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SOUTHERN NEVADA WATER AUTHORITY

Hydrologic Data Analysis Report for Test Well 184W105 in Spring Valley Hydrographic Area 184

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August 2009

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

CONTENTS

FIGURES

NUMBER **TITLE** **PAGE**

FIGURES (CONTINUED)

TABLES

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Acronyms

Barker GRFM	Barker generalized radial flow model
EPA	U.S. Environmental Protection Agency
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
NDOT	Nevada Department of Transportation
NTU	nephelometric turbidity unit
SNWA	Southern Nevada Water Authority
TDH	total dynamic head
UTM	Universal Transverse Mercator

Abbreviations

°C	degrees Celsius
afa	acre-feet per annum
amsl	above mean sea level
bgs	below ground surface
cm	centimeter
ft	foot
gal	gallon
gpm	gallons per minute
I.D.	inside diameter (of casing)
in.	inch
in. Hg	inches of mercury
L	liter
lb	pound
m	meter
mEq	milliequivalent
mg	milligram
mi	mile
min	minute
ml	milliliter

ABBREVIATIONS (CONTINUED)

mrem	millirem
µg	microgram
µS	microsiemen
O.D.	outside diameter (of casing)
‰	per mil
pmc	percent modern carbon
pCi	picocurie
psi	pounds per square inch
rpm	revolutions per minute
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 184W105 and Monitor Well 184W506M located in western Spring Valley, White Pine County, Nevada. This report also presents groundwater-level data collected at the site post-test through August 2008.

The development and hydraulic testing program of Test Well 184W105 was performed from February 26 through March 10, 2007. The test well and associated Monitor Well 184W506M are completed stratigraphically in the Ely Limestone to a depth of 1,160 ft bgs. The wells are completed in an unconfined, fractured, carbonate-rock aquifer system. Static depth to water in the test well is approximately 208 ft bgs.

The development phase pumping extracted 8,241,000 gallons of water and improved specific capacity, a ratio of discharge (Q) to drawdown (s) in the test well, from 56 to 70 gpm/ft at 2,400 gpm for a 24 percent improvement. A five-interval step-drawdown test was conducted at discharge rates ranging from 2,300 to 3,700 gpm to estimate the optimal 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 target discharge rate of 3,000 gpm. Hydrogeologic data and diagnostic log-log and derivative drawdown data plots indicated that a dual-porosity conceptual model is the most appropriate primary solution method. The Barker generalized radial flow model 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 evaluation software.

Results of the Barker analysis using the optimal best-fit of all site pumping and recovery data indicate an estimated hydraulic conductivity (K) of approximately 60.5 ft/day and a specific storage of 1.0×10^{-5} ft^{-1}. This equates to a storativity (S) of 9.46×10^{-3} assuming a saturated thickness of 946 ft. Matrix hydraulic conductivity (K') for a fracture spacing of 10 ft is 6.30×10^{-3} ft/day. A secondary analysis for transmissivity (T) using the Cooper-Jacob solution indicates that the flow regime may have been dominated by radial flow near the end of the test period. Results of the analysis indicate a T of approximately 5.4×10^{4} ft^2/day and S of 2.05×10^{-4}. Assuming a saturated thickness of 946 ft, the resulting K value is 57 ft/day. A sensitivity analysis was performed for varying fracture spacing, anisotropy ratios, and matrix skin factors. The estimated effective saturated thickness used has a direct proportional relationship to the K value derived from T. Partial penetration of the test well was also evaluated.

Specific capacity during the last 12 hours of the 3,000 gpm, 72-hour constant-rate test ranged from 54.32 to 55.62 gpm/ft. The optimal initial operational pumping rate is projected to range up to 3,500 gpm based upon test results. A total of 22,652,000 gallons of water was extracted throughout the well development and hydraulic testing program.

Groundwater samples were collected from Test Well 184W105 and Monitor Well 184W506M 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. All samples exhibited a calcium-magnesium-bicarbonate facies characteristic of groundwater of a carbonate-rock aquifer. Light stable isotope (δD and $\delta^{18}O$) 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 (^{14}C and $\delta^{13}C$) and strontium ($^{87}Sr/^{86}Sr$) were indicative of groundwater interaction with carbonate minerals along the flow path.

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 184W105 and Monitor Well 184W506M located in Hydrographic Area (HA) 184, Spring Valley, Nevada. The two wells are completed within the unconfined, fractured carbonate aquifer of the Ely Limestone stratigraphic unit. This report also presents groundwater-level data collected at the site post-test through August 2008. A separate document entitled *Geologic Data Analysis Report for Monitor Well 184W506M and Test Well 184W105 in Spring Valley* (Eastman and Muller, 2009) includes the documentation and detailed results for the drilling program, including evaluation of lithology, structural features, drilling parameters, and geophysical logs.

1.1 Program Objectives

The objectives of developing Test Well 184W105 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 the 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 hydraulic testing program was performed from February 26 through March 10, 2007, and consisted of the following activities:

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

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

Monitor Well 184W506M is part of the Spring Valley regional baseline water-level monitoring network. Water-level data have been collected continuously from this location since its 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 performance 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 water-chemistry laboratory data reports.

2.0 Well Site Description

SNWA Test Well 184W105 is located on the west side of Spring Valley, on Bureau of Land Management property, approximately 14 mi north of the Lincoln County and White Pine County boundary in Section 26, T12N, R66E. Access to the site is from U.S. Highway 93 along a dirt road to the west approximately one half mile. A topographic map with the site location and other SNWA test and monitor wells installed as of August 2008 is presented on Figure 2-1.

Two monitor wells were used during testing for observation and background control purposes. Monitor Well 184W506M, located 212 ft to the west-northwest 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 8 mi south of the test well.

2.1 Hydrogeologic Setting

This section presents the regional and local hydrogeologic setting of the Test Well 184W105 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. Adjacent valleys are shown in Figure 2-1.

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 the 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 center axis of the valley with discharge occurring through evapotranspiration. Regional 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 through 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

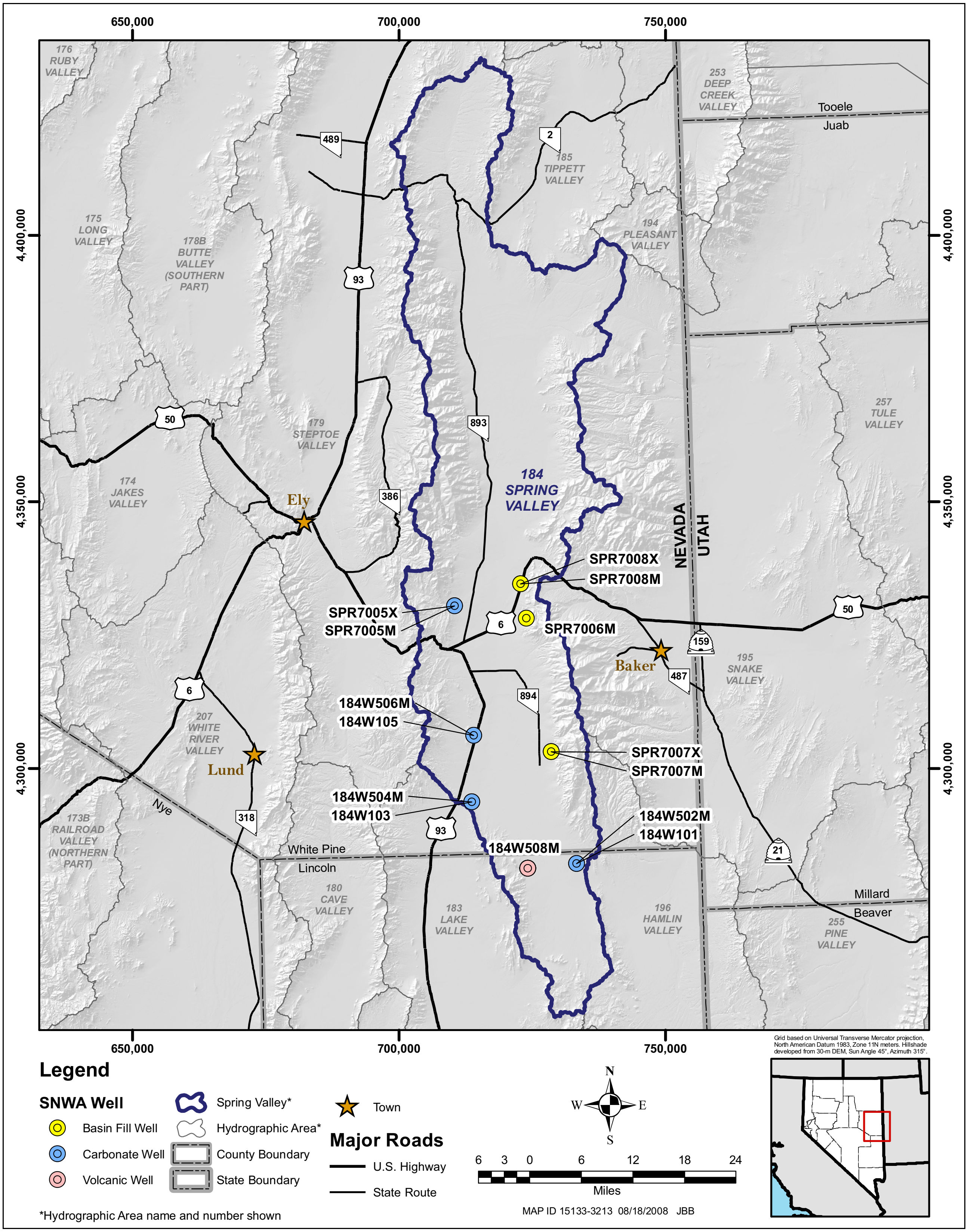


Figure 2-1
SNWA Exploratory and Test Wells in Spring Valley (as of August 2008)

investigations, recharge and discharge estimations, and other hydrologic studies. The regional hydrogeologic framework and a summary of results of previous studies have been presented in several reports. These reports include:

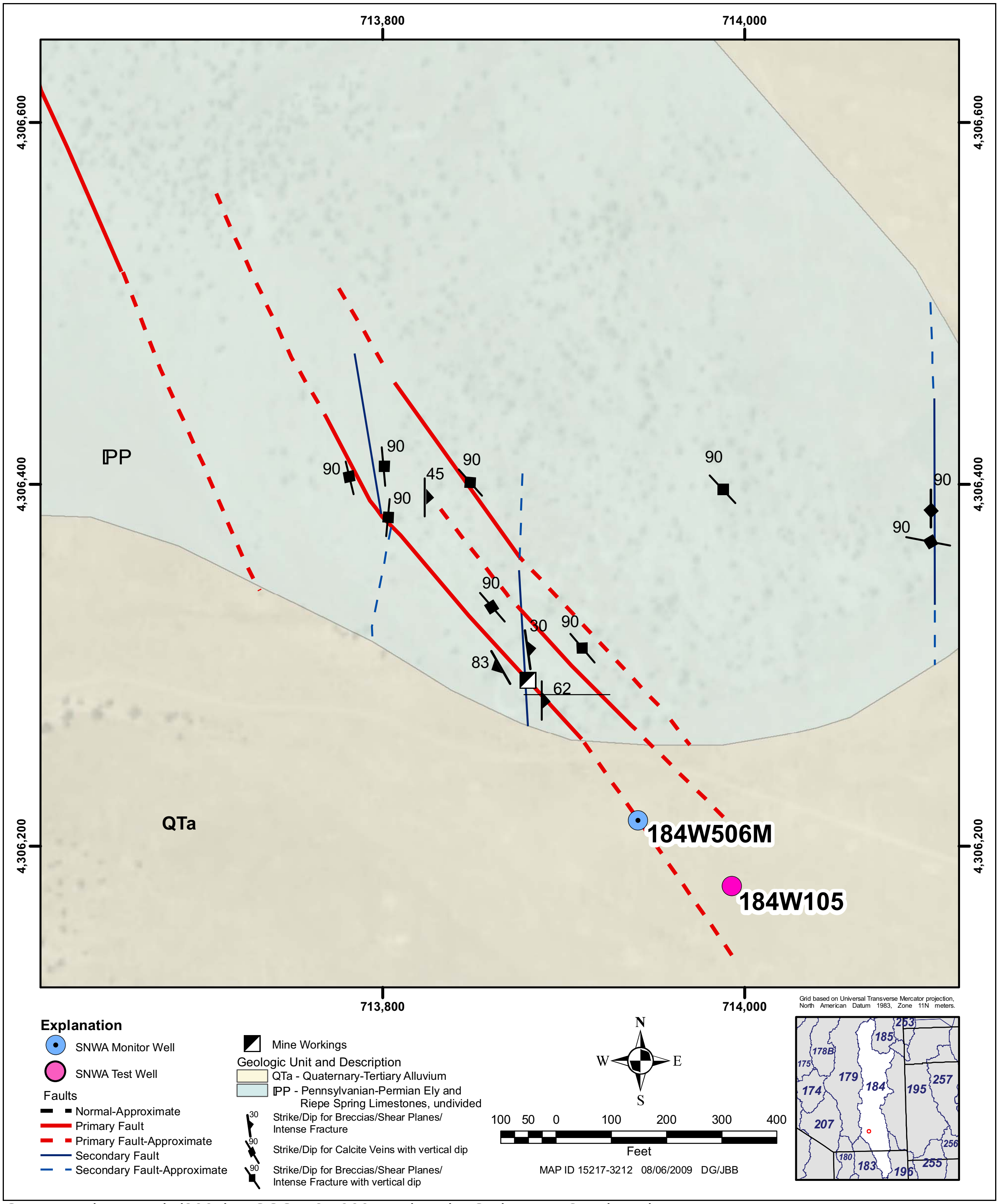
- *Water Resources Appraisal of Spring Valley, White Pine and Lincoln Counties, Nevada* (Rush and Kazmi, 1965)
- *Major Ground-Water Flow Systems in the Great Basin Region of Nevada, Utah, and Adjacent States* (Harrill et al., 1988)
- *Geologic and Hydrogeologic Framework for the Spring Valley Area* (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, and evaluation of surface structural features using aerial photography. Regional data and geologic mapping in the vicinity indicate the presence of faulting and related structures at the site.

Quaternary surface alluvium overlays the Pennsylvanian-Permian Ely Limestone at the well site. The Ely Limestone is light-olive gray to medium-gray limestone composed almost entirely of organic detritus and is approximately 1,900 to 2,500 ft thick in this area (Hose and Blake, 1976). This formation also includes yellowish-gray to tan, silty limestone layers with some portions that are dolomitic. The Pennsylvanian-Permian Ely Limestone is inferred to be underlain by Mississippian Scottie Wash Quartzite, which is underlain in turn by the Mississippian Chainman Shale. The two units may act as local and regional aquitards.

The test and monitor wells are situated along strike and within the damage zone of faults exposed in the nearby Ely Limestone outcrops to the northwest. The orientation of the faults relative to the test and monitor well, including measured dips, is presented in Figure 2-2. A detailed hydrogeologic cross section through the test site was not presented because of the limited available data. A more



Source: Dixon et al. (2007); USGS 1:24,000 North Point Spring 7.5' Quadrangle.

Figure 2-2
Surficial Geology and Structural Features at Monitor Well 184W506M and Test Well 184W105

detailed discussion of local geologic structure is presented in the Geologic Data Analysis Report (Eastman and Muller, 2009).

2.2 Well Data

Test Well 184W105 and Monitor Well 184W506M are completed in the unconfined, fractured carbonate-rock aquifer, stratigraphically in the Pennsylvanian-Permian Ely Limestone. Unsaturated Quaternary surface alluvium overlays the carbonate rock at this location to a depth of 15 to 35 ft.

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 logging. A detailed presentation and analysis of the geologic data at this site, including local structural features, are presented in the Geologic Data Analysis Report for this site (Eastman and Muller, 2009). Summary data for these wells are provided in Sections 2.2.1 and 2.2.2 of this report.

Based on the drill cuttings for the two wells, the Ely Limestone is commonly silty in the upper third of the boreholes and becomes less silty and more cherty with depth. This variation is in accord with the description of the Ely Limestone by Drewes (1967). Fracturing is commonly evident in the cuttings, often associated with clay-rich intervals and/or abundant calcite veinlets. Fracturing with calcite and/or clay zones was noted in both wells from about 200 to 300, 460 to 550, 750 to 940, and 980 to 1,040 ft bgs.

Geophysical data indicate open fractures associated with clay-rich intervals between 490 and 575 ft bgs in both boreholes. The data also suggest open fracturing from 660 to 725 and 795 to 870 ft bgs in Monitor Well 184W506M and from 760 to 810 and at 950 ft bgs in Test Well 184W105.

2.2.1 Test Well 184W105

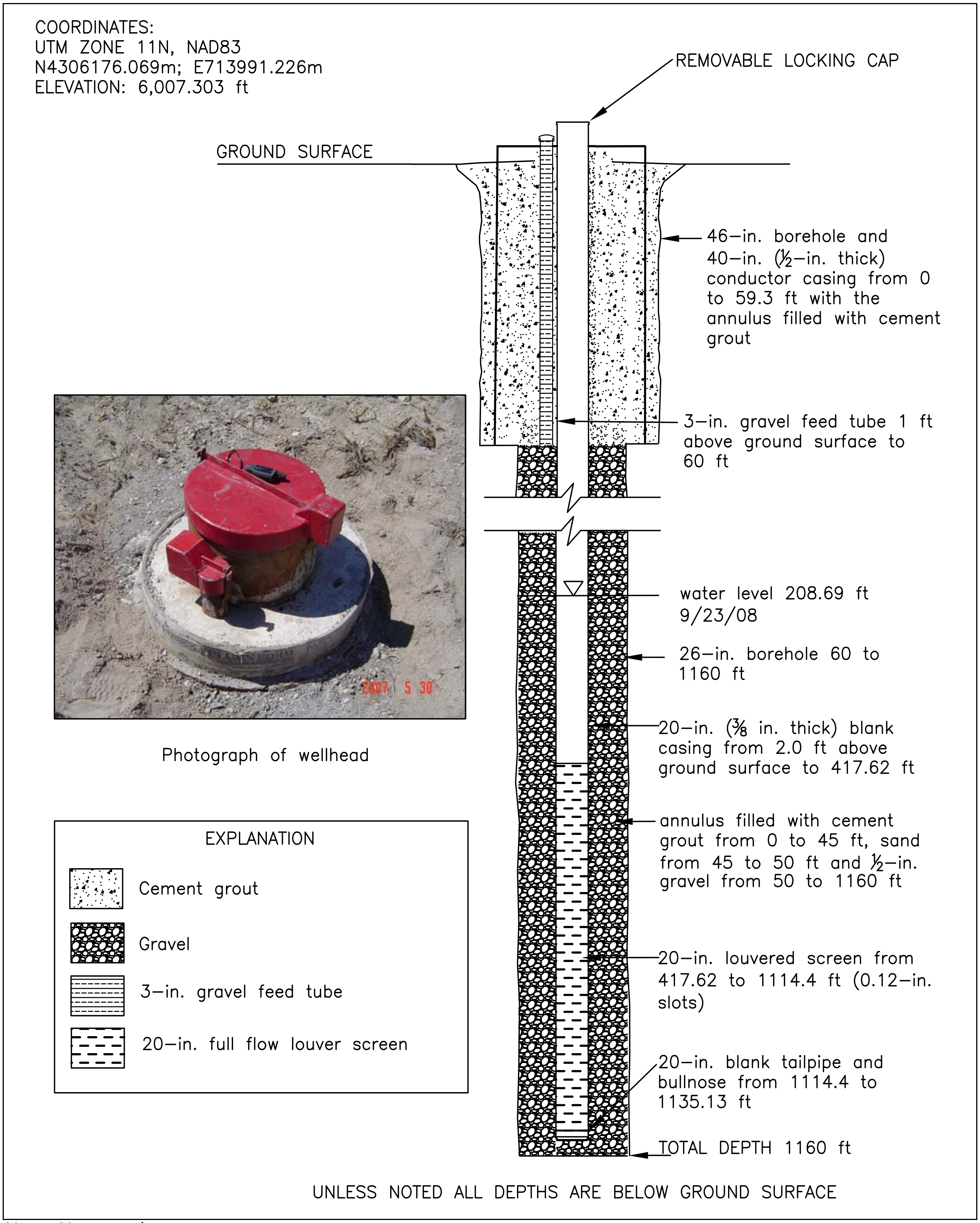
Test Well 184W105 was drilled to a total depth of 1,160 ft bgs between October 20 and November 6, 2006, using mud rotary techniques. A 40-in. O.D. conductor casing was placed to a depth of 59.3 ft bgs and grouted in place. After the borehole was advanced to completion depth, downhole geophysical logging was performed. A 20-in. O.D. completion string, including approximately 696.78 ft of Ful-Flo louvered screen, was then installed. The gravel pack extends from a depth of 50 ft bgs to the bottom of the borehole. A summary chart of Test Well 184W105 drilling and well construction statistics is presented in Table 2-1, and a well construction schematic is presented on Figure 2-3. The borehole lithologic log for Test Well 184W105 is presented in Figure 2-4.

