United States Department of the Interior

U. S. GEOLOGICAL SURVEY

2730 N. Deer Run Rd.
Carson City, NV 89701
Phone: 775-887-7614

January 18, 2010

MEMORANDUM

To: Devin Galloway, Ground-Water Specialist, Western Region, USGS

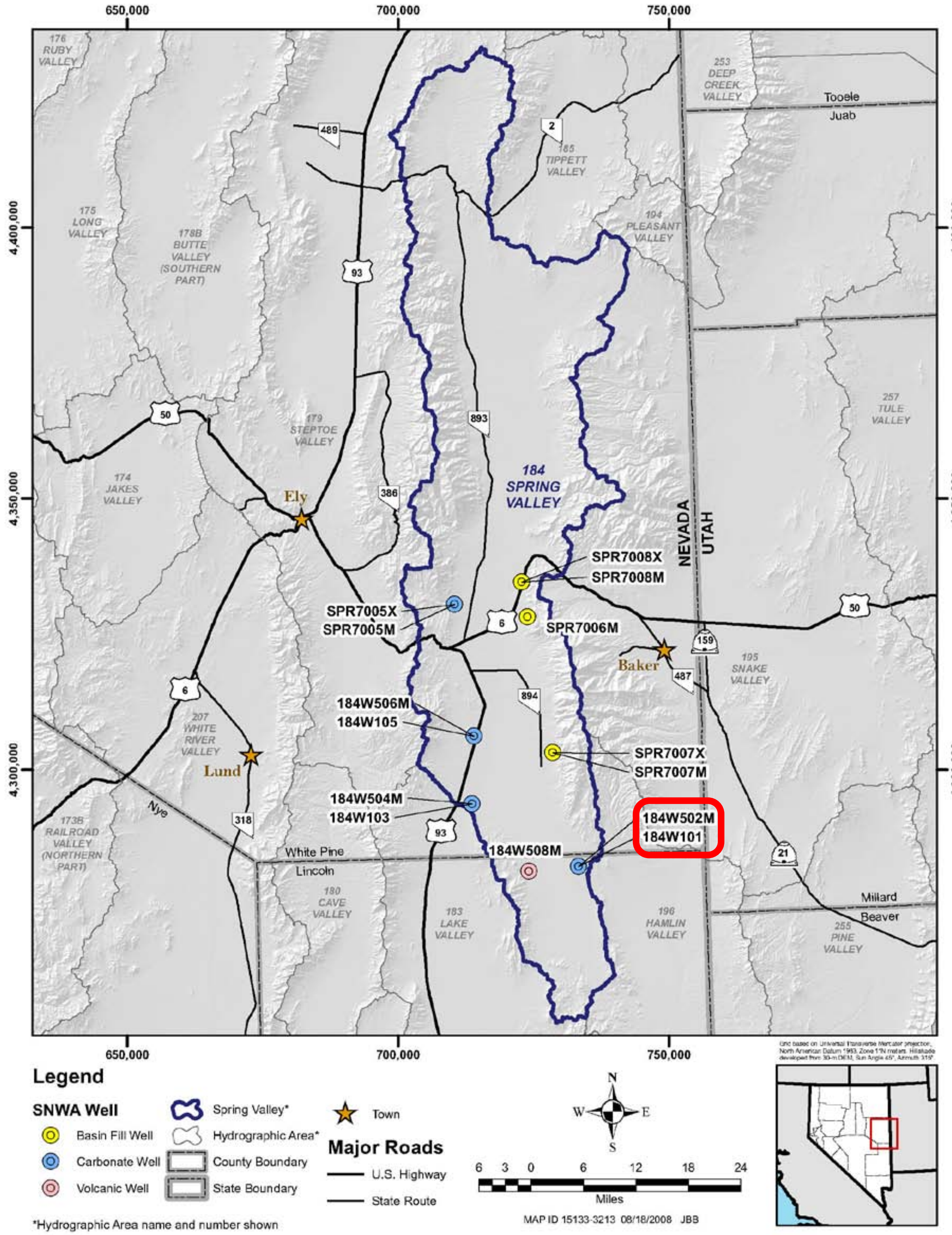
From: Weiquan Dong, Hydrologist, Southern Nevada Water Authority and Keith J. Halford, Ground-Water Specialist, Nevada WSC, U.S. Geological Survey

Subject: AQUIFER TEST—Analysis of multiple-well aquifer test of carbonate-rock aquifer, southeastern Spring Valley, HA184, near Great Basin National Park, NV

A multiple-well aquifer test was conducted by Southern Nevada Water Authority (SNWA) in southeastern Spring Valley, HA184, near Great Basin National Park to estimate the hydraulic properties of the carbonate-rock aquifer (184W101; Figure 1). Well 184W101 was pumped for 72 hours at 2,520 gpm between April 9 and 12, 2007. Results from the well 184W101 aquifer test were reinterpreted to investigate the effects of induced flow in the observation well on hydraulic property estimates. These estimates will constrain calibration of regional ground-water flow models that encompass Spring Valley.

