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Southern Nevada Water Authority

Hydrologic Data Analysis Report for Test Well 184W103 in Spring Valley Hydrographic Area 184

July 2010

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SOUTHERN NEVADA WATER AUTHORITY

Hydrologic Data Analysis Report for Test Well 184W103 in Spring Valley Hydrographic Area 184

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

July 2010

1. Southern Nevada Water Authority, Las Vegas, NV

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

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ACRONYMS

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

ABBREVIATIONS

°C	degrees Celsius
amsl	above mean sea level
bgs	below ground surface
cm	centimeter
ft	foot
ft^2	square foot
gal	gallon
gpm	gallons per minute
in.	inch
L	liter
lb	pound
m	meter
mEq	milliequivalent
mg	milligram
mi	mile
min	minute
ml	milliliter
mrem	millirem
µg	microgram
µS	microsiemen

ABBREVIATIONS (CONTINUED)

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

ES.1.0 EXECUTIVE SUMMARY

In support of its Clark, Lincoln, and White Pine Counties Groundwater Development Project, Southern Nevada Water Authority (SNWA) installed test and monitor wells in Spring Valley (Hydrographic Area 184) to evaluate hydrogeologic conditions. This report documents the collection, analysis, and evaluation of data obtained during the well development and hydraulic testing of Test Well 184W103 located in southwestern Spring Valley, White Pine County, Nevada. The development and hydraulic testing program at this site was performed from March 18 through March 26, 2007. This report also presents groundwater-level data collected at the site post-test through June 2010.

The test well and associated Monitor Well 184W504M are situated stratigraphically in the Permian Arcturus Formation to depths of 1,046 and 1,040 ft bgs, respectively. Hydrogeologically, the wells are completed in an unconfined, fractured, carbonate-rock aquifer system. Static depth to water is approximately 98 ft bgs.

The development phase extracted 1,076,000 gallons of water. The specific capacity, a ratio of discharge (*Q*) to drawdown (*s*) in the test well, improved slightly throughout the course of development. Specific capacity improved from 4.2 gpm/ft at the beginning of development to 4.3 gpm/ft at a comparable duration of pumping at a discharge rate of 550 gpm during the constant-rate test. A five-interval well performance step test was conducted at discharge rates ranging from 410 to 630 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 discharge rate of 550 gpm. Hydrologeologic 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 (GRFM) was applied to the site data as the primary analytical solution. A secondary analytical solution using the Cooper-Jacob semi-log straight-line approximation was also performed for comparison. Analyses were performed using AQTESOLV aquifer-test evaluation software.

Results of the primary analysis using the GRFM with optimal best-fit of all site pumping and recovery data indicate an estimated hydraulic conductivity (*K*) of approximately 11.64 to 11.66 ft/day and a specific storage of 3.75 to 7.27×10^{-5} ft^{-1}. This equates to a transmissivity of 11,000 ft^2/day and storativity (*S*) of 0.035 to 0.069 assuming a saturated thickness of 943 ft. Matrix hydraulic conductivity (K') ranged from 5.29×10^{-7} to 3.13×10^{-6} ft/day. Results of the secondary analysis for transmissivity (*T*) using the Cooper-Jacob solution on test and monitor well data ranged from approximately 4,700 to 18,900 ft^2/day. The resulting *K* value ranged from 4.98 to 20.04 ft/day assuming a saturated thickness of 943 ft.

Specific capacity during the last 12 hours of the 550 gpm, 72-hour constant-rate test ranged from 4.17 to 4.19 gpm/ft. A total of 3,734,500 gallons of water were extracted throughout the development and testing program.

Groundwater samples were collected from Test Well 184W103 and Monitor Well 184W504M 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 ($\delta^{13}C$ and ^{14}C) and strontium ($^{87}Sr/^{86}Sr$) were indicative of groundwater interaction with carbonate minerals along the flowpath.

1.0 INTRODUCTION

In support of its Clark, Lincoln, and White Pine Counties Groundwater Development Project, Southern Nevada Water Authority (SNWA) installed test and monitor wells in Spring Valley to evaluate hydrogeologic conditions. This report documents the collection, analysis, and evaluation of data obtained during the well development and hydraulic testing of Test Well 184W103 and Monitor Well 184W504M located in Hydrographic Area (HA) 184, Spring Valley, Nevada. The two wells are completed in the unconfined, fractured carbonate aquifer of the Permian Arcturus Formation limestone stratigraphic unit. This report also presents groundwater-level data collected at the site post-test through June 2010. A separate document entitled *Geologic Data Analysis Report for Monitor Well 184W504M and Test Well 184W103 in Spring Valley* (Eastman and Muller, 2009) includes the documentation and detailed results for the surface geophysics profiles and drilling program, including evaluation of lithology, structural features, drilling parameters, and geophysical logs.

1.1 Program Objectives

The objectives of developing Test Well 184W103 were to remove any remaining drilling fluids and improve the hydraulic connection with the formation. This phase of development consisted of pump and surge activities and was in addition to airlifting and swabbing development that were performed immediately after well installation.

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

1.2 Testing and Monitoring Program

The well development and hydraulic testing program was performed from March 18 through March 26, 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.
- Collection of groundwater samples for laboratory chemical analysis.

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

Monitor Well 184W504M is part of the Spring Valley regional baseline water-level monitoring network. Water-level data have been collected from this location since the hydraulic testing program.

1.3 Report Organization

This report is divided into seven sections and two appendices.

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

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

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

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

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

Section 6.0 presents the groundwater-chemistry results and evaluation.

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

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

Appendix B presents the groundwater-chemistry laboratory data reports.

2.0 WELL SITE DESCRIPTION

SNWA Test Well 184W103 is located in the southwest portion of Spring Valley, on public land managed by Bureau of Land Management, approximately 6 mi north of the Lincoln and White Pine County line near the boundary between Sections 34 and 35, T11N, R66E, at an elevation of 5,899 ft amsl. Access to the site is to the south along a dirt road off of Atlanta Road approximately 1.5 mi east of Highway 93. A topographic map showing the site location and other SNWA test and monitor wells installed as of June 2010 is presented on Figure 2-1.

Three wells were used during testing for observation and background control purposes. Monitor well 184W504M, located 177 ft to the west of the test well, was used as an observation well during testing. Monitor Well 184W502M, used to observe background conditions during testing, is located approximately 14 mi southeast of the test well. The South Fox flowing artesian well, located approximately 4,500 ft northeast of the test well, was used as an additional observation well during testing.

2.1 Hydrogeologic Setting

This section presents the regional and local hydrogeologic setting of the Test Well 184W103 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. It is bounded by the Schell Creek Range to the west, the Antelope Range to the north, the Snake Range and Limestone Hills to the east, the Wilson Creek Range to the south, and the Fortification Range to the southwest.

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

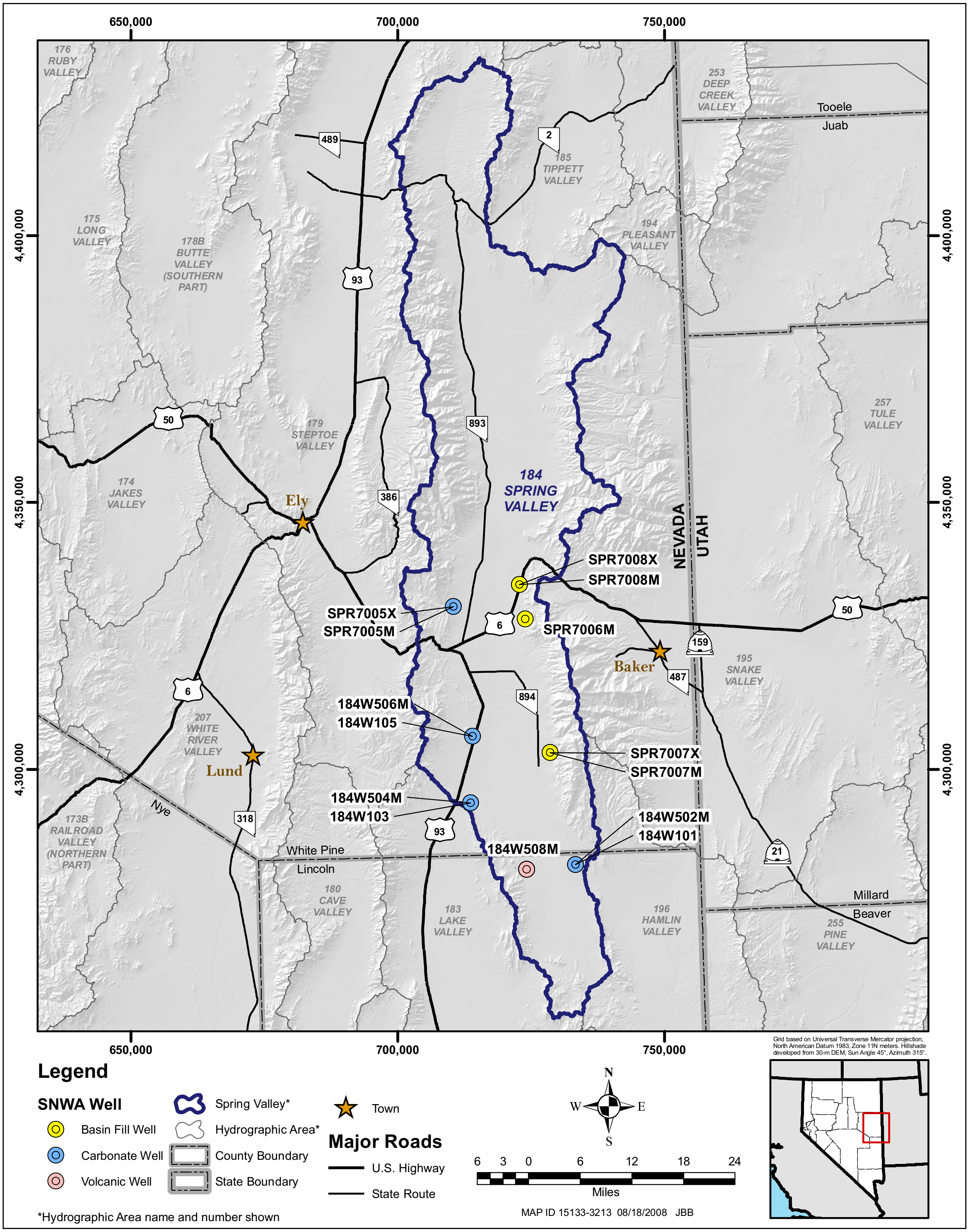


Figure 2-1
SNWA Exploratory and Test Wells in Spring Valley (as of June 2010)

Numerous studies related to Spring Valley and adjacent basins have been performed since the late 1940s. These studies have included water-resource investigations, geologic and hydrogeologic investigations, recharge and discharge estimations, and other hydrologic studies. The regional 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 Resource Assessment for Spring Valley* (SNWA, 2006c)
- *Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah—The Geologic Framework for 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)
- *2009 Spring Valley Hydrologic Monitoring and Mitigation Plan Status and Data Report* (SNWA, 2010)

2.1.2 Local Hydrogeologic Setting

The site location was selected after conducting a geologic reconnaissance of the area, including field mapping, review of regional geophysical and well data, evaluation of surface structural features using aerial photography, and evaluation of local geophysical data. Surface geophysical profiles were also performed in the vicinity of the well site by SNWA. Regional data and geologic mapping in the vicinity of the site indicate the presence of faulting and related structures. The dip of the Arcturus Formation in the vicinity where the wells are drilled is very steep to slightly overturned, ranging from 60°E to 83°W.

Quaternary surface alluvium overlays the Arcturus Formation at the well site. The Permian Arcturus Formation is commonly described by Hose and Blake (1976) as being a massive resistant limestone, generally sandy or silty, with interbeds of platy, limey siltsone, and very fine-grained, calcareous sandstone. The Pennsylvanian-Permian Ely Limestone outcrops to the southwest of this site.

A site geologic map presenting the audiomagnetotellurics (AMT) surface geophysical profile is presented in Figure 2-2. A detailed discussion of SNWA geophysical profiles, local geologic structure, and detailed lithologic descriptions of the stratigraphic units encountered are presented in Eastman and Muller (2009).

2.2 Well Data

Test Well 184W103 and Monitor Well 184W504M are completed in the unconfined, fractured carbonate-rock aquifer, stratigraphically in the Permian Arcturus formation. Unsaturated Quaternary surface alluvium overlays the carbonate rock at this location to a depth of 40 to 55 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.

Clay zones representing shearing, faulting, and/or fracturing within the formation, were commonly encountered within the borehole. These clay zones are dispersed throughout the borehole and are particularly common from 170 to 460 ft bgs, of which 100 ft of this interval is clay dominant with small amounts of siltstone, silty limestone, and limestone fragments. Fault zones in non-argillaceous units are more typically evident from abundant calcite veining and/or brecciated or sheared material within the cuttings. Common to abundant calcite veinlets are present in only a few intervals in the borehole. In the interval from 290 to 370 ft bgs, common to abundant calcite veinlets are present in limestone, siltstone, and clay. Calcite veinlets are also common to abundant from 550 to 560, 640 to 660 (with clay), 890 to 920, and 1,010 to 1,020 ft bgs (Eastman and Muller, 2009).

2.2.1 Test Well 184W103

Test Well 184W103 was drilled to a total depth of 1,046 ft bgs between November 19 and December 6, 2006, using mud rotary techniques. A 40-in.-diameter conductor casing was placed to a depth of approximately 57 ft bgs and grouted in place. After the borehole was advanced to completion depth, downhole geophysical logging was performed. A 20-in.-diameter completion string, including approximately 700 ft of Ful-Flo louvered screen, was then installed. The gravel pack extends from a depth of 54 ft to the base of the borehole. A summary chart of Test Well 184W103 drilling and well construction statistics and well schematic are presented in Table 2-1 and Figure 2-3, respectively. The borehole lithologic log for Test Well 184W103 is presented in Figure 2-4.

2.2.2 Monitor Wells 184W504M and 184W502M

Monitor Well 184W504M was completed at a depth of 1,040 ft bgs between November 9 and 17, 2006. A 20-in.-diameter conductor casing was set to a depth of 61 ft bgs and grouted in place. A 14.75-in. borehole was then advanced to completion depth. The 8-in.-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 and well

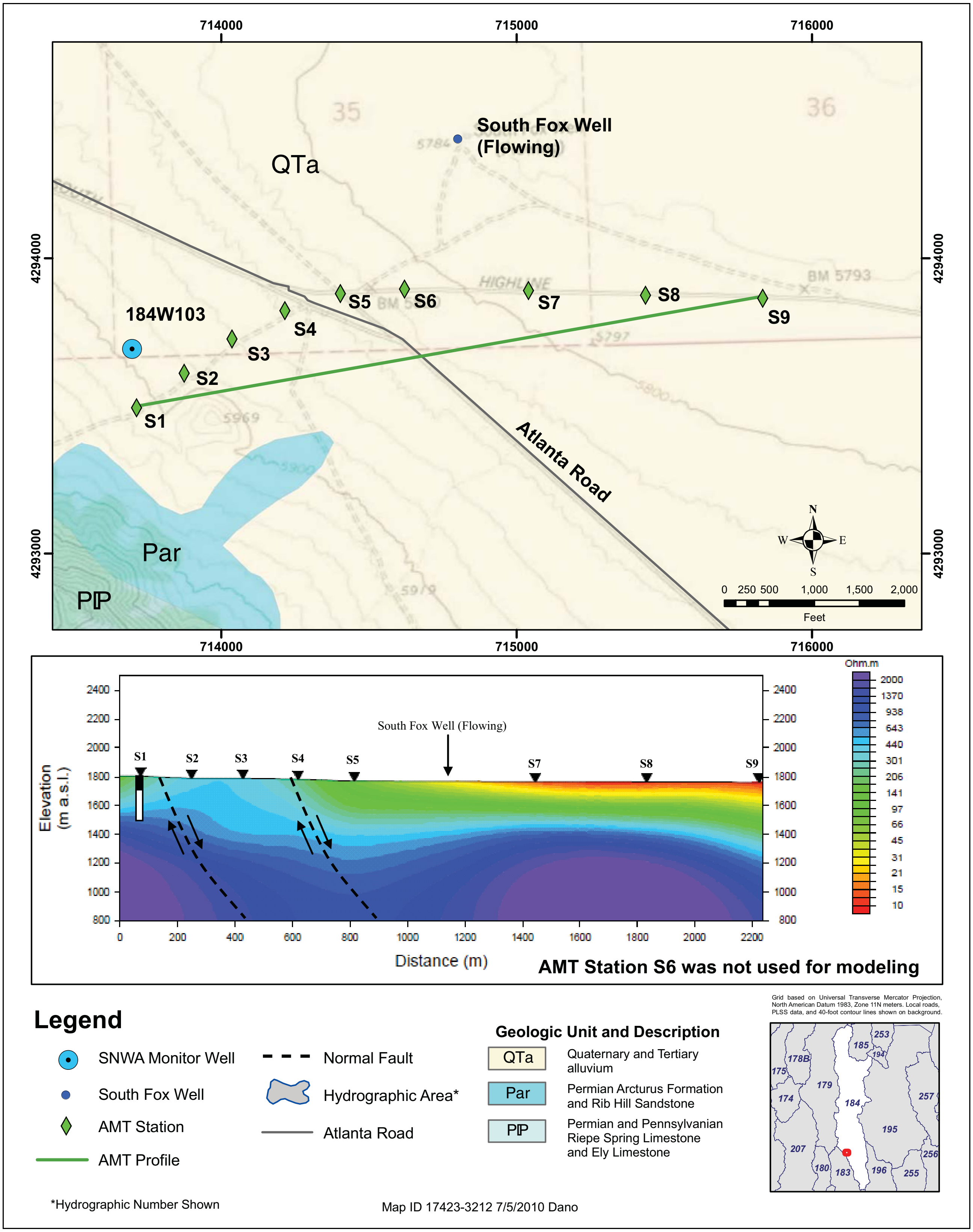
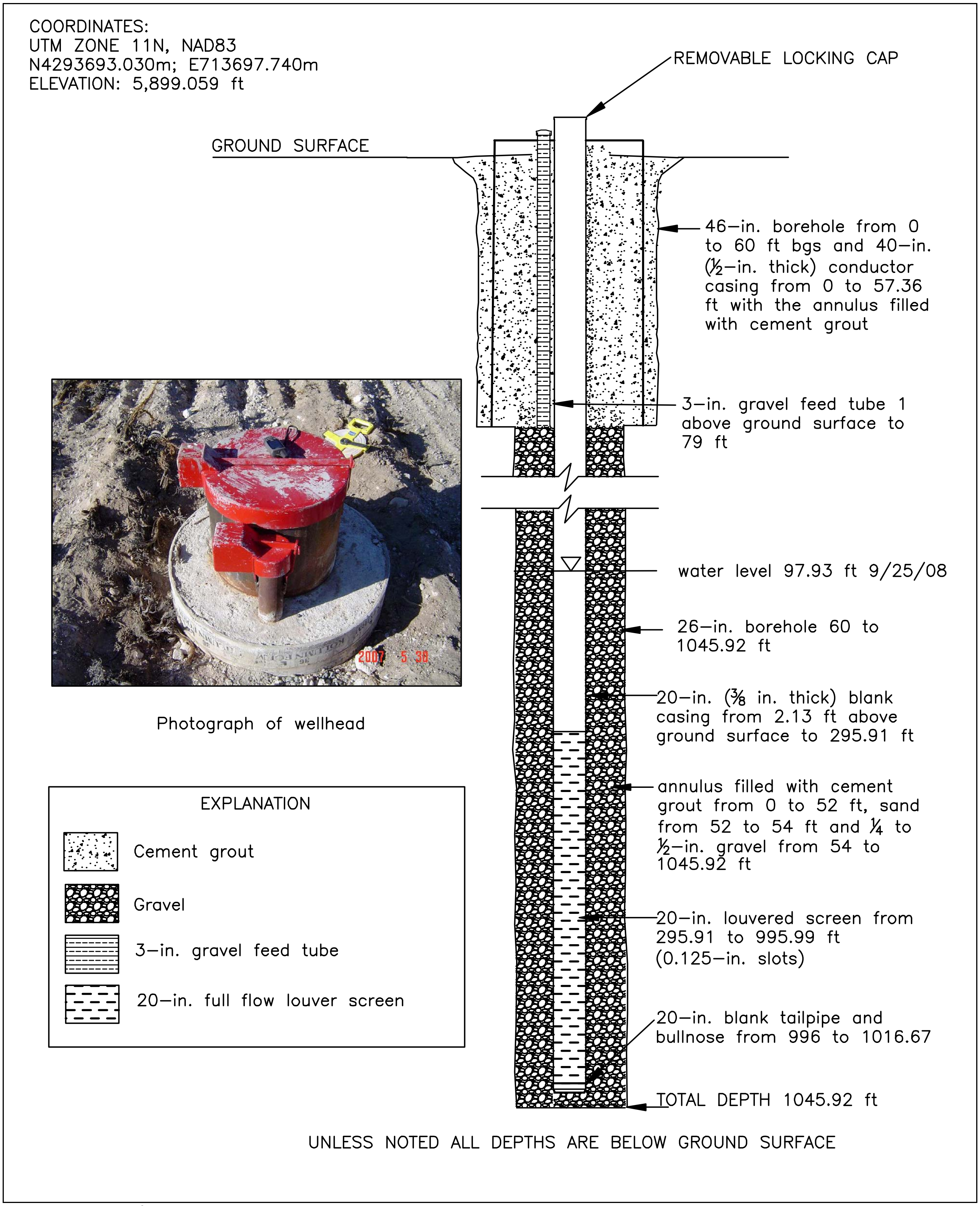