2.2.2 Monitor Wells 184W506M and 184W504M

Monitor Well 184W506M was completed at a depth of 1,160 ft bgs between October 9 and October 19, 2006. A 20-in. O.D. conductor casing was set to a depth of 77.5 ft bgs and grouted in place. A 14.75-in. borehole was then advanced to completion depth. The 8-in. nominal-diameter completion string, including approximately 690 ft of slotted casing, was placed in the open borehole. No gravel pack was used in the well. A summary chart of well drilling and well construction statistics

Table 2-1
Test Well 184W105 Borehole and Well Statistics

LOCATION DATA Estimated Coordinates	N 4,306,176 m; E 713,991 m (UTM, Zone 11, NAD83)	
Ground Elevation	6,007.303 ft amsl	
DRILLING DATA Spud Date	10/20/2006	
Total Depth (TD)	1,160 ft bgs	
Date TD Reached	10/30/2006	
Date Well Completed	11/7/2006	
Hole Diameter	46-in. from 0 to 60 ft bgs 26-in. from 60 to 1,160 ft bgs	
Drilling Techniques	Conventional Circulation from 0 to 160 ft bgs Reverse Circulation from 160 to 1,160 ft bgs	
Drilling Fluid Materials Used	Aqua Clear (5) 25 gal Max-Gel (50) 50-lb bags Soda Ash (66) 50-lb bags DrisPac (28) 50-lb bags Quick Gel (1084) 50 lb bags	Granulated Chlorine (1) 5 gal Gel (653) 50-lb bags BiCarb (1,084) 50-lb Calcium (10) 50-lb bags Cement (7) Supersacks
Drilling Fluid Properties	Viscosity Range = 34 to 75 sec/qt Weight Range = 8.5 to 10.0 lbs Filtrate Range = 5.1 to 28 ml Filter Cake Range = 1/32 to 3/32 in.	*Average = 45.8* *Average = 9* *Average = 13* *Average = 1.6/32nd*
CASING DATA	40-in. MS Conductor Casing from 0 to 59.3 ft bgs 20-in. HSLA Completion Casing from +2 to 1,135.13 ft bgs	
WELL COMPLETION DATA	60 ft of 3-in. gravel sounding tube from 0 to 60 ft 419.62 ft of blank HSLA 20-in. casing from +2 to 417.62 ft bgs 696.78 of 20-in. Ful-Flo louver screen from 417.62 to 1,114.4 ft bgs 20.40 ft blank 20-in. sump MS casing from 1,114.4 to 1,134.80 ft bgs 0.33 ft bullnose CS casing from 1,134.80 to 1,135.13 ft bgs Cement, Plug and Gravel Pack Depth 0 to 60 ft on outside of conductor casing (cement) 50 to 1,160 ft from bottom of Conductor Casing to TD (1/2 in. gravel pack) 45 to 50 ft bgs sand 0 to 45 ft bgs grout outside of completion casing, and inside of conductor	
MONITOR WELL	Static Water Level: 208.69 ft bgs (9/23/08) Groundwater Elevation: 5,798.61 ft amsl	
DRILLING CONTRACTOR	Lang Exploration Drilling	
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)	
OVERSIGHT	Southern Nevada Water Authority	



Note: Not to scale

Figure 2-3
Test Well 184W105 Construction Schematic

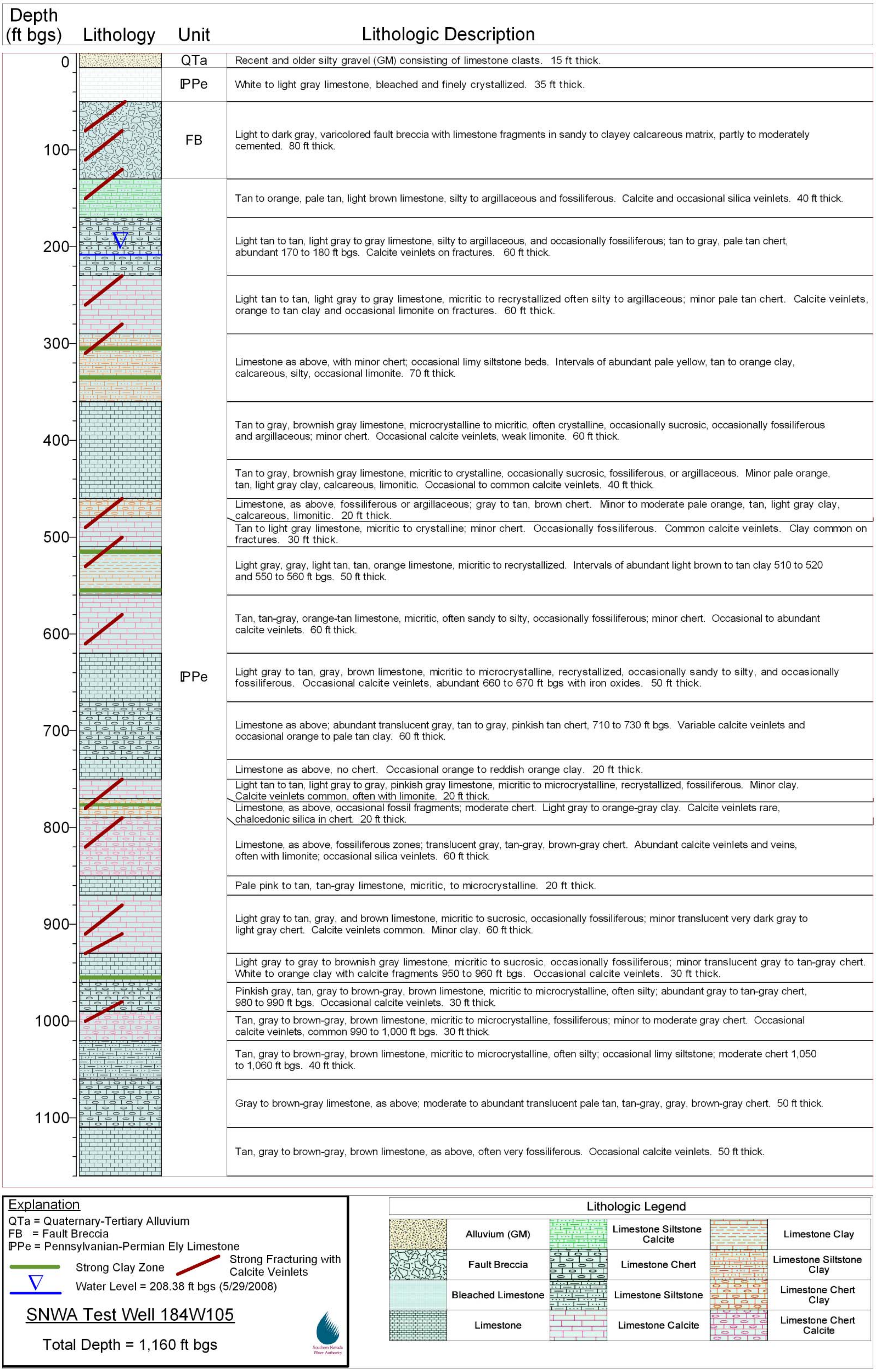


Figure 2-4
Borehole Stratigraphic Column of Test Well 184W105

for Monitor Well 184W506M is presented in Table 2-2, and a well construction schematic is presented on Figure 2-5. The borehole lithologic log for Monitor Well 184W506M is presented in Figure 2-6.

Monitor Well 184W504M 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 well is also completed in the unconfined, fractured carbonate-aquifer system. The 8-in.-diameter well is completed 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

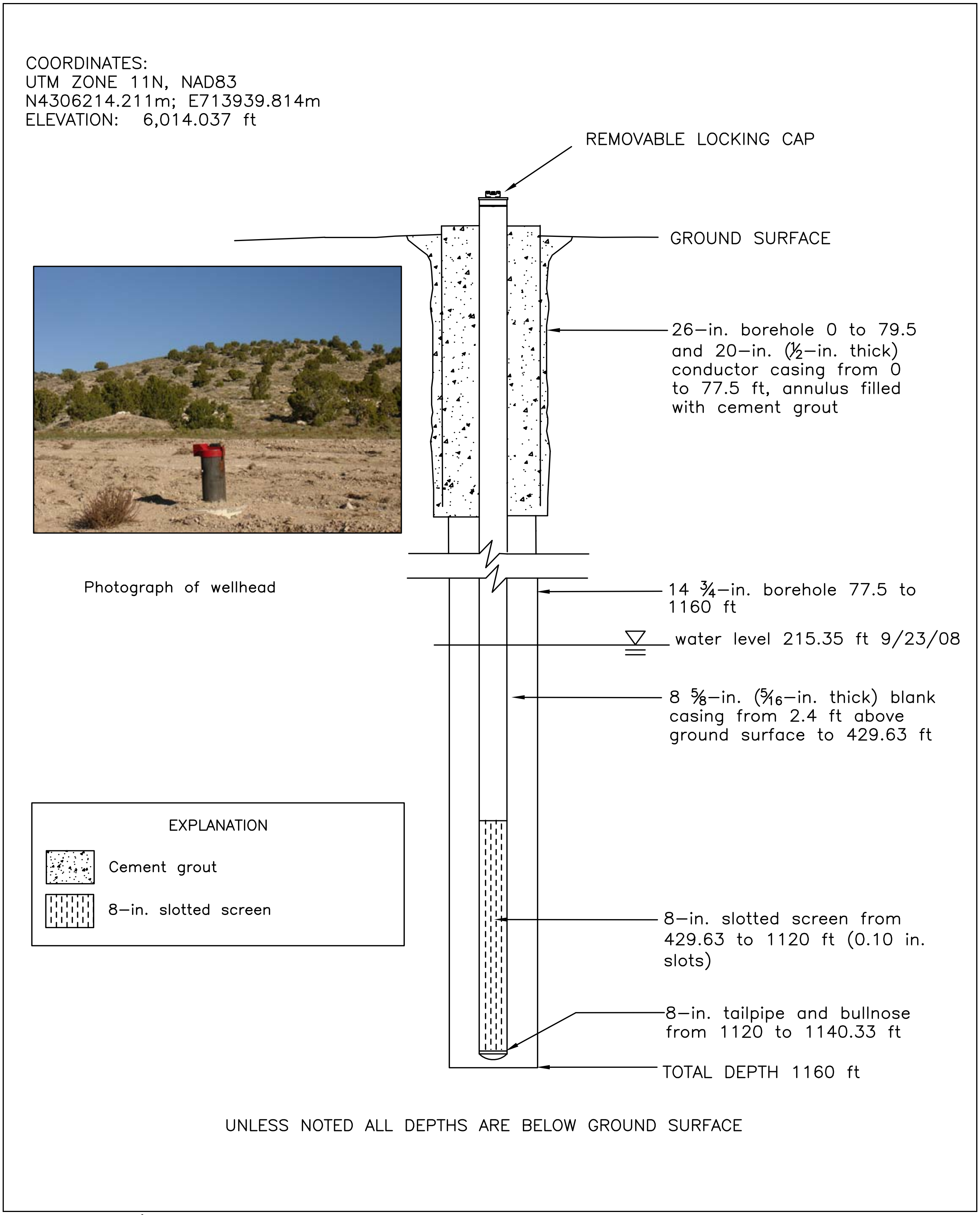
Depth-to-water measurements were obtained at the wells relative to a marked temporary or permanent reference measuring point. Professional survey elevations for the measuring points and ground-surface elevations for the wells are presented in Table 2-3.

Static groundwater-elevation data have been collected on a continuous basis at Monitor Wells 184W506M and 184W504M from just preceding the test to present. These wells are currently equipped with In-Situ Level TROLL 700 integrated transducers. Physical measurements are collected from the test well on a six-week to quarterly frequency. The two monitor wells are included in the SNWA regional groundwater monitoring network.

Static groundwater elevation is approximately 5,798 to 5,799 ft amsl at Test Well 184W105, which corresponds to a depth to water of approximately 208 to 208.5 ft bgs. Static groundwater elevation at Monitor Well 184W506M is approximately 5,799 ft amsl, which corresponds to a depth to water of 215 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 on Figures 2-7 through 2-9. The hydrograph for the background well highlights time intervals during this test and a later unrelated test performed at another test well, 184W103, located adjacent to 184W504M. Static water levels have remained within a narrow range since the test period. A detailed background hydrograph at 184W504M during the testing period is presented in Section 3.4.

Table 2-2
Monitor Well 184W506M Borehole and Well Statistics

LOCATION DATA Estimated Coordinates	N 4,306,214 m; E 713,940 m (UTM, Zone 11, NAD83)	
Ground Elevation	6,014.0370 ft amsl	
DRILLING DATA Spud Date	10/09/2006	
Total Depth (TD)	1,160 ft bgs	
Date TD Reached	10/17/2006	
Date Well Completed	10/19/2006	
Hole Diameter	26-in. from 0 to 79.5 ft bgs 14.75-in. from 79.5 to 1,160 ft bgs	
Drilling Techniques	Conventional Circulation from 0 to 220 ft bgs Reverse Circulation from 220 to 1,160 ft bgs	
Drilling Fluid Materials Used	Max-Gel = (42) 50-lb bags Soda Ash = (12) 50-lb bags DrisPac = (14) 50-lb bags EZ-Mud = (7) 5-gal buckets Gel (1915) 50-lb bags	BiCarb (5) 50-lb bags Quick Gel (98) 50-lb bags Calcium (4) 50-lb bags Cement (25) 98 lb sacks Cement (3) Supersacks
Drilling Fluid Properties	Viscosity Range = 32 to 166 sec/qt Weight Range = 8 to 9 lbs Filtrate Range = 10 to 22.8 ml Filter Cake Range = 1/32 to 4/32 in.	*Average = 48.5* *Average = 8.9* *Average = 15.2* *Average = 1.96/32nd*
CASING DATA	20-in. MS Conductor Casing from 0 to 77.5 ft bgs 8-in. MS Completion Casing from +2.4 to 1,140.33 ft bgs	
WELL COMPLETION DATA	432.03 ft of blank MS 8-in. casing from +2.4 to 429.63 ft bgs 690.37 ft of slotted MS 8-in. casing from 429.63 to 1,120 ft bgs 20 ft blank sump MS 8-in. casing from 1,120 to 1,140 ft bgs 0.33 ft bullnose CS casing from 1,140 to 1,140.33 ft bgs Cement Depth 0 to 79.5 ft on outside of conductor casing	
WATER	Static Water Level: 215.35 ft bgs Groundwater Elevation: 5,798.68	
DRILLING CONTRACTOR	Lang Exploration Drilling	
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)	
OVERSIGHT	Southern Nevada Water Authority	



Note: Not to scale

Figure 2-5
Monitor Well 184W506M Construction Schematic

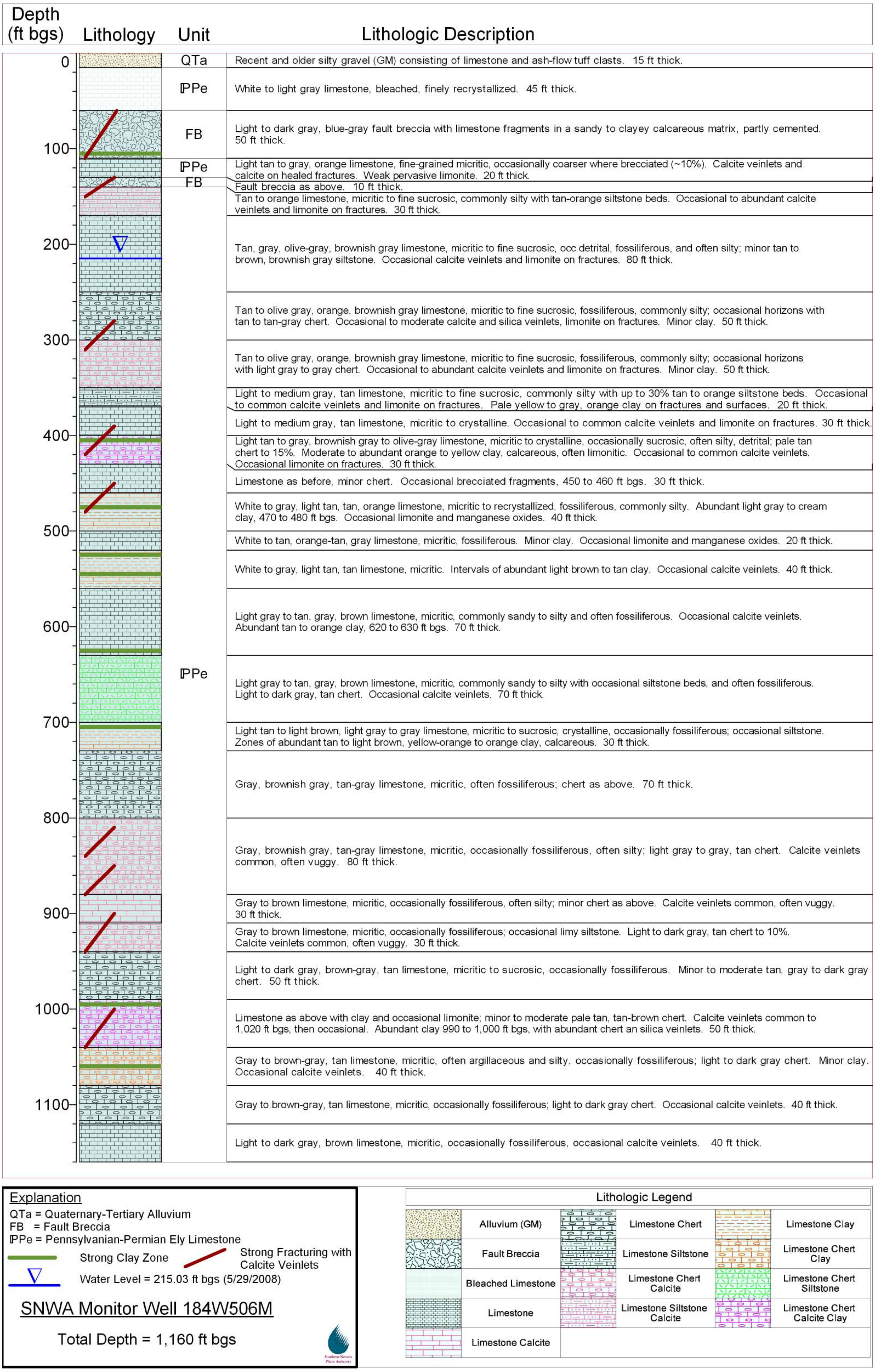


Figure 2-6
Borehole Stratigraphic Column of Monitor Well 184W506M

Table 2-3
Measuring-Point Information

Well ID	Well Use During Testing	UTM Northing (m)[a]	UTM Easting (m)[a]	Temporary MP (ft amsl)	Permanent MP (ft amsl)	Ground Surface Elevation (ft amsl)
184W105	Test Well	4,306,176	713,991	6,013.10	6,009.15	6,007.30
184W506M	Observation Well	4,306,214	713,940	6,016.59	6,016.44	6,014.04
184W504M	Background Well	4,293,712	713,647	5,901.44	5,901.44	5,900.11