Site and Geology

The aquifer test occurred in southeastern Spring Valley where groundwater development has been proposed (Figure 1). Fractured limestone was encountered primarily from land surface to more than 1,800 ft below land surface (Prieur and others, 2009). A few stringers of clay exist that were less than 20 ft thick. More than 1,300 ft of saturated carbonate-rock aquifer were observed because the unpumped depth to water was about 480 ft. The carbonate-rock was interpreted as a homogeneous, vertically anisotropic aquifer with a saturated thickness of 2,000 ft. A finite thickness was assigned to the carbonate-rock for interpretation because the actual thickness is unknown (Welch and others, 2007).



(Modified from Prieur and others, 2009)

Figure 1.—Location of wells 184W101 and 184W502M in Spring Valley, Nevada.

Observation well 184W502M was 175 ft north of the pumping well, 184W101 (Table 1, Figure 1) and was completed with 8.625 in. diameter screens between 481 and 1,780 ft below land surface (Figure 2). The screen was in a 14.75 in. diameter open hole that extended from the water table to 1,820 ft below land surface with no fill in the annular space.

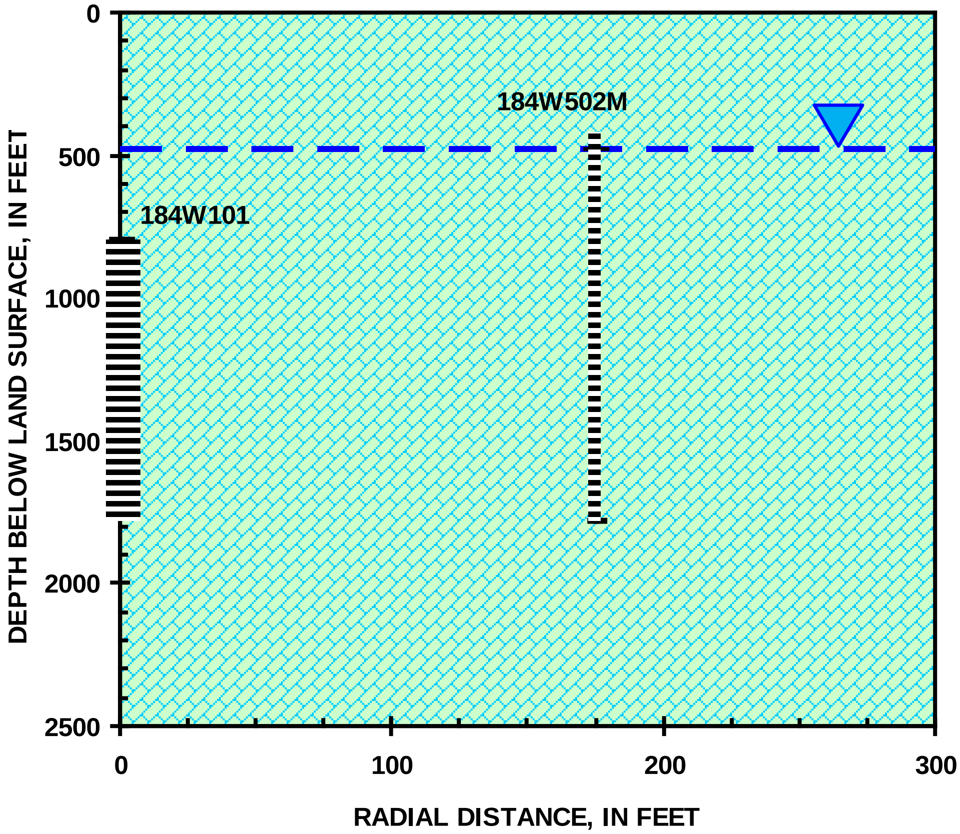


Figure 2.—Radial cross-section about pumping well 184W101.

Table 1.—Well location and construction data for pumping and observation wells.

[Latitude and longitude are in degrees, minutes, and seconds and referenced to North American Datum of 1983; ft amsl, feet above North American Vertical Datum of 1988 (NAVD 88); ft bgs, feet below ground surface.]

Map Identifier	SITE IDENTIFIER	Latitude	Longitude	Ground surface elevation, ft amsl	Drillers log	Total Depth, ft bgs	Depth to Water, ft bgs
184W502M	383925114190801	38°39'25''	114°19'08''	6,200	102843	1820	480.6
184W101	383933114190501	38°39'33''	114°19'05''	6,214	102847	1760	484.6

Water Levels, Drawdowns, and Temperatures

Water levels were measured more than 4,300 times in each well during the three-day aquifer test (Prieur and others, 2009). Water levels in wells 184W101 and 184W502M were 486 and 480 feet below land surface, respectively, prior to pumping.

Drawdowns were estimated by subtracting static water levels from water levels after pumping began April 9, 2007 at 0900. The number of drawdown observations was reduced to less than 30 in each well by averaging in sub-periods (Figure 3). Sub-periods were of variable duration so observations were near equally spaced on a logarithmic time scale.

