ±65% quartz, ±30% feldspar, ±5% lithics, dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), saturated, Ogallala Formation.
156–160	split spoon[1] 160–160.25 ft, blows: 26 for 3 inches	Silty sand, slightly clayey, ±20% fines, slightly gravelly (±10%), fine to coarse grained, gravel up to 16 mm in size, subangular to subrounded, ±60% quartz, ±30% feldspar, ±10% lithics, very dense, dark yellowish orange (10YR 6/6), saturated, Ogallala Formation.
160–174.2	none	Mostly smooth and slow drilling with no return. Probably sand and (or) silty sand similar to 153–160 ft.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 11

Latitude/longitude: 39°51′38.1″/102°31′10.7″, North American Datum of 1983
Land surface altitude: 4,067 feet, North American Vertical Datum of 1929
Date well completed: 7/25/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty sand, ±15% silt, fine to medium grained with minor (<5%) coarse, subrounded to rounded, ±70% quartz, ±30 % feldspar, nonplastic, loose, pale yellowish brown (10YR 6/2), dry, surface soil.
2–10	cuttings	Sand, slightly silty (±10%), fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±75% quartz, ±20% feldspar, ±5% lithics, loose, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), dry to damp, eolian sand.
10–23	cuttings	Sandy silt, ±20% sand, slightly clayey below 15 ft, sand is very fine to fine grained, low plasticity, loose to medium dense, dark yellowish brown (10YR 5/4), damp, Ogallala Formation.
23–62	cuttings	Clay, slightly sand to sandy (10–20%), sand is fine to medium grained with 5–10% coarse, subangular to subrounded, ±65% quartz, ±35% feldspar, low plasticity, very stiff, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
62–75	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, low plasticity, dense, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR 4/2), moist, Ogallala Formation.
75–96	cuttings	Sand, fine to medium grained, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, medium dense to dense, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
96–99	cuttings	Sand, slightly clayey to clayey (10–20%), fine to medium grained with minor (±5%) coarse, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, very low to low plasticity, dense to very dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
99–121	split spoon[1] 105–106 ft blows: 19/50	Sand similar to 75–96 ft but grayish orange (10YR 7/4) to dark yellowish orange (10YR6/6) and very dense, Ogallala Formation.
121–127	on bit at 125 ft	Silty clay, slightly sandy to sandy (10–20%), sand is fine grained with ±10% medium and coarse, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, low plasticity very stiff to hard, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
127–135	cuttings	Sand (same as 96–99 ft), Ogallala Formation.
135–140	split spoon[1] 140–140.5 ft blows: 25 for 4 inches	Silty clay (similar to 121–127 ft but wet), Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 12

Latitude/longitude: 39°04′21.5″/102°24′46.1″, North American Datum of 1983
Land surface altitude: 4,301 feet, North American Vertical Datum of 1929
Date well completed: 8/12/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–3	cuttings	Sandy silty clay, ±15% sand, sand is fine grained with ±10% medium and coarse, subrounded to rounded, ±80% quartz, ±20% feldspar, organic rich, low plasticity, stiff, dark yellowish brown (10YR 4/2), moist (recently rained), top soil.
3–27	cuttings	Silty clay, slightly sandy to sandy (10–20%), sand is fine to medium grained with minor (<5%) coarse, subrounded to rounded, ±80% quartz, ±15% feldspar, ±5% lithics, mottled with caliche, low plasticity, stiff to very stiff, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), dry to damp, Ogallala Formation.
27–35	cuttings	Clayey sand, 15–20% clay, fine to coarse grained, minor (±5%) gravel up to 15 mm in size, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, very low plasticity, medium dense, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
35–56	cuttings	Sandy, gravelly (20–30%), fine to coarse grained, gravel up to 60 mm in size, slightly clayey to clayey (10–20%) from 40–45 ft, subangular to subrounded, ±65% quartz, ±25% feldspar, ±10% lithics, nonplastic, dense, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
56–85	cuttings	Clayey sand, 15–20% clay, fine to coarse grained, minor (±5%) gravel up to 17 mm in size, gravelly (20–30%) from 75–80 ft, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, very low plasticity, dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
85–96	cuttings	Sand, gravelly (±30%), fine to coarse grained, gravel up to 10 mm in size, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, dense to very dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
96–98	cuttings	Gravel, sandy (30–40%), sand is fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, dense to very dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
98–110	cuttings	Sand, slightly clayey (10–15%), fine to coarse grained, minor (±5%) gravel up to 13 mm in size, subangular to subrounded, ±80% quartz, ±15% feldspar, ±5% lithics, nonplastic, dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
110–115	cuttings	Clayey sand, ±30% clay, fine to coarse grained, minor (±5%) gravel up to 25 mm in size, subangular to subrounded, ±80% quartz, ±15% feldspar, <5% lithics, low plasticity, dense, moderate yellowish brown (10YR 5/4), moist to wet, Ogallala Formation.
115–123	split spoon[1] 120–121 ft blows: 13/15	Sand, medium to coarse grained with ±10% fine, minor (<5%) gravel up to 33 mm in size, subangular to subrounded, ±80% quartz, ±15% feldspar, ±5% lithics, medium dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), saturated, Ogallala Formation.
123–126	cuttings	Clayey sand (similar to 110–115 ft), Ogallala Formation.
126–135	on bit and augers	Easy drilling with no return, probably similar to 115–123 ft with thin (a few inches) clay layers.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 13

Latitude/longitude: 39°13′18.4″/102°20′35.1″, North American Datum of 1983
Land surface altitude: 4,180 feet, North American Vertical Datum of 1929
Date well completed: 8/21/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–3	cuttings	Clayey silt, slightly sandy to sandy (10–20%), sand is fine grained with ±10% medium and coarse, low plasticity, loose, pale yellowish brown (10YR 6/2), dry to damp, surface soil (loess).
3–9	cuttings	Silty, clayey sand, 20–30% fines, slightly gravelly (±10%), fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, ±65% quartz, ±20% feldspar, ±15% lithics (dark and $CaCO_3$), loose to medium dense, moderate yellowish brown (10YR 5/4), dry, Ogallala Formation.
9–51	cuttings	Sand, gravelly (30–40%), fine to coarse grained, gravel up to 40 mm in size, subangular to subrounded, ±50% quartz, ±25% feldspar, ±25% lithics (dark and $CaCO_3$), medium dense, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), damp, Ogallala Formation.
51–63	cuttings	Sand, fine to coarse grained, subangular to subrounded, ±60% quartz, ±20% feldspar, ±20% lithics, medium dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
63–72	cuttings	Sand, gravelly (±20%), slightly clayey (5–10%), fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, ±60% quartz, ±20% feldspar, ±20% lithics, medium dense to dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
72–142	cuttings	Sandy clay, 30–40% sand, sand is fine to coarse with minor (<5%) gravel up to 8 mm in size, subangular to subrounded, ±60% quartz, ±20% feldspar, ±20% lithics, low plasticity, very stiff to hard, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
142–160	split spoon[1] 150–150.25 ft blows: 33 for 3 inches	Sand, slightly silty to silty (10–20%), fine to medium grained with minor (±5%) coarse and minor (<5%) gravel up to 30 mm in size, subangular to subrounded, ±75% quartz, ±15% feldspar, ±10% lithics (dark and $CaCO_3$), dense to very dense with infrequent cementation, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 14

Latitude/longitude: 39°21′31.9″/102°16′39.2″, North American Datum of 1983
Land surface altitude: 4,060 feet, North American Vertical Datum of 1929
Date well completed: 8/26/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–2	cuttings	Sandy clay, ±20% sand, sand is fine to medium grained with ±10% coarse, subangular to subrounded, ±80% quartz, ±10% feldspar, ±10% lithics, organic rich, low plasticity, medium soft, dark yellowish brown (10YR 4/2), moist, top soil.
2–9	cuttings	Silty clay, low plasticity, medium soft to stiff, dark yellowish orange (10YR 6/6), dry, Ogallala Formation.
9–16	cuttings	Clay, slightly sandy (±10%), sand is fine to medium grained with minor (±5%) coarse, subangular to subrounded, ±80% quartz, ±15% feldspar, ±15% lithics, low plasticity, dark yellowish orange (10YR 6/6) to medium yellowish brown (10YR 5/4), moist, Ogallala Formation.
16–35	cuttings	Sand, slightly gravelly to gravelly (10–30%), slightly clayey below 30 ft, fine to coarse grained, gravel up to 25 mm in size, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics, punctuated by infrequent clay layers up to 1 ft thick, nonplastic, medium dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
35–42	cuttings	Clayey sand, ±30% clay, fine to coarse grained with minor (±5%) gravel up to 13 mm in size, subangular to subrounded, ±80% quartz, ±15% feldspar, ±5% lithics, low plasticity, medium dense to dense, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
42–49	cuttings	Sandy clay, 20–30% sand, sand is fine to coarse grained, subangular to subrounded, ±80% quartz, ±15% feldspar, ±5% lithics, low plasticity, hard, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
49–63	cuttings	Clayey sand (similar to 35–42 ft), Ogallala Formation.
63–174	cuttings and split spoon[1] 169–170.5 ft blows: 27/32/29	Sandy clay (similar to 42–49 ft) but varies from moderate yellowish brown (10YR 5/4) to grayish orange (10YR 7/4), caliche mottling and chips of $CaCO_3$ from 63 to 70 ft, punctuated by infrequent sand layers up to 2 ft thick that become more frequent below 154 ft. Sand layer from 169 to 169.5 ft (in split spoon) is fine grained with minor medium and coarse, contains ±20% silt, nonplastic, dense, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 16

Latitude/longitude: 40°04'35.3"/102°26'09.5", North American Datum of 1983
Land surface altitude: 3,860 feet, North American Vertical Datum of 1929
Date well completed: 7/13/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–4	cuttings	Silty sand, ±15% silt, fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±70% quartz, ±20% feldspar, ±10% lithics, nonplastic, loose, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), dry to damp, surface soil.
4–10	cuttings	Silty sand, slightly clayey, 20–30% fines, fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±75% quartz, ±20% feldspar, ±5% lithics, low plasticity, loose, moderate yellowish brown (10YR 5/4), damp, eolian sand.
10–16	cuttings	Sandy clay, 15–20% sand, fine to coarse grained, slightly gravelly (5–10%), subangular to subrounded, ±40% quartz, ±10% feldspar, ±50% lithics ($CaCO_3$), low plasticity, medium soft, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
16–36	cuttings	Silty sand, ±15% silt, fine to medium grained, ±10% coarse, subangular to rounded, ±60% quartz, ±10% lithics, nonplastic, medium dense, grayish orange (10YR 7/4) to light brown (5YR 5/6), damp, Ogallala Formation.
36–41	cuttings	Sandy clay, ±40% sand, fine to coarse grained sand, minor (<5%) gravel up to 8 mm in size, subangular to rounded, ±40% quartz, ±30% feldspar, ±40% lithics ($CaCO_3$), low plasticity, stiff, grayish orange (10YR 7/4), moist, Ogallala Formation.
41–61	cuttings	Silty sand, ±15% silt, fine to medium grained with ±10% coarse, minor (±5%) gravel up to 10 mm in size, subangular to subrounded, ±50% quartz, ±20% feldspar, ±30% lithics ($CaCO_3$), nonplastic, medium dense, grayish orange (10YR 7/4) to dark yellowish brown (10YR 5/4), damp, Ogallala Formation.
61–85	cuttings	Clayey sand, 20–30% clay, fine to coarse grained, minor gravel (±5%) up to 16 mm in size, fewer coarse grains below 70 ft, ±50% quartz, ±20% feldspar, ±30% lithics ($CaCO_3$), low plasticity, medium dense to dense, grayish orange (10YR 7/4) to pale yellowish brown (10YR 6/2), moist, Ogallala Formation.
85–115	on bit at 105 ft	Very hard drilling, heavy chatter, and no return. Sandstone on bit at 105 ft is fine to medium grained with ±10% coarse, subangular to subrounded, ±40% quartz, ±20% feldspar, ±40% lithics ($CaCO_3$), very dense, moderately to well cemented, pinkish gray (5YR 8/1), dry, Ogallala Formation.
115–122	on augers	Easier drilling with no chatter or return. Sediment on augers is sandy gravel, ±20% sand, slightly clayey (5–10%), sand is fine to coarse grained, gravel up to 10 mm in size, subangular to subrounded, ±30% quartz, ±55% feldspar, ±15% lithics, nonplastic, medium dense to dense, pale yellowish brown (10YR 6/2), saturated, Ogallala Formation.
122–129	none	Very hard drilling, heavy chatter, and no return. Probably sandstone similar to 85–115 ft. Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 17