Figure 2-2
Geology Map and Surface Geophysical Profile at Test Well 184W103

Table 2-1
Test Well 184W103 Borehole and Well Statistics

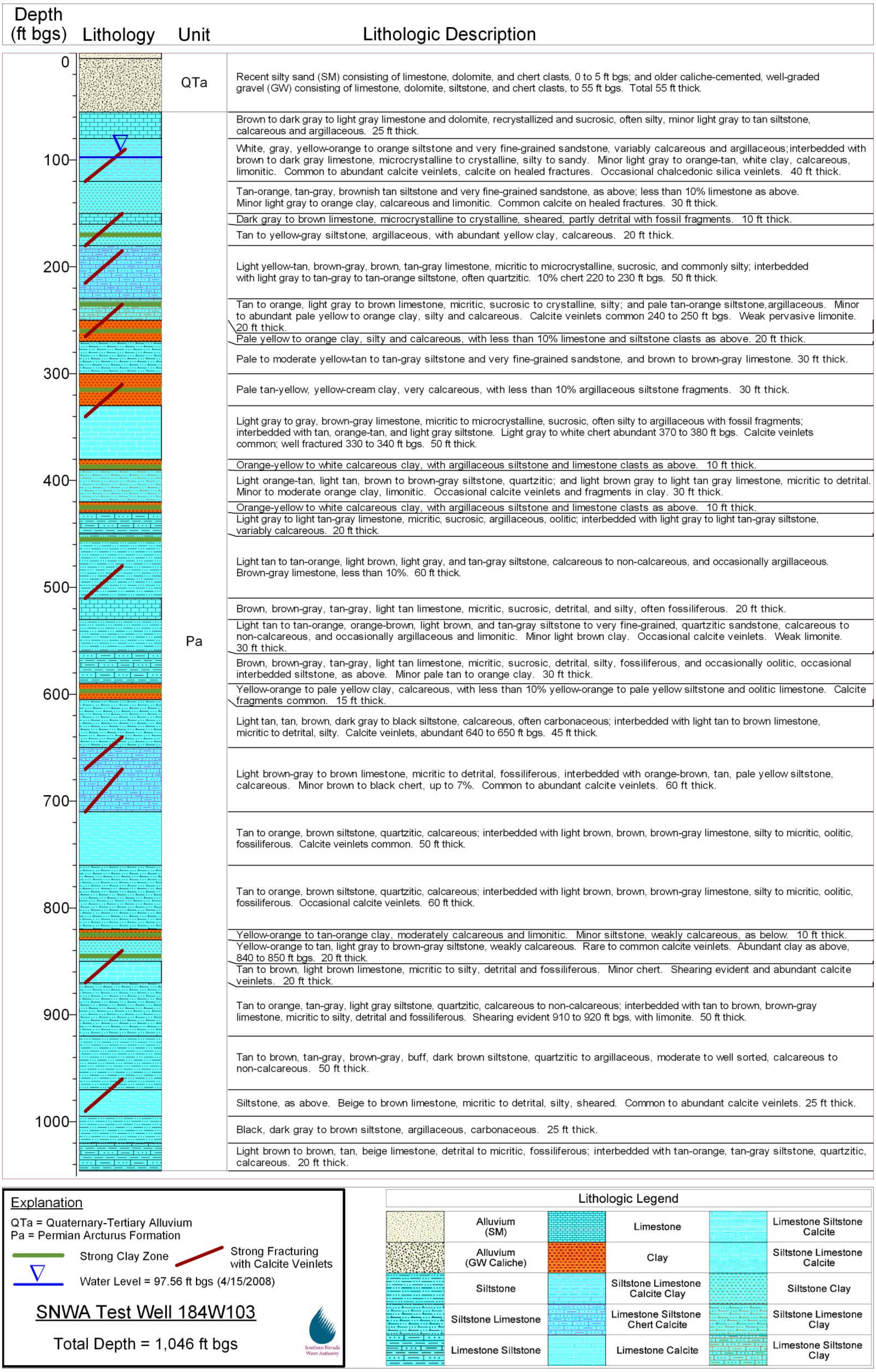
LOCATION DATA Surveyed Coordinates	N 4,293,693.03 m; E 713,697.74 m (UTM, Zone 11, NAD83)	
Surveyed Ground Elevation	5,899.059 ft amsl	
DRILLING DATA Spud Date	11/19/2006	
Total Depth (TD)	1,045.92 ft bgs	
Date TD Reached	11/28/2006	
Date Well Completed	12/6/2006	
Hole Diameter	46-in. from 0 to 60 ft bgs 26-in. from 60 to 1,045.92 ft bgs	
Drilling Techniques	Conventional Circulation from 0 to 133 ft bgs Reverse Circulation from 133 to 1,045.92 ft bgs	
Drilling Fluid Materials Used	Soda Ash = (15) 50-lb bags DrisPac = (13) 50-lb bags Quick Gel = (67) 50-lb bags Reg Pac = (2) 50-lb bags	Gel = (107) 50-lb bags BiCarb = (5) 50-lb bags Calcium = (8) 50-lb bags Poly PacR = (3) 50-lb bags
Drilling Fluid Properties	Viscosity Range = 33 to 93 sec/qt Density Range = 9.0 to 10.2 lb/gal Filtrate Range = 9.6 to 17.6 ml Filter Cake Range = 1/32 to 4/32 in.	
CASING DATA	40-in. MS Conductor Casing from 0 to 57 ft bgs 20-in. HSLA Completion Casing from -2.13 to 1,016.67 ft bgs	
WELL COMPLETION DATA	80 ft of 3-in. gravel sounding tube from -1 to 79 ft bgs 298.04 ft of blank HSLA 20-in. casing from -2.13 to 295.91 ft bgs 700.08 of 20-in. Ful-Flo louver screen from 295.91 to 995.99 ft bgs 19.93 ft blank 20-in. sump MS casing from 995.99 to 1,015.92 ft bgs 0.75 ft bullnose CS casing from 1,015.92 to 1,016.67 ft bgs <u>Cement, Plug and Gravel Pack Depth</u> 0 to 60 ft bgs on outside of conductor casing (cement) 0 to 52 ft bgs between completion casing and conductor casing (cement) 52 to 54 ft bgs sand 54 to 1,045.92 ft from bottom of sand to TD (1/4 to 1/2 in. gravel pack)	
WATER	Static Water Level: 98.25 ft bgs (7/1/2009) Groundwater Elevation: 5,800.81 ft amsl	
DRILLING CONTRACTOR	Lang Exploration Drilling	
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)	
OVERSIGHT	S.M. Stoller Corporation	

HSLA = High strength low alloy
MS = Mild steel



Note: Not to scale

Figure 2-3
Test Well 184W103 Construction Schematic



Source: Eastman and Muller (2009)

Figure 2-4
Borehole Stratigraphic Column of Test Well 184W103

schematic for Monitor Well 184W504M is presented in Table 2-2 and Figure 2-5, respectively. The borehole and lithologic log for Monitor Well 184W504M is presented in Figure 2-6.

Monitor Well 184W502M, located in the southeast portion of the valley, was monitored during the hydraulic testing to observe regional groundwater trends and to identify outside influences affecting regional water levels, such as changes in barometric pressure, earthquakes, and lunar effects. The hydrologic conditions affecting the water levels in this well are expected to be the same as those affecting the test well. This 8-in.-diameter well is also completed in the unconfined, fractured carbonate-aquifer system at a depth of 1,828 ft bgs with an open borehole interval of 58 to 1,828 ft bgs.

The South Fox flowing artesian well, located 4,500 ft northeast of the test well, was used as an additional observation well during testing. Well completion log indicates the well was completed on April 16, 1959 at 240 ft. The well log reported clay from 0 to 220 ft underlain by a sand layer. The well was flowing at 5 gpm at time of completion. A pressure gage was attached to the well during the testing period. No influence from pumping was observed.

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 were collected on a continuous basis at Monitor Wells 184W504M with an In-Situ Level TROLL 700 integrated pressure transducer from preceding the test to July 13, 2009. At that time, the In-Situ equipment was replaced with Design Analysis H-312 pressure transducers and a XL-500 data logger as part of a long-term monitoring program. Physical depth to water measurements were also collected from the test well on a regular basis from preceding the test through present. Continuous groundwater-elevation data was collected from background monitor well 184W502M during the testing period. This well is also included in the SNWA regional groundwater monitoring network.

Static groundwater elevation over the period of record ranged from approximately 5,800 to 5,802 ft amsl at Test Well 184W103, which corresponds to a depth to water of approximately 97 to 99 ft bgs. Static groundwater elevation at Monitor Well 184W504M is approximately 5,799 to 5,801ft amsl, which corresponds to a depth to water of approximately 99 to 101 ft bgs. Background well 184W502M static groundwater elevation is approximately 5,707 to 5,712 ft amsl, which corresponds to a depth to water of 478 to 483 ft bgs. Period-of-record hydrographs for the wells are presented on Figures 2-7 through 2-9.

The hydrograph for the background well 184W502M highlights time intervals during this test and a later unrelated test performed at Test Well 184W101 located adjacent to the background well. Static depth-to-water levels at well 184W502M have trended lower during the period of record. This corresponds to trends observed in other monitoring wells on the east side of Spring Valley. The cause of this water level decline is related to decrease in precipitation and local recharge during the period

Table 2-2
Monitor Well 184W504M Borehole and Well Statistics

LOCATION DATA Surveyed Coordinates	N 4,293,712.49 m; E 713,647.12 m (UTM, Zone 11, NAD83)	
Surveyed Ground Elevation	5,900.11 ft amsl	
DRILLING DATA Spud Date	11/9/2006	
Total Depth (TD)	1,040 ft bgs	
Date TD Reached	11/16/2006	
Date Well Completed	11/17/2006	
Hole Diameter	26-in. from 0 to 60.51 ft bgs 14.75-in. from 60.51 to 1,040 ft bgs	
Drilling Techniques	Conventional Direct Circulation with mud from 0 to 220 ft bgs Flooded Mud Reverse Circulation from 220 to 1,040 ft bgs	
Drilling Fluid Materials Used	Quick Gel = (49) 50-lb bags Soda Ash = (14) 50-lb bags Calcium = (5) 50-lb bags Gel = (191) 50-lb bags	Sodium Bicarbonate = (5) 50-lb bags DrisPac = (13) 50-lb bags Max Gel = (59) 50-lb bags
Drilling Fluid Properties	Viscosity Range = 41 to 62 sec/qt Density Range = 8.0 to 9.2 lb/gal Filtrate Range = 9.2 to 18.0 ml Filter Cake Range = 1/32 to 2/32 in.	
CASING DATA	20-in. MS Conductor Casing from 0 to 60.51 ft bgs 8-in. MS Production Casing from -1.33 to 1,019.98 ft bgs	
WELL COMPLETION DATA	310.27 ft of blank MS 8-in. casing from -1.33 to 308.94 ft bgs 689.99 ft of slotted MS casing from 308.94 to 998.93 ft bgs 20.72 ft blank sump MS casing from 998.93 to 1,019.65 ft bgs 0.33 ft bullnose CS casing from 1,019.65 to 1,019.98 ft bgs Cement Depth 0 to 60.51 ft bgs on outside of conductor casing	
WATER	Static Water Level: 99.77 ft bgs (9/25/2008) Groundwater Elevation: 5,800.34 ft amsl	
DRILLING CONTRACTOR	Lang Exploration Drilling	
GEOPHYSICAL LOGS BY	Raymond Federwisch, Geophysical Logging Services (Prescott, Arizona)	
OVERSIGHT	S.M. Stoller Corporation	

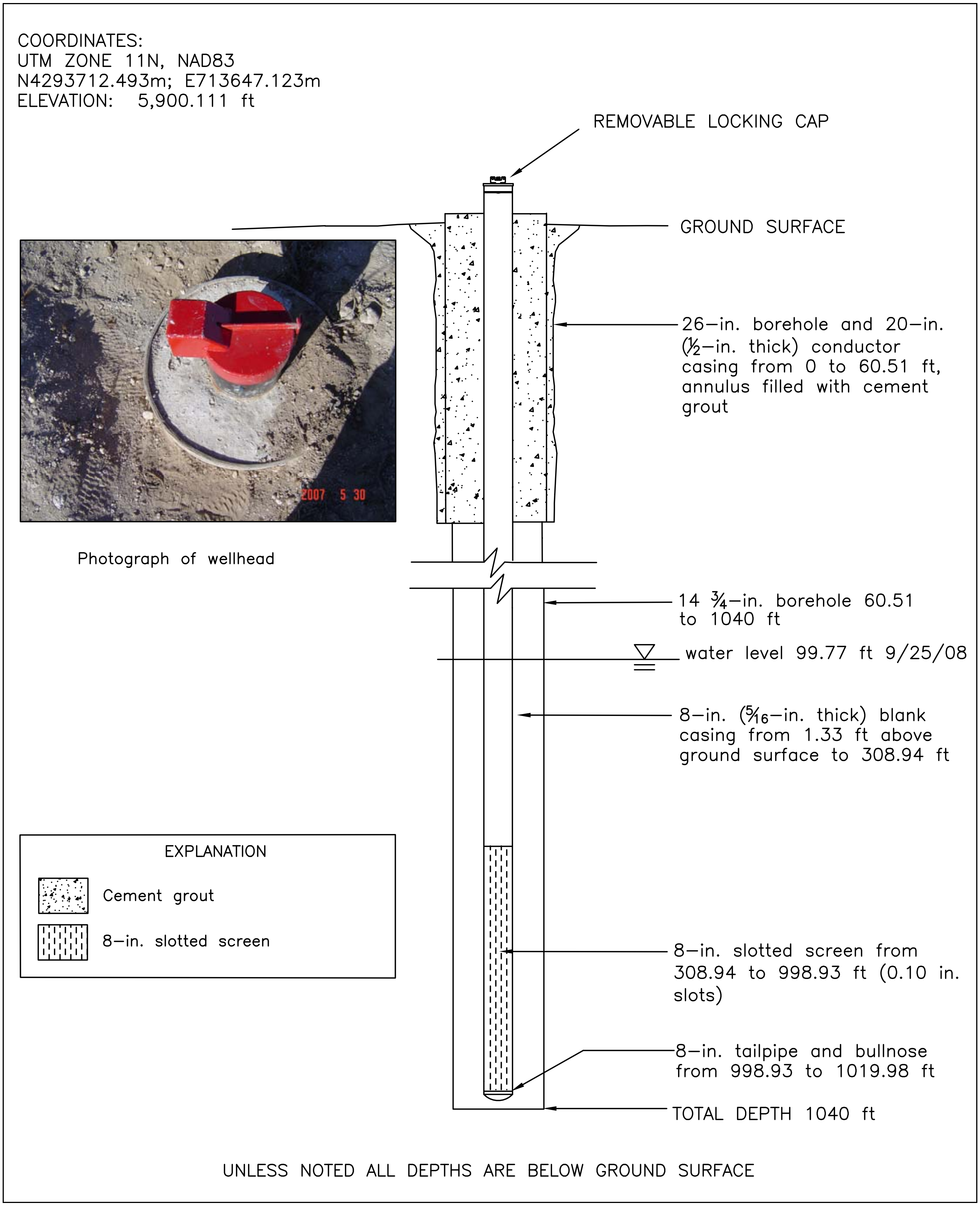


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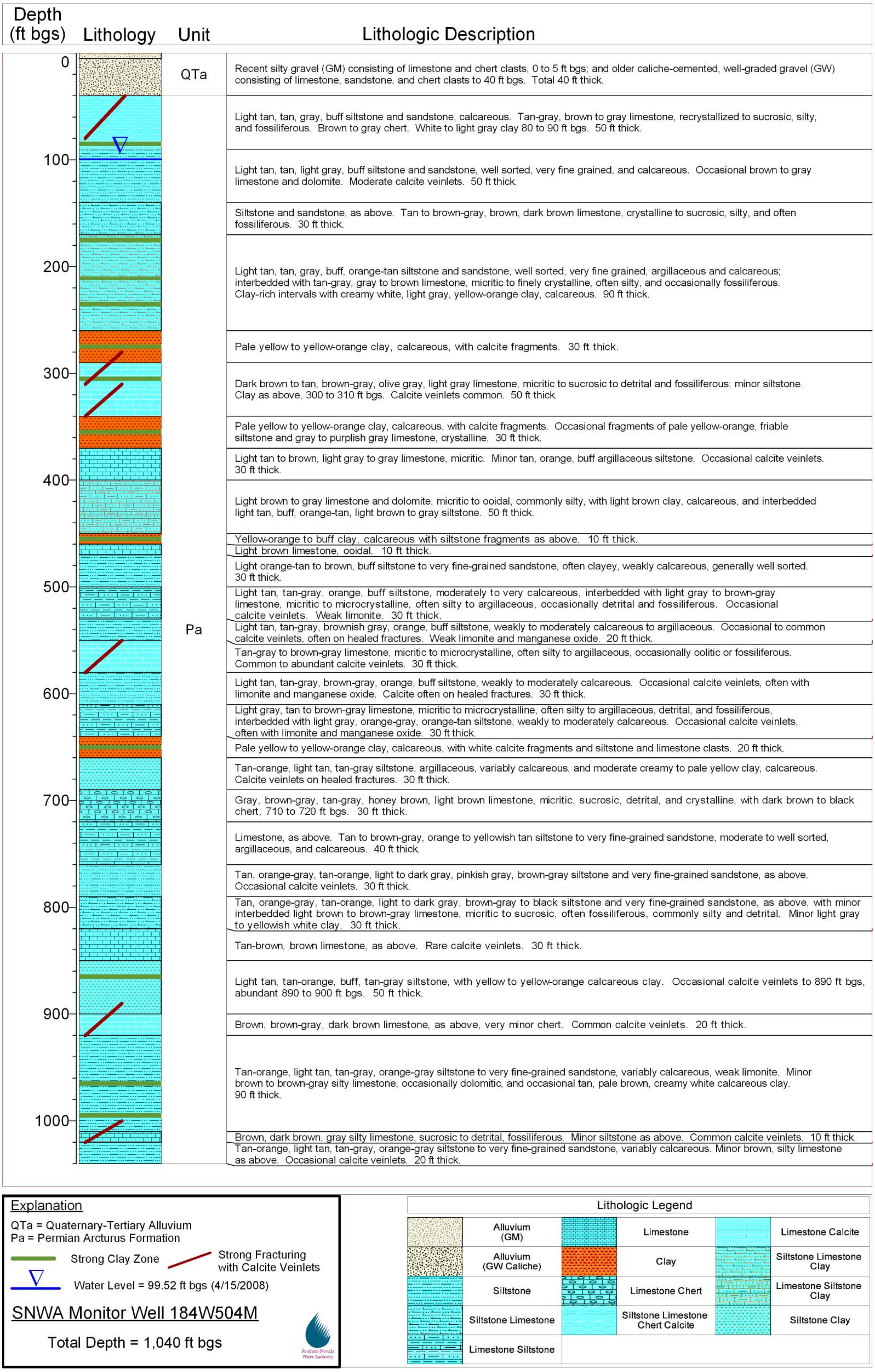
Figure 2-5
Monitor Well 184W504M Construction Schematic



