Doc No. DAR-ED-0003

Southern Nevada Water Authority

Hydrologic Data Analysis Report for Test Well 184W101 in Spring Valley Hydrographic Area 184

April 2010

Suggested citation:
Prieur, J.P., Farnham, I.M., and Ashinhurst C.S., 2010, Hydrologic data analysis report for Test Well 184W101 in Spring Valley Hydrographic Area 184: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. DAR-ED-0003, 78 p.

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Hydrologic Data Analysis Report for Test Well 184W101 in Spring Valley Hydrographic Area 184

By: James P. Prieur[1], Irene M. Farnham[1], and Chris S. Ashinhurst[1]

April 2010

1. Southern Nevada Water Authority, Las Vegas, NV

SOUTHERN NEVADA WATER AUTHORITY
Groundwater Resources Department
Water Resources Division
snwa.com

CONTENTS

CONTENTS (CONTINUED)

Appendix A - CD-ROM Contents

Appendix B - Groundwater-Chemistry Data

FIGURES

FIGURES (CONTINUED)

TABLES

NUMBER **TITLE** **PAGE**

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ACRONYMS

Barker GRFM	Barker generalized radial flow model
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
GSLDFS	Great Salt Lake Desert Flow System
HA	hydrographic area
HSLA	high strength low alloy
MCL	maximum contaminant level
MS	mild steel
NAD83	North American Datum of 1983
NTU	nephelometric turbidity unit
SNWA	Southern Nevada Water Authority
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

ABBREVIATIONS

°C	degrees Celsius
amsl	above mean sea level
bgs	below ground surface
cm	centimeter
ft	foot
gal	gallon
gpm	gallons per minute
in.	inch
L	liter
lb	pound
m	meter
mEq	milliequivalent
mg	milligram
mi	mile
min	minute
ml	milliliter
mrem	millirem
µg	microgram
µS	microsiemen

ABBREVIATIONS (CONTINUED)

‰	per mil
pmc	percent modern carbon
pCi	picocurie
psi	pounds per square inch
qt	quart
rpm	revolutions per minute
sec	second
yr	year

ES.1.0 EXECUTIVE SUMMARY

In support of its Clark, Lincoln, and White Pine Counties Groundwater Development Project, Southern Nevada Water Authority (SNWA) installed test and monitor wells in Spring Valley (Hydrographic Area 184) to evaluate hydrogeologic conditions. This report documents the collection, analysis, and evaluation of data obtained during the well development and hydraulic testing of Test Well 184W101 and Monitor Well 184W502M located in southeastern Spring Valley, White Pine County, Nevada. The development and hydraulic testing of Test Well 184W101 was performed from April 4 through 12, 2007. This report also presents groundwater-level data collected at the site post-test through December, 2009.

Test Well 184W101 and associated Monitor Well 184W502M are completed in an unconfined, fractured carbonate-rock aquifer system and are stratigraphically in the Devonian Guilmette Formation, Simonson Dolomite, and Sevy Dolomite to depths of 1,760 ft bgs and 1,828 ft bgs, respectively. Static depth to water is approximately 480 ft bgs. Drilling observations, geophysics, and water temperature indicate a larger relative contribution of groundwater to the well from a zone of increased secondary porosity approximately 570 ft thick near the base of the test well.

The development phase pumping extracted 4,248,500 gallons of water and improved specific capacity, a ratio of discharge (Q) to drawdown (s) in the test well, from 14.1 to 15.5 gpm/ft at a comparable duration of pumping at a discharge rate of 2,200 gpm for an improvement of at least 10 percent. A four-interval step-drawdown test was conducted at discharge rates ranging from 2,200 to 2,600 gpm to estimate the optimal test pumping rate, evaluate well loss coefficients, and determine the discharge rate for the constant-rate test.

A 72-hour constant-rate test was performed at a discharge rate of 2,520 gpm. Hydrogeologic data and diagnostic log-log and derivative time-drawdown data plots indicated that a dual-porosity conceptual model is the most appropriate primary solution method. The Barker Generalized Radial Flow Model (GRFM) was applied to the site data as the primary analytical solution. A secondary analytical solution using the Cooper-Jacob semi-log straight-line approximation was also performed for comparison. Analyses were performed using AQTESOLV aquifer-test evaluation software.

Results of the Barker GRFM analysis using the optimal best-fit of all site pumping and recovery data indicate an estimated hydraulic conductivity (K) of approximately 7.6 to 8.0 ft/day and a specific storage of 3.90 to 4.5×10^{-6} ft^{-1}. This equates to a storativity (S) of 0.005 to 0.0058 assuming a saturated thickness of 1,280 ft. This is within the range of secondary analysis for transmissivity (T) using the Cooper-Jacob solution, which indicates that the flow regime may have been dominated by radial flow near the end of the test period. Results of the secondary analysis indicate a T range of approximately 2,500 to 18,200 ft^2/day and S of 7.35 x 10^{-4} to 0.03, and assuming a saturated thickness of 1,280, the resulting K value is 2.0 to 14.2 ft/day. The drawdown slope increased slightly at approximately 800 minutes elapsed time and may be interpreted as a potential low transmissivity flow boundary to approximately 2,500 ft to the west of the test well as identified using surface geophysical results.

Specific capacity during the last 12 hours of the 2,520-gpm, 72-hour constant-rate test ranged from 11.0 to 11.3 gpm/ft. A total of 16,159,000 gallons of water was extracted throughout the development and testing program.

Groundwater samples were collected from Test Well 184W101 and Monitor Well 184W502M and analyzed for a suite of chemical parameters. Stabilization of the water-quality parameters, measured in the field, was observed prior to sample collection. The chemistry of these samples was compared to that of other SNWA wells in the vicinity. Both study wells exhibited a warmer temperature than other wells in the area, indicating a larger contribution of deeper groundwater to the well. All samples exhibited a calcium-magnesium-bicarbonate facies characteristic of groundwater of a carbonate-rock aquifer. Light, stable isotope (δD and δ^{18}O) compositions, typical of recharge at high elevations and cold temperatures, were observed for all groundwater samples. The isotopic composition of chloride (^{36}Cl/Cl) was also consistent with precipitation in the southwestern United States. The isotopic compositions of carbon (δ^{13}C and ^{14}C) and strontium (^{87}Sr/^{86}Sr) were indicative of groundwater interaction with carbonate minerals along the flowpath.

1.0 INTRODUCTION

In support of its Clark, Lincoln, and White Pine Counties Groundwater Development Project, Southern Nevada Water Authority (SNWA) installed test and monitor wells in Spring Valley to evaluate hydrogeologic conditions. This report documents the collection, analysis, and evaluation of data obtained during the well development and hydraulic testing of Test Well 184W101 and Monitor Well 184W502M located in Hydrographic Area (HA) 184, Spring Valley, Nevada. The two wells are completed in the unconfined, fractured carbonate aquifer within the Guilmette, Simonson, and Sevy stratigraphic units. This report also presents groundwater-level data collected at the site post-test through July 2009. A separate document entitled *Geologic Data Analysis Report for Monitor Well 184W502M and Test Well 184W101 in Spring Valley* (Eastman and Muller, 2009) includes the documentation and detailed results for the surface geophysical profiles and drilling program, including evaluation of lithology, structural features, drilling parameters, and borehole geophysical logs.

1.1 Program Objectives

The objectives of developing Test Well 184W101 were to remove any remaining drilling fluids and improve the hydraulic connection with the formation. This phase of development consisted of pump and surge activities and was in addition to airlifting and swabbing development that were performed immediately after well installation.

Hydraulic testing was performed to evaluate well performance and to provide data on the hydraulic properties of the carbonate-rock aquifer in the vicinity of the test well. Groundwater samples were also collected for laboratory analysis to evaluate the groundwater chemistry of the aquifer in the vicinity of the well.

1.2 Testing and Monitoring Program

The well development and hydrologic testing program was performed from April 4 through 12, 2007, and consisted of the following activities:

- Final well development, using surging methods.
- Well hydraulic testing and performance evaluation, using a four-interval step-drawdown test.
- Aquifer-property evaluation testing, using a 72-hour constant-rate test and subsequent water-level recovery measurements.
- Collection of groundwater-chemistry samples for laboratory analysis.

A complete schedule of test program activities is presented in Section 3.1.

Monitor Well 184W502M is part of the Spring Valley regional baseline water-level monitoring network. Water-level data have been collected from this location since the testing.

1.3 Report Organization

This report is divided into seven sections and two appendixes.

Section 1.0 presents introductory information about the testing program and this report.

Section 2.0 describes the well-site hydrogeology and summarizes the well construction, borehole lithology, and water-level data for the test and monitor wells.

Section 3.0 describes the test program and presents information on test instrumentation and background data.

Section 4.0 presents the analysis and evaluation of the results from the test well development and step-drawdown testing.

Section 5.0 presents the analysis and evaluation of the constant-rate aquifer test.

Section 6.0 presents the groundwater-chemistry results and evaluation.

Section 7.0 provides a list of references cited in this report.

Appendix A presents site photos and documentation of site physical and transducer test data. The data package on the CD-ROM includes regional background monitor-well water levels, barometric pressure, and hydrologic data collected from the test and monitor wells.

Appendix B presents the groundwater-chemistry laboratory data reports.

2.0 WELL SITE DESCRIPTION

SNWA Test Well 184W101 is located on the east side of Spring Valley, on public land managed Bureau of Land Management, approximately 2 mi south of the Lincoln County and White Pine County boundary in Section 11, T9N, R68E. Access to the site is from State Route 894 along a dirt road 1 mi south of Indian Springs Fence Line Road. A topographic map showing the site location and other SNWA test and monitor wells installed as of April 2010 is presented on Figure 2-1.

Two monitor wells were used during testing for observation and background control purposes. Monitor Well 184W502M, located approximately 175 ft to the north of the test well, was used as an observation well during testing. Monitor Well 184W504M, used to observe background conditions during testing, is located approximately 14 mi to the northwest of the test well.

2.1 Hydrogeologic Setting

This section presents the regional and local hydrogeologic setting of the Test Well 184W101 well site. Previous studies and reports that detail the regional hydrogeology are referenced. A description of the local hydrogeologic setting is provided and is based on field mapping and review of existing hydrogeologic and geophysical information.

2.1.1 Regional Hydrogeologic Setting

Spring Valley, located in east-central Nevada, is approximately 120 mi in length and averages approximately 16 mi in width. The valley is located within the Basin and Range province and is an up-gradient basin within the Great Salt Lake Desert Flow System (GSLDFS). It is bounded by the Schell Creek Range to the west, the Antelope Range to the north, the Snake Range and Limestone Hills to the east, the Wilson Creek Range to the south, and the Fortification Range to the southwest.

The primary aquifer systems within Spring Valley are carbonate and basin fill, with a volcanic aquifer occurring in the southwest portion of the valley. Extensive north-south-trending range-front faults and related structures are the primary control of groundwater flow in the carbonates and are present on both east and west sides of the valley. The local discharge of groundwater in south-central Spring Valley is through the basin fill generally toward the central axis of the valley with discharge occurring through evapotranspiration (ET). Groundwater flow in the southern portion of Spring Valley is postulated to occur south of the Snake Range through fractures in the carbonates of the Limestone Hills into Hamlin Valley and to Snake Valley.

Numerous studies related to Spring Valley and adjacent basins have been performed since the late 1940s. These studies have included water-resource investigations, geologic and hydrogeologic investigations, recharge and discharge estimations, and other hydrologic studies. The regional

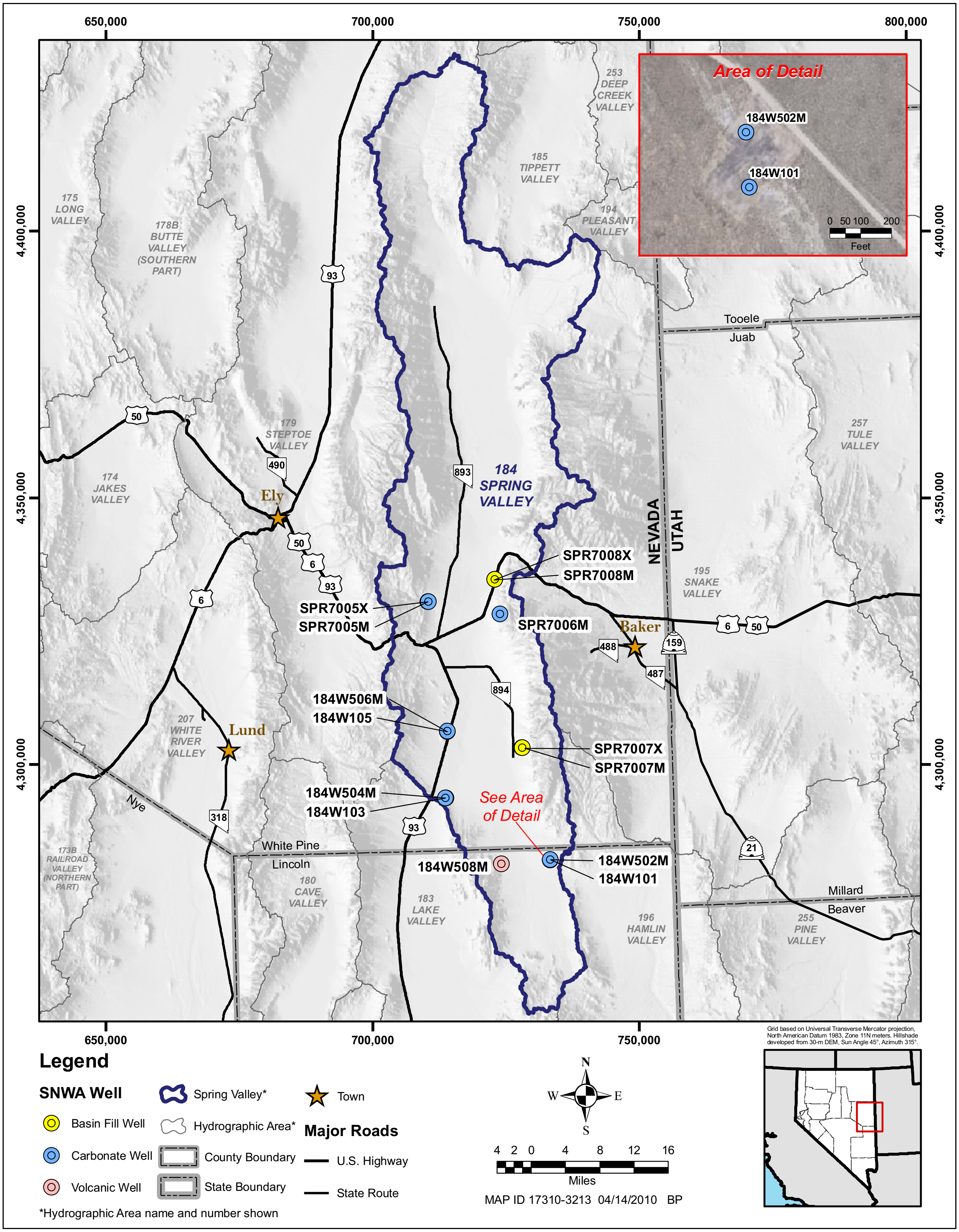


Figure 2-1

SNWA Exploratory and Test Wells in Spring Valley as of April 2010

hydrogeologic framework and a summary of results of previous studies have been presented in several reports. These reports include:

- *Water Resources Appraisal of Spring Valley, White Pine and Lincoln Counties, Nevada* (Rush and Kazmi, 1965)
- *Major Ground-Water Flow Systems in the Great Basin Region of Nevada, Utah, and Adjacent States* (Harrill et al., 1988)
- *Geologic and Hydrogeologic Framework for the Spring Valley Area* (SNWA, 2006a)
- *Summary of Groundwater Water-Rights and Current Water Uses in Spring Valley* (SNWA, 2006b)
- *Water Resources Assessment for Spring Valley* (SNWA, 2006c)
- *Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah—The Geologic Framework of Regional Groundwater Flow Systems* (Dixon et al., 2007)
- *Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County Nevada, and Adjacent Areas in Nevada and Utah* (Welch et al., 2008)
- *2008 Spring Valley Hydrologic Monitoring and Mitigation Plan Status and Data Report* (SNWA, 2009)

2.1.2 Local Hydrogeologic Setting

The site location was selected after conducting a geologic reconnaissance of the area, including field mapping, review of regional geophysical and well data, evaluation of surface structural features using aerial photography, and evaluation of local geophysical data. Surface geophysical profiles were also performed in the vicinity of the site by SNWA. Regional data and geologic mapping in the vicinity indicate the presence of faulting and related structures at the site. The well is completed in Devonian Guilmette Formation, Simonson Dolomite, and Sevy Dolomite.

The test and monitor wells are likely situated approximately 200 ft to the northeast of a northwest-southeast-trending normal fault dipping to the northeast. The fault's orientation relative to the test and monitor wells is presented in Figure 2-2. A detailed discussion of SNWA geophysical profiles, local geologic structure, and detailed lithologic descriptions of the stratigraphic units encountered are presented in Eastman and Muller (2009).

2.2 Well Data

Detailed geologic data for lithologic and hydrogeologic evaluation were collected during drilling and field mapping. This included collection and identification of drill cuttings, documentation of drilling parameters including penetration rate, fluid loss and mud viscosity, and downhole geophysical

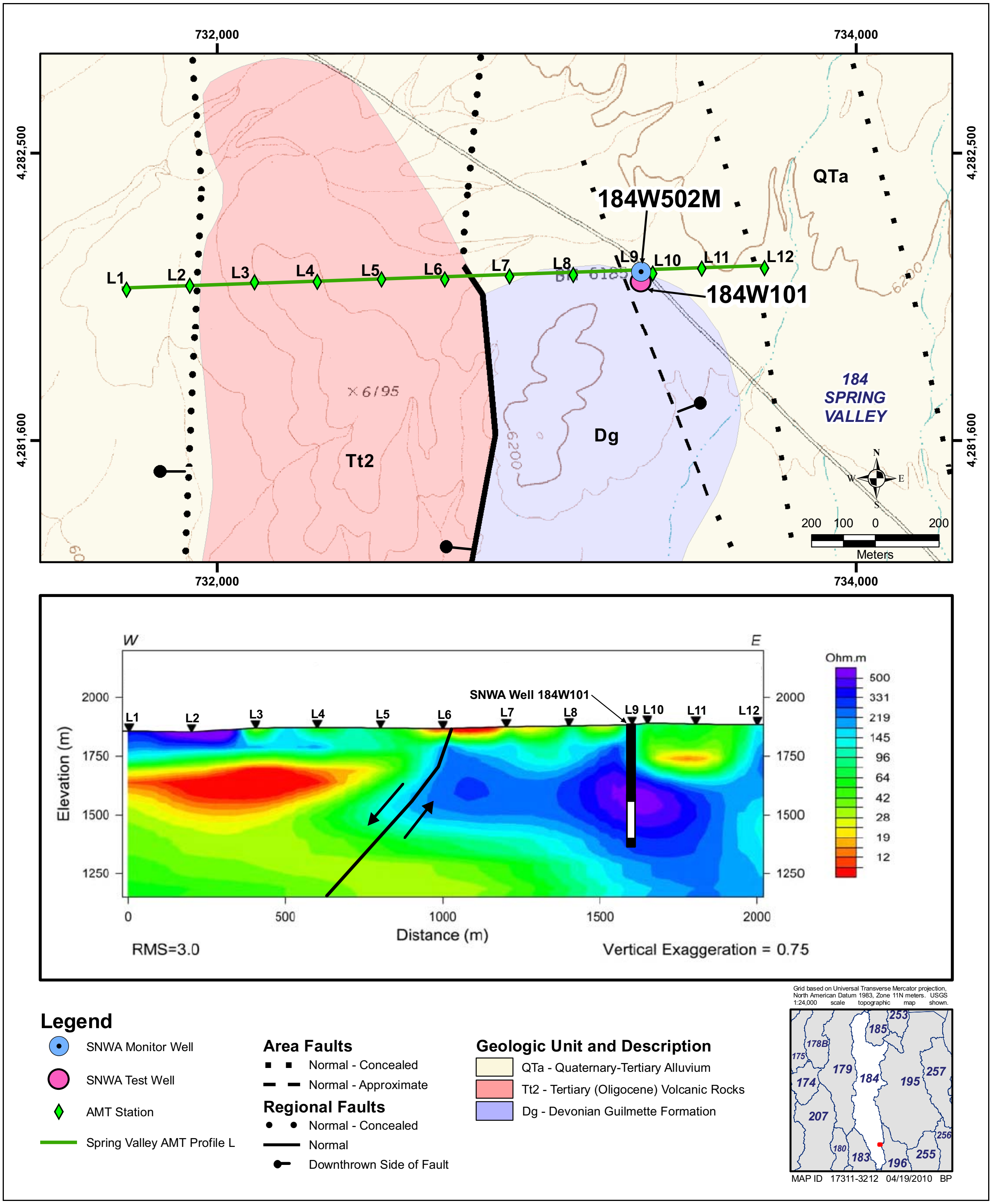


Figure 2-2
Geologic Map and Surface Geophysical Profile at Test Well 184W101

logging. Based on drill cuttings from the wells, stromatoporoid fossils noted in dark-gray to black dolomite between 1,090 and 1,160 ft bgs indicate the third unit of the Simonson Dolomite. Quartz beds interbedded with dolomite from 1,690 to 1,820 ft bgs distinguish the upper part of the Sevy Dolomite (Eastman and Muller, 2009).

Geophysical data indicate significant open fractures between 485 and 540 and 1,250 and 1,300 ft bgs in Test Well 184W101. The data also suggest open fractures from 480 to 540, 1,250 to 1,270, and 1,300 to 1,340 ft bgs in Monitor Well 184W502M.

2.2.1 Test Well 184W101

Test Well 184W101 was drilled to a total depth of 1,760 ft bgs between January 26 and February 18, 2007, using mud rotary techniques. A 40-in.-diameter conductor casing was placed to a depth of approximately 54 ft bgs and grouted in place. After the borehole was advanced to completion depth, downhole geophysical logging was performed. A 20-in.-diameter completion string, including approximately 932 ft of Ful-Flo louver screen, was then installed. The gravel pack extends from a depth of approximately 135 ft bgs to the base of the borehole. A summary chart of Test Well 184W101 drilling and well construction statistics is presented in Table 2-1, and a well construction schematic for Test Well 184W101 is presented on Figure 2-3. The borehole lithologic log for Test Well 184W101 is presented in Figure 2-4.

2.2.2 Monitor Wells 184W502M and 184W504M

Monitor Well 184W502M was completed at a depth of 1,828 ft bgs between January 3 and 22, 2007. A 20-in.-diameter conductor casing was set to a depth of 58 ft bgs and grouted in place. A 14.75-in. borehole was then advanced to completion depth. The 8-in. completion string, including approximately 1,284 ft of slotted casing, was placed in the open borehole. No gravel pack was used in this well. A summary chart of well drilling and well construction statistics for Monitor Well 184W502M is presented in Table 2-2, and a well construction schematic for Monitor Well 184W502M is presented on Figure 2-5. The borehole lithologic log for Monitor Well 184W502M is presented in Figure 2-6.

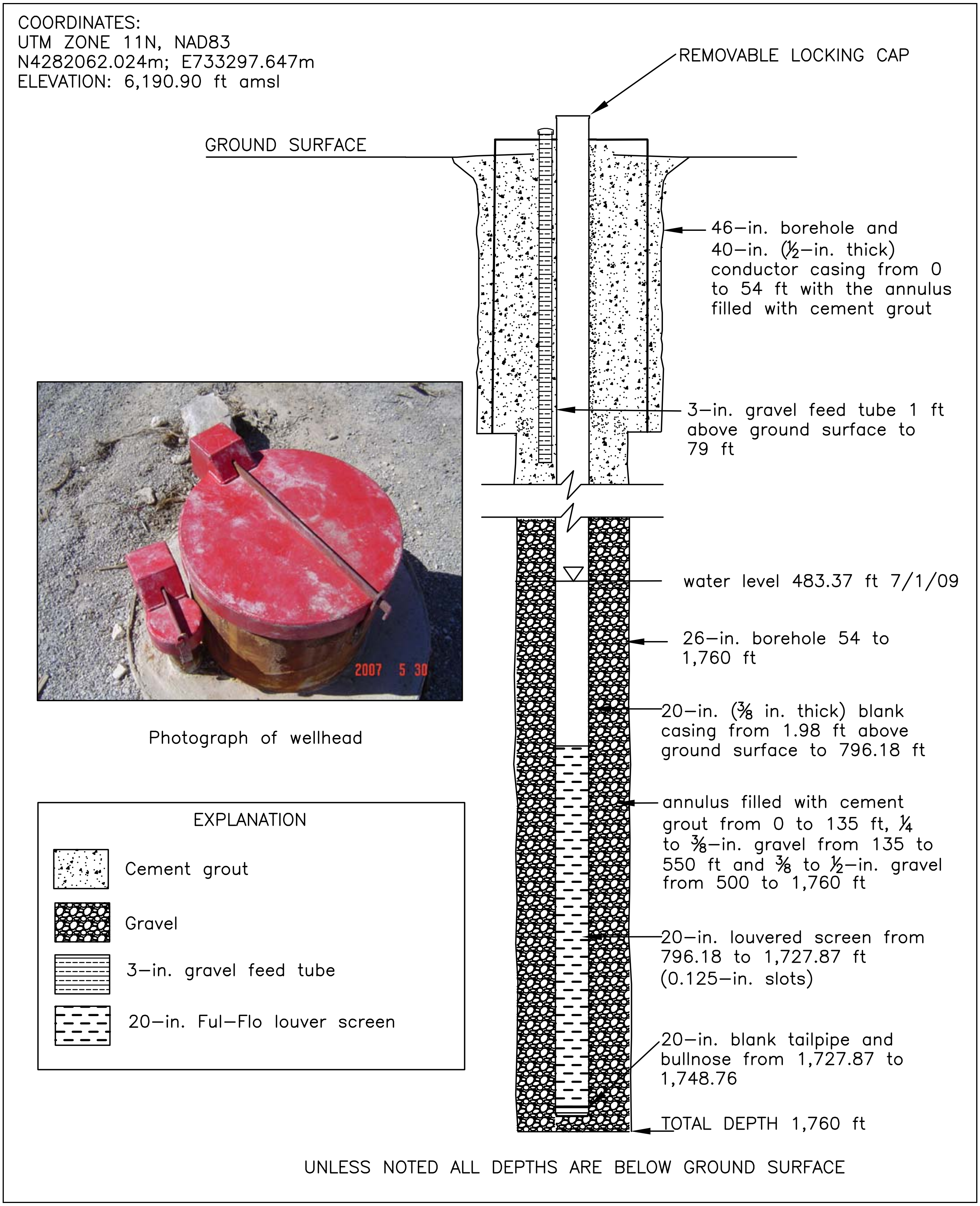
Monitor Well 184W504M, located on the west side of the valley, was monitored during the hydraulic testing to observe regional groundwater trends and to identify outside influences affecting regional water levels, such as changes in barometric pressure, earthquakes, and lunar effects. The hydrologic conditions affecting the water levels in this well are expected to be the same as those affecting the test well. This 8-in.-diameter monitor well is also completed in the unconfined, fractured carbonate-aquifer system at a depth of 1,020 ft bgs with an open borehole interval of 60 to 1,040 ft bgs.