Latitude/longitude: 40°11'41.4"/102°24'19.9", North American Datum of 1983
Land surface altitude: 3,841 feet, North American Vertical Datum of 1929
Date well completed: 7/9/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty sand, slightly clayey, ±20% fines, fine to coarse grained, subrounded to rounded, very low plasticity, loose, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), dry, surface soil.
2–27	cuttings	Silty sand, ±15% silt, fine to medium grained with ±15% coarse, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, nonplastic, loose, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), dry to damp, eolian sand.
27–120	cuttings	Sandy clay, 30–40% sand, fine to coarse grained, subangular to subrounded, ±55% quartz, ±40% feldspar, ±5% lithics, contains infrequent lenses of clayey sand and calcium carbonate to rich clay, low plasticity, stiff to very stiff, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
120–130	split spoon[1] 125–126 ft blows: 31/31	Silty clay, slightly sandy to sandy (10–20%), sand is fine grained with minor (±5%) medium and coarse, mottled with caliche, low plasticity, very hard, light brown (5YR 6/4–5YR 5/6), moist to wet, Ogallala Formation.
130–140	none	Very hard drilling, heavy chatter, and no return. Probably sandstone or very dense gravel.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 19

Latitude/longitude: 40°31′43.6″/102°18′06.7″, North American Datum of 1983
Land surface altitude: 3,750 feet, North American Vertical Datum of 1929
Date well completed: 6/28/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Clayey sand, silty, 30–40% fines, fine grained with minor medium, subangular to subrounded, organic rich, loose, moist, grayish brown (5YR 3/2), top soil.
2–8	cuttings	Silty sand, slightly clayey, ±20% fines, fine to medium grained with minor coarse (<5%), ±60% quartz, ±40% feldspar, nonplastic, loose, moderate yellowish brown (10YR 5/4) to dark yellowish orange (10YR 6/6), damp, eolian sand.
8–27	cuttings	Sand, slightly clayey to clayey (10–20%), minor gravel (5%) up to 8 mm in size from 8–17 ft, gravelly (±30%) from 17–27 ft with gravel up to 27 mm in size, subangular to subrounded, ±40% quartz, ±60% feldpsar, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
27–58	cuttings	Clayey sand, ±30% clay, slightly gravelly (±10%), fine to coarse grained with gravel up to 20 mm in size, subangular to subrounded, ±55% quartz, ±40% feldspar, ±5% lithics, low plasticity, medium dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
58 – 62	cuttings	Clayey gravel, 10–20% clay, sandy (30–40%), sand is fine to coarse grained, gravel up to 25 mm in size, subangular to subrounded, ±50% feldspar, ±40% quartz, ±10% lithics, very low plasticity, medium dense, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
62–87	cuttings	Sand, slightly gravelly to gravelly (10–20%), slightly clayey in lenses, fine to coarse grained, gravel up to 15 mm in size, subangular to subrounded, ±45% quartz, ±45% feldspar, ±10% lithics, medium dense, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
87–115	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, slightly gravelly (5–15%) up to 12 mm in size, subangular to subrounded, ±45% quartz, ±45% feldspar, ±10% lithics, dense, low plasticity, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
115 – 132	split spoon[1] 125–126.5 ft blows: 23/21/23	Sand, slightly gravelly (10–15%), slightly clayey (±5%), fine to coarse grained, gravel up to 15 mm in size, subangular to subrounded, ±45% quartz, ±45% feldspar, ±10% lithics, dense, light brown (5YR 5/6), moist to wet, no return from 115 to 130 ft, Ogallala Formation.
132–145	cuttings	Clayey sand (same as 87–115 ft), Ogallala Formation.
145–157	none	No return (probably sand similar to 115 to 132 ft).
157–165	cuttings	Sandy clay, 30–40% sand, sand portion is fine to coarse grained with minor gravel (<5%) up to 10 mm in size, subangular to subrounded, ±45% quartz, ±45% feldspar, ±10% lithics, low to high plasticity, stiff to very stiff, pale yellowish brown (10YR 6/2), moist to wet, Ogallala Formation.
165–183	split spoon[1] 175–176.5 ft blows: 9/16/27	Silty sand, slightly clayey, 20–30% fines, fine grained with minor (±5%) medium and coarse, subangular to subrounded, ±50% quartz, ±40% feldspar, ±10% lithics, micaceous, very low plasticity, dense, moderate yellowish brown (10YR 5/4), moist to wet, Ogallala Formation.
183–200	on bit at 190 ft	Sand, gravelly (±30%), slightly clayey (±5%), fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, ±40% quartz, ±40% feldspar, ±20% lithics, medium dense, light brown (5YR 5/6) to moderate yellowish brown (10YR 5/4), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 20

Latitude/longitude: 40°29'54.4"/102°15'46.7", North American Datum of 1983
Land surface altitude: 3,715 feet, North American Vertical Datum of 1929
Date well completed: 7/1/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty clay, sand (±30%), sand portion is very fine to fine grained, low plasticity, soft, pale yellowish brown (10YR 6/2), moist, surface soil.
2–6	cuttings	Silty sand, ±15% silt, fine to coarse grained, subrounded to rounded, ±60% quartz, ±35% feldspar, <5% lithics, loose, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), damp, eolian sand.
6–23	cuttings	Clayey sand, slightly silty, 15–20% fines, fine to medium grained with minor (<5%) coarse, subangular to subrounded, ±50% quartz, ±45% feldspar, ±5% lithics, clay content decreases and sand content increases (up to ±15%) with depth, contains minor (<5%) gravel up to 7 mm in size below 25 ft, low plasticity, loose to medium dense, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
23–42	cuttings	Sand, slightly silty (10–15%), fine to coarse grained, subangular to subrounded, ±60% quartz, ±40% feldspar, nonplastic, loose to medium dense, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
42–58	cuttings	Sandy clay, ±40% sand, sand is fine to coarse grained, minor gravel (<5%) up to 15 mm in size, subangular to subrounded, ±50% quartz, ±45% feldspar, ±5% lithics, low plasticity, firm to stiff, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
58–80	cuttings	Clayey sand, ±30% clay, gravelly (±20%), fine to coarse grained, gravel up to 18 mm in size, subangular to subrounded, ±45% quartz, ±40% feldspar, ±15% lithics, low plasticity medium dense, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), moist, Ogallala Formation.
80–101	cuttings	Silty sand, ±15% silt, fine to medium grained with ±10% coarse, subangular to subrounded, ±55% quartz, ±40% feldspar, ±5% lithics, nonplastic, medium dense, moderate yellowish brown (10YR 5/4), damp to moist, slightly clayey below 99 ft, Ogallala Formation.
101–117	cuttings	Clayey sand, ±20% clay, fine to coarse grained, minor (<5%) gravel up to 8 mm in size, subangular to subrounded, ±45% quartz, ±50% feldspar, ±5% lithics, low plasticity, medium dense to dense, moderate yellowish brown (10YR 5/4), moist, clay content increases with depth up to ±50%, Ogallala Formation.
117–142	cuttings	Sandy clay, 30–40% sand, sand is fine to coarse grained, subangular to subrounded, ±40% quartz, ±50% feldspar, ±10% lithics, low plasticity, very stiff, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
142–148	none	Heavy chatter with no return. Probably gravel.
148 – 153	cuttings	Sandy clay (same as 117–142 ft).
153–170	split spoon[1] blows: 50 for 9 inches	Sand, slightly gravelly to gravelly (10–20%), gravel up to 24 mm in size, subangular to subrounded, ±45% quartz, ±45% feldspar, ±10% lithics, very dense, moderate yellowish brown (10YR 5/4) to light brown (5YR 5/6), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 21

Latitude/longitude: 40°16′13.1″/102°14′29.8″, North American Datum of 1983
Land surface altitude: 3,711 feet, North American Vertical Datum of 1929
Date well completed: 7/11/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty sand, slightly clayey, ±20% fines, fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±70% quartz, ±25% feldspar, ±5% lithics, very low plasticity, loose, dark yellowish brown (10YR 4/2), dry to damp, surface soil.
2–28	cuttings	Sand, slightly silty to silty (10–20%), fine to medium grained with ±10% coarse, becomes less silty and more coarse grained below 20 ft, ±70% quartz, ±20% feldspar, ±10% lithics, nonplastic, loose, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), damp, eolian sand.
28–56	cuttings	Sandy clay, 20–30% sand, sand is fine to coarse grained, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, stiff, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
56–64	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, minor (<5%) gravel up to 8 mm in size, subangular to subrounded, ±55% quartz, ±40% feldspar, ±5% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
64–67	cuttings	Sandy clay (same as 28–56 ft), Ogallala Formation.
67–105	cuttings	Clayey sand, ±30% clay, fine to coarse grained, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), moist to wet, Ogallala Formation.
105–115	split spoon[1] 115–116.5 ft blows: 10/16/24	Silty sand, slightly clayey (±20% fines), fine to medium grained with ±10% coarse, minor (<5%) gravel up to 13 mm in size, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, nonplastic, dense, moderate yellowish brown (10YR 5/4), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 24a

Latitude/longitude: 39°10′18.4″/102°05′23.9″, North American Datum of 1983
Land surface altitude: 4,013 feet, North American Vertical Datum of 1929
Date well completed: 8/23/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–3	cuttings	Silty clay, organic rich, low plasticity, soft, dark yellowish brown (10YR 4/2), moist, top soil.
3–26	cuttings	Silty clay, low plasticity, medium soft, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
26–37	cuttings	Clay, minor (±5%) sand (fine–coarse grained), low plasticity, stiff to very stiff, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
37–53	cuttings	Sandy clay, 20–30% sand, slightly gravelly (5–15%), sand is fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, ±65% quartz, ±20% feldspar, ±15% lithics, low plasticity, hard, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
53–60	cuttings	Clayey sand, 20–30% clay, slightly gravelly (5–10%), fine to coarse grained, gravel up to 12 mm in size, subangular to subrounded, ±65% quartz, ±20% feldspar, ±15% lithics, low plasticity, very dense, light brown (5YR 5/6) to moderate yellowish brown (10YR 5/4), moist Ogallala Formation.
60–73	cuttings	Sandy clay, ±40% sand, sand is fine to coarse grained, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics, low plasticity, hard, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
73–78	cuttings	Clayey sand (similar to 53–60 ft), Ogallala Formation.
78–165	cuttings	Sandy clay (similar to 60–73 ft), less sandy (±20% sand) below ±130 ft, Ogallala Formation.
165–175.4	split spoon[1] 170–171 ft blows: 12/30	Sand, slightly silty (±10%), fine to coarse grained with minor (<5%) gravel up to 15 mm in size, subangular to subrounded, ±80% quartz, ±10% feldspar, ±10% lithics, nonplastic, dense, grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 24b

