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Installation of a Groundwater Monitoring-Well Network on the East Side of the Uncompahgre River in the Lower Gunnison River Basin, Colorado, 2012

Data Series 923

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

Cover. Monitoring well adjacent to corn field, lower Gunnison River Basin, Montrose County, Colorado, June 2013.
Photo by Judith Thomas, U.S. Geological Survey.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.0393701	inch (in.)
	Area	
square mile (mi^2)	.590	square kilometer (km^2)
	Volume	
gallon (gal)	.785	liter (L)
	Flow rate	
gallon per minute (gal/min)	.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

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

°F=(1.8×°C)+32

Vertical coordinate information was referenced to North American Vertical Datum of 1988 (NAVD 88).

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

Specific conductance was given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Installation of a Groundwater Monitoring-Well Network on the East Side of the Uncompahgre River in the Lower Gunnison River Basin, Colorado, 2012

By Judith C. Thomas and L. Rick Arnold

Abstract

The east side of the Uncompahgre River Basin has been a known contributor of dissolved selenium to recipient streams. Discharge of groundwater containing dissolved selenium contributes to surface-water selenium concentrations and loads; however, the groundwater system on the east side of the Uncompahgre River Basin is not well characterized. The U.S. Geological Survey, in cooperation with the Colorado Water Conservation Board and the Bureau of Reclamation, has established a groundwater-monitoring network on the east side of the Uncompahgre River Basin. Ten monitoring wells were installed during October and November 2012. This report presents location data, lithologic logs, well-construction diagrams, and well-development information. Understanding the groundwater system will provide managers with an additional metric for evaluating the effectiveness of salinity and selenium control projects.

Introduction

The east side of the Uncompahgre River Basin has been a known contributor of dissolved selenium to recipient streams. The U.S. Fish and Wildlife Service and the U.S. Geological Survey (USGS), as part of National Irrigation Water Quality Program (NIQWP), found that dissolved selenium concentrations were elevated for both groundwater and river systems in irrigated parts of the Uncompahgre River Basin in the lower Gunnison River Basin (Butler and others, 1996). As a result, selenium produced by irrigated areas was thought to be detrimentally affecting native Colorado River Basin fish species. The Colorado Department of Public Health and Environment (CDPHE) have since adopted standards for selenium in the lower Gunnison River Basin. Many rivers and streams of the east side of the Uncompahgre River Basin are selenium impaired for cold water fisheries on the Colorado's 303(d) list (Colorado Department of Public Health and Environment, 1998), and concentrations have exceeded the 85th percentile chronic aquatic-life standard for dissolved selenium (4.6 micrograms per liter) as established by the State of Colorado (Butler and Leib, 2002; Thomas and others, 2007). Despite the implementation of control projects (designed to limit the mobilization of selenium) in the region, there are indications that selenium loads may be increasing (Moore, 2011).

Perennial streamflow on the east side of the Uncompahgre River Basin is supported by seasonal tributary inflow, irrigation-return flows, and shallow groundwater discharge from areas underlain by selenium-bearing shale. Previous work in the basin (Bureau of Reclamation, 1982) supports a conceptual model of water-table (unconfined) groundwater conditions present beneath irrigated areas and in proximity to streams. Discharge of groundwater containing dissolved selenium contributes to surface-water selenium concentrations and loads; however, the groundwater system on the east side of the Uncompahgre River Basin is not well characterized. Additional information such as depth to water, extent and thickness of saturation, hydraulic conductivity, and groundwater selenium concentrations are needed to understand characteristics of the groundwater system. Understanding the groundwater system will provide managers with an additional metric for evaluating the effectiveness of salinity and selenium control projects. Coupled with current surface-water monitoring, groundwater monitoring will provide a more complete understanding of all the factors involved in achieving success in control projects. The USGS, in cooperation with Colorado Water Conservation Board and the Bureau of Reclamation has established a groundwater-monitoring network on the east side of the Uncompahgre River Basin. This report describes the first phase of the implementation of a monitoring-well network designed to characterize the groundwater quality on the east side of the Uncompahgre River Basin.

The purpose of this report is to document the design and installation of a groundwater-monitoring network on the east side of the Uncompahgre River Basin in Colorado (fig. 1). This report documents network design, well drilling and installation of 10 sites, and well development.

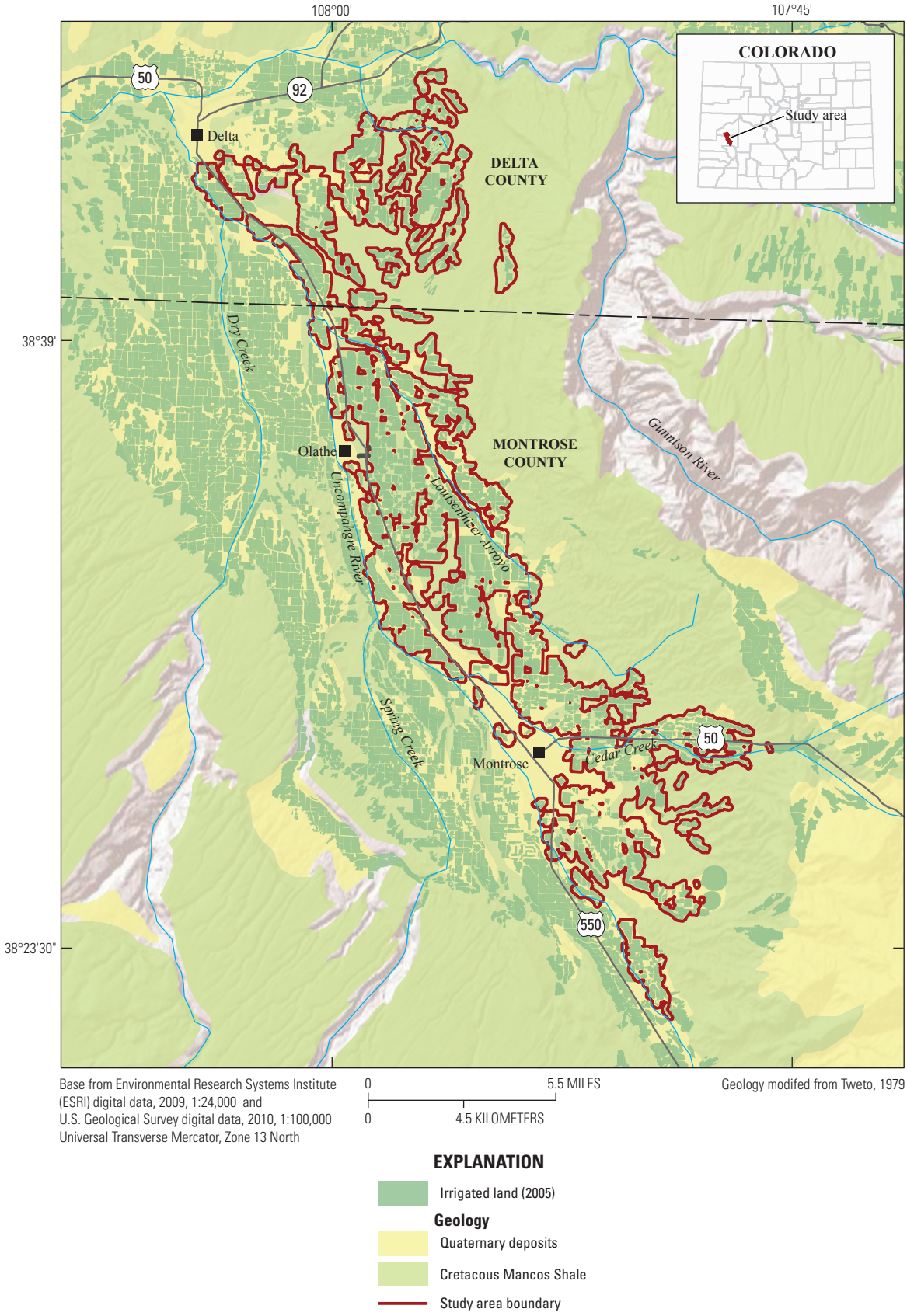

Figure 1. Location of study area on the east side of the Uncompahgre River Basin, Colorado.