Source: Eastman and Muller (2009)

Figure 2-6
Borehole Stratigraphic Column of Test Well 184W504M

Table 2-3
Measuring-Point Information

Well ID	Well Use During Testing	Location[a] UTM Northing (m)	Location[a] UTM Easting (m)	Temporary MP (ft amsl)[b]	Permanent MP (ft amsl)[b]	Ground Surface Elevation (ft amsl)
184W103	Test Well	4,293,693	713,698	5,904.26	5,901.19	5,899.06
184W504M	Observation Well	4,293,712	713,647	5,901.44	5,901.44	5,900.11
384620114313601	Observation Well	4,294,398	714,797	5,789.02	5,789.02	5,789.02
184W506M	Background Well	4,306,214	713,940	6,016.44	6,016.44	6,014.04

[a]Universal Transverse Mercator, North American Datum of 1983, Zone 11N, Meters
[b]North American Vertical Datum of 1988 (NAVD88)
MP = Measuring Point

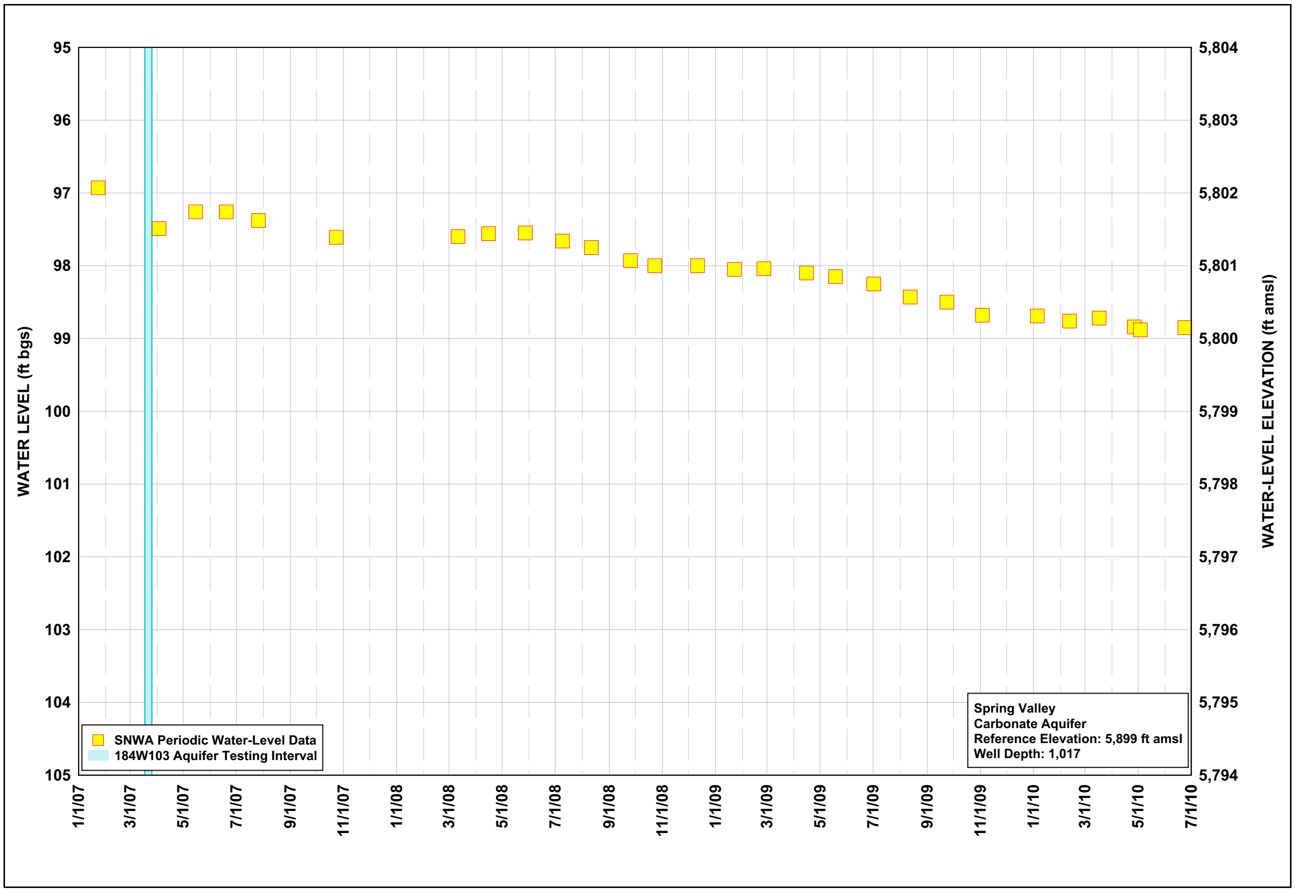


Figure 2-7
Test Well 184W103 Historic Hydrograph

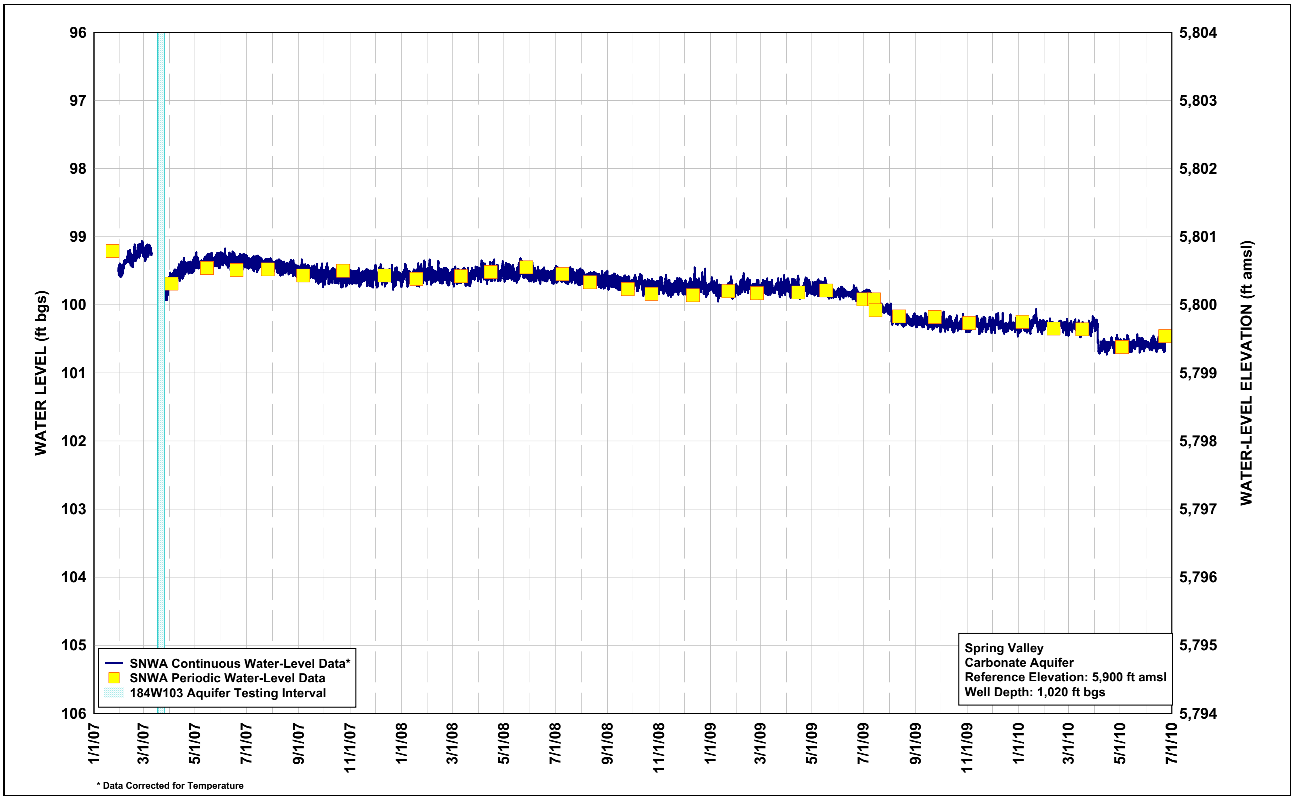


Figure 2-8
Monitor Well 184W504M Historic Hydrograph

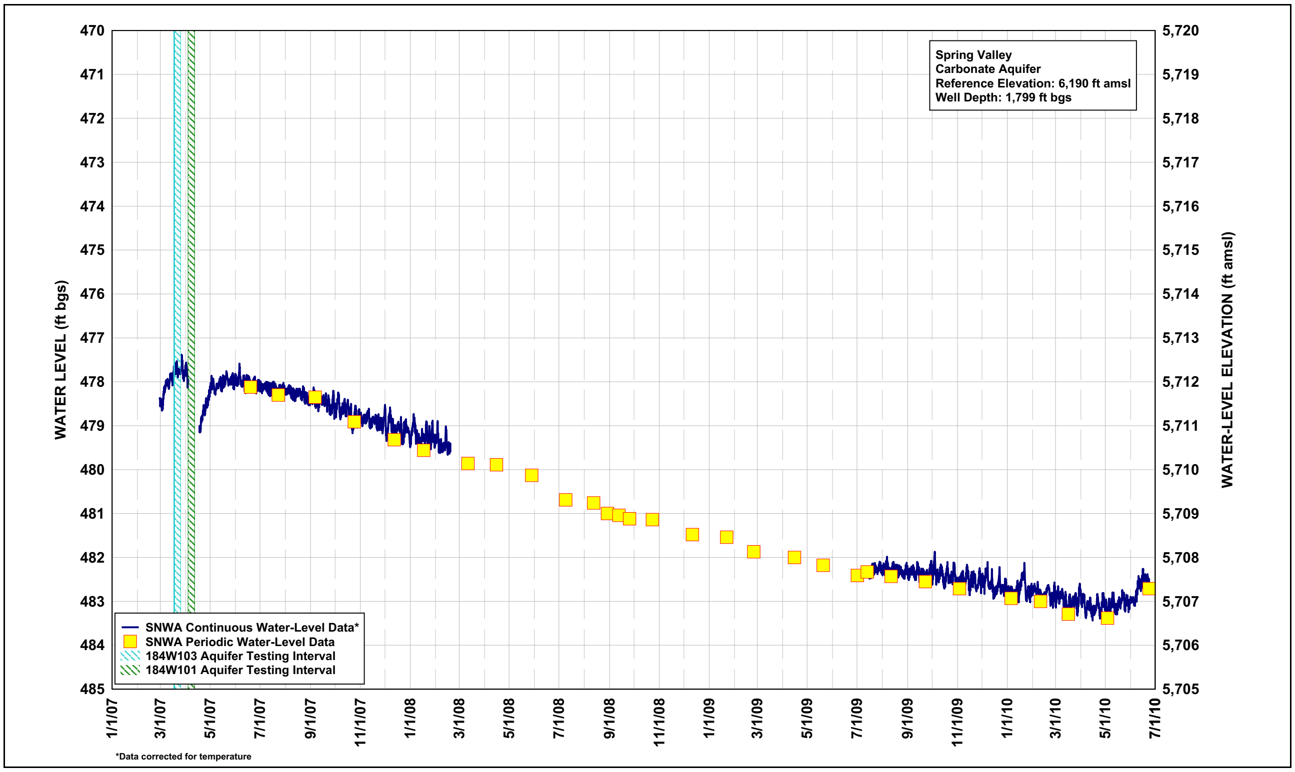


Figure 2-9
Monitor Well 184W502M Historic Hydrograph

of record. A detailed background hydrograph at 184W502M during the hydraulic testing period is presented in Section 3.4.

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3.0 TEST DESCRIPTION AND INFORMATION

This section describes the activities, pump equipment, and monitoring instrumentation associated with development and testing of 184W103. 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:

- March 18 to 20: Developed the test well using surge and pump methods. The well was developed at rates ranging from 450 to 635 gpm.
- March 21: Performed step-drawdown test at rates ranging from 410 to 630 gpm.
- March 23 to 26: Performed 72-hour constant-rate test at 550 gpm.

3.2 Test Equipment and Site Layout

A Johnson Pump Company vertical line shaft turbine pump was used in Test Well 184W103. The intake was set at 283 ft bgs. The test-well transducer was set at approximately 275 ft bgs. A pump discharge-line check valve was not used during the test to allow more effective development activities.

3.3 Discharge Information

Pumped water was discharged north of the site through approximately 1,500 ft of 12-in.-diameter piping. The discharge line passed through a culvert under Atlanta Road, then discharged onto an energy dissipation device. A total of 3,734,500 gal were pumped over the course of the development and testing periods for Test Well 184W103.

3.4 Instrumentation and Background Data

Regional and site background water levels were continuously recorded prior to, during, and after the test period. Groundwater levels in Test Well 184W103 were recorded during the test period using an In-Situ HERMIT 3000 data logger and In-Situ 250 psi pressure transducer. Monitor Well 184W504M and background well 184W502M were equipped during testing with an In-Situ Level TROLL 700 integrated pressure transducer and data logger. Barometric pressure was recorded at the test well and at ET Station SV1 located approximately 4 mi to the east-northeast of the test well.

Manual measurements were performed at both the test and monitor wells using a Heron 1,000 ft electronic water-level indicator probe at prescribed intervals and in accordance with SNWA procedures and applicable industry standards. Field groundwater-quality 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 in on the CD-ROM that accompanies this report.

Data collected from background well 184W502M were used to identify any significant regional trend in groundwater level. A hydrograph for background well 184W502M during the test period is presented on Figure 3-1.

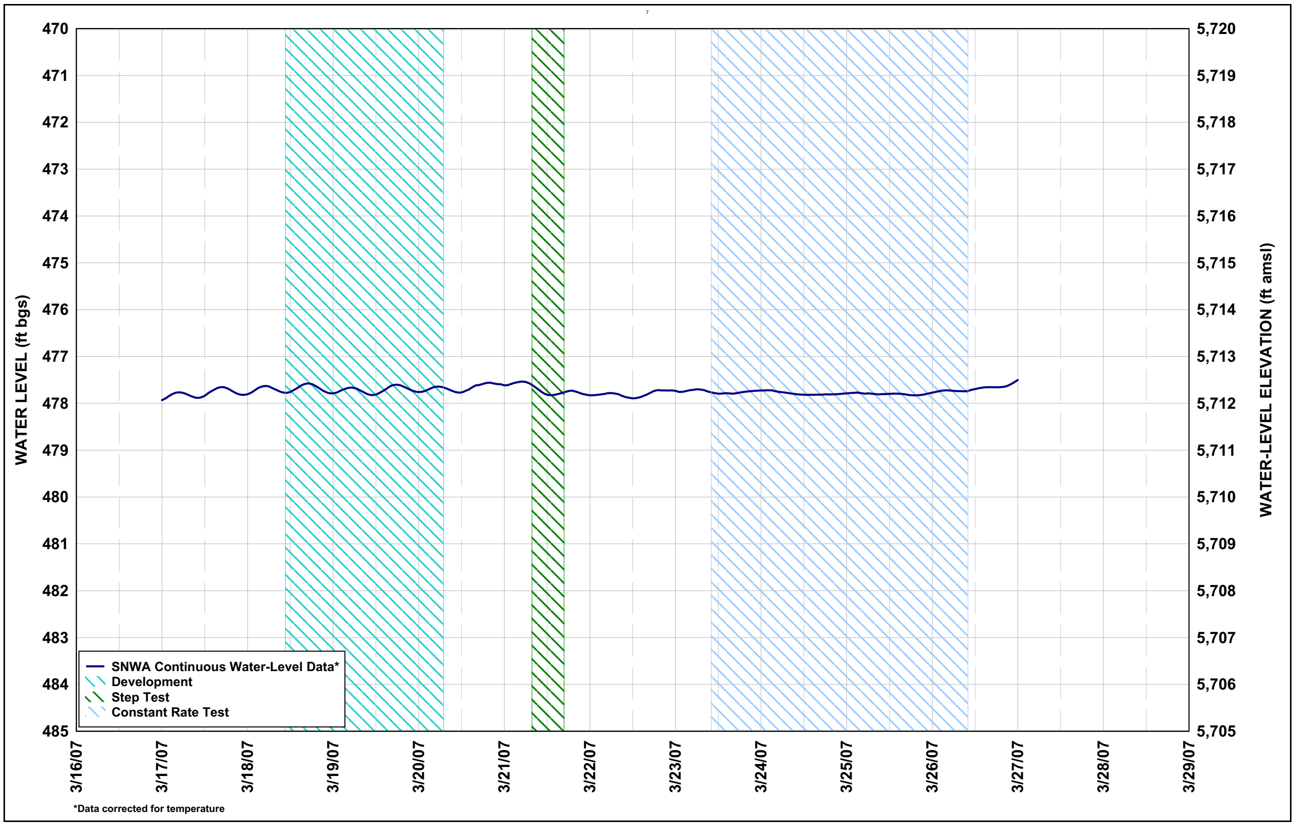

Figure 3-1
Hydrograph for Background Well 184W502M During Test Period

The hydrograph for background well 184W502M indicates no significant trend that would influence the results of the tests. An average daily cycle of water-level change of 0.08 ft was observed during the constant-rate test. A larger daily fluctuation was observed during development which was attributed to greater tidal effects. This background change is insignificant with respect to the magnitude of drawdowns observed during testing and is not incorporated as an adjustment to the test records used for the analysis of the test.

Figure 3-2 presents a plot of barometric-pressure data and groundwater-level measurements in Monitor Well 184W504M collected during the constant-rate test. The barometric-pressure record, recorded at Test Well 184W103 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

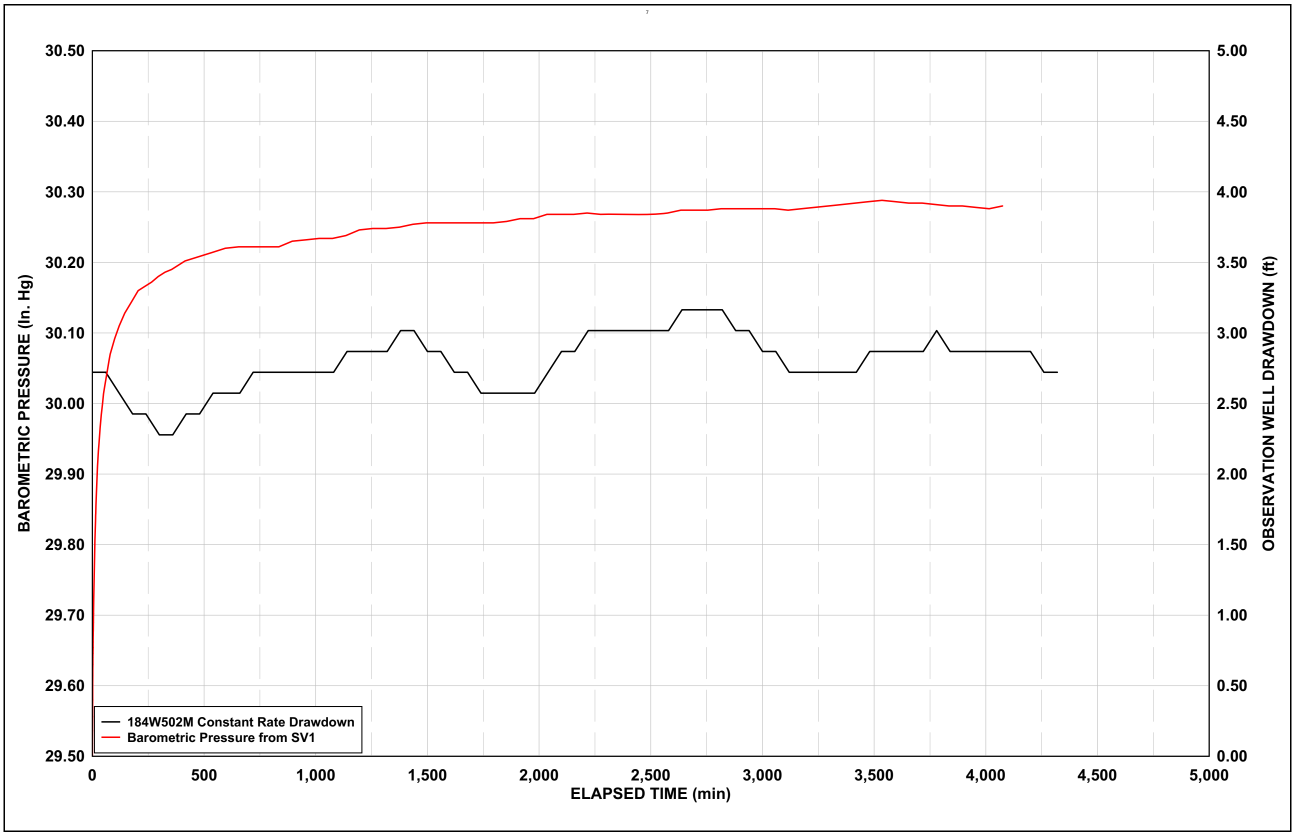

Figure 3-2
Local Barometric-Pressure Variation and
Groundwater-Level Measurements at Monitor Well 184W504M

equates to 0.20 ft water based on 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 magnitude of drawdowns observed during testing.