2.2.3 Water-Level Data

Depth-to-water measurements were obtained at the wells relative to a marked temporary or permanent reference measuring point. Professional survey elevations for the measuring points and ground-surface elevations for the wells are presented in Table 2-3.

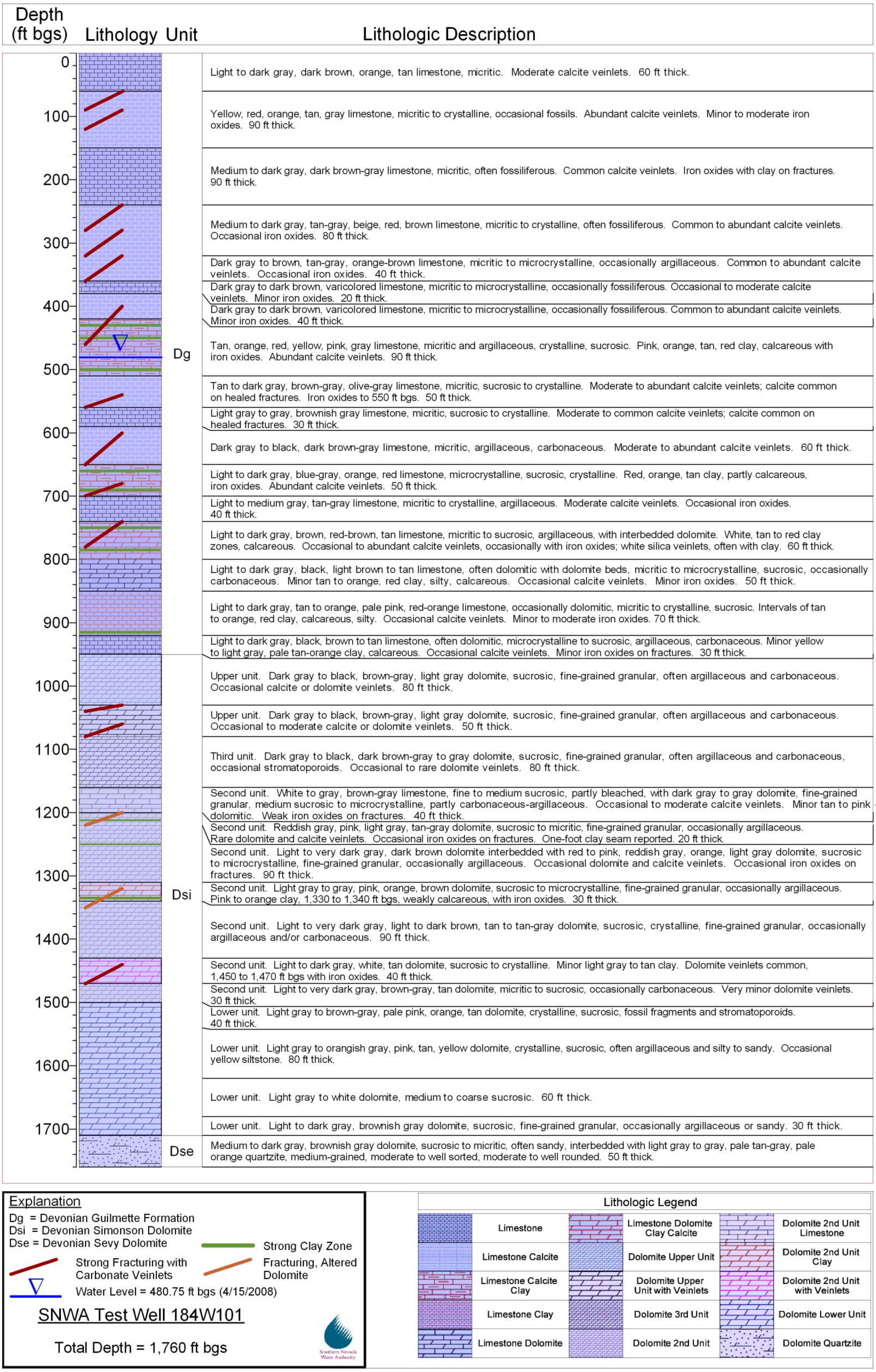
Table 2-1
Test Well 184W101 Borehole and Well Statistics

LOCATION DATA	
Coordinates	N 4,282,062.024 m; E 733,297.647 m (UTM, Zone 11, NAD83)
Ground Elevation	6,190.90 ft amsl
DRILLING DATA	
Spud Date	01/26/2007
Total Depth (TD)	1,760 ft bgs
Date TD Reached	02/14/2007
Date Well Completed	02/24/2007
Hole Diameter	46-in. from 0 to 54 ft bgs 26-in. from 54 to 1,760 ft bgs
Drilling Techniques	Conventional Circulation from 0 to 134 ft bgs Reverse Circulation from 134 to 1,760 ft bgs
Drilling Fluid Materials Used	Max-Gel = (643) 50-lb bags Soda Ash = (39) 50-lb bags DrisPac = (36) 50-lb bags Pac-R = (17) 50-lb bags Calcium = (2) 50-lb bags Sodium Bicarbonate = (5) 50-lb bags
Drilling Fluid Properties	Viscosity = 35 to 80 sec/qt Density = 8.3 to 9.7 lb/gal Filtrate = 6.8 to 16.2 ml Filter cake = 5/32 to 1/32 in.
CASING DATA	40-in. MS Conductor Casing from 0 to 54 ft bgs 20-in. HSLA Completion Casing from +1.98 to 1,749 ft bgs
WELL COMPLETION DATA	80 ft of 3-in. gravel feed tube from +1.0 to 79 ft bgs 798.16 ft of blank HSLA 20-in. casing from +1.98 to 796.18 ft bgs 931.69 of 20-in. Ful-Flo louver screen from 796.18 to 1,727.87 ft bgs 20.56 ft blank 20-in. sump HSLA casing from 1,727.87 to 1,748.43 ft bgs 0.33 ft bullnose CS casing from 1,748.43 to 1,748.76 ft bgs Cement, Plug and Gravel Pack Depth 0 to 135 ft (cement) 135 to 1,760 ft from bottom of Conductor Casing to TD (1/4 to 1/2 in. gravel pack)
WATER	Static Water Level: 483.37 ft bgs (7/1/2009) Water Elevation: 5,707.53 ft amsl
DRILLING CONTRACTOR	Lang Exploration Drilling
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)
OVERSIGHT	S. M. Stoller Corporation



Note: Not to Scale

Figure 2-3
Test Well 184W101 Well Diagram



Light to dark gray, dark brown, orange, tan limestone, micritic. Moderate calcite veinlets. 60 ft thick.

Yellow, red, orange, tan, gray limestone, micritic to crystalline, occasional fossils. Abundant calcite veinlets. Minor to moderate iron oxides. 90 ft thick.

Medium to dark gray, dark brown-gray limestone, micritic, often fossiliferous. Common calcite veinlets. Iron oxides with clay on fractures. 90 ft thick.

Medium to dark gray, tan-gray, beige, red, brown limestone, micritic to crystalline, often fossiliferous. Common to abundant calcite veinlets. Occasional iron oxides. 80 ft thick.

Dark gray to brown, tan-gray, orange-brown limestone, micritic to microcrystalline, occasionally argillaceous. Common to abundant calcite veinlets. Occasional iron oxides. 40 ft thick.

Dark gray to dark brown, varicolored limestone, micritic to microcrystalline, occasionally fossiliferous. Occasional to moderate calcite veinlets. Minor iron oxides. 20 ft thick.

Dark gray to dark brown, varicolored limestone, micritic to microcrystalline, occasionally fossiliferous. Common to abundant calcite veinlets. Minor iron oxides. 40 ft thick.

Tan, orange, red, yellow, pink, gray limestone, micritic and argillaceous, crystalline, sucrosic. Pink, orange, tan, red clay, calcareous with iron oxides. Abundant calcite veinlets. 90 ft thick.

Tan to dark gray, brown-gray, olive-gray limestone, micritic, sucrosic to crystalline. Moderate to abundant calcite veinlets; calcite common on healed fractures. Iron oxides to 550 ft bgs. 50 ft thick.

Light gray to gray, brownish gray limestone, micritic, sucrosic to crystalline. Moderate to common calcite veinlets; calcite common on healed fractures. 30 ft thick.

Dark gray to black, dark brown-gray limestone, micritic, argillaceous, carbonaceous. Moderate to abundant calcite veinlets. 60 ft thick.

Light to dark gray, blue-gray, orange, red limestone, microcrystalline, sucrosic, crystalline. Red, orange, tan clay, partly calcareous, iron oxides. Abundant calcite veinlets. 50 ft thick.

Light to medium gray, tan-gray limestone, micritic to crystalline, argillaceous. Moderate calcite veinlets. Occasional iron oxides. 40 ft thick.

Light to dark gray, brown, red-brown, tan limestone, micritic to sucrosic, argillaceous, with interbedded dolomite. White, tan to red clay zones, calcareous. Occasional to abundant calcite veinlets, occasionally with iron oxides; white silica veinlets, often with clay. 60 ft thick.

Light to dark gray, black, light brown to tan limestone, often dolomitic with dolomite beds, micritic to microcrystalline, sucrosic, occasionally carbonaceous. Minor tan to orange, red clay, silty, calcareous. Occasional calcite veinlets. Minor iron oxides. 50 ft thick.

Light to dark gray, tan to orange, pale pink, red-orange limestone, occasionally dolomitic, micritic to crystalline, sucrosic. Intervals of tan to orange, red clay, calcareous, silty. Occasional calcite veinlets. Minor to moderate iron oxides. 70 ft thick.

Light to dark gray, black, brown to tan limestone, often dolomitic, microcrystalline to sucrosic, argillaceous, carbonaceous. Minor yellow to light gray, pale tan-orange clay, calcareous. Occasional calcite veinlets. Minor iron oxides on fractures. 30 ft thick.

Upper unit. Dark gray to black, brown-gray, light gray dolomite, sucrosic, fine-grained granular, often argillaceous and carbonaceous. Occasional calcite or dolomite veinlets. 80 ft thick.

Upper unit. Dark gray to black, brown-gray, light gray dolomite, sucrosic, fine-grained granular, often argillaceous and carbonaceous. Occasional to moderate calcite or dolomite veinlets. 50 ft thick.

Third unit. Dark gray to black, dark brown-gray to gray dolomite, sucrosic, fine-grained granular, often argillaceous and carbonaceous, occasional stromatoporoids. Occasional to rare dolomite veinlets. 80 ft thick.

Second unit. White to gray, brown-gray limestone, fine to medium sucrosic, partly bleached, with dark gray to gray dolomite, fine-grained granular, medium sucrosic to microcrystalline, partly carbonaceous-argillaceous. Occasional to moderate calcite veinlets. Minor tan to pink dolomitic. Weak iron oxides on fractures. 40 ft thick.

Second unit. Reddish gray, pink, light gray, tan-gray dolomite, sucrosic to micritic, fine-grained granular, occasionally argillaceous. Rare dolomite and calcite veinlets. Occasional iron oxides on fractures. One-foot clay seam reported. 20 ft thick.

Second unit. Light to very dark gray, dark brown dolomite interbedded with red to pink, reddish gray, orange, light gray dolomite, sucrosic to microcrystalline, fine-grained granular, occasionally argillaceous. Occasional dolomite and calcite veinlets. Occasional iron oxides on fractures. 90 ft thick.

Second unit. Light gray to gray, pink, orange, brown dolomite, sucrosic to microcrystalline, fine-grained granular, occasionally argillaceous. Pink to orange clay, 1,330 to 1,340 ft bgs, weakly calcareous, with iron oxides. 30 ft thick.

Second unit. Light to very dark gray, light to dark brown, tan to tan-gray dolomite, sucrosic, crystalline, fine-grained granular, occasionally argillaceous and/or carbonaceous. 90 ft thick.

Second unit. Light to dark gray, white, tan dolomite, sucrosic to crystalline. Minor light gray to tan clay. Dolomite veinlets common, 1,450 to 1,470 ft bgs with iron oxides. 40 ft thick.

Second unit. Light to very dark gray, brown-gray, tan dolomite, micritic to sucrosic, occasionally carbonaceous. Very minor dolomite veinlets. 30 ft thick.

Lower unit. Light gray to brown-gray, pale pink, orange, tan dolomite, crystalline, sucrosic, fossil fragments and stromatoporoids. 40 ft thick.

Lower unit. Light gray to orangish gray, pink, tan, yellow dolomite, crystalline, sucrosic, often argillaceous and silty to sandy. Occasional yellow siltstone. 80 ft thick.

Lower unit. Light gray to white dolomite, medium to coarse sucrosic. 60 ft thick.

Lower unit. Light to dark gray, brownish gray dolomite, sucrosic, fine-grained granular, occasionally argillaceous or sandy. 30 ft thick.

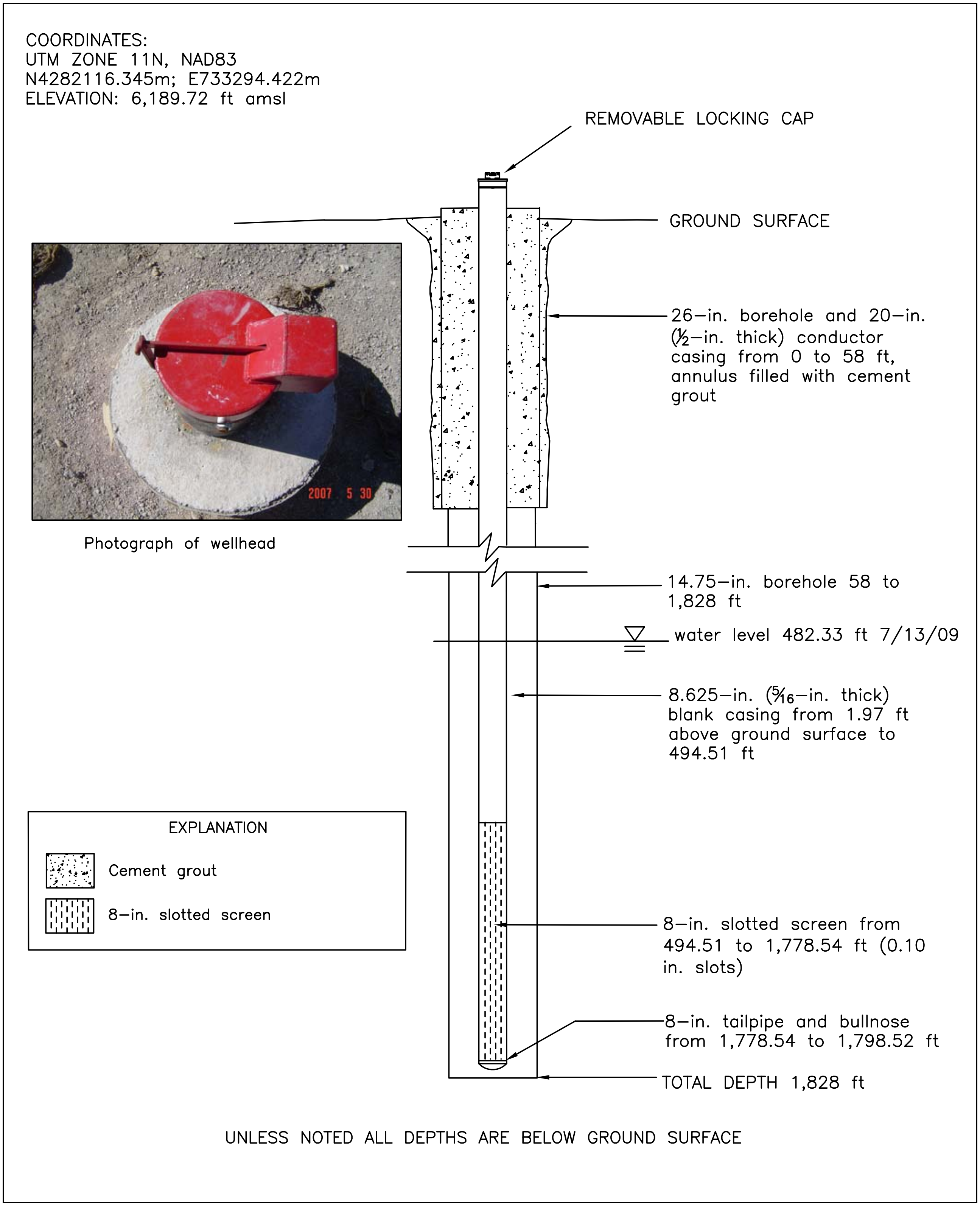
Medium to dark gray, brownish gray dolomite, sucrosic to micritic, often sandy, interbedded with light gray to gray, pale tan-gray, pale orange quartzite, medium-grained, moderate to well sorted, moderate to well rounded. 50 ft thick.

Source: Eastman and Muller (2009)

Figure 2-4
Borehole Stratigraphic Column of Test Well 184W101

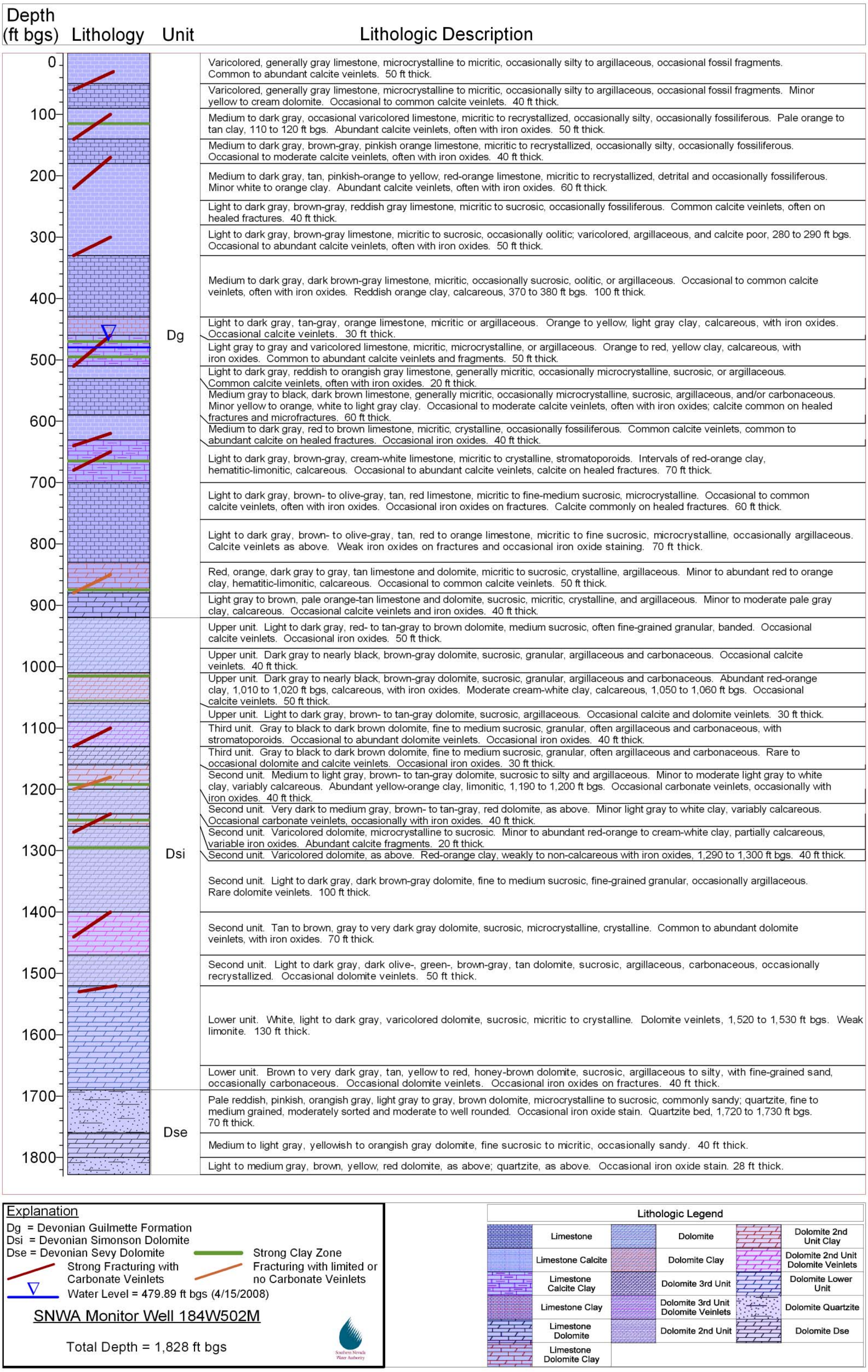
Table 2-2
Monitor Well 184W502M Borehole and Well Statistics

LOCATION DATA	
Coordinates	N 4,282,116.345 m; E 733,294.422 m (UTM, Zone 11, NAD83)
Ground Elevation	6,189.72 ft amsl
DRILLING DATA	
Spud Date	01/03/2007
Total Depth (TD)	1,828 ft bgs
Date TD Reached	01/20/2007
Date Well Completed	01/22/2007
Hole Diameter	26-in. from 0 to 58 ft bgs 14.75-in. from 58 to 1,828 ft bgs
Drilling Techniques	Conventional Direct Circulation with mud from 0 to 209 ft bgs Reverse Circulation from 209 to 1,828 ft bgs
Drilling Fluid Materials Used	Quick Gel = (487) 50-lb bags Soda Ash= (20) 50-lb bags Drispac= (14) 50-lb bags
Drilling Fluid Properties	Viscosity = 39 to 62 sec/qt Density = 8.6 to 9.2 lb/gal Filtrate = 7.6 to 20.8 mL Filter cake = 1/32 to 3/32 in.
CASING DATA	20-in. MS Conductor Casing from 0 to 58 ft bgs 8.625-in. MS Production Casing from +1.97 to 1,799 ft bgs
WELL COMPLETION DATA	496.48 ft of blank MS 20-in casing from +1.97 to 494.51 ft bgs 1,284.03 ft of 8-in slotted MS screen from 494.51 to 1,778.54 ft bgs 19.65 ft of 8-in blank MS from casing from 1,778.54 to 1,798.19 ft bgs 0.33 ft bullnose CS casing from 1,798.19 to 1,798.52 ft bgs Cement Depth 0 to 58 ft bgs on outside of conductor casing
WATER	Static Water Level: 482.33 ft bgs (7/13/2009) Water Elevation: 5,707.39 ft amsl
DRILLING CONTRACTOR	Lang Exploration Drilling
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)
OVERSIGHT	S. M. Stoller Corporation