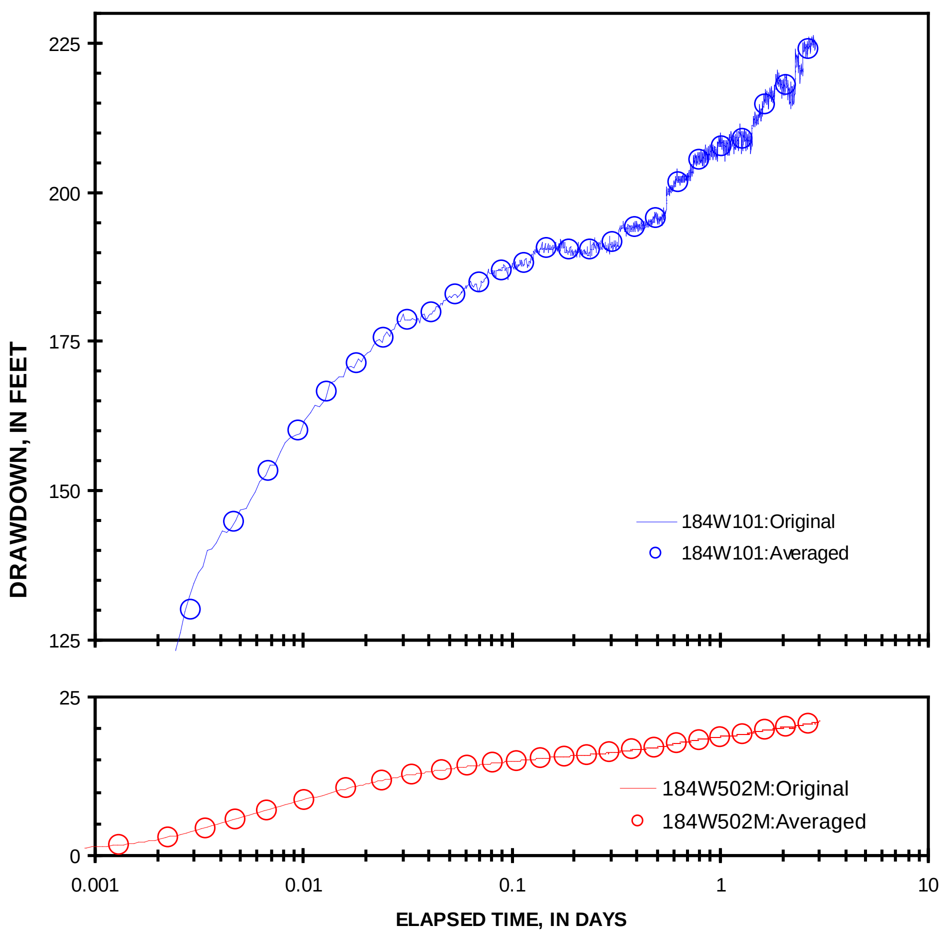


Figure 3.—Original and averaged drawdown estimates in wells 184W101 and 184W502M.

Water temperature at the top of observation well 184W502M decreased more than 2 degrees Celsius,°C, during the 3-dayaquifer test (Figure 4a), which indicated flow occurred in the observation well. This was possible because the long screen and open borehole allowed drainage from the water table to migrate directly through observation well 184W502M. Flow through an observation well is assumed to be minimal in most analytical solutions so the potential effect on hydraulic property estimates warranted further investigation.