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

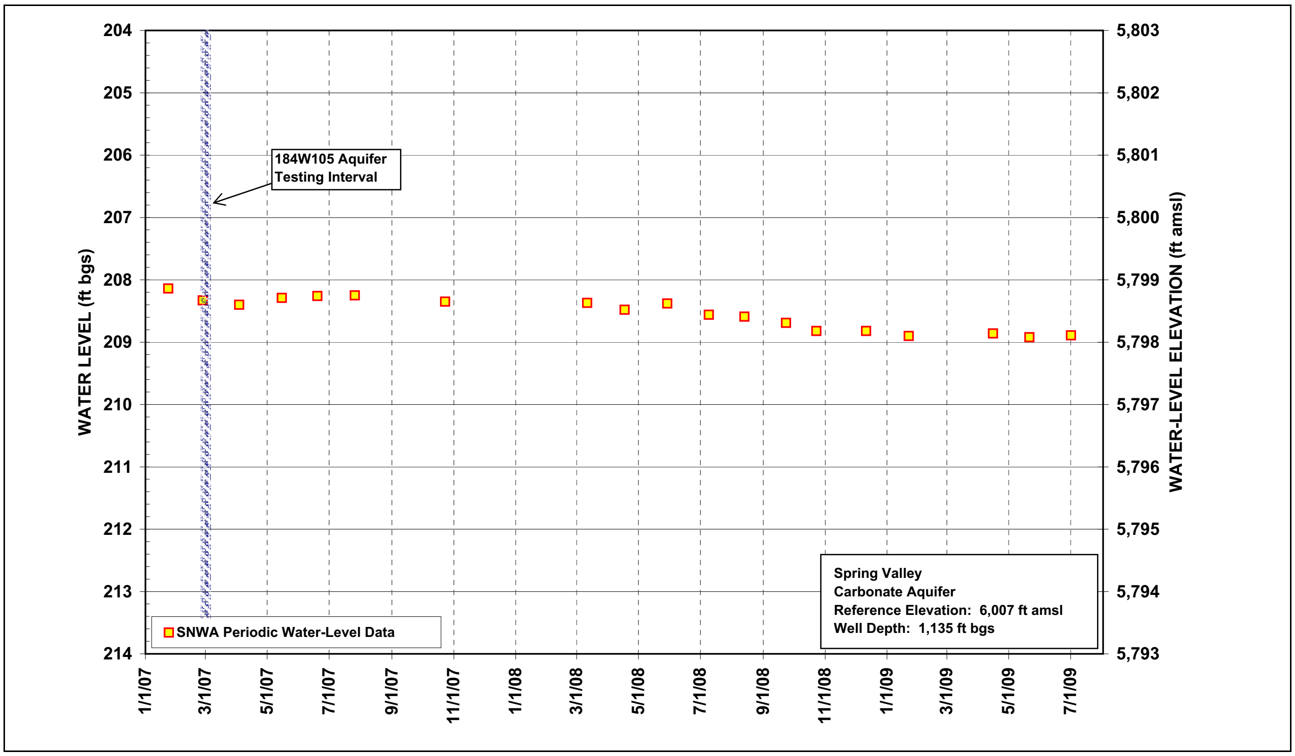


Figure 2-7
Test Well 184W105 Historic Hydrograph

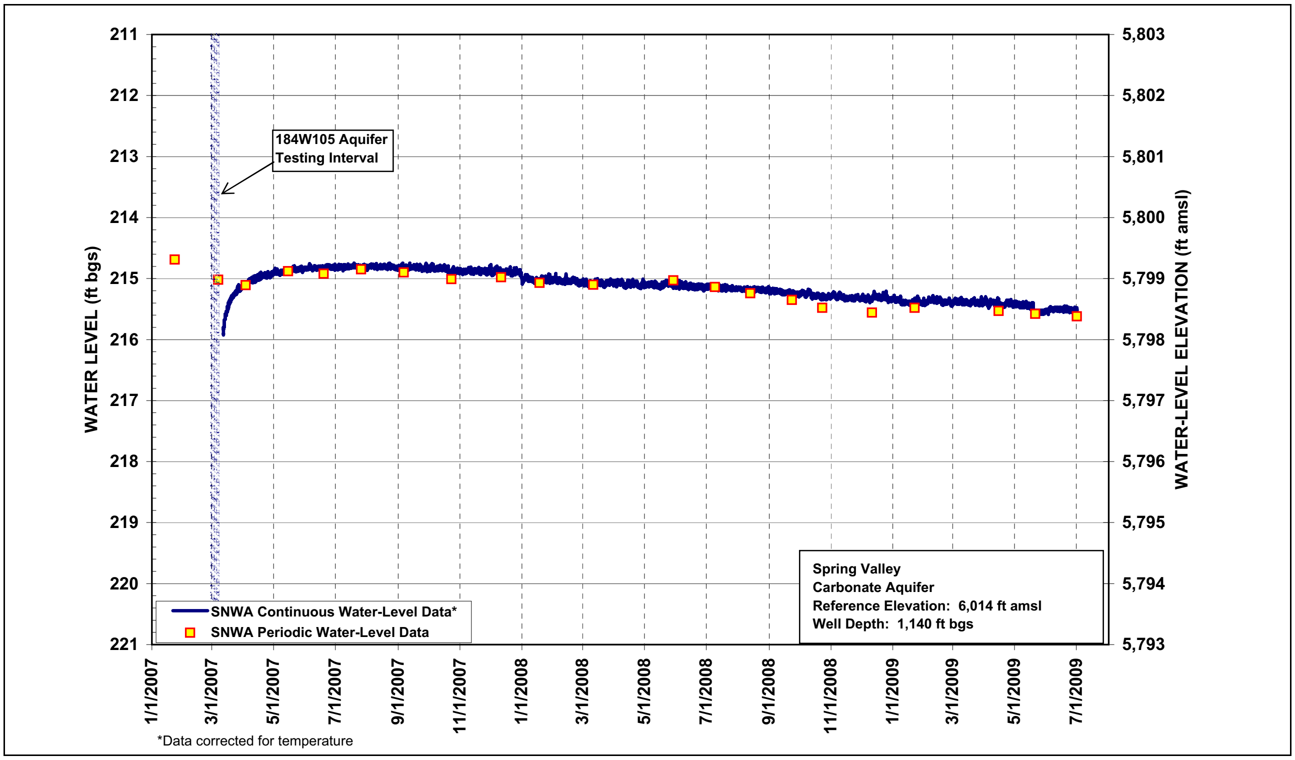
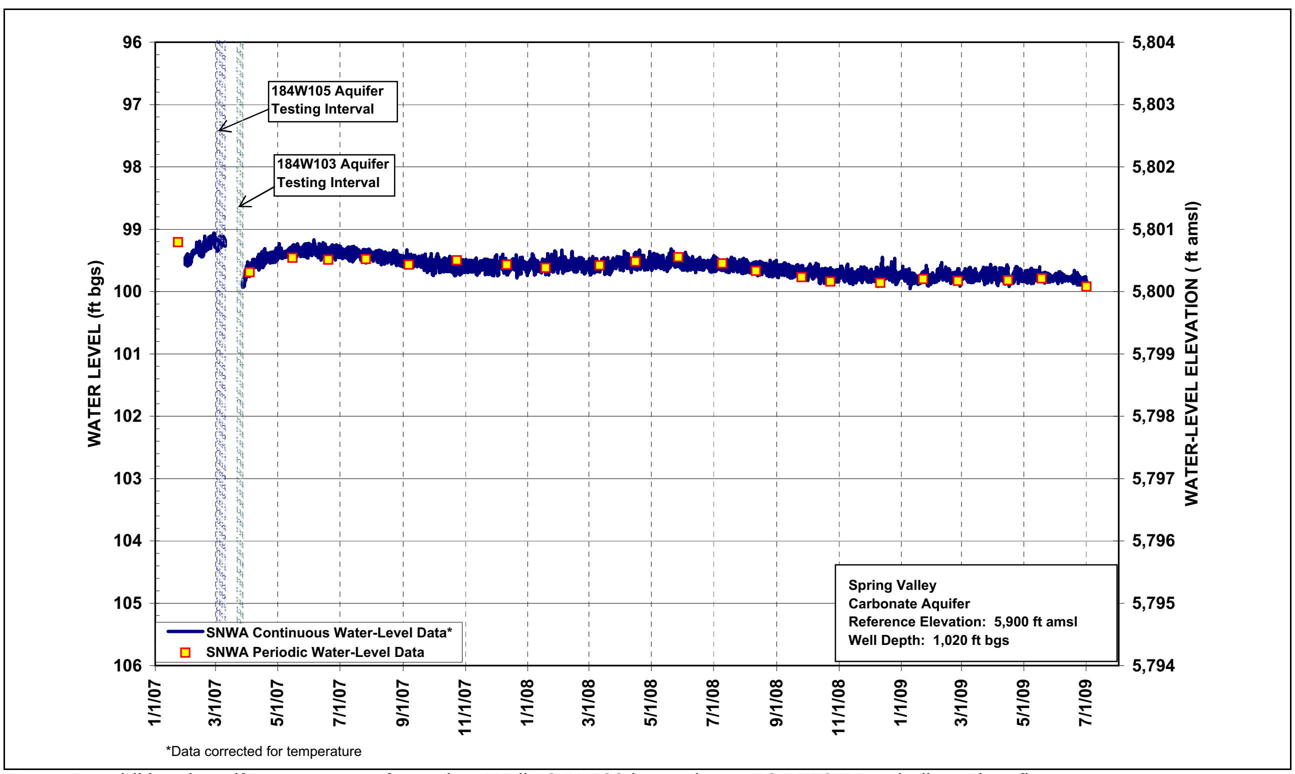


Figure 2-8
Monitor Well 184W506M Historic Hydrograph



Note: An additional aquifer test was performed on Well 184W103 located near 184W504M as indicated on figure.

Figure 2-9
Monitor Well 184W504M Historic Hydrograph

3.0 TEST DESCRIPTION AND BACKGROUND DATA

This section describes the activities, pump equipment, and monitoring instrumentation associated with development and testing of 184W105. 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:

- February 26 to 27: Developed the test well using surge and pump methods. The well was developed at rates ranging from 1,500 to 2,625 gpm.
- February 28: Performed initial step-drawdown test at discharge rates ranging from 1,750 to 2,500 gpm.
- March 2: Performed 12-hour constant-rate test at 2,300 gpm.
- March 3: Reset pump intake 100 ft deeper.
- March 4 to 5: Performed an additional 21 hours of development using surging methods. Pumped at rates ranging from 2,400 to 3,640 gpm.
- March 6: Performed step-drawdown test at rates ranging from 2,300 to 3,700 gpm.
- March 7 to 10: Performed 72-hour constant-rate test at 3,000 gpm and collected recovery data.

3.2 Test Equipment and Site Layout

A Johnson Pump Company vertical line shaft turbine pump was used in Test Well 184W105. The intake was initially set at 283 ft bgs and then lowered to 383 ft bgs prior to the step-drawdown test. The test well transducer was set at 278 ft below the measuring point and then lowered to 358 ft when the intake was lowered. 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 east of the site through approximately 2,000 ft of 12-in.-diameter piping. To comply with Nevada Department of Transportation (NDOT) permit requirements, the line was reduced to an 8-in.-diameter assembly in order to pass through a culvert under U.S. Highway 93. The discharge pipe/line then was expanded back to 12-in. diameter east of the highway. The discharge point was located near the edge of the NDOT right-of-way on the east side of U.S. Highway 93.

A total of 22,652,000 gallons was pumped over the course of the development and testing periods for Test Well 184W105.

3.4 Instrumentation and Background Data

Regional and background water levels were continuously recorded prior to, during, and after the test period. Groundwater levels in Test Well 184W105 were recorded during the test period using an In-Situ HERMIT 3000 Data Logger. Test Well 184W105 was equipped with an In-Situ 250 psi pressure transducer. Monitor Well 184W506M and background well 184W504M were equipped with an In-Situ Level TROLL 700 integrated transducer. Barometric pressure was recorded at the test well and at evapotranspiration (ET) station SV1 located approximately 8 mi south-southeast of the test well.

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

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

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 0.10 ft was observed. This background change is insignificant with respect to the magnitudes 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 184W506M collected during the constant-rate test. The barometric-pressure record, recorded at Test Well 184W105 and ET station SV1, covers the time period during the constant-rate test. During the record period, the barometric pressure varied by approximately 0.18 in. Hg. This equates to 0.20 ft of head, assuming 100 percent barometric efficiency of the well. The amount and duration of change in barometric pressure did not 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.

No other outside influences, such as the existence of other pumping wells in the vicinity of Test Well 184W105, were identified.

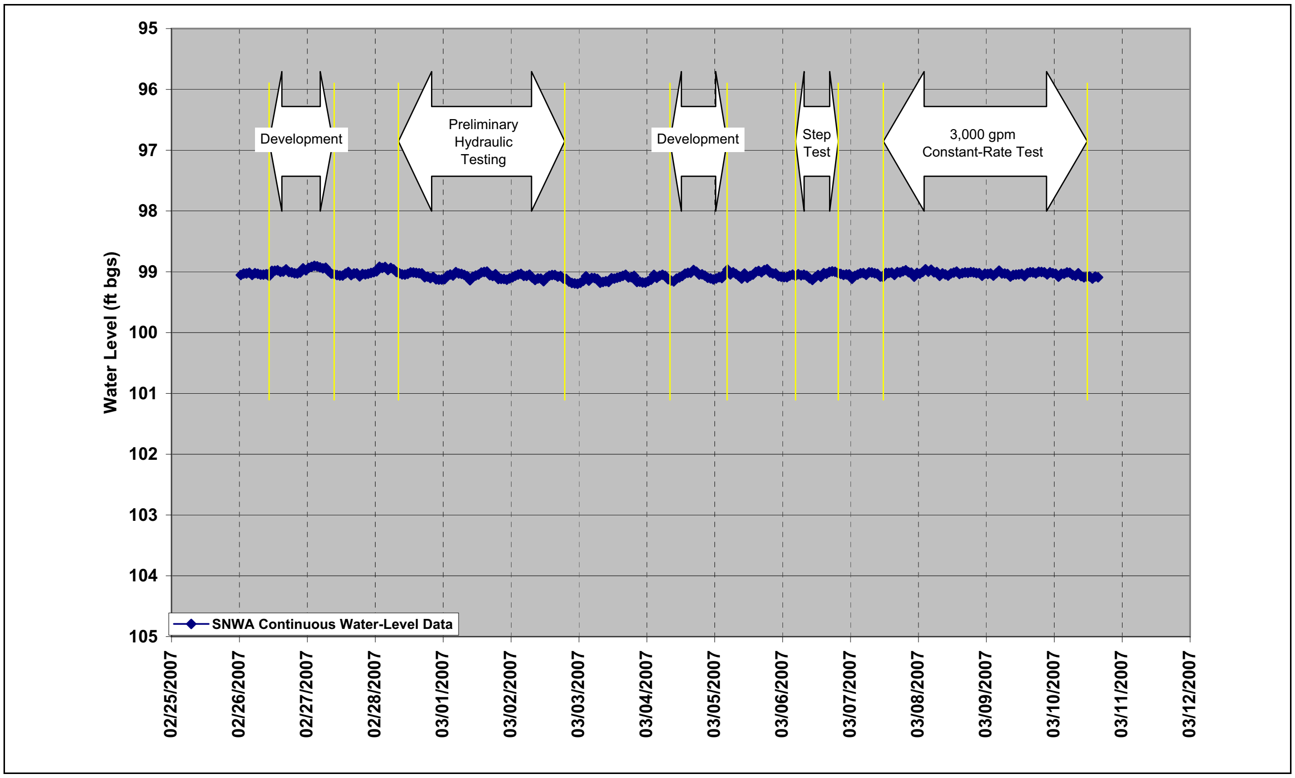


Figure 3-1
Hydrograph for Background Well 184W504M During Test Period

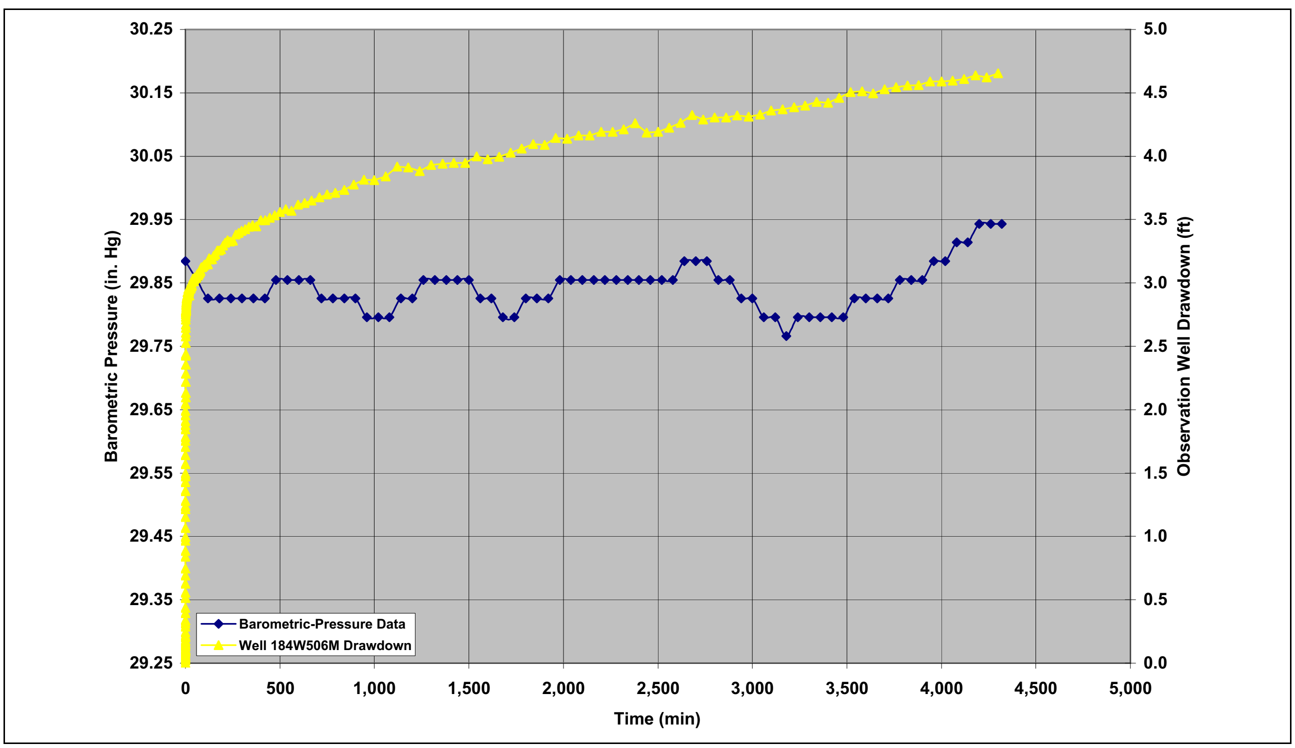


Figure 3-2
Local Barometric-Pressure Variation and Groundwater-Level Measurements at Monitor Well 184W506M

The respective borehole deviations for wells 184W105 and 184W506M 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 measurement results.

Transducer data collected in the wells were compared to manually collected data. Only minor inconsistencies were identified, and these 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.

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, the well 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 184W105 was 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 8,241,000 gallons of water was pumped during this phase of pump development. Development at this site was very effective. The specific capacity at 2,400 gpm improved from 55.9 gpm/ft (42.9 ft of drawdown) on February 26, 2007, to 69.5 gpm/ft (34.5 ft of drawdown) on March 5, 2007, for a 24.3 percent improvement.

4.2 Step-Drawdown Test

A step-drawdown test was performed using five different pumping rates ranging from 2,300 to 3,700 gpm. The pumping periods ranged from 60 to 90 minutes in duration and were continuous. Figure 4-1 presents a graph showing plots of the drawdown versus time for each pumping interval.