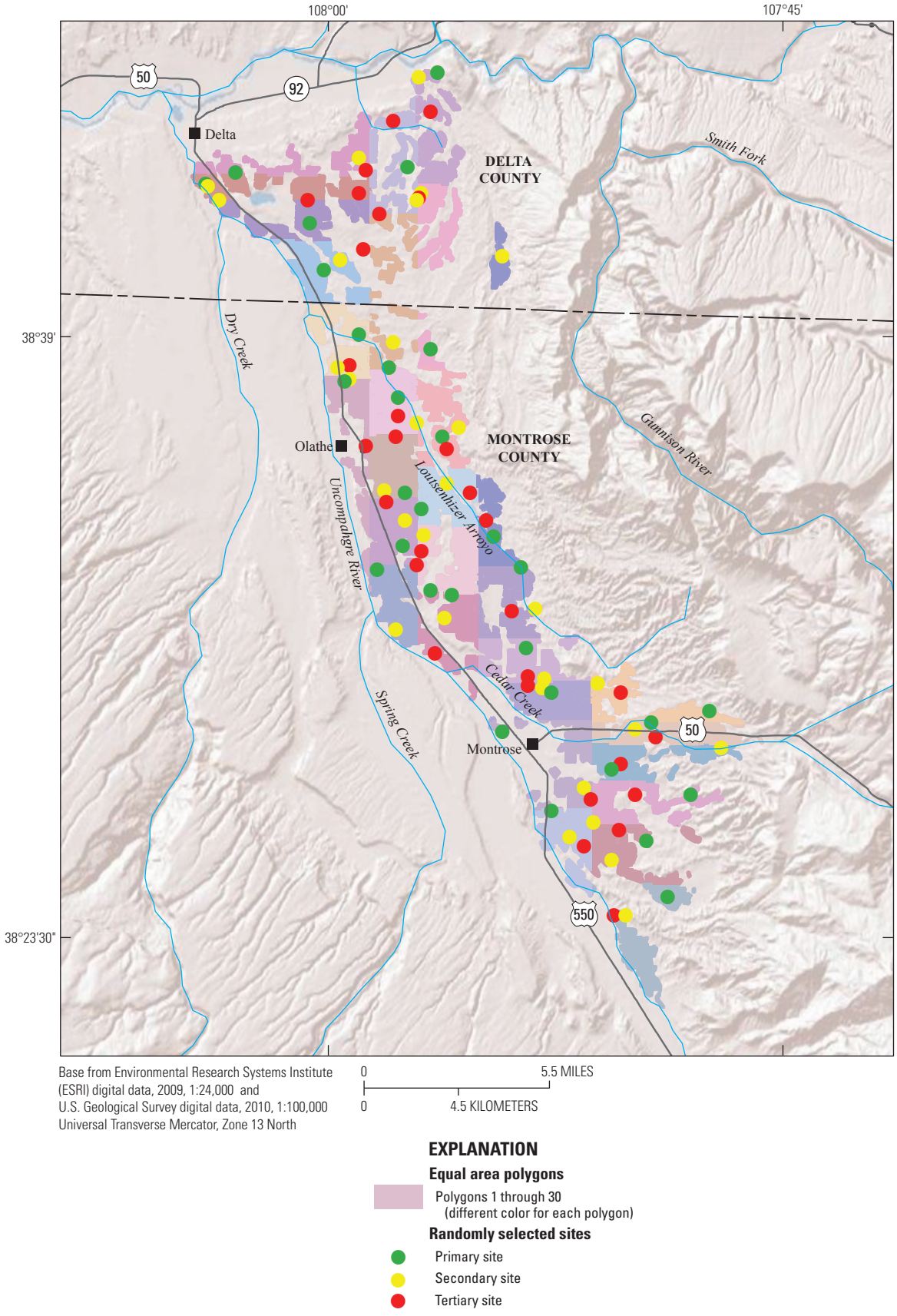

Figure 2. Location of the 30 equal-area polygons and the randomly selected sites considered for drilling within each (primary, secondary, and tertiary sites), east side of the Uncompahgre River Basin, Colorado.

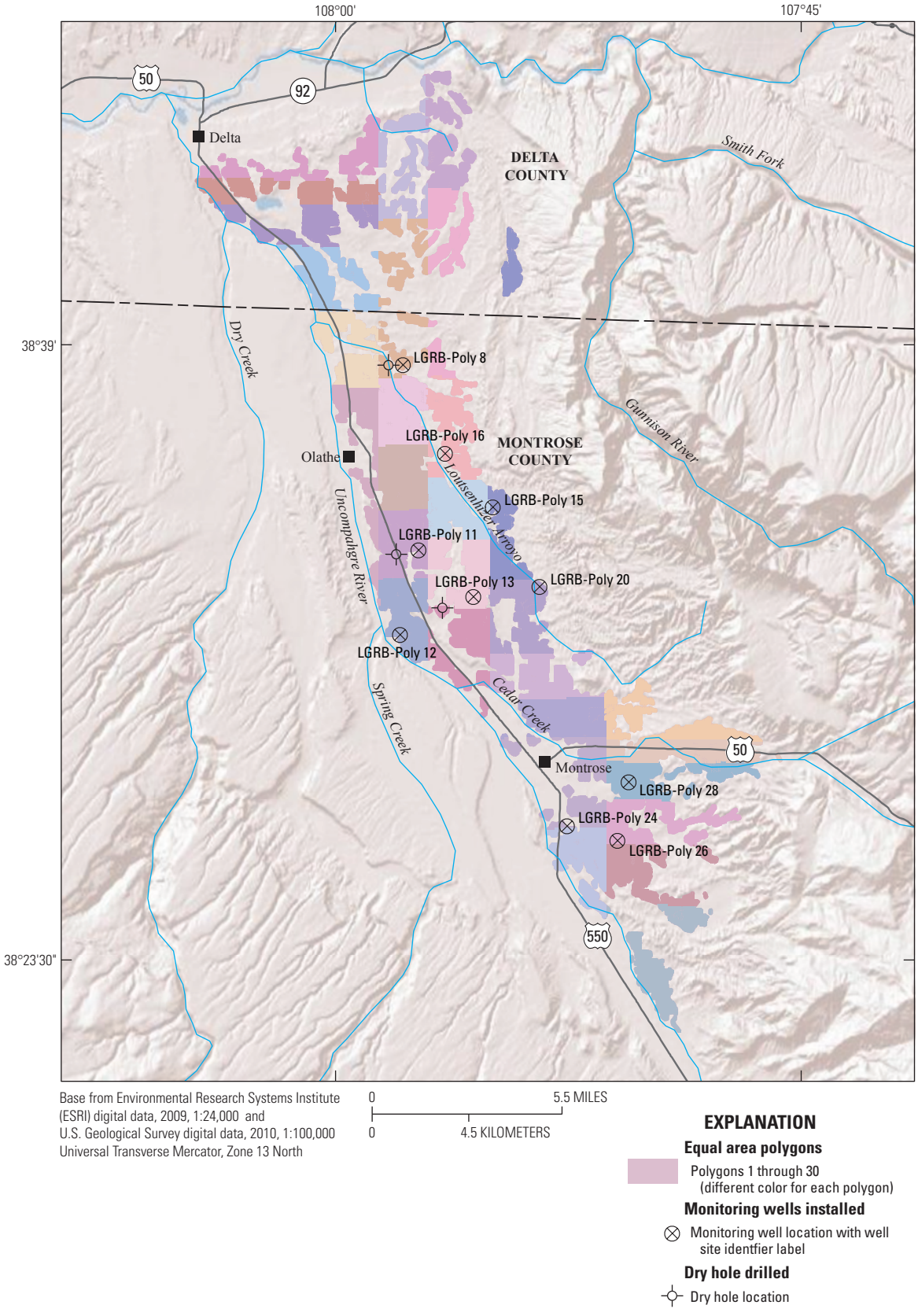

Figure 3. Location of monitoring wells installed and dry holes drilled during October and November of calendar year 2012, east side of the Uncompahgre River Basin, Colorado.

Network Design

In order to better understand the shallow groundwater system, a 30-well uniform randomized groundwater-monitoring network was developed to provide a statistically robust groundwater-monitoring network design. The study area is on the east side of the Uncompahgre River Basin (fig. 1) where irrigation is occurring within the Bureau of Reclamation's Uncompahgre Project. The Uncompahgre Project is in west-central Colorado and includes lands that surround the town of Montrose and extend 34 miles along both sides of the Uncompahgre River to Delta, Colorado (Bureau of Reclamation, 2014). The project is a series of dams, canals, laterals, and drains and draws water from the Uncompahgre and Gunnison Rivers for irrigation of project land. Network design was based on information from Alley (1993) and has been used by the USGS National Water Quality Assessment program in national investigations. The network design was created using a computerized technique (Scott, 1990) that generates a random distribution of potential groundwater-sampling sites. The study area was determined by intersecting digital maps of irrigated land within the Uncompahgre Project. The resulting study area was used as input to the program developed by Scott (1990) for site selection. The random site-selection process divided the study area into 30 equal-area polygons and then generated three potential groundwater-monitoring sites within each polygon: a primary, secondary, and tertiary site (fig. 2). When establishing sites, the primary site was considered first, followed by the secondary and tertiary sites.

Phase I Site Selection

Ten of the 30 randomly determined sites were installed in October and November of calendar year 2012 (fig. 3). These 10 sites were selected from among the first primary sites where landowners were contacted and agreed to participate in the study.

Well Drilling and Installation

Monitoring-well drilling and installation occurred during October and November 2012 (table 1). Drilling services were provided by the Bureau of Reclamation Drilling Operations Group of Pleasant Grove, Utah. Borehole drilling and well installation was overseen by a USGS hydrologist, who documented daily drilling operations, logged and packaged geologic materials encountered while drilling, and prepared well-construction reports in accordance with USGS Guidelines (http://ga.water.usgs.gov/gwqa/gwpd.7.4.16.html, accessed June 25, 2012) and State of Colorado drilling regulations (http://water.state.co.us/groundwater/BOE/Pages/BOERules.aspx, accessed December 31, 2013). USGS staff were responsible for coordination of 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 (in) 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 Wentworth classification system (Wentworth, 1922). Of the 13 holes drilled in October and November 2012, 3 were dry, indicating discontinuous groundwater within the study area (fig. 3).

Individual well-construction diagrams are presented in Appendix 2. Wells were constructed using 2-in diameter Schedule 40 polyvinyl chloride (PVC) casing with a locking cap and protective surface casing. Well screens were either 5 or 10 feet (ft) long and installed near the bottom of the saturated thickness. A 2- to 5-ft-long sump was installed below the screen in some of the monitoring wells (where possible). Annular space adjacent to the screened interval was backfilled with a graded sand pack. Annular space above the screened interval was plugged with bentonite, and a concrete well pad was placed at the surface. Other aspects of well construction were in accordance with USGS specifications for water-quality wells (Lapham and others, 1997) and Colorado State regulations (http://water.state.co.us/groundwater/BOE/Pages/BOERules.aspx, accessed December 31, 2013).

Well Development

Wells were developed after drilling to remove mud and any foreign material from the well and to help improve the hydraulic connection between the well and aquifer. Well development was completed in May 2013 and was accomplished using a combination of bailing, pumping, and mechanical surging for a maximum of 8 hours or until the produced water was clear and parameters such as turbidity, specific conductance, and pH were stable. A Waterra Hydrolift 2 inertial pump system was used to develop the wells. Well development information is provided for each well in Appendix 3.

Table 1. Summary of groundwater monitoring well locations, construction, and depth to water.