The respective borehole deviations for wells 184W103 and 184W504M 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.

No other outside influences, such as the existence of other pumping wells in the vicinity of Test Well 184W103, were identified.

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4.0 WELL HYDRAULICS AND PERFORMANCE TESTING

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

4.1 Development

Prior to this phase of development, Test Well 184W103 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 184W103 was then developed using a surging and pumping technique. The well was pumped at a constant rate for a short period of time (usually under an hour) until turbidity data reached a certain low threshold and then surged repeatedly. Water-level and field groundwater-quality 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 1,076,000 gal of water was pumped during this phase of development which resulted in a slight improvement of approximately 2.4 percent in specific capacity. The specific capacity improved from 4.2 gpm/ft on March 18, 2007, to 4.3 gpm/ft on March 23, 2007 at a similar pumping rate of 550 gpm and pumping duration.

4.2 Step-Drawdown Test

A step-drawdown test was performed using five different pumping rates ranging from 410 to 630 gpm. The pumping periods ranged from 90 to 120 minutes in duration during which the pumping rate was held constant. Pumping rates were increased in each subsequent pumping period. Figure 4-1 presents a graph showing plots of the drawdown versus time for each pumping interval during the step test.

4.2.1 Well Performance and Specific Capacity

Well specific capacity is a measure of the well's productivity and efficiency. Specific capacity generally decreases with pumping duration and increased discharge rate. Graphs of drawdown versus

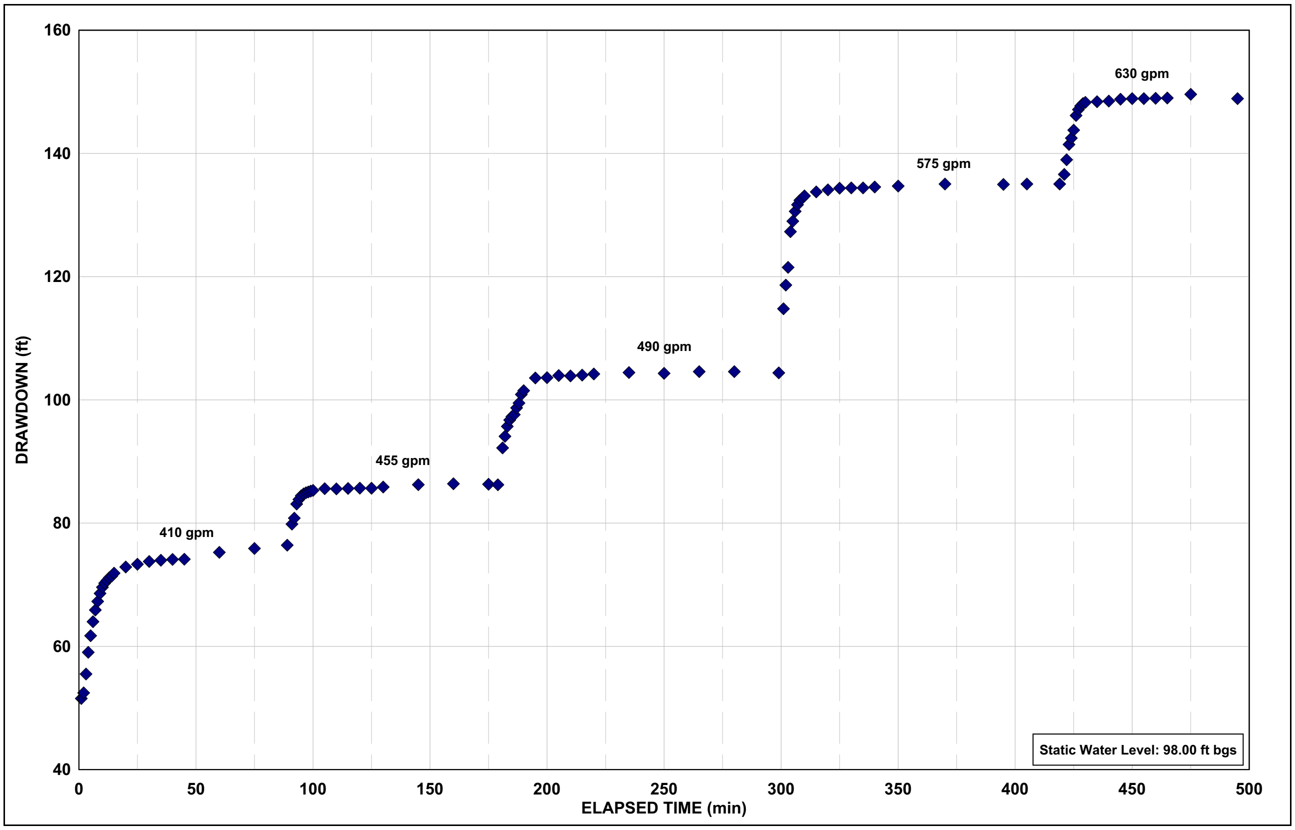

Figure 4-1
Linear Plot of Drawdown for Each Pumping Interval During Step-Drawdown Testing of Test Well 184W103

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

Results of the step-drawdown test indicate specific capacity values ranging from 4.2 to 5.3 gpm/ft for associated short term pumping rates of 410 to 630 gpm. Specific capacity during the last 12 hours of the 72-hour, 550-gpm constant-rate test was 4.2 gpm/ft with 131 to 132 ft of drawdown.

4.2.2 Well Loss Analysis

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

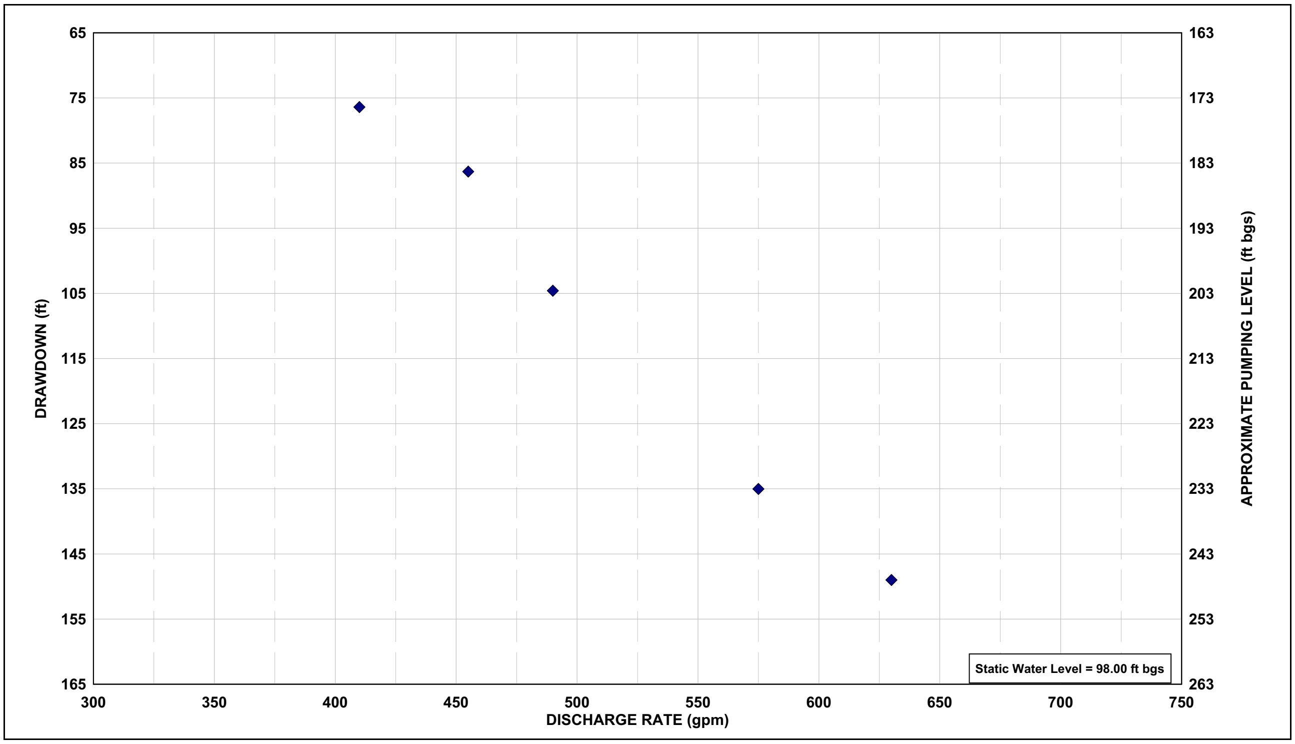

Figure 4-2
Linear Plot of Step-Test Drawdown and Depth-to-Pumping Level for Various Discharge Rates for Test Well 184W103

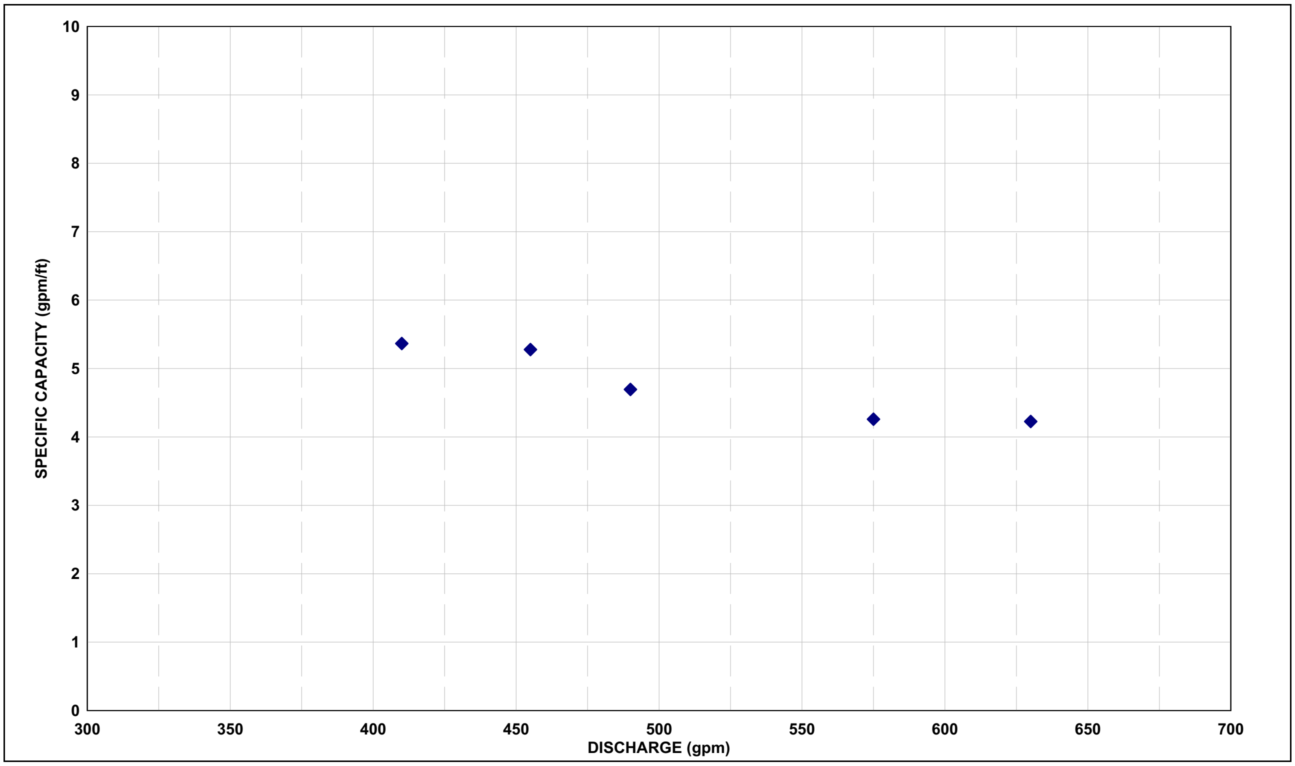

Figure 4-3
Step-Drawdown Test Specific Capacity versus Discharge Rate for Test Well 184W103

Determination of well loss allows the calculation of 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 to some degree at higher pumping rates because of an increase of turbulent flow at the well and a decrease in saturated thickness at the borehole wall under unconfined conditions. The evaluation of well losses allows for better projection of the optimal pumping rate and estimation of actual drawdown in the aquifer near the well, removed from the effects of losses caused by pumping and well inefficiencies, friction loss, and turbulent flow.

Head loss coefficients are calculated by the equation:

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

where,

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

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

The loss coefficient for B is 0.07928 and C of 2.6×10^{-4} was calculated using the Hantush-Bierschenk method. The coefficient of determination, R^2, is the proportion of variability in a data set. Using these values, specific capacity and drawdown estimates can be projected for any pumping rate using the equation:

$$\frac{s}{Q} = 0.07928 + 2.6 \times 10^{-4} Q \qquad \text{(Eq. 4-2)}$$

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

The percent of head loss attributed to linear and nonlinear losses can also be estimated using the equation:

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

Table 4-1 shows that the nonlinear losses compose about 57 to 67 percent of the drawdown, the percentage increasing with increasing production rate. This analysis indicates that the nonlinear losses are significant, which is reflected in a substantial well loss contribution to pumping-well drawdown.

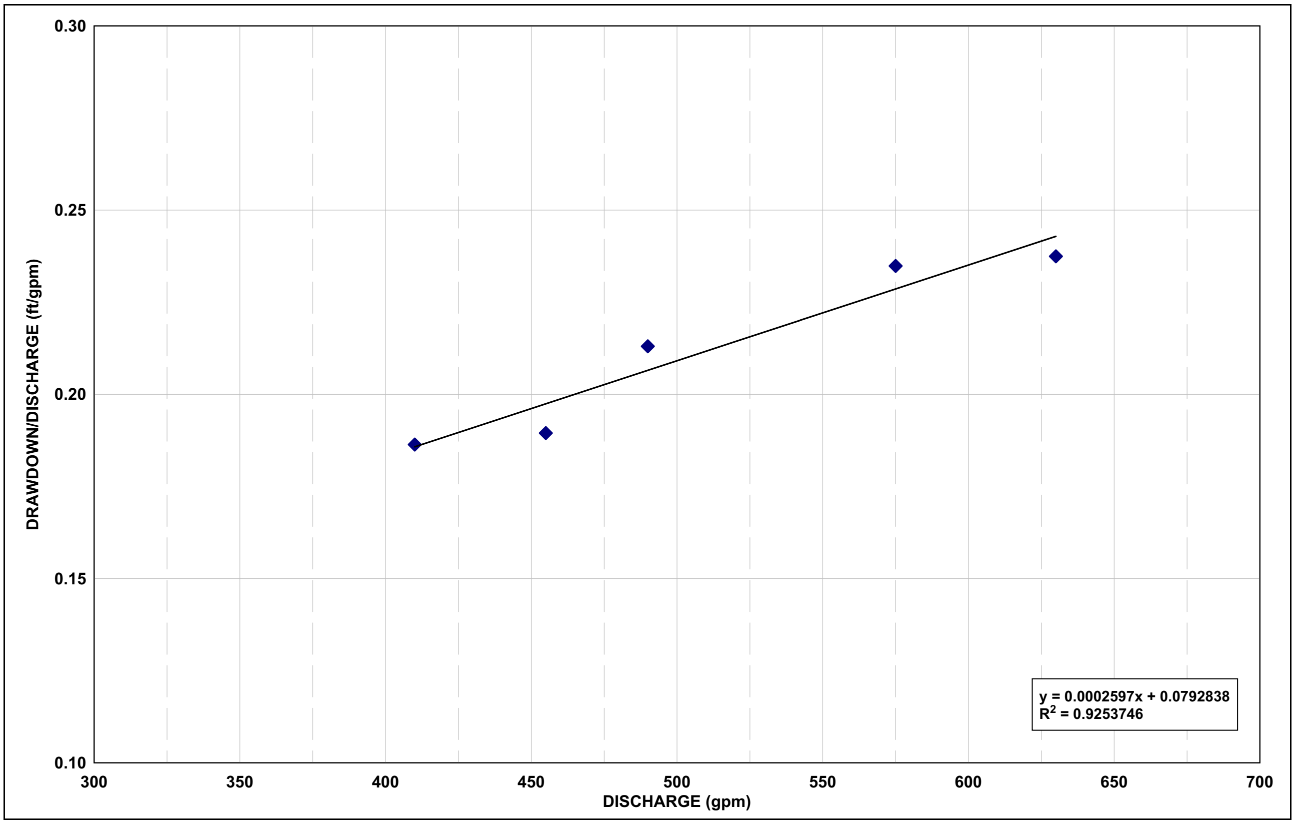

Figure 4-4
Evaluation of Head Loss Coefficients Using Hantush-Bierschenk Method from Step-Drawdown Test Results

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 (%)
410	76.41	0.1863659	43.66	32.51	76.16	57
455	86.22	0.1894945	53.76	36.07	89.84	60
490	104.39	0.2130408	62.35	38.85	101.20	62
575	135.03	0.2348348	85.86	45.59	131.45	65
630	149.60	0.2374603	103.07	49.95	153.02	67

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5.0 AQUIFER EVALUATION TESTING

This section summarizes the collection of hydraulic testing data, selection of the analytical solutions for evaluation of drawdown and pumping data, and the analysis results of the 72-hour constant-rate and recovery at Test Well 184W103.

5.1 Data Review and Adjustments

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

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

Totalizer readings indicated a total volume of 2,378,000 gal were pumped during the 72-hour test, an average of 550 gpm during the test. No significant flow adjustments or interruptions occurred during the test.

During the initial four minutes of the test, small variations in drawdown were observed. These were the result of borehole storage effects, water filling the pump column, and pressure variations at the flow control valve. Vertical flow losses within the well were considered during analysis. The friction losses within the test well were calculated to be relatively small compared to the drawdown observed in the well.

Minor smoothing of the test-well transducer data was performed to average noise in the record caused by turbulence at the pump intake and vibrations. The synthetic record was used in subsequent evaluation and analysis.

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 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 record. The recovery water level then quickly decayed back to the aquifer recovery response. This effect is observed in both the test well and 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 discharge rate of 550 gpm. A summary of time-drawdown data for Monitor Well 184W504M and Test Well 184W103 is presented graphically in log-log and semi-log form on Figures 5-1 through 5-4. Transducer and manual measurement data are presented in Appendix A.