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 time and increased discharge rate. Graphs of 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 a productive well with specific capacity values of 50 to 70 gpm/ft for associated short-term pumping rates of 3,500 to 2,300 gpm, respectively. Specific

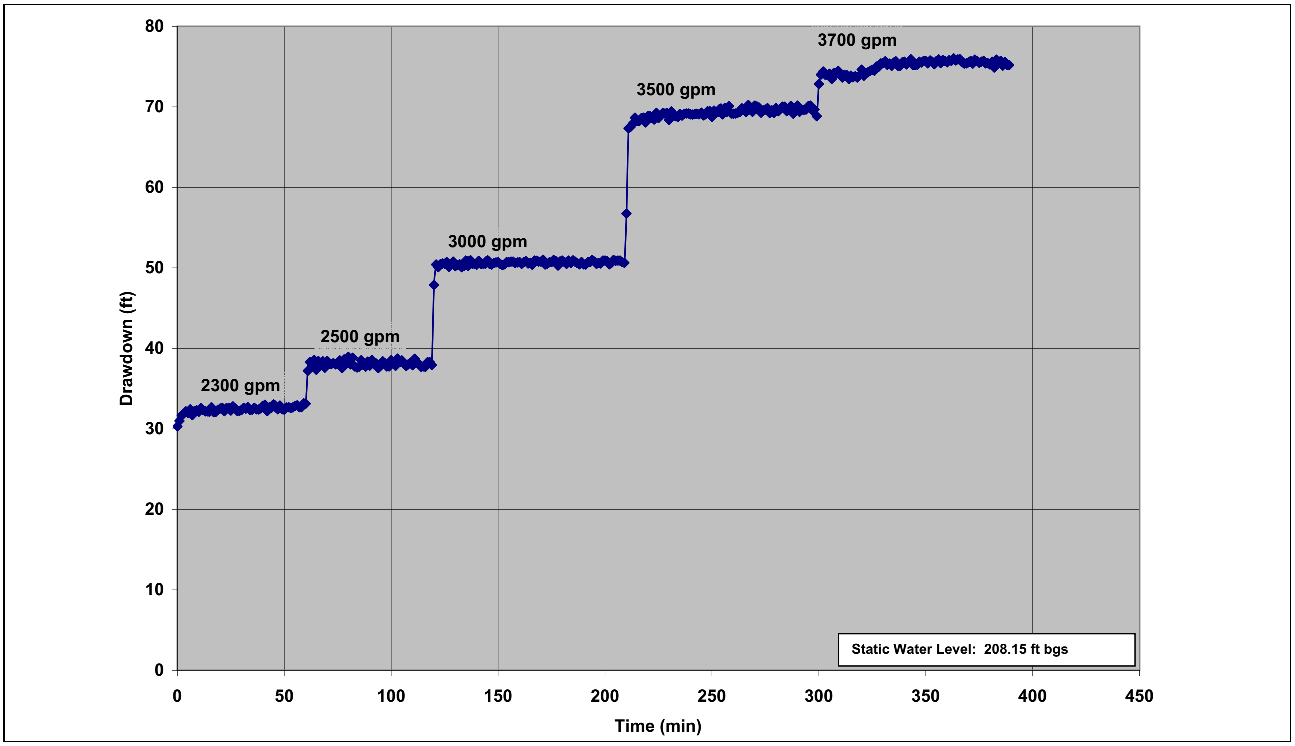


Figure 4-1
Linear Plot of Drawdown for Each Pumping Interval
During Step-Drawdown Testing of Test Well 184W105

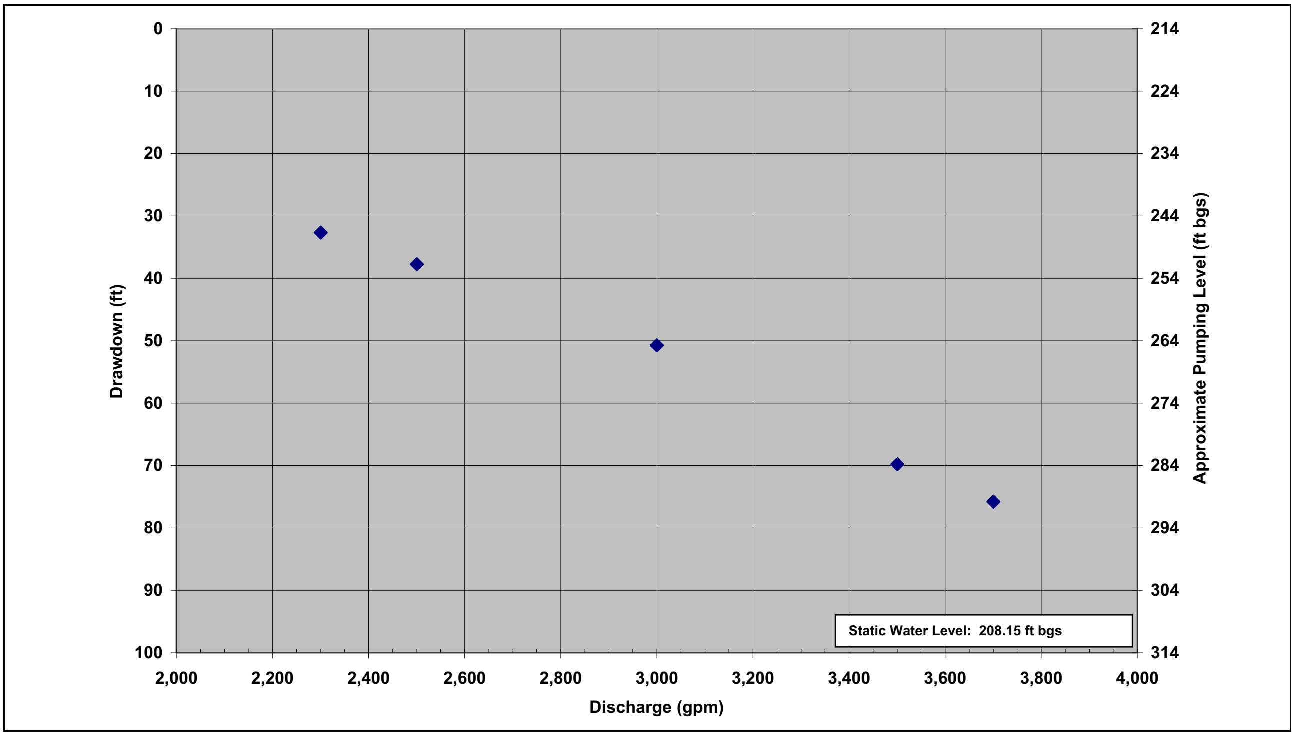


Figure 4-2
Linear Plot of Step-Test Drawdown and
Depth-to-Pumping Level Various Discharge Rates for Test Well 184W105

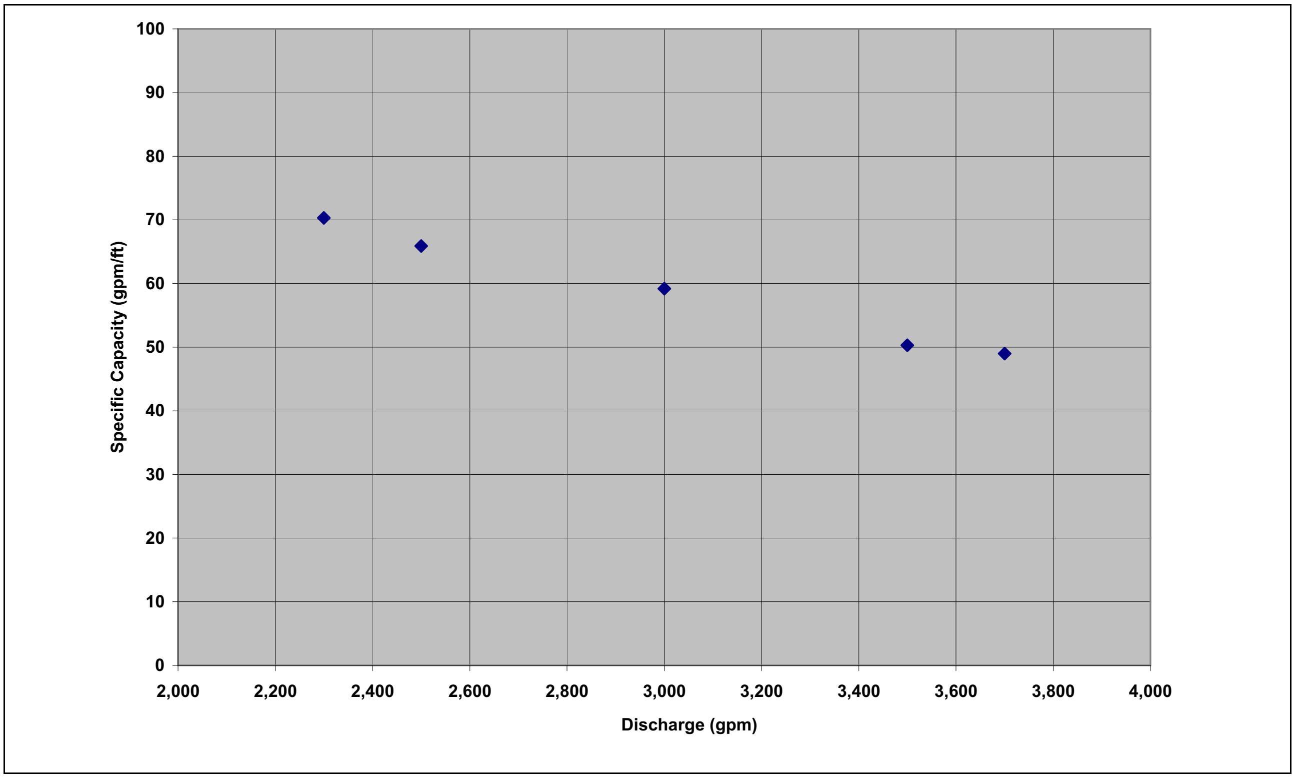


Figure 4-3
Step-Test Specific Capacity versus Discharge Rate for Test Well 184W105

capacity during the last 12 hours of the 72-hour, 3,000-gpm constant-rate test ranged from 54.33 to 55.62 gpm/ft. Based on these results, an operational pumping rate could range up to 3,000 to 3,500 gpm.

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 in the pumping well caused by the turbulent flow and frictional head loss effects in or adjacent to the well. Loss components are also classified as linear and nonlinear losses. 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 head losses are caused by turbulent flow occurring inside the well screen pump column and the fracture zone adjacent to the well. Higher turbulent well losses caused by the formation are expected to occur more often in a fractured bedrock aquifer than in granular porous media.

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 rate. Generally, specific capacity decreases at higher pumping rates due to increase of turbulent flow at the well. 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 evaluate head loss coefficients using the Hantush-Bierschenk method (Bierschenk, 1963; Hantush, 1964) are presented in Figure 4-4. Evaluation using the Rorabaugh method (Rorabaugh, 1953) was also performed and compared to the results of other analysis methods.

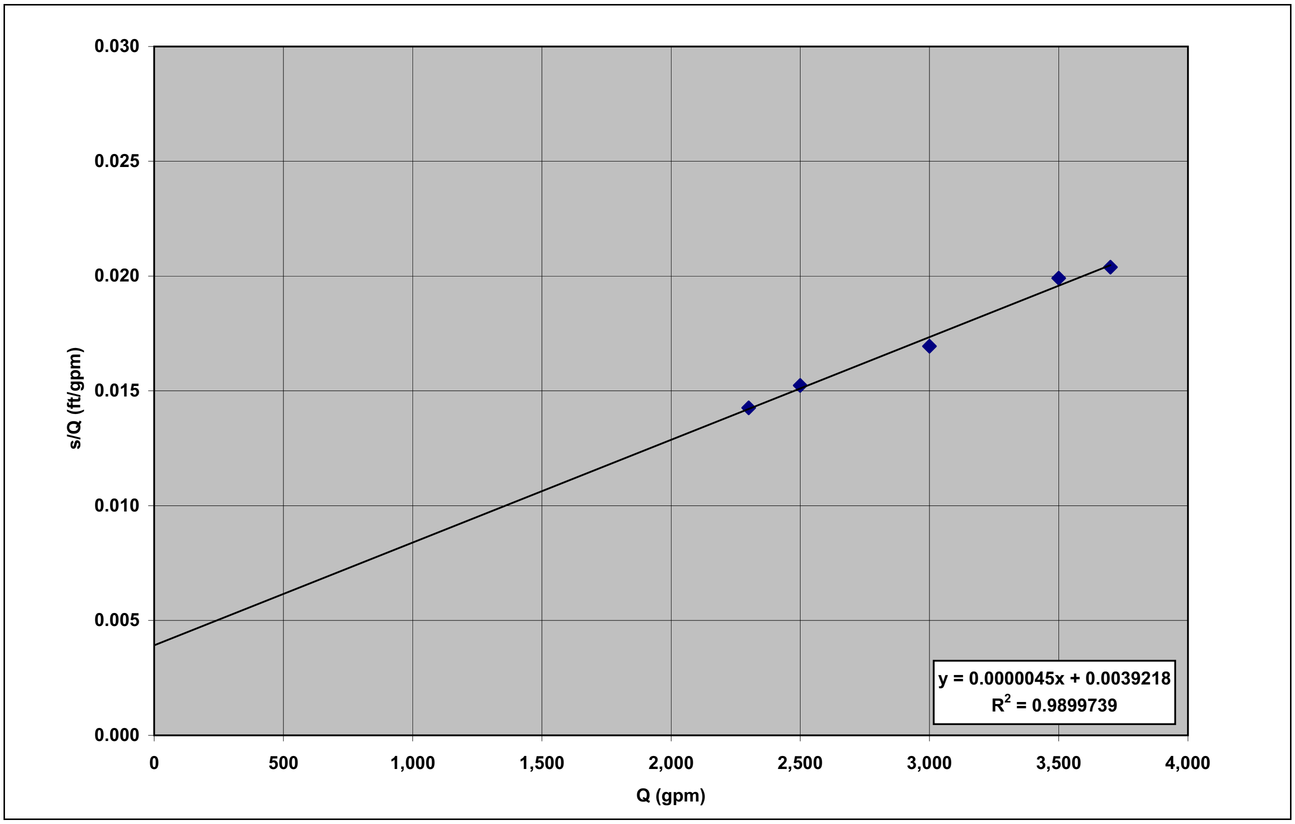


Figure 4-4
Evaluation of Head Loss Coefficients Using Hantush-Bierschenk Method from Step-Drawdown Test Results

The loss coefficient for *B* is 0.0039218 and *C* equals 4.5×10^{-6} using the Hantush-Bierschenk Method. R^2 is the coefficient of determination, which 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

$$Q/s = 1/(4.5 \times 10^{-6} Q + 0.00392) \quad \text{(Eq. 4-2)}$$

The reliability of the projection is highest within the discharge testing range of the step-drawdown test. Results from applying the Rorabaugh method calculated *C* as equal to 4.69×10^{-6}.

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

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

Table 4-1 shows that the nonlinear losses compose about 73 to 81 percent of the drawdown, the percentage increasing with increasing production rate. This analysis indicates that the nonlinear losses are substantial, which should be reflected in a substantial well loss contribution to pumping-well drawdown. Evaluation assumed a saturated thickness of 946 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 *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. Based on the preferred analysis presented in Section 5.4, the drawdown at the end of the test period was estimated to be approximately 22 ft. The actual drawdown observed was about 53 ft, yielding an estimated efficiency of 42 percent using well loss calculated from the step-drawdown test results. This is within an expected range for wells completed in fractured aquifers.

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 (%)
2,300	32.80	0.0142603	23.81	9.02	32.83	73
2,500	38.11	0.0152427	28.13	9.80	37.93	74
3,000	50.83	0.0169439	40.50	11.77	52.27	77
3,500	69.70	0.0199152	55.13	13.73	68.85	80
3,700	75.43	0.0203863	61.61	14.51	76.12	81

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5.0 CONSTANT-RATE TEST EVALUATION

This section summarizes the collection of hydraulic testing data, selection of the analytical solutions for analysis of drawdown and pumping data, and the results of the 72-hour constant-rate and recovery test at Test Well 184W105.

5.1 Data Review and Adjustments

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

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.

The target discharge rate for the constant-rate test was 3,000 gpm; however, three minor discharge flow adjustments occurred during the test. The first was a readjustment down and back up at approximately 1,100 minutes elapsed time into the test at 07:00 on March 8, 2007, due to a stuck rpm meter on the generator. A second flow readjustment downward occurred at 2,400 minutes at 04:00 on March 9, 2007, when the flow meter indicated 3,050 gpm. A reading of 2,900 gpm was made at approximately 2,600 minutes into the test at 07:30 on March 9, 2007, and flow was adjusted up to 3,000 gpm. The observed variations were approximately 1.7 to 3.3 percent of the target discharge rate. Totalizer readings indicated a total volume of 13,177,000 gallons pumped during the 72-hour test, which averages 3,050 gpm for the duration of the test or a 1.7 percent variance from the target discharge rate. The flow variations had no significant effect on the test analysis. However, in order to capture the variation during the test and incorporate it into the curve-fitting, the incremental average flow rate was calculated from the totalizer record; the running average rate was then calculated, and a set of incremental rates at 0.5-day time steps was calculated based on the running average. This captures the variation of the applied stress while smoothing the instantaneous adjustments.

During the initial minute of the test, small variations in drawdown were observed. These were the result of water filling the pump column and pressure variations at the flow control valve.

Vertical flow losses within the well were considered during analysis. Upward flow within the well screen and casing to the pump intake is subject to friction losses that are a function of the screen and casing diameters, friction coefficient, and flow rate. Since the flow rate varies along the depth of the well screen because of distributed water intake along the screen, the losses vary with depth.

Assuming consistent hydraulic conductivity along the well depth and no vertical gradient, the friction losses due to upward flow in the well were calculated to reach a maximum of just under 1 ft at total depth of the screen. A nominal friction factor of 2X smooth pipe was used for the screen. Relative to the drawdown observed during the test, this influence is negligible, and the total length of the screened interval was considered to have been stressed equally.

Minor smoothing of the transducer data record was performed to average noise in the test well data record. The record indicates some noise in the drawdown data caused by turbulence at the pump intake and shifts in drawdown associated with minor variation of the production rate described earlier in this section. The synthetic production record was developed to smooth the shifts while preserving the total volumes recorded periodically.

The data logger time for recovery at Monitor Well 184W506M lagged from the test well record by about 7.44 seconds (0.000086 days) based on the start of recovery. The monitor-well recovery record was shifted by this amount.

Early-time recovery data after cessation of pumping are obscured because the pump was not fitted with a check valve. After the pump was stopped, the water column in the pump column flowed back into the well. This created a short-term injection pulse into the well that is superimposed on the recovery. Examination of the recovery response indicates that this pulse almost instantaneously raises the water level above the original static water level. The recovery water level then decays back to the aquifer recovery response. This effect is observed in both the test well and in the monitor well and does not influence the analysis of the recovery data after the pulse reaches equilibrium.

5.2 Constant-Rate Test Data

The constant-rate test was performed for a duration of 72 hours at a target pumping rate of 3,000 gpm. A summary of drawdown data for Monitor Well 184W506M and Test Well 184W105 is presented graphically in log-log and semi-log form on Figures 5-1 through 5-4. Transducer and physical test 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.