[LGRB, lower Gunnison River basin; Poly, polygon number; DDMMSS, degrees, minutes, seconds; stick-up height in feet above land surface; all depths in feet below land surface]

Well identifier	USGS site identification number	Latitude (DDMMSS)	Longitude (DDMMSS)	Date completed	Depth to water	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	Depth to bottom of sand pack	Total well depth
LGRB Poly 8 (dry hole)	--	383858	1075723	10/28/2012	No completion-dry hole. Refusal at 34.2 ft							
LGRB Poly 8	383844107572801			11/11/2012	11.8	2.8	15.1	20.0	1.4	14.1	21.6	24.0
LGRB Poly 11 (dry hole)	--	383408	1075645	10/28/2012	No completion-dry hole. Refusal at 19.2 ft							
LGRB Poly 11	383405107564701			11/10/2012	6	2.3	7.2	16.9	1.8	6.0	19.0	19.0
LGRB Poly 12	383156107571701			11/11/2012	9.0	1.8	11.1	16.0	1.0	5.5	19.0	19.0
LGRB Poly 13 (dry hole)	--	383245	1075516	10/27/2012	No completion-dry hole. Refusal at 13.2 ft							
LGRB Poly 13	383257107545801			11/10/2012	8.2	2.6	10.1	15.0	0.5	8.5	18.0	19.0
LGRB Poly 15	383513107542601			10/27/2012	9.7	2.6	17.9	27.6	0.8	15.7	26.6	31.7
LGRB Poly 16	383632107560201			10/28/2012	21.1	2.8	24.3	34.0	1.0	21.6	36.3	39.3
LGRB Poly 20	383315107525201			10/26/2012	14	2.9	19.2	28.9	1.6	17.0	31.0	34.2
LGRB Poly 24	382715107514501			6/13/2013	14.8	3.1	17.0	21.9	0.5	15.3	24.0	27.1
LGRB Poly 26	382656107500701			10/25/2012	10.4	2.5	15.0	19.9	1.0	13.1	22.0	24.4
LGRB Poly 28	382824107494801			10/25/2012	9.9	2.7	15.7	20.6	1.0	13.8	20.8	20.8

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Appendix 1. Lithologic Logs

LGRB Poly 8 (Dry hole)

Date well completed: 10/28/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–22.4	surface and core	Weathered Mancos Shale—Sand and clay, pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4), sand portion is very fine grained with trace fine–medium grains, clay content increases with depth, little silt, lenses of fine sand with some silt and trace clay, well sorted, weakly fissile, angular–subangular, medium dense–dense, dry–damp, trace calcium carbonate mottling, reacts to HCl.
22.4–31.2	core	Weathered Mancos Shale—Clay, moderate yellowish brown (10YR5/4), little very fine sand and trace fine–medium sand, hard–very hard, moist with occasional thin lenses of wet, trace calcium carbonate mottling, reacts to HCl, drilling refusal at 34.2 ft.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 8

Date well completed: 11/11/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–12.5	cuttings and core	Alluvium—Clay, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR4/2), little–some very fine sand, stiff, damp–moist, becoming wet below 11.1 ft, trace calcium carbonate mottling, reacts to HCl.
12.5–18	core	Alluvium—Sand, moderate yellowish brown (10YR5/4), very fine–medium grained, some clay, moderately sorted, angular–subangular, loose, saturated.
18–20.2	core	Alluvium—Sand, moderate yellowish brown (10YR5/4), very fine–very coarse grained, trace clay, trace gravel up to 40 mm, poorly sorted, angular–subangular, loose, saturated.
20.2–24	core	Alluvium—Sand, moderate yellowish brown (10YR5/4), very fine–medium grained, some clay, lenses of clay with some sand and sand with little clay, well sorted, angular–subangular, loose, saturated.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 11 (Dry hole)

Date well completed: 10/28/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–4.4	surface and core	Fill—Clay, mottled pale yellowish brown (10YR6/2) to dark yellowish brown (10YR4/2), some very fine sand and trace fine–medium sand, soft, damp–moist, some organic material, reacts to HCl.
4.4–19.2	core	Weathered Mancos Shale—Clay, mottled moderate yellowish brown (10YR5/4), dark yellowish orange (10YR6/6), and medium dark gray (N4), becoming dark gray (N3) below about 15 ft, little very fine sand and trace fine–medium sand, occasional lenses of fine sand with some clay, fissile, hard–very hard, dry–damp, trace small gypsum crystals in partings, trace iron staining, reacts to HCl, drilling refusal at 19.2 ft.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 11

Date well completed: 11/10/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–16.7	surface and core	Alluvium—Clay and sand, dusky yellow (5Y6/4) to moderate yellowish brown (10YR5/4), sand portion is very fine grained with trace fine–medium grains, soft, damp–moist, becoming wet–saturated below about 6 ft, trace calcium carbonate mottling, some organic material 0–1 ft, reacts to HCl.
16.7–19	core	Weathered Mancos Shale—Clay, light olive gray (5Y5/2) to olive gray (5Y3/2), trace very fine sand, nonfissile, hard, dry–damp, trace calcium carbonate mottling, small gypsum crystals, and iron staining, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 12

Date well completed: 11/11/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–5.3	surface and core	Alluvium—Sand, dark yellowish brown (10YR4/2), very fine grained with trace fine–medium grains, trace clay with lenses of little clay, well sorted, loose, moist, some organic material 0–1 ft.
5.3–19	cuttings and core	Alluvium—Gravel and cobbles, grayish brown (5YR3/2), cobbles up to 100 mm in size, some very fine–very coarse sand, trace clay, poorly sorted, dense, angular–rounded, saturated.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 13 (Dry hole)

Date well completed: 10/27/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–1	surface	Surface soil—Sand, grayish orange (10YR7/4), very fine grained with trace fine–medium grains, some clay, well sorted, subangular, loose, dry–damp, reacts to HCl.
1–13.2	cuttings and core	Weathered Mancos Shale—Clay, grayish orange (10YR7/4) to pale yellowish brown (10YR6/2), becoming olive gray (5Y4/1) below about 8 ft, some very fine sand and trace fine–medium sand, occasional lenses of fine sand with some clay, fissile, hard–very hard, dry–damp, trace small gypsum crystals in partings, trace iron staining, reacts to HCl, drilling refusal at 13.2 ft.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 13

Date well completed: 11/10/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–10	surface and core	Alluvium—Sand, grayish orange (10YR7/4) to dark yellowish brown (10YR6/6), very fine grained with trace fine–medium grains, some clay, well sorted, angular–subangular, loose–medium dense, moist, becoming wet–saturated below 7.5 ft, trace calcium carbonate mottling and iron staining, reacts to HCl.
10–14.5	core	Alluvium—Sand, grayish orange (10YR7/4) to dark yellowish brown (10YR6/6), very fine–very coarse grained, some clay, trace gravel up to 40 mm diameter, poorly sorted, angular–subangular, loose–medium dense, saturated, trace calcium carbonate mottling, iron staining, and fossil fragments, reacts to HCl.
14.5–19	core	Weathered Mancos Shale—Clay, light olive brown (5Y5/6) to olive gray (5Y3/2), trace very fine sand, fissile, hard, damp–moist, some small gypsum crystals in partings, trace iron staining, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 15

Date well completed: 10/27/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–34.2	surface and core	Alluvium—Sand, grayish orange (10YR7/4) to pale yellowish brown (10YR6/2), very fine grained with trace fine–medium grains, some clay, lens of fine–coarse sand with trace gravel from 29.0–29.8 ft, well sorted, angular–subangular, loose, dry–damp, becoming wet–saturated below 18 ft, some organic material 0–2 ft, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 16

Date well completed: 10/28/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–25.8	surface and core	Alluvium—Clay, pale yellowish brown (10YR6/2), some very fine sand and trace fine–medium sand, soft, damp–moist, becoming wet below 23.3 ft, some organic material 0–3 ft, reacts to HCl.
25.8–31.9	core	Alluvium—Sand, pale yellowish brown (10YR6/2), very fine grained with trace fine–medium grains and lenses of little–some medium–coarse sand, some clay, well sorted, subangular, loose, saturated, reacts to HCl.
31.9–34.8	core	Alluvium—Sand, moderate yellowish brown (10YR5/4), very fine–very coarse grained, trace clay with thin (0.1 ft) lenses of some clay, trace gravel up to 14 mm diameter, poorly sorted, loose, angular–subangular, saturated, mild reaction to HCl.
34.8–39.3	core	Alluvium—Sand, pale yellowish brown (10YR6/2), very fine grained with little fine–medium grains and lenses of little–some medium–coarse sand, well sorted, subangular, loose, saturated, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 20

Date well completed: 10/26/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–29.1	surface and core	Alluvium—Clay, dark yellowish brown (10YR4/2), some very fine sand and trace fine–medium sand, soft, damp–moist, becoming wet below 14 ft, some calcium carbonate mottling, trace iron staining, some organic material 0–2 ft, reacts to HCl.
29.1–39.3	core	Weathered Mancos Shale—Clay, mottled light olive gray (5Y5/2), light olive brown (5Y5/6), and olive gray (5Y3/2), trace very fine sand with lenses containing some very fine sand and trace fine–medium sand, fissile, stiff–very stiff, damp–moist, some small gypsum crystals in partings, some iron staining, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 24

Date well completed: 10/24/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–1.5	surface	Surface soil—Sand, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR4/2), fine–coarse grained, some clay, little gravel up to 38 mm diameter, poorly sorted, angular–subangular, loose, dry, some organic material.
1.5–20.5	cuttings and core	Alluvium—Clay, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR4/2), some very fine sand and trace fine–medium sand, soft, damp, becoming wet–saturated below 16.8 ft, trace calcium carbonate mottling, carbon specks, and iron staining, reacts to HCl.
20.5–22.5	core	Alluvium—Sand, pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4), fine–coarse grained, some gravel up to 33 mm from 21.6–22.5 ft, little clay, poorly sorted, angular–subrounded, loose–medium dense, saturated, alluvium.
22.5–29.1	core	Weathered Mancos Shale—Clay, mottled dusky yellow (5Y6/4), light olive gray (5Y5/2), and medium dark gray (N4), becoming more dark gray (N4) with depth, fissile, occasional thin (up to 5 mm) lenses of some very fine–fine sand, very stiff–hard, damp, trace small gypsum crystals and iron staining, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 26

Date well completed: 10/25/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; mm, millimeters; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

Depth	Sample type	Description[1]
0–14.5	surface and core	Alluvium—Clay, moderate yellowish brown (10YR5/4) to dark yellowish brown (10YR4/2), some very fine–fine sand with trace medium–coarse sand, soft, dry–damp, becoming wet below 14 ft, trace calcium carbonate mottling, trace organic matter and carbon specks 0–9.5 ft, reacts to HCl.
14.5–19.7	core	Alluvium—Sand, pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4), fine–coarse grained, some clay, some gravel up to 50 mm diameter, poorly sorted, loose, saturated.
19.7–20.6	core	Alluvium—Gravel, pale yellowish brown (10YR6/2), up to 40 mm diameter, some clay, some fine–very coarse sand, poorly sorted, angular–subangular, loose-medium dense, saturated.
20.6–24.5	core	Weathered Mancos Shale—Clay, mottled dusky yellow (5Y6/4) to light olive gray (5Y5/2), becoming olive gray (5Y3/2) with depth, trace very fine sand, fissile, very stiff–hard, damp–moist, trace small gypsum crystals and iron staining, reacts to HCl.