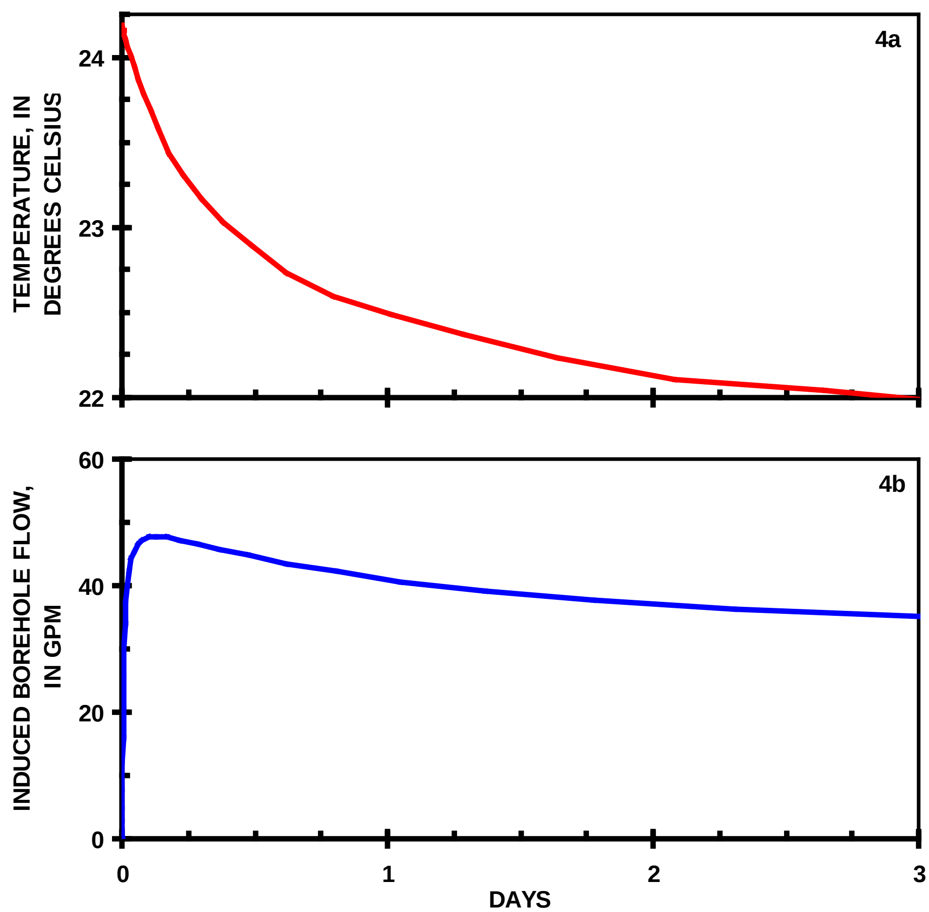


Figure 4.—Measured temperature at top of well 184W502M and simulated flow through well 184W502M while pumping well 184W101 at 2,520 gpm.

Analysis

The carbonate-rock aquifer was conceptualized as a homogeneous, vertically anisotropic, thick unconfined aquifer which was characterized with a transmissivity, vertical-to-horizontal anisotropy, specific yield, and specific storage. These hydraulic properties were estimated with the Moench, analytical solution (Barlow and Moench, 1999) and a numerical model. The numerical model primarily differed from the analytical solution by simulating well 184W502M as a high hydraulic conductivity interval, which allowed flow to be simulated in the observation well.

Two sets of hydraulic properties were estimated to investigate the effect of flow through an observation well. Hydraulic properties of the carbonate-rock aquifer were estimated by minimizing differences between simulated and measured drawdowns. Drawdowns were simulated with both the analytical solution and a three-dimensional, MODFLOW model (Harbaugh and McDonald, 1996). Parameter estimation was performed by minimizing a weighted sum-of-squares objective function where the Moench solution was minimized with the Solver in Excel and the numerical model was minimized with MODOPTIM (Halford, 2006).

Hydraulic property estimates from the Moench analytical solution were reasonable for a carbonate-rock aquifer (Table 2). Hydraulic conductivity is 5 ft/d if a 9,800-ft^2/d transmissivity is divided by a 2,000-ft aquifer thickness. Specific-storage of 1.2×10^{-6} ft^{-1} and specific yield of 0.024 generally agree with other estimates for carbonate rocks. A vertical-to-horizontal anisotropy of 1.2 exceeds an expected ratio of less than 1 but bedding is absent.

Table 2.—Hydraulic properties estimated with the numerical model.

[Saturated aquifer thickness of 2000 was assumed.]

MATERIAL	Hydraulic property: Moench	Hydraulic property: MODOPTIM
Transmissivity, ft^2/d	9,800	11,000
Hydraulic conductivity, ft/d	4.9	5.3
Specific yield, d'less	0.024	0.020
Vertical-to-horizontal anisotropy, d'less	1.2	1.0
Specific Storage, 1/ft	1.2E-06	4.7E-07

Numerical model: MODFLOW

Results from the aquifer test also were analyzed with a numerical model to test the effect of flow in the observation well on hydraulic property estimates. Only half of the area was simulated because drawdowns and flow were assumed to be symmetrical about a line that passes through wells 184W101 and 184W502M. Model discretization conformed to the diameters of the observation and pumping wells. Each well was simulated as a zone of virtually infinite hydraulic conductivity, 500 million ft/d. Hydraulic conductivity was assumed to be homogeneous and vertically anisotropic in the undisturbed aquifer as in the analytical model.

The model domain was discretized into 29 layers of 158 rows and 57 columns (Figure 5). The numerical model extended laterally 200,000 ft away from the pumping well 184W101. The vertical extent was from 479 to 2,479 ft below land surface, which conformed to the assumed saturated thickness of 2,000 ft. Column 1 intersected both wells with a width of 0.83 ft which is the radius of well 184W101. Column 2 was 0.2 ft wide and each successive column was 1.25 times wider to the furthest column. Rows 58 and 102 were 1.23 and 1.67 ft wide, respectively, which are the diameters of wells 184W101 and 184W502M. Rows adjacent to the wells were 0.2 ft wide and successive rows are 1.25 times wider away from the wells. The maximum row width between the wells is 18 ft. Layer thicknesses ranged from 1 ft at the water table to 360 ft at the base of the aquifer and were less than 10 ft thick near tops and bottoms of the open intervals in both wells 184W101 and 184W502M (Figure 5). All external boundaries were no-flow. Changes in the wetted thickness of the aquifer were not simulated because the maximum drawdown near the water table was small relative to the total thickness. The aquifer test was simulated with a 3-day stress period.