Latitude/longitude: 39°09′00.3″/102°09′23.3″, North American Datum of 1983
Land surface altitude: 4,073 feet, North American Vertical Datum of 1929
Date well completed: 8/24/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–3	cuttings	Silty clay, organic rich, low plasticity, dark yellowish brown (10YR 8/6), damp, stiff, top soil.
3–27	cuttings	Silty clay, low plasticity, stiff, pale yellowish orange (10YR 8/6) to dark yellowish orange (10YR 6/6), damp, Ogallala Formation.
27–45	cuttings	Clay, slightly sandy (5–10%), sand is fine to coarse grained, subangular to subrounded, ±80% quartz, ±10% feldspar, ±10% lithics (dark and $CaCO_3$), low plasticity, very stiff, pale yellowish brown (10YR 8/6) to dark yellowish brown (10YR 6/6), damp to moist, Ogallala Formation.
45–50	cuttings	Sand, gravelly (30–40%), slightly clayey (±10%), medium to coarse grained with minor (±5%) fine, gravel up to 30 mm in size, Ogallala Formation.
50–56	cuttings	Clayey sand, ±20% clay, slightly gravelly (±10%), fine to coarse grained, gravel up to 8 mm in size, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
56–62	cuttings	Clay (same as 27–45 ft), Ogallala Formation.
62–67	cuttings	Clayey sand (similar to 50–56 ft) but with gravel up to 20 mm in size, Ogallala Formation.
67–84	cuttings	Sand, slightly clayey (5–10%), fine to coarse grained, slightly gravelly (5–10%), gravel up to 15 mm in size, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics, nonplastic to very low plasticity, medium dense, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), moist, Ogallala Formation.
84–130	cuttings and split spoon[1] 110–111.5 ft blows: 7/14/20	Clayey sand, 30–40% clay, fine to coarse grained, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, low plasticity, some caliche mottling, dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.
130–153	cuttings	Sandy clay, ±30% sand, sand is fine to coarse grained, minor (±5%) gravel up to 7 mm in size, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics, low plasticity, very stiff to hard, pale yellowish brown (10YR 6/2), moist, Ogallala Formation.
153–168	cuttings	Clayey sand (same as 84–130 ft), Ogallala Formation.
168–180	cuttings and on bit	Silty, slightly clayey to clayey sand, 20–30% fines, fine to medium grained with minor (±5%) coarse, subrounded to rounded, ±90% quartz, ±5% feldspar, <5% lithics, very low plasticity, medium dense, dark yellowish orange (10YR 6/6), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 26

Latitude/longitude: 40°13′59.6″/102°09′02.1″, North American Datum of 1983
Land surface altitude: 3,659 feet, North American Vertical Datum of 1929
Date well completed: 7/02/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Silty sand, 15–20% silt, fine to medium grained, subrounded to rounded, ±60% quartz, ±35% feldspar, <5% lithics, nonplastic, very loose to loose, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), damp, top soil.
2–31	cuttings	Sand, slightly silty to silty (10–15%), fine to medium grained with minor (<5%) coarse, subrounded to rounded, ±60% quartz, ±35% feldspar, <5% lithics, loose, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), damp, eolian sand.
31–36	cuttings	Clayey sand, 15–20% clay, fine to medium grained with minor coarse (<5%), subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, loose to medium dense, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
36–76	cuttings	Sandy clay, 30–40% sand, sand is fine to coarse grained, subangular to subrounded, ±55% quartz, ±40% feldspar, ±5% lithics, low to high plasticity), stiff to very stiff, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
76–80	cuttings	Clayey sand, ±20% clay, fine to coarse grained, subangular to subrounded, ±60% quartz, ±35% feldspar, ±5% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
80–93	cuttings	Sandy clay (same as 36–76 ft), Ogallala Formation.
93–115	split spoon[1] 114.5–116 ft blows: 10/23/40	Sand, gravelly (±30%), slightly clayey (±5%), fine to coarse grained, gravel up to 25 mm in size, subangular to subrounded, ±40% quartz, ±45% feldspar, ±15% lithics, nonplastic, very dense, moderate yellowish brown (10YR 5/4) to light brown (5YR 5/6), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 28

Latitude/longitude: 40°24′39.4″/102°03′09.4″, North American Datum of 1983
Land surface altitude: 3,558 feet, North American Vertical Datum of 1929
Date well completed: 7/08/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–4	cuttings	Silty clay, sand (20–30%), sand is fine grained, organic rich, low plasticity, soft, grayish brown (5YR 3/2), becoming pale yellowish brown (10YR 6/2) below 2 ft, damp, top soil.
4–23	cuttings	Sand, fine to coarse grained, subrounded to rounded, ±60% quartz, ±35% feldspar, ±5% lithics, loose, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), dry to damp, eolian sand.
23–70	cuttings	Sandy clay, 30–40% sand, fine to medium grained with minor (±5%) coarse, minor (±5%) gravel up to 18 mm in size, ±55% quartz, ±40% feldspar, ±5% lithics, low plasticity, stiff to very stiff, moderate yellowish brown (10YR 5/4), damp to moist, Ogallala Formation.
70–81	split spoon[1] 74–75.5 blows: 13/27/35	Silty sand, 30–40% silt, fine to coarse grained, subangular to subrounded, ±30% quartz, ±10% feldspar, ±60% lithics ($CaCO_3$), very low plasticity, very dense, mottled dusky yellow brown (5YR 6/4), light olive brown (5YR 5/6), pale greenish yellow (10YR 8/2), and light brown (5YR 6/4), wet, Ogallala Formation.
81–85	none	Heavy chatter with no return. Probably gravel.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 29

Latitude/longitude: 40°32′30.3″/102°07′17.6″, North American Datum of 1983
Land surface altitude: 3,601 feet, North American Vertical Datum of 1929
Date well completed: 6/26/2008
Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than]

Depth	Sample type	Description[2]
0–2	cuttings	Clayey sand, silty, ±30% fines, fine to medium grained, subangular to subrounded, organic rich, low plasticity, loose, grayish brown (5YR 3/2), damp, top soil.
2–17	cuttings	Silty sand, slightly clayey, ±20% fines, fine to medium grained with minor coarse (<5%), subangular to subrounded, ±60% quartz, ±40% feldspar, very low plasticity, loose, moderate yellowish brown (10YR 5/4) to dark yellowish orange (10YR 6/6), damp, eolian sand.
17–38	cuttings	Clayey gravel, sandy (±20%), ±20% clay, sand portion is fine to coarse grained, gravel up to 30 mm in size, subangular to subrounded, ±50% quartz, ±50% feldspar, clay content increases with depth, very low plasticity, medium dense, dark yellowish brown (10YR 4/2), damp, Ogallala Formation.
38–102	cuttings	Sandy clay, 30–40% sand, sand is fine to coarse grained with minor gravel (<5%) up to 10 mm in size, subangular to subrounded, ±50% quartz, ±50% feldspar, low plasticity, stiff, pale yellowish brown (10YR 6/2), damp to moist, Ogallala Formation.
102–121.5	split spoon[1] 120–121.5 ft blows: 1/4/23	Sand, gravelly (±20%), fine to coarse grained, gravel up to 18 mm in size, subangular to subrounded, ±50% quartz, ±45% feldspar, ±5% lithics, medium dense, light brown (5YR 6/4–5YR 5/6), saturated, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Well 30

Latitude/longitude: 40°36'50.7"/102°06'18.5", North American Datum of 1983
Land surface altitude: 3,618 feet, North American Vertical Datum of 1929
Date well completed: 6/25/2008
Log prepared by L.R. Arnold

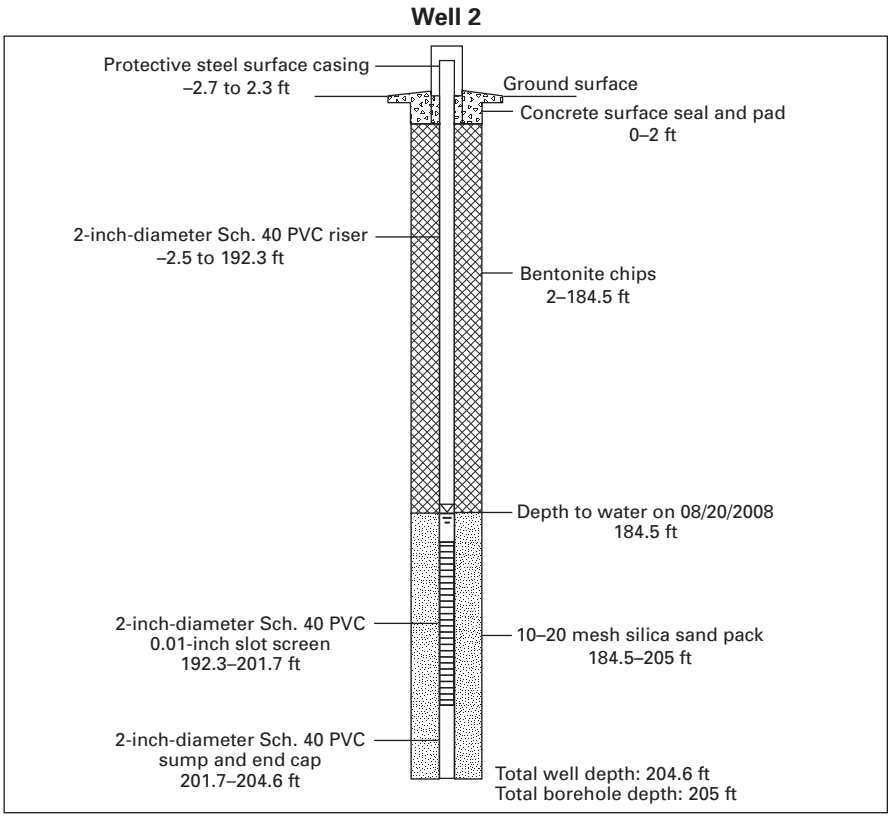
[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