[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

LGRB Poly 28

Date well completed: 10/25/2012

Log prepared by L.R. Arnold

[Depth intervals in feet below land surface; ft, feet; HCl, hydrochloric acid, LGRB, lower Gunnison River Basin; Poly, polygon number]

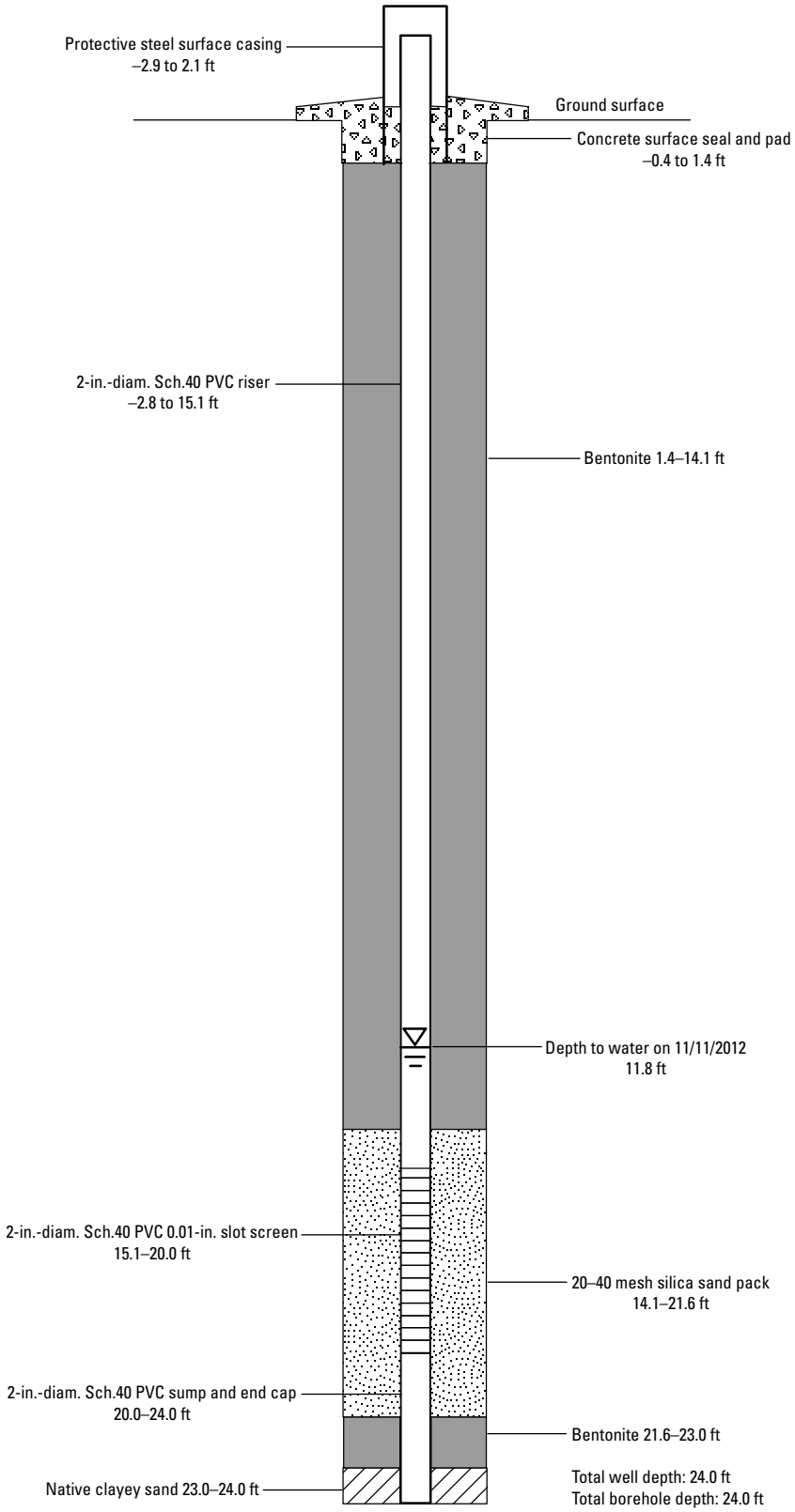
Depth	Sample type	Description[1]
0–3	surface and cuttings	Alluvium—Clay, pale yellowish brown (10YR6/2) to pale brown (5YR5/2), some very fine sand and trace fine–medium sand, soft, dry–damp, some organic matter, reacts to HCl.
3–20.8	core	Weathered Mancos Shale—Clay, mottled yellowish gray (5Y7/2), dusky yellow (5Y6/4), and light olive gray (5Y5/2), becoming olive gray (5Y3/2) to dark gray (N3) with depth, trace very fine sand, fissile, very stiff–very hard, dry–damp, water-bearing fractures and partings 19.0–20.8 ft, some small gypsum crystals in partings, trace iron staining, react to HCl, drilling refusal at 20.8 ft.

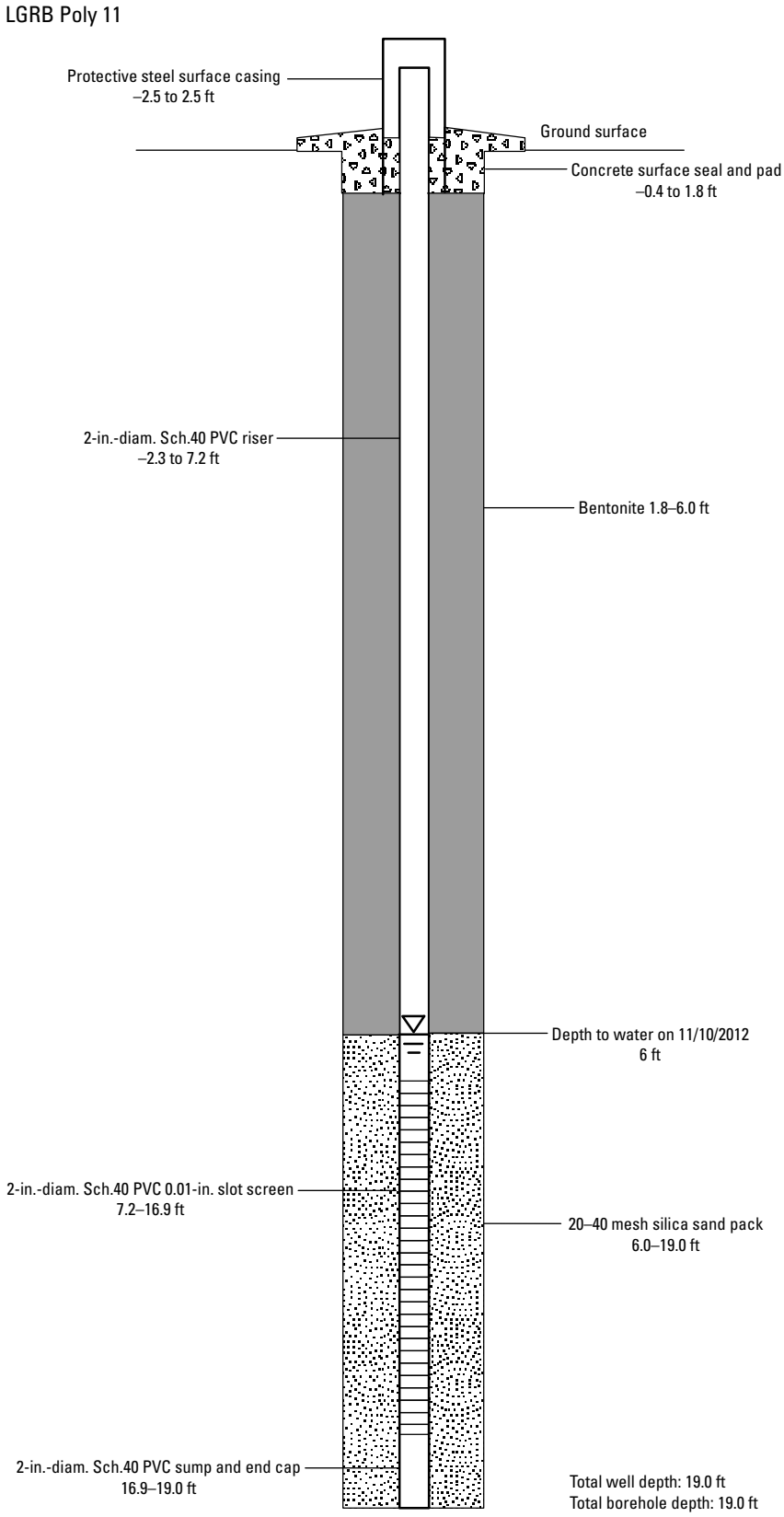
[1]Grain size based on the Wentworth classification system (Wentworth, 1922). Proportions defined using the following terms: "trace" (0–10 percent), "little" (10–20 percent), "some" (20–35 percent), and "and" (35–50 percent). Color codes (for example, 10YR6/2) refer to the Munsell color system (Geological Society of America, 1995).