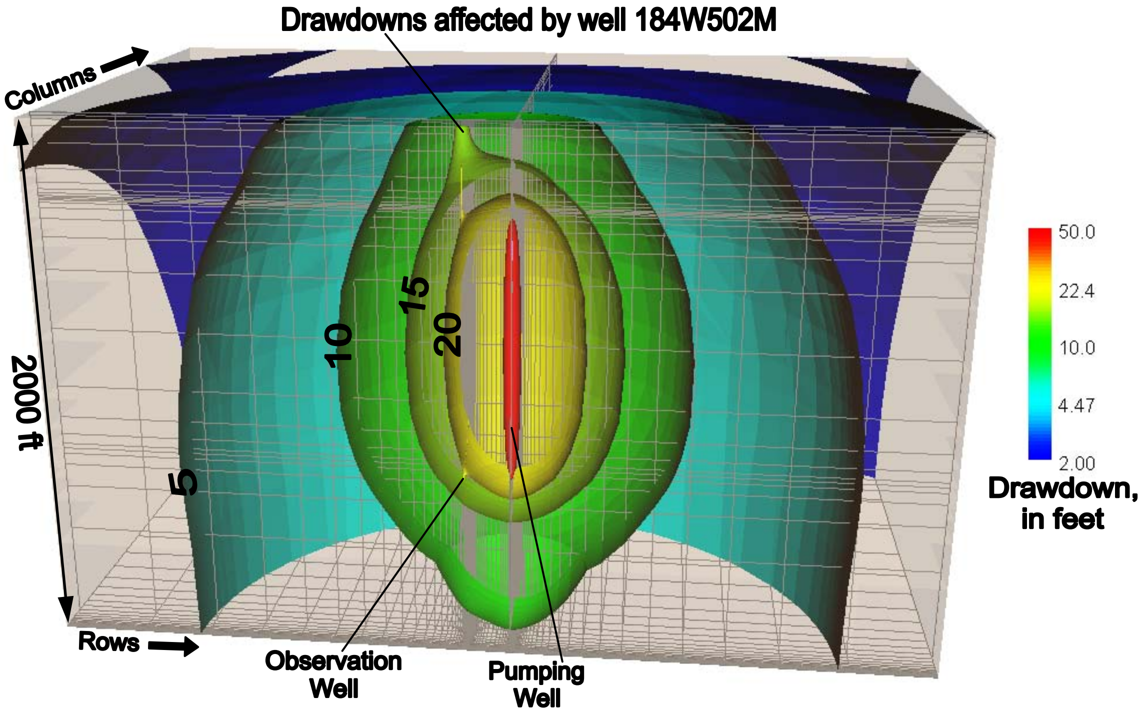


Figure 5.—Discretization of the numerical model and simulated drawdown surface after 3 days of pumping well 184W101 at 2,520 gpm.

Simulated and measured drawdowns matched within 0.5 ft in observation well 184W502M (Figure 6). The root-mean-square error of 0.5 ft was less than 3 percent of the 21-ft drawdown range analyzed. Simulated point observations were sampled 175 ft south of the pumping well where the simulated aquifer was undisturbed at depths of 0, 320, and 1,300 ft below land surface. Simulated drawdowns are noticeably different than point observations where flow is not simulated in the observation well (Figure 6). None of these time series duplicated the simulated drawdown in observation well 184W502M, but the deepest time series was most similar.