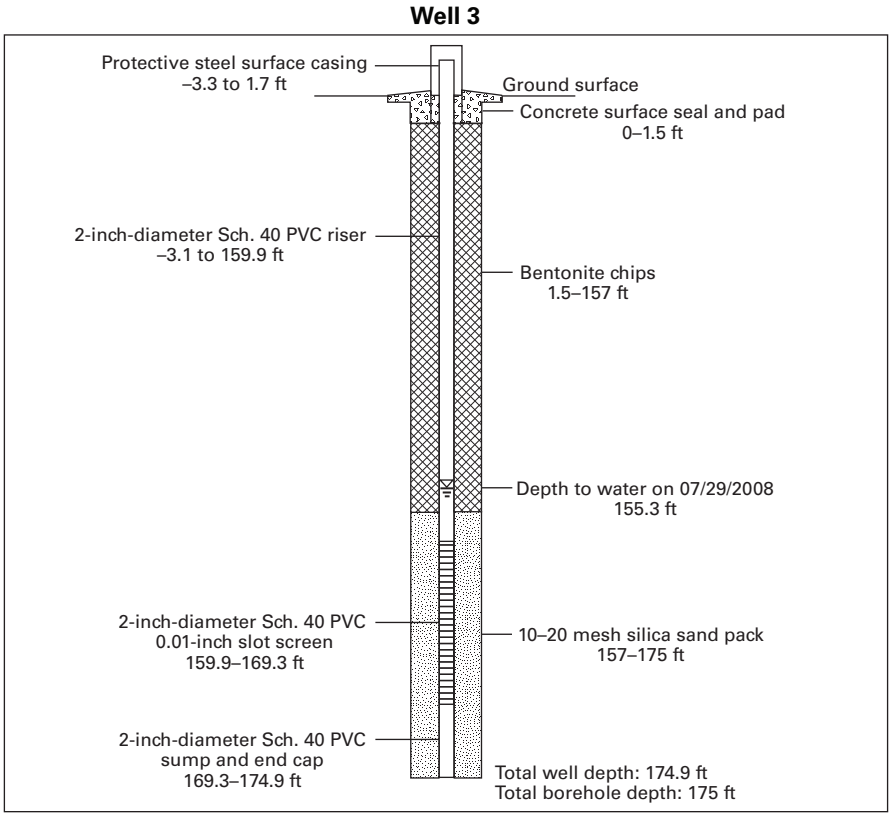
Depth	Sample type	Description[2]
0–2	cuttings	Clayey sand, silty, 30–40% fines, fine to medium grained, subangular to subrounded, organic rich, low plasticity, loose to medium dense, dusky brown (5YR 2/2), damp, top soil.
2–22	cuttings	Clayey sand, silty, 20–40% fines, fine to coarse grained with minor (±5%) fine gravel, subangular to subrounded, ±50% feldspar, ±40% quartz, ±10% lithics, contains infrequent thin clay lenses, caliche nodules from 2–5 ft, low plasticity, medium dense, grayish to orange pink (5YR 7/2) to pale yellowish brown (10YR 6/2), damp, Ogallala Formation.
22–25	cuttings	Sandy clay, 40–50% sand, sand is fine to coarse grained with minor (±5%) fine gravel, subangular to subrounded, ±50% feldspar, ±40% quartz, ±10% lithics, low plasticity, medium soft to stiff, moderate yellowish brown (10YR 5/4), damp, Ogallala Formation.
25–32	cuttings	Gravel, sandy (30–40%), slightly clayey (±5%), sand is fine to coarse grained, gravel up to 13 mm in size, subangular to subrounded, ±50% feldspar, ±40% quartz, ±10% lithics, medium dense, light brown (5YR 6/4), damp, Ogallala Formation.
32–41	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, ±5% gravel up to 8 mm in size, subangular to subrounded, ±50% feldspar, ±40% quartz, ±10% lithics, low plasticity, medium dense, moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2), damp, Ogallala Formation.
41–54	cuttings	Sand, gravelly (20–30%), slightly clayey (10%), fine to coarse grained, gravel up to 17 mm in size, subangular to subrounded, 55% feldspar, 40% quartz, 5% lithics, medium dense, moderate brown (5YR 3/4), damp, Ogallala Formation.
54–67	cuttings	Clayey sand (same as 32–41 ft), clay content increases with depth, Ogallala Formation.
67–129	cuttings	Sandy clay, 30–40% sand, sand is fine to medium grained with minor coarse, subangular to subrounded, 50% feldspar, 40% quartz, 10% lithics, stiff to very stiff, low to high plasticity, moderate yellowish brown (10YR 5/4), light brown (5YR 6/4) below 80 ft, damp to moist, Ogallala Formation.
129–155.2	split spoon[1] 140–141.5 ft blows: 11/17/22	Sand, gravelly (20–30%), medium to coarse grained with minor fine, gravel up to 15 mm in size, subangular to subrounded, 45% quartz, 40% feldspar, 15% lithics, dense, light brown (5YR 6/4–5YR 5/6), saturated below 133.4 ft, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

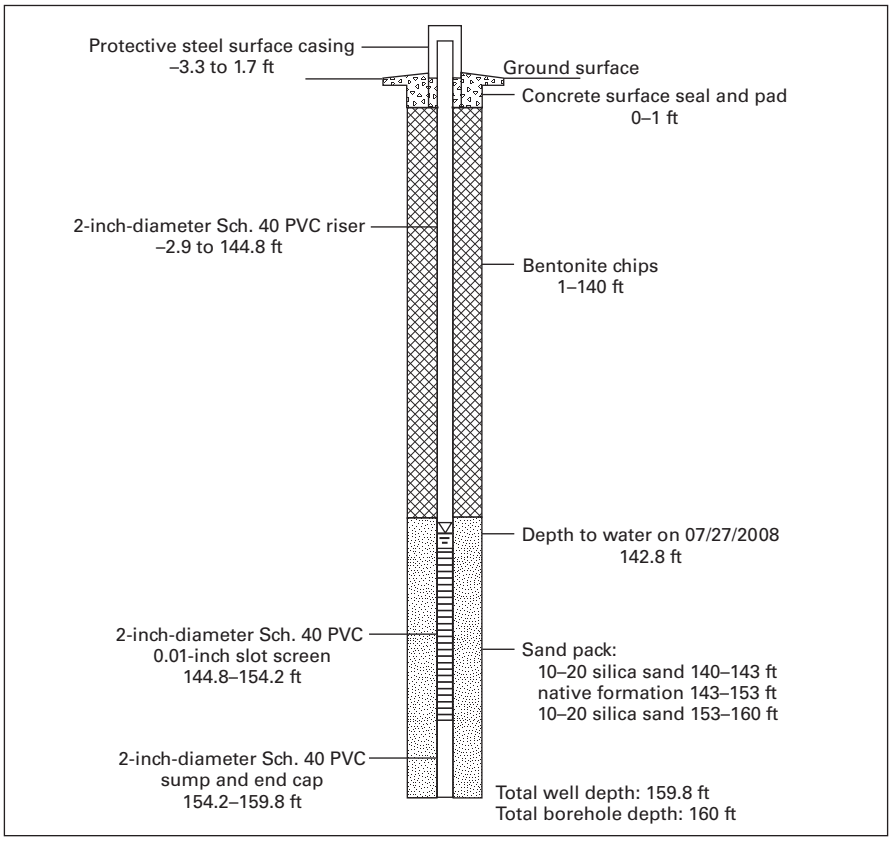
[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Appendix 2. Well-Construction Diagrams

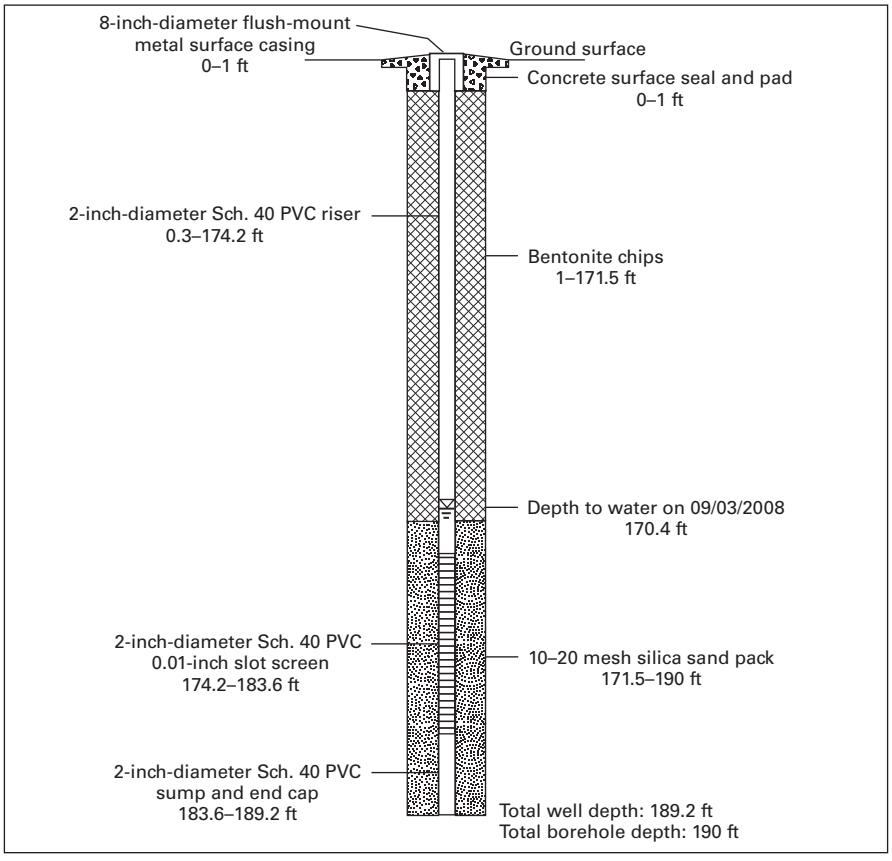




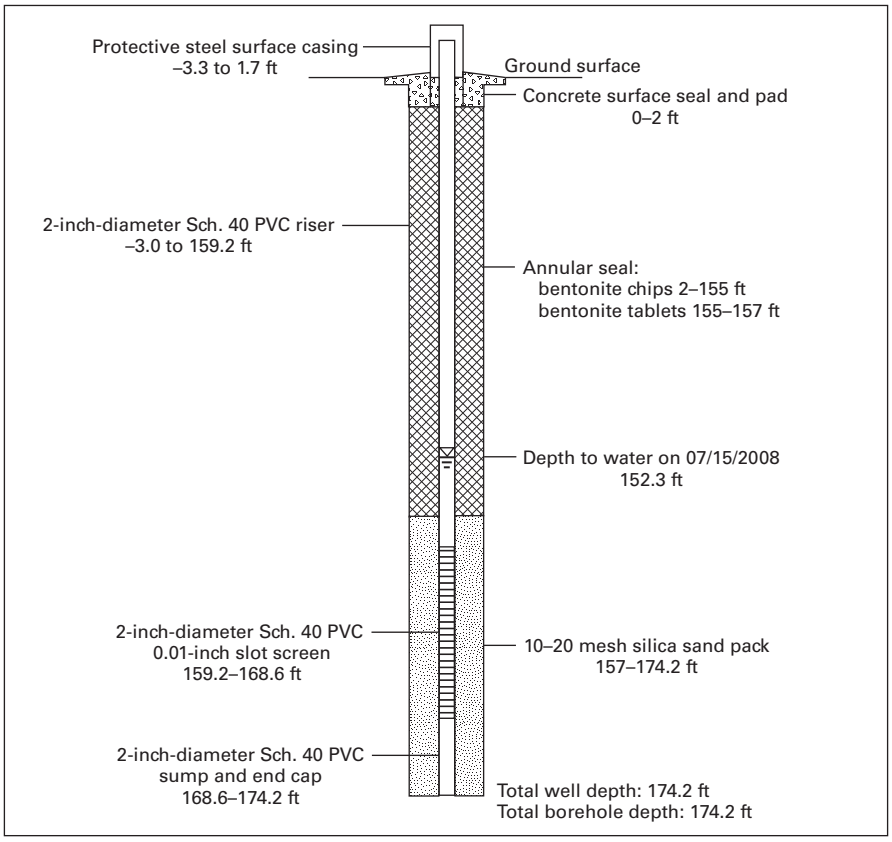
Well 4


Protective steel surface casing
–3.3 to 1.7 ft
Ground surface
Concrete surface seal and pad
0–1 ft
2-inch-diameter Sch. 40 PVC riser
–2.9 to 144.8 ft
Bentonite chips
1–140 ft
Depth to water on 07/27/2008
142.8 ft
2-inch-diameter Sch. 40 PVC
0.01-inch slot screen
144.8–154.2 ft
Sand pack:
10–20 silica sand 140–143 ft
native formation 143–153 ft
10–20 silica sand 153–160 ft
2-inch-diameter Sch. 40 PVC
sump and end cap
154.2–159.8 ft
Total well depth: 159.8 ft
Total borehole depth: 160 ft