Appendix 2. Well-Construction Diagrams

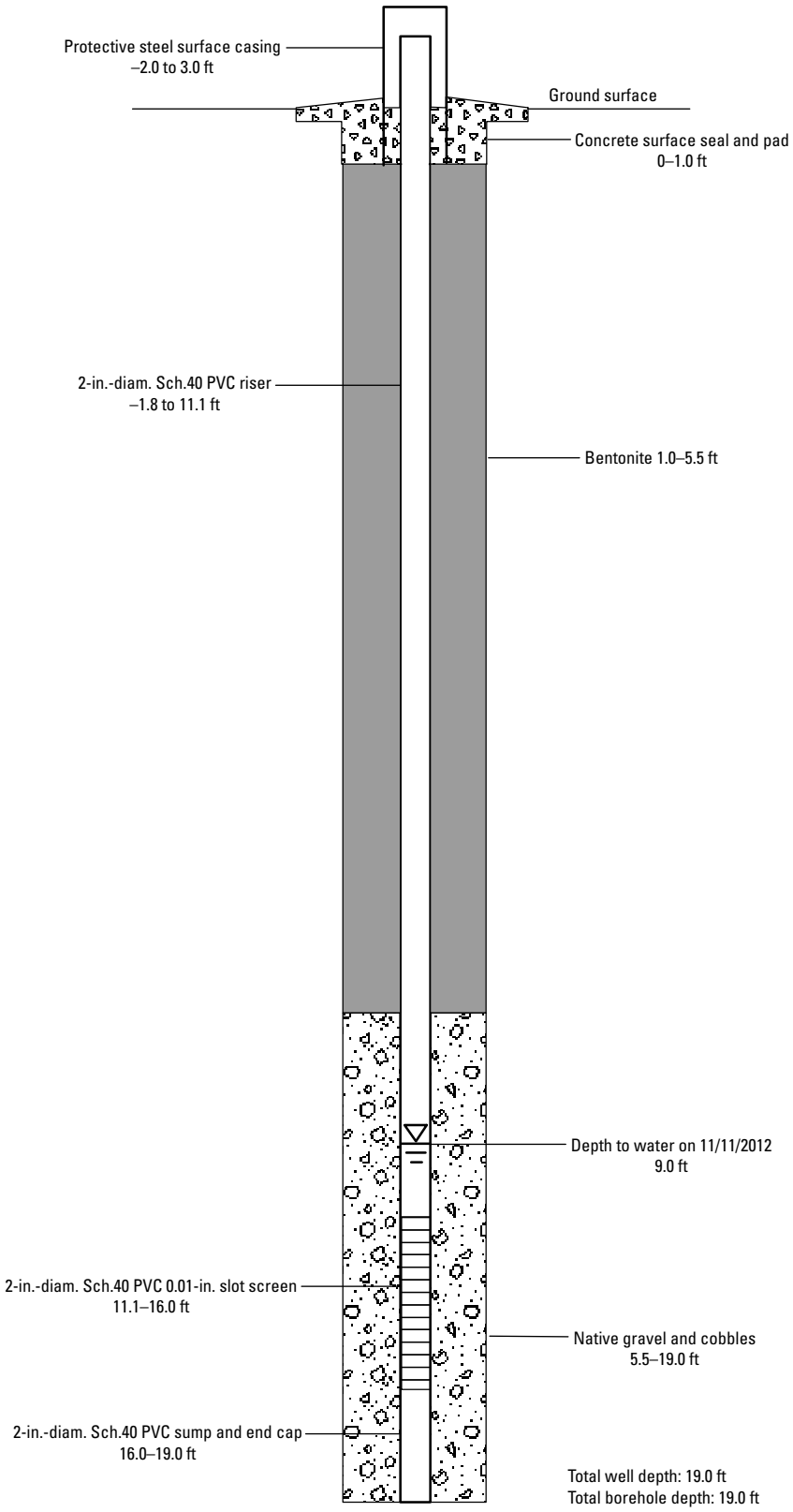
[LGRB, lower Gunnison River Basin; Poly, polygon number; PVC, polyvinyl chloride; ft, feet; in., inch; diam., diameter; Sch.40, Schedule 40]

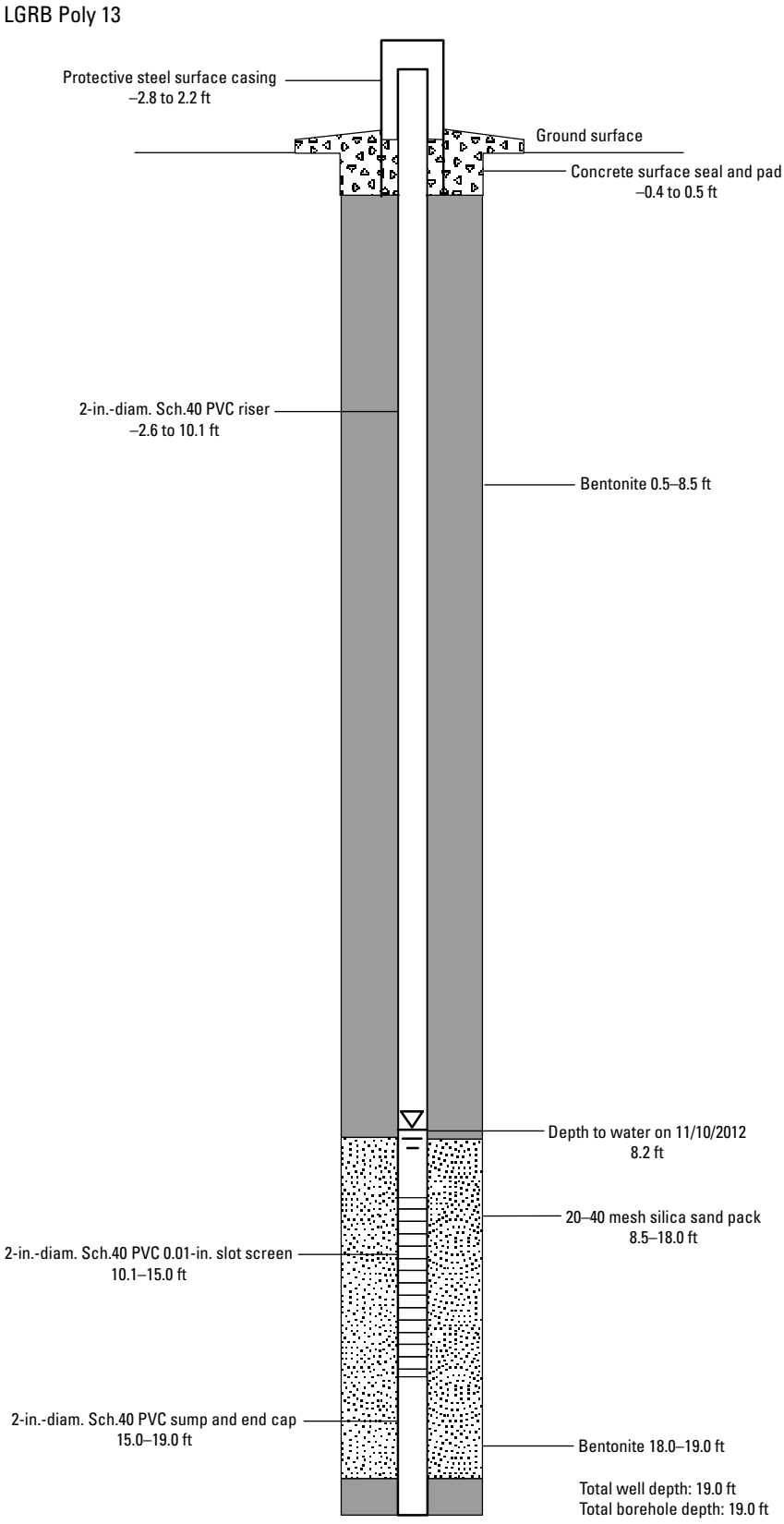
LGRB Poly 8


Protective steel surface casing
–2.9 to 2.1 ft
Ground surface
Concrete surface seal and pad
–0.4 to 1.4 ft
2-in.-diam. Sch.40 PVC riser
–2.8 to 15.1 ft
Bentonite 1.4–14.1 ft
Depth to water on 11/11/2012
11.8 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
15.1–20.0 ft
20–40 mesh silica sand pack
14.1–21.6 ft
2-in.-diam. Sch.40 PVC sump and end cap
20.0–24.0 ft
Bentonite 21.6–23.0 ft
Native clayey sand 23.0–24.0 ft
Total well depth: 24.0 ft
Total borehole depth: 24.0 ft

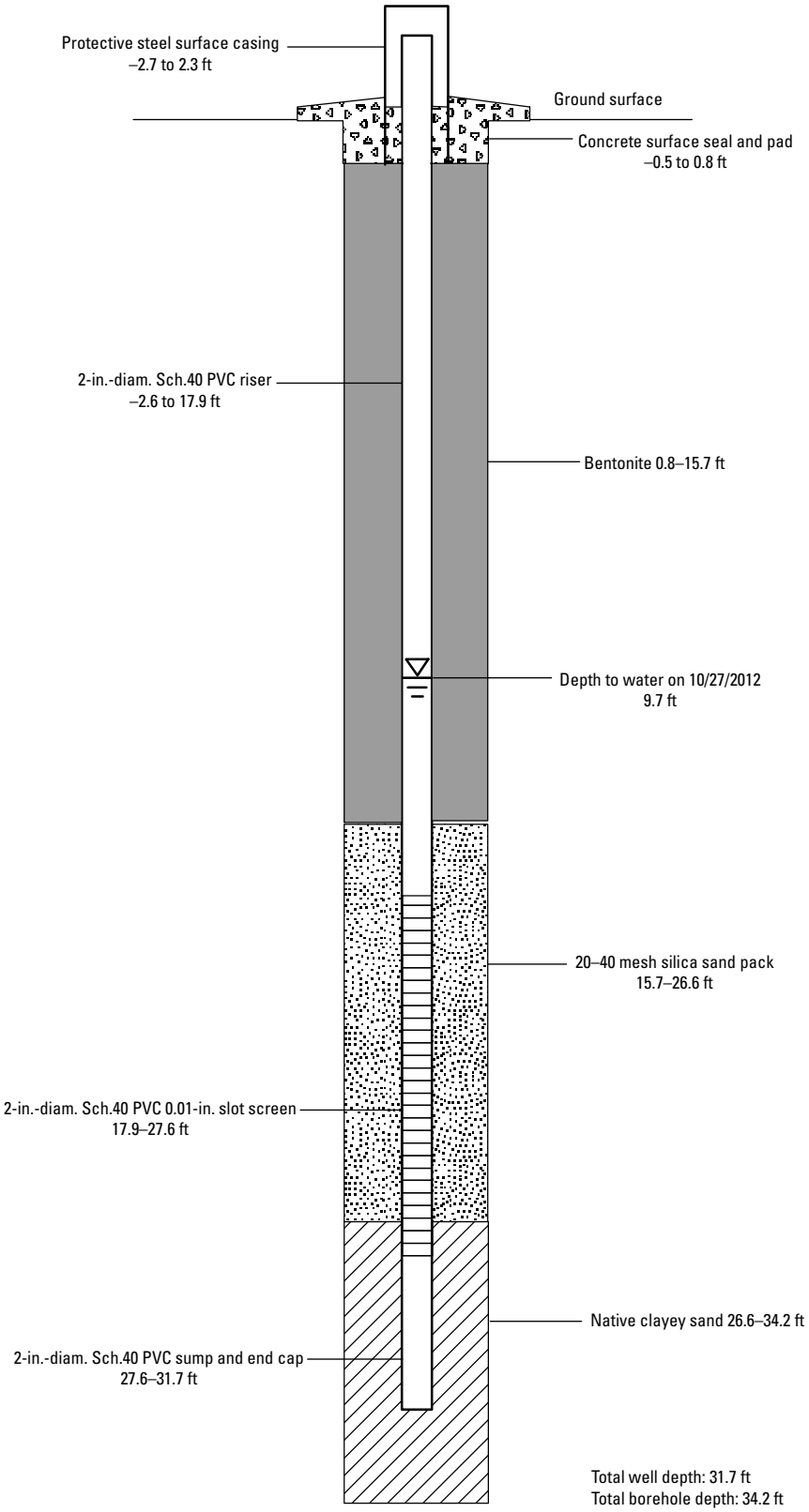

LGRB Poly 11
Protective steel surface casing
–2.5 to 2.5 ft
Ground surface
Concrete surface seal and pad
–0.4 to 1.8 ft
2-in.-diam. Sch.40 PVC riser
–2.3 to 7.2 ft
Bentonite 1.8–6.0 ft
Depth to water on 11/10/2012
6 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
7.2–16.9 ft
20–40 mesh silica sand pack
6.0–19.0 ft
2-in.-diam. Sch.40 PVC sump and end cap
16.9–19.0 ft
Total well depth: 19.0 ft
Total borehole depth: 19.0 ft