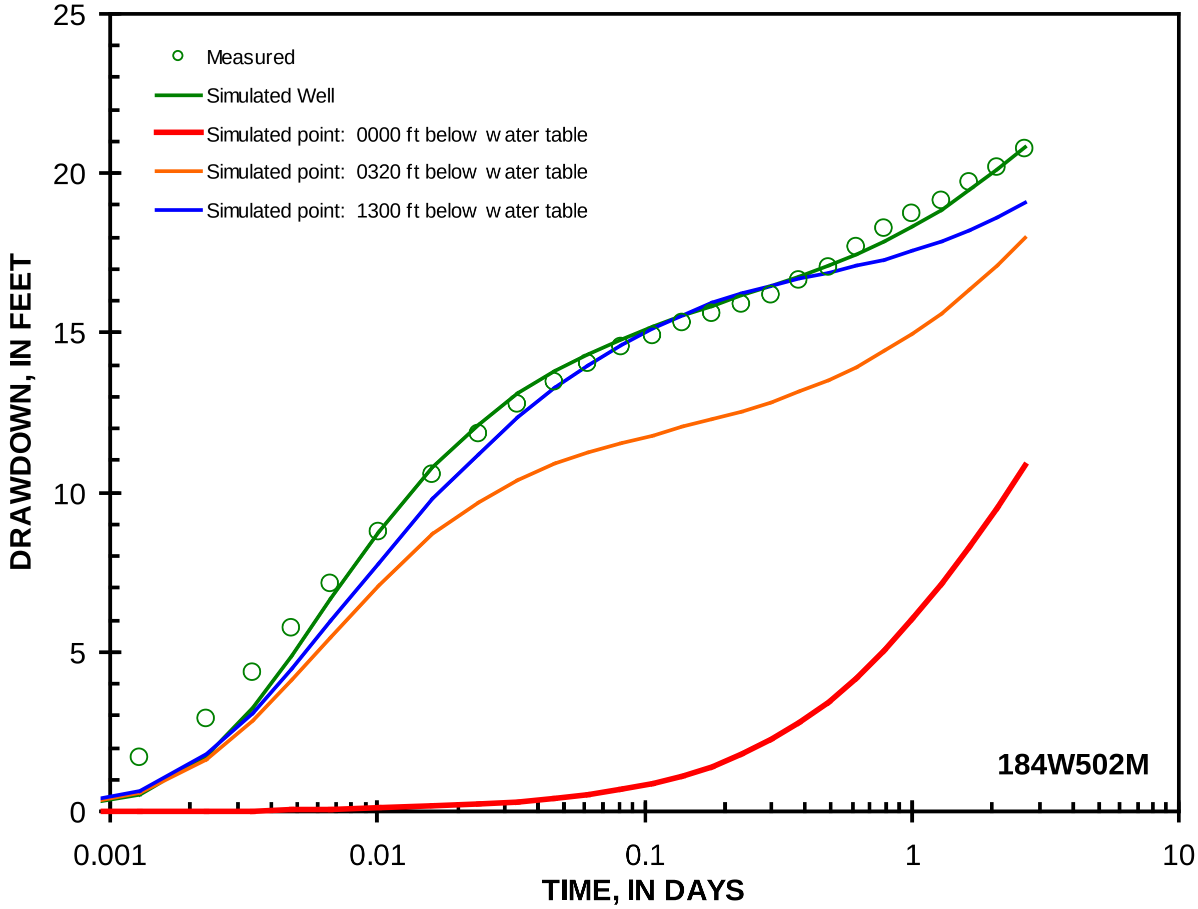


Figure 6.—Measured and simulated drawdowns in observation well 184W502M and simulated drawdowns at points 0, 320, and 1,300 ft below the water table during 3-day aquifer test.

Simulated and measured drawdowns matched within 13 ft in the pumping well 184W101 which is within 6 percent of the 220-ft drawdown range (Figure 7). Simulated and measured drawdowns departed more after the first day of pumping. This likely was caused by increased losses in the pumping well. A nearby impermeable boundary might similarly affect drawdowns. This is unlikely because drawdowns in the observation well also would be affected by a nearby boundary.

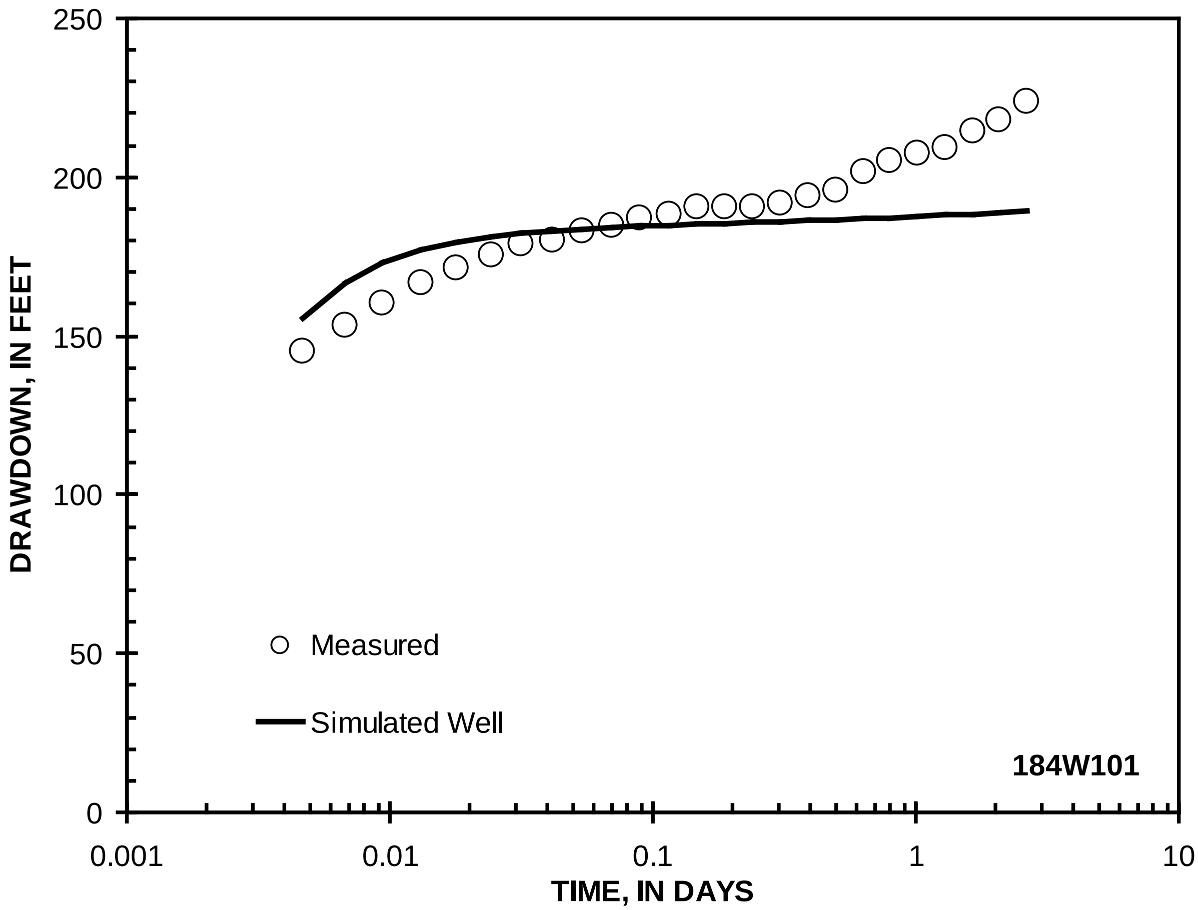


Figure 7.—Measured and simulated drawdowns in pumping well 184W101 during 3-day aquifer test.