5.3 Analytical Model Selection

The analytical model used for the evaluation of the site data was selected based upon the conceptual model of site hydrogeologic conditions and diagnostic log-log 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 fractured carbonate bedrock. 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. Rate of release would be dependent upon the matrix skin effect. As pumping continues, release of matrix water decreases,

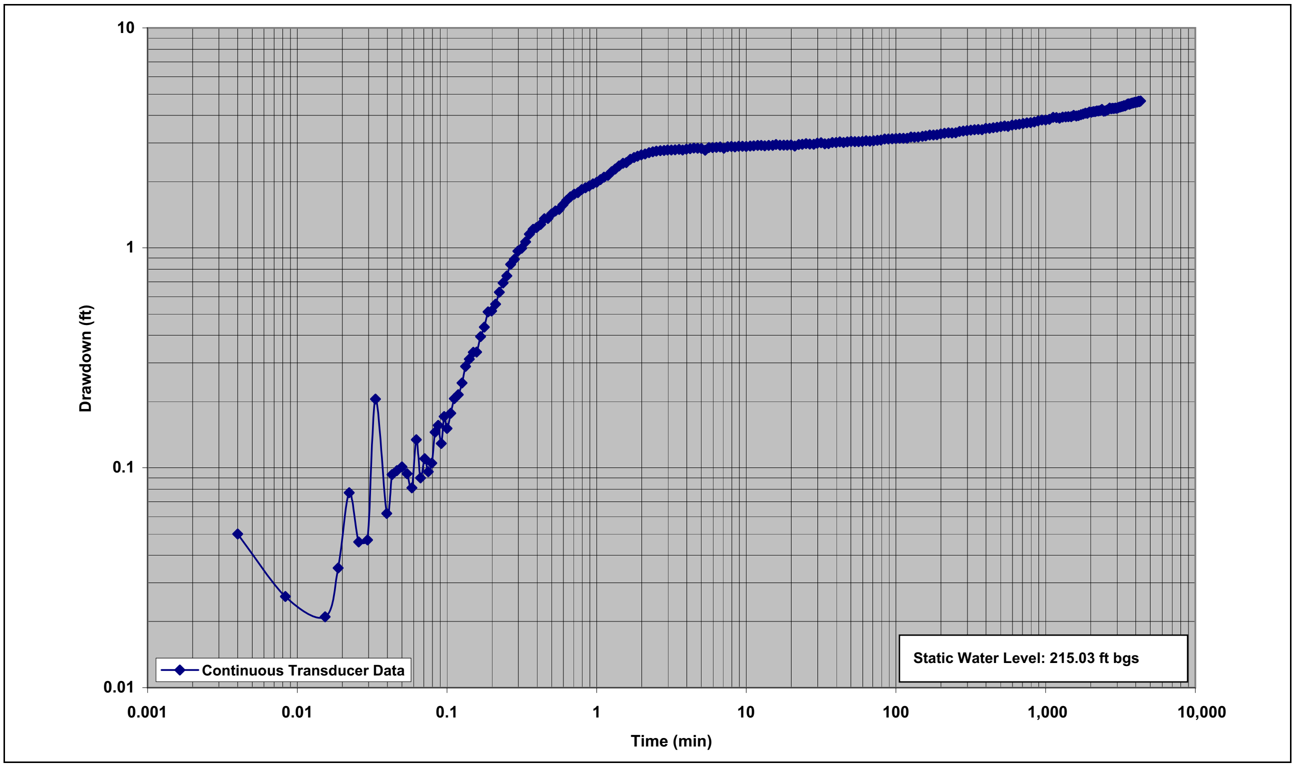


Figure 5-1
Log-Log Data Plot of Drawdown versus Time from Monitor Well 184W506M

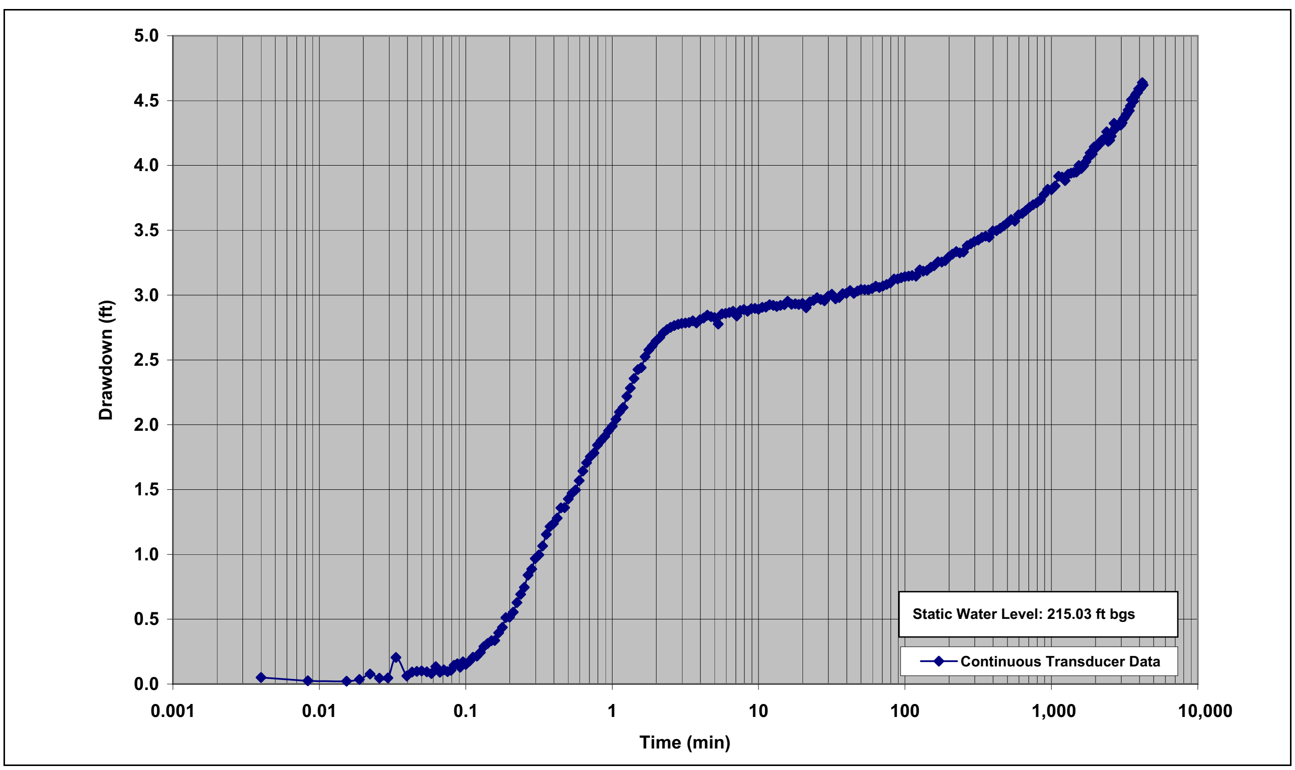


Figure 5-2
Semi-Log Data Plot of Drawdown versus Time from Monitor Well 184W506M

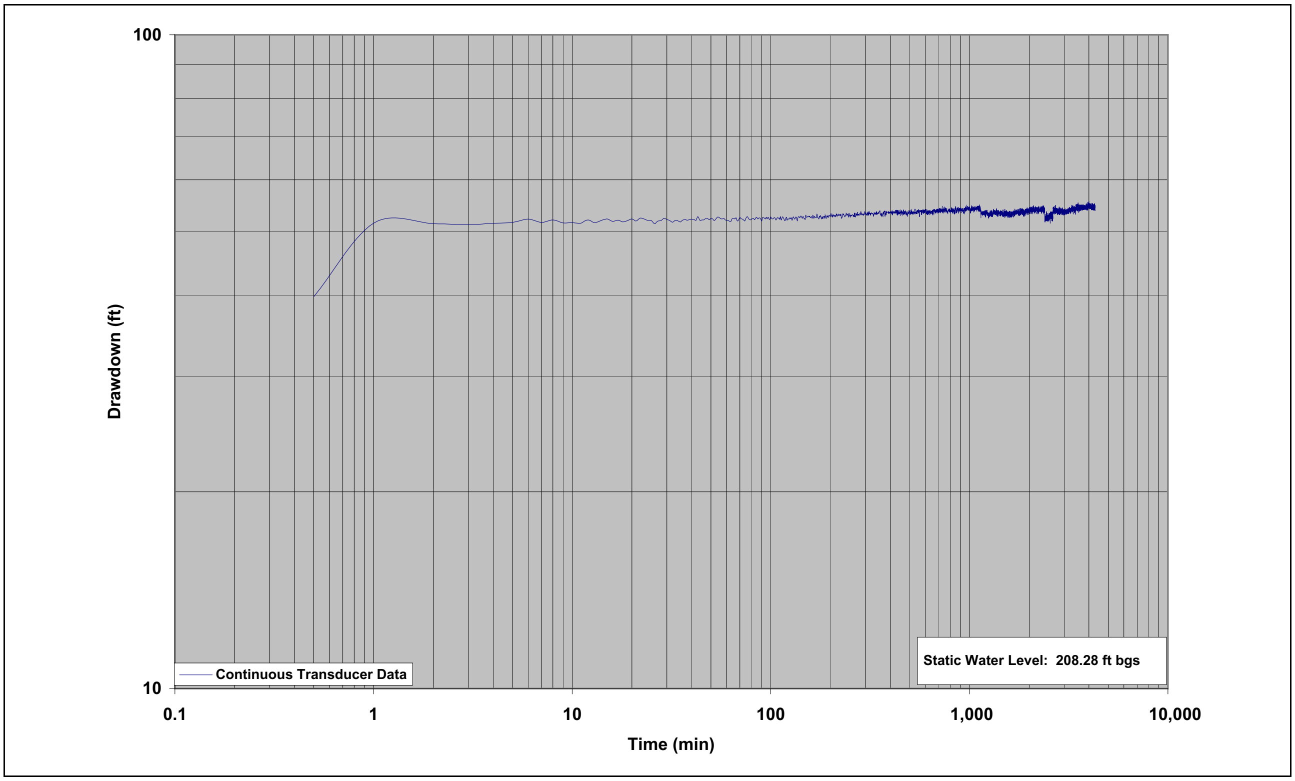


Figure 5-3
Log-Log Data Plot of Drawdown versus Time from Test Well 184W105

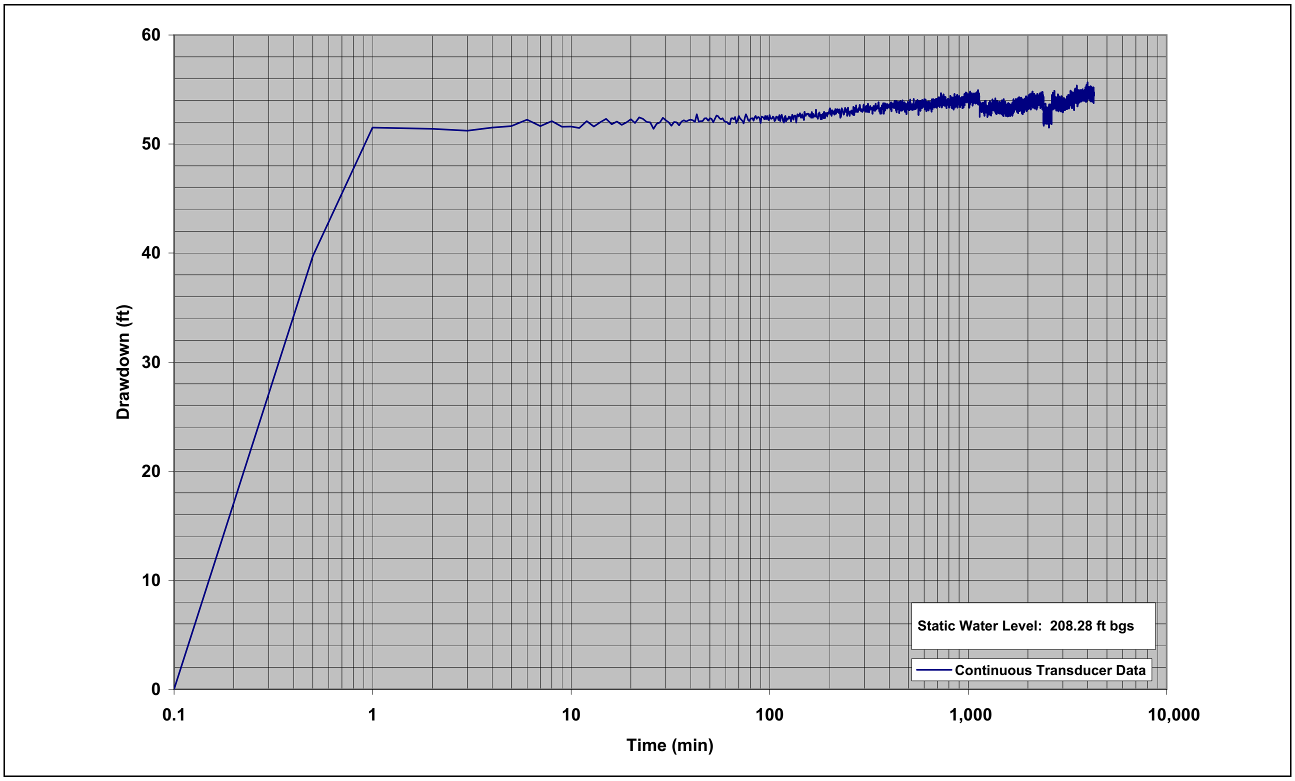
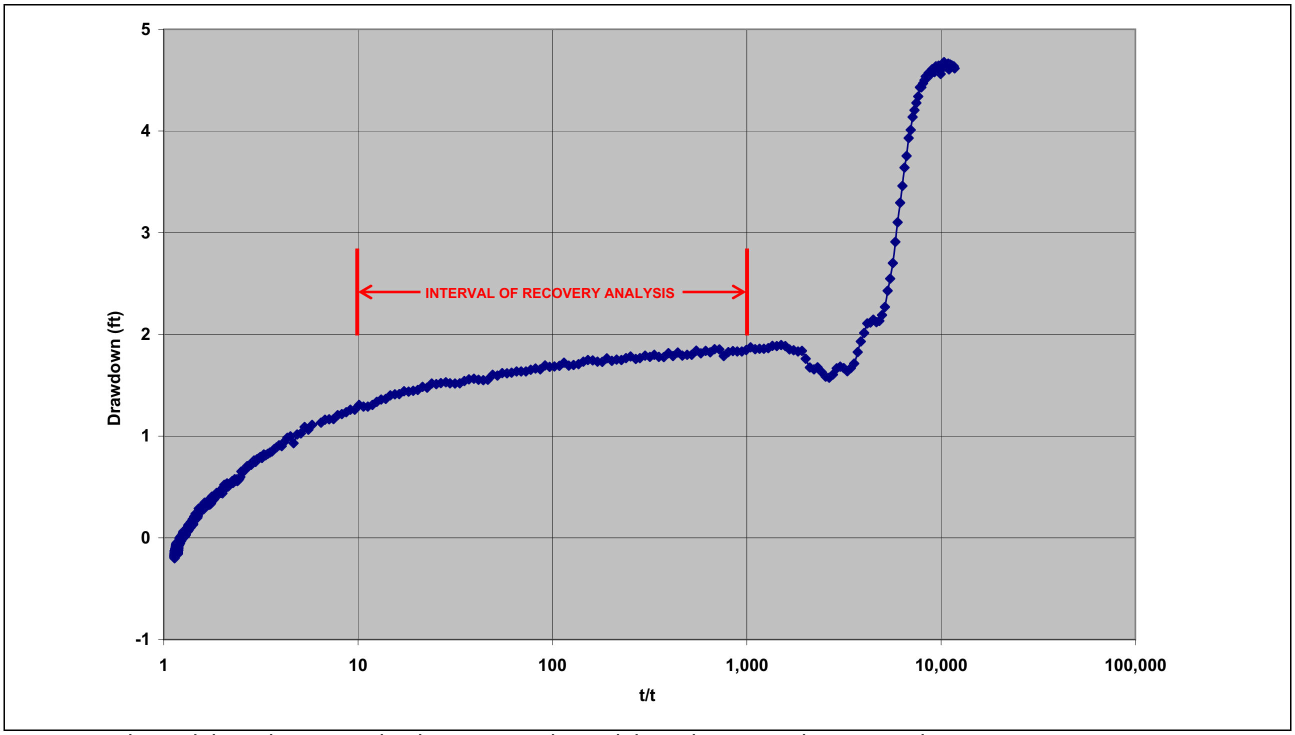


Figure 5-4
Semi-Log Data Plot of Drawdown versus Time from Test Well 184W105



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

Figure 5-5
Monitor Well 184W506M Recovery Data Presenting Residual Drawdown versus the Log of the Ratio of t/t'

drawdown increases, and the flow regime approaches radial flow conditions. This is illustrated in Figure 5-2.

The Barker generalized radial flow model (Barker GRFM) (Barker, 1988), which is a generalized radial flow model for an unsteady, confined, fractured media, dual-porosity conceptual analytical model, was 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 has application 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 that cannot be estimated in advance. 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. In an unconfined condition, a correction equation for dewatering (Kruseman and De Ridder, 1994, p. 101) was applied to the drawdown response before analysis to account for the variation in effective saturated thickness influencing the test. This approach provides for bounding of the effect of dewatering and was applied in this solution. The aquifer test analysis software AQTESOLV V4.50 (Duffield, 1996-2007) was used for curve fitting.

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 flow dimension may be adjusted to compensate for spherical flow caused by partial penetration. The dewatering correction may be applied to compensate for unconfined response.

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.

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, radial-flow, dual-porosity 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.

5.4 Constant-Rate and Recovery-Test Analysis

5.4.1 Test Analysis Methodology

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	0.42 ft
r Radial distance from 184W105 to 184W506M[a]	212 ft
b Aquifer saturated thickness[b]	946 ft
b' Fracture spacing	3.3, 10 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)

A sensitivity analysis was performed on three primary parameters to evaluate effects on fracture hydraulic conductivity (*K*). These parameters were (1) dewatering correction for drawdown, (2) fracture spacing, and (3) matrix-specific storage (*Ss´*). The correction for dewatering was considered because the aquifer is unconfined, and drawdown in the vicinity of the well was a significant fraction of the aquifer saturated thickness. Average fracture spacing is estimated from borehole geophysics and for practical purposes has nonuniform spacing and characteristics, and for comparison purposes, fracture spacing of 3.3 ft and 10 ft was used for analysis to evaluate sensitivity to the parameter. There is also no independent data for anisotropy of vertical/horizontal hydraulic conductivity. The sensitivity to this anisotropy was checked for general effect on the solution and was determined to be negligible. Because the well is located in a fault zone and faulting in the test area is high-angle, vertical hydraulic conductivity may be expected to be relatively high and default anisotropy of 1 is judged reasonable. The sensitivity to *Ss´* was evaluated progressively in conjunction with the correlated parameter *K*.

The Barker GRFM solution was fitted to the drawdown and recovery responses of both the test well and the monitor well sequentially and iteratively to determine the model parameter set that would best fit all of the data. Initially, the paired drawdown responses could be fitted similarly well with a wide range of *K*, with differences in values for the other parameters adjusting the fit. The selection of the most representative set of parameter values depends upon the conceptual model for the aquifer system, the constraints placed upon storage parameter values, and interpretation of well borehole skin as related to nonlinear flow losses at the test well distorting actual drawdown near the test well.

The monitor well 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 the single monitor well is not as definitive as multiple observation wells to evaluate and define asymmetry and horizontal anisotropy.

5.4.2 Test Analysis Result 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 was verified through application of a more simplified Cooper-Jacob secondary solution. Results of the Barker GRFM and Cooper-Jacob solutions are summarized in Table 5-2. The optimal solution analysis plots for each method are presented below.