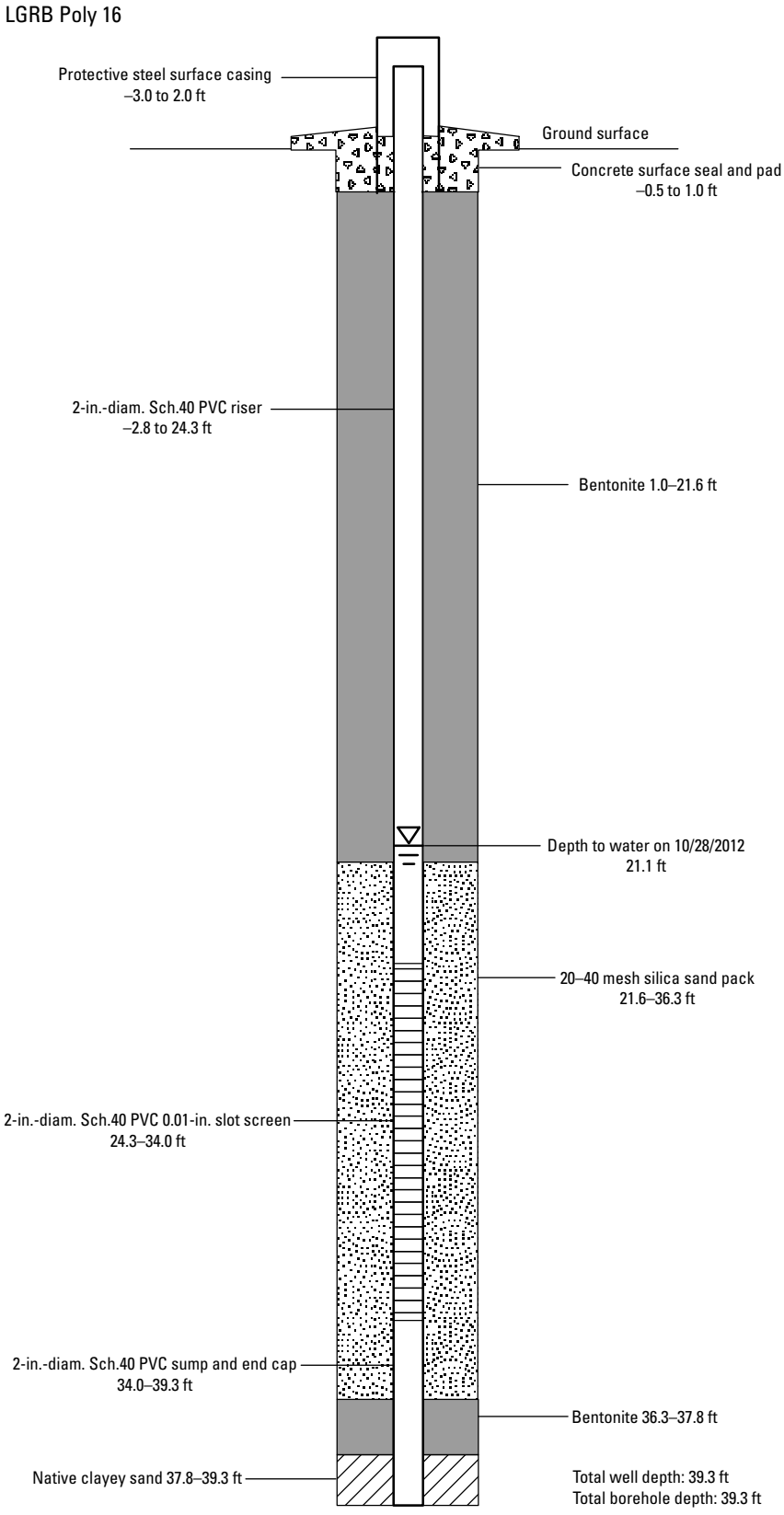
LGRB Poly 12


Protective steel surface casing
–2.0 to 3.0 ft
Ground surface
Concrete surface seal and pad
0–1.0 ft
2-in.-diam. Sch.40 PVC riser
–1.8 to 11.1 ft
Bentonite 1.0–5.5 ft
Depth to water on 11/11/2012
9.0 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
11.1–16.0 ft
Native gravel and cobbles
5.5–19.0 ft
2-in.-diam. Sch.40 PVC sump and end cap
16.0–19.0 ft
Total well depth: 19.0 ft
Total borehole depth: 19.0 ft

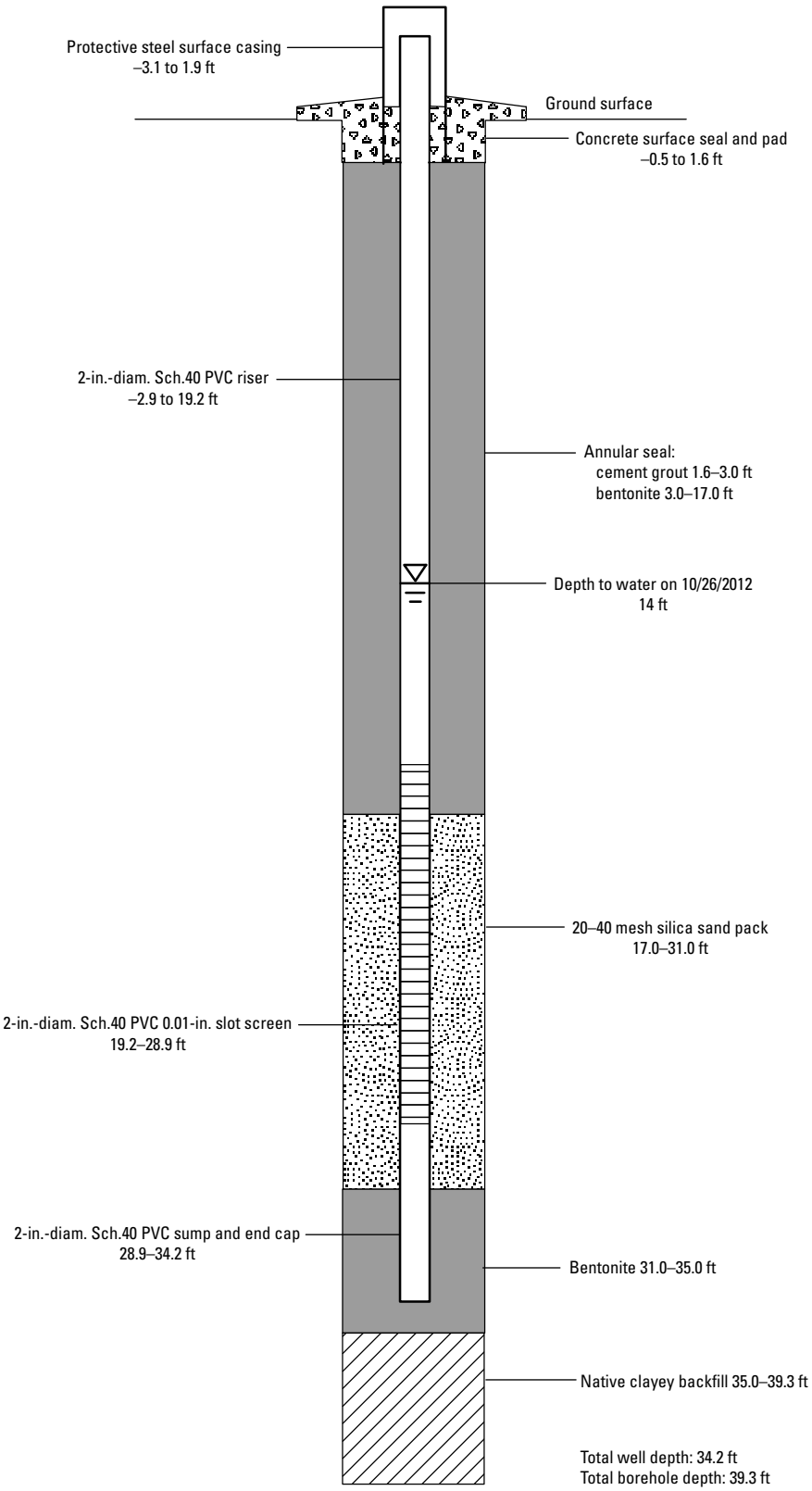

LGRB Poly 13
Protective steel surface casing
–2.8 to 2.2 ft
Ground surface
Concrete surface seal and pad
–0.4 to 0.5 ft
2-in.-diam. Sch.40 PVC riser
–2.6 to 10.1 ft
Bentonite 0.5–8.5 ft
Depth to water on 11/10/2012
8.2 ft
20–40 mesh silica sand pack
8.5–18.0 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
10.1–15.0 ft
2-in.-diam. Sch.40 PVC sump and end cap
15.0–19.0 ft
Bentonite 18.0–19.0 ft
Total well depth: 19.0 ft
Total borehole depth: 19.0 ft