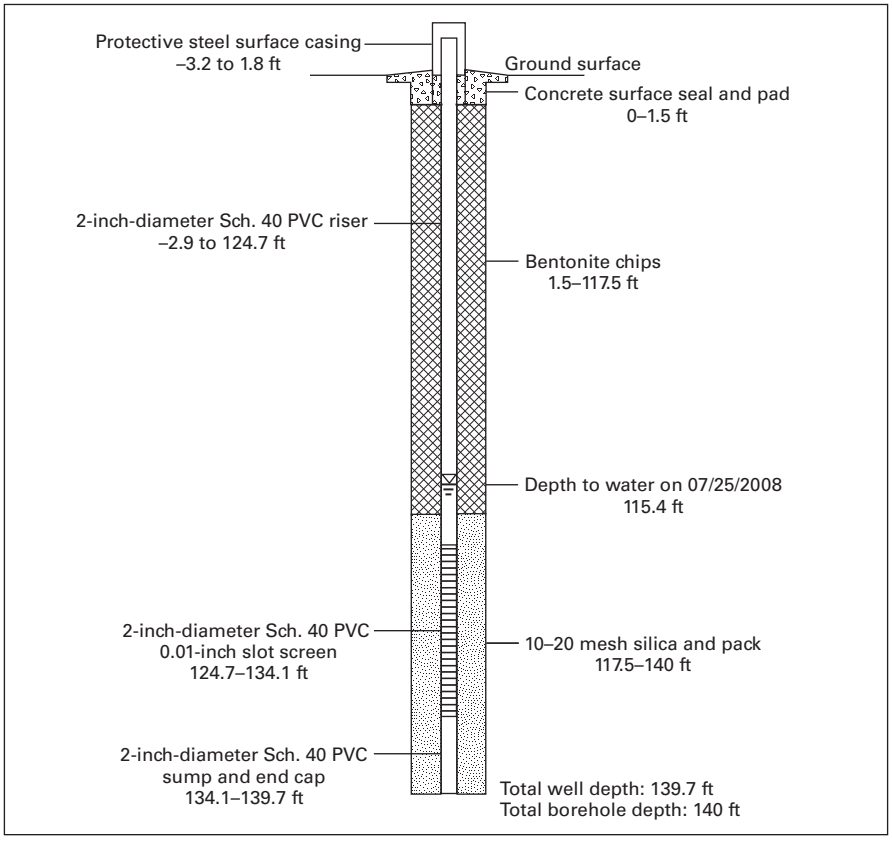
Well 5


8-inch-diameter flush-mount
metal surface casing
0–1 ft
Ground surface
Concrete surface seal and pad
0–1 ft
2-inch-diameter Sch. 40 PVC riser
0.3–174.2 ft
Bentonite chips
1–171.5 ft
Depth to water on 09/03/2008
170.4 ft
2-inch-diameter Sch. 40 PVC
0.01-inch slot screen
174.2–183.6 ft
10–20 mesh silica sand pack
171.5–190 ft
2-inch-diameter Sch. 40 PVC
sump and end cap
183.6–189.2 ft
Total well depth: 189.2 ft
Total borehole depth: 190 ft