Recovery data were collected immediately upon cessation of pumping activities. Recovery data are presented in a plot of residual drawdown versus log of t/t' (elapsed time from beginning pumping/ time of recovery) in Figure 5-5. Recovery period on the graph begins on the right and ends on the left.

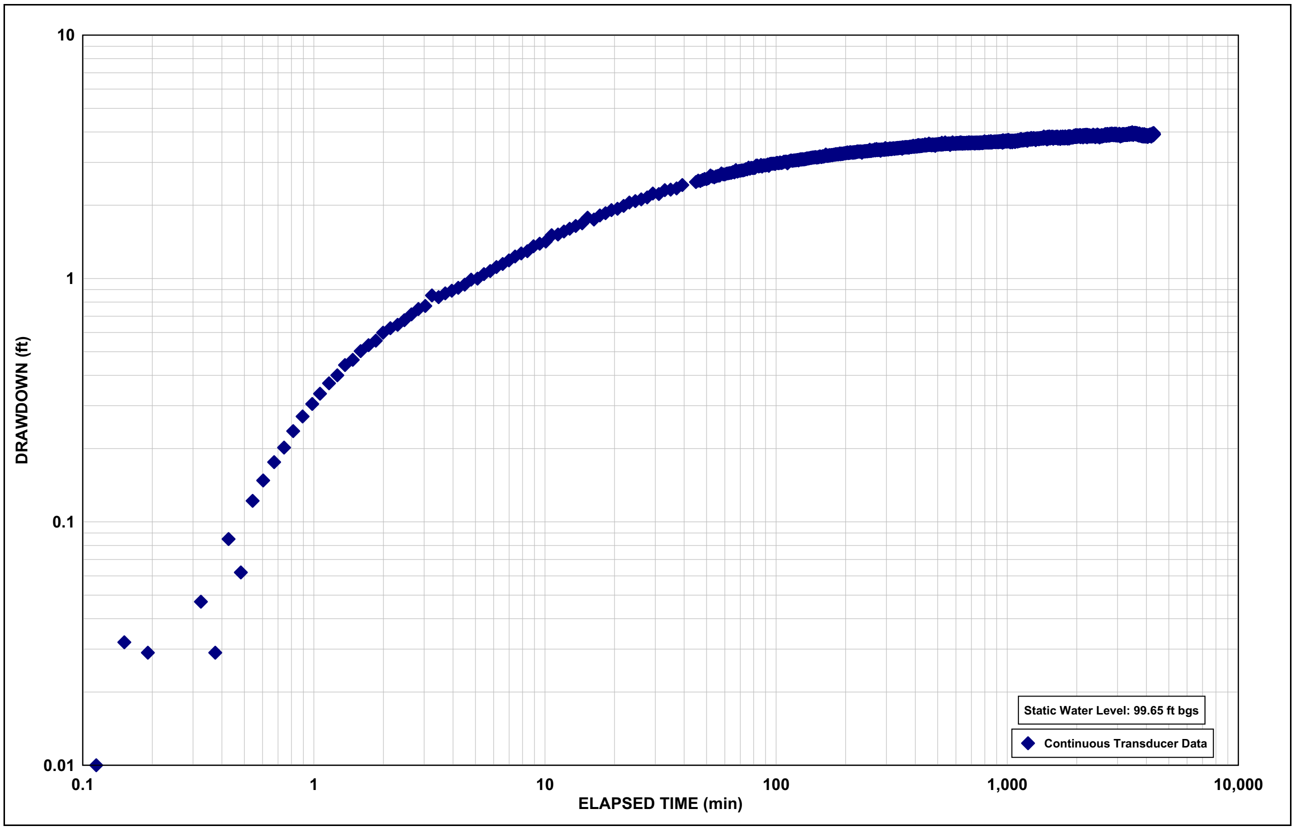

Figure 5-1
Drawdown versus Time log-log Data Plot at Monitor Well 184W504M

5.3 Analytical Model Selection

The analytical model used for the aquifer-properties evaluation was selected based upon observed 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 observed drawdown response curves. The drawdown curve and derivative plot are representative of a dual-porosity system, which would be expected in a fractured carbonate-rock aquifer.

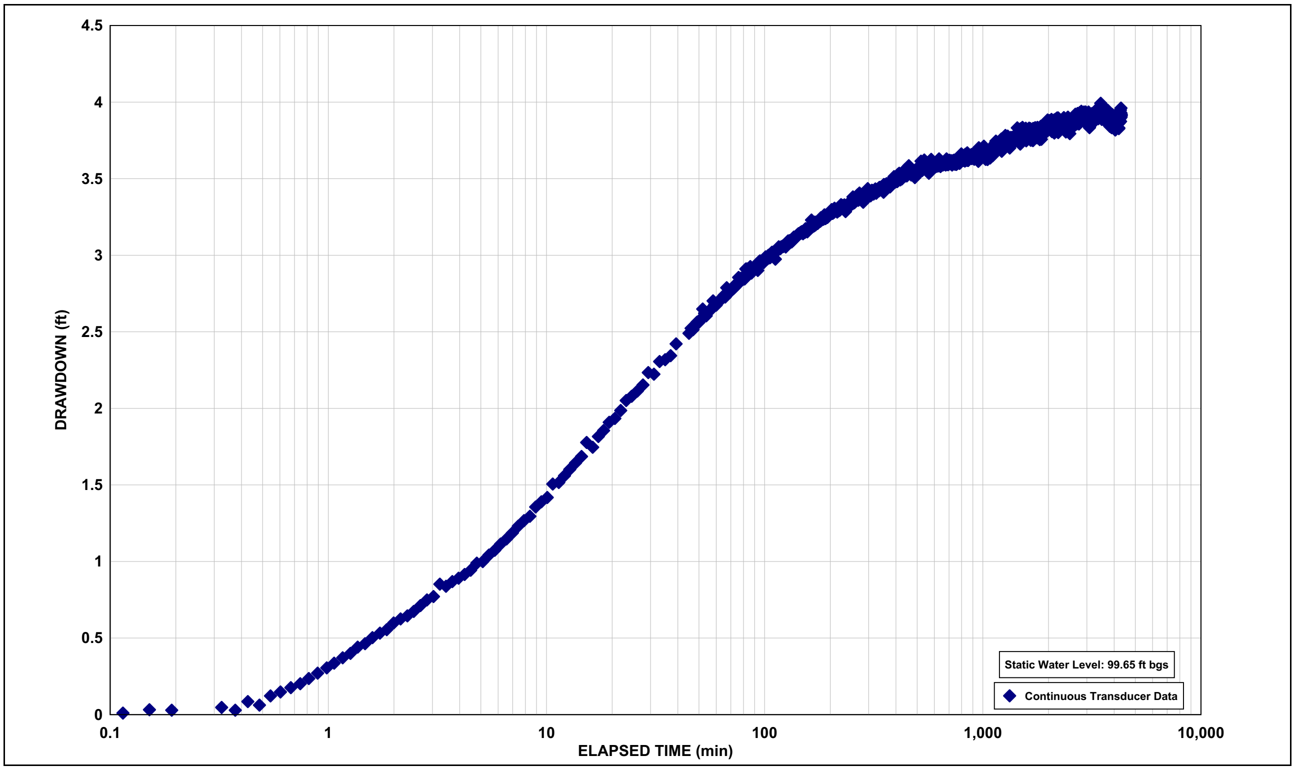

Figure 5-2
Semi-Log Data Plot of Drawdown Versus Time from Monitor Well 184W504M

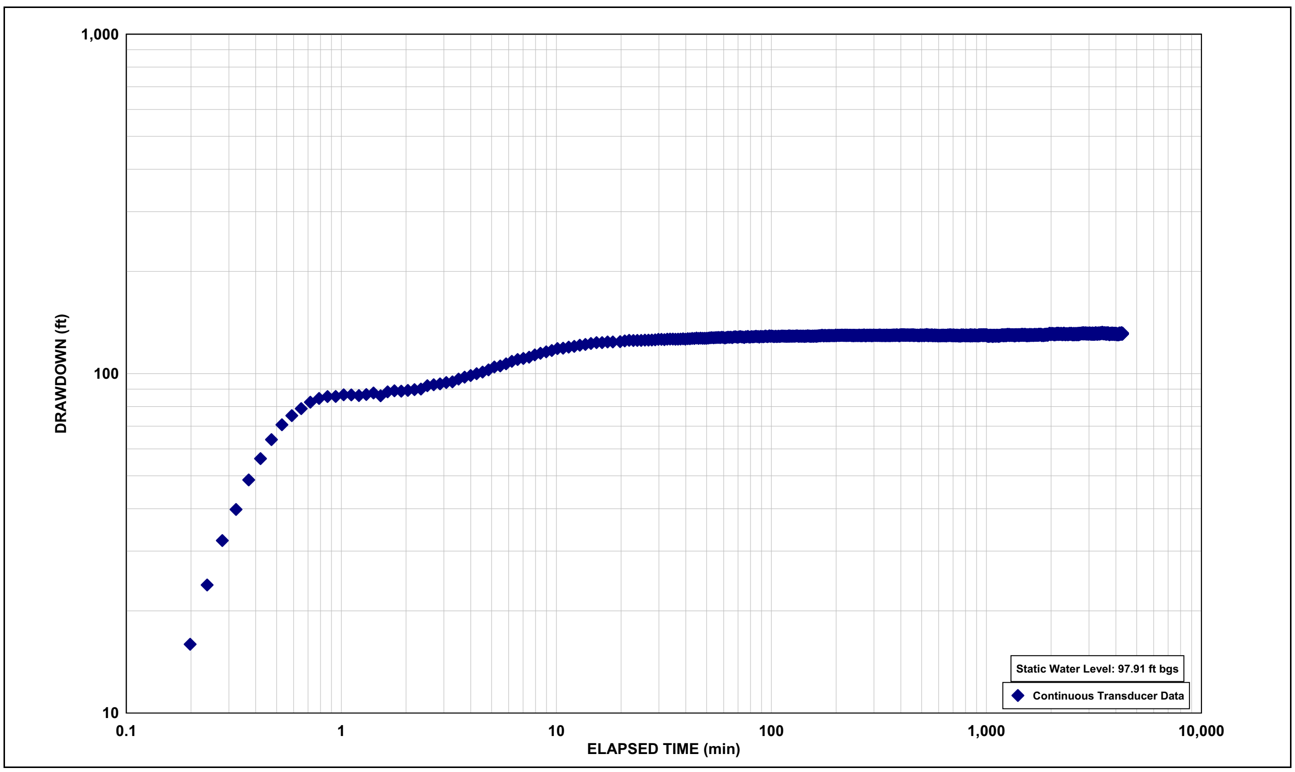

Figure 5-3
Log-Log Data Plot of Drawdown Versus Time from Test Well 184W103

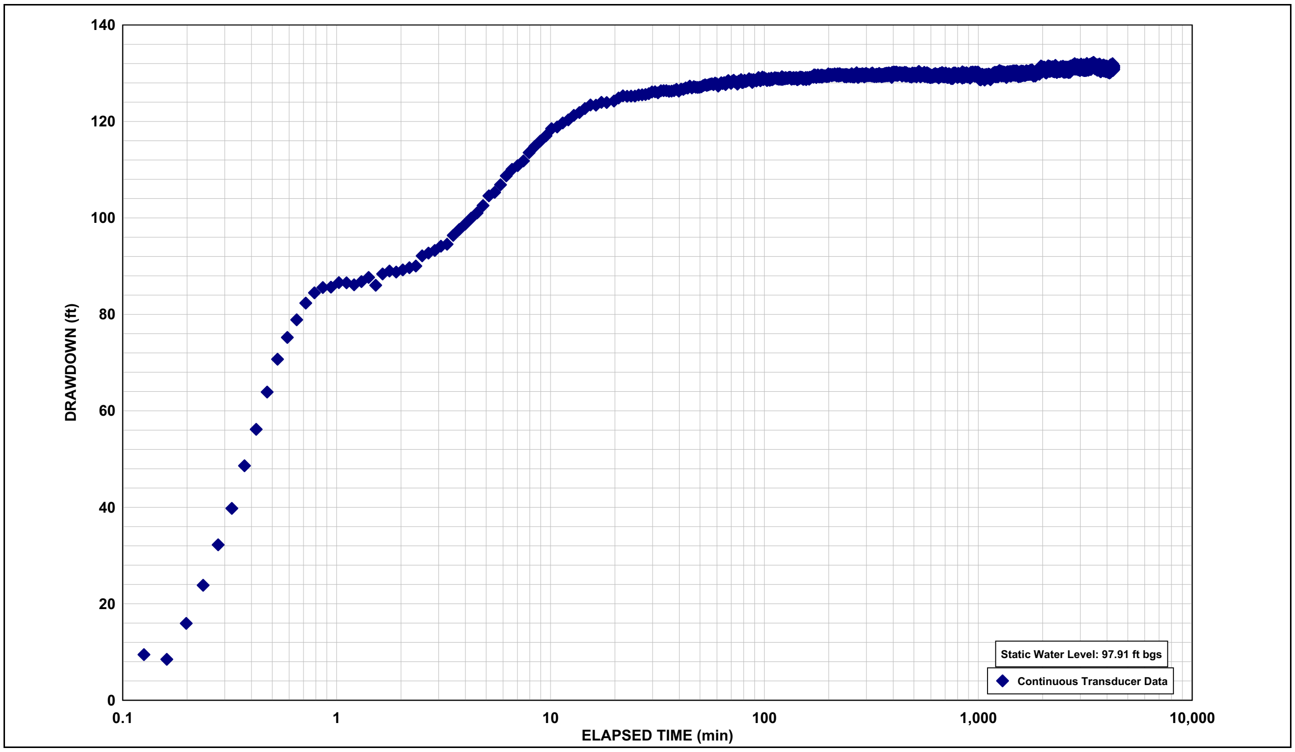

Figure 5-4
Semi-Log Data Plot of Drawdown Versus Time from Test Well 184W103

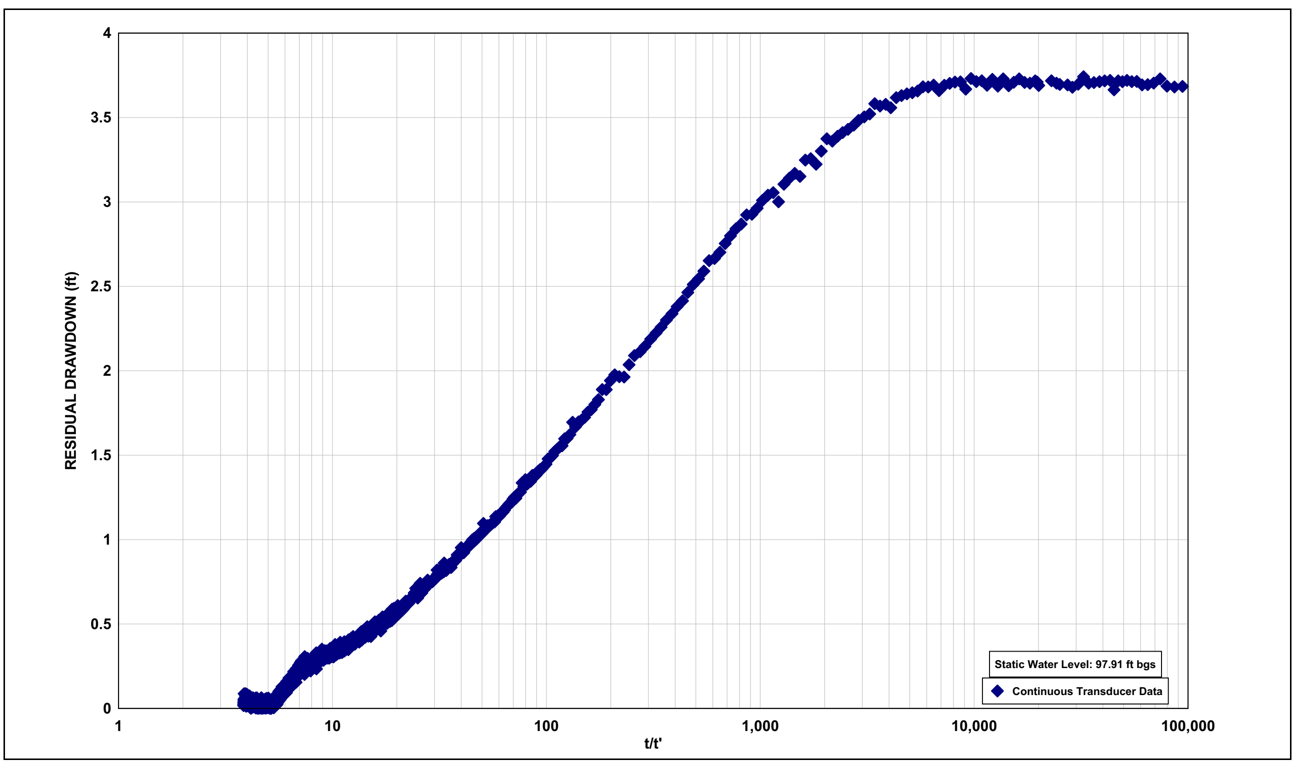

Figure 5-5
Monitor Well 184W504M Recovery Data Presenting
Residual Drawdown versus the Log of the Ratio of t/t'

The Barker Generalized Radial Flow Model (Barker GRFM) (Barker, 1988), which is a generalized flow model for an unsteady, confined, fractured media, is the dual-porosity aquifer conceptual analytical model selected as the primary solution. This analytical model is equivalent to the Moench (1984) fractured media, dual-porosity, radial flow model. However, the Barker GRFM incorporates a flow dimension term. Flow dimension (n) provides adjustment of the response for variation in the flow geometry, ranging from $n = 1$ for linear flow, to $n = 2$ for radial flow, to $n = 3$ for spherical flow. This parameter can be applied to situations in which a linear feature, such as a fault, may affect the drawdown response or conversely as an adjustment for partial penetration (shift to slightly spherical flow dimension) effects. An analytical model with these features that also incorporates specific aspects of unconfined aquifer response, such as delayed gravity drainage or dewatering, is not available. A dual-porosity solution is more appropriate over an unconfined solution, such as the Neuman solution (Neuman, 1975), which considers delayed response or gravity drainage of the formation. Given that the water table was located within fractured carbonate with low storage, the delayed gravity drainage effect would not be expected to be as substantial as dual-porosity effects.

General assumptions associated with the Barker GRFM solution are that:

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

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

Cooper-Jacob semi-log straight-line approximation (Cooper and Jacob, 1946) was used as a secondary analytical solution. This approach was used to fit late-time data. The early-time response can only be evaluated after the effects of wellbore storage have dissipated, and before matrix effects begins.

5.4 Constant-Rate and Recovery-Test Analysis

5.4.1 Test Analysis Methodology

The aquifer test analysis software AQTESOLV V4.50 (Duffield, 1996-2007) was used for curve fitting. The data logger records of pressure transducer output were used to create AQTESOLV input files of the drawdown and recover 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 184W103 to 184W504M[a]	177 ft
b Aquifer saturated thickness[b]	943 ft
b' Fracture spacing	3.3 and 10 ft

[a]Surface measurement
[b]Static Water Level to bottom of borehole

Parameter definitions used in this section are presented below:

K = Aquifer/fracture hydraulic conductivity (ft/day)
K´ = Matrix hydraulic conductivity (ft/day)
n = Flow dimension; 1 = linear, 2 = radial, and 3 = spherical (dimensionless)
Q = Pumping discharge rate (gpm)
Sf = Fracture skin factor (dimensionless)
Ss = Fracture-specific storage (ft^{-1})
Ss´ = Matrix-specific storage (ft^{-1})
Sw = Borehole skin factor or well-loss coefficient value (dimensionless)
s = Drawdown at pumping well
t = Time
T = Transmissivity (ft^2/day)
S = Storativity (dimensionless)

The Barker GRFM was fitted to the drawdown and recovery responses of both the monitor and test wells sequentially and iteratively to determine the set of model parameter values that best fit the data. The selection of the most representative set of parameter values for the Barker GRFM depends upon the hydrogeologic conceptual model, interpretations of aquifer response components, constraints placed upon storage parameter values, and interpretation of well borehole skin effect (i.e., nonlinear flow losses at the test well distorting actual drawdown near the test well). The most representative set of parameter values is a range of approximate values for each parameter, based on applicable constraints. The model fit is optimized for hydraulic conductivity. Various parameters are correlated and can be adjusted, to some degree, with no uniqueness. The model, fit to all of the data and constraints, is optimal within a restricted range for the major parameters.

