United States Department of the Interior

U. S. GEOLOGICAL SURVEY

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MEMORANDUM

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

From: Tracie R. Jackson, Master's Graduate Student, University of Nevada Reno
Keith J. Halford, Ground-Water Specialist, Nevada WSC, USGS

Subject: AQUIFER TEST—Analysis of multiple-well aquifer test along Baker Creek on southern Snake Range mountain front, White Pine County, Nevada

A multiple-well aquifer test was done at Baker Creek along the southern Snake Range mountain front east of Great Basin National Park on Bureau of Land Management land (Figure 1). The purpose of the study was to characterize the hydraulic connection between the groundwater and surface water along Baker Creek by estimating streambed and underlying aquifer hydraulic properties over a 400-m stream section. The aquifer test was about 94 hours in duration and started on October 7, 2009 at 14:39 and ended on October 11, 2009 at 12:31. The test consisted of pumping a well 16 m away from the creek at a constant rate of 1.64 liters per second. The USGS site identifier and local well name of the pumped well are 385947114113201 and 195 N13 E69 14DACD1 BAKER CREEK, respectively. Results from this aquifer test will help quantify potential effects of groundwater development in Snake Valley, Nevada.

SITE AND GEOLOGY

The aquifer test occurred along a 400-m long section of Baker Creek that began about 200 m upstream of where multiple wells were drilled along an access road to the creek and ended about 200 m downstream (Figures 1 and 2). The test site is situated within Quaternary alluvium and Miocene deposits. Results of a study by Jackson (2010) indicate that the contact between the

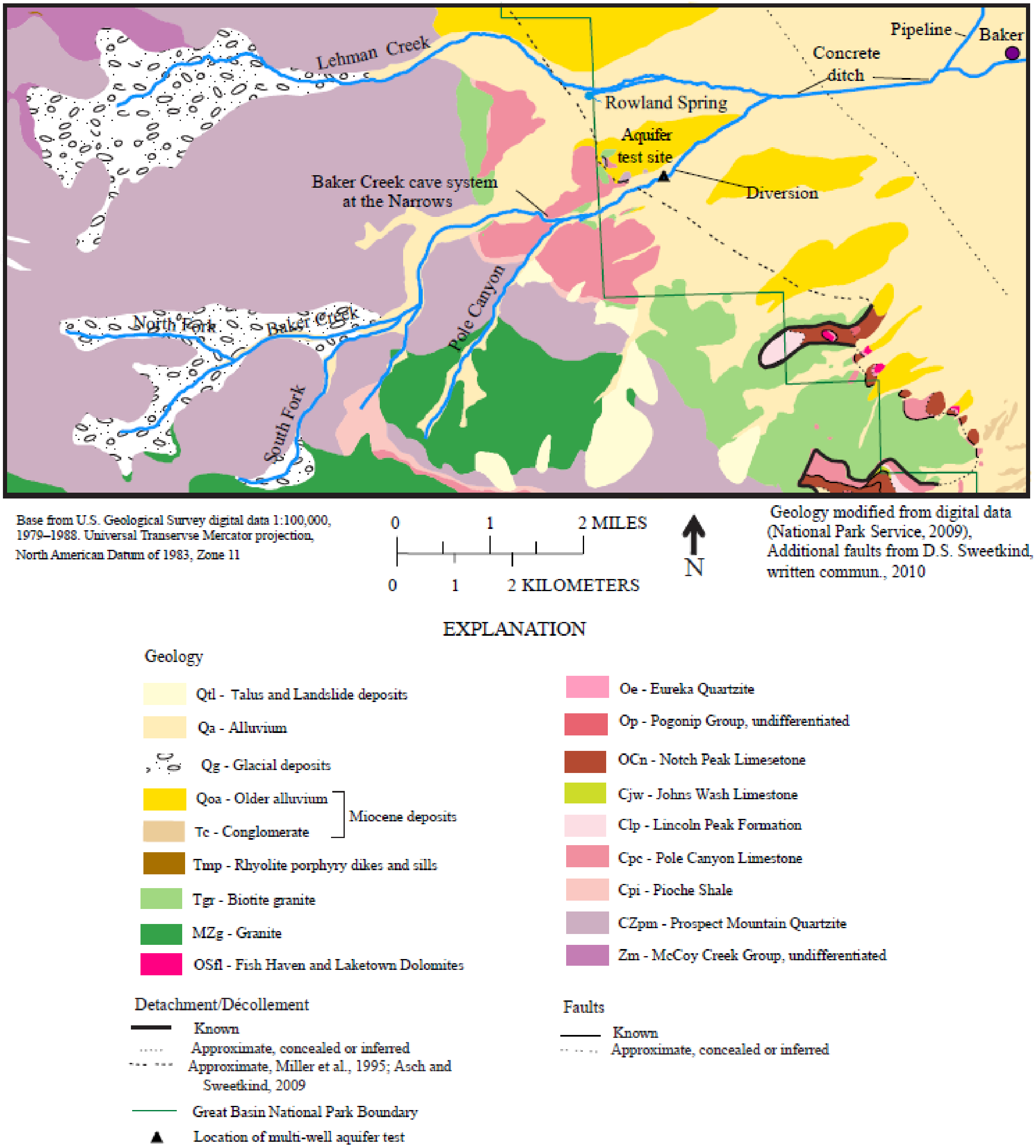

Figure 1—Location of aquifer test site, Baker Creek, and Great Basin National Park, White Pine County, Nevada, U.S.A. (Source: Geology modified from a digital geologic map available from the National Park Service (2009) that is based on 1:24,000 scale maps by Miller (2007)).

Miocene deposits and Quaternary alluvium dips into the alluvium from the north and south of the test site and at least one brecciated megablock is situated within the Miocene deposits. Audio-

Magneto-Telluric (AMT) soundings by Asch and Sweetkind (2010) suggest that the Quaternary alluvium, Miocene deposits, and brecciated megablocks occur from the land surface to a depth of 200 m at the test site. Seismic refraction results suggest that the Quaternary alluvium has a thickness of less than 40 m within Great Basin National Park downstream of the Narrows (Allander and Berger, 2009) (Figure 1).

The Quaternary alluvium contains unconsolidated boulders, gravels, sands, silts, and clays derived from glacial outwash and sediments that were transported by modern drainage systems flanking the Snake Range (Miller et al., 1995). The Miocene deposits are composed of coarse-grained, moderately to well-cemented alluvial deposits that formed during middle