Table 5-2
Summary of Optimal Analysis Results

Primary Solution Barker GRFM Analysis								
Fracture Spacing (ft)	*K* (ft/day)	*Ss* (ft^{-1})	*K´* (ft/day)	*Ss´* (ft^{-1})	*n*	*Sf*	*Sw*	*T*[a] (ft^2/day)
3.3	64.00	1.25×10^{-7}	4.83×10^{-4}	1.00×10^{-5}	2.20	2.84	6.25	60,544
10	60.50	1.53×10^{-7}	6.30×10^{-3}	1.00×10^{-5}	2.20	5.00	5.73	57,233
Secondary Solution Cooper-Jacob Analysis								
Analysis Time Interval	***K* (ft/day)**	**Location**	***S***			***T* (ft^2/day)**		
Early-Time	56.36	Monitor Well	2.05×10^{-4}			53,320		
Late-Time	57.83	Monitor Well	NA			54,710		

[a]Assume saturated thickness of 946 ft to derive *T*.
NA = Not applicable

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 model fit to all of the data and constraints is optimal within a relatively restricted range for the major parameters. The initial fitting was first to the observation well drawdown, then to the test well drawdown, then to the observation well recovery, and then to the test well recovery. Fitting started with a radial flow system ($n = 2$), $Sf = 0$, and well loss coefficient $Sw = 0$. The flow dimension was maintained at $n = 2$ until the final model fitting. Fitting started from lower fracture hydraulic conductivity (*K*) values, which required matrix-specific storage (*Ss´*) that was greater than could be supported by reported value ranges (independent of the site) on carbonates. Also, these parameter sets did not simulate the observed recovery of the test well. Through an iterative process, analysis matched the test well recovery with an increase in the *K* value. Constraints were then imposed on the *Ss* and *Ss´* values, allowing an *Ss* range from $1 \times 10^{-8} – 1 \times 10^{-9}$, and an *Ss´* maximum value of 1×10^{-5}. Fitting is not sensitive to *Ss* values in the range 1×10^{-7} to 1×10^{-10}; however, fitting is very sensitive to the *Ss´* value. The *K´* and *Ss´* parameters are highly correlated, so there is no unique solution, and the external constraint for *Ss´* is important.

Constraints on fracture-specific storage (*Ss*) for carbonates for Nevada are based on information from Kilroy (1992) (1.06×10^{-7} - 4.57×10^{-8} ft^{-1}), Galloway and Rojstaczer (1989) (1.1×10^{-11} ft^{-1}), and Bredehoeft (1997) (9×10^{-10} ft^{-1}). Matrix-specific storage in carbonates is several orders of magnitude larger that fracture-specific storage, so the overall storage (sum of fracture and matrix storage) is similar to the matrix storage. Specific storage can be equated to storativity (*S*) as the product of specific storage and aquifer thickness. SNWA has documented ranges of storativity for the lower and upper carbonate aquifers from 8.14×10^{-3} to 1.70×10^{-9}. For the test well, with a nominal aquifer thickness of 946 ft, the *Ss* would be 8.6×10^{-6} to 1.8×10^{-12} ft^{-1}. This indicates that there is considerable latitude in *Ss* values, with the upper bound for the range for values about 1×10^{-5}. 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 drawdown magnitude between the monitor well and the test well had to be accounted for. The step-drawdown test analysis indicated that a large proportion of the test well drawdown was nonlinear losses, which typically are due to well losses. However, the well construction provides substantial screen-open area, 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 that results from 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 the great difference in drawdown between the monitor well and the test well. A small increase of the flow dimension (*n*) above 2 (radial flow) helped tune the drawdown difference between the wells. This may indicate a partial penetration effect because the well does not fully penetrate the formation into a confining unit. The fact that the well is completed in a high-angle fault zone suggests that the vertical *K* within the tested area, primarily the fault zone, could be similar to the horizontal *K*, and production could have induced vertical flow within the formation from below the bottom of the well. The parameters *K*, *n*, and *Sw* are highly correlated, and a unique solution is not identifiable. However, the confidence intervals for these parameters for the Barker GRFM solution are not wide, so the given values are approximately optimal.

There is no quantitative information, such as spacing and aperture, on the hydraulically active fractures. During analysis, fracture spacing of 1 (nominal), 3.3, and 10 ft were used. The results are presented in Table 5-2 for both the 3.3- and 10-ft spacing, providing an indication of the effect of fracture spacing on the parameter values. In general, fracture *K* must be increased to compensate for fewer fractures and *Ss´*. Fracture spacing of 10 ft is probably the best general estimate for the well, based upon available data.

The Barker GRFM solution optimal aquifer hydraulic conductivity (*K*), which is dominated by fracture hydraulic conductivity, ranged from 60.50 to 64.00 ft/day using a fracture spacing sensitivity analysis range of 10 and 3.3 ft, respectively. Matrix hydraulic conductivity (*K´*) ranged from 4.83×10^{-4} to 6.30×10^{-3} ft/day. Fracture-specific storage ranged from 1.25×10^{-7} to 1.53×10^{-7} ft^{-1}. Matrix-specific storage of 1.00×10^{-5} ft^{-1} relates to aquifer storativity of 9.46×10^{-3}, assuming a saturated thickness of 946 ft. Increased estimated saturated thickness would equate to a theoretical proportional increase in aquifer storativity.

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 184W506M and Test Well 184W105 are presented in Figures 5-8 and 5-9, respectively. The derivative drawdown response in the monitor well is consistent with a dual-porosity fractured bedrock system.

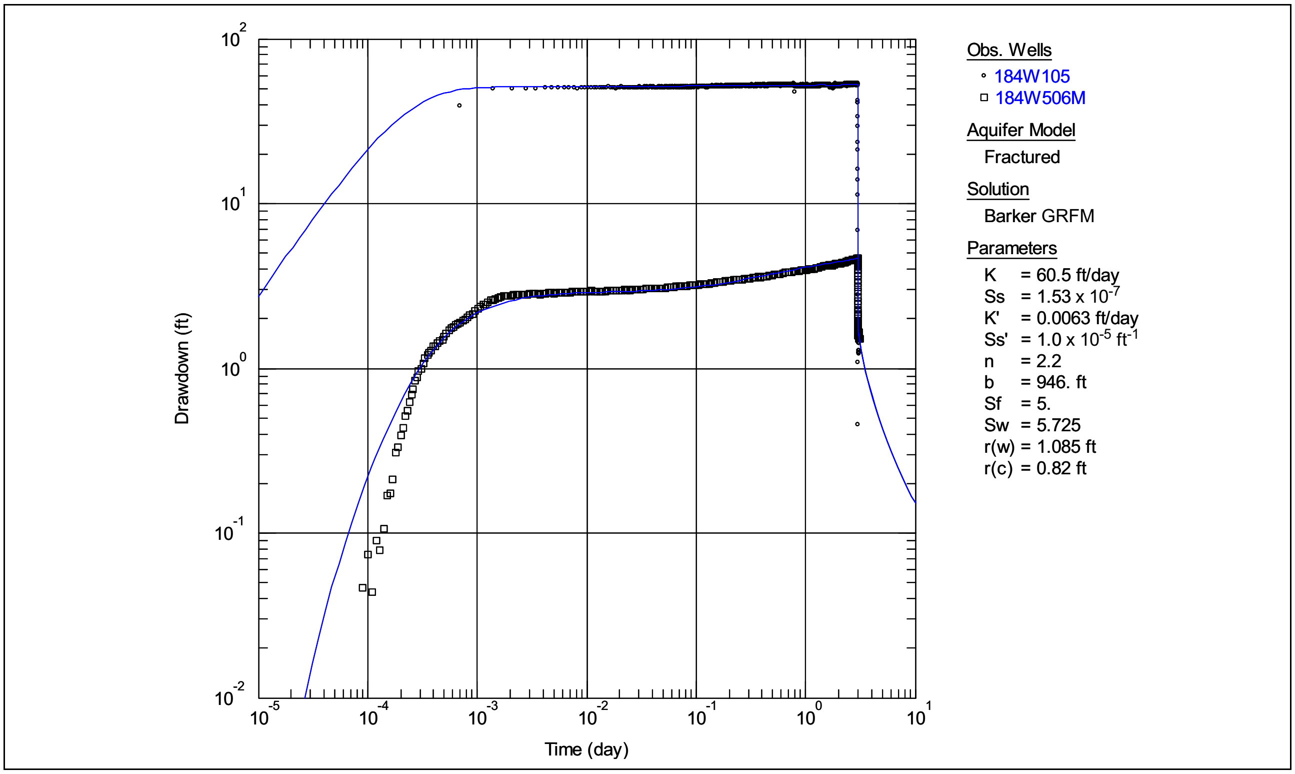


Figure 5-6
Optimal Barker GRFM Solution Pumping Period Log-Log Plot

Well loss analysis of Test Well 184W105 is presented in Section 4.2.2. An evaluation and removal of well loss components are presented in Figure 5-10, 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 losses provides a more realistic 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 is presented in Figure 5-11. 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.

5.4.4 Cooper-Jacob Analysis

The Cooper-Jacob secondary solution at the monitor well, where well loss does not distort the drawdown, compared favorably to the Barker GRFM results. Transmissivity values of 53,320 and 54,710 ft^2/day were derived from the early-time and late-time data, respectively. Using a saturated

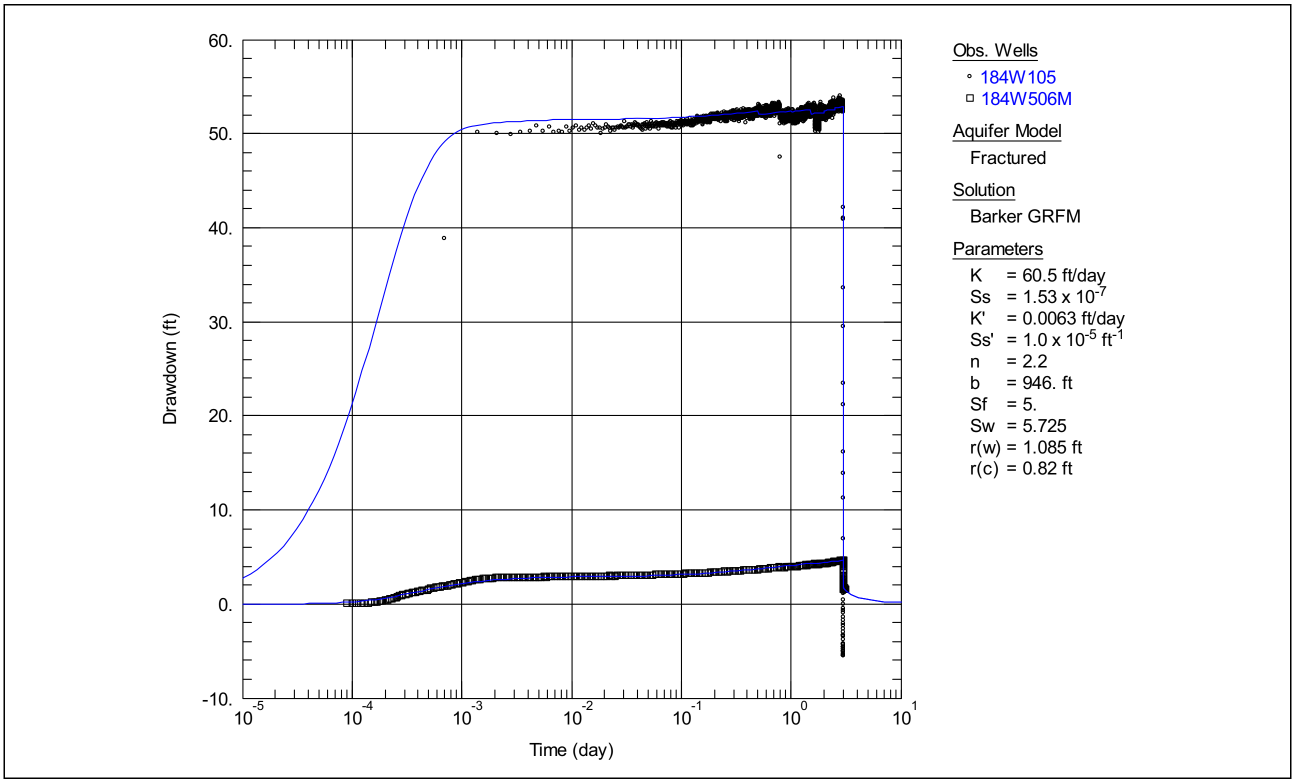


Figure 5-7
Optimal Barker GRFM Solution Pumping Period Semi-Log Plot

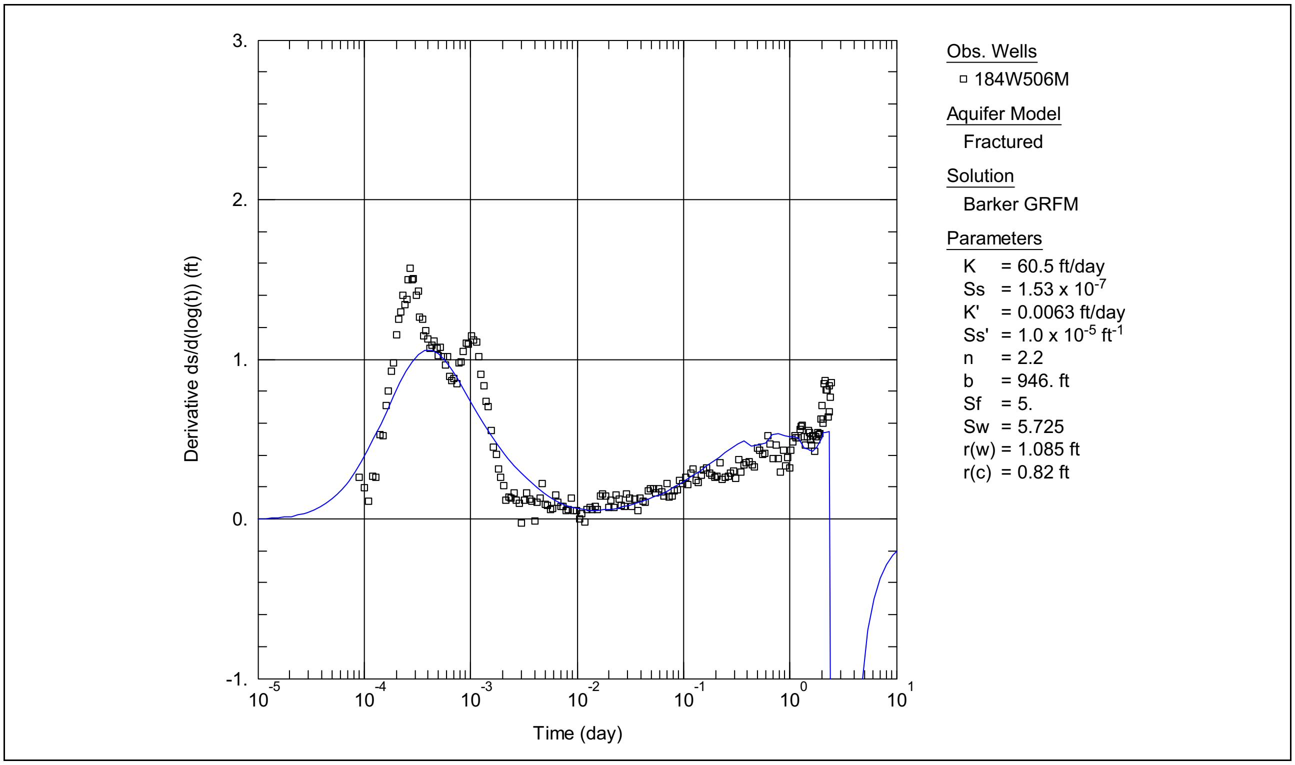


Figure 5-8
Optimal Barker GRFM Solution Drawdown Derivative for Monitor Well 184W506M

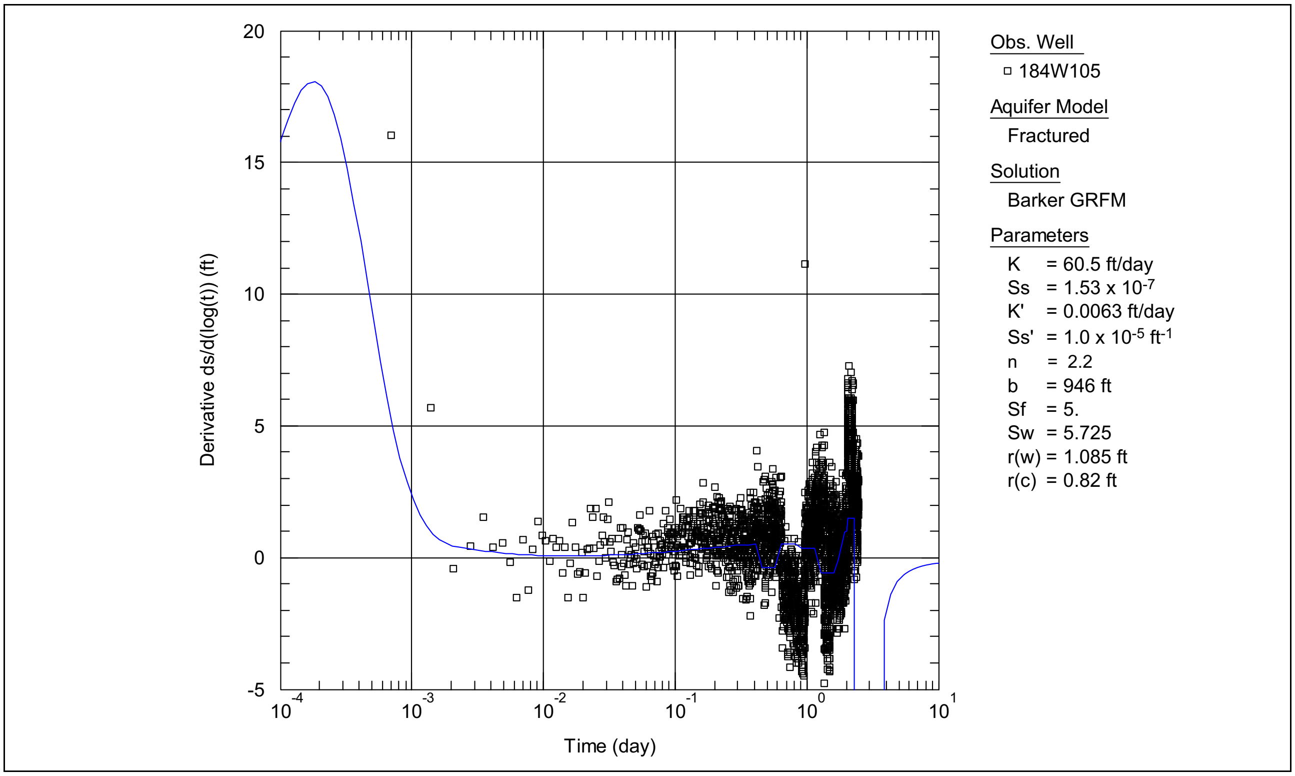


Figure 5-9
Optimal Barker GRFM Solution Drawdown Derivative for Test Well 184W105