Note: Not to Scale

Figure 2-5
Monitor Well 184W502M Well Diagram



Unit	Lithologic Description
Dg	Varicolored, generally gray limestone, microcrystalline to micritic, occasionally silty to argillaceous, occasional fossil fragments. Common to abundant calcite veinlets. 50 ft thick.
	Varicolored, generally gray limestone, microcrystalline to micritic, occasionally silty to argillaceous, occasional fossil fragments. Minor yellow to cream dolomite. Occasional to common calcite veinlets. 40 ft thick.
	Medium to dark gray, occasional varicolored limestone, micritic to recrystallized, occasionally silty, occasionally fossiliferous. Pale orange to tan clay, 110 to 120 ft bgs. Abundant calcite veinlets, often with iron oxides. 50 ft thick.
	Medium to dark gray, brown-gray, pinkish orange limestone, micritic to recrystallized, occasionally silty, occasionally fossiliferous. Occasional to moderate calcite veinlets, often with iron oxides. 40 ft thick.
	Medium to dark gray, tan, pinkish-orange to yellow, red-orange limestone, micritic to recrystallized, detrital and occasionally fossiliferous. Minor white to orange clay. Abundant calcite veinlets, often with iron oxides. 60 ft thick.
	Light to dark gray, brown-gray, reddish gray limestone, micritic to sucrosic, occasionally fossiliferous. Common calcite veinlets, often on healed fractures. 40 ft thick.
	Light to dark gray, brown-gray limestone, micritic to sucrosic, occasionally oolitic; varicolored, argillaceous, and calcite poor, 280 to 290 ft bgs. Occasional to abundant calcite veinlets, often with iron oxides. 50 ft thick.
	Medium to dark gray, dark brown-gray limestone, micritic, occasionally sucrosic, oolitic, or argillaceous. Occasional to common calcite veinlets, often with iron oxides. Reddish orange clay, calcareous, 370 to 380 ft bgs. 100 ft thick.
	Light to dark gray, tan-gray, orange limestone, micritic or argillaceous. Orange to yellow, light gray clay, calcareous, with iron oxides. Occasional calcite veinlets. 30 ft thick.
	Light gray to gray and varicolored limestone, micritic, microcrystalline, or argillaceous. Orange to red, yellow clay, calcareous, with iron oxides. Common to abundant calcite veinlets and fragments. 50 ft thick.
	Light to dark gray, reddish to orangish gray limestone, generally micritic, occasionally microcrystalline, sucrosic, or argillaceous. Common calcite veinlets, often with iron oxides. 20 ft thick.
	Medium gray to black, dark brown limestone, generally micritic, occasionally microcrystalline, sucrosic, argillaceous, and/or carbonaceous. Minor yellow to orange, white to light gray clay. Occasional to moderate calcite veinlets, often with iron oxides; calcite common on healed fractures and microfractures. 60 ft thick.
	Medium to dark gray, red to brown limestone, micritic, crystalline, occasionally fossiliferous. Common calcite veinlets, common to abundant calcite on healed fractures. Occasional iron oxides. 40 ft thick.
	Light to dark gray, brown-gray, cream-white limestone, micritic to crystalline, stromatoporoids. Intervals of red-orange clay, hematitic-limonitic, calcareous. Occasional to abundant calcite veinlets, calcite on healed fractures. 70 ft thick.
	Light to dark gray, brown- to olive-gray, tan, red limestone, micritic to fine-medium sucrosic, microcrystalline. Occasional to common calcite veinlets, often with iron oxides. Occasional iron oxides on fractures. Calcite commonly on healed fractures. 60 ft thick.
	Light to dark gray, brown- to olive-gray, tan, red to orange limestone, micritic to fine sucrosic, microcrystalline, occasionally argillaceous. Calcite veinlets as above. Weak iron oxides on fractures and occasional iron oxide staining. 70 ft thick.
	Red, orange, dark gray to gray, tan limestone and dolomite, micritic to sucrosic, crystalline, argillaceous. Minor to abundant red to orange clay, hematitic-limonitic, calcareous. Occasional to common calcite veinlets. 50 ft thick.
	Light gray to brown, pale orange-tan limestone and dolomite, sucrosic, micritic, crystalline, and argillaceous. Minor to moderate pale gray clay, calcareous. Occasional calcite veinlets and iron oxides. 40 ft thick.
Dsi	Upper unit. Light to dark gray, red- to tan-gray to brown dolomite, medium sucrosic, often fine-grained granular, banded. Occasional calcite veinlets. Occasional iron oxides. 50 ft thick.
	Upper unit. Dark gray to nearly black, brown-gray dolomite, sucrosic, granular, argillaceous and carbonaceous. Occasional calcite veinlets. 40 ft thick.
	Upper unit. Dark gray to nearly black, brown-gray dolomite, sucrosic, granular, argillaceous and carbonaceous. Abundant red-orange clay, 1,010 to 1,020 ft bgs, calcareous, with iron oxides. Moderate cream-white clay, calcareous, 1,050 to 1,060 ft bgs. Occasional calcite veinlets. 50 ft thick.
	Upper unit. Light to dark gray, brown- to tan-gray dolomite, sucrosic, argillaceous. Occasional calcite and dolomite veinlets. 30 ft thick.
	Third unit. Gray to black to dark brown dolomite, fine to medium sucrosic, granular, often argillaceous and carbonaceous, with stromatoporoids. Occasional to abundant dolomite veinlets. Occasional iron oxides. 40 ft thick.
	Third unit. Gray to black to dark brown dolomite, fine to medium sucrosic, granular, often argillaceous and carbonaceous. Rare to occasional dolomite and calcite veinlets. Occasional iron oxides. 30 ft thick.
	Second unit. Medium to light gray, brown- to tan-gray dolomite, sucrosic to silty and argillaceous. Minor to moderate light gray to white clay, variably calcareous. Abundant yellow-orange clay, limonitic, 1,190 to 1,200 ft bgs. Occasional carbonate veinlets, occasionally with iron oxides. 40 ft thick.
	Second unit. Very dark to medium gray, brown- to tan-gray, red dolomite, as above. Minor light gray to white clay, variably calcareous. Occasional carbonate veinlets, occasionally with iron oxides. 40 ft thick.
	Second unit. Varicolored dolomite, microcrystalline to sucrosic. Minor to abundant red-orange to cream-white clay, partially calcareous, variable iron oxides. Abundant calcite fragments. 20 ft thick.
	Second unit. Varicolored dolomite, as above. Red-orange clay, weakly to non-calcareous with iron oxides, 1,290 to 1,300 ft bgs. 40 ft thick.
	Second unit. Light to dark gray, dark brown-gray dolomite, fine to medium sucrosic, fine-grained granular, occasionally argillaceous. Rare dolomite veinlets. 100 ft thick.
	Second unit. Tan to brown, gray to very dark gray dolomite, sucrosic, microcrystalline, crystalline. Common to abundant dolomite veinlets, with iron oxides. 70 ft thick.
	Second unit. Light to dark gray, dark olive-, green-, brown-gray, tan dolomite, sucrosic, argillaceous, carbonaceous, occasionally recrystallized. Occasional dolomite veinlets. 50 ft thick.
	Lower unit. White, light to dark gray, varicolored dolomite, sucrosic, micritic to crystalline. Dolomite veinlets, 1,520 to 1,530 ft bgs. Weak limonite. 130 ft thick.
	Lower unit. Brown to very dark gray, tan, yellow to red, honey-brown dolomite, sucrosic, argillaceous to silty, with fine-grained sand, occasionally carbonaceous. Occasional dolomite veinlets. Occasional iron oxides on fractures. 40 ft thick.
Dse	Pale reddish, pinkish, orangish gray, light gray to gray, brown dolomite, microcrystalline to sucrosic, commonly sandy; quartzite, fine to medium grained, moderately sorted and moderate to well rounded. Occasional iron oxide stain. Quartzite bed, 1,720 to 1,730 ft bgs. 70 ft thick.
	Medium to light gray, yellowish to orangish gray dolomite, fine sucrosic to micritic, occasionally sandy. 40 ft thick.
	Light to medium gray, brown, yellow, red dolomite, as above; quartzite, as above. Occasional iron oxide stain. 28 ft thick.

Source: Eastman and Muller (2009)

Figure 2-6
Borehole Stratigraphic Column of Monitor Well 184W502M

Table 2-3
Measuring-Point Information

Well ID	Well Use During Testing	Location[a]		Temporary MP (ft amsl)	Permanent MP (ft amsl)	Ground Surface Elevation (ft amsl)
		UTM Northing (m)	UTM Easting (m)			
184W101	Test Well	4,282,062.02	733,297.65	6,196.20	6,192.88	6,190.90
184W502M	Observation Well	4,282,116.34	733,294.42	6,191.69	6,191.69	6,189.72
184W504M	Background Well	4,293,712.49	713,647.12	5,901.44	5,901.44	5,900.11

[a] Universal Transverse Mercator, North American Datum of 1983, Zone 11N, Meters
MP = Measuring Point

Static groundwater-elevation data were collected on a continuous basis at Monitor Well 184W502M with an In-Situ MINI TROLL pressure transducer from preceding the test to February 19, 2008. At that time, the integrated pressure transducer failed and was removed. Periodic measurements were collected regularly until a Design Analysis H-310 pressure transducer and XL-500 data logger were installed on July 13, 2009, as part of the long-term monitoring program. Periodic, manual depth-to-water measurements are taken at least quarterly.

Static groundwater-elevation data have been collected on a continuous basis at Monitor Well 184W504M from preceding the test to the present. This well had been equipped with an In-Situ Level TROLL 700 integrated pressure transducer and data logger. However, on July 13, 2009, a Design Analysis H-312 pressure transducer and XL-500 data logger replaced the In-Situ equipment.

Physical measurements are collected from Test Well 184W101 on a six-week to quarterly frequency.

Static groundwater elevation ranged from approximately 5,708 to 5,712 ft amsl at Test Well 184W101, which corresponds to a depth of water of approximately 479 to 483 ft bgs. Static groundwater elevation ranged from approximately 5,707 to 5,710 ft amsl at Monitor Well 184W502M, which corresponds to a depth of water ranging from approximately 478 to 482 ft bgs. Background well 184W504M static groundwater elevation is approximately 5,800 ft amsl and approximately 100 ft bgs. Period-of-record hydrographs for the wells are presented in Figures 2-7 through 2-9. The hydrograph for the background well highlights time intervals during this test and two earlier, unrelated tests performed at two other wells, 184W105 and 184W103. A detailed background hydrograph for well 184W504M during the test period is presented in Section 3.4. Static water levels at Test Well 184W101 and Monitor Well 184W502M have trended lower during the period of record. This corresponds to trends observed in other monitor wells located on the east side of Spring Valley, which are believed to be associated with lower precipitation and recharge during this period.

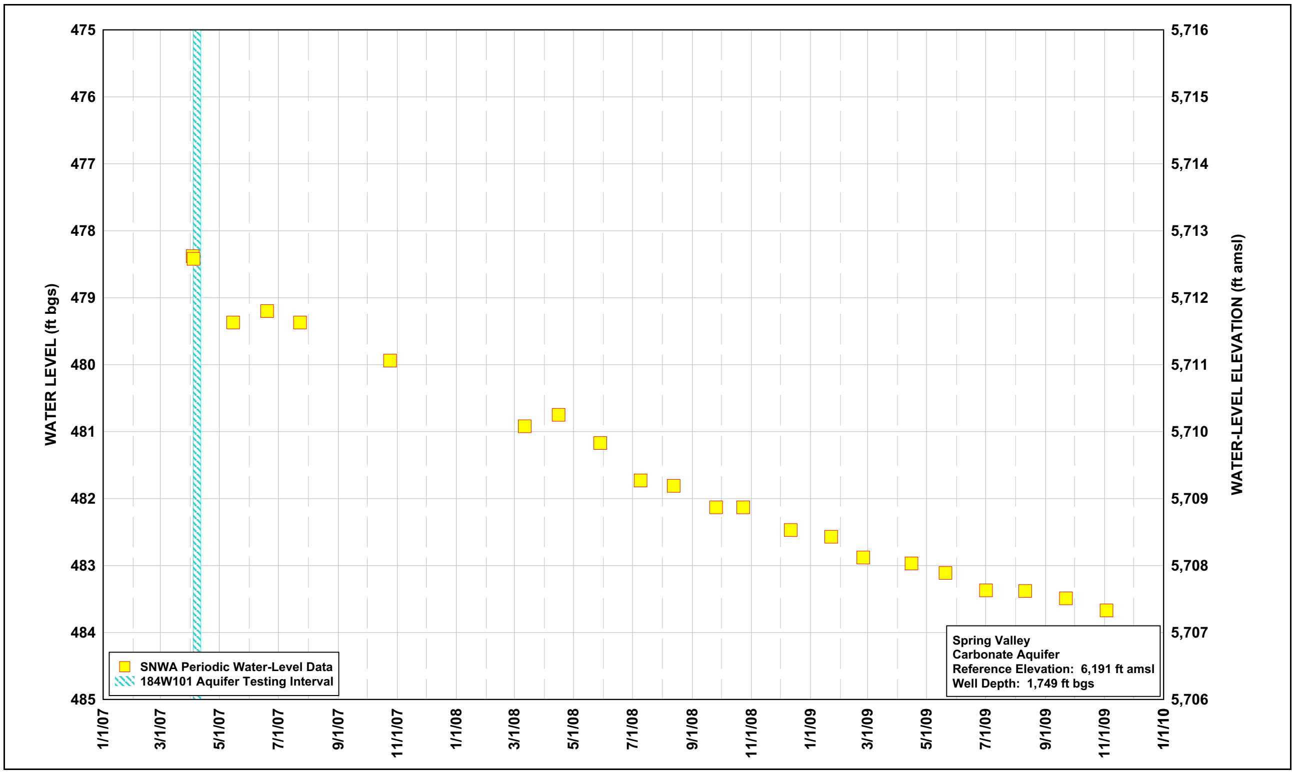


Figure 2-7
Test Well 184W101 Historical Hydrograph

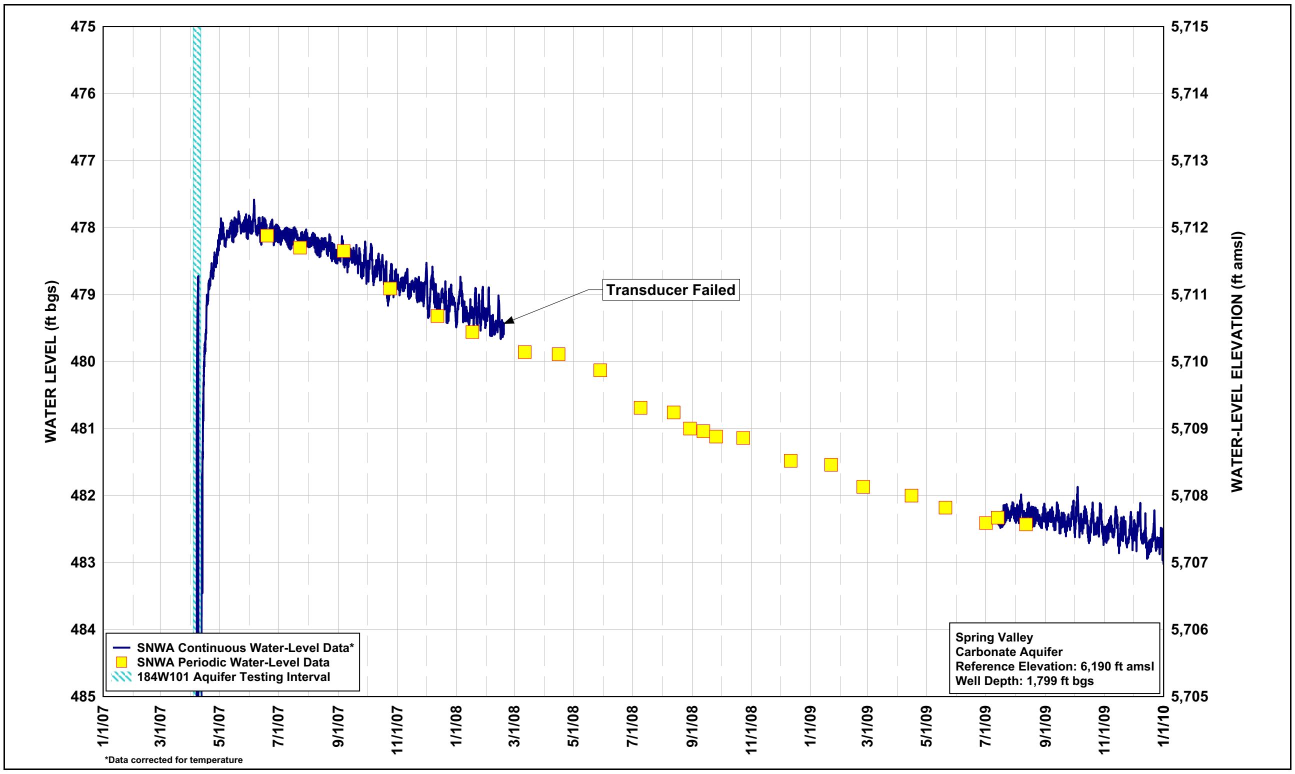


Figure 2-8
Monitor Well 184W502M Historical Hydrograph

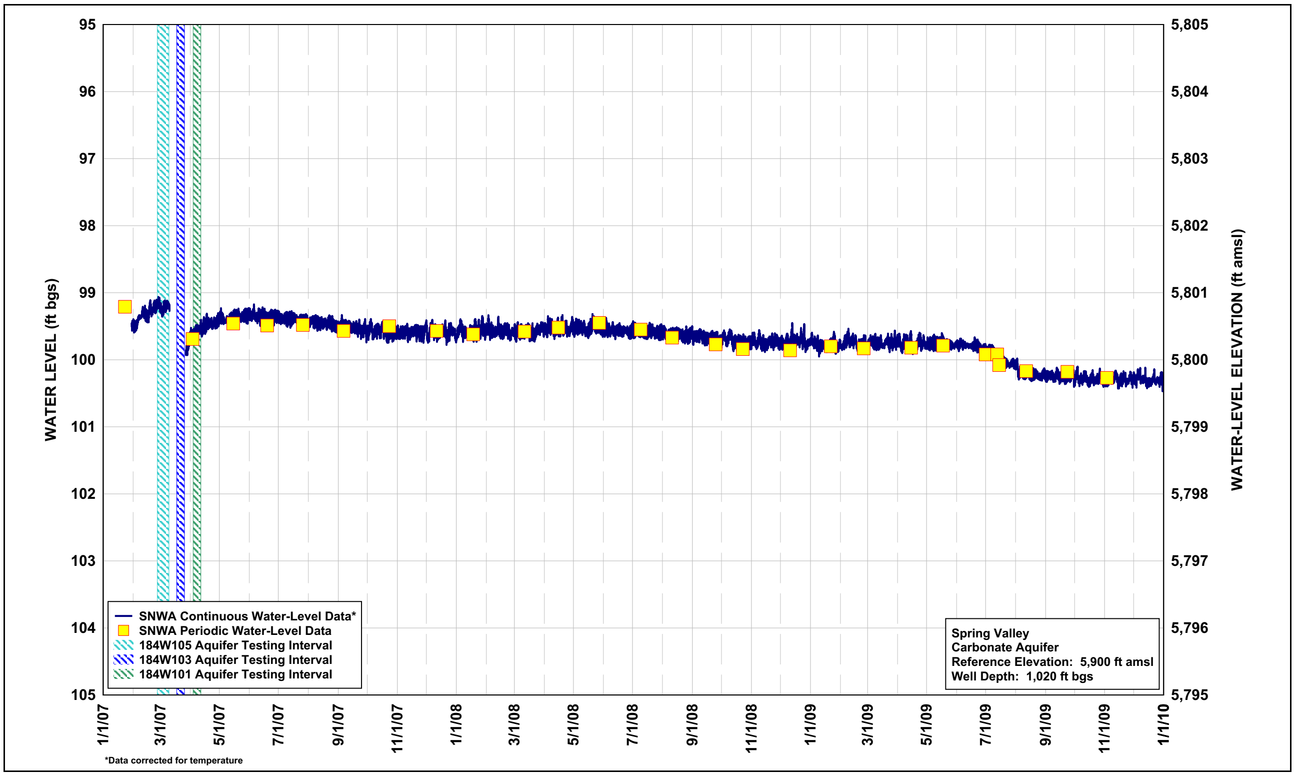


Figure 2-9
Monitor Well 184W504M Historical Hydrograph

3.0 TEST DESCRIPTION AND BACKGROUND INFORMATION

This section describes the activities, pump equipment, and monitoring instrumentation associated with development and testing of 184W101. Background hydrologic data and regional trends are also presented and evaluated in this section.

3.1 Site Activities

The following summarizes the development and testing activities performed in 2007 at the well site:

- April 4 to 6: Developed the test well using surge and pump methods. The well was developed at rates ranging from 800 to 2,600 gpm.

- April 7: Performed step-drawdown test at rates ranging from 2,200 to 2,600 gpm.

- April 9 to 12: Performed 72-hour constant-rate test at 2,520 gpm.

3.2 Test Equipment and Site Layout

A Johnson Pump Company vertical line shaft turbine pump was used in Test Well 184W101. The intake was set at 788 ft bgs. The test well transducer was set at approximately 755 ft bgs. A pump discharge line check valve was not used during the test to allow more effective development activities.

3.3 Discharge Information

Pumped water was discharged northwest of the site through approximately 500 ft of 12-in.-diameter piping. A total of 16,159,000 gal was pumped over the course of the development and testing periods for Test Well 184W101.

3.4 Instrumentation and Background Data

Regional and site background water levels were continuously recorded prior to, during, and after the test period. Groundwater levels in Test Well 184W101 were recorded during the test period using an In-Situ HERMIT 3000 data logger. Test Well 184W101 was equipped with an In-Situ 250 psi transducer. Monitor Well 184W502M was equipped with an In-Situ 30 psi Level TROLL 700 integrated transducer.

Manual measurements were performed at both the test and monitor wells using a Heron Instruments 1,000-ft, electronic water-level indicator probe at prescribed intervals and in accordance with SNWA procedures and applicable industry standards. Groundwater-chemistry samples were collected and analyzed regularly for pH, conductivity, temperature, and turbidity throughout the testing period. Program test data are presented in data files found on the CD-ROM that accompanies this report.

Data collected from background well 184W504M were used to identify any significant regional trend in groundwater level. A depth-to-water hydrograph for background well 184W504M is presented on Figure 3-1.

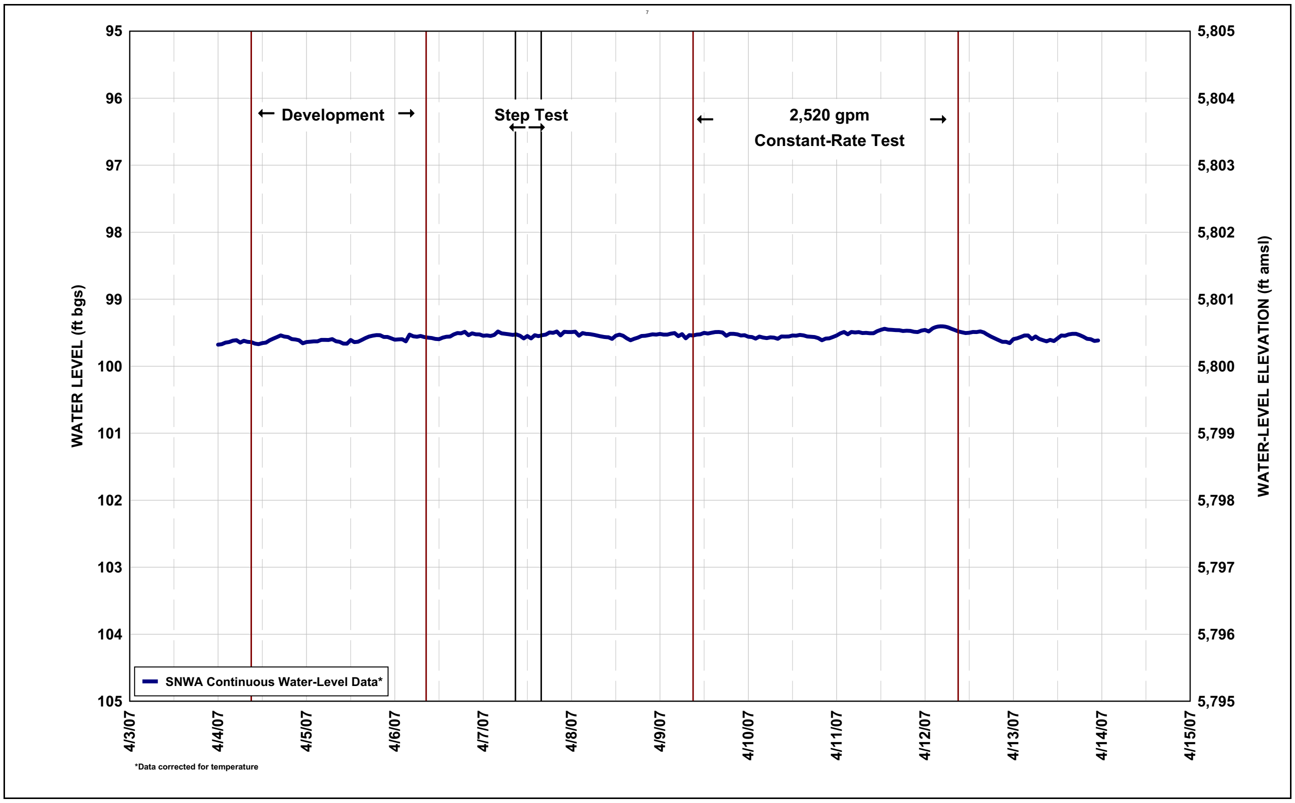


Figure 3-1
Hydrograph for Background Well 184W504M During Test Period

The hydrograph for background well 184W504M indicates no significant trend that would influence the results of the tests. During the constant-rate test, an average daily cycle of water-level change of 0.11 ft was observed. This background change is insignificant with respect to the magnitude of drawdowns observed during testing and is not incorporated as an adjustment to the test records used for the analysis of the test.