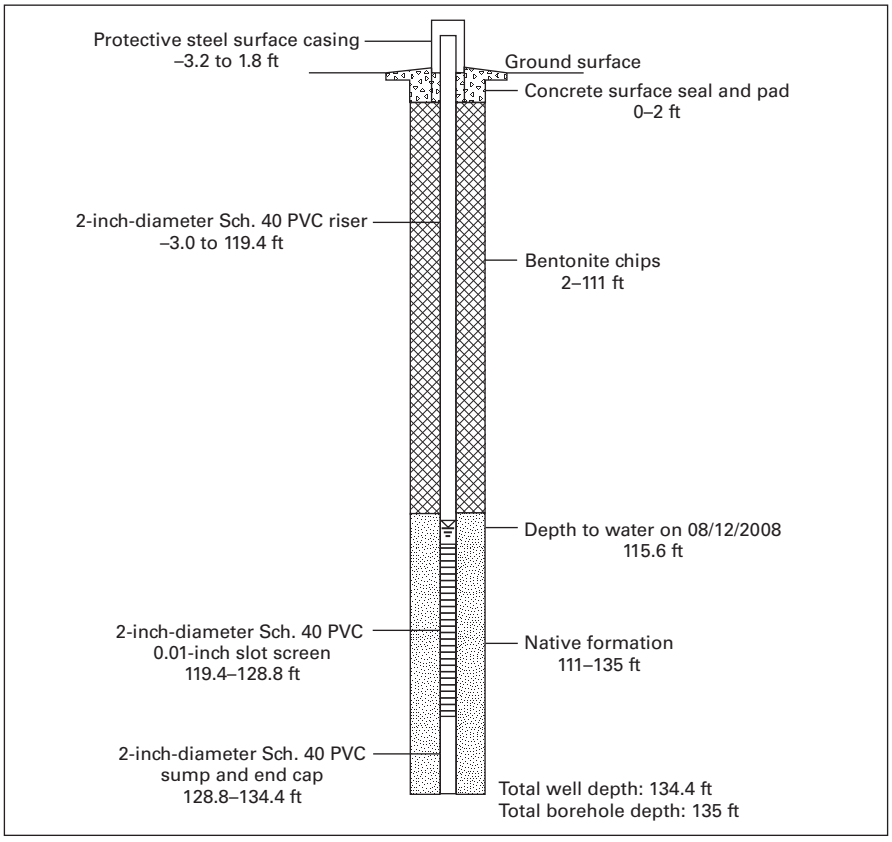
Well 7



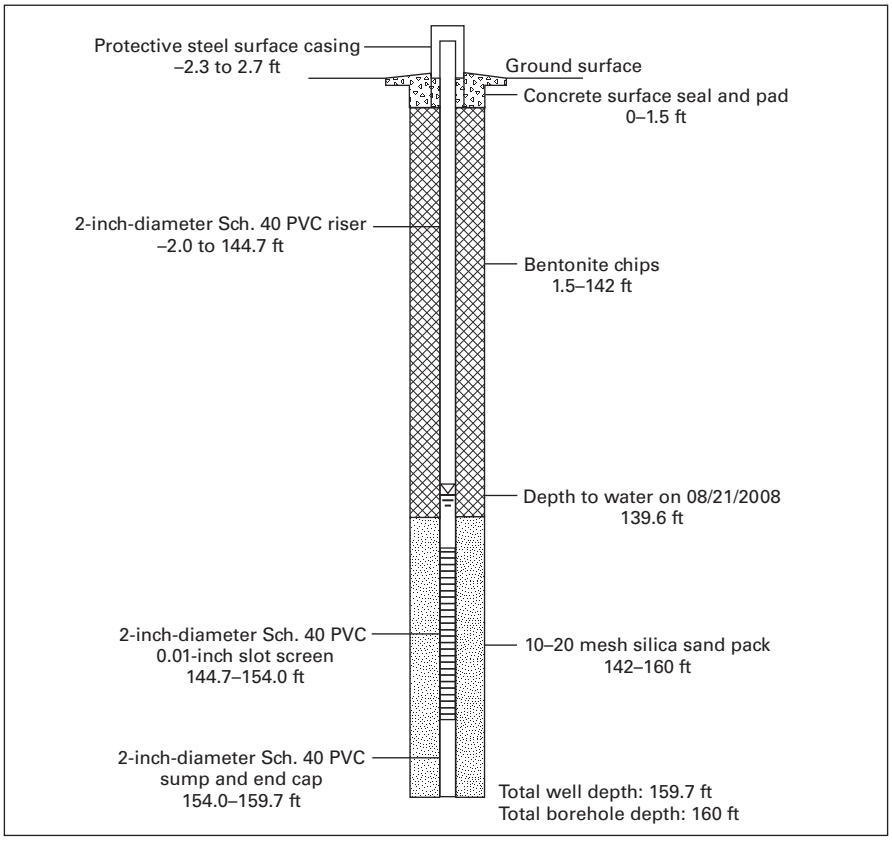
Well 11



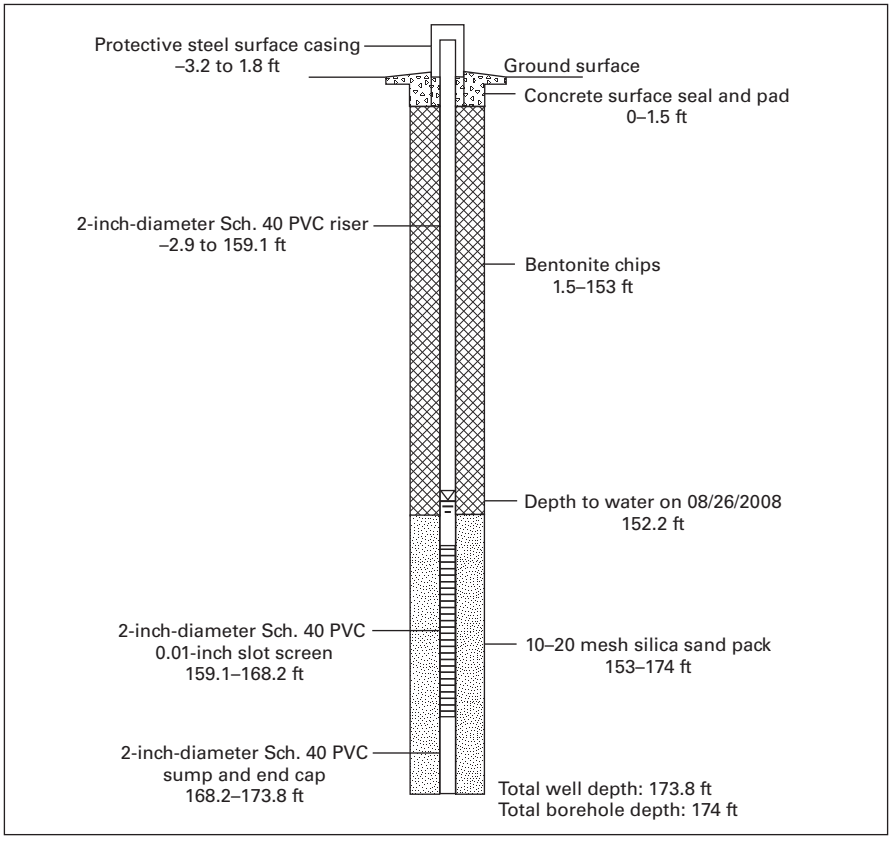
Well 12



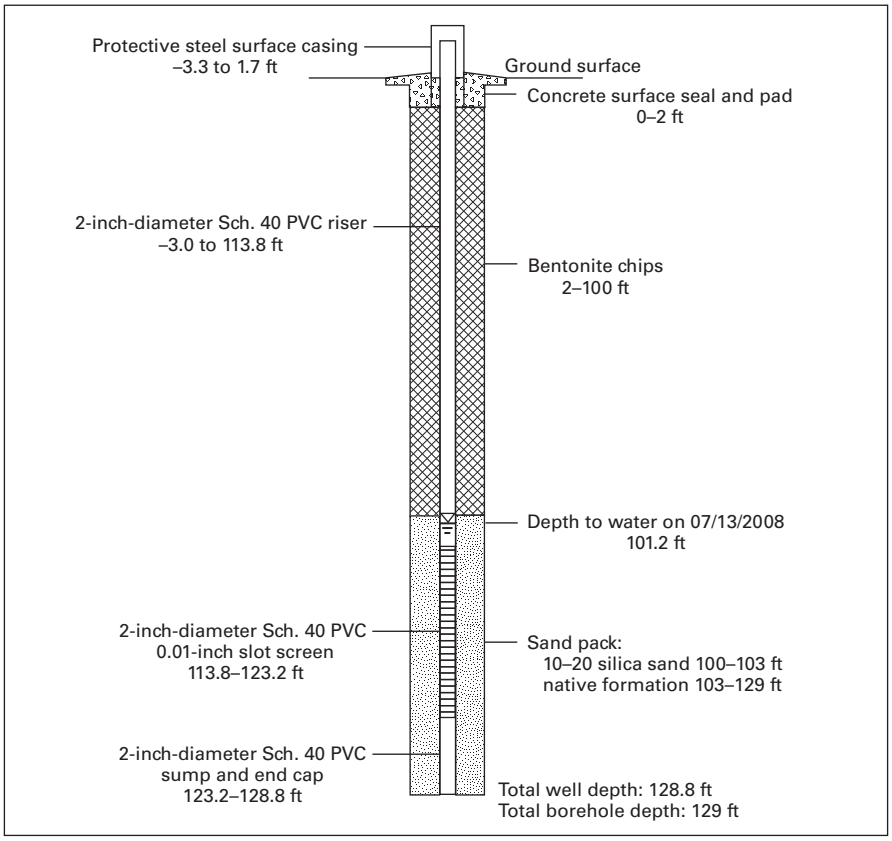
Well 13



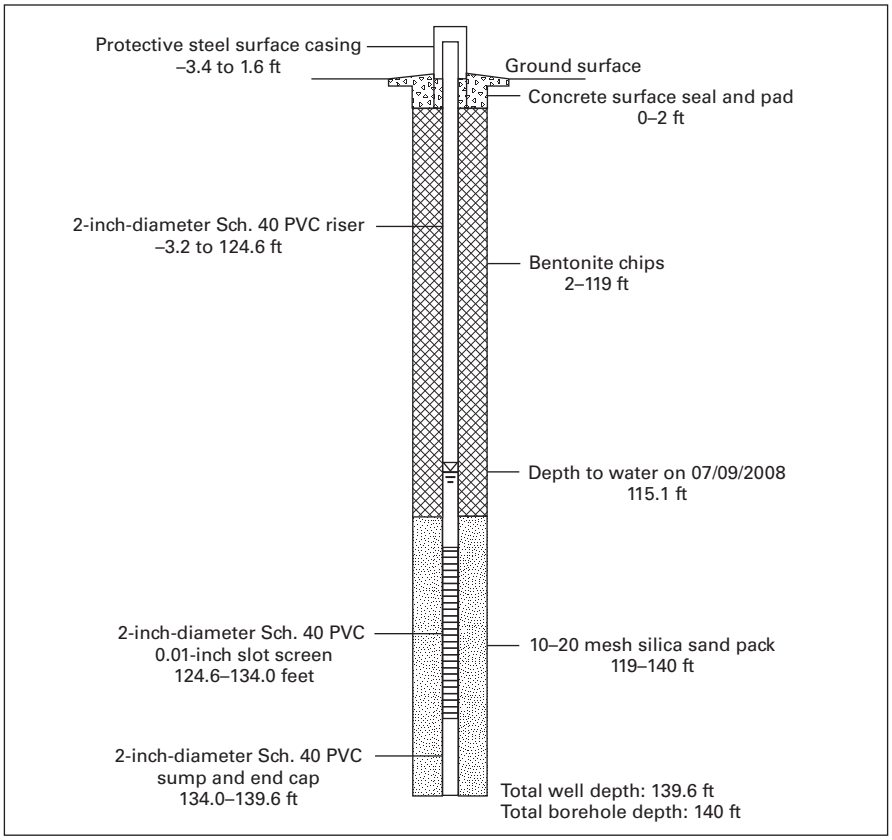
Well 14



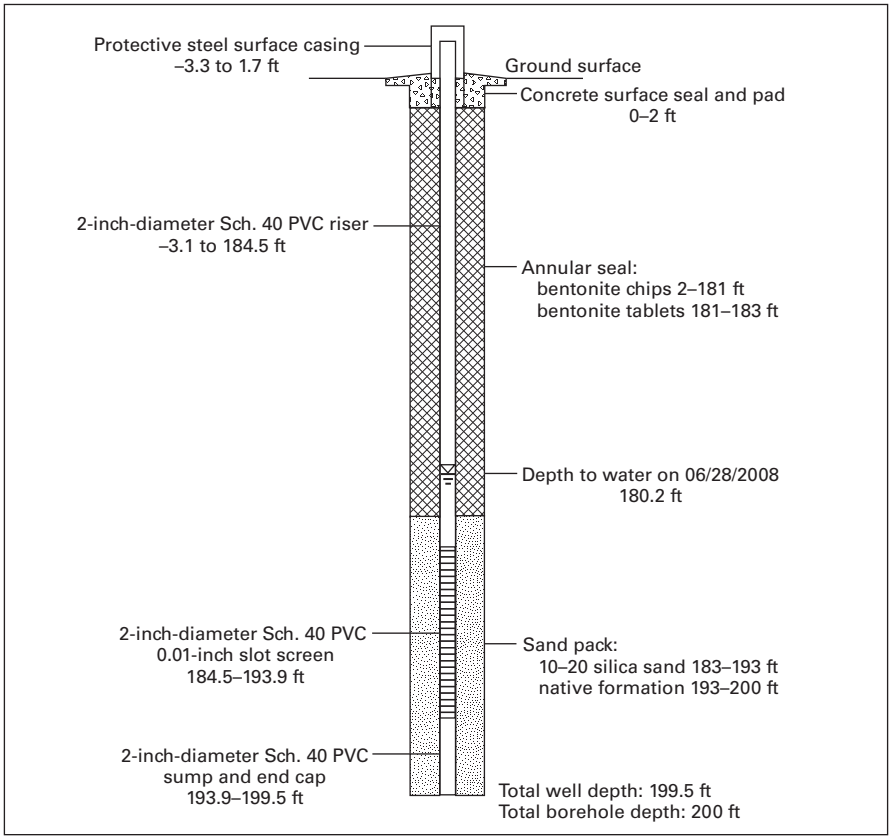
Well 16



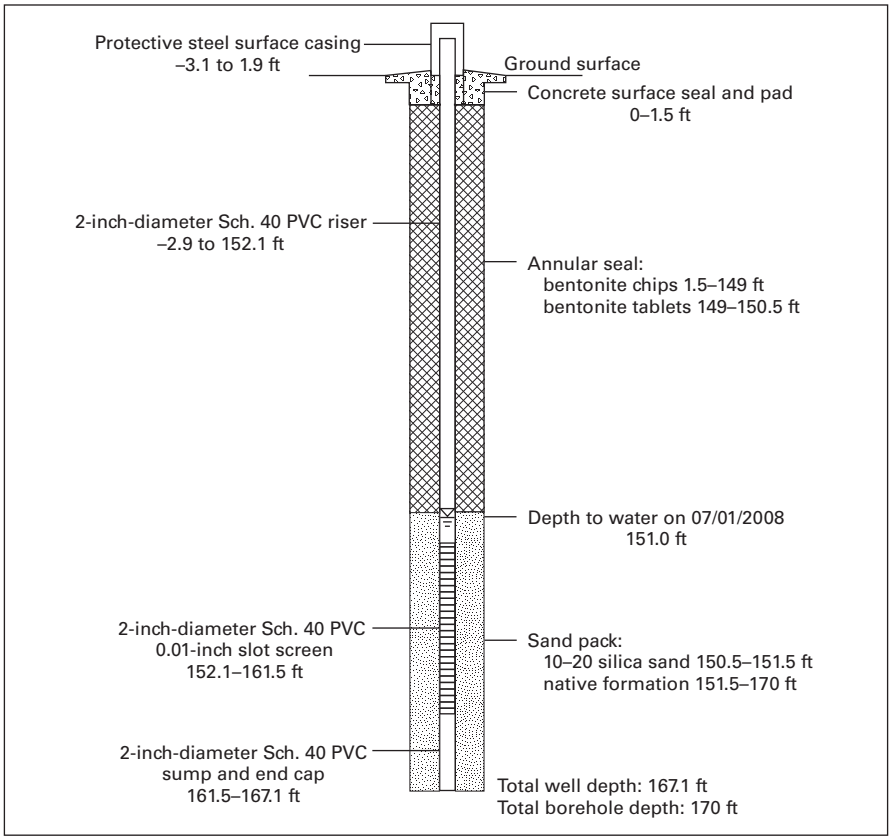
Well 17



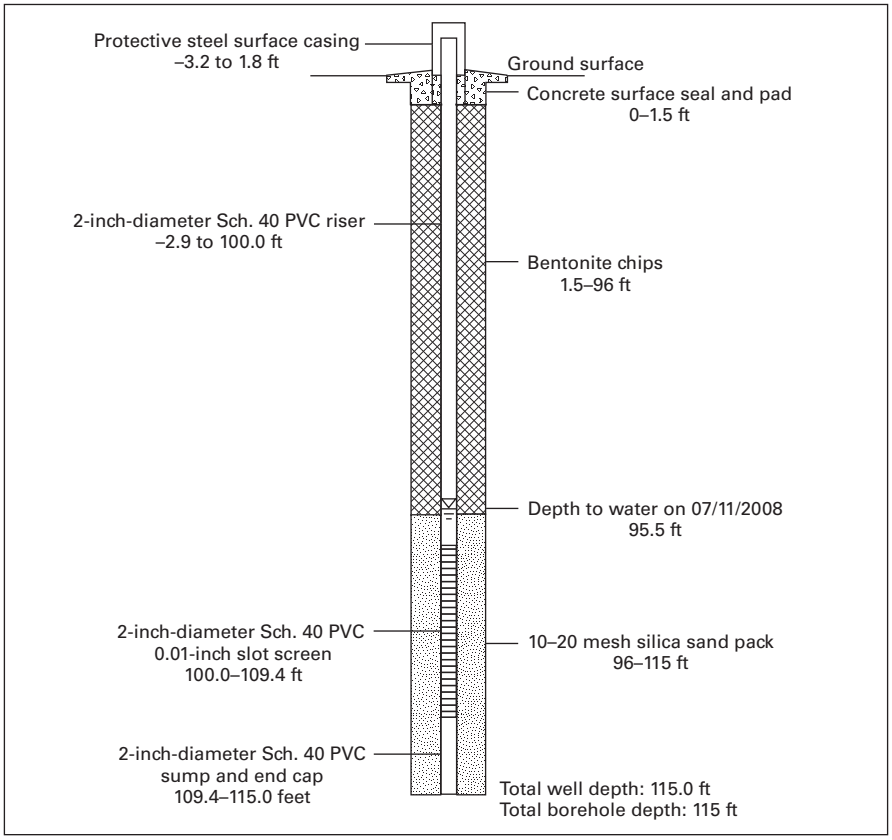
Well 19



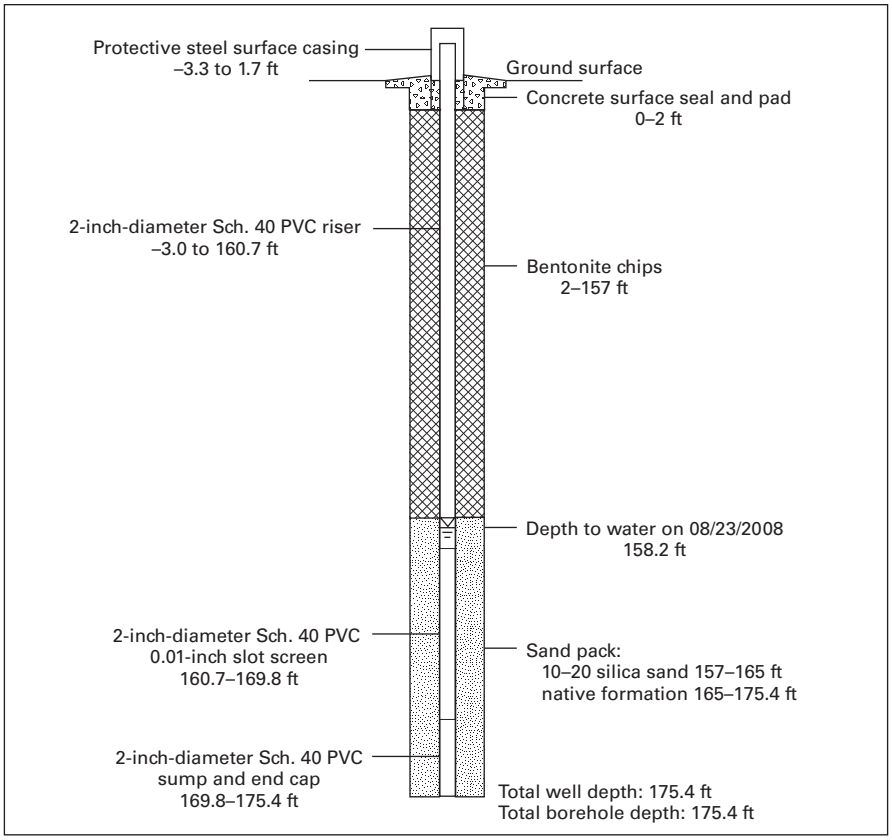
Well 20



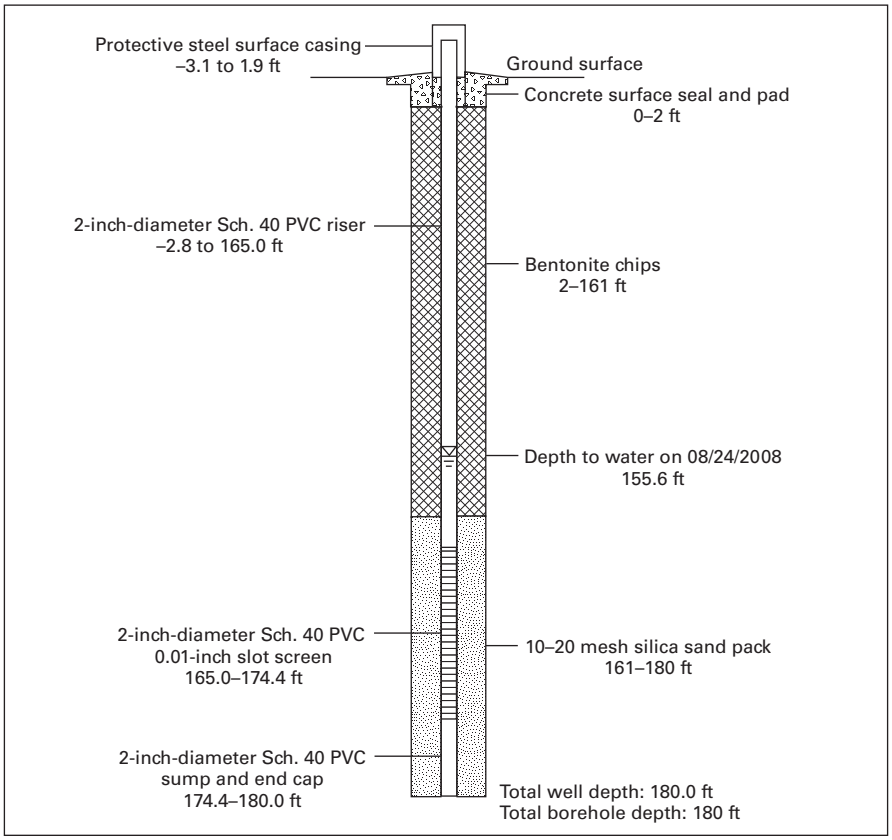
Well 21



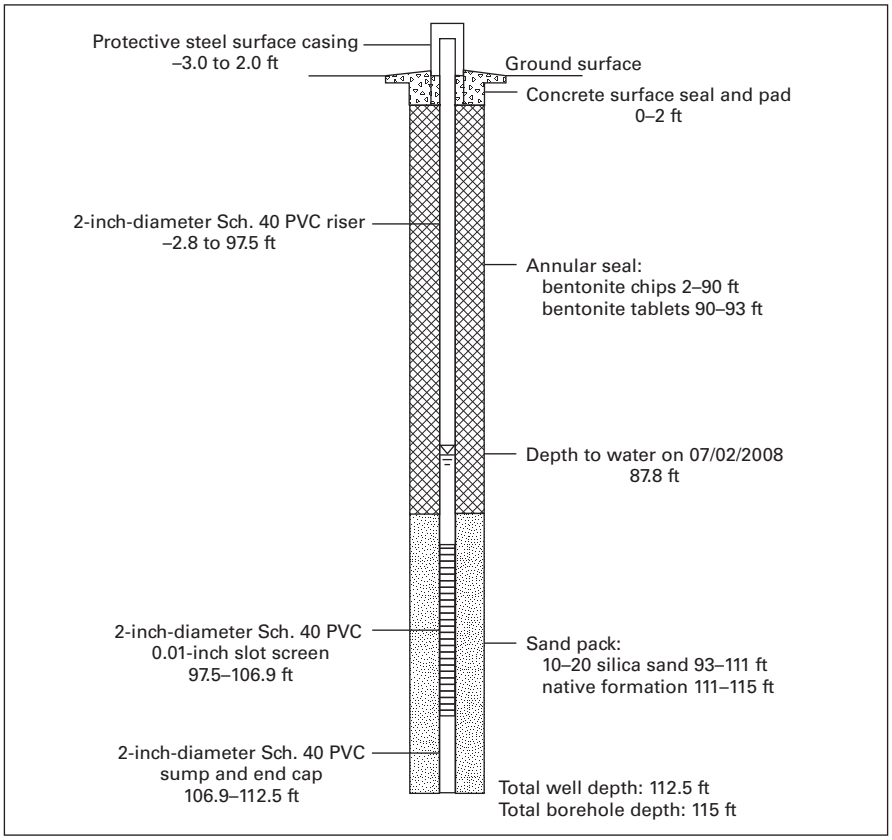
Well 24a