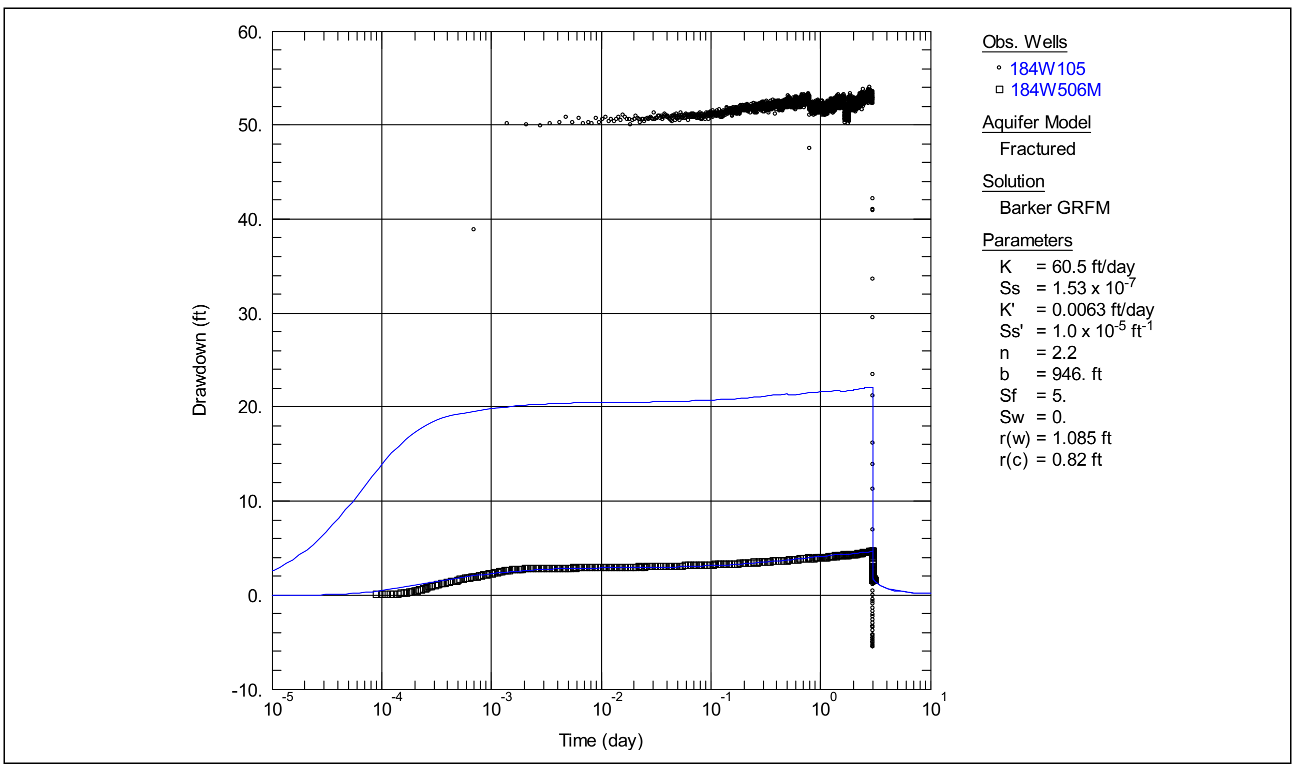


Figure 5-10
Optimal Barker GRFM Solution, Test Well 184W105 Well Losses Removed

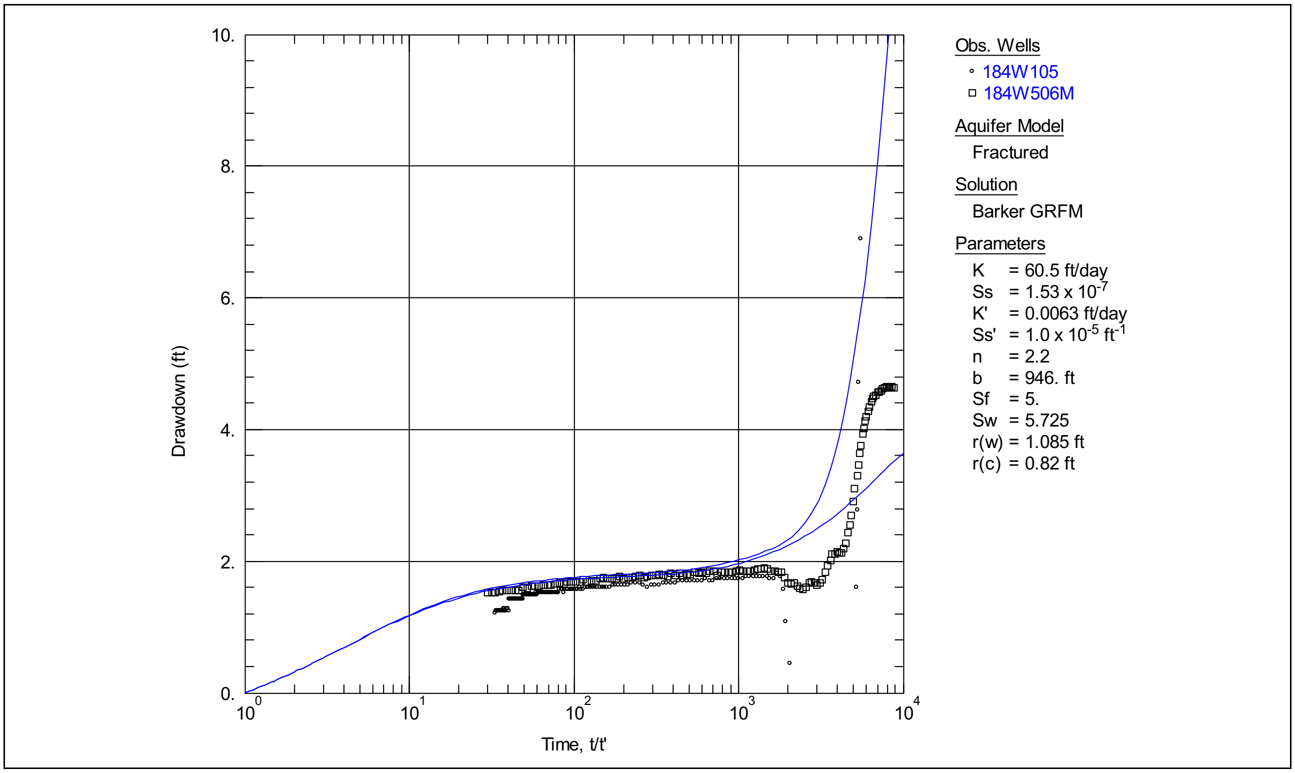


Figure 5-11
Optimal Barker GRFM Optimal Solution Recovery Period

thickness of 946 ft resulted in a hydraulic conductivity of 56.36 to 57.83 ft/day. The hydraulic conductivity value derived from transmissivity using the Cooper-Jacob method is directly related to the effective aquifer saturated thickness used. Storativity was calculated using early-time data and is estimated to be 2.05×10^{-4}. This corresponds to a fracture-specific storage of 2.16×10^{-7}/ft assuming an effective saturated thickness of 946 ft, which would dominate early pumping time.

The Cooper-Jacob straight-line analysis of the semi-log plot for time versus drawdown of Monitor Well 184W506M early-time and late-time data is presented in Figures 5-12 and 5-13, respectively. The early-time aquifer response can only be evaluated after the casing storage effects are past and before dual-porosity matrix flow begins. 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 test well response data do not have a sufficient early-time record for analysis because of the influence of wellbore storage. 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. It was not definitive that the late-time drawdown response had stabilized sufficiently to accurately determine the stabilized slope. However, the early-time and late-time fitted slopes are similar, which is expected for a dual-porosity response after matrix effect is complete and radial flow is reached. This suggests that both periods achieved near stabilization. Additional longer-term pumping would be needed to confirm that the straight line indicating radial flow continues or whether any boundary conditions are encountered. The *T* values determined for both analyses are similar to the optimal solution from the dual-porosity analysis. The

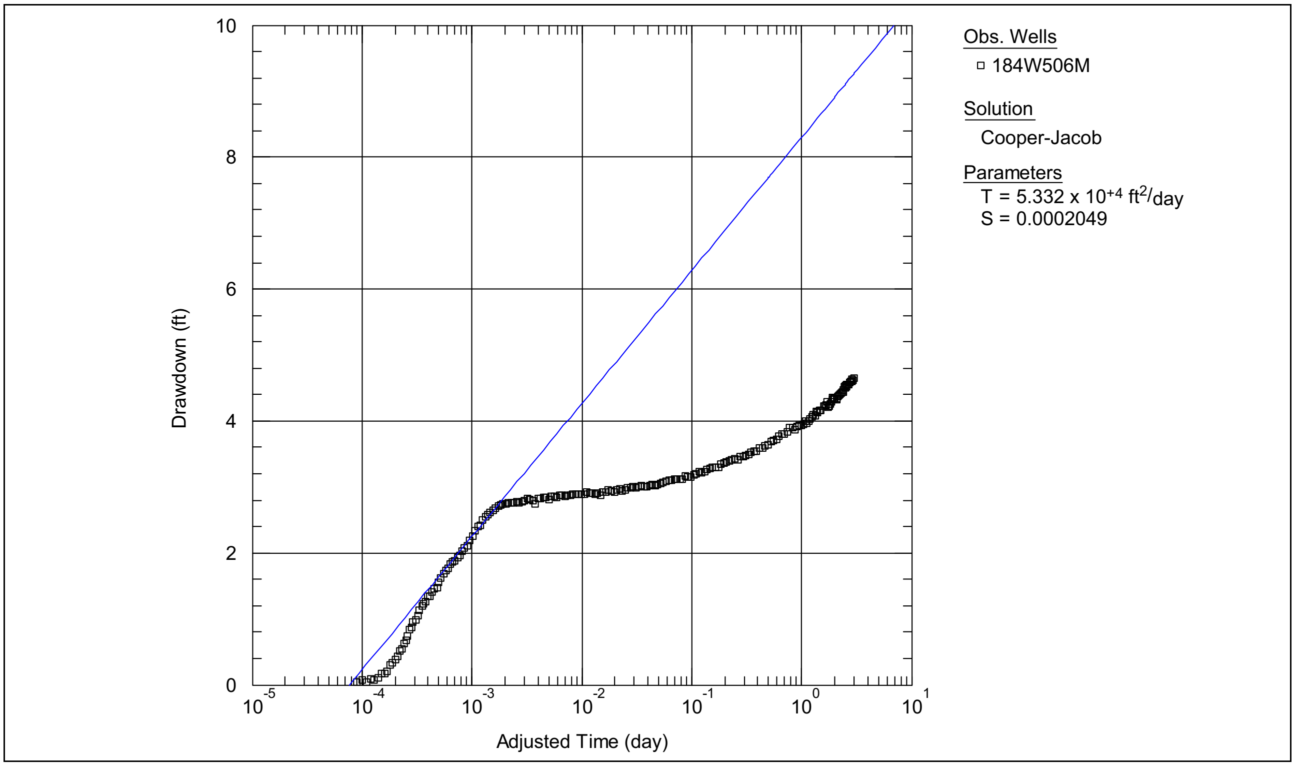


Figure 5-12
Cooper-Jacob Analysis, Monitor Well, Early-Time

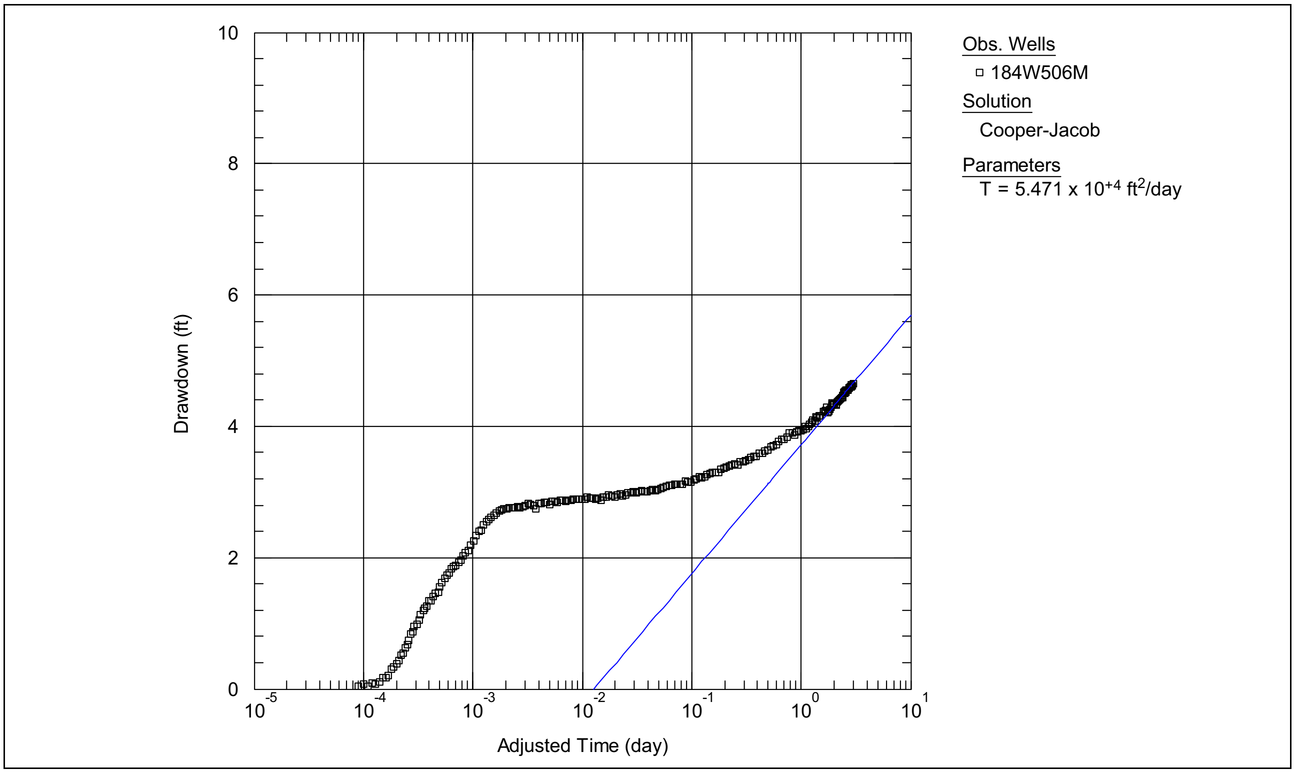


Figure 5-13
Cooper-Jacob Analysis, Monitor Well, Late-Time

early-time solution yields an *S* value that is also similar to the storage determined for the preferred dual-porosity analysis. The late-time *S* value is not applicable because of the offset resulting from the matrix-dominated flow period.

5.5 Discussion

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 two primary fracture zones 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.

The controlling factor for determination of *K* from *T* from the Cooper-Jacob secondary solution is the estimated saturated thickness (*b*). The highest *K* results from assuming a full penetration of the saturated zone by the pumping well, resulting in a *b* of 946 ft. Proportional lower *K* values would be derived from this secondary method with larger *b* estimates. Specific storage derived from the Barker GRFM solution multiplied by the saturated thickness results in storativity. The thicker the saturated thickness the larger the storativity value for the aquifer, assuming a consistent specific storage value.

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.

The test provided representative data about the aquifer system without outside pumping or natural hydrologic variation influence. Diagnostic data plots and site hydrogeologic conditions were indicative of a dual-porosity aquifer system. The plots indicate the early-time wellbore storage effects, fracture network response phase, transition zone of matrix or delayed response phase, and system equilibrium reflected in the suggested late-time equivalent radial flow. No significant recharge or barrier condition boundaries were identified in the data results.

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 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.

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6.0 WATER CHEMISTRY

Groundwater-chemistry data for Test Well 184W105 and Monitor Well 184W506M 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 184W105 on March 8, 2007, at 08:00 after pumping over 22 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 USGS Earth Surface Processes Radiogenic Isotope Laboratory.

Water samples were collected from Monitor Well 184W506M on October 31, 2006, at 11:53 after pumping approximately 469,000 gallons. 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 184W506M was used as the water source for drilling Test Well 184W105 and as the main water source for drilling background well 184W504M. The water source for drilling Monitor Well 184W506M was the small well at Harbecke Ranch.

For comparison, the groundwater chemistry of additional wells in the area are presented in this section. The wells, all drilled by the 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. A single constituent, di(2-ethylhexyl) phthalate (DEHP), exceeded the primary drinking water standards for the groundwater of Test Well 184W105; no constituent exceeded the secondary MCL. Groundwater samples taken from Monitor Well 184W506M exceeded the secondary MCL for aluminum. These exceedances will be discussed further in Sections 6.3.3 and 6.3.6.

6.3 Groundwater-Chemistry Results

In this section, the field measurements and analytical results for the groundwater of Monitor Well 184W506M and Test Well 184W105 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 184W105 and for the samples collected for laboratory analysis (see Table B-1). For Test Well 184W105, these parameters stabilized within the first hour of the constant-rate test. Measurements ranged from 0.38 to 1.25 nephelometric turbidity units (NTUs) (turbidity), 7.44 to 8.21 (pH), 322 to 383 μS/cm (specific conductance), and 12.6°C to 15.0°C (temperature) over the remaining period of pumping (71 hours) with no observable trends. Field measurements made at the time of sample collection are reported as 0.41 NTU, 282 μS/cm, 7.8, 13.0°C, and 5.08 mg/L for turbidity, specific conductance, pH, water temperature, and dissolved oxygen concentration, respectively.

During the 8-hour constant-rate test for Monitor Well 184W506M, field measurements of pH, specific conductance, and temperature ranged from 8.04 to 8.18, 394 to 374 μS/cm (slight decreasing trend), and 12.0°C to 15.6°C, respectively. No turbidity or dissolved oxygen concentration measurements were performed for the groundwater of Monitor Well 184W506M. Field measurements made at the time of sample collection are reported as 385 µS/cm, 8.1, and 12.7°C for specific conductance, pH, and water temperature, respectively.

When compared to Test Well 184W105 and Monitor Well 184W506M, the water temperatures in the deeper wells were significantly higher, 24.1°C (184W101) and 20.5°C (184W502M), but were quite similar in 184W103 (12.0°C) and 184W504M (12.1°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 from 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 184W105 and Monitor Well 184W506M 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), sulfate (SO_4). 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 balance for Test Well 184W105 and Monitor Well 184W506M groundwater analyses, 2.0 and 3.2 percent, respectively, indicate that the analyses were performed adequately (Table B-1).

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 is 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 wells.