A correction equation for dewatering (Kruseman and De Ridder, 1994, p. 101) was considered and applied to the drawdown response record before analysis to account for a reduction in saturated thickness, resulting from drawdown in unconfined conditions that are assumed to, or occur at the site; thus, influencing the area near the test well. This approach provides for bounding of the effect of dewatering.

Average fracture spacing, which for practical purposes is unknown, has been assigned various values and characteristics for a sensitivity analysis. The sensitivity of hydraulic conductivity to this parameter is low as indicated by the results of an analysis of fracture spacing of 3.3 and 10 ft. No independent data exists for anisotropy. The sensitivity to anisotropy is low.

5.5 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 compared to a simplified Cooper-Jacob secondary solution. Emphasis should be placed on the primary solution because of underlying solution limitations and site hydrogeologic conditions. Results of the Barker GRFM and Cooper-Jacob solutions are summarized in Table 5-2. Discussion of analysis approach and representative optimal solution plots 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***	***S***	**T^a (ft^2/day)**
3.3	11.64	5.05×10^{-7}	5.29×10^{-7}	3.75×10^{-5}	2.3	0.035	11,000
10	11.66	5.27×10^{-7}	3.13×10^{-6}	7.27×10^{-5}	2.3	0.069	11,000
Secondary Solution Using Cooper-Jacob Analysis							
Analysis Time Interval	***K* (ft/day)**	**Location**	***S***			***T* (ft^2/day)**	
Late-Time	4.98	Test Well 184W103	N/A			4,700	
Late-Time	20.04	Monitor Well 184W504M	N/A			18,900	

[a]Transmissivity derived from the Equation $T = K \times b$. b is defined as the saturated thickness (943 ft).

5.5.1 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 hydraulic parameters. The interpreted solution set of model parameters does not represent exact values for each parameter, rather, it represents a set of approximate values that locate the parameter space in which the solution is optimized for hydraulic conductivity.

Fracture specific storage (*Ss*) ranged from 5.05×10^{-7} to 5.27×10^{-7} ft^{-1}. The values are generally within ranges (1.06×10^{-7} to 4.57×10^{-8} ft^{-1}) for generally similar conditions reported in Kilroy (1992). 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 approximately 3×10^{-5} ft^{-1}. Matrix specific storage (*Ss*´) of the carbonates is generally expected to be larger than fracture specific storage. *Ss*´ was calculated to range from 3.75×10^{-5} to 7.27×10^{-5} ft^{-1}. The matrix-specific storage usually provides the majority of the storage component relative to fracture storage. Specific storage can be equated to storativity (*S*) as the product of specific storage and aquifer thickness and related to compressibility of fluid in the aquifer. Calculated *S* values assuming a saturated thickness of 943 ft ranged from 0.035 to 0.069 which is within the range expected for unconfined carbonate-rock aquifers.

With *Ss* and *Ss´* values constrained, the *K* value required to fit the monitor-well drawdown was determined followed by the test-well drawdown, monitor-well recovery, and then the test-well recovery. Fitting started with the radial flow system (n = 2). Fitting of the flow dimension was maintained at n = 2 until fitting was optimized as much as possible with other parameters. The difference in the magnitude of the drawdown between the observation well and the test well had to be accounted for. Therefore, an evaluation of well loss was performed. The step-drawdown test analysis indicated that a large portion of the test well drawdown was due to non-linear losses, which typically are due to well losses. The well construction, however, provides a substantial screened interval, and the gravel pack likewise should not be restrictive because of extensive well development. Therefore, it is concluded that the well losses are mainly attributed to the turbulent flow in the near-well radius which is caused by converging flow in the fractures, which are restrictive. The large proportion of drawdown attributed to nonlinear losses equates to a large well-loss coefficient value (*Sw*). In turn, these large well losses account for a great difference in drawdown between the observation well and the test well.

The Barker GRFM solution optimal aquifer *K* value, which is dominated by fracture hydraulic conductivity, ranged from 11.64 to 11.66 ft/day. This relates to a transmissivity of approximately 11,000 ft^2/day, assuming a saturated thickness of 943 ft. Matrix *K* ranged from 5.29×10^{-7} to 3.13×10^{-6} ft/day.

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 184W504M is presented in Figure 5-8. The derivative drawdown response in the monitor well is consistent with a dual-porosity fractured bedrock system.

Well-loss analysis of Test Well 184W103 is presented in Section 4.2.2. An evaluation and removal of well-loss components are presented in Figure 5-9, which provides an indication of drawdown in the formation in the vicinity of the test well outside of the drawdown distortion caused by well losses from turbulent flow and well construction. This calculation of drawdown removing well or wellbore skin losses provides an estimated value of aquifer drawdown in the vicinity of the test well during testing.

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

5.5.2 Cooper-Jacob Analysis

The Cooper-Jacob straight line analysis was used to derive a secondary solution, using data from the monitor and test wells, to compare to the Barker GRFM results. These values should be viewed with

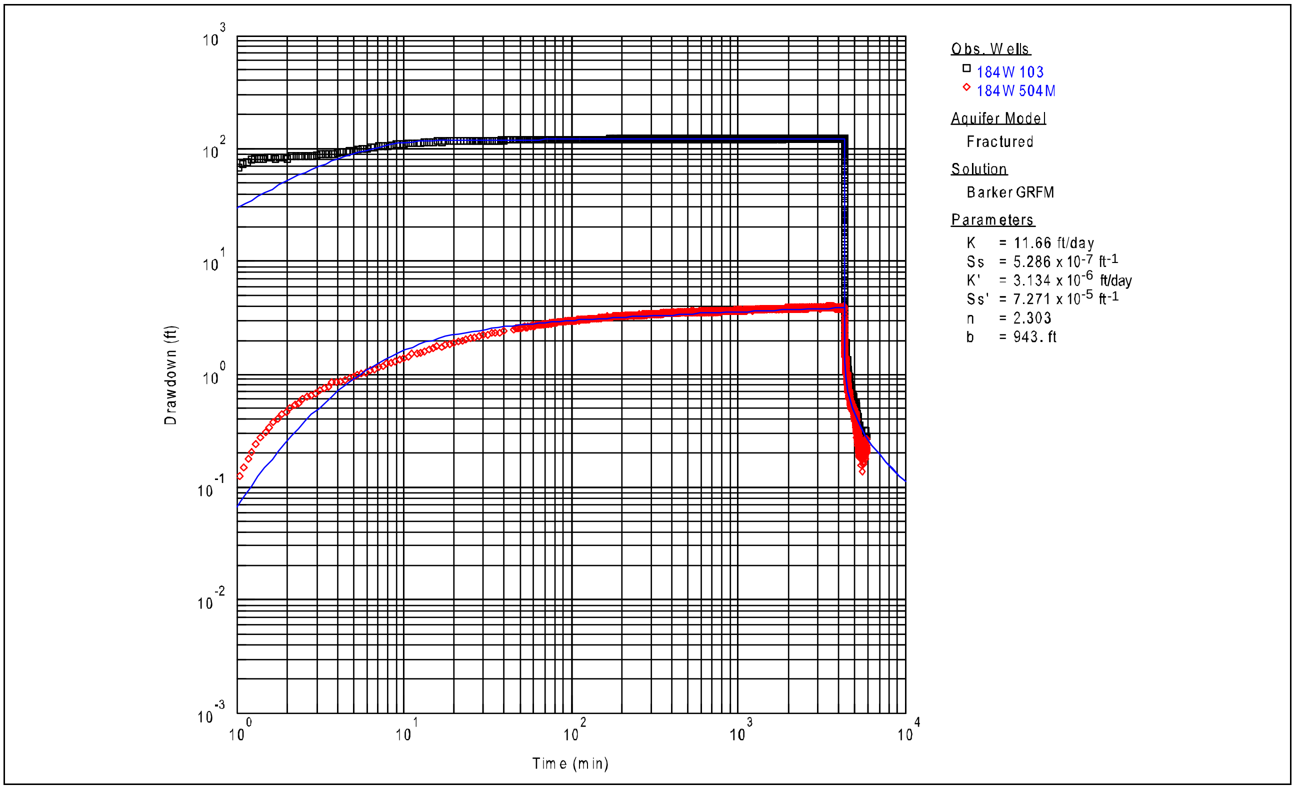

Figure 5-6
Optimal Barker GRFM Solution Log-Log Plot

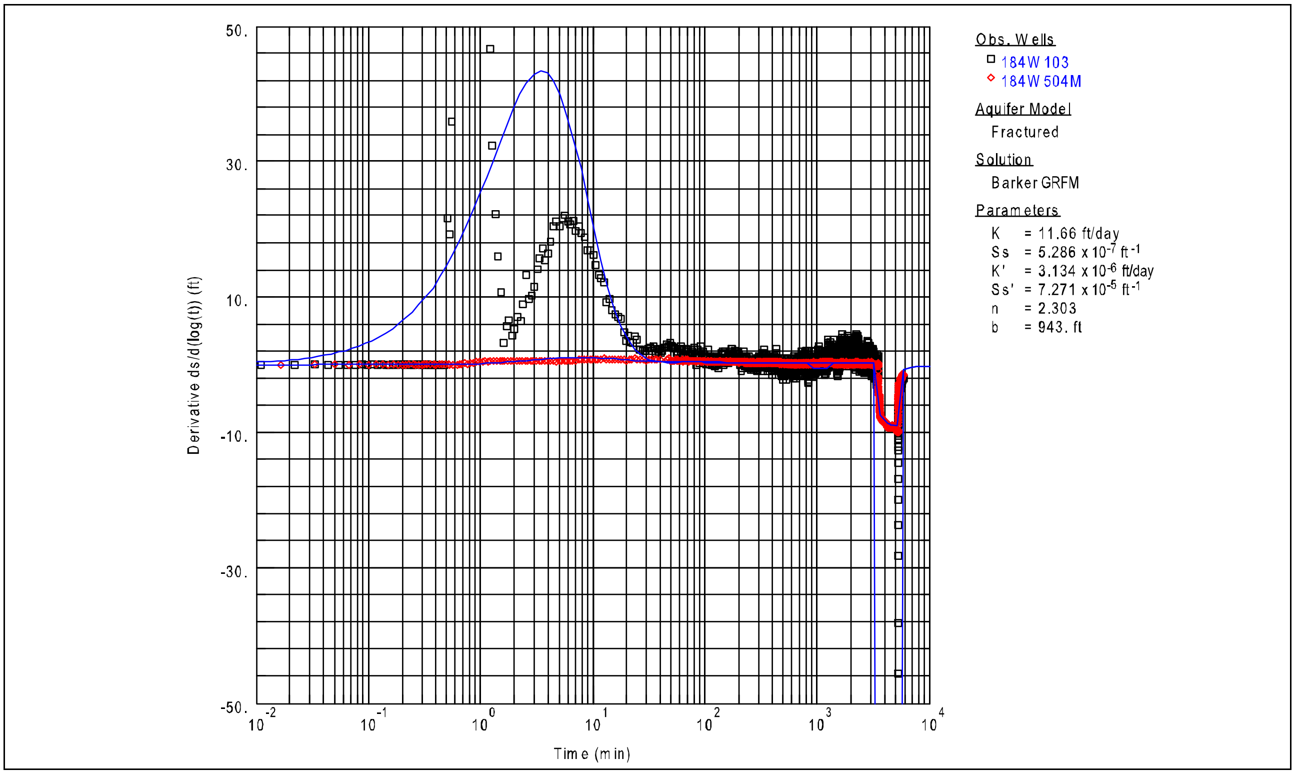

Figure 5-7
Optimal Barker GRFM Solution Drawdown Derivative Plot

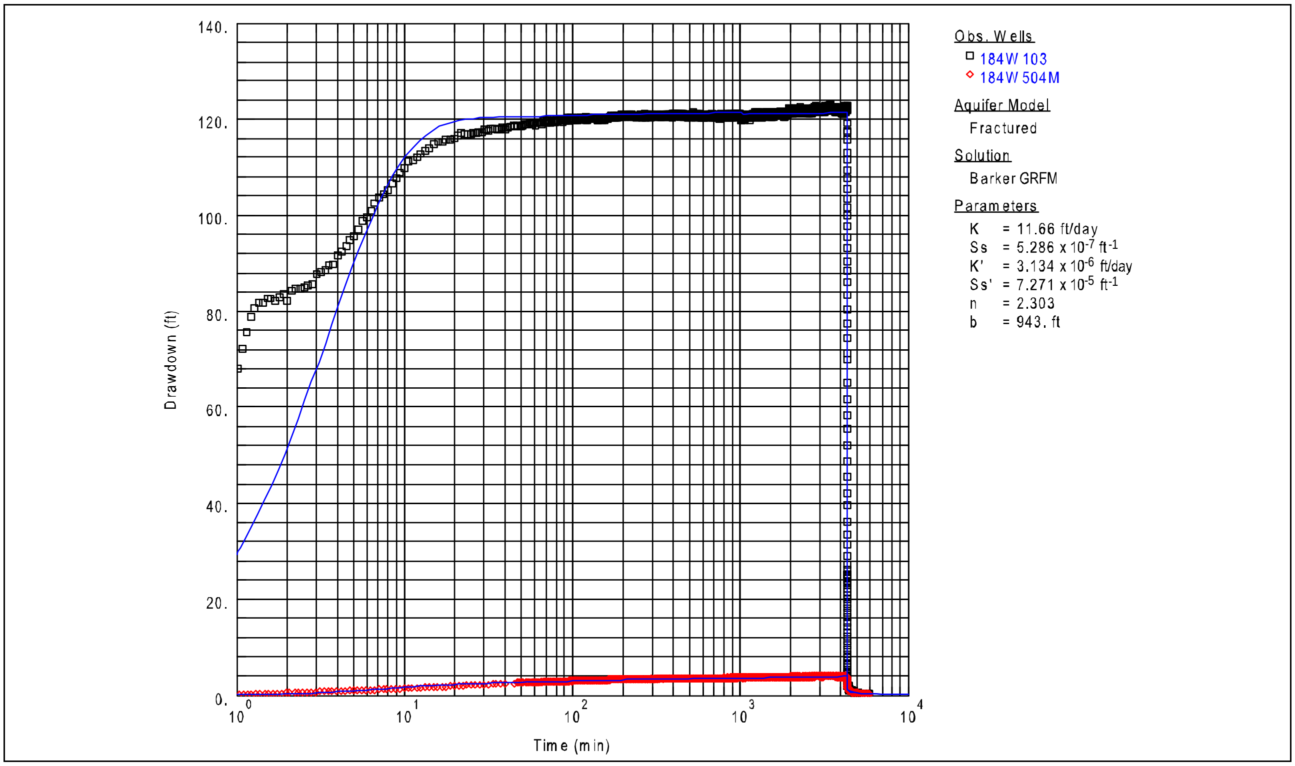

Figure 5-8
Optimal Barker GRFM Solution Semi-Log Plot

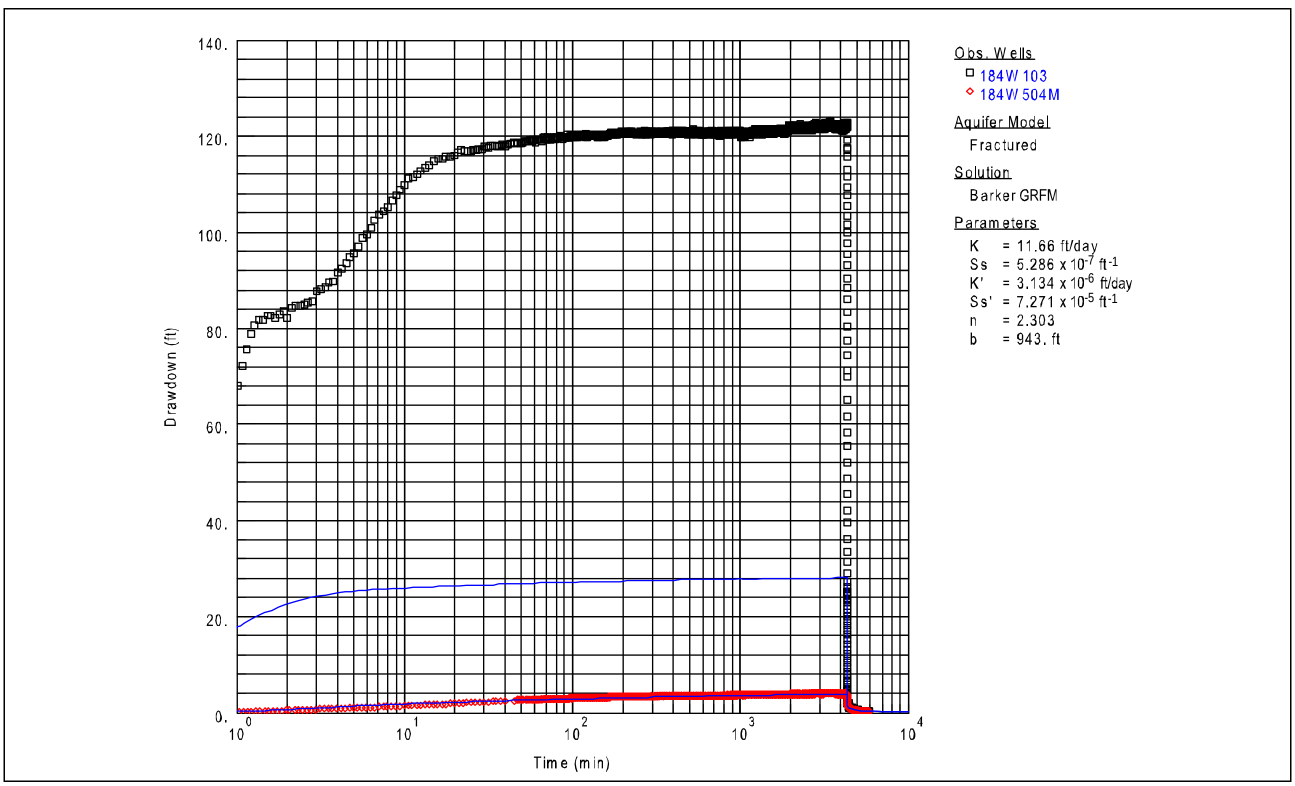

Figure 5-9
Optimal Barker GRFM Solution, Test Well 184W103 Well Losses Removed

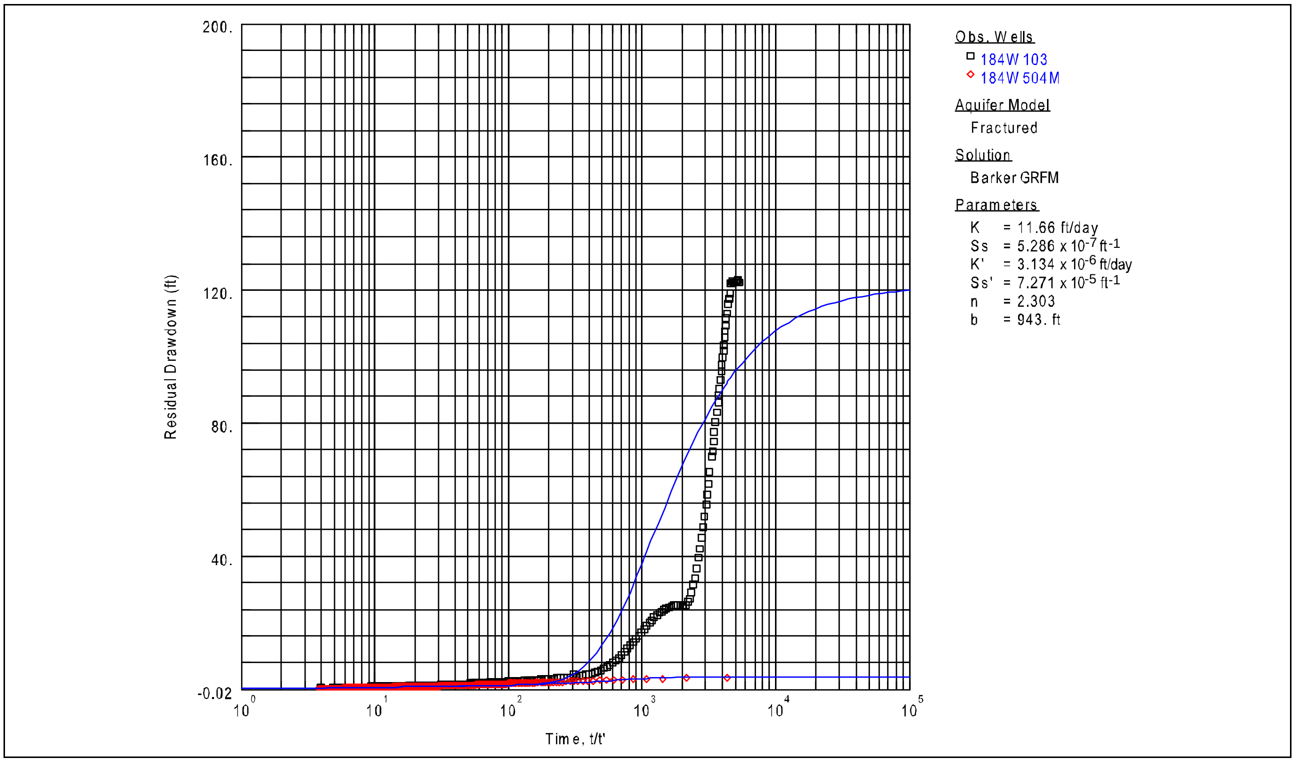

Figure 5-10
Optimal Barker GRFM Optimal Solution Recovery Period

less confidence than the Barker GRFM solution due to the limitations of the Cooper-Jacob analysis relative to the hydrogeologic conditions encountered at the test site.