Figure 3-2 presents a plot of barometric-pressure data and groundwater-level measurements in Monitor Well 184W502M collected during the constant-rate test. The barometric-pressure record, recorded at Test Well 184W101 and ET station SV1 (located 11.4 mi northwest of the test well), covers the time period during the constant-rate test. During the record period, the barometric pressure varied by approximately 0.30 in. Hg. This equates to 0.34 ft of head, assuming 100 percent barometric efficiency of the well. The amount and duration of change in barometric pressure did not

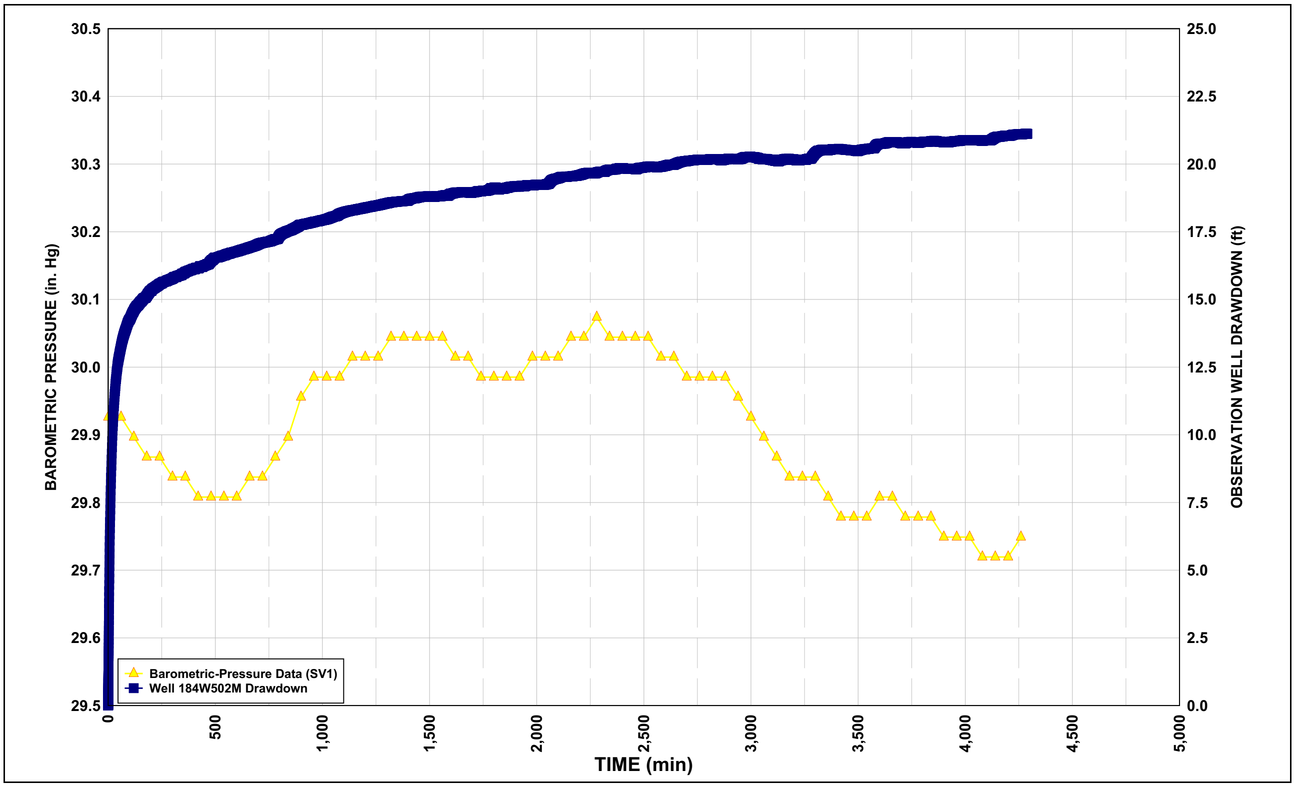


Figure 3-2
Local Barometric-Pressure Variation and
Groundwater-Level Measurements at Monitor Well 184W502M

significantly influence the test results, as shown on Figure 3-2. Any barometric effect in this hydrogeologic setting is insignificant with respect to the magnitudes of drawdown observed during testing.

The respective borehole deviations for wells 184W101 and 184W502M are presented in the geophysical logs in the Closure Distance plots provided in the Geologic Data Analysis Report (Eastman and Muller, 2009). Evaluation of borehole deviation and depth to groundwater indicated negligible influence on depth-to-water measurements.

Transducer data collected in the test and observation wells were compared to manually collected data. Only minor inconsistencies were identified, which were within the accuracy range of the instrumentation. No variation between the transducer and manually collected data was observed that would influence the test results.

No other outside influences, such as the existence of other pumping wells in the vicinity of Test Well 184W101, were identified.

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4.0 WELL HYDRAULICS AND PERFORMANCE TESTING

This section presents development results and analysis of the step-drawdown well performance testing.

4.1 Development

Prior to this phase of development, Test Well 184W101 was initially developed after drilling using a dual-swab technique. A dual swab was used prior to and after placement of the gravel pack. AQUA-CLEAR PFD, a polymer dispersant, was added to the well to break up residual drilling mud, and a final swab was performed the length of the screen.

Test Well 184W101 was then developed using a surging and pumping technique. The well was pumped at a constant rate for a short period of time (usually under an hour) until turbidity data reached a certain low threshold and then surged repeatedly. Water-level and groundwater-chemistry data were collected during the pumping period. Specific capacity (discharge [Q] in gpm/drawdown [s] in ft) was determined during and at the end of each pumping period to evaluate development effectiveness and the need for additional development.

4.1.1 Development Results

A total of 4,248,500 gal of water was pumped during this phase of development which resulted in at least a 10 percent improvement in specific capacity. The specific capacity improved from 14.1 gpm/ft (156.58 ft of drawdown) on April 5, 2007, one hour into the first development pumping interval at 2,200 gpm, to 15.5 gpm/ft (141.84 ft of drawdown) on April 7, 2007, one hour into the first step interval during the step test also at 2,200 gpm.

4.2 Step-Drawdown Test

A step-drawdown test was performed using four different pumping rates ranging from 2,200 to 2,600 gpm. The pumping periods ranged from 90 to 120 minutes in duration where the pumping rate was held constant. Pumping rates were increased in each subsequent pumping period. Figure 4-1 presents a graph showing plots of the drawdown versus time for each pumping interval during the step test.

4.2.1 Well Performance and Specific Capacity

Well specific capacity is a measure of the well’s productivity and efficiency. Specific capacity usually decreases to some degree with pumping duration and increased discharge rate. Graphs of

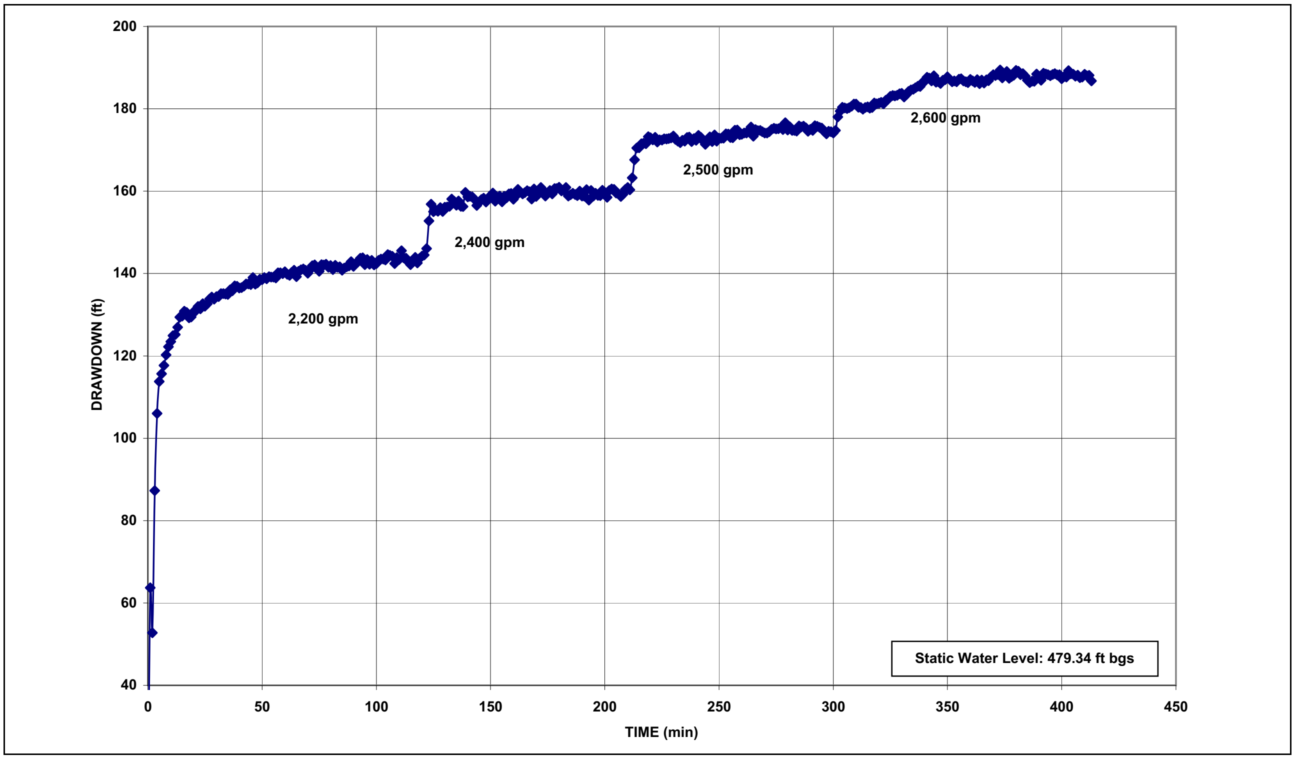


Figure 4-1
Linear Plot of Drawdown for Each Pumping Interval
During Step-Drawdown Testing of Test Well 184W101

drawdown versus discharge rate and specific capacity versus discharge rate are presented on Figures 4-2 and 4-3, respectively.

Results of the step-drawdown test indicate specific capacity values ranging from 13.8 to 15.5 gpm/ft for associated short-term pumping rates of 2,600 to 2,200 gpm, respectively. Specific capacity during the last 12 hours of the 72-hour, 2,520-gpm constant-rate test ranged from 11.0 to 11.3 gpm/ft.

4.2.2 Well Loss Analysis

The drawdown observed in a pumping well is the effect of aquifer and well losses. The aquifer loss is the theoretical drawdown expected at the pumping well in a perfectly efficient well where flow is laminar. The well loss is the additional drawdown observed in the pumping well caused by turbulent flow and frictional head loss effects in or adjacent to the well. Loss components are also classified as linear and nonlinear. Linear well losses are usually caused by damage to the formation during drilling, residual drilling fluids not removed during well development, or head losses as groundwater flows through the gravel pack and screen. Nonlinear well losses are caused by turbulent flow occurring inside the well screen, pump column, and the fracture zone adjacent to the well. Higher well losses caused by the formation are expected to be more pronounced in a fractured bedrock aquifer than in granular porous media as turbulence occurs within the fractures.

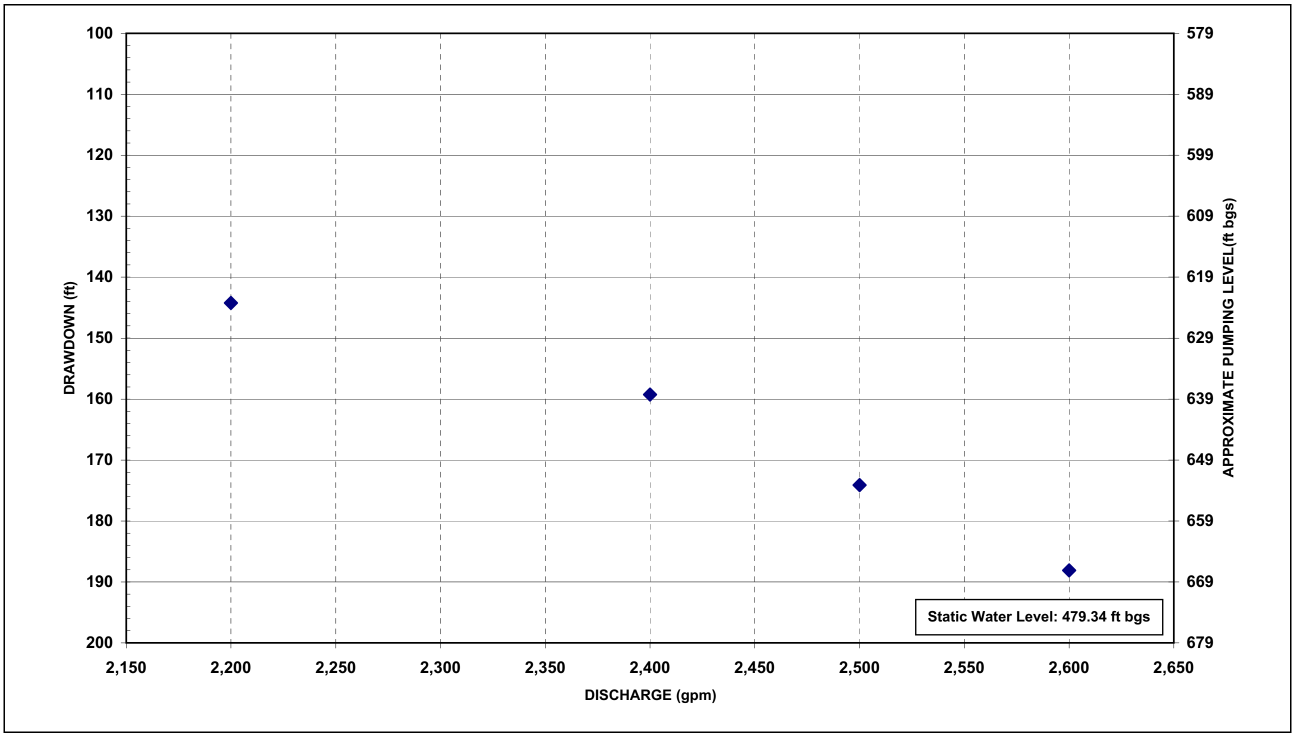


Figure 4-2
Linear Plot of Step-Test Drawdown and
Depth-to-Pumping Level versus Discharge Rate for Test Well 184W101

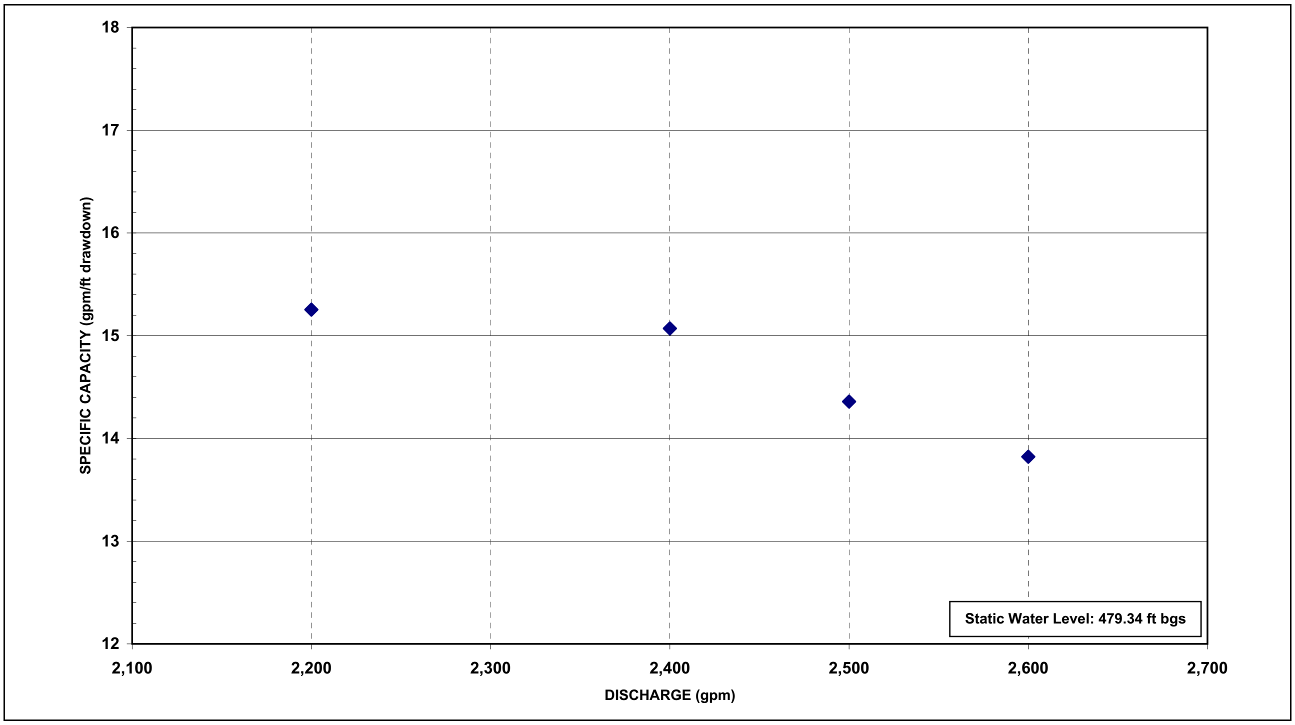


Figure 4-3
Step-Drawdown Test
Specific Capacity versus Discharge Rate for Test Well 184W101

Determination of well loss allows the calculation of a drawdown and specific capacity expected in the pumping well at various discharge rates. Evaluation of well loss also includes the evaluation of turbulent flow with increased pumping rates. Generally, specific capacity decreases at higher pumping rates because of an increase of turbulent flow at the well and a decrease in saturated thickness at the borehole wall under unconfined conditions. The evaluation of well loss allows for better projection of the optimal pumping rate and estimation of actual drawdown in the aquifer near the well, removed from the effects of losses caused by pumping and well inefficiencies, friction loss, and turbulent flow.

Head loss coefficients are calculated by the equation:

$$s = BQ + CQ^2 \qquad \text{(Eq. 4-1)}$$

where,

s = Drawdown in the pumping well
B = Linear loss coefficient
C = Nonlinear well loss coefficient caused by turbulent flow
Q = Discharge rate

Results of the evaluation and a graph of specific drawdown (drawdown/discharge) versus discharge rate used to calculate head loss coefficients using the Hantush-Bierschenk method (Bierschenk, 1963; Hantush, 1964) are presented in Figure 4-4. The drawdown at the end of each step was used to derive in the analysis. Calculations using the Rorabaugh method (Rorabaugh, 1953) were also performed as a comparison.

The loss coefficient for B of 0.0286397 and C of 1.65×10^{-5} was calculated using the Hantush-Bierschenk method. Results from applying the Rorabaugh method calculated C as equal to 4.0×10^{-5}. The coefficient of determination, R^2, is the proportion of variability in a data set. Using these values, specific capacity and drawdown estimates can be projected for any pumping rate using the equation:

$$\frac{s}{Q} = 0.0286 + 1.65 \times 10^{-5} Q \qquad \text{(Eq. 4-2)}$$

The reliability of the projection is highest within the discharge testing range of the step-drawdown test.

The percent of head loss attributed to laminar flow can also be estimated using the equation:

$$((BQ)/(BQ + CQ^2)) \times 100 \qquad \text{(Eq. 4-3)}$$

Analyses were performed using step-drawdown results with and without dewatering corrections. The values not corrected for dewatering are more representative at this location because of the relatively large contribution of groundwater from the deeper fracture/fault zone, as supported by the warmer

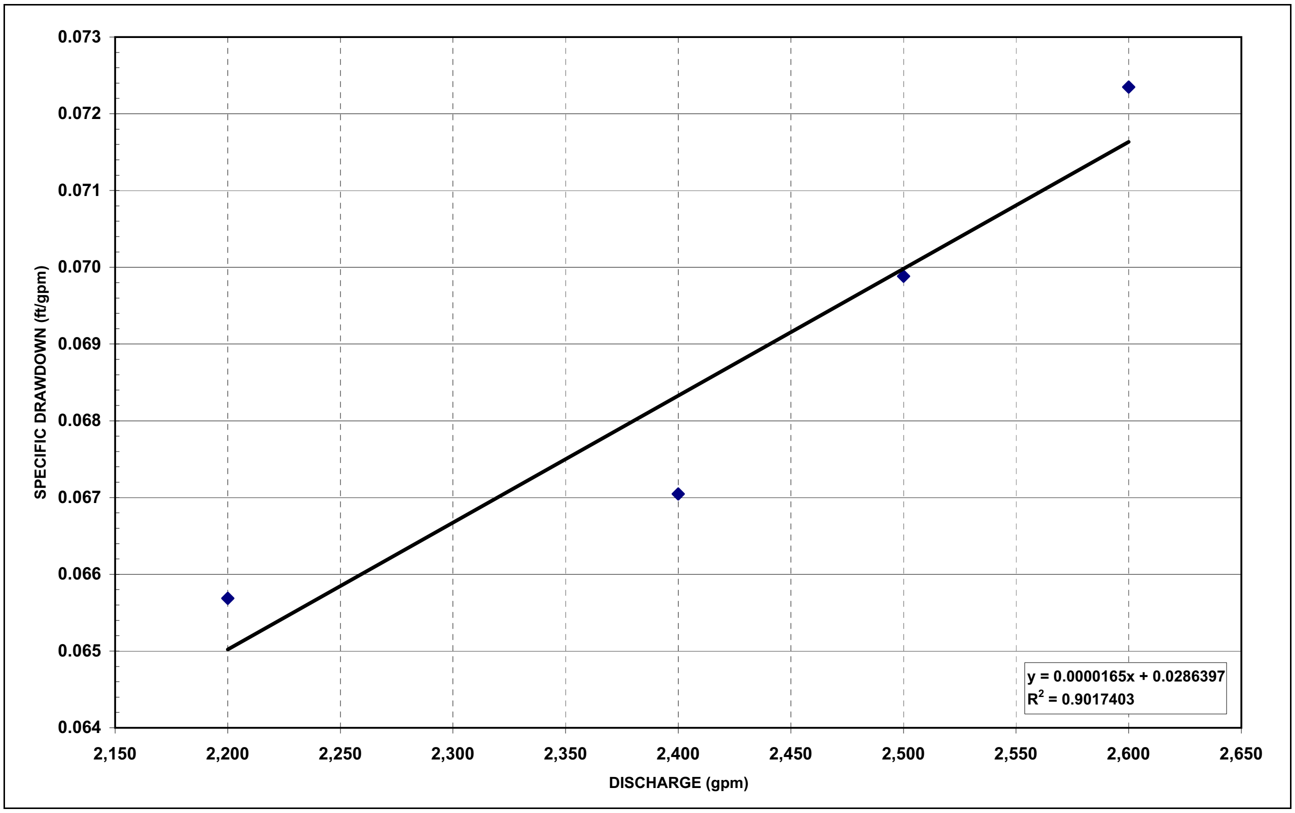


Figure 4-4
Evaluation of Head Loss Coefficients Using
Hantush-Bierschenk Method from Step-Drawdown Test Results

temperature and drilling observations. Table 4-1 shows that the nonlinear losses compose about 56 to 60 percent of the drawdown, the percentage increasing with increasing production rate. This analysis indicates that the nonlinear losses are significant, which should be reflected in a substantial well loss contribution to pumping-well drawdown. Evaluation assumed a saturated thickness of 1,280 ft.

Well efficiency can be evaluated by estimating the drawdown in the test well if there were no well losses. Well efficiency can also be calculated using an estimated transmissivity (*T*) or, if multiple observation wells were present and a distance drawdown graph prepared, projecting estimated drawdown at the test well. The calculations are more reliable if no cascading water is entering the borehole, which commonly occurs in a fractured bedrock aquifer system. Calculation of well efficiency would not be relevant because of the number of factors influencing the analysis and therefore was not performed.

Table 4-1
Step-Drawdown Test Analysis

Q (gpm)	*s* (ft)	*s/Q* (ft/gpm)	Nonlinear Losses (ft)	Linear Losses (ft)	Total Losses (ft)	Nonlinear Total (%)
2,200	144.51	0.0657	79.86	63.01	142.87	56
2,400	160.91	0.0670	95.04	68.74	163.78	58
2,500	174.71	0.0699	103.13	71.60	174.72	59
2,600	188.11	0.0724	111.54	74.46	186.00	60

5.0 CONSTANT-RATE TEST EVALUATION

This section summarizes the collection of hydraulic testing data, selection of the analytical solutions for evaluation of drawdown and pumping data, and the analysis results of the 72-hour constant-rate and recovery test at Test Well 184W101.

5.1 Data Review and Adjustments

Water-level data were collected using pressure transducer and manual methods using the instrumentation described in Section 3.4. Data collection time intervals were logarithmic and in accordance with SNWA procedures and consistent with industry standards. The manual water-level measurements were used to confirm the transducer data. No significant variations between the two data sets were observed.

Outside effects, such as changes in barometric pressure, regional water-level trends, and precipitation events, were monitored during the test period. No influences that would significantly affect the test results were identified. No other pumping wells were present in the area to influence the test results. A detailed discussion of background data and outside influences is presented in Section 3.4.

Totalizer readings indicated a total volume of 10,894,700 gal was pumped during the 72-hour test, which averages 2,520 gpm for the duration of the test. No significant discharge flow adjustment or interruptions occurred during the test. The initial four minutes of test drawdown data were observed to be influenced by borehole storage effects, water filling the pump column, and pressure variations at the flow control valve.

Vertical flow losses within the well were considered during analysis. The friction losses within the well were calculated to be relatively small compared to the drawdown observed in the test well.

5.2 Constant-Rate Test Data

The constant-rate test was performed for a duration of 72 hours at a pumping rate of 2,520 gpm. A summary of time-drawdown data for Monitor Well 184W502M and Test Well 184W101 is presented graphically in log-log and semi-log form on Figures 5-1 through 5-4. Pressure transducer and manual measurement data are presented in Appendix A.