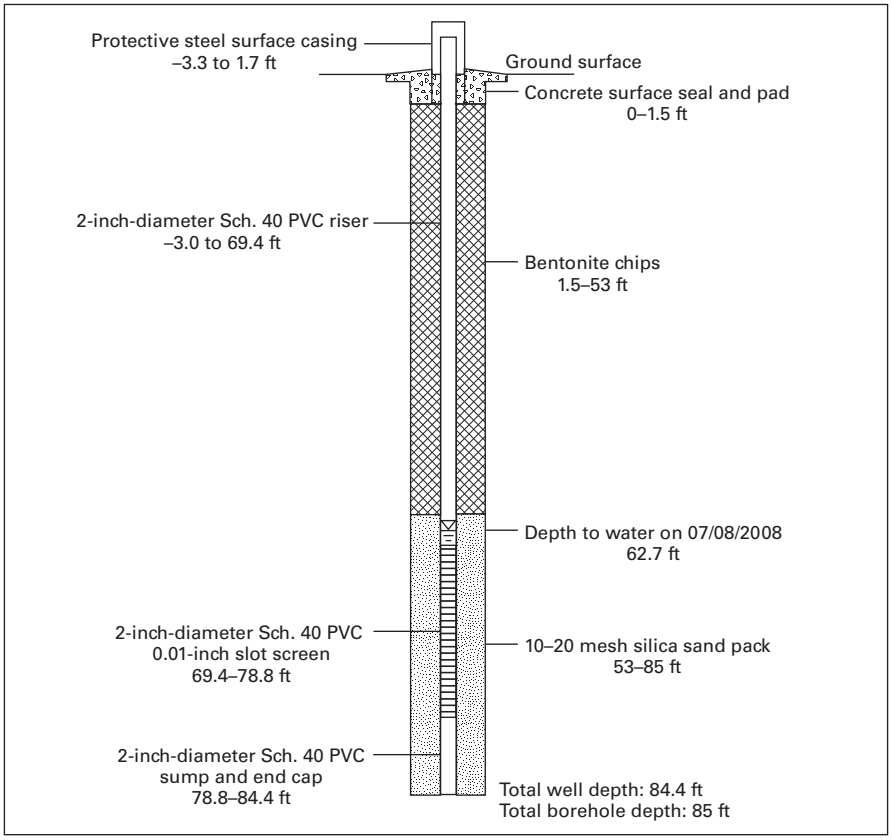
Well 24b



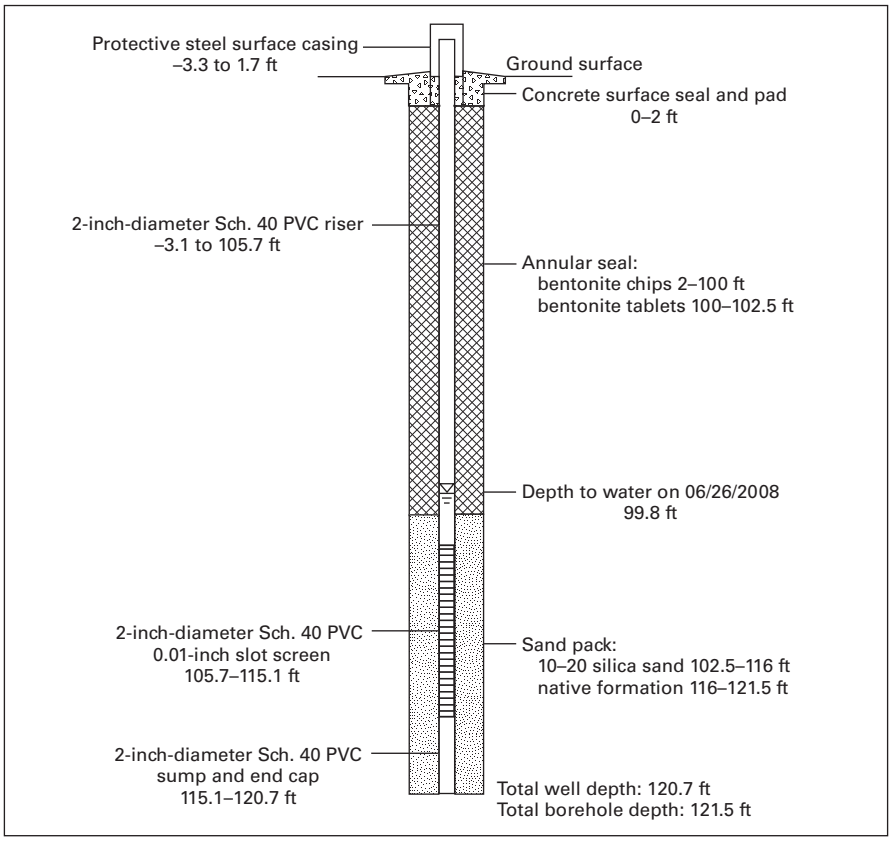
Well 26



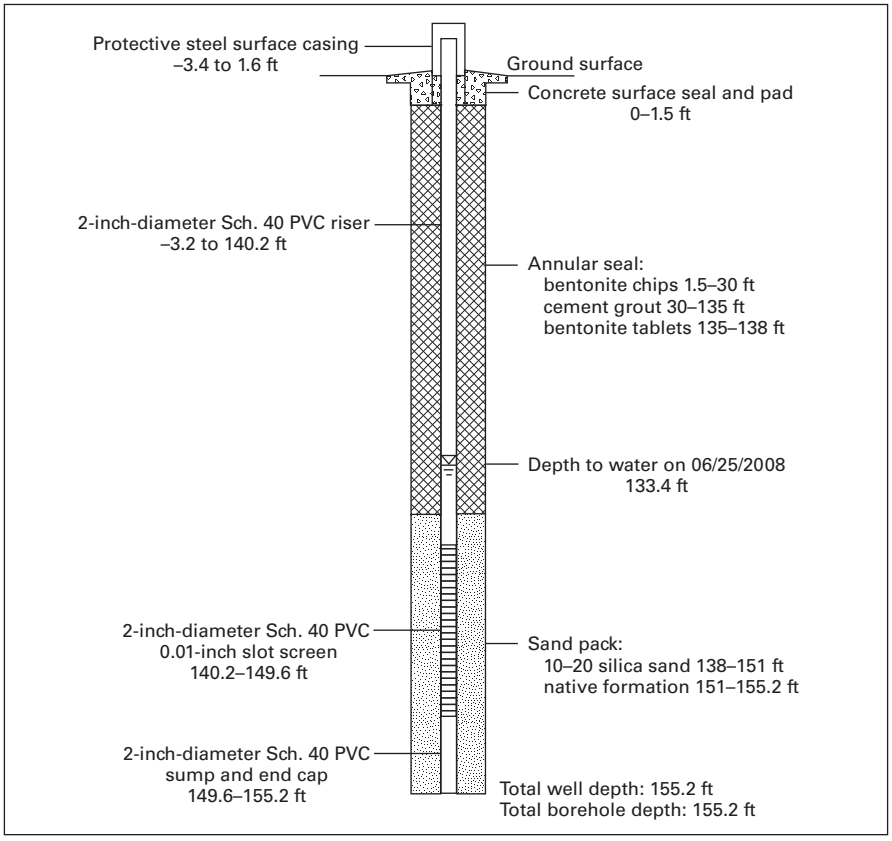
Well 28



Well 29



Well 30



Appendix 3. Well-Development Records

Well 2

Date developed: 10/07/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
70	0.3	--	--	--	--	Muddy
160	0.3	--	--	--	--	Muddy
220	0.3	16.8	369	--	--	Slightly muddy
250	0.4	16.6	362	8.1	853	Murky
280	0.3	16.2	361	7.8	359	Murky
310	0.3	16.1	360	7.8	175	Slightly murky
340	0.3	16.1	359	7.8	108	Mostly clear
355	0.3	16.2	359	7.8	89.4	Mostly clear
360			Pump off			