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

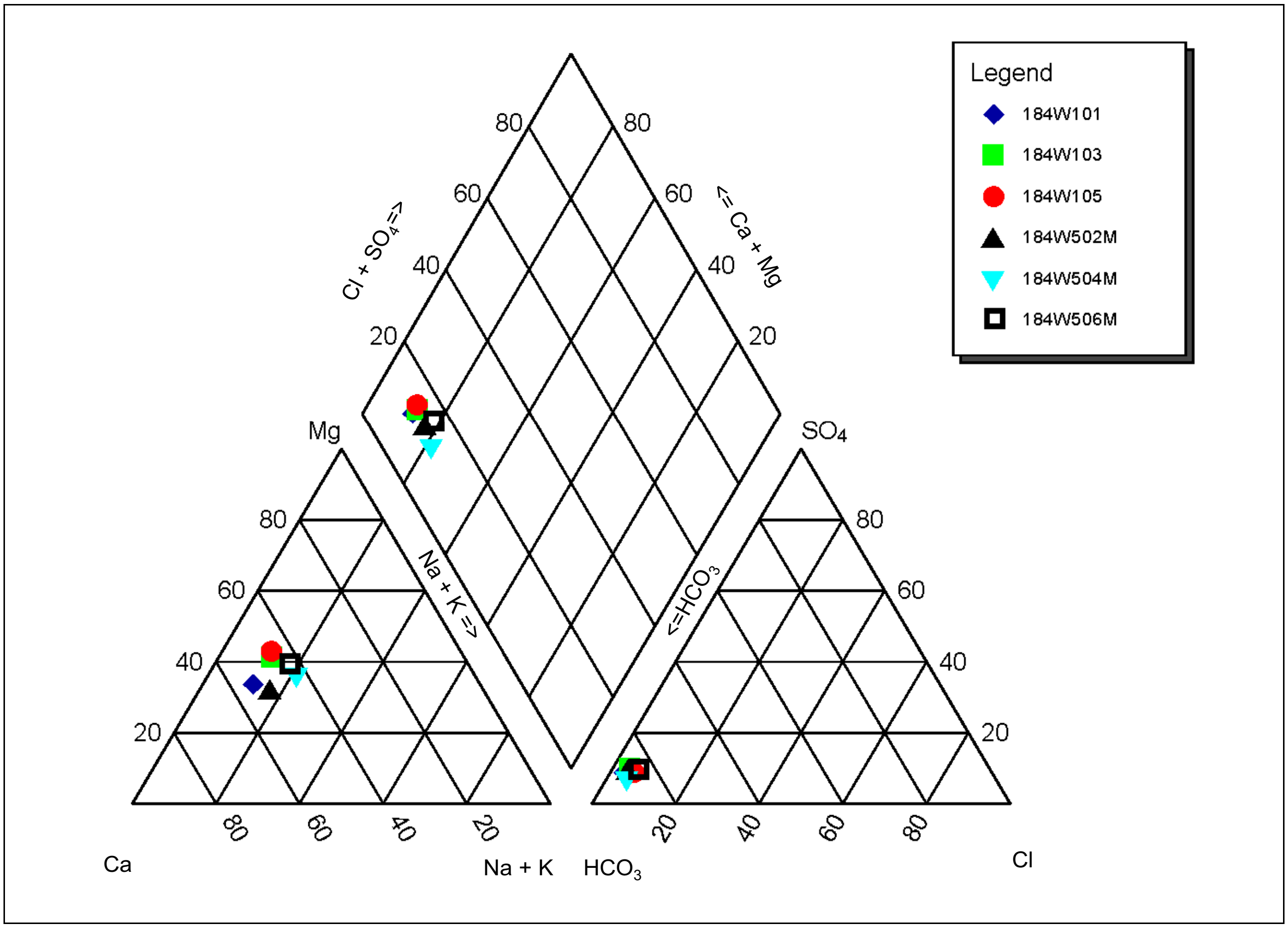

Figure 6-1
Piper Diagram Illustrating Relative Major-Ion Compositions

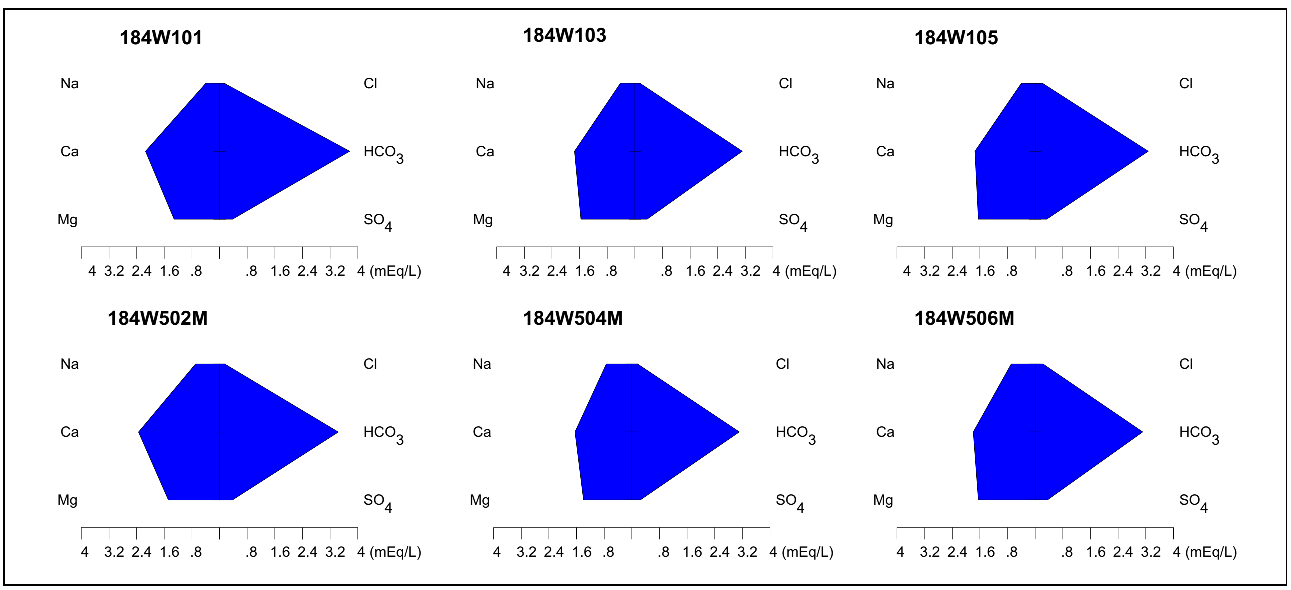

Figure 6-2
Stiff Diagrams Illustrating Major-Ion Concentrations

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 groundwater of these wells.

6.3.3 Trace and Minor Constituents

The concentrations of trace elements in the groundwater from Test Well 184W105 and Monitor Well 184W506M are presented in Table B-1. The dominant trace element present in the groundwater from Test Well 184W105 is strontium, which is consistent with the relatively high concentration of strontium in carbonate rocks (i.e., limestone) (Drever, 1988). Relatively higher concentrations of aluminum, iron, manganese, and zinc were observed in the groundwater from Monitor Well 184W506M (Table B-1) when compared to the concentrations in the groundwater of Test Well 184W105. 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.

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
184W506M	320	300	62	29
184W105	26	<20	0.78	<5
184W502M	180	5,700	39	56
184W101	8.4	<20	2.8	<5
184W504M	130	500	24	55
184W103	<5	<20	1.8	5.5

6.3.4 Stable Isotopes and Environmental Tracers

The stable hydrogen, oxygen, and carbon isotopic compositions of the groundwater samples from Test Well 184W105 and the stable hydrogen and oxygen isotopic compositions of the groundwater samples of Monitor Well 184W506M are presented in Table B-1. Table B-1 also presents chlorine-36, strontium-87/86, and uranium-234/238 data for the groundwater samples collected from Test Well 184W105.

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 184W105 and Monitor Well 184W506M 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.

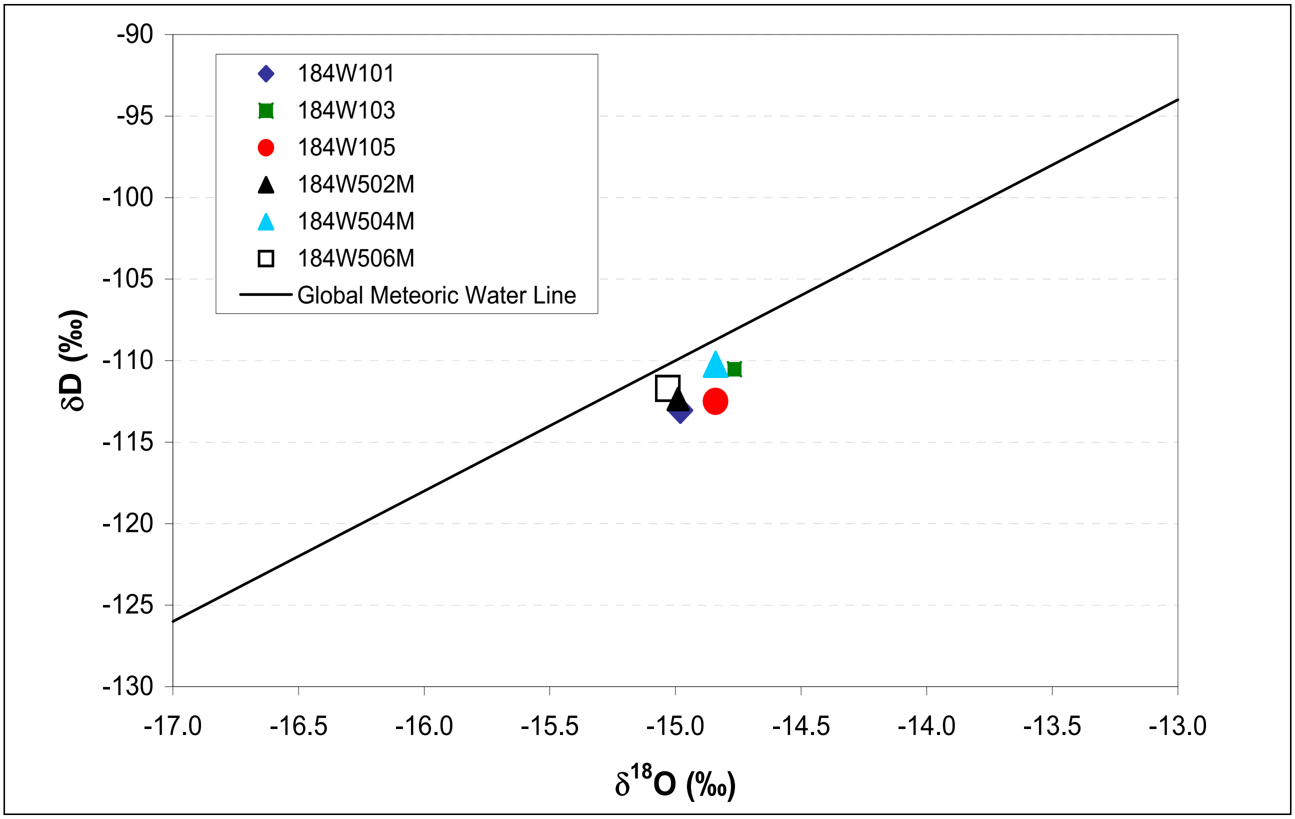

Figure 6-3
Plot of δD versus $\delta^{18}O$

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 δ^{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 δ^{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 flow path. 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 (0.70928) for Test Well 184W105 are quite similar to those of test wells 184W101 (0.71054) and 184W103 (0.70902) 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 the 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 groundwater from Test Well 184W105, 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 groundwater.

6.3.6 Organic Compounds

A large suite of organic compounds was analyzed for groundwater samples collected from Test Well 184W105. The corresponding minimum detection levels and MCLs (if applicable) are presented in Table B-1. With the exception of DEHP, no organic compounds were detected. DEHP was detected at a concentration of 6.1 µg/L, which is slightly above the MCL of 6.0 µg/L (Table B-1). This compound is present in many plastic products and may have been introduced from tubing or other plastic materials during groundwater sampling. No analyses for organic compounds were performed for the groundwater of Monitor Well 184W506M.

6.4 Summary

Groundwater samples were collected from Test Well 184W105 and Monitor Well 184W506M and analyzed for a suite of chemical parameters. Field measurement of water-quality parameters was also performed during aquifer testing and used to demonstrate stabilization of the water 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 184W105 was consistent with precipitation in the southwestern United States, and the low ^{14}C and relatively heavy values of δ^{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, δ^{13}C, ^{14}C, ^{87}Sr/^{86}Sr, or ^{34}U/^{238}U activity ratios.

The data were also evaluated with respect to the EPA Safe Drinking Water Act standards. For Test Well 184W105, a single constituent, DEHP, exceeded the primary drinking water MCL, and no constituent exceeded the secondary MCL. Groundwater from Monitor Well 184W506M exceeded the secondary MCL for aluminum. Both of these exceedances are attributed to sampling or to the well construction and are not considered to reflect the natural water.

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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 pump and motor setup (Figure A-2), the site setup (Figure A-3), discharge line (Figure A-4), and energy dissipation at the termination of the discharge line for erosion prevention (Figure A-5).

Figure A-1
184W105 Test Well Site, Facing Southwest

Figure A-2
184W105 Test Wellhead Equipment and Piping Layout

Figure A-3
184W105 Test Wellhead Equipment with Generator

Figure A-4
Discharge Piping, Facing East from Well Site 184W105

Figure A-5
Discharge Location East of U.S. Highway 93 for
Hydrologic Testing Performed at Test Well 184W105

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. There is also an index of the files and folders in the form of a PDF document.

A.1.3 Background Water-Level Data

A spreadsheet containing the continuous water-level data and corresponding chart from SNWA Monitor Well 184W504M. This well was used to monitor background conditions during development and testing at Test Well 184W105.

A.1.4 Barometric-Pressure Data

Barometric-pressure data are located in the continuous record data files associated with Test Well 184W105. An In-situ HERMIT 3000 data logger recorded the barometric pressure during the development and testing at well 184W105. Barometric data from SNWA ET site SV1 are also included. These data can be found in files labeled “184W105 XDR PRIMARY Data CR.xls” for the constant-rate test and “184W105 Man PRIMARY XDR Data Develop and STEP.xls” for the development and the step-drawdown test.

All barometric-pressure data are reported in inches Hg.

A.1.5 Step-Drawdown Test Data

A summary spreadsheet for the initial step test, which compiles all of the manual data, including charts, is labeled “184W105 Man Data Step Summary.xls.” The manual and continuous record of the water levels for the final step test in Test Well 184W105 is provided in the spreadsheet labeled “184W105 Man PRIMARY XDR Data Develop and STEP.xls.”

A.1.6 Constant-Rate Test

The constant-rate test data from Test Well 184W105 are provided in the spreadsheets labeled “184W105 Man Data 12hr CR 2300 gpm.xls” for the manual data for the 2300 gpm test; “184W105 Man PRIMARY Data CR.xls” for the manual data for the 3,000 gpm test; and “184W105 XDR PRIMARY Data CR.xls” for the continuously recorded transducer data for the 3000 gpm test. The constant-rate test data from the observation well 184W506M are provided in the spreadsheets labeled “184W506M Man PRIMARY Data CR.xls” for the manual data and “184W506M XDR Chart CR.xls” for the continuously recorded transducer data.

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 also been included with basic information, such as casing, borehole, and downhole equipment radius, as well as approximate saturated thickness.

A.1.8 Water Chemistry

The laboratory results from Weck Labs, Inc., are included in PDF format and labeled "184W105_WL_Chemistry.pdf" for well 184W105 and "184W506M_WL_Chemistry.pdf" for well 184W506M.

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Appendix B

Water-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 184W105 and Monitor Well 184W506M
(Page 1 of 3)

Constituent Name	Unit	Analysis Method	RL	184W105 3/8/2007 08:00	184W506M 10/31/2006 11:53	Primary MCL	Secondary MCL
Field Measured							
pH	units	Field	---	7.8	8.1	---	6.5 to 8.5
Conductivity	µS/cm	Field	---	282	385	---	---
Dissolved Oxygen	mg/L	Field	---	5.08	---	---	---
Temperature	°C	Field	---	13.0	12.7	---	---
Turbidity	NTU	Field	---	0.41	---	---	---
Stable Isotopes and Environmental Tracers							
Carbon-14 (^{14}C)	pmc	NA	---	6.09	---	---	---
Carbon-13/12 ($\delta^{13}C$)	per mil (‰)	NA	---	-5.8	---	---	---
Chlorine-36/Chloride ($^{36}Cl/Cl$)	ratio	NA	---	4.292×10^{-13}	---	---	---
Hydrogen-2/1 (δD)	per mil (‰)	NA	---	-112.8/-112.2	-111.8/-111.7	---	---
Oxygen-18/16 ($\delta^{18}O$)	per mil (‰)	NA	---	-14.84	-15.09/-14.97	---	---
Strontium-87/86	ratio	NA	---	0.70928	---	---	---
Uranium-234/238	Activity Ratio	NA	---	2.0803	---	---	---
Major Solutes							
Alkalinity Bicarbonate	mg/L as HCO_3	SM 2320B	2	200	190	---	---
Alkalinity Carbonate	mg/L as $CaCO_3$	SM 2320B	2	ND	4.5	---	---
Alkalinity Hydroxide	mg/L as $CaCO_3$	SM 2320B	2	ND	ND	---	---
Alkalinity Total	mg/L as $CaCO_3$	SM 2320B	2	170	160	---	---
Calcium	mg/L	EPA 200.7	0.1	35	36	---	---
Chloride	mg/L	EPA 300.0	0.5	7.5	7.9	---	250
Fluoride	mg/L	EPA 300.0	0.1	0.16	0.25	4	2.0
Magnesium	mg/L	EPA 200.7	0.1	20	20	---	---
Nitrate	mg/L as N	EPA 353.2	0.1	0.7	0.7	10	---
Potassium	mg/L	EPA 200.7	1	1.8	1.8	---	---
Silica	mg/L	EPA 200.7	0.1	17	17	---	---
Sodium	mg/L	EPA 200.7	1	9.3	16	---	---
Sulfate	mg/L	EPA 300.0	0.5	16	17	---	250
Cation/Anion Balance	%	Calculation	---	2	3.2	---	---

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 184W105 and Monitor Well 184W506M
(Page 2 of 3)

Constituent Name	Unit	Analysis Method	RL	184W105 3/8/2007 08:00	184W506M 10/31/2006 11:53	Primary MCL	Secondary MCL
Trace and Minor Constituents							
Aluminum, total	µg/L	EPA 200.8	5	26	320	---	50 to 200
Antimony, total	µg/L	EPA 200.8	0.5	ND	ND	6	---
Arsenic, total	µg/L	EPA 200.8	0.4	2.4	1.8	10	---
Arsenic (III)	µg/L	EPA 200.8	1	2.4	---	---	---
Arsenic (V)	µg/L	EPA 200.8	1	ND	---	---	---
Barium, total	µg/L	EPA 200.8	0.5	92	47	2,000	---
Beryllium, total	µg/L	EPA 200.8	0.1	ND	ND	4	---
Boron, total	µg/L	EPA 200.7	10	40	54	---	---
Bromide	µg/L	EPA 300.1	10	66	72	---	---
Cadmium, total	µg/L	EPA 200.8	0.1	ND	ND	5	---
Chlorate	µg/L	EPA 300.1	10	ND	ND	---	---
Chromium, total	µg/L	EPA 200.8	0.2	3.6	2	100	---
Chromium (VI)	µg/L	EPA 218.6	0.3	1.8[a]	---	---	---
Chromium (III)	µg/L	Calculation	0.2	1.8	---	---	---
Copper, total	µg/L	EPA 200.8	0.5	ND	2.7	1,300[b]	1,000
Iron, total	µg/L	EPA 200.7	20	ND	300	---	300
Lead, total	µg/L	EPA 200.8	0.2	0.46	0.78	15[b]	---
Lithium, total	µg/L	EPA 200.7	10	ND	ND	---	---
Manganese, total	µg/L	EPA 200.8	0.2	0.78	62	---	50
Mercury, total	µg/L	EPA 245.1	0.1	ND	ND	2.0	---
Molybdenum, total	µg/L	EPA 200.8	0.1	2.2	2.1	---	---
Nickel, total	µg/L	EPA 200.8	0.8	ND	1.4	---	---
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	2.1	1.5	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 184W105 and Monitor Well 184W506M
(Page 3 of 3)

Constituent Name	Unit	Analysis Method	RL	184W105 3/8/2007 08:00	184W506M 10/31/2006 11:53	Primary MCL	Secondary MCL
Trace and Minor Constituents (Continued)							
Strontium, total	µg/L	EPA 200.7	5	170	190	---	---
Thallium, total	µg/L	EPA 200.8	0.2	ND	ND	2	---
Uranium, total	µg/L	NA	---	2.82	---	30	---
Vanadium, total	µg/L	EPA 200.8	0.5	3.7	3.0	---	---
Zinc, total	µg/L	EPA 200.8	5	ND	29	---	5,000
Miscellaneous Parameters							
Total Dissolved Solids	mg/L	SM 2540C	10	200	250	---	500
Total Organic Carbon	mg/L	SM 5310C	0.3	ND	1.4	---	---
Total Suspended Solids	mg/L	EPA 160.2	5	ND	25	---	---
Hardness	mg/L as $CaCO_3$	EPA 200.7	1	170	---	---	---
Langelier Index	@ 60°C	SM 2330B	-10	0.7	---	---	---
Langelier Index	@ Source Temp.	SM 2330B	-10	0.073	---	---	---
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	3.1 ± 0.82	---	15	---
Gross Beta	pCi/L	EPA 900.0	0.87	1.8 ± 0.56	---	4 mrem/yr	---
Radium, total gross	pCi/L	EPA 903.1	---	0.5 ± 0.1	---	5	---
Radium-226	pCi/L	EPA 903.1	---	0.5 ± 0.1	---	---	---
Radium-228	pCi/L	EPA 904	0.4	ND	---	---	---
Radon	pCi/L	SM 7500	---	353 ± 37	---	---	---
Strontium-90	pCi/L	EPA 905.0	0.6	ND	---	---	---
Tritium	TU	NA	0.8	ND	---	---	---
Tritium	pCi/L	EPA 906.0	340	ND	---	---	---
Uranium	pCi/L	EPA 200.8	2	0.13	---	30 µg/L	---

[a]Holding time was exceeded.
[b]Reported value is the action limit.
MBAS = Methylene blue active substances
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 184W105, 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	--	Methyl tertiary butyl ether (MTBE)	3	--
Bromochloromethane	0.5	--	1,1-Dichloroethylene	0.5	5	Naphthalene	0.5	--
Bromodichloromethane	0.5	--	cis-1,2-Dichloroethylene	0.5	7	n-Propylbenzene	0.5	--
Bromoform	0.5	--	trans-1,2-Dichloroethylene	0.5	70	Styrene	0.5	100
2-Butanone	5	--	Dichlorodifluoromethane	0.5	100	Tetrachloroethylene	0.5	5
n-Butylbenzene	0.5	--	1,2-Dichloropropane	0.5	--	1,1,1,2-Tetrachloroethane	0.5	--
sec-Butylbenzene	0.5	--	1,3-Dichloropropane	0.5	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 184W105, Including the EPA Method, Reporting Limit, and Maximum Contaminant Level
(Page 2 of 2)

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 (µg/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

B.1.0 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.