Recovery data were collected immediately upon cessation of pumping activities. Recovery data are presented in a plot of residual drawdown versus log of t/t’ (elapsed time from beginning pumping/time of recovery) in Figure 5-5. Recovery period on the figure begins on the right and ends on the left. Approximately 25 hours after cessation of pumping, pump removal activities commenced. The activities involved in removing the pump caused temporary water-level

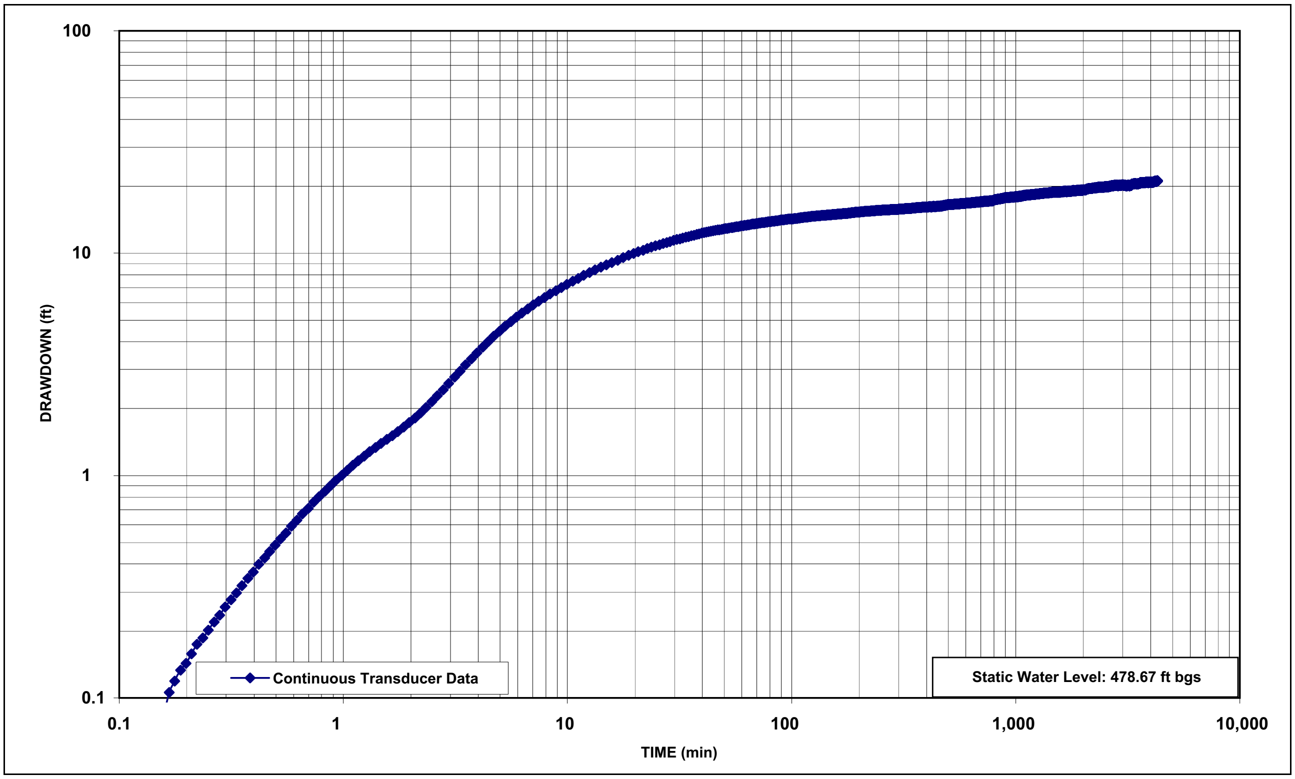


Figure 5-1
Log-Log Data Plot of Drawdown versus Time from Monitor Well 184W502M

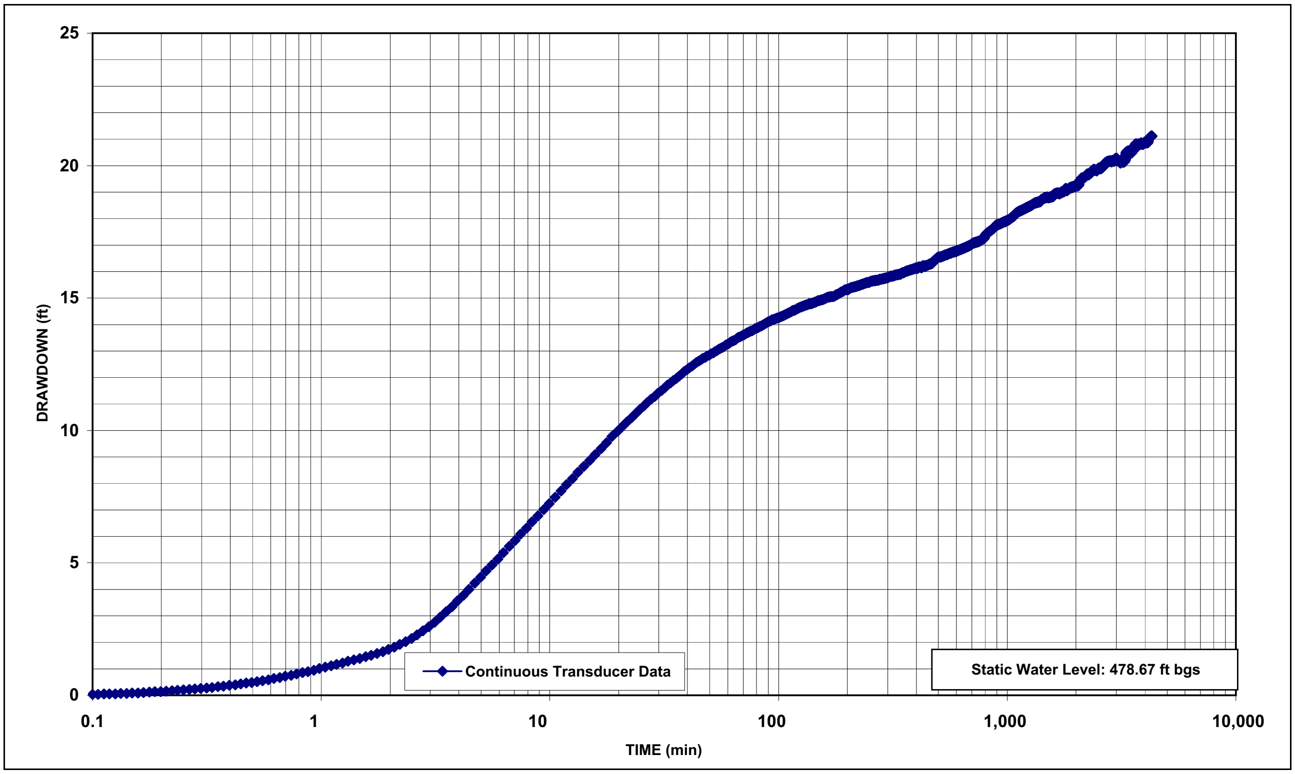


Figure 5-2
Semi-Log Data Plot of Drawdown versus Time from Monitor Well 184W502M

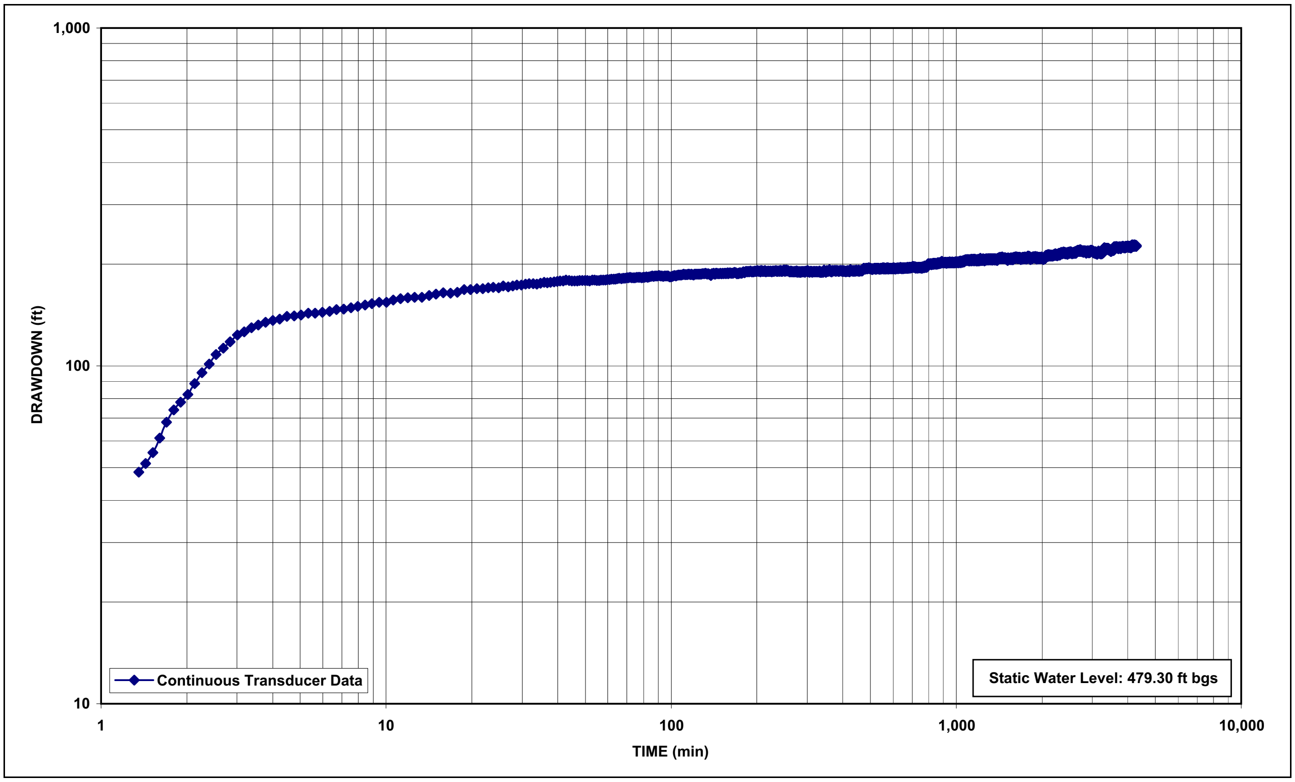


Figure 5-3
Log-Log Data Plot of Drawdown versus Time from Test Well 184W101

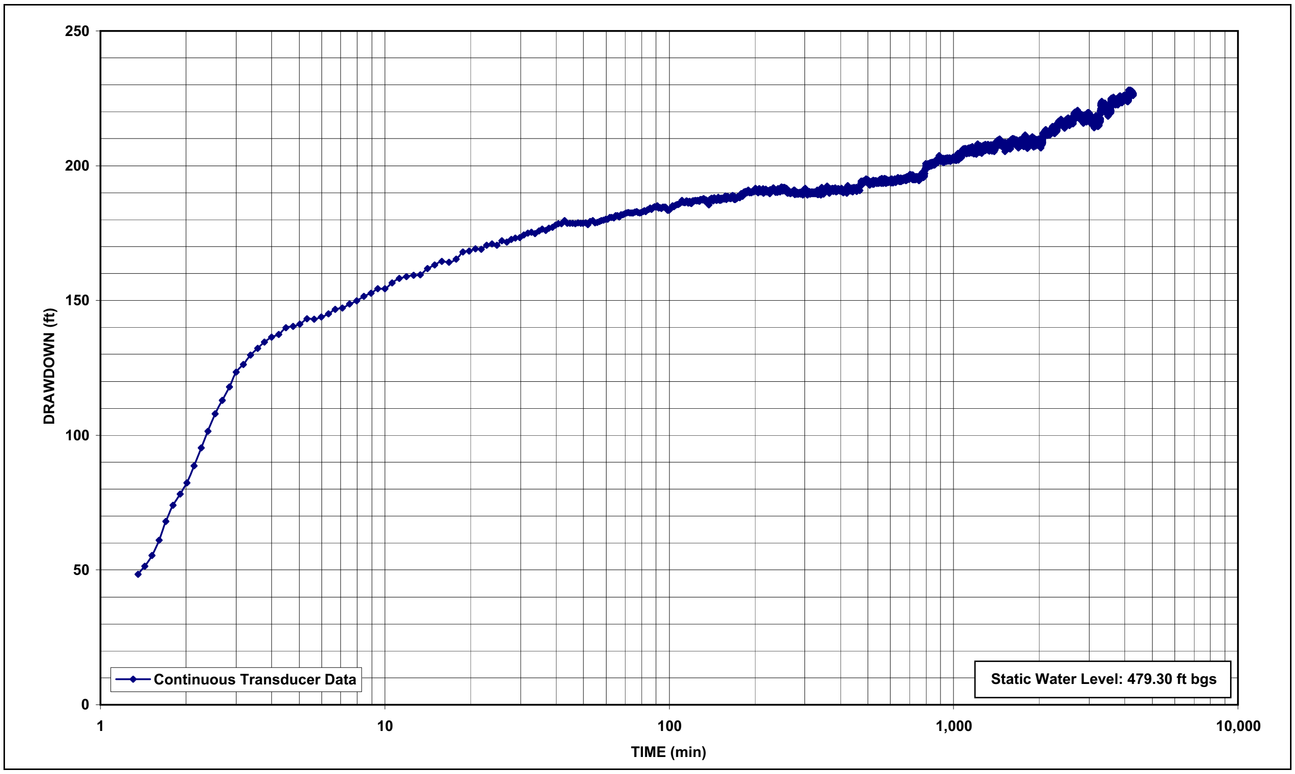
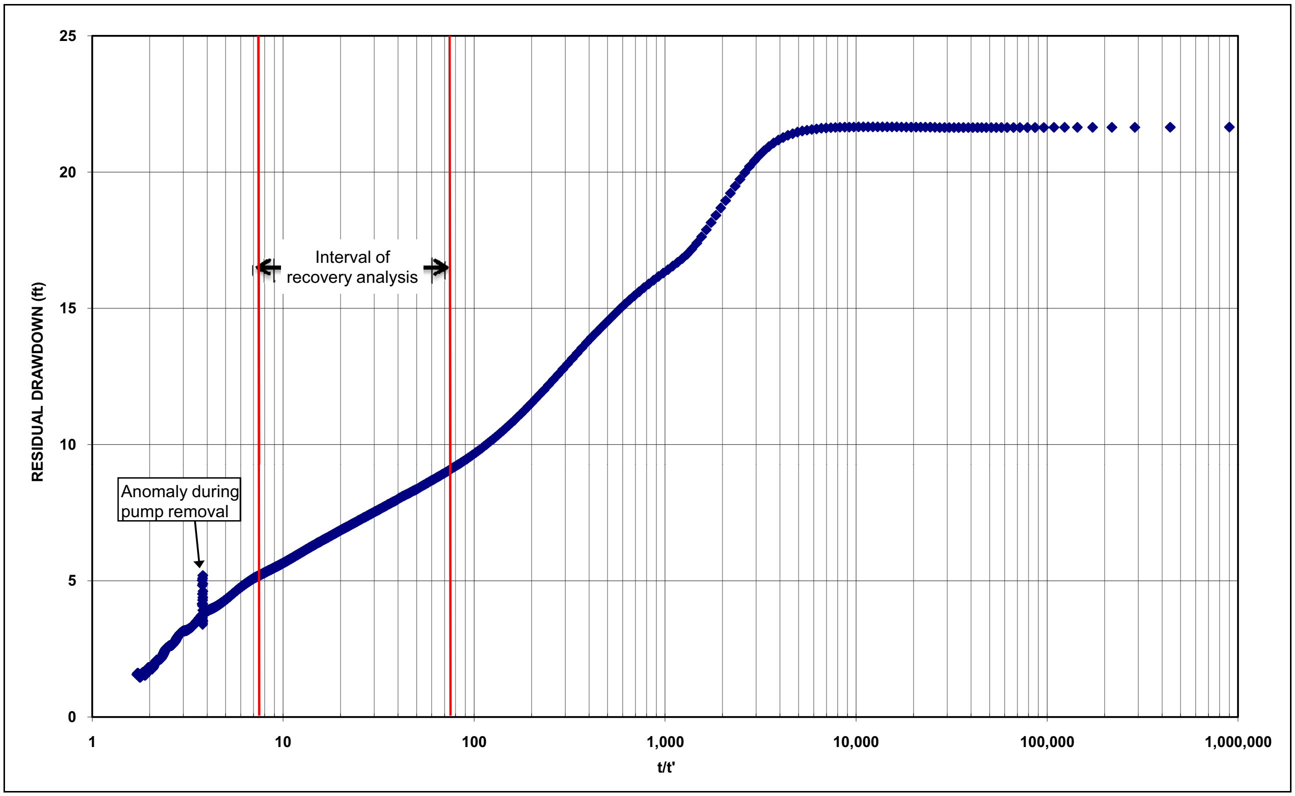


Figure 5-4
Semi-Log Data Plot of Drawdown versus Time from Test Well 184W101



Note: t = Elapsed time since pumping began; t' = elapsed time since pumping stopped.

Figure 5-5
Monitor Well 184W502M Recovery Data Presenting
Residual Drawdown versus the Log of the Ratio of t/t'

fluctuations in Monitor Well 184W502M on the order of 1.5 ft. This is noted on the residual plot in Figure 5-5.

5.3 Analytical Model Selection

The analytical model used for the evaluation of the site data was based upon observed site hydrogeologic conditions and diagnostic log-log time drawdown and drawdown derivative plots. A dual-porosity model was selected as the primary evaluation method because of the presence of saturated fractured bedrock encountered at the site and the drawdown response curves observed. The drawdown curve and derivative plot are representative of the signature of a dual-porosity system, which would be expected in a fractured carbonate-rock aquifer. Initial response in the main fracture network would start to occur as borehole storage effects diminish in early time. A mid-time transition, semi-stabilization period then occurs, during which water in the formation matrix material is released to the fracture network and the drawdown curve flattens to some degree. Rate of release would be dependent upon the matrix skin effect. As pumping continues, release of matrix water decreases, resulting in an increase in the slope of the late-time drawdown curve.

The Barker generalized radial flow model (Barker GRFM) (Barker, 1988), which is a generalized radial flow model for an unsteady, confined, fractured media, is the dual-porosity conceptual analytical model selected as the primary solution. This analytical model is equivalent to the Moench

(1984) fractured media, dual-porosity, radial flow model. However, the Barker GRFM incorporates a flow dimension term. Flow dimension (*n*) provides adjustment of the response for variation in the flow geometry, ranging from $n = 1$ for linear flow, to $n = 2$ for radial flow, to $n = 3$ for spherical flow. This parameter can be applied to situations in which a linear feature, such as a fault, may affect the drawdown response or conversely as an adjustment for partial penetration (shift to slightly spherical flow dimension) effects. An analytical model with these features that also incorporates specific aspects of unconfined aquifer response, such as delayed gravity drainage or dewatering, is not available. A dual-porosity solution is more appropriate over an unconfined solution, such as the Neuman solution (Neuman, 1975), which considers only delayed response or gravity drainage of the formation. Given that the water table was located within fractured carbonate with low storage, the delayed gravity drainage effect would not be expected to be as substantial as dual-porosity effects.

General assumptions associated with the Barker GRFM solution are that:

- An aquifer has infinite extent and uniform extent of flow.
- Pumping and observation wells are fully penetrating.
- An aquifer is confined with single or dual porosity.
- Matrix blocks are slab shaped or spherical.
- Flow is unsteady.

The complexities of the aquifer system do not fully conform to the assumptions of the analytical model. However, the Barker GRFM solution is the most appropriate of the analytical solutions available for the observed hydrogeologic conditions at this test location. While the assumptions related to aquifer and flow conditions are not perfectly satisfied, they are sufficiently satisfied to provide a reasonable estimate of aquifer parameters.

A correction equation for dewatering (Kruseman and De Ridder, 1994, p. 101) was considered and applied to the drawdown response before analysis to account for the reduction in saturated thickness, resulting from unconfined conditions which may occur at the site, influencing the area near the test well. This approach provides for bounding of the effect of dewatering and was applied in this solution with minor effect on results.

The Cooper-Jacob semi-log straight-line approximation (Cooper and Jacob, 1946) was used as a secondary evaluation solution method. This approach was used to fit early- and late-time data. For a homogeneous, dual-porosity, radial-flow system, the early-time (after casing storage, but before matrix effect) and late-time (after the matrix effect period approaching radial-flow conditions) slopes on a semi-log plot would be similar if not influenced by boundary conditions.

5.4 Constant-Rate and Recovery-Test Analysis

5.4.1 Test Analysis Methodology

The aquifer test-analysis software AQTESOLV V4.50 (Duffield, 1996-2007) was used for curve fitting. The data logger records of pressure transducer output were used to create AQTESOLV input files of the drawdown and recovery data. The time representing the measurement at the start of identifiable drawdown at the test well was used as the start time to determine the elapsed time and drawdown magnitude. The basic input measurement and parameter values used for analysis are shown in Table 5-1.

Table 5-1
Measurement and Parameter Values Used for Analysis

r(w) Radius of the well	1.08 ft
r(c) radius of the well casing	0.83 ft
r(e) Radius of the production tubing	0.25 ft
r Radial distance from 184W101 to 184W502M[a]	175 ft
b Aquifer saturated thickness[b]	1,280 ft
b’ Fracture spacing	10 and 3.3 ft

[a] Surface measurement
[b] Static water level to bottom of the borehole

Parameter symbols used in this section are presented below:

K = Aquifer/fracture hydraulic conductivity (ft/day)
K' = Matrix hydraulic conductivity (ft/day)
n = Flow dimension; 1 = linear, 2 = radial, and 3 = spherical (dimensionless)
Q = Pumping discharge rate (gpm)
Sf = Fracture skin factor (dimensionless)
Ss = Fracture-specific storage (ft^{-1})
Ss' = Matrix-specific storage (ft^{-1})
Sw = Borehole skin factor or well loss coefficient value (dimensionless)
s = Drawdown at pumping well
t = Time
T = Transmissivity (ft^2/day)
S = Storativity (dimensionless)

The Barker GRFM was fitted to the drawdown and recovery responses of both the monitor and test wells sequentially and iteratively to determine the set of model parameter values that best fit the data. The selection of the most representative set of parameter values for the Barker GRFM depends upon the hydrogeologic conceptual model and interpretations of aquifer-response components. The most representative set of parameter values is a range of approximate values for each parameter, based on applicable constraints. The model fit is optimized for hydraulic conductivity. Various parameters are correlated and can be adjusted, to some degree, with no uniqueness. The model, fitted to all of the data and constraints, is optimal within a restricted range for the major parameters.

Average fracture spacing, which for practical purposes is unknown, has been assigned various spacing and characteristics for a sensitivity analysis. The sensitivity of hydraulic conductivity to this parameter is low, as indicated by the results of an analysis of fracture spacing of 3.3 and 10 ft. No independent data exist for anisotropy. The ratio of vertical or horizontal hydraulic conductivity was assumed to be 1 because of the presence of high-angle faulting in the well area.

5.4.2 Test Analysis Results Summary

The Barker GRFM solution was derived through an extensive, iterative analysis process that converged to provide an optimal match for all test data. The primary solution range was compared to a simplified Cooper-Jacob secondary solution. Emphasis should be placed on the primary solution because of underlying solution limitations and site hydrogeologic conditions. Results of the Barker GRFM and Cooper-Jacob solutions are summarized in Table 5-2. Discussions of the analysis approach and representative optimal solution plots are presented below.

Table 5-2
Summary of Optimal Analysis Results

<table>
<tr><th colspan="9">Primary Composite Solution, Barker GRFM Analysis</th></tr>
<tr><th>Fracture Spacing (ft)</th><th>K (ft/day)</th><th>Ss (ft^{-1})</th><th>K' (ft/day)</th><th>Ss' (ft^{-1})</th><th>n</th><th>Sf</th><th>S</th><th>T^a (ft^2/day)</th></tr>
<tr><td>3.3 to 10</td><td>7.6 to 8.0</td><td>6.85×10^{-7}</td><td>1.07 to 6.50×10^{-5}</td><td>3.90 to 4.50×10^{-6}</td><td>2.35</td><td>0</td><td>5.0 to 5.8×10^{-3}</td><td>9,700 to 10,200</td></tr>
<tr><th colspan="9">Secondary Individual Well Solution, Cooper-Jacob Analysis</th></tr>
<tr><th>Analysis Time Interval</th><th>K (ft/day)</th><th>Location</th><th colspan="3">S</th><th colspan="3">T (ft^2/day)</th></tr>
<tr><td>Early-Time</td><td>7.8</td><td>184W502M</td><td colspan="3">7.35×10^{-4}</td><td colspan="3">10,000</td></tr>
<tr><td>Late-Time</td><td>14.2</td><td>184W502M</td><td colspan="3">---</td><td colspan="3">18,200</td></tr>
<tr><td>Late-Time</td><td>2.0</td><td>184W103</td><td colspan="3">0.03</td><td colspan="3">2,500</td></tr>
</table>

[a] Assume saturated thickness of 1,280 ft to derive *T*.

5.4.3 Barker GRFM Analysis

The Barker GRFM solution was fitted to the data iteratively, applying constraints successively to refine the fit and produce an overall model that was consistent with all site and literature data and to determine the parameter range in which the solution is optimized. The interpreted solution set of model parameters does not represent exact values for each parameter; rather, it represents a set of approximate values that locate the parameter space in which the solution is optimized for hydraulic conductivity.

Fracture-specific storage (Ss) was estimated and constrained at 6.85×10^{-7} ft^{-1}. Constraints on Ss are within ranges (1.06×10^{-7} to 4.57×10^{-8} ft^{-1}) for generally similar conditions reported in Kilroy (1992). Matrix-specific storage (Ss') of the carbonates is generally expected to be larger than fracture-specific storage. The Ss' calculated range was 3.90 to 4.50×10^{-6} ft^{-1}. The matrix-specific storage usually provides the majority of the storage component relative to fracture storage. Specific storage can be equated to storativity (S) as the product of specific storage and aquifer thickness and related to compressibility of fluid in the aquifer. General information from Freeze and Cherry (1979) for carbonate compressibility for jointed rock can be used to calculate the theoretical Ss, which extends the upper range to about 3×10^{-5} ft^{-1}.

With *Ss* and *Ss′* values constrained, the *K* value required to fit the monitor well drawdown was determined. Then, the difference in the magnitude of the drawdown between the monitor well and the test well had to be accounted for. The step-drawdown test analysis indicated that a large portion of the test well drawdown was due to nonlinear losses, which typically are due to well losses. The well construction, however, provides a substantial screened interval, and the gravel pack likewise should not be restrictive because of extensive well development. Consequently, the well losses are mainly attributed to the turbulent flow in the near-well radius caused by converging flow in the fractures, which are restrictive. The large proportion of drawdown attributed to nonlinear losses equates to a large well loss coefficient value (*Sw*). In turn, these large well losses account for a great difference in drawdown between the monitor well and the test well.

The drawdown responses observed in the monitor and test wells differ significantly. During the constant-rate test, the drawdown response indicates a greater *K* value in the monitor well than in the test well. During the recovery test, however, the response for both wells was similar. It was necessary to use an *n* greater than 2 for an appropriate model fit for the monitor well. This introduced a correction for vertical flow in the aquifer, which may reflect a limited-height fracture zone intersecting the production well. This parameter can be used to produce the large difference in drawdown during production. It was also necessary to use an *n* greater than 2 to fit the early-time data to the observation well. The parameters *n* and *Sw* are highly correlated, and a unique solution is not identifiable. The value of *n* greater than 2 is approximately correct, but some uncertainty exists for the *n* value with respect to *Sw* value equal to 0.

The Barker GRFM solution's optimal aquifer *K* value, which is dominated by fracture hydraulic conductivity, ranged from 7.60 to 8.00 ft/day. Matrix *K* ranged from 1.07 to 6.5×10^{-5} ft/day. Fracture-specific storage was calculated to be 6.85×10^{-7} ft^{-1}. Matrix-specific storage ranging from 3.9 to 4.5×10^{-6} ft^{-1} relates to a storativity range of 0.005 to 0.0058 assuming a saturated thickness of 1,280 ft.