Well 3

Date developed: 10/08/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
90	0.4	--	--	--	--	Muddy
120	0.4	15.6	399	7.6	--	Slightly muddy
150	0.4	15.2	387	7.9	254	Murky
165	0.4	15.6	387	7.9	81.3	Mostly clear
180	0.4	15.6	385	7.9	41.3	Mostly clear
195	0.4	15.7	384	7.9	27.7	Clear
205			Pump off			

Well 4

Date developed:10/09/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
180	--	--	--	--	--	Muddy
240	0.25	--	--	--	--	Muddy
300	0.25	14.5	374	8.2	>1,000	Slightly muddy
375	--	15.6	373	8.3	551	Murky
405	0.25	15.0	374	7.9	428	Murky
450	0.25	--	--	--	--	Muddy
510	0.25	15.9	381	7.9	500	Murky
515			Pump off			

Comments: Well was pumped dry 13 times during development. Water-level recovery rate after development is about 0.7 foot per minute.

Well 5

Date developed: 09/11/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
180	0.3	--	--	--	--	Muddy
270	0.35	16.5	730	7.6	>1,000	Slightly muddy
300	0.4	16.2	737	7.7	612	Murky
360	0.3	16.0	749	7.6	586	Murky
390	0.3	15.1	754	7.7	211	Slightly murky
405	0.3	15.1	756	7.6	170	Slightly murky
420	0.3	15.1	757	7.7	92.6	Mostly clear
430			Pump off			

Well 7

Date developed: 09/04/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
30	0.4	--	--	--	--	Muddy
240	0.3	15.9	382	7.7	--	Muddy
255	0.3	15.2	377	7.8	444	Murky
270	0.3	15.1	377	7.8	152	Slightly murky
285	0.3	15.3	377	7.9	64.5	Mostly clear
300	0.3	15.0	377	7.8	26.5	Mostly clear
315	0.3	14.5	377	7.7	14.5	Clear
330	0.3	14.3	377	7.7	10.6	Clear
335			Pump off			

Well 11

Date developed: 09/12/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
180	0.35	--	--	--	--	Muddy
270	0.3	14.0	404	7.6	--	Slightly muddy
300	0.3	14.0	400	7.6	--	Slightly muddy
330	0.3	14.1	398	7.7	578	Murky
360	0.3	13.8	395	7.7	306	Murky
390	0.3	14.0	392	7.7	201	Slightly murky
405	0.3	14.0	392	7.7	162	Slightly murky
420	0.3	13.9	391	7.7	143	Slightly murky
425			Pump off			

Well 12

Date developed: 10/14/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
120	0.5	--	--	--	--	Muddy
165	0.5	12.4	302	--	--	Slightly muddy
180	0.5	12.2	302	--	617	Murky
195	0.4	12.1	302	--	256	Murky
210	0.4	12.5	301	--	201	Slightly murky
225	0.4	12.7	302	--	143	Slightly murky
240	0.4	12.6	302	--	92.4	Mostly clear
255	0.4	12.8	301	--	70.3	Mostly clear
260			Pump off			

Well 13

Date developed: 10/09/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
75	0.5	--	--	--	--	Muddy
90	0.5	16.7	366	7.7	--	Slightly muddy
105	0.5	16.2	355	7.7	226	Murky
120	0.5	16.3	355	7.8	104	Slightly murky
135	0.5	15.9	355	7.8	54.7	Mostly clear
150	0.5	15.9	354	7.8	27.0	Clear
165	0.5	15.8	355	7.8	16.2	Clear
170			Pump off			

Well 14

Date developed: 10/09/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
75	0.5	--	--	--	--	Muddy
90	0.5	15.1	297	8.3	--	Slightly muddy
105	0.5	15.2	296	8.2	250	Murky
120	0.5	15.2	296	8.0	134	Slightly murky
135	0.5	15.5	295	8.0	120	Slightly murky
150	0.5	15.5	296	8.0	61.6	Mostly clear
165	0.5	15.6	295	8.0	33.9	Mostly clear
180	0.5	15.6	295	7.9	17.2	Clear
190			Pump off			

Well 16

Dates developed: 09/10/2008, 10/16/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on 09/10/2008			
30	0.5	--	--	--	--	Muddy
105	0.3	--	--	--	--	Muddy
225	0.4	--	--	--	--	Muddy
285	0.4	15.6	418	7.5	--	Muddy
345	0.3	15.8	413	7.6	--	Muddy
405	0.5	15.7	413	7.4	--	Slightly muddy
465	0.5	16.0	413	7.4	--	Slightly muddy
525	0.5	15.8	414	7.5	--	Slightly muddy
555			Pump off 09/10/2008			
555			Pump on 10/16/2008			
570	0.8	14.2	412	--	46.3	Mostly clear
585	0.8	14.2	412	--	48.7	Mostly clear
590			Pump off 10/16/2008			

Comments: Well initially pumped dry. After development, water level in well remained stable during pumping.

Well 17

Date developed: 09/04/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
135	0.5	16.5	409	7.4	--	Muddy
285	0.8	15.1	404	7.3	>1,000	Slightly muddy
345	0.7	14.3	405	7.8	>1,000	Slightly muddy
390	0.5	16.6	407	7.7	415	Murky
420	0.5	16.4	402	7.7	195	Slightly murky
450	0.6	16.0	400	7.7	264	Slightly murky
480	0.6	15.7	399	7.7	495	Murky
510	0.4	16.1	399	7.6	180	Slightly murky
525	0.4	16.4	397	7.7	92.7	Mostly clear
530			Pump off			

Well 19

Date developed: 10/02/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
60	0.25	--	--	--	--	Muddy
120	0.3	16.8	599	--	--	Slightly muddy
150	0.3	17.1	589	--	485	Murky
165	0.3	16.9	586	--	335	Murky
180	0.3	17.2	583	--	248	Murky
195	0.3	16.9	582	--	154	Slightly murky
210	0.3	17.1	581	--	95.4	Mostly clear
225	0.3	17.2	577	--	55.8	Mostly clear
240	0.3	16.9	577		37.7	Mostly clear
250			Pump off			

Well 20

Date developed: 10/01/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
120	0.3	--	--	--	--	Muddy
225	0.3	15.8	366	--	--	Slightly muddy
255	0.3	--	369	--	443	Murky
285	0.3	15.4	366	--	367	Murky
300	0.4	15.3	366	--	247	Murky
315	0.4	15.1	366	--	151	Slightly murky
330	0.3	14.9	366	--	79.9	Mostly clear
345	0.3	14.8	366	--	49.4	Mostly clear
360	0.3	14.8	366	--	33.4	Mostly clear
375	0.3	14.5	367	--	24.3	Clear
380			Pump off			

Well 21

Date developed: 10/03/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
120	0.7	--	--	--	--	Muddy
150	0.5	14.8	590	--	>1,000	Slightly muddy
165	0.5	14.5	589	--	226	Murky
180	0.5	14.8	591	--	98.9	Slightly murky
195	0.5	14.9	591	--	72.9	Mostly clear
210	0.5	14.9	590	--	57.2	Mostly clear
225	0.5	14.8	591	--	42.5	Mostly clear
240	0.5	14.9	591	--	36.2	Mostly clear
255	0.5	14.9	591	--	19.5	Clear
260			Pump off			

Well 24a

Date developed: 10/15/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
120	0.4	--	--	--	--	Muddy
150	0.4	13.9	588	--	--	Slightly muddy
180	0.4	14.1	590	--	>1,000	Slightly muddy
210	0.4	14.2	590	--	720	Murky
225	0.4	14.3	590	--	430	Murky
240	0.4	14.4	593	--	290	Murky
255	0.4	14.5	593	--	180	Slightly murky
270	0.4	14.6	592	--	118	Slightly murky
275			Pump off			

Well 24b

Date developed: 10/16/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
105	0.4	--	--	--	--	Muddy
135	0.4	12.6	436	--	--	Slightly muddy
165	0.4	12.9	434	--	277	Murky
180	0.4	13.5	435	--	77.4	Mostly clear
195	0.4	13.5	434	--	36.8	Mostly clear
210	0.4	13.6	434	--	24.8	Clear
215			Pump off			

Well 26

Date developed: 10/06/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
90	0.5	--	--	--	--	Muddy
105	0.75	15.3	209	--	--	Slightly muddy
120	0.75	14.8	201	--	405	Murky
135	0.75	14.6	200	7.7	254	Murky
150	0.75	14.6	200	7.8	180	Slightly murky
180	0.75	14.2	199	8.0	116	Slightly murky
210	0.75	14.1	198	8.0	82.0	Mostly clear
240	0.75	13.9	197	8.1	69.8	Mostly clear
255	0.75	13.8	198	8.1	55.0	Mostly clear
260			Pump off			

Well 28

Date developed: 10/02/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data; >, greater than]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
90	0.7	--	--	--	--	Muddy
120	0.75	13.6	633	--	>1,000	Slightly muddy
150	0.75	13.1	641	--	>1,000	Slightly muddy
165	0.7	12.8	647	--	205	Murky
180	0.5	12.7	647	--	44.7	Mostly clear
195	0.5	12.6	651	--	29.3	Mostly clear
200			Pump off			

Well 29

Date developed: 09/30/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
15	0.5	--	--	--	--	Muddy
90	0.5	13.8	340	--	--	Slightly muddy
105	0.8	13.9	340	--	55.9	Mostly clear
120	0.9	14.0	339	--	28.7	Mostly clear
135	0.9	14.0	339	--	17.0	Clear
150	0.9	14.0	339	--	11.4	Clear
165	0.9	14.0	339	--	8.48	Clear
175			Pump off			

Well 30

Date developed: 09/29/2008

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; --, no data]

Pumping duration (minutes)	Pumping rate (gal/min)	Temperature (°C)	Specific conductance (µS/cm)	pH	Turbidity (NTU)	Appearance
0			Pump on			
45	0.5	--	--	--	--	Muddy
120	0.7	14.2	484	--	--	Slightly muddy
150	0.5	15.0	484	--	--	Slightly muddy
165	0.7	14.0	482	--	149	Slightly murky
180	0.6	14.2	482	--	45.7	Mostly clear
195	0.6	14.0	482	--	44.8	Mostly clear
225	0.5	14.0	483		9.42	Clear
240	0.5	13.9	483		4.49	Clear
245			Pump off			

Publishing support provided by:
Denver Publishing Service Center, Denver, Colorado
Manuscript approved for publication, July 10, 2009
Edited by Mary Kidd
Graphics and layout by Joy Monson

For more information concerning this publication, contact:
Director, USGS Colorado Water Science Center
Box 25046, Mail Stop 415
Denver, CO 80225
(303) 236-4882

Or visit the Colorado Water Science Center Web site at:
http://co.water.usgs.gov/

This publication is available online at:
http://pubs.usgs.gov/ds/456/