Drawdown surfaces were predominantly ellipsoidal shells near pumping well 184W101 that were perturbed by flow through observation well 184W502M (Figure 5). Greater drawdowns occurred near the water table as flow entered the observation well. Some flow also was induced at the bottom of observation well 184W502M. The maximum flow rate through observation well 184W502M was 50 gpm and flow rates averaged 40 gpm during the 3-day aquifer test (Figure 4b). Flow became mostly radial more than 2,000 ft from well pumping well 184W101.

Hydraulic Property Estimates

Hydraulic property estimates for the alluvial aquifer from the analytical and numerical models differed little (Table 2). Hydraulic conductivity is 5.5 ft/d if an 11,000-ft^2/d transmissivity is divided by a 2,000-ft aquifer thickness. Specific-storage was about

0.5×10^{-6} ft^{-1} and was 40 percent of the analytical estimate. This was the greatest difference between hydraulic property estimates, which was insignificant. A specific yield estimate of 0.02 from the numerical model agrees with the analytical estimate of 0.024. A vertical-to-horizontal anisotropy of 1.0 from the numerical model is not appreciably different than an estimate of 1.2 from the analytical solution. Borehole flow in the observation well did not significantly affect hydraulic property estimates from the analytical solution despite violating the assumption of no borehole flow.

The transmissivity of the carbonate-rock aquifer around well 184W101 was 10,000 ft^2/d after rounding to 1 significant figure. Vertical-to-horizontal anisotropy of 1 was estimated which is reasonable given the lack of bedding in the carbonate. A specific yield of 0.02 agrees with other aquifer test results and effective porosity estimates in carbonate rocks.

References

Barlow, P.M., and Moench, A.F., 1999, WTAQ—A computer program for calculating drawdowns and estimating hydraulic properties for confined and water-table aquifers, U.S. Geological Survey Water-Resources Investigations Report 99-4225, 84 p.

Halford, K.J., 2006, MODOPTIM: a general optimization program for ground-water flow model calibration and groundwater management with MODFLOW, U.S. Geological Survey Scientific Investigation Report 2006-5009.

Harbaugh, A.W., and McDonald, M.G., 1996, Programmer's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite difference ground-water flow model: U.S. Geological Survey Open-File Report 96-486, 220 p.

Prieur, J.P., Farnham, I.M., and Fryer, W., 2009, Hydrologic Data Analysis Report for Test Well 184W101 in Spring Valley Hydrographic Area 184, Southern Nevada Water Authority, Las Vegas, NV, Doc No. DAR-ED-0002.

Rush, F.E., 1976, Water Requirement and Efficiency of Sprinkler Irrigation of Alfalfa, Smith Valley, Nevada—A Case History: Nevada Division of Water Resources, Information Report 24, 14 p.

Welch, A.H., Bright, D.J., and Knochenmus, L.A., 2007, 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 Scientific Investigations Report 2007-5261, 96 p.

Wellborn, T.L., and Moreo, M.T., 2007, Irrigated acreage within the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Data Series 273, 18 p.

PRINT OR TYPE ONLY

STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT

Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 102847
Permit No.
Basin 184

NOTICE OF INTENT NO. 58836

1. OWNER SNWA 184W101
MAILING ADDRESS 1900 E. Flamingo Road Suite 107 Las Vegas, NV. 89119
NE

ADDRESS AT WELL LOCATION 50 miles southeast of Ely, NV.
Subdivision Name: N/A   County: Lincoln

2. LOCATION SE¼NW¼ Sec11 T9N/ R68E

PERMIT/WAIVER NO. N/A (Issued by Water Resources)   N/A (Parcel. No.)

Latitude 38° 39'33.2"N   Longitude 114° 19' 4.6"W
UTM E ____ N ____   ☒ NAD 27   ☐ NAD 83/WGS 84

3. WORK PERFORMED
☒ New Well ☐ Replace ☐ Recondition ☐ Deepen ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☒ Test ☐ Municipal/Industrial ☐ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC ☐ Air ☒ Other Flooded Reverse

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Limestone		0	400'	400'
Limestone with clay		400'	490'	90'
Limestone		490'	590'	100'
Limestone with clay		590'	740'	150'
Limestone		740'	1200'	460'
Limestone with clay		1200'	1460'	260'
Fractured limestone		1460'	1760'	300'

N 38.659222
W 114.317944 NAD27

[redacted]

Date started: 01/26, 20 07
Date completed: 02/27, 20 07

7. *Water Level*
Static water level: 490 feet below land surface
Artesian Flow: ____ G.P.M. ____ P.S.I
Water Temperature: ____ °F
Quality: Good

8. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☒ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
460		1

9. *WELL CONSTRUCTION*

Depth Drilled 1760 Feet   Depth Cased 1749 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
46 Inches	0 Feet	55 Feet
26 Inches	55 Feet	1760 Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
40	210.93	0.500	0	55
20	48.60	0.375	+2	777
20	67.68	0.222	777	1749