Log-log and semi-log time-drawdown plots for the pumping period using the optimal Barker GRFM solution with a fracture spacing of 10 ft are presented in Figures 5-6 and 5-7, respectively. Derivative drawdown versus time for Monitor Well 184W502M is presented in Figure 5-8. The derivative drawdown response in the monitor well is consistent with a dual-porosity, fractured bedrock system.

Well loss analysis of Test Well 184W101 is presented in Section 4.2.2. An evaluation and removal of well loss components are presented in Figure 5-9, which provides an indication of drawdown in the formation in the vicinity of the test well outside of the drawdown distortion caused by well losses from turbulent flow and well construction. This calculation of drawdown without well or wellbore skin losses provides an approximation value of aquifer drawdown in the vicinity of the test well during testing.

Analysis results of recovery data collected from the test and monitor well are presented in Figure 5-10. This figure presents a plot of residual drawdown versus log *t/t′* (ratio of total pumping elapsed time to time since pumping stopped). In this plot, initial recovery is to the right, and later recovery is to the left.

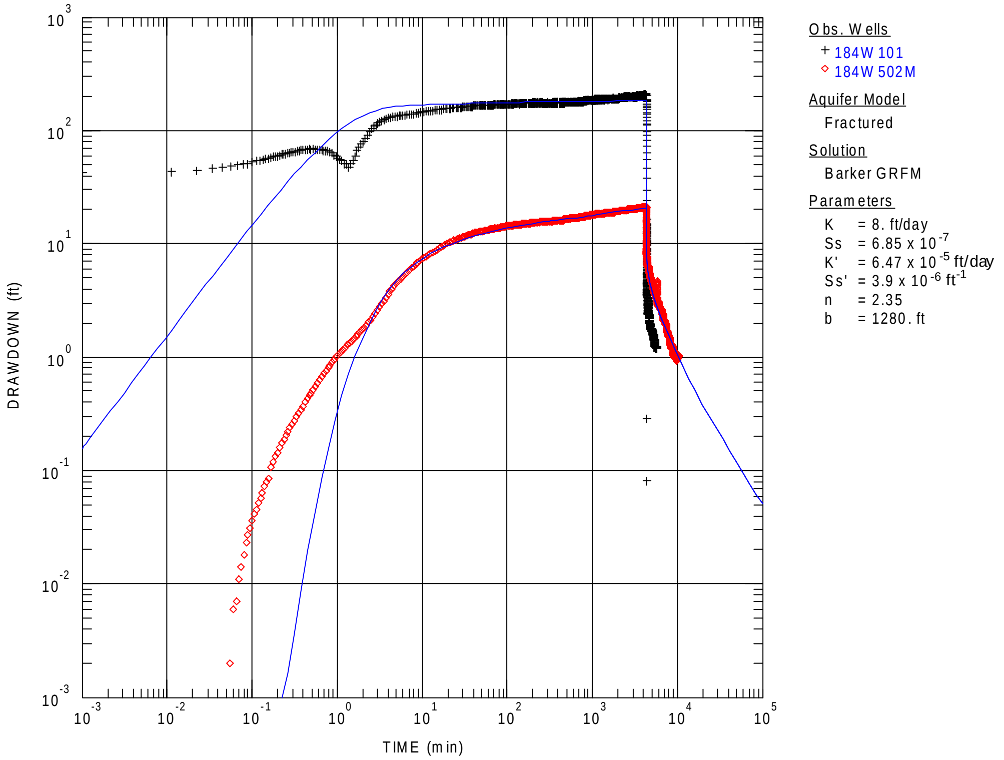


Figure 5-6

Optimal Barker GRFM Solution Pumping Period Log-Log Plot

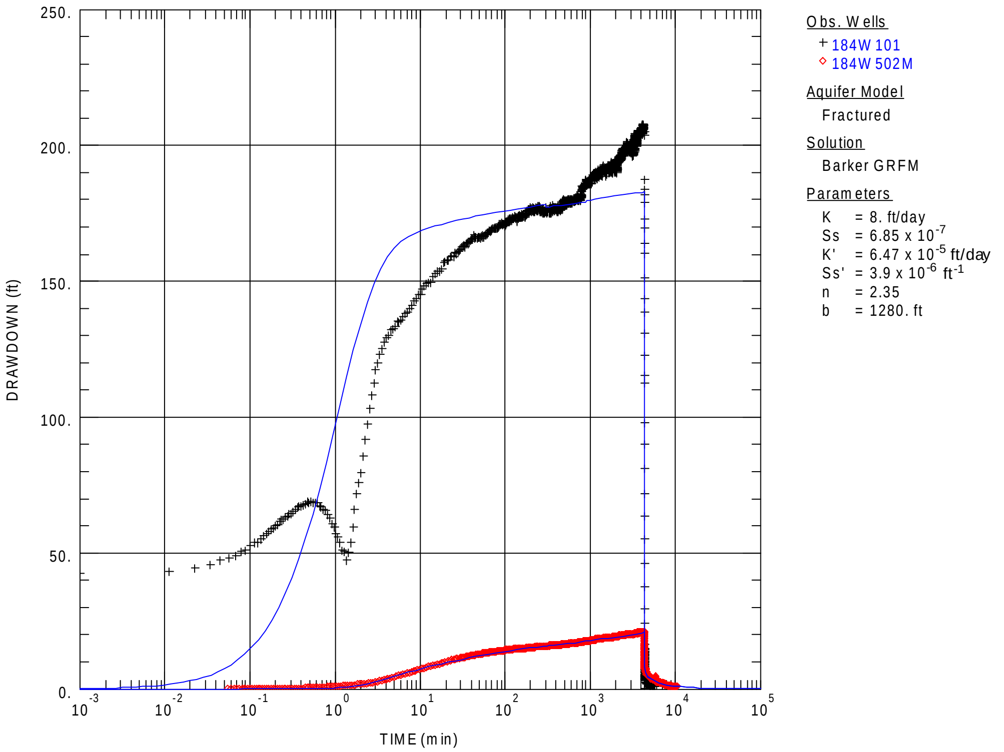


Figure 5-7

Optimal Barker GRFM Solution Pumping Period Semi-Log Plot

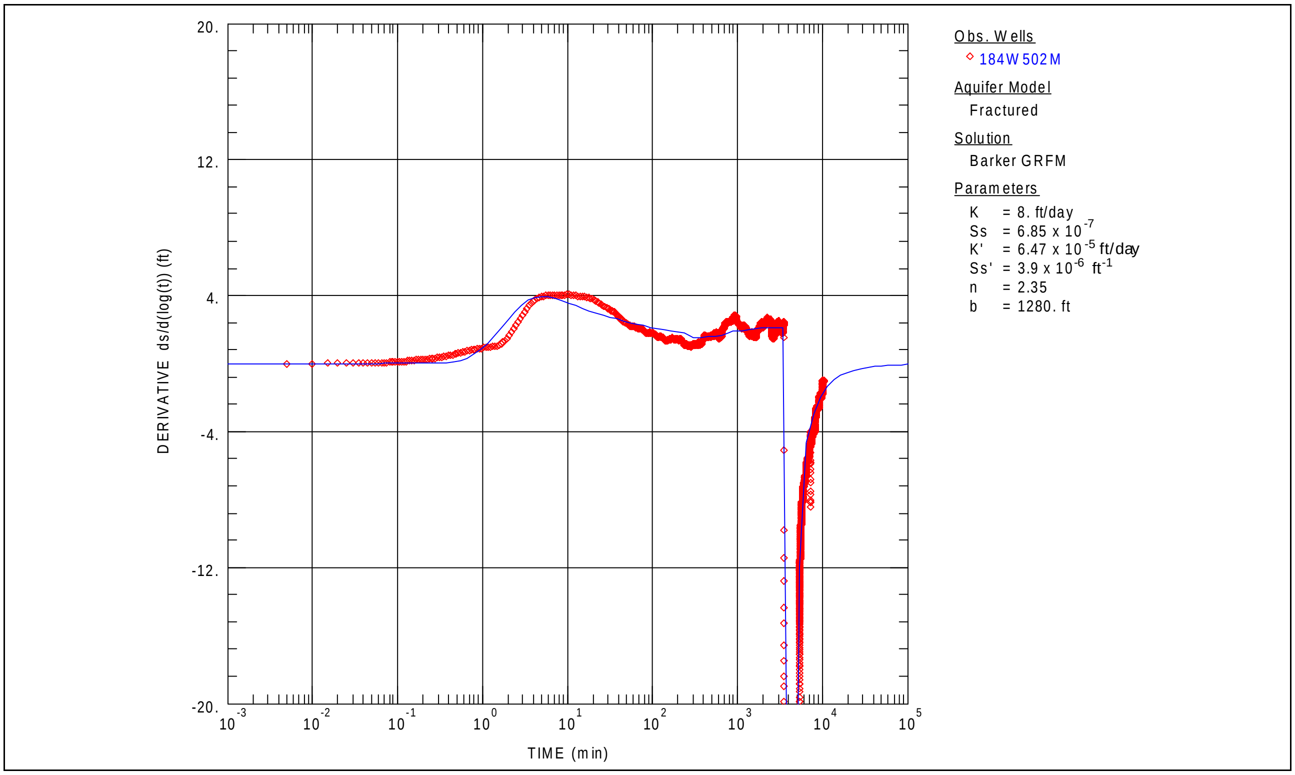


Figure 5-8
Optimal Barker GRFM Solution Drawdown Derivative for Monitor Well 184W502M

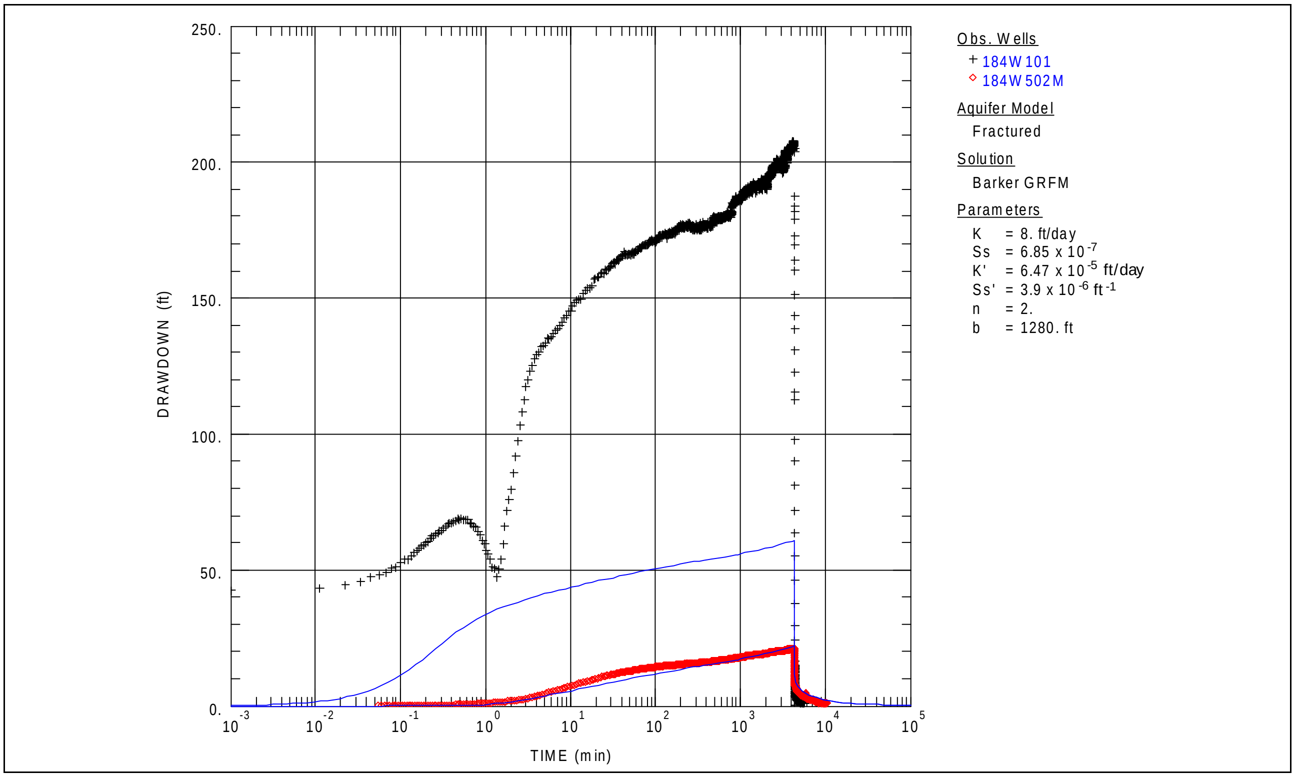


Figure 5-9
Optimal Barker GRFM Solution, Test Well 184W101 Well Losses Removed

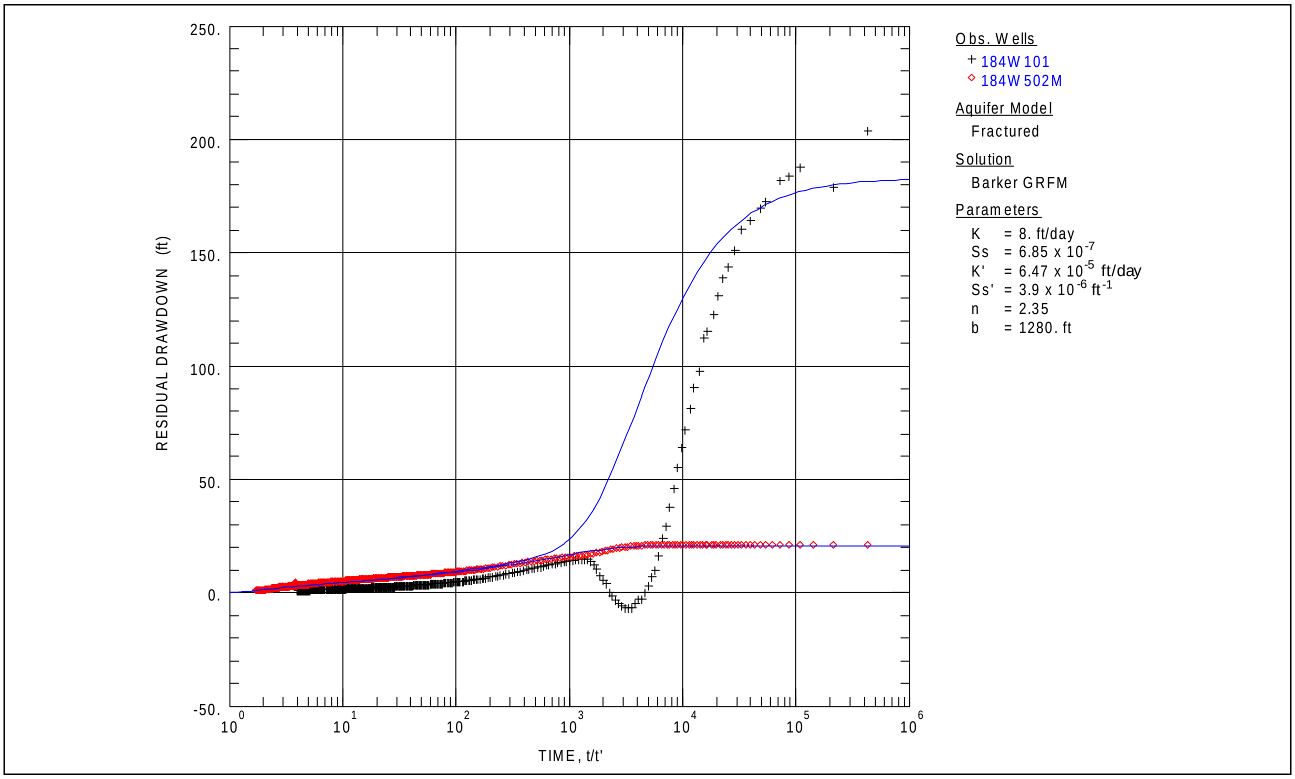


Figure 5-10
Optimal Barker GRFM Solution Recovery Period

The drawdown increase at approximately 800 min of elapsed time may be interpreted as a low-flow boundary. One possibility is a fault plane where volcanics are juxtaposed against the carbonates located approximately 2,500 ft to the west, as identified by surface geophysical profile. Boundary conditions in the vicinity of the test well can be evaluated further with longer-term pumping.

5.4.4 Cooper-Jacob Analysis

The Cooper-Jacob straight-line analysis was used to derive a secondary solution, using data from the monitor and test wells, and was compared to the Barker GRFM results. These values should be viewed with less confidence than the Barker GRFM solution because of the limitations of the Cooper-Jacob analysis relative to the hydrogeologic conditions encountered at the test site.

Monitor Well 184W502M data were used as the principal comparison to the primary solution because well loss and partial penetration would not be expected to distort the drawdown as they would in the test well. Transmissivity values of 10,000 and 18,200 ft^2/day were derived from the early- and late-time data from the monitor well, respectively. Using a saturated thickness of 1,280 ft, the resulting *K* values are 7.8 and 14.2 ft/day, respectively. Late-time data at the test well were also evaluated, resulting in an estimated *K* of 2.0 ft/day and *S* of 0.03. Early-time analysis with this method resulted in a *K* of 3.81 ft/day. Values for *K* derived from *T* using the Cooper-Jacob method are directly related to the effective aquifer saturated thickness used.

The Cooper-Jacob straight-line analysis of the semi-log, time-drawdown plot of Monitor Well 184W502M early-time and late-time data is presented in Figures 5-11 and 5-12, respectively. The initial phase of early-time data at the start of a test is usually affected by flow system instability associated with variation in discharge rates prior to stabilization and borehole storage effects where water is removed from the storage within the well. The early-time aquifer response can only be evaluated after the casing storage effects are past and before dual-porosity matrix flow begins. The Cooper-Jacob straight-line solution was fitted to the stabilized slope just before matrix flow began. The late-time data, after the second day of pumping, were also fitted with a Cooper-Jacob straight-line solution. The slopes of the lines fitted to both the late-time and early-time data are dissimilar. This indicates that the early-time data may not have been sufficiently stabilized prior to the beginning of matrix flow. The *S* value taken from the early-time data is an order of magnitude less than the *S* value calculated with the Barker GRFM. The late-time *S* value is not representative of the aquifer because of the time offset of the matrix-dominated flow period. Due to the apparent stabilization of the late-time data, the *T* value is probably more representative of the aquifer than the *T* value calculated using the early-time data.

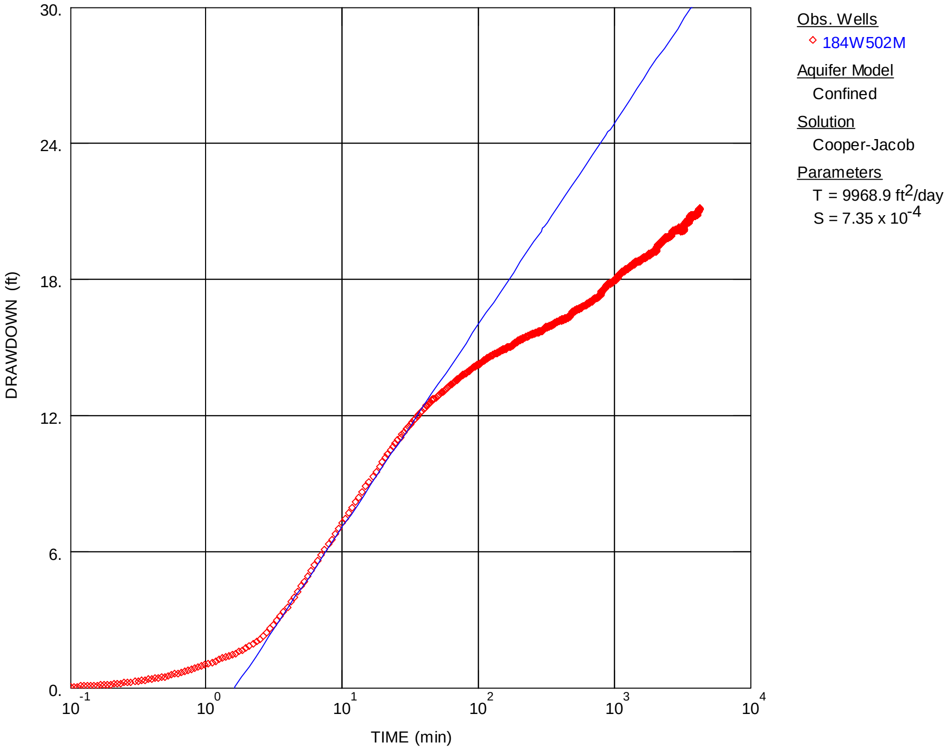


Figure 5-11
Cooper-Jacob Early-Time Solution, Monitor Well 184W502M

5.5 Discussion

The test results provide representative data about the aquifer system without influences from outside pumping or natural hydrologic variation. Diagnostic time-drawdown data plots and site hydrogeologic conditions are indicative of a dual-porosity aquifer system. The plots indicate the early-time wellbore storage effects, fracture network response phase, transition zone of matrix

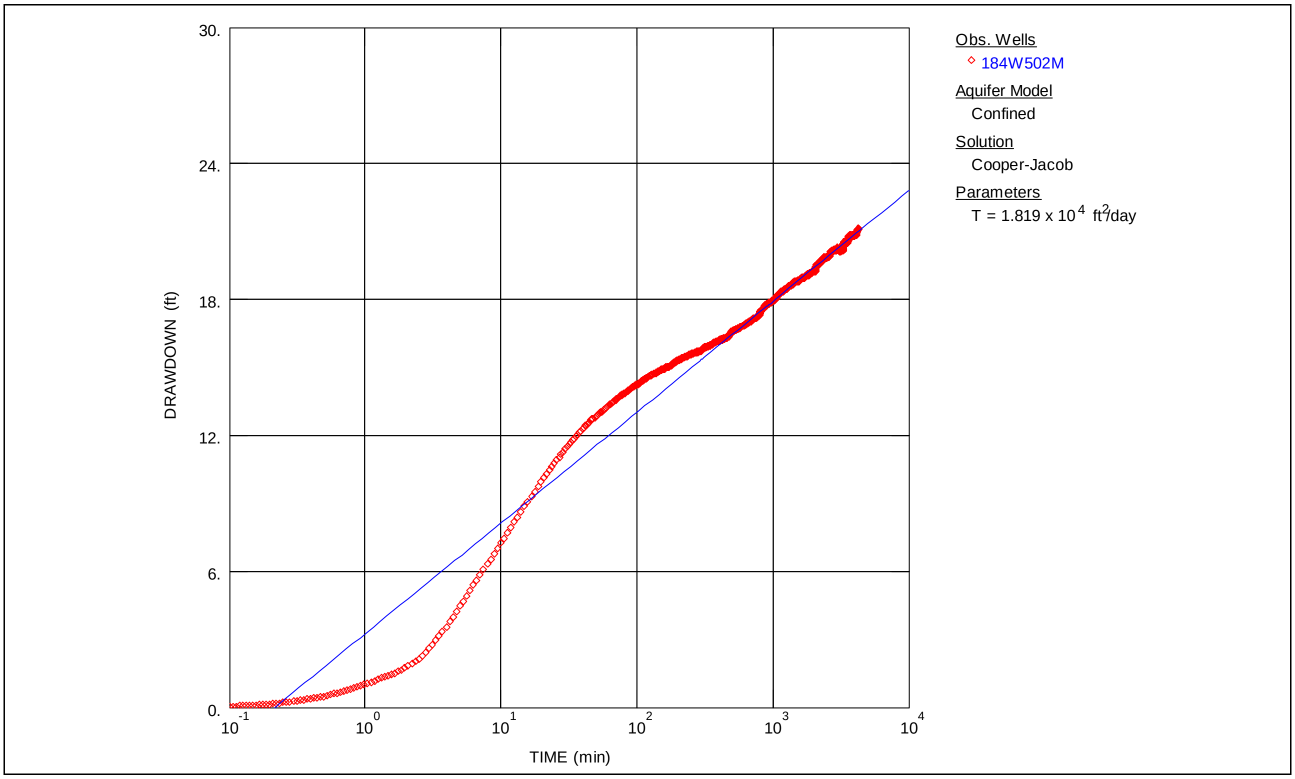


Figure 5-12
Cooper-Jacob Late-Time Solution, Monitor Well 184W502M

response phase, identification of a potential boundary condition, and system equilibrium reflected in the suggested late-time data approaching radial flow.

Analysis of the test results indicates an optimal *K* and *S* value based upon the data collected during the 72-hour constant-rate test and subsequent recovery period. The carbonate aquifer system at the site is complex, with a primary fracture zone identified as hydrologically connected to the wells. The results of the testing provide a composite hydraulic conductivity over the length of the saturated interval of the wells.

Based on the geophysical logs for the test well, there is a zone from approximately 950 to 1,520 ft bgs where the spontaneous potential indicates secondary porosity that is much greater than the rest of the borehole (Eastman and Muller, 2009). The bulk of the well production comes from this zone, based on drilling observations, geophysics, and groundwater temperature. This is consistent with a possible high-angle fault that may be intersected by the wells. The aquifer thickness, considering the water level to the total depth, is 1,280 ft. The aquifer thickness, using this zone of increased secondary porosity, is 570 ft. Decreasing the aquifer thickness provides for greater *K* values for this zone.

The controlling factor for determination of *K* from *T* from the Cooper-Jacob secondary solution is the estimated saturated thickness (*b*). If a saturated thickness of 570 ft is assumed, the resulting *K* from the late-time Cooper-Jacob *T* is 31.9 ft/day. This value is closer to that of previous hydraulic testing results performed at well 184W105, which is completed within a more heavily fractured fault zone

(Prieur et al., 2009). However, because using a larger, estimated saturated thickness is more conservative, an estimated saturated thickness of 1,280 ft was used in this analysis.