The Cooper-Jacob straight-line analysis of the semi-log time-drawdown plot of Monitor Well 184W504M late-time data is presented in Figure 5-11. The late-time data, after the second day of pumping, were also fitted with a Cooper-Jacob straight-line solution with a *T* result of 18,900 ft^2/day, which is higher that other analysis results. Using a saturated thickness of 943 ft, the resulting *K* values are 20.04 ft/day. A transmissivity (*T*) value of approximately 4,700 ft^2/day was derived from the late-time data from the test well. Using a saturated thickness of 943 ft, the resulting *K* values are 4.98 ft/day. An analysis of early time data at the test well was not deemed appropriate due the effects of wellbore storage. The late-time *S* value is not representative due to the time offset of the matrix-dominated flow period.

5.6 Discussion

The test results provided representative data about the aquifer system without outside pumping or natural hydrologic variation influence. Diagnostic time-drawdown data plots and site hydrogeologic conditions were indicative of a dual-porosity aquifer system.

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 results of the testing provide a composite hydraulic conductivity over the length of the saturated interval of the wells, and the material between the wells.

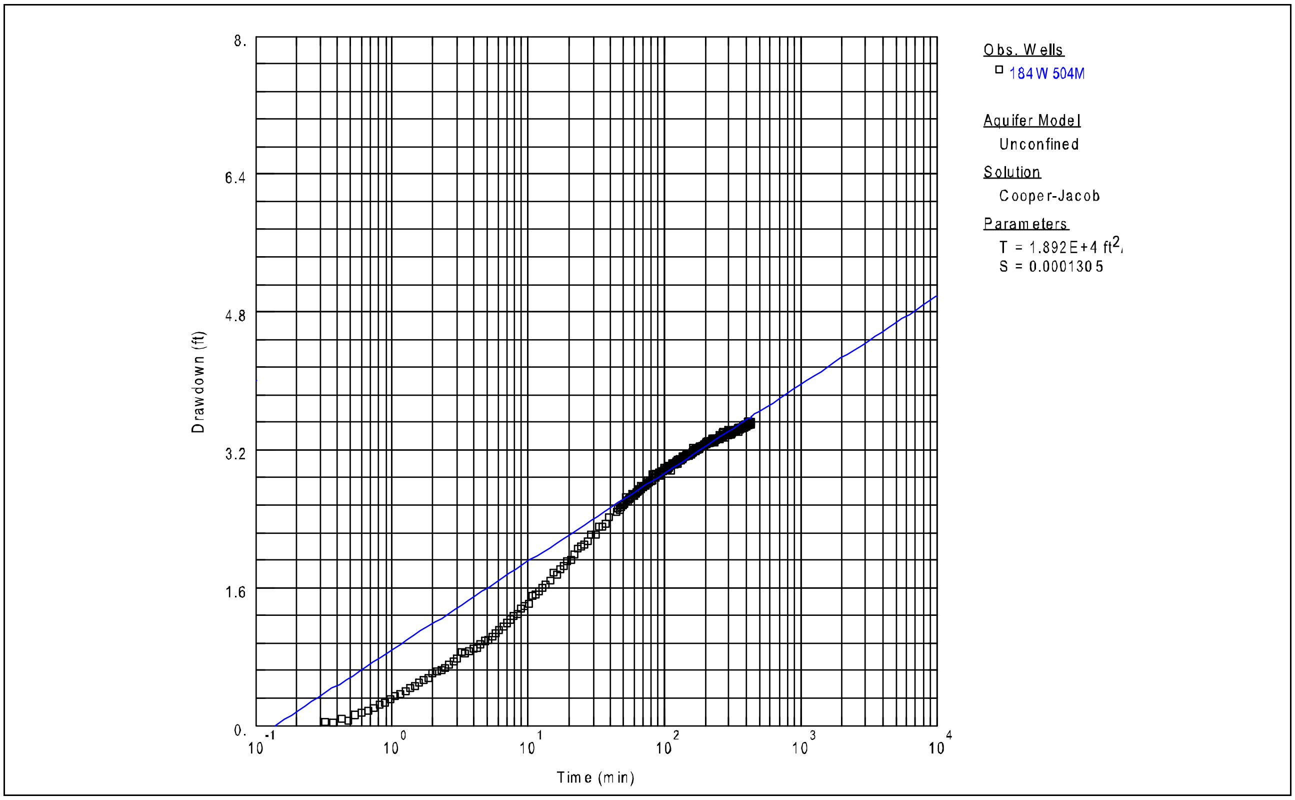

Figure 5-11
Cooper-Jacob Secondary Analysis of Monitor Well 184W504M

Monitor Well 184W504M's response provides information on the formation hydraulic properties independent of linear and nonlinear head losses associated with the pumping well and theoretically provides the information necessary to determine storage. However, the information from the single monitor well is not as definitive as multiple observation wells to evaluate and define asymmetry and horizontal anisotropy.

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

6.0 GROUNDWATER CHEMISTRY

Groundwater-chemistry data for Test Well 184W103 and Monitor Well 184W504M are presented within this section. Additional data for other SNWA wells and the South Fox Flowing Well located within the vicinity of these wells (see Figures 2-1 and 2-2) are also presented for comparison.

6.1 Groundwater Sample Collection and Analysis

Water samples were collected from Test Well 184W103 on March 26, 2007, at 08:30 after pumping approximately 3.7 million gal (following well development, step-drawdown testing, and the majority of the constant-rate test). For these samples, turbidity, pH, specific conductance, dissolved oxygen, and temperature were measured in the field. With the exception of dissolved oxygen, these parameters were also measured periodically during well development and testing. Sampling and field measurement of the water-quality parameters were performed using the *National Field Manual for the Collection of Water-Quality Data* (USGS, 2007) as the basis. All measurement equipment was calibrated according to the manufacturers' calibration procedures. Samples were sent to Weck Laboratories, Inc., (Weck) for analysis of a large suite of parameters including major solutes, minor and trace constituents, radiological parameters, and organic compounds. Weck is certified by the State of Nevada and performs all analyses according to U.S. Environmental Protection Agency (EPA) methods or methods published in *Standard Methods for the Examination of Water and Wastewater* (Eaton et al., 2005). The parameters analyzed and the corresponding analysis method are presented in Tables B-1 and B-2. Weck provided all sample containers and preservatives. Radiation Safety Engineering, Inc., and Frontier Analytical Laboratory were contracted by Weck for the analysis of radiological parameters and dioxin, respectively. In addition, samples were collected for analysis of oxygen and hydrogen isotopes by University of Waterloo's Environmental Isotope Laboratory, carbon isotopes by University of Arizona's NSF-Arizona Accelerator Mass Spectrometry Laboratory, chlorine-36 by Purdue University's Purdue Rare Isotope Measurement (PRIME) Laboratory and strontium and uranium isotopes (and uranium concentration) by the U.S. Geological Survey Earth Surface Processes Radiogenic Isotope Laboratory.

Water samples were collected from Monitor Well 184W504M on December 14, 2006, at 10:21 after pumping approximately 126,000 gal. Samples were sent to Weck for analysis of major solutes and trace and minor constituents. A sample was also collected for the analysis of oxygen and hydrogen isotopes by University of Waterloo's Environmental Isotope Laboratory (Table B-1). The pH, specific conductance, and temperature associated with these samples were measured in the field. Monitor Well 184W504M was used as the water source for drilling Test Well 184W103. The water source for drilling Monitor Well 184W504M was the small well at Harbecke Ranch.

For comparison, 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. As shown in Tables B-1 and B-2, no constituents exceeded the primary or secondary drinking water standards for groundwater of Test Well 184W103. Groundwater of Monitor Well 184W504M exceeds the secondary MCL for iron. This exceedance will be discussed further in Section 6.3.3.

6.3 Groundwater-Chemistry Results

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 184W103 and for the samples collected for laboratory analysis (see Table B-1). For Test Well 184W103 these parameters stabilized within the first hour of the constant-rate test. After removal of outliers, the measurements ranged from 0.36 to 2.0 NTU (turbidity), 7.6 to 8.0 (pH), 303 to 308 µS/cm (specific conductance), and 11.4°C to 13.9°C (temperature) over the remaining period of pumping (71 hours). Field measurements made at the time of sample collection are reported as 0.77 NTU, 263 µS/cm, 7.9, 12.0°C, and 6.34 mg/L for turbidity, specific conductance, pH, water temperature, and dissolved oxygen concentration, respectively.

During the initial 8-hour constant-rate pump test after completion of Monitor Well 184W504M, field measurements of turbidity, pH, specific conductance, and temperature ranged from 395 to 28.7 NTU (decreasing trend), 7.2 to 7.9, 330 to 358 µS/cm, and 11.2°C to 14.1°C, respectively. Field measurements made at the time of sample collection are reported as 35.6 NTU, 333 µS/cm, 7.5, and 12.1°C for turbidity, specific conductance, pH, and water temperature, respectively.

The temperatures of the groundwater of Test Well 184W103 (12.0°C) and Monitor Well 184W504M are quite similar to those measured for Test Well 184W105 (12.1°C), Monitor Well 184W506M

(12.7°C), and South Fox Flowing Well (12.0 to 16.5°C) but are significantly lower than measured for the deeper groundwater of Test Well 184W101 (24.1°C) and Monitor Well 184W502M (20.5°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 the test wells, 359 µS/cm (184W101), 263 µS/cm (184W103), and 282 µS/cm (184W105). The specific conductivity for South Fox Flowing Well ranged from 256 to 328 µS/cm; the greater specific conductivity corresponds to the greater temperature. The casing material used in the monitor and test wells are composed of mild steel and high strength low alloy material, respectively. The higher specific conductivities observed for the groundwaters from 184W101 and 184W502M are attributed to increased mineral dissolution in the warmer groundwaters. 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 184W103 and Monitor Well 184W504M are presented in Table B-1. Major constituents are defined as those commonly present in groundwater at concentrations greater than 1 mg/L and typically include bicarbonate (HCO_3), calcium (Ca), chloride (Cl), magnesium (Mg), potassium (K), silica (SiO_2), sodium (Na), and sulfate (SO_4). Other major constituents may include carbonate (CO_3), fluoride (F), and nitrate (NO_3). The sum of the charge of major cations should equal the sum of the charge of the major anions in solution (in milliequivalents per liter [mEq/L]); thus, calculation of the anion-cation (charge) balance is used to assess the accuracy of the analyses and to ensure that the full suite of anions and cations present as major constituents in the groundwater have been included in the analyses. The charge balance for Test Well 184W103 and Monitor Well 184W504M groundwater analyses, 0.13 and 2.0 percent, respectively, indicate that the analyses were performed adequately (Table B-1).

To illustrate the relative major-ion compositions in these groundwaters, a Piper diagram is presented in Figure 6-1. A Piper diagram consists of two triangular plots presenting the major cations (left triangle) and major anions (right triangle) in percent milliequivalents. The two triangular plots are then projected to a central diamond where the relative abundance of all major ions are presented. A Piper diagram is used to evaluate similarities in groundwater major-ion compositions, to identify the hydrochemical water type representing the aquifer(s) from which the groundwater was collected, and to assess possible evolutionary trends that have occurred along a flowpath. As shown in Figure 6-1, the relative concentrations of major ions are similar for all groundwaters. The groundwaters 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 the associated test well.

Stiff diagrams for these groundwater samples are presented in Figure 6-2. Major solutes are presented in a Stiff diagram so that their relative proportions are identified by its shape and the magnitude of the concentrations by its size. As apparent in the Stiff diagrams in Figure 6-2, groundwater samples from the four wells 184W105, 184W103, 184W506M, 184W504M, and South Fox Flowing Well are nearly identical, with a somewhat greater concentration of sodium in the monitor wells. The relative concentrations of calcium and magnesium are slightly greater in South

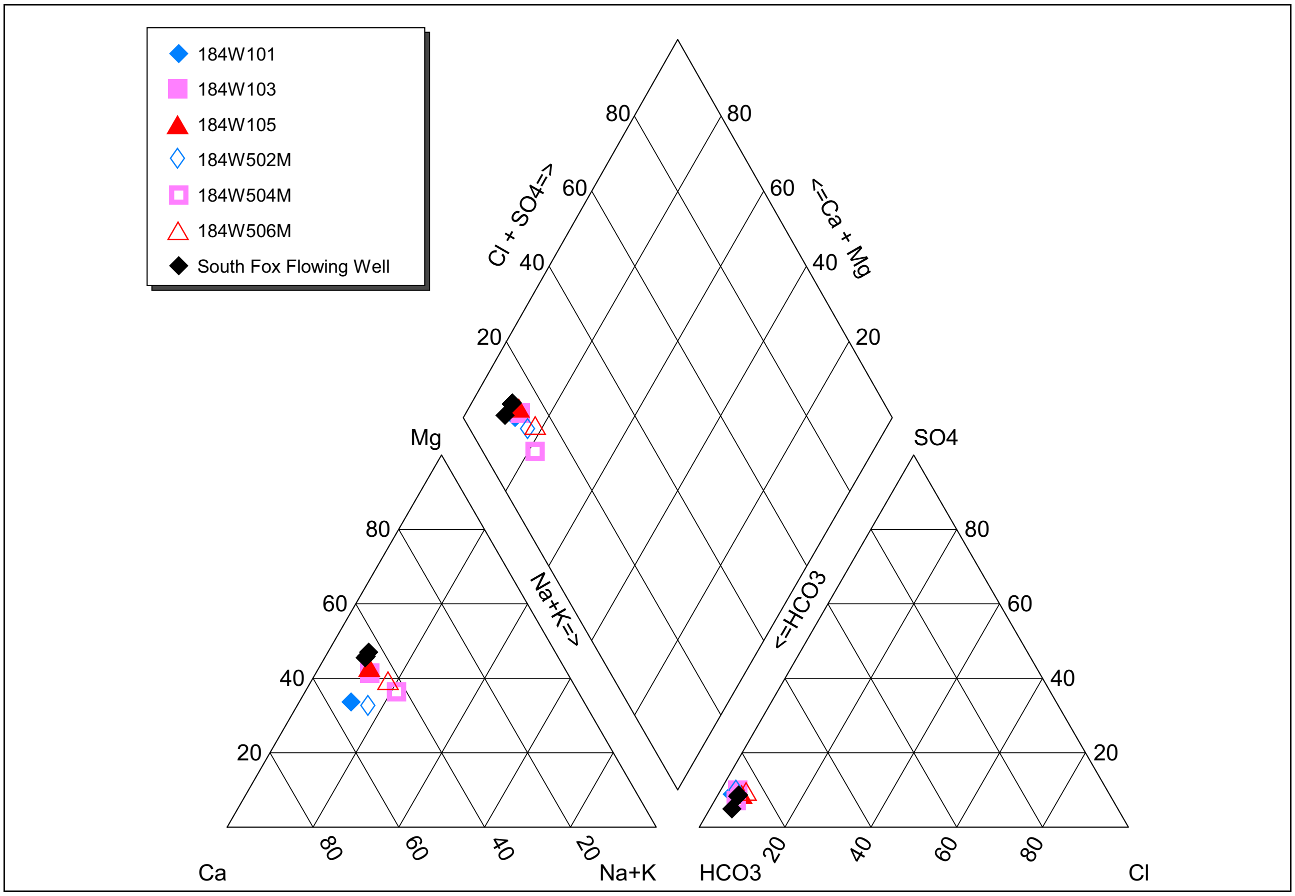

Figure 6-1
Piper Diagram Illustrating Relative Major-Ion Compositions

Fox Flowing Well. The concentrations of calcium and bicarbonate are greater in the groundwater samples from Test Well 184W101 and Monitor Well 184W502M. This may be attributed to increased dissolution of carbonate minerals in the deeper and warmer groundwaters of these wells.

6.3.3 Trace and Minor Constituents

The concentrations of trace elements in groundwater from Test Well 184W103 and Monitor Well 184W504M are presented in Table B-1. The dominant trace element present in groundwater from Test Well 184W103 is strontium, which is consistent with the relatively high concentration of strontium in carbonate rocks (i.e., limestone; Drever, 1988). Relatively high concentrations of aluminum, iron, manganese, and zinc were observed in the groundwater from Monitor Well 184W504M (Table B-1) when compared to concentrations in the groundwater of Test Well 184W103. In fact, the concentrations of these elements are consistently higher in the monitor wells than the test wells (Table 6-1). The elevated concentration of these elements in groundwater of the monitor wells is therefore thought to result from interaction with the mild steel casing used for the monitor wells and is not expected to reflect naturally occurring concentrations in the groundwater.