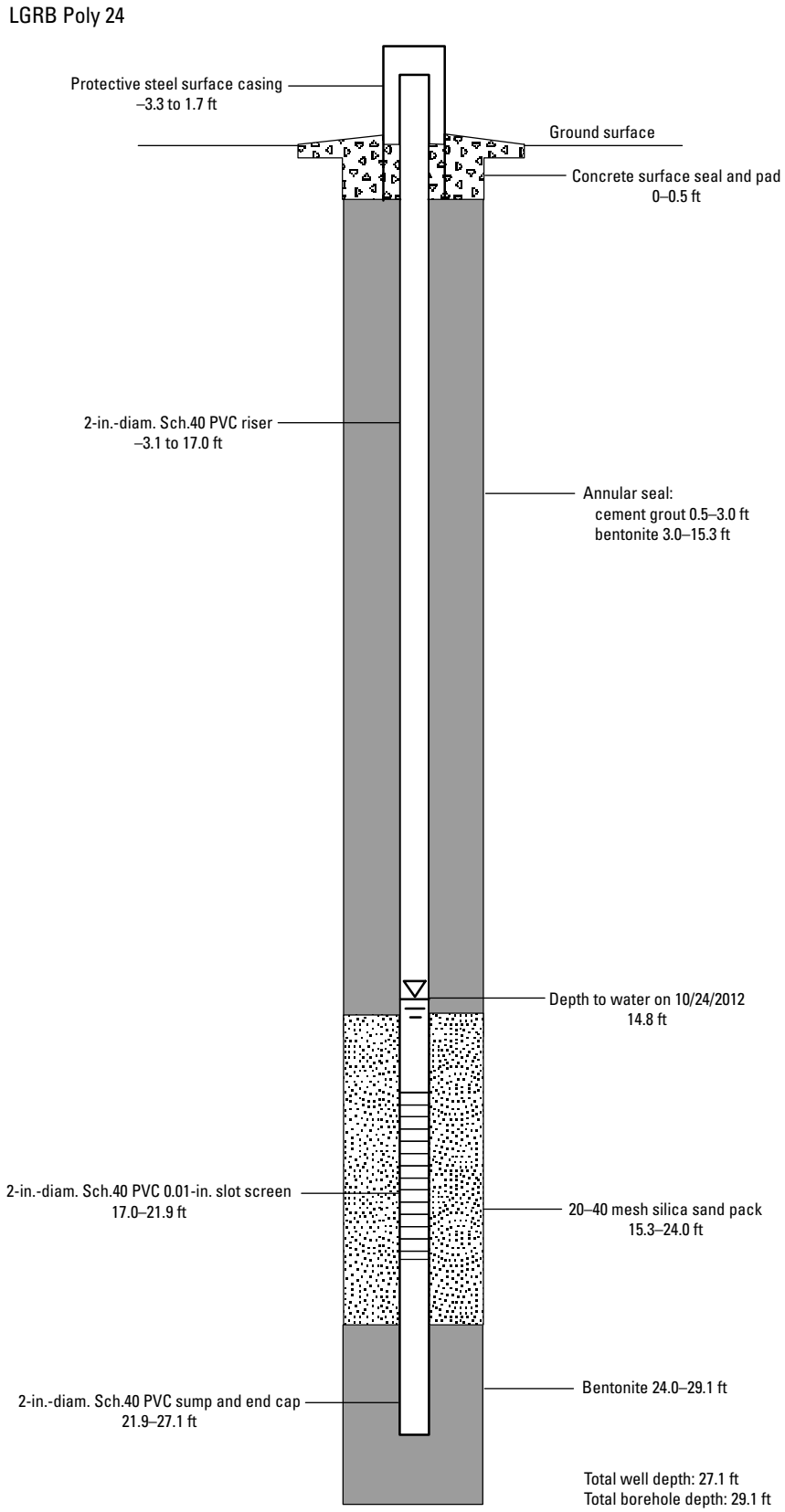
LGRB Poly 15


Protective steel surface casing
–2.7 to 2.3 ft
Ground surface
Concrete surface seal and pad
–0.5 to 0.8 ft
2-in.-diam. Sch.40 PVC riser
–2.6 to 17.9 ft
Bentonite 0.8–15.7 ft
Depth to water on 10/27/2012
9.7 ft
20–40 mesh silica sand pack
15.7–26.6 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
17.9–27.6 ft
Native clayey sand 26.6–34.2 ft
2-in.-diam. Sch.40 PVC sump and end cap
27.6–31.7 ft
Total well depth: 31.7 ft
Total borehole depth: 34.2 ft

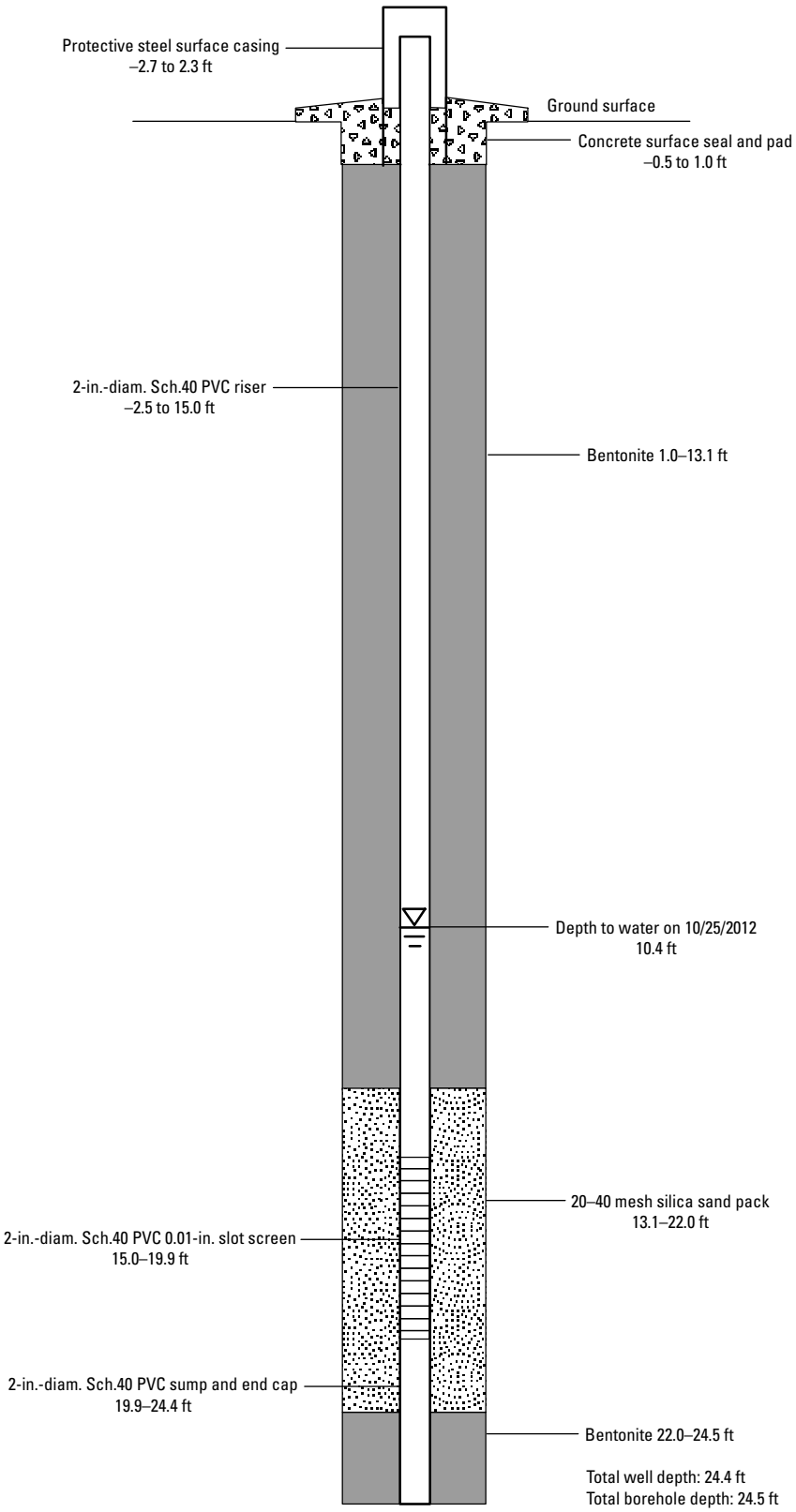

LGRB Poly 16
Protective steel surface casing
–3.0 to 2.0 ft
Ground surface
Concrete surface seal and pad
–0.5 to 1.0 ft
2-in.-diam. Sch.40 PVC riser
–2.8 to 24.3 ft
Bentonite 1.0–21.6 ft
Depth to water on 10/28/2012
21.1 ft
20–40 mesh silica sand pack
21.6–36.3 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
24.3–34.0 ft
2-in.-diam. Sch.40 PVC sump and end cap
34.0–39.3 ft
Bentonite 36.3–37.8 ft
Native clayey sand 37.8–39.3 ft
Total well depth: 39.3 ft
Total borehole depth: 39.3 ft