It is significant that the recovery curves for both wells are almost identical once past the effect of the pump column injection phenomenon, which is caused by the return of water in the pump column to the formation after the pump is stopped. This occurs because no check valve was used in the pump column. The crux of determining a solution that coordinates all aspects of the test data is evaluation of the site hydrogeologic conditions, simulating both the large difference in drawdown between the test well and the monitor well through identification of well loss and the almost identical recoveries.

Monitor Well 184W502M's response provides information on the formation hydraulic properties independent of linear and nonlinear head losses associated with the pumping well and theoretically provides the information necessary to determine storage. However, the information from this single monitor well is not as definitive as multiple observation wells to evaluate and define asymmetry and horizontal anisotropy. Fitting of the early-time drawdown can be done consistently with the observation well response-based hydraulic conductivity but not consistently with respect to the storage values.

The short-term pumping period, availability of one observation well, and expected aquifer heterogeneities limit the ability to scale results to determine horizontal anistropy or evaluate potential boundary conditions. The presence and characteristics of boundaries and/or higher or lower hydraulic-conductivity zones that may appear after extended pumping cannot be evaluated until extended pumping is performed. Additional analysis and review should be performed as longer-term operational pumping data become available for the well site or as additional regional hydrogeologic data are obtained.

6.0 GROUNDWATER CHEMISTRY

Groundwater-chemistry data for Test Well 184W101 and Monitor Well 184W502M are presented within this section. Additional data for other SNWA wells located within the vicinity of these wells (see Figure 2-1) are also presented for comparison.

6.1 Groundwater Sample Collection and Analysis

Water samples were collected from Test Well 184W101 on April 12, 2007, at 08:00 after pumping over 16 million gallons (following well development, step-drawdown testing, and a portion of the constant-rate test). For these samples, turbidity, pH, specific conductance, dissolved oxygen, and temperature were measured in the field. With the exception of dissolved oxygen, these parameters were also measured periodically during well development and testing. Sampling and field measurement of the water-quality parameters were performed using the *National Field Manual for the Collection of Water-Quality Data* (USGS, 2007) as the basis. All measurement equipment was calibrated according to the manufacturers' calibration procedures. Samples were sent to Weck Laboratories, Inc., (Weck) for analysis of a large suite of parameters, including major solutes, minor and trace constituents, radiological parameters, and organic compounds. Weck is certified by the State of Nevada and performs all analyses according to U.S. Environmental Protection Agency (EPA) methods or methods published in *Standard Methods for the Examination of Water and Wastewater* (Eaton et al., 2005). The parameters analyzed and the corresponding analysis method are presented in Tables B-1 and B-2. Weck provided all sample containers and preservatives. Radiation Safety Engineering, Inc., and Frontier Analytical Laboratory were contracted by Weck for the analysis of radiological parameters and dioxin, respectively. In addition, samples were collected for analysis of oxygen and hydrogen isotopes by University of Waterloo's Environmental Isotope Laboratory, carbon isotopes by University of Arizona's NSF-Arizona Accelerator Mass Spectrometry Laboratory, chlorine-36 by Purdue University's Purdue Rare Isotope Measurement (PRIME) Laboratory, and strontium and uranium isotopes (and uranium concentration) by the U.S. Geological Survey (USGS) Earth Surface Processes Radiogenic Isotope Laboratory.

Water samples were collected from Monitor Well 184W502M on January 29, 2007, at 10:00 after pumping approximately 122,500 gal. Samples were sent to Weck for analysis of major solutes and trace and minor constituents. A sample was also collected for the analysis of oxygen and hydrogen isotopes by University of Waterloo's Environmental Isotope Laboratory (Table B-1). The pH, specific conductance, and temperature associated with these samples were measured in the field. Monitor Well 184W502M was used as the water source for drilling Test Well 184W101. The water source for drilling Monitor Well 184W502M was a well located at the Harbecke Ranch.

For comparison, the groundwater chemistry of other wells in the area are presented in this section. The wells, all drilled by SNWA (see Figure 2-1), were completed in a carbonate-rock aquifer to the following depths:

184W101	1,760 ft bgs
184W502M	1,828 ft bgs
184W103	1,046 ft bgs
184W504M	1,040 ft bgs
184W105	1,160 ft bgs
184W506M	1,160 ft bgs

6.2 EPA Drinking Water Standards

The national maximum contaminant levels (MCLs) for drinking water, established by the EPA and authorized by the Safe Drinking Water Act, are presented in Tables B-1 and B-2. These national health-based standards are to protect against both naturally occurring and man-made contaminants that may be found in drinking water. Also presented in Table B-1 are the secondary drinking water standards established by the EPA. These are nonenforceable guidelines that regulate contaminants that may cause cosmetic or aesthetic effects in drinking water. As shown in Tables B-1 and B-2, no constituents exceeded the primary or secondary drinking water standards for groundwater of Test Well 184W101. Groundwater samples taken from Monitor Well 184W502M exceeded the secondary MCL for iron. This exceedance is discussed further in Section 6.3.3.

6.3 Groundwater-Chemistry Results

In this section, the field measurements and analytical results for the groundwater of Monitor Well 184W502M and Test Well 184W101 are presented and compared to those of groundwater samples from four wells within the vicinity.

6.3.1 Field Results

Field measurements of turbidity, pH, specific conductance, and temperature were performed periodically throughout well development and testing of Test Well 184W101 and for the samples collected for laboratory analysis (see Table B-1). For Test Well 184W101, these parameters stabilized within the first 11 hours of the constant-rate test. Measurements ranged from 0.69 to 1.93 nephelometric turbidity units (NTUs) (turbidity), 7.79 to 7.99 (pH), 323 to 332 µS/cm (specific conductance), and 22.4°C to 24.9°C (temperature) over the remaining period of pumping (61 hours). Field measurements made at the time of sample collection are reported as 0.96 NTU, 359 µS/cm, 7.7, 24.1°C, and 2.29 mg/L for turbidity, specific conductance, pH, water temperature, and dissolved oxygen concentration, respectively.

For Monitor Well 184W502M, field measurements made at the time of sample collection are reported as 394 µS/cm, 8.49, and 20.5°C for specific conductance, pH, and water temperature, respectively. No turbidity or dissolved oxygen concentration measurements were performed for the groundwater of Monitor Well 184W502M.

When compared to Test Well 184W101 and Monitor Well 184W502M, the water temperatures in the shallower wells were significantly lower, 184W103 (12.0°C), 184W504M (12.1°C), 184W105 (13.0°C), and 184W506M (12.7°C). In general, the specific conductivities were greater in the monitor wells, 394 µS/cm (184W502M), 333 µS/cm (184W504M), and 385 µS/cm (184W506M), than in the test wells, 359 µS/cm (184W101), 263 µS/cm (184W103), and 282 µS/cm (184W105). The higher specific conductivities observed for the groundwater in 184W101 and 184W502M are attributed to increased mineral dissolution in the warmer groundwater. The pH values ranged from 7.5 (184W504M) to 8.5 (184W502M) with no clear trend between the monitor and test wells.

6.3.2 Major Constituents

The concentration of the major constituents in groundwater samples from Test Well 184W101 and Monitor Well 184W502M are presented in Table B-1. Major constituents are defined as those commonly present in groundwater at concentrations greater than 1 mg/L and typically include bicarbonate (HCO_3), calcium (Ca), chloride (Cl), magnesium (Mg), potassium (K), silica (SiO_2), sodium (Na), and sulfate (SO_4). Other major constituents may include carbonate (CO_3), fluoride (F), and nitrate (NO_3). The sum of the charge of major cations should equal the sum of the charge of the major anions in solution (in milliequivalents per liter [mEq/L]); thus, calculation of the anion-cation (charge) balance is used to assess the accuracy of the analyses and to ensure that the full suite of anions and cations present as major constituents in the groundwater have been included in the analyses. The charge balances for Test Well 184W101 and Monitor Well 184W502M groundwater analyses, 4.7 and 7.5 percent, respectively (Table B-1), are relatively high resulting from an excess of cations when compared to the anions. This is possibly due to a change in the water chemistry (e.g., loss of carbon dioxide, mineral precipitation, and/or mineral dissolution) as the temperature of the sample decreased from the time of sample collection to the time of analyses.

To illustrate the relative major-ion compositions in these groundwater samples, a Piper diagram is presented in Figure 6-1. A Piper diagram consists of two triangular plots presenting the major cations (left triangle) and major anions (right triangle) in percent milliequivalents. The two triangular plots are then projected to a central diamond where the relative abundance of all major ions are presented. A Piper diagram is used to evaluate similarities in groundwater major-ion compositions, to identify the hydrochemical water type representing the aquifer(s) from which the groundwater was collected, and to assess possible evolutionary trends that have occurred along a flowpath. As shown in Figure 6-1, the relative concentrations of major ions are similar for all six groundwater samples. The groundwater samples all represent a calcium-magnesium-bicarbonate facies that is typical of dissolution of calcite and dolomite in waters of a carbonate-rock aquifer. The relative concentrations of sodium plus potassium (Na + K) tend to be slightly greater in the groundwater samples from the monitor wells than in that of the associated test well.

Stiff diagrams for these groundwater samples are presented in Figure 6-2. Major solutes are presented in a Stiff diagram so that their relative proportions are identified by their shape and the magnitude of the concentrations by its size. As apparent in the Stiff diagrams in Figure 6-2, the concentrations of calcium and bicarbonate are greater in the groundwater samples from Test Well 184W101 and Monitor Well 184W502M. This may be attributed to increased dissolution of carbonate minerals in the deeper and warmer groundwaters of these wells. Groundwater from the

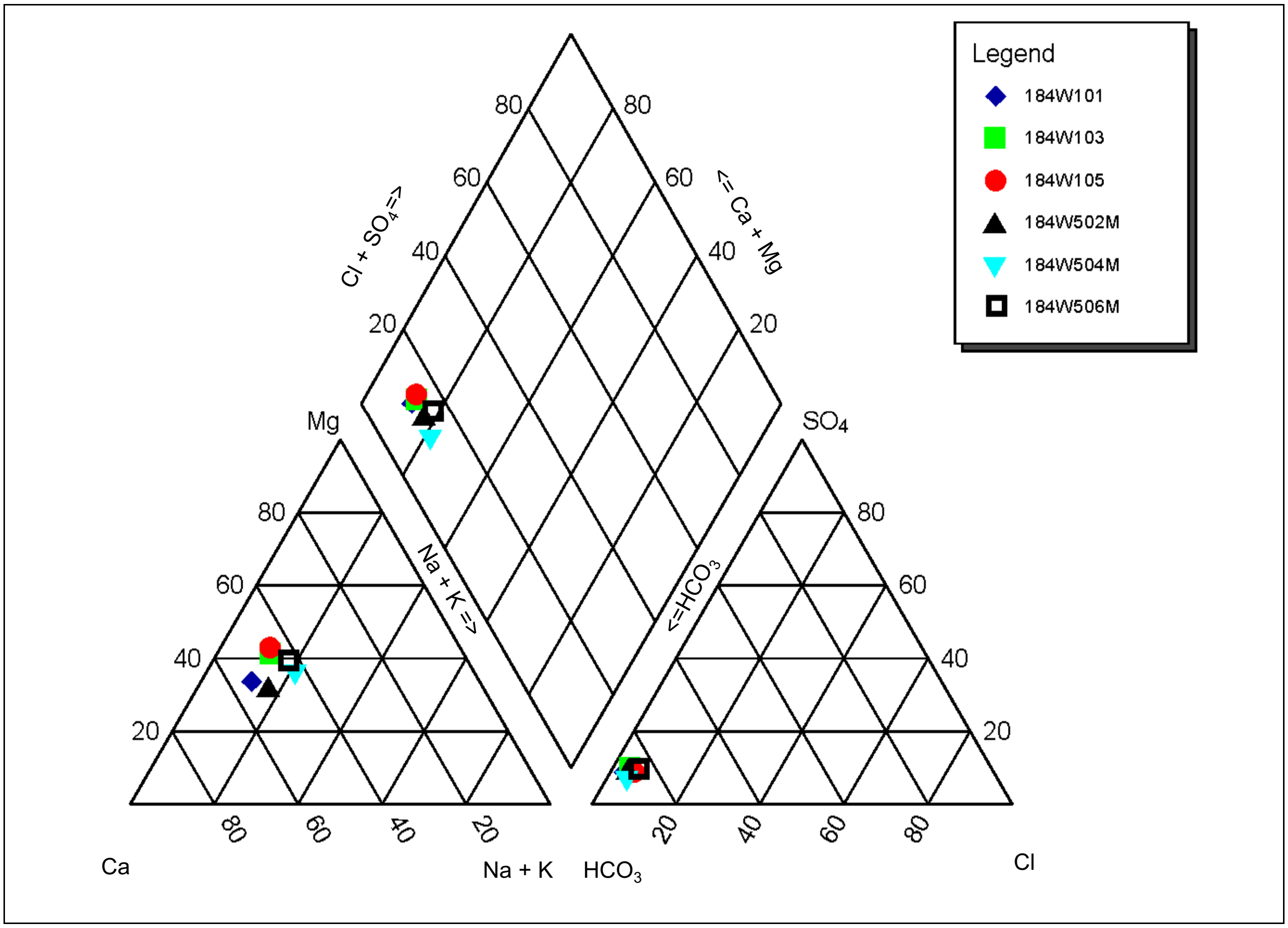


Figure 6-1
Piper Diagram Illustrating Relative Major-Ion Compositions

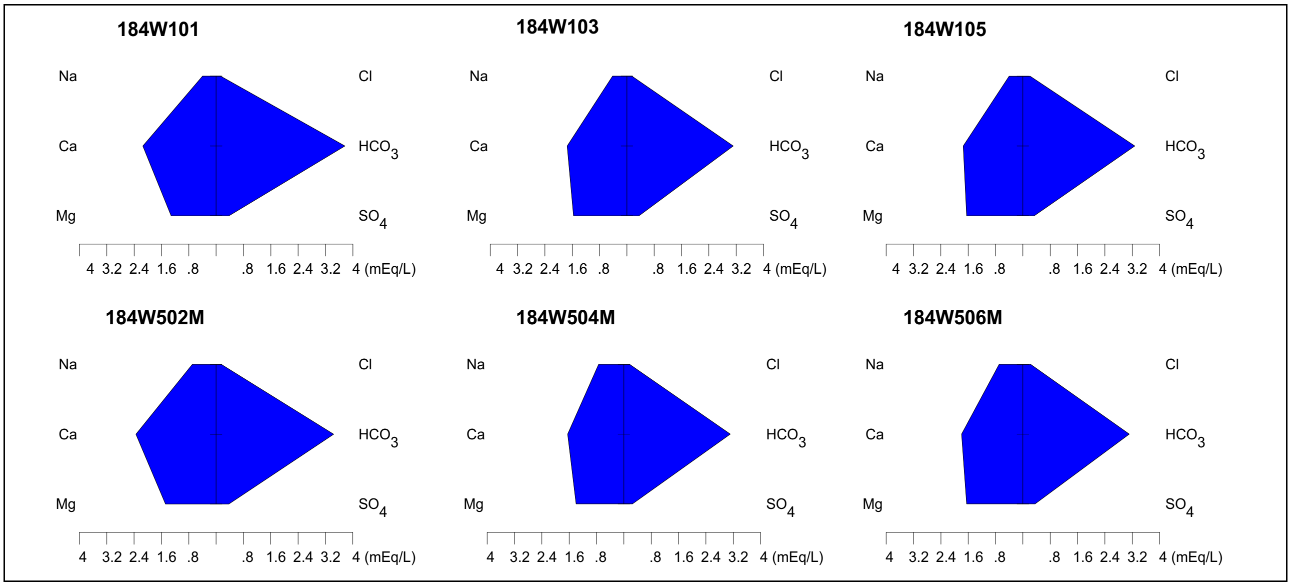


Figure 6-2
Stiff Diagrams Illustrating Major-Ion Concentrations

four wells 184W103, 184W105, 184W504M, and 184W506M, are nearly identical with a somewhat greater concentration of sodium in the monitor wells.

6.3.3 Trace and Minor Constituents

The concentrations of trace elements in groundwater from Test Well 184W101 and Monitor Well 184W502M are presented in Table B-1. The dominant trace element present in groundwater from Test Well 184W101 is strontium, which is consistent with the relatively high concentration of strontium in carbonate rocks (i.e., limestone) (Drever, 1988). Relatively high concentrations of aluminum, iron, manganese, and zinc were observed in the groundwater from Monitor Well 184W502M (Table B-1) when compared to concentrations in the groundwater of Test Well 184W101. In fact, the concentrations of these elements are consistently higher in the monitor wells than in the test wells (Table 6-1). The elevated concentration of these elements in the groundwater of the monitor wells is therefore thought to result from interaction with the casing used for the monitor wells and is not expected to reflect naturally occurring concentrations in the groundwater. The monitor wells we also not developed and pumped as extensively as the test wells.

Table 6-1
Trace Elements Present in Higher Concentrations in the Monitor Wells than in the Test Wells

Well Name	Concentration (µg/L)			
	Aluminum	Iron	Manganese	Zinc
184W502M	180	5,700	39	56
184W101	8.4	<20	2.8	<5
184W506M	320	300	62	29
184W105	26	<20	0.78	<5
184W504M	130	500	24	55
184W103	<5	<20	1.8	5.5

6.3.4 Stable Isotopes/Environmental Tracers

The stable hydrogen, oxygen, and carbon isotopic compositions of the groundwater samples from Test Well 184W101 and the stable hydrogen and oxygen isotopic compositions of the groundwater samples from Monitor Well 184W502M are presented in Table B-1. Table B-1 also presents chlorine-36, strontium-87/86, and uranium-234/238 data for groundwater samples collected from Test Well 184W101.

6.3.4.1 Hydrogen and Oxygen Isotopes

Stable isotopes of hydrogen and oxygen behave conservatively in most groundwater systems and therefore can be used to indicate groundwater source, trace groundwater flowpaths, evaluate possible mixing of groundwater along a flowpath, and evaluate water budgets. Isotopic concentrations are reported using delta notation (δD and $\delta^{18}O$) as the relative difference between the isotopic ratio ($D/^{1}H$ or $^{18}O/^{16}O$) measured for the sample and that of the Vienna Standard Mean Ocean Water (VSMOW) reference standard. The analytical precisions for δD and $\delta^{18}O$ are typically ± 1‰ and ± 0.2‰, respectively.

The analytical results for δD and $\delta^{18}O$ for Test Well 184W101 and Monitor Well 184W502M are presented in Table B-1 and Figure 6-3 (mean value). Figure 6-3 also presents data for the four SNWA wells in the vicinity along with the Global Meteoric Water Line ($\delta D = 8\delta^{18}O + 10$) (Craig, 1961). These groundwater samples exhibit similar relatively light stable isotope ratios that are typical of recharge at high elevations and cold temperatures. The samples all plot slightly below the Global Meteoric Water Line, suggesting that the water underwent only slight evaporation prior to recharging.

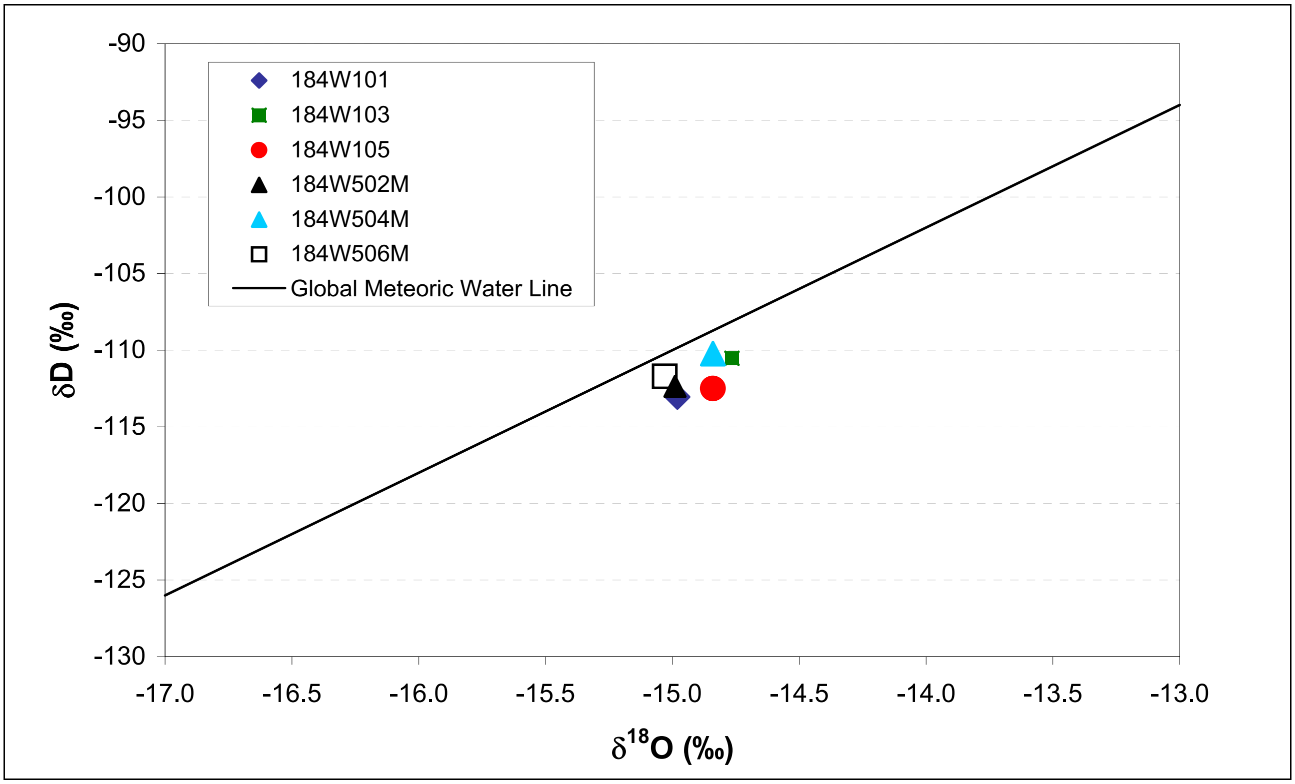


Figure 6-3
Plot of δD versus $\delta^{18}O$

6.3.4.2 Carbon Isotopes

The isotopic composition of stable carbon ($\delta^{13}C$) in groundwater is used to assess the extent of isotope mass transfer that occurred along a groundwater flowpath. Corrections based on this assessment can then be applied to Carbon-14 (^{14}C) data to determine the age of the groundwater. The $\delta^{13}C$ composition is reported as the relative difference between the isotopic ratio, $^{13}C/^{12}C$, for the sample and that of the Pee Dee Belemnite (PDB) reference standard. The analytical precision for $\delta^{13}C$ is typically ± 0.3‰. Carbon-14 is reported as percent modern carbon (pmc), where modern carbon is defined as the approximate ^{14}C activity of wood grown in 1890 (13.56 disintegrations per minute per gram of carbon), before the dilution of ^{14}C in the atmosphere by burning fossil fuels. The analytical precision for ^{14}C in these groundwater samples is ± 0.1 pmc.

Relatively similar values of $\delta^{13}C$ and ^{14}C were measured in the groundwater of the test wells: 184W101 (–5.8‰, 4.93 pmc), 184W103 (–6.7‰, 10.37 pmc), and 184W105 (–5.8‰, 6.09 pmc); carbon isotopes were not measured for the monitor wells. The low ^{14}C and relatively heavy values of $\delta^{13}C$ suggest that the groundwater has interacted with isotopically heavy and ^{14}C-free carbonate minerals. From these data, it appears that water-rock interaction has occurred to a lesser extent along the groundwater flowpath to Test Well 184W103 as compared to the other test wells. This suggests a shorter residence time for this groundwater. Further evaluation of groundwater flowpaths is required to assess the extent of these reactions and to accurately estimate the groundwater age.

6.3.4.3 Chlorine-36/Chloride Ratios

The ratio of atoms of chlorine-36 to chloride ($^{36}Cl/Cl$) can be used to trace groundwater flow. Dominant factors controlling the observed $^{36}Cl/Cl$ ratios and Cl concentrations are the initial values inherited during recharge, the progressive dissolution of Cl-rich (low ^{36}Cl) carbonate rocks along the groundwater flowpath, and the mixing of water with different $^{36}Cl/Cl$ ratios (Moran and Rose, 2003). The interpretation of $^{36}Cl/Cl$ data requires knowledge of the compositions of the recharge water and the potential mixing components along the groundwater flowpath. The $^{36}Cl/Cl$ ratio in precipitation varies with distance from the ocean and has not been previously evaluated in this region. Ratios measured in recently recharged groundwater and soils throughout the southwestern United States of 500×10^{-15} to 880×10^{-15} have been reported (Davis et al., 1998; Phillips, 2000).

The $^{36}Cl/Cl$ ratios are consistent with precipitation in the southwestern United States. Of the three test wells, the $^{36}Cl/Cl$ ratios are the lowest (429.2×10^{-15}) and the chloride concentrations the greatest (7.5 mg/L) for 184W105, as compared to 486.1×10^{-15} and 4.6 mg/L for 184W101 and 545.1×10^{-15} and 5.2 mg/L for 184W103. This suggests greater water-rock interaction and a longer residence time for the groundwater from Test Well 184W105.

6.3.4.4 Strontium and Uranium Isotopes

The ratio of radiogenic to nonradiogenic strontium ($^{87}Sr/^{86}Sr$) has been used to identify groundwater sources, to evaluate potential mixing components, and to identify rock types through which groundwater has flowed. Groundwater $^{87}Sr/^{86}Sr$ ratios (0.71054) for Test Well 184W101 are quite similar to those of test wells 184W103 (0.70902) and 184W105 (0.70928) and to those expected from water-rock interaction with marine carbonates (0.707 to 0.709) (Peterman et al., 1970; Burke et al., 1982).

The ratio of uranium-234 activity to that of uranium-238 ($^{234}U/^{238}U$ Activity Ratio) has also been used to evaluate groundwater flow systems. As with other chemical constituents, the $^{234}U/^{238}U$ activity ratios are relatively similar for groundwater samples from test wells 184W105 (2.08), 184W101 (2.97), and 184W103 (3.75).