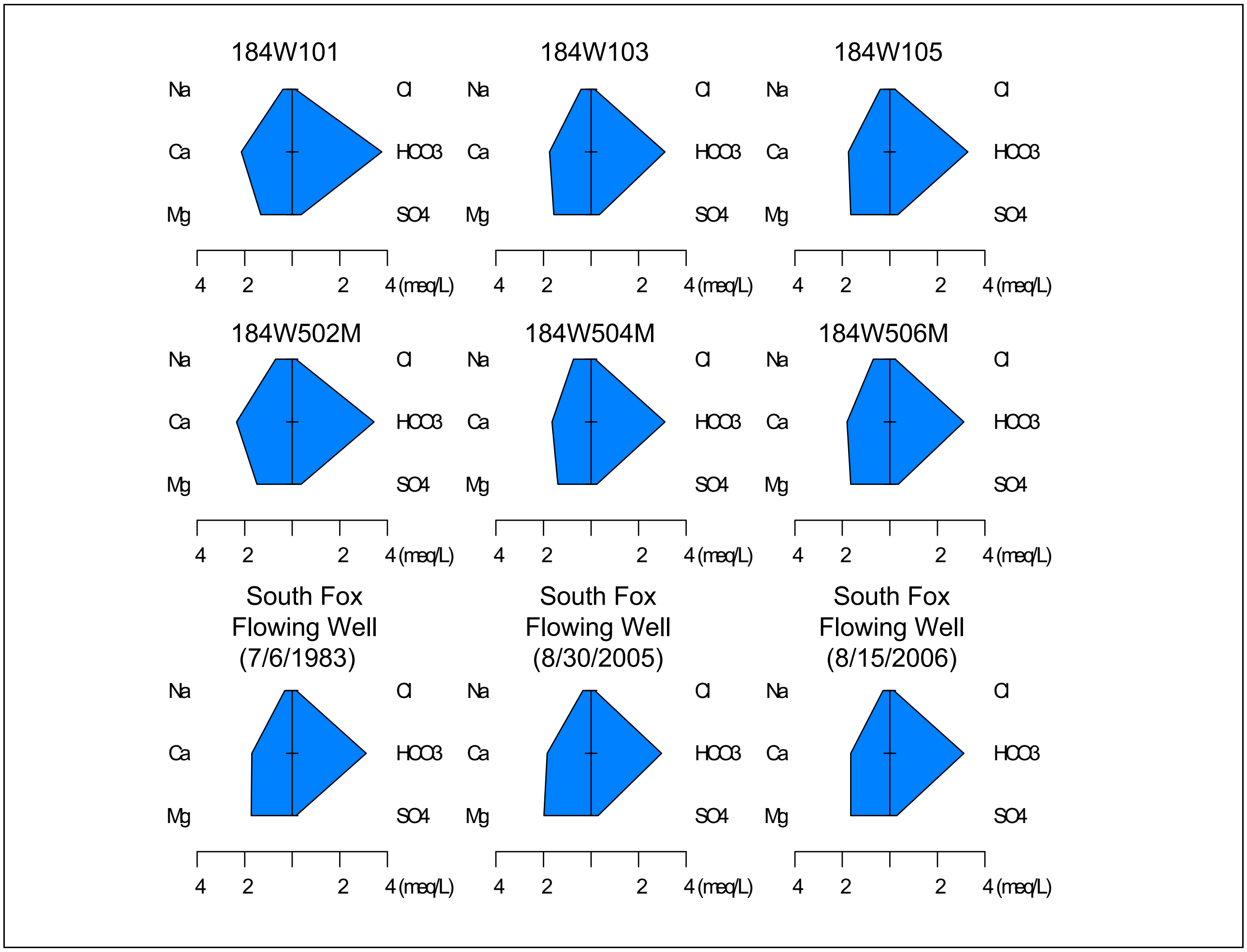

Figure 6-2
Stiff Diagrams Illustrating Major-Ion Concentrations

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/Environmental Tracers

The stable hydrogen, oxygen, and carbon isotopic compositions of the groundwater samples from Test Well 184W103 and stable hydrogen and oxygen isotopic compositions of the groundwater samples of Monitor Well 184W504M are presented in are presented in Table B-1. Table B-1 also presents chlorine-36, strontium-87/86, and uranium-234/238 data for groundwater samples collected from Test Well 184W105, completed in carbonate, for comparison.

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 184W103 and Monitor Well 184W504M 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, South Fox Flowing Well, and 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.

6.3.4.2 Carbon Isotopes

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

Relatively similar values of $\delta^{13}C$ and ^{14}C were measured in groundwaters of the test wells: 184W101 (–5.8‰, 4.9 pmc), 184W103 (–6.7‰, 10.4 pmc), and 184W105 (–5.8‰, 6.1 pmc); carbon isotopes were not measured for the monitor wells. The low ^{14}C and relatively heavy values of $\delta^{13}C$ suggest that the groundwaters have 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 when compared to the other test wells. This suggests a shorter

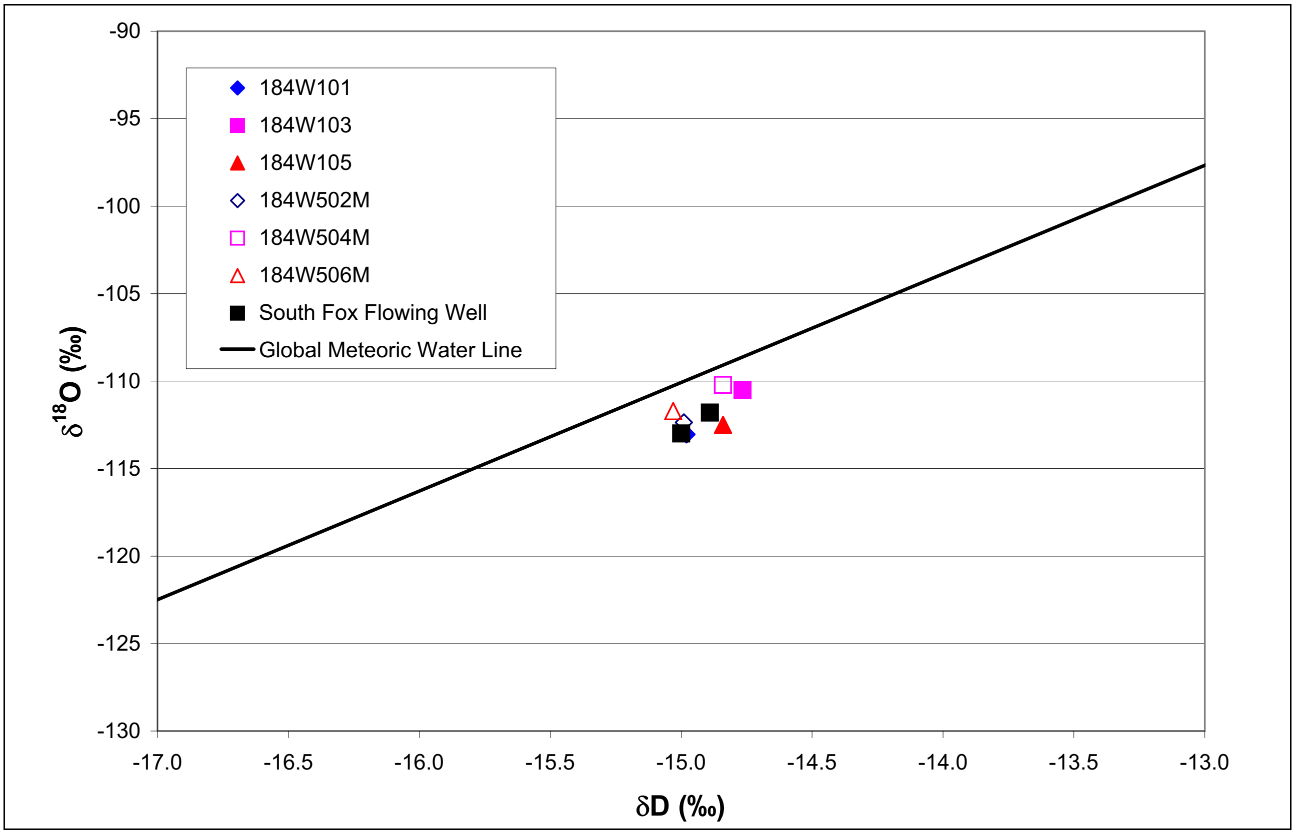

Figure 6-3
Plot of δD Versus $\delta^{18}O$

residence time for these groundwaters. 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 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. No $^{36}Cl/Cl$ data are available for South Fox Flowing Well.

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 $^{87}Sr/^{86}Sr$ for Test Well 184W105 (0.70928) is quite similar to that of 184W101 (0.71054), 184W103 (0.70902), South Fox Flowing Well (0.70890), and also to those expected from water–rock interaction with marine carbonates (0.707 to 0.709) (Peterman et al., 1970; Burke et al., 1982).

The ratio of uranium-234 activity to that of uranium-238 ($^{234}U/^{238}U$ Activity Ratio) has also been used to evaluate groundwater flow systems. As with other chemical constituents, the $^{234}U/^{238}U$ Activity Ratios are relatively similar for groundwater samples from 184W105 (2.08), 184W101 (2.97), 184W103 (3.75), and South Fox Flowing Well (3.00).

6.3.5 Radiological Parameters

Radiological parameters were analyzed in groundwater from Test Well 184W103, and the corresponding results are presented in Table B-1. The reported activity for each of these parameters is consistent with background concentrations in natural groundwaters.

6.3.6 Organic Compounds

No organic compounds were detected in the groundwaters of Test Well 184W103; analyses were not performed for Monitor Well 184W504M. The compounds analyzed, and the corresponding minimum detection limit and MCL (if applicable) are presented in Table B-2.

6.4 Summary

Groundwater samples were collected from Test Well 184W103 and Monitor Well 184W504M 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. Three samples from South Fox Flowing Well are also presented. 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 184W103 was consistent with precipitation in the southwestern United States, and the low ^{14}C and relatively heavy values of $\delta^{13}C$ suggest that the groundwater has interacted with isotopically heavy and ^{14}C-free carbonate minerals. The $^{87}Sr/^{86}Sr$ ratios were similar between the samples collected from the test wells and were typical of water-rock interaction with marine carbonates. The $^{234}U/^{238}U$ activity ratios were also relatively similar for the groundwater samples of the test wells. The samples from the monitor wells were not analyzed for $^{36}Cl/Cl$, $\delta^{13}C$, ^{14}C, $^{87}Sr/^{86}Sr$, or $^{234}U/^{238}U$ activity ratios.

The data were also evaluated with respect to the EPA Safe Drinking Water Act standards. For Test Well 184W103, no constituents exceeded the primary or secondary drinking water MCL. Groundwater from Monitor Well 184W504M exceeded the secondary MCL for iron. This exceedance is attributed to the well construction and is not considered to reflect the natural water.

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7.0 REFERENCES

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

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

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

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

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

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

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

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

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

Eastman, H.S., and Muller, D.C., 2009, Geologic data analysis report for Monitor Well 184W504M and Test Well 184W103 in Spring Valley: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. RDS-ED-0008, 49 p.

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

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

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

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

Hose, R.K., and Blake, M.C., 1976, Geology and mineral resources of White Pine County, Nevada—Part I, Geology: Nevada Bureau of Mines and Geology Bulletin 85, 35 p.

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

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

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

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

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

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

Phillips, F.M., 2000, Chlorine-36 *in* Cook, P.G., and Herczeg, A.L., eds., Environmental tracers in subsurface hydrology: Boston, Kluwer.

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

SNWA, see Southern Nevada Water Authority.

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

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

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

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

Southern Nevada Water Authority, 2010, 2009 Spring Valley hydrologic monitoring and mitigation plan status and data report: Southern Nevada Water Authority, Las Vegas, Nevada, Doc. No. WRD-ED-0007, 120 p.

U.S. Geological Survey, 2007, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations Book 9, Chapters A1-A9, [Internet], [accessed on July 14, 2010], available from http://www.mrlc.gov/.

USGS, see U.S. Geological Survey.

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

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Appendix A

CD-ROM Contents

A.1.0 INTRODUCTION

This appendix provides site photos and 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 the 184W103 wellhead equipment and instrumentation setup (Figure A-1), Monitor Well 184W504M (Figure A-2), development and hydraulic testing discharge line as it passes through a new culvert under Atlanta Road (Figure A-3), and energy dissipation at the discharge point (Figure A-4). The report cover shows the discharge line from the well site.

A.1.2 Read-Me File

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

A.1.3 Background Water-Level Data

A spreadsheet is presented containing the continuous water-level data from well 184W502M which was used to monitor regional background conditions during development and testing at Test Well 184W103.

A.1.4 Barometric-Pressure Data

Barometric-pressure data are presented in the continuous record data files associated with Test Well 184W103. An In-Situ HERMIT 3000 data logger recorded barometric pressure at the site during development and hydraulic testing of 184W103.

A.1.5 Step-Drawdown Test Data

A summary spreadsheet for the step-drawdown test, which complies all of the continuous and manual data is presented.

A.1.6 Constant-Rate Test Data

The continuous and manual data from the constant rate test and subsequent recovery for 184W103 and 184W504M are presented.

A.1.7 AQTESOLV

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

Figure A-1
Wellhead Configuration

Figure A-2
Monitor Well 184W504M

Figure A-3
Discharge Line through Culvert on Atlanta Road

Figure A-4
Energy Dissipation at Discharge Point

Appendix B

Groundwater-Chemistry Data

Table B-1
Field and Analytical Results, Analytical Methods, Reporting Limits, and Maximum Contaminant Levels for Inorganic, Stable Isotopic, and Radiological Constituents in Groundwater Samples from Test Well 184W103 and Monitor Well 184W504M
(Page 1 of 3)

Constituent Name	Unit	Analysis Method	RL	184W103 3/26/2007 08:30	184W504M 12/14/2006 10:21	Primary MCL	Secondary MCL
Field Measured							
pH	standard unit	Field	---	7.9	7.46	---	6.5 to 8.5
Specific Conductance	µS/cm	Field	---	263	333	---	---
Dissolved Oxygen	mg/L	Field	---	6.34	---	---	---
Temperature	°C	Field	---	12.0	12.1	---	---
Turbidity	NTU	Field	---	0.77	35.6	---	---
Stable Isotopes/Environmental Tracers							
Carbon-14 (^{14}C)	pmc	NA	---	10.37	---	---	---
Carbon-13/12 ($\delta^{13}C$)	per mil (‰)	NA	---	-6.7	---	---	---
Chlorine-36/Chloride ($^{36}Cl/Cl$)	ratio	NA	---	5.451×10^{-13}	---	---	---
Hydrogen-2/1 (δD)	per mil (‰)	NA	---	-110.4/-110.7	-110.0/-110.4	---	---
Oxygen-18/16 ($\delta^{18}O$)	per mil (‰)	NA	---	-14.76/-14.77	-14.84	---	---
Strontium-87/86	ratio	NA	---	0.70902	---	---	---
Uranium-234/238	Activity Ratio	NA	---	3.7492/ 3.7482	---	---	---
Major Solutes							
Alkalinity Bicarbonate	mg/L as HCO_3	SM 2320B	2	190	190	---	---
Alkalinity Carbonate	mg/L as $CaCO_3$	SM 2320B	2	ND	ND	---	---
Alkalinity Hydroxide	mg/L as $CaCO_3$	SM 2320B	2	ND	ND	---	---
Alkalinity Total	mg/L as $CaCO_3$	SM 2320B	2	160	160	---	---
Calcium	mg/L	EPA 200.7	0.1	35	33	---	---
Chloride	mg/L	EPA 300.0	0.5	5.2	6.0	---	250
Fluoride	mg/L	EPA 300.0	0.1	0.18	0.23	4	2
Magnesium	mg/L	EPA 200.7	0.1	19	17	---	---
Nitrate	mg/L as N	EPA 353.2	0.1	0.99	1.0[a]	10	---
Potassium	mg/L	EPA 200.7	1	2.4	2.8	---	---
Silica	mg/L	EPA 200.7	0.1	27	27	---	---
Sodium	mg/L	EPA 200.7	1	9.6	17	---	---
Sulfate	mg/L	EPA 300.0	0.5	17	12	---	250
Cation/Anion Balance	%	Calculation	---	0.13	2.0	---	---

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 184W103 and Monitor Well 184W504M
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Constituent Name	Unit	Analysis Method	RL	184W103 3/26/2007 08:30	184W504M 12/14/2006 10:21	Primary MCL	Secondary MCL
Trace and Minor Constituents							
Aluminum, total	µg/L	EPA 200.8	5	ND	130	---	50 to 200
Antimony, total	µg/L	EPA 200.8	0.5	ND	ND	6	---
Arsenic, total	µg/L	EPA 200.8	0.4	2.8	2.8	10	---
Arsenic (III)	µg/L	EPA 200.8	1	3.3	---	---	---
Arsenic (V)	µg/L	EPA 200.8	1	ND	---	---	---
Barium, total	µg/L	EPA 200.8	0.5	52	38	2,000	---
Beryllium, total	µg/L	EPA 200.8	0.1	ND	ND	4	---
Boron, total	µg/L	EPA 200.7	10	37	63	---	---
Bromide	µg/L	EPA 300.1	33/10	51	47	---	---
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	1.2	1.4	100	---
Chromium (VI)	µg/L	EPA 218.6	0.3	1.2[a]	---	---	---
Chromium (III)	µg/L	Calculation	0.2	ND	---	---	---
Copper, total	µg/L	EPA 200.8	0.5	ND	ND	1,300[b]	1,000
Iron, total	µg/L	EPA 200.7	20	ND	500	---	300
Lead, total	µg/L	EPA 200.8	0.2	0.31	0.28	15[b]	---
Lithium, total	µg/L	EPA 200.7	10	ND	16	---	---
Manganese, total	µg/L	EPA 200.8	0.2	1.8	24	---	50
Mercury, total	µg/L	EPA 245.1	0.1	ND	ND	2.0	---
Molybdenum, total	µg/L	EPA 200.8	0.1	0.91	1.4	---	---
Nickel, total	µg/L	EPA 200.8	0.8	ND	ND	---	---
Nitrite	mg/L as N	EPA 353.2	0.1	ND	---	1	---
Orthophosphate	µg/L as P	EPA 365.1	2	4.4	---	---	---
Phosphorus, total	µg/L as P	EPA 365.1	10	ND	---	---	---
Selenium, total	µg/L	EPA 200.8	0.4	0.84	0.69	50	---
Silver, total	µg/L	EPA 200.8	0.2	ND	ND	---	100
Strontium, total	µg/L	EPA 200.7	5	280	180	---	---

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 184W103 and Monitor Well 184W504M
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Constituent Name	Unit	Analysis Method	RL	184W103 3/26/2007 08:30	184W504M 12/14/2006 10:21	Primary MCL	Secondary MCL
Trace and Minor Constituents (Continued)							
Thallium, total	µg/L	EPA 200.8	0.2	ND	ND	2	---
Uranium, total	µg/L	NA	---	1.70/1.72	---	30	---
Vanadium, total	µg/L	EPA 200.8	0.5	4.9	3.0	---	---
Zinc, total	µg/L	EPA 200.8	5	5.5	55	---	5,000
Miscellaneous Parameters							
Cyanide	mg/L	SM 4500CN E	0.01	ND	---	0.2	---
Hardness	mg/L as $CaCO_3$	EPA 200.7	1	170	---	---	---
Langelier Index	@ 60°C	SM 2330B	-10	0.777	---	---	---
Langelier Index	@ Source Temp.	SM 2330B	-10	0.134	---	---	---
MBAS	mg/L	SM 5540 C	0.05	ND	---	---	---
pH, Lab	standard unit	SM 4500	---	---	8.3[a]	---	
Specific Conductance, Lab	µS/cm	SM 2510B	2	---	340[a]	---	
Total Dissolved Solids	mg/L	SM 2540C	10	190	200	---	500
Total Organic Carbon	mg/L	SM 5310C	0.3	ND	0.92	---	---
Total Suspended Solids	mg/L	EPA 160.2	5	ND	ND	---	---
Radiochemical Parameters							
Gross Alpha	pCi/L	EPA 900.0	1.1	4.1±0.92	---	15	---
Gross Beta	pCi/L	EPA 900.0	0.75	2.2±0.50	---	4 mrem/yr	---
Radium, total gross	pCi/L	EPA 903.1	---	0.400±0.100	---	5	---
Radium-226	pCi/L	EPA 903.1	---	0.400±0.100	---	---	---
Radium-228	pCi/L	EPA 904	0.3	ND	---	---	---
Radon	pCi/L	SM 7500	---	515±53.0	---	---	---
Strontium-90	pCi/L	EPA 905.0	0.6	ND	---	---	---
Tritium	TU	NA	0.8	ND	---	---	---
Tritium	pCi/L	EPA 906.0	519	ND	---	---	---
Uranium	pCi/L	EPA 200.8	0.13	1.1	---	30 µg/L	---

[a]Holding time was exceeded
[b]Reported value is the action limit
MBAS = Methylene blue active substance
mrem/yr = Millirem per year
NA = Not available
ND = Not detected
RL = Reporting limit
SM = Standard method (Eaton et al., 2005)
TU = Tritium Unit

Table B-2
Organic Compounds Analyzed in Groundwater Samples from Test Well 184W103 Including the EPA Method, Reporting Limit, and Maximum Contaminant Level
(Page 1 of 2)

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

Table B-2
Organic Compounds Analyzed in Groundwater Samples from Test Well 184W103 Including the EPA Method, Reporting Limit, and Maximum Contaminant Level
(Page 2 of 2)

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

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.