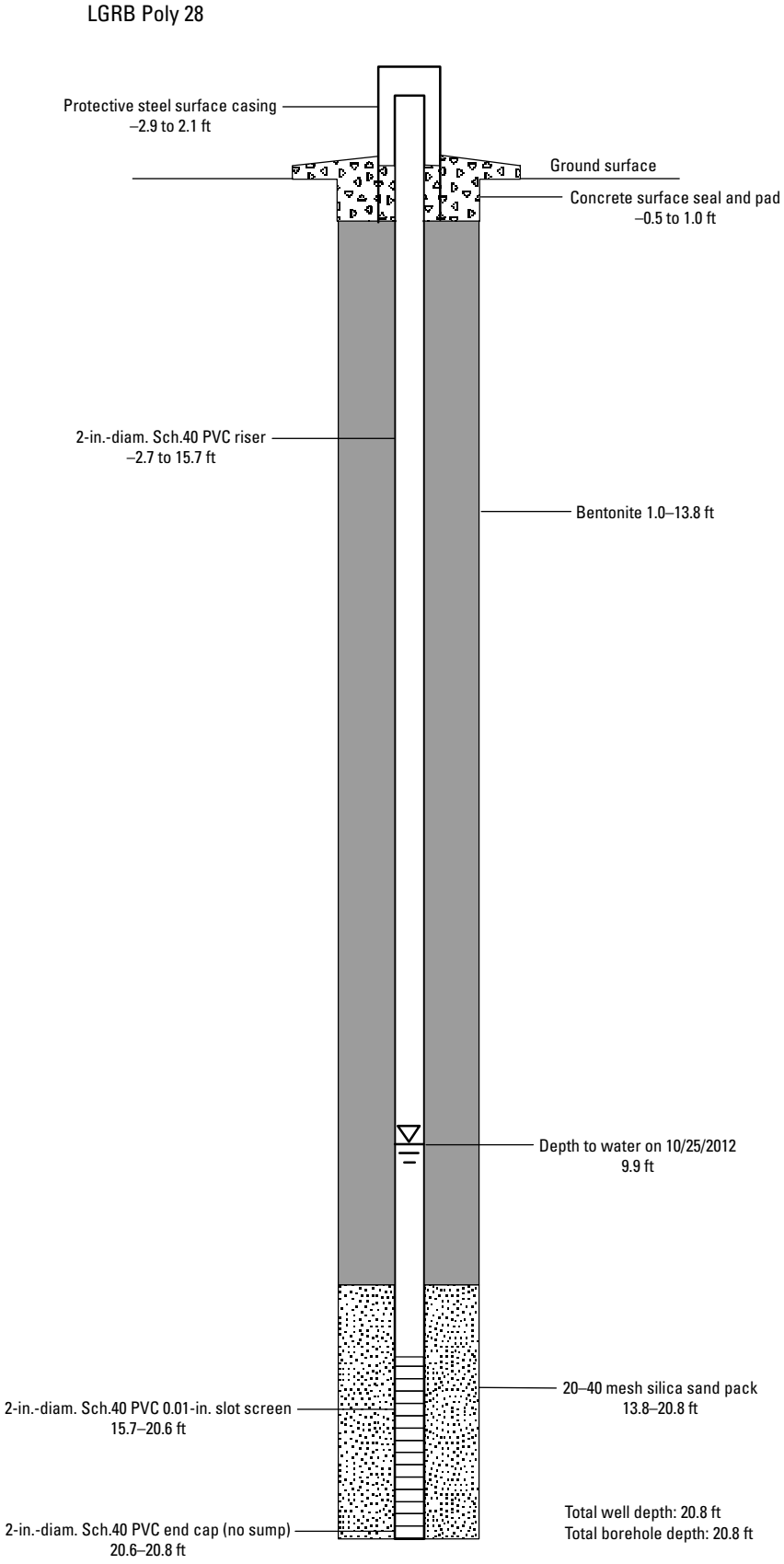
LGRB Poly 20


Protective steel surface casing
–3.1 to 1.9 ft
Ground surface
Concrete surface seal and pad
–0.5 to 1.6 ft
2-in.-diam. Sch.40 PVC riser
–2.9 to 19.2 ft
Annular seal:
cement grout 1.6–3.0 ft
bentonite 3.0–17.0 ft
Depth to water on 10/26/2012
14 ft
20–40 mesh silica sand pack
17.0–31.0 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
19.2–28.9 ft
2-in.-diam. Sch.40 PVC sump and end cap
28.9–34.2 ft
Bentonite 31.0–35.0 ft
Native clayey backfill 35.0–39.3 ft
Total well depth: 34.2 ft
Total borehole depth: 39.3 ft


LGRB Poly 24
Protective steel surface casing
–3.3 to 1.7 ft
Ground surface
Concrete surface seal and pad
0–0.5 ft
2-in.-diam. Sch.40 PVC riser
–3.1 to 17.0 ft
Annular seal:
cement grout 0.5–3.0 ft
bentonite 3.0–15.3 ft
Depth to water on 10/24/2012
14.8 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
17.0–21.9 ft
20–40 mesh silica sand pack
15.3–24.0 ft
Bentonite 24.0–29.1 ft
2-in.-diam. Sch.40 PVC sump and end cap
21.9–27.1 ft
Total well depth: 27.1 ft
Total borehole depth: 29.1 ft

LGRB Poly 26


Protective steel surface casing
–2.7 to 2.3 ft
Ground surface
Concrete surface seal and pad
–0.5 to 1.0 ft
2-in.-diam. Sch.40 PVC riser
–2.5 to 15.0 ft
Bentonite 1.0–13.1 ft
Depth to water on 10/25/2012
10.4 ft
20–40 mesh silica sand pack
13.1–22.0 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
15.0–19.9 ft
2-in.-diam. Sch.40 PVC sump and end cap
19.9–24.4 ft
Bentonite 22.0–24.5 ft
Total well depth: 24.4 ft
Total borehole depth: 24.5 ft


LGRB Poly 28
Protective steel surface casing
–2.9 to 2.1 ft
Ground surface
Concrete surface seal and pad
–0.5 to 1.0 ft
2-in.-diam. Sch.40 PVC riser
–2.7 to 15.7 ft
Bentonite 1.0–13.8 ft
Depth to water on 10/25/2012
9.9 ft
20–40 mesh silica sand pack
13.8–20.8 ft
2-in.-diam. Sch.40 PVC 0.01-in. slot screen
15.7–20.6 ft
2-in.-diam. Sch.40 PVC end cap (no sump)
20.6–20.8 ft
Total well depth: 20.8 ft
Total borehole depth: 20.8 ft

Appendix 3. Well-Development Records

LGRB Poly 8

Date developed: 5/13/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0					
50	13.9	10,660	>1,000	0.5	Muddy
65	13.3	10,920	>1,000	0.5	Slightly muddy
80	12.8	11,030	437	—	Murky
95	12.5	11,100	228	0.8	Murky
110	12.7	11,050	300	0.5	Murky
125	13.8	10,980	235	0.5	Murky
140	13.7	11,020	162	—	Slightly murky
155	13.3	11,110	116	0.7	Slightly murky
170	13.1	11,130	69	—	Mostly clear
185	13.6	11,120	43	—	Mostly clear

LGRB Poly 11

Date developed: 5/16/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	—
70	—	—	—	—	—
75	12.5	3,250	—	0.5	Muddy
120	12.6	3,240	>1,000	0.4	Slightly muddy
150	11.9	3,230	930	0.5	Murky
180	12.2	3,240	>1,000	0.5	Murky
210	12.7	3,200	412	0.5	Murky
225	12.2	3,230	61	—	Mostly clear
240	12.2	3,250	16	0.4	Clear

LGRB Poly 12

Date developed: 5/15/2013 through 5/17/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; ±, plus or minus; —, no data; gal, gallons; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
40	—	—	—		
45	20	1,832	>1,000	0.1	Muddy
60	20.8	1,698	887	0.1	Murky
1st bail	12.5	1,852	30	± 2 gal	Clear
2nd bail	11.3	1,798	69	± 2 gal	Mostly clear
3rd bail	—	—	—	± 2.5 gal	Clear
4th bail	10.7	1,802	7	± 2.5 gal	Clear

Comments: Poor producer, pumped dry in 75 minutes, recover rate of 0.2 feet per minute. Allowed to recover to 9.1 feet below land surface and started bailing, 7 gallons removed. 1st and 2nd bails on 5/15/2013 at 1235 and 1805 respectively. 3rd bail on 5/16/2013. 4th bail on 5/17/2013.

LGRB Poly 13

Date developed: 5/15/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
40	—	—	—	—	
45	13.7	4,220	>1,000	0.5	Muddy
75	12.5	3,860	>1,000	—	Slightly muddy
105	12.8	3,840	922	0.5	Murky
120	11.8	3,820	641	—	Murky
135	12	3,860	222	0.5	Slightly murky
150	12.1	3,830	57	—	Mostly clear
165	12.5	3,850	41	0.5	Mostly clear
180	12.1	3,840	32	—	Clear
195	—	—	—	pump off	

LGRB Poly 15

Date developed: 5/17/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; <, less than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0					
63					
75	17.3	7,780	—	0.1	Muddy
90	19.6	8,400	411	0.1	Murky
120	20.7	9,520	>1,000	0.1	Slightly muddy
135	20	8,680	537	<0.1	Murky
150	21.6	9,430	154	<0.1	Slightly murky
165	22.4	9,740	62	<0.1	Mostly clear
180	19.6	10,660	48	<0.1	Mostly clear
195	—	—	—	pump off	—

LGRB Poly 16

Date developed: 5/16/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0					
48					
60	13	4,180	off scale	0.6	Muddy
90	12.9	4,210	>1,000	0.7	Slightly muddy
120	12.7	4,220	>1,000	1	Slightly muddy
150	13.5	4,220	>1,000	0.5	Slightly muddy
180	15	4,210	>1,000	0.4	Slightly muddy
240	12.9	4,220	426	0.8	Murky
270	13.4	4,220	258	0.4	Murky
300	13.3	4,230	262	0.5	Murky
330	13.8	4,220	222	—	Slightly murky
360	14.3	4,210	229	0.4	Slightly murky

LGRB Poly 20

Date developed: 5/15/2013 and 5/17/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; ±, plus or minus; —, no data; gal, gallons; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
70					
75	15.4	14,410	>1,000	0.5	Muddy
90					
1st bail	14.6	18,500	27	±5 gal	Murky
2nd bail	12.3	18,560	18	±10 gal	Clear yellow

Comments: Bailed well dry on 5/15/2013 (1st bail); bailed well dry on 5/17/2013 (2nd bail).

LGRB Poly 24

Date developed: 5/14/2013 and 5/17/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
40	—	—	—	—	
45	13.5	3,210	>1,000	0.6	Muddy
90	13.1	3,120	>1,000	0.8	Muddy
120	13.8	3,120	>1,000	0.5	Slightly muddy
15	13.8	3,140	625	0.5	Murky
10	14.4	3,150	536	0.5	Murky
210	16.5	3,160	234	0.3	Slightly murky
225	18.1	3,170	139	—	Slightly murky
240	18	3,180		0.5	Slightly murky
255	17	3,180	116	0.3	Slightly murky
bailer	10.9	3,250	4	—	Clear

LGRB Poly 26

Date developed: 5/14/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
40				—	
45	12.3	5,560	>1,000	0.8	Muddy
60	12.4	5,530	177	0.8	Slightly murky
75	12.1	5,520	114	—	Slightly murky
90	12	5,520	62	0.8	Mostly clear
105	11.4	5,510	40	—	Mostly clear
120	11	5,500	25	0.8	Clear

LGRB Poly 28

Date developed: 5/14/2013

[gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; >, greater than; —, no data; LGRB, lower Gunnison River Basin; Poly, polygon number]

Pumping duration (minutes)	Temperature (°C)	Specific conductance (µS/cm)	Turbidity (NTU)	Pumping rate (gal/min)	Appearance
0	—	—	—	pump on	
40	—				
45	13.7	4,320	>1,000	0.4	Muddy
60	12.2	4,320	590	0.5	Murky
75	12.3	4,310	320	—	Murky
90	12.3	4,300	214	0.5	Slightly murky
105	12.4	4,300	142	—	Slightly murky
120	12.2	4,310	88	0.5	Mostly clear
135	12.2	4,300	68	—	Mostly clear
150	12.3	4,310	35	0.5	Clear

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