Perforations:
Type of perforation Louvered
Size of perforation 0.125"
From 777 feet to 1729 feet
From ____ feet to ____ feet
From ____ feet to ____ feet
From ____ feet to ____ feet
From ____ feet to ____ feet

Annular Seal: ☒ Yes ☐ No
☒ Neat Cement 0 to 55' ☒ Pumped ☐ Poured
☐ Cement Grout ____ to ____ ☐ Pumped ☐ Poured
☐ Concrete Grout ____ to ____ ☐ Pumped ☐ Poured
☐ ≥30% Bentonite Grout ____ to ____ ☐ Pumped ☐ Poured
Gravel Pack: ☒ Yes ☐ No 55' to 1760' ☐ Pumped ☒ Poured
Type: 3/8" x 1/2" SRI
Bentonite Chips: ☐ Yes ☒ No ____ to ____ ☐ Pumped ☐ Poured
Type:

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Lang Exploratory Drilling (CONTRACTOR)
Address P.O. Box 5279 (CONTRACTOR) Elko, NV 89802-5279
Nevada contractor's license number issued by the *State Contractor's Board* 0021976
Nevada driller's license number issued by the Division of Water Resources, the *on-site driller* 1995
Signed ____ By driller performing actual drilling on site or contractor
Date 02/27/07

(Rev 05-06)   USE ADDITIONAL SHEETS IF NECESSARY   Forms Provided by Forms-On-A-Disk · (214) 340-9429 · FormsOnADisk.com

OFFICE USE ONLY
Log No. 102843
Permit No.
Basin 184

STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT

PRINT OR TYPE ONLY

Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

NOTICE OF INTENT NO. **58840**

1. OWNER **SNWA** **184W-502M**
MAILING ADDRESS **1900 E. Flamingo Road, suite 107** **Las Vegas, NV. 89119**

ADDRESS AT WELL LOCATION **South Spring Valley, NV.**
Subdivision Name: **N/A** *County:* **Lincoln**

2. LOCATION **SE¼NW¼ Sec11T9N/ R68E**
PERMIT/WAIVER NO. **R-1323** (Issued by Water Resources) **N/A** (Parcel. No.)

Latitude **38° 39.420' N** UTM E ____ ☐ NAD 27
Longitude **114° 19.137'W** N ____ ☒ NAD 83/WGS 84

3. WORK PERFORMED
☒ New Well ☐ Replace ☐ Recondition ☐ Deepen ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test ☐ Municipal/Industrial ☒ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☒ RVC ☐ Air ☐ Other

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Topsoil		0	1'	1'
Limestone		1'	460'	459'
Clay		460'	480'	20'
Limestone		480'	870'	390'
Clay		870'	880'	10'
Limestone		880'	1180'	300'
Limestone with clay		1180'	1200'	20'
Limestone		1200'	1240'	40'
Limestone with clay		1240'	1260'	20'
Limestone		1260'	1380'	120'
Fractured limestone		1380'	1400'	20'
Limestone with clay		1400'	1470'	70'
Fractured limestone		1470'	1510'	40'
Limestone		1510'	1710'	200'
Fractured limestone		1710'	1760'	50'
Limestone		1760'	1820'	60'
	[redacted]			
N 38.657052				
W 114.318109 NAD27				

2007 FEB -5 PM
STATE ENGINEER'S OFFICE

Date started: 01/04, 20 07
Date completed: 01/24, 20 07

9. WELL CONSTRUCTION

Depth Drilled **1820** Feet Depth Cased **1800** Feet

HOLE DIAMETER (BIT SIZE)

Inches	From (Feet)	To (Feet)
26	0	57
14.75	57	1820

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
20	104.13	0.500	0	57
8.625	28.55	0.322	+2	1800

Perforations:
Type of perforation **Slot**
Size of perforation **1/16"**
From **481** feet to **1780** feet

Annular Seal: ☒ Yes ☐ No
☒ Neat Cement 0 to 57' ☒ Pumped ☐ Poured
☐ Cement Grout to ☐ Pumped ☐ Poured
☐ Concrete Grout to ☐ Pumped ☐ Poured
☐ ≥30% Bentonite Grout to ☐ Pumped ☐ Poured
Gravel Pack: ☐ Yes ☒ No to ☐ Pumped ☐ Poured
Type:
Bentonite Chips: ☐ Yes ☒ No to ☐ Pumped ☐ Poured
Type:

7. *Water Level*
Static water level: **482** feet below land surface
Artesian Flow: G.P.M. P.S.I
Water Temperature: **59** °F
Quality:

8. WELL TEST DATA

TEST METHOD: ☐ Bailer ☒ Pump ☒ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
200	31	8

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name **Lang Exploratory Drilling** (CONTRACTOR)
Address **P.O. Box 5279** **Elko, NV 89802-5279** (CONTRACTOR)
Nevada contractor's license number issued by the *State Contractor's Board* **0021976**
Nevada driller's license number issued by the Division of Water Resources, the *on-site driller* **1995**
Signed [signature]
By driller performing actual drilling on site or contractor
Date **01/29/07**

(Rev 05-06) USE ADDITIONAL SHEETS IF NECESSARY