6.3.5 Radiological Parameters

Radiological parameters were analyzed in the groundwater of Test Well 184W101, and the corresponding results are presented in Table B-1. The reported activity for each of these parameters is consistent with background concentrations in natural groundwaters.

6.3.6 Organic Compounds

No organic compounds were detected in the groundwater of Test Well 184W101; analyses were not performed for Monitor Well 184W502M. The compounds analyzed, and the corresponding method detection limit and MCL (if applicable), are presented in Table B-2.

6.4 Summary

Groundwater samples were collected from Test Well 184W101 and Monitor Well 184W502M and were analyzed for a suite of chemical parameters. Field measurements of water-quality parameters were also performed during aquifer testing and were used to demonstrate stabilization of the groundwater chemistry prior to collection of the samples. The resulting data were compared to data from samples collected from other SNWA wells in the vicinity; all wells were completed in a carbonate-rock aquifer. As is characteristic of dissolution of calcite and dolomite in waters of a carbonate-rock aquifer, the groundwater represents a calcium-magnesium-bicarbonate facies. The relative concentrations of sodium plus potassium (Na + K) tend to be slightly greater in the groundwater samples from the monitor wells than in those of the associated test wells. Similar relatively light, stable isotope ratios, typical of recharge at high elevations and cold temperatures, were observed for all of the groundwater samples evaluated. The $^{36}Cl/Cl$ ratio measured for the sample collected from Test Well 184W101 was consistent with precipitation in the southwestern United States, and the low ^{14}C and relatively heavy values of $\delta^{13}C$ suggest that the groundwater has interacted with isotopically heavy and ^{14}C-free carbonate minerals. The $^{87}Sr/^{86}Sr$ ratios were similar between the samples collected from the test wells and were typical of water-rock interaction with marine carbonates. The $^{234}U/^{238}U$ activity ratios were also relatively similar for the groundwater samples of the test wells. The samples from the monitor wells were not analyzed for $^{36}Cl/Cl$, $\delta^{13}C$, ^{14}C, $^{87}Sr/^{86}Sr$, or $^{234}U/^{238}U$ activity ratios.

The data were also evaluated with respect to the EPA Safe Drinking Water Act standards. For Test Well 184W101, no constituents exceeded the primary or secondary drinking water MCL. Groundwater from Monitor Well 184W502M exceeded the secondary MCL for iron. This exceedance is attributed to the well construction and is not considered to reflect the natural water.

7.0 REFERENCES

Barker, J.A., 1988, A generalized radial-flow model for hydraulic tests in fractured rock: Water Resources Research, Vol. 24, No. 10, p. 1796-1804.

Bierschenk, W.H., 1963, Determining well efficiency by multiple step-drawdown tests: International Association Science Hydrology Publication, Vol. 64, p. 493-507.

Burke, W.H., Denison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, N.F., and Otto, J.B., 1982, Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time: Geology, Vol. 10, p. 516-519.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, Vol. 27, No. 4, p. 526-534.

Craig, H., 1961, Isotopic variations in meteoric waters: Science, Vol. 133, p. 1702-1703.

Davis S.N., Cecil, L.D., Zreda, M., and Sharma, P., 1998, Chlorine-36 and the initial valve problem: Hydrogeology Journal, Vol. 6, No 1, p. 104-114.

Dixon, G.L., Rowley, P.D., Burns, A.G., Watrus, J.M., Donovan, D.J., and Ekren, E.B., 2007, Geology of White Pine and Lincoln counties and adjacent areas, Nevada and Utah—The geologic framework of regional groundwater flow systems: Southern Nevada Water Authority, Las Vegas Nevada. Doc. No. HAM-ED-0001, 157 p.

Drever, J.I., 1988, The geochemistry of natural waters. Second edition: Englewood Cliffs, New Jersey, Prentice Hall.

Duffield, G.M., 1996-2007, HydroSOLVE, Inc, AQTESOLV Version 4.50 Professional software.

Eastman, H.S., and Muller D.C., 2009, Geologic Data Analysis Report for Monitor Well 184W502M and Test Well 184W101 in Spring Valley: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. RDS-ED-0009, 48 p.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E., and Franson, M.H., eds., 2005, Standard methods for the examination of water and wastewater. Twenty first edition: Washington, D.C., American Public Health Association.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice Hall.

Hantush, M.S., 1964, Hydraulics of wells, *in* Advances in Hydroscience: Chow, V.T., eds., Vol. I, Academic Press, New York and London, p. 281-432.

Harrill, J.R., Gates, J.S., and Thomas, J.M., 1988, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas Report No. HA-694-C, scale 1:1,000,000, two sheets.

Kilroy, K.C., 1992, Aquifer storage characteristics of Paleozoic carbonate rocks in southeastern Nevada estimated from harmonic analysis of water-level fluctuations [Ph.D. dissertation]: University of Nevada, Reno, 77 p.

Kruseman, G.P., and De Ridder, N.A., 1994, Analysis and evaluation of pumping test data, second edition, Publication 47: International Institute for Land Reclamation and Improvement, Netherlands, 377 p.

Moench, A.F., 1984, Double-porosity models for a fissured groundwater reservoir with fracture skin: Water Resources Research, Vol. 20, No. 7, p. 831–846.

Moran J.E., and Rose, T.P., 2003, A chlorine-36 study of regional groundwater flow and vertical transport in southern Nevada: Environmental Geology, Vol. 43, p. 592-605.

Neuman, S.P., 1975, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response: Water Resources Research, Vol. 11, Issue 2, p. 329–342.

Peterman, Z.E., Hedge, C.E., and Tourtelot, H.A., 1970, Isotopic composition of strontium in sea water throughout Phanerozoic time: Geochimica et Cosmochimica Acta, Vol. 34, p. 105-120.

Phillips, F.M., 2000, Chlorine-36—environmental tracers in subsurface hydrology: P.G. Cook and A.L. Herczeg, ed., Kluwer, Boston.

Prieur, J.P., Farnham, I.M., and Fryer, W., 2009, Hydrologic data analysis report for Test Well 184W105 in Spring Valley Hydrographic Area 184: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. DAR-ED-0002, 81 p.

Rorabaugh, M.J., 1953, Graphical and theoretical analysis of step-drawdown test of artesian well, *in* Proceedings of the American Society of Civil Engineers, Vol. 79, separate no. 362, 23 p.

Rush, F.E., and Kazmi, S.A.T., 1965, Water resources appraisal of Spring Valley, White Pine, and Lincoln Counties, Nevada: Nevada Department of Conservation and Natural Resources, Water Resources Reconnaissance Series Report 33, 36 p.

SNWA, see Southern Nevada Water Authority.

Southern Nevada Water Authority, 2006a, Geologic and hydrogeologic framework for the Spring Valley area—Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada, 122 p.

Southern Nevada Water Authority, 2006b, Summary of groundwater water-rights and current water uses in Spring Valley—Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada, 97 p.

Southern Nevada Water Authority, 2006c, Water resources assessment for Spring Valley—Presentation to the Office of the Nevada State Engineer: Southern Nevada Water Authority, Las Vegas, Nevada, 167 p.

Southern Nevada Water Authority, 2009, 2008 Spring Valley hydrologic monitoring and mitigation plan status and data report: Doc. No. WRD-ED-0004, Las Vegas, Nevada, 109 p.

U.S. Geological Survey, 2007, National field manual for the collection of water-quality data [Internet]: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, chaps. A1-A9, available from http://pubs.water.usgs.gov/twri9A.

USGS, see U.S. Geological Survey.

Welch, A.H., Bright, D.J., and Knochenmus, L.A., eds., 2008, Water resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Open-File Report 2007-5261, 97 p.

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Appendix A

CD-ROM Contents

A.1.0 INTRODUCTION

This appendix describes the digital contents of the CD-ROM that accompanies this report. The CD-ROM contains background water-level, barometric-pressure, step-drawdown test, and constant-rate test data. This CD-ROM also includes an electronic copy of the groundwater-chemistry data, as well as the AQTESOLV input files for the step-drawdown and constant-rate tests.

A.1.1 Photos

The following photos show an overview of the site (Figure A-1), the site setup (Figure A-2), the wellhead equipment setup (Figure A-3), the discharge line (Figure A-4), the energy dissipation at the termination of the discharge line for erosion prevention (Figure A-5), and the test well screen (Figure A-6).

Figure A-1
184W101 Test Well Site Overview

Figure A-2
184W101 Test Wellhead Equipment and Site Setup

Figure A-3
184W101 Test Wellhead Equipment Setup

Figure A-4
184W101 Discharge Line

Figure A-5
184W101 Energy Dissipation at Discharge Termination

Figure A-6
Test Well Screen

A.1.2 Read-Me File

Included on the CD-ROM is a text file version of this appendix that describes the contents of the CD-ROM. An index of the files and folders in the form of a PDF document is also included.

A.1.3 Background Water-Level Data

A spreadsheet contains the continuous water-level data and a corresponding chart from SNWA Monitor Well 154W504M. This well was used to monitor background conditions during development and testing at Test Well 184W101.

A.1.4 Barometric-Pressure Data

Barometric-pressure data are located in the continuous record data files associated with Test Well 184W101. An In-Situ HERMIT 3000 data logger recorded the barometric pressure during the development and testing at 184W101. Barometric data from SNWA ET site SV1 are also included. These data can be found in files labeled “184W502M Transducer Data Constant Rate Test at Well 184W101.xls” for the step-drawdown and constant-rate tests.

All barometric-pressure data are reported in in. Hg.

A.1.5 Step-Drawdown Test Data

A summary spreadsheet for the step-drawdown test, which compiles all of the manual data, is labeled "184W101 Manual Data from Step test.xls." The continuous record of water levels from Test Well 184W101 for the step-drawdown test is provided in the spreadsheet labeled "184W101 Transducer Data from Step Test.xls." The continuous record of water levels from Monitor Well 184W502M for the step-drawdown test is provided in the spreadsheet labeled "184W502M Transducer Data for Step Test on Well 184W101.xls."

A.1.6 Constant-Rate Test Data

The manual and continuous constant-rate test data from Test Well 184W101 are provided in the spreadsheets labeled "184W101 Manual Data Constant Rate Test.xls" and "184W101 Transducer Data Constant Rate Test.xls," respectively. The manual and continuous constant-rate test data from Monitor Well 184W502M are provided in the spreadsheets labeled "184W502M Manual Data Constant Rate Test at Well 184W101.xls" and "184W502M Transducer Data Constant Rate Test at Well 184W101.xls," respectively.

A.1.7 AQTESOLV

The input files for using AQTESOLV software for aquifer analysis are provided. The input files are in the form of Excel spreadsheets with water-level and discharge data for both the step-drawdown and constant-rate tests. AQTESOLV files have been included with basic information, such as casing, borehole, and downhole equipment radius, as well as approximate saturated thickness.

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Appendix B

Groundwater-Chemistry Data

Table B-1
Field and Analytical Results, Analytical Methods, Reporting Limits, and Maximum Contaminant Levels for Inorganic, Stable Isotopic, and Radiological Constituents in Groundwater Samples from Test Well 184W101 and Monitor Well 184W502M
(Page 1 of 3)

Constituent Name	Unit	Analysis Method	RL	184W101 4/12/2007 08:00	184W502M 1/29/2007 10:00	Primary MCL	Secondary MCL
Field Measured							
pH	standard unit	Field	---	7.7	8.49	---	6.5 to 8.5
Specific Conductance	µS/cm	Field	---	359	394	---	---
Dissolved Oxygen	mg/L	Field	---	2.29	---	---	---
Temperature	°C	Field	---	24.1	20.5	---	---
Turbidity	NTU	Field	---	0.96	---	---	---
Stable Isotopes/Environmental Tracers							
Carbon-14 (^{14}C)	pmc	NA	---	4.93	---	---	---
Carbon-13/12 (δ^{13}C)	per mil (‰)	NA	---	-5.8	---	---	---
Chlorine-36/Chloride (^{36}Cl/Cl)	ratio	NA	---	4.861×10^{-13}	---	---	---
Hydrogen-2/1 (δD)	per mil (‰)	NA	---	-113.1/-113.1	-112.2/-112.6	---	---
Oxygen-18/16 (δ^{18}O)	per mil (‰)	NA	---	-14.98	-14.99	---	---
Strontium-87/86	ratio	NA	---	0.71054/ 0.71054	---	---	---
Uranium-234/238	Activity Ratio	NA	---	2.9748/ 2.9735	---	---	---
Major Solutes							
Alkalinity Bicarbonate	mg/L as HCO_3	SM 2320B	2	230	210	---	---
Alkalinity Carbonate	mg/L as $CaCO_3$	SM 2320B	2	ND	ND	---	---
Alkalinity Hydroxide	mg/L as $CaCO_3$	SM 2320B	2	ND	ND	---	---
Alkalinity Total	mg/L as $CaCO_3$	SM 2320B	2	190	170	---	---
Calcium	mg/L	EPA 200.7	0.1	43	47	---	---
Chloride	mg/L	EPA 300.0	0.5	4.6	5.4	---	250
Fluoride	mg/L	EPA 300.0	0.1	0.27	0.36	4	2
Magnesium	mg/L	EPA 200.7	0.1	16	18	---	---
Nitrate	mg/L as N	EPA 353.2	0.1	ND	0.15[a]	10	---
Potassium	mg/L	EPA 200.7	1	2.7	2.7	---	---
Silica	mg/L	EPA 200.7	0.1	25	22	---	---
Sodium	mg/L	EPA 200.7	1	9.1	16	---	---
Sulfate	mg/L	EPA 300.0	0.5	18	18	---	250
Cation/Anion Balance	%	Calculation	---	4.7	7.5	---	---

Table B-1
Field and Analytical Results, Analytical Methods, Reporting Limits, and Maximum Contaminant Levels for Inorganic, Stable Isotopic, and Radiological Constituents in Groundwater Samples from Test Well 184W101 and Monitor Well 184W502M
(Page 2 of 3)

Constituent Name	Unit	Analysis Method	RL	184W101 4/12/2007 08:00	184W502M 1/29/2007 10:00	Primary MCL	Secondary MCL
Trace and Minor Constituents							
Aluminum, total	µg/L	EPA 200.8	5	8.4	180	---	50 to 200
Antimony, total	µg/L	EPA 200.8	0.5	ND	ND	6	---
Arsenic, total	µg/L	EPA 200.8	0.4	4.3/4.9	5.6	10	---
Arsenic (III)	µg/L	EPA 200.8	1	ND	---	---	---
Arsenic (V)	µg/L	EPA 200.8	1	4.2	---	---	---
Barium, total	µg/L	EPA 200.8	0.5	210	200	2,000	---
Beryllium, total	µg/L	EPA 200.8	0.1	ND	ND	4	---
Boron, total	µg/L	EPA 200.7	10	41	28	---	---
Bromide	µg/L	EPA 300.1	10	42	43	---	---
Cadmium, total	µg/L	EPA 200.8	0.1	ND	ND	5	---
Chlorate	µg/L	EPA 300.1	10	ND	---	---	---
Chromium, total	µg/L	EPA 200.8	0.2	0.33	0.77	100	---
Chromium (VI)	µg/L	EPA 218.6	0.3	ND	---	---	---
Chromium (III)	µg/L	Calculation	0.2	0.21	---	---	---
Copper, total	µg/L	EPA 200.8	0.5	0.73	2.6	1,300[b]	1,000
Iron, total	µg/L	EPA 200.7	20	ND	5,700	---	300
Lead, total	µg/L	EPA 200.8	0.2	0.3	3.6	15[b]	---
Lithium, total	µg/L	EPA 200.7	10	11	19	---	---
Manganese, total	µg/L	EPA 200.8	0.2	2.8	39	---	50
Mercury, total	µg/L	EPA 245.1	0.1	ND	ND	2.0	---
Molybdenum, total	µg/L	EPA 200.8	0.1	5.4	6.2	---	---
Nickel, total	µg/L	EPA 200.8	0.8	2.3	0.98	---	---
Nitrite	mg/L as N	EPA 353.2	0.1	ND	---	1	---
Orthophosphate	µg/L as P	EPA 365.1	2	ND	---	---	---
Phosphorus, total	µg/L as P	EPA 365.1	10	ND	---	---	---
Selenium, total	µg/L	EPA 200.8	0.4	0.42	ND	50	---
Silver, total	µg/L	EPA 200.8	0.2	ND	ND	---	100

Table B-1
Field and Analytical Results, Analytical Methods, Reporting Limits, and Maximum Contaminant Levels for Inorganic, Stable Isotopic, and Radiological Constituents in Groundwater Samples from Test Well 184W101 and Monitor Well 184W502M
(Page 3 of 3)

Constituent Name	Unit	Analysis Method	RL	184W101 4/12/2007 08:00	184W502M 1/29/2007 10:00	Primary MCL	Secondary MCL
Trace and Minor Constituents (Continued)							
Strontium, total	µg/L	EPA 200.7	5	180	170	---	---
Thallium, total	µg/L	EPA 200.8	0.2	0.42	0.39	2	---
Uranium, total	µg/L	NA	---	2.73/2.71	---	30	---
Vanadium, total	µg/L	EPA 200.8	0.5	3.0	3.2	---	---
Zinc, total	µg/L	EPA 200.8	5	ND	56	---	5,000
Miscellaneous Parameters							
Total Dissolved Solids	mg/L	SM 2540C	10	180	170	---	500
Total Organic Carbon	mg/L	SM 5310C	0.3	ND	0.5	---	---
Total Suspended Solids	mg/L	EPA 160.2	5	---	48	---	---
Hardness	mg/L as $CaCO_3$	EPA 200.7	1	180	---	---	---
Langelier Index	@ 60 °C	SM 2330B	-10	0.746	---	---	---
Langelier Index	@ Source Temp.	SM 2330B	-10	0.282	---	---	---
MBAS	mg/L	SM 5540 C	0.05	ND	---	---	---
Cyanide	mg/L	SM 4500CN E	0.01	ND	---	0.2	---
Radiochemical Parameters							
Gross Alpha	pCi/L	EPA 900.0	1.7	3.8±1.2	---	15	---
Gross Beta	pCi/L	EPA 900.0	1.0	ND	---	4 mrem/yr	---
Radium, total gross	pCi/L	EPA 903.1	---	1.20±0.100	---	5	---
Radium-226	pCi/L	EPA 903.1	---	1.20±0.100	---	---	---
Radium-228	pCi/L	EPA 904	0.4	ND	---	---	---
Radon	pCi/L	SM 7500	---	353±37.0	---	---	---
Strontium-90	pCi/L	EPA 905.0	0.6	ND	---	---	---
Tritium	TU	NA	0.8	ND	---	---	---
Tritium	pCi/L	EPA 906.0	337	ND	---	---	---
Uranium	pCi/L	EPA 200.8	0.13	1.8	---	30 µg/L	---

[a] Holding time was exceeded
[b] Reported value is the action limit
MBAS = Methylene blue active substance
mrem/yr = Millirem per year
NA = Not available

ND = Not detected
RL = Reporting limit
SM = Standard method (Eaton et al., 2005)
TU = Tritium Unit

Table B-2

Organic Compounds Analyzed in Groundwater Samples from Test Well 184W101 Including the EPA Method, Reporting Limit, and Maximum Contaminant Level

(Page 1 of 2)

Analyte	RL	MCL	Analyte	RL	MCL	Analyte	RL	MCL
Chlorinated Pesticides by EPA 508 (µg/L)								
Aldrin	0.075	---	Endosulfan II	0.01	---	PCB 1016 Aroclor	0.1	---
BHC (Alpha)	0.01	---	Endosulfan sulfate	0.05	---	PCB 1221 Aroclor	0.1	---
BHC (Beta)	0.05	---	Endrin	0.1	2	PCB 1232 Aroclor	0.1	---
BHC (Delta)	0.05	---	Endrin aldehyde	0.05	---	PCB 1242 Aroclor	0.1	---
Chlordane (tech)	0.1	2	Heptachlor	0.01	0.4	PCB 1248 Aroclor	0.1	---
Chlorothalonil	5	---	Heptachlor epoxide	0.01	0.2	PCB 1254 Aroclor	0.1	---
4,4'-DDD	0.02	---	Hexachlorobenzene	0.5	1.0	PCB 1260 Aroclor	0.1	---
4,4'-DDE	0.01	---	Hexachlorocyclopentadiene	1	50	Propachlor	0.5	---
4,4'-DDT	0.02	---	Lindane	0.2	0.2	Toxaphene	1	3
Dieldrin	0.02	---	Methoxychlor	10	40	Trifluralin	0.01	---
Endosulfan I	0.02	---	Polychlorinated biphenyls (PCBs)	0.5	0.5			
Organic Compounds by EPA 525.2 (µg/L)								
Alachlor	0.1	2	Di(2-ethylhexyl) phthalate	3	6	Prometon	0.2	---
Atrazine	0.1	3	Diazinon	0.1	---	Prometryn	0.1	---
Benzo(a)pyrene	0.1	0.2	Dimethoate	0.2	---	Simazine	0.1	4
Bromacil	1	---	Metolachlor	0.1	---	Thiobencarb	0.2	---
Butachlor	0.2	---	Metribuzin	0.1	---			
Di(2-ethylhexyl) adipate	5	400	Molinate	0.1	---			
Purgeable Organic Compounds by EPA 524.2 (µg/L)								
tert-Amyl methyl ether	3	---	Di-isopropyl ether	3	---	1,2,3-Trichlorobenzene	0.5	---
Benzene	0.5	5	1,1-Dichloroethane	0.5	---	1,2,4-Trichlorobenzene	0.5	70
Bromobenzene	0.5	---	1,2-Dichloroethane	0.5	5	Methyl tertiary butyl ether (MTBE)	3	---
Bromochloromethane	0.5	---	1,1-Dichloroethylene	0.5	7	Naphthalene	0.5	---
Bromodichloromethane	0.5	---	cis-1,2-Dichloroethylene	0.5	70	n-Propylbenzene	0.5	---
Bromoform	0.5	---	trans-1,2-Dichloroethylene	0.5	100	Styrene	0.5	100
2-Butanone	5	---	Dichlorodifluoromethane	0.5	---	Tetrachloroethylene	0.5	5
n-Butylbenzene	0.5	---	1,2-Dichloropropane	0.5	5	1,1,1,2-Tetrachloroethane	0.5	---
sec-Butylbenzene	0.5	---	1,3-Dichloropropane	0.5	---	1,1,2,2-Tetrachloroethane	0.5	---
tert-Butylbenzene	0.5	---	2,2-Dichloropropane	0.5	---	Toluene	0.5	1,000
tert-Butyl ethyl ether	3	---	1,1-Dichloropropene	0.5	---	1,1,1-Trichloroethane	0.5	200
Carbon tetrachloride	0.5	5	cis-1,3-Dichloropropene	0.5	---	1,1,2-Trichloroethane	0.5	5
Chlorobenzene	0.5	100	trans-1,3-Dichloropropene	0.5	---	Trichloroethylene	0.5	5
Chloroethane	0.5	---	total-1,3-Dichloropropene	0.5	---	Trichlorofluoromethane	5	---

Table B-2
Organic Compounds Analyzed in Groundwater Samples from Test Well 184W101 Including the EPA Method, Reporting Limit, and Maximum Contaminant Level
(Page 2 of 2)

Analyte	RL	MCL	Analyte	RL	MCL	Analyte	RL	MCL
Purgeable Organic Compounds by EPA 524.2 (μg/L) (Continued)								
2-Chloroethylvinyl ether	1	---	Ethylbenzene	0.5	700	1,2,3-Trichloropropane	0.5	---
Chloroform	0.5	---	Hexachlorobutadiene	0.5	---	1,1,2-Trichloro-1,2,2-trifluoroethane	10	---
2-Chlorotoluene	0.5	---	2-Hexanone	5	---	1,2,4-Trimethylbenzene	0.5	---
4-Chlorotoluene	0.5	---	Isopropylbenzene	0.5	---	1,3,5-Trimethylbenzene	0.5	---
Dibromochloromethane	0.5	---	p-Isopropyltoluene	0.5	---	Vinyl chloride	0.5	2
Dibromomethane	0.5	---	Methyl bromide	0.5	---	Xylene (m,p) isometric pair	0.5	---
m-Dichlorobenzene	0.5	---	Methyl chloride	0.5	---	Xylenes (total)	0.5	10,000
o-Dichlorobenzene	0.5	600	Methylene chloride	0.5	5	o-Xylene	0.5	---
p-Dichlorobenzene	0.5	75	4-Methyl-2-pentanone	5	---			
Chlorinated Acids by EPA 515.3 (μg/L)								
2,4,5-T	0.2	---	Acifluorfen	0.5	---	Dichlorprop	0.3	---
2,4,5-TP (Silvex)	0.2	50	Bentazon	2	---	Dinoseb	0.5	7
2,4-D	0.5	70	Dalapon	0.5	200	Pentachlorophenol	0.2	1
2,4-DB	2	---	DCPA	0.1	---	Picloram	1	500
3,5-Dichlorobenzoic acid	1	---	Dicamba	0.6	---			
N-Methylcarbamoyloximes and N-Methylcarbamates by EPA 531.1 (ug/L)								
3-Hydroxycarbofuran	2	---	Baygon	5	---	Methomyl	2	---
Aldicarb	2	---	Carbaryl	2	---	Oxamyl (Vydate)	2	200
Aldicarb sulfone	2	---	Carbofuran	5	40			
Aldicarb sulfoxide	2	---	Methiocarb	3	---			
Organics by Other EPA Methods (μg/L)								
Glyphosate (EPA 547)	5	700	Diquat (EPA 549.2)	4	20	1,2-Dibromo-3-chloropropane (EPA 504.1)	0.01	0.2
Endothall (EPA 548.1)	45	100	Dioxin (EPA 1613)	5 pg/L	30 pg/L	Ethylene dibromide (EPA 504.1)	0.02	0.05

RL = Reporting limit

References

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E., and Franson, M.H., eds., 2005, Standard methods for the examination of water and wastewater. Twenty first edition: Washington, D.C., American Public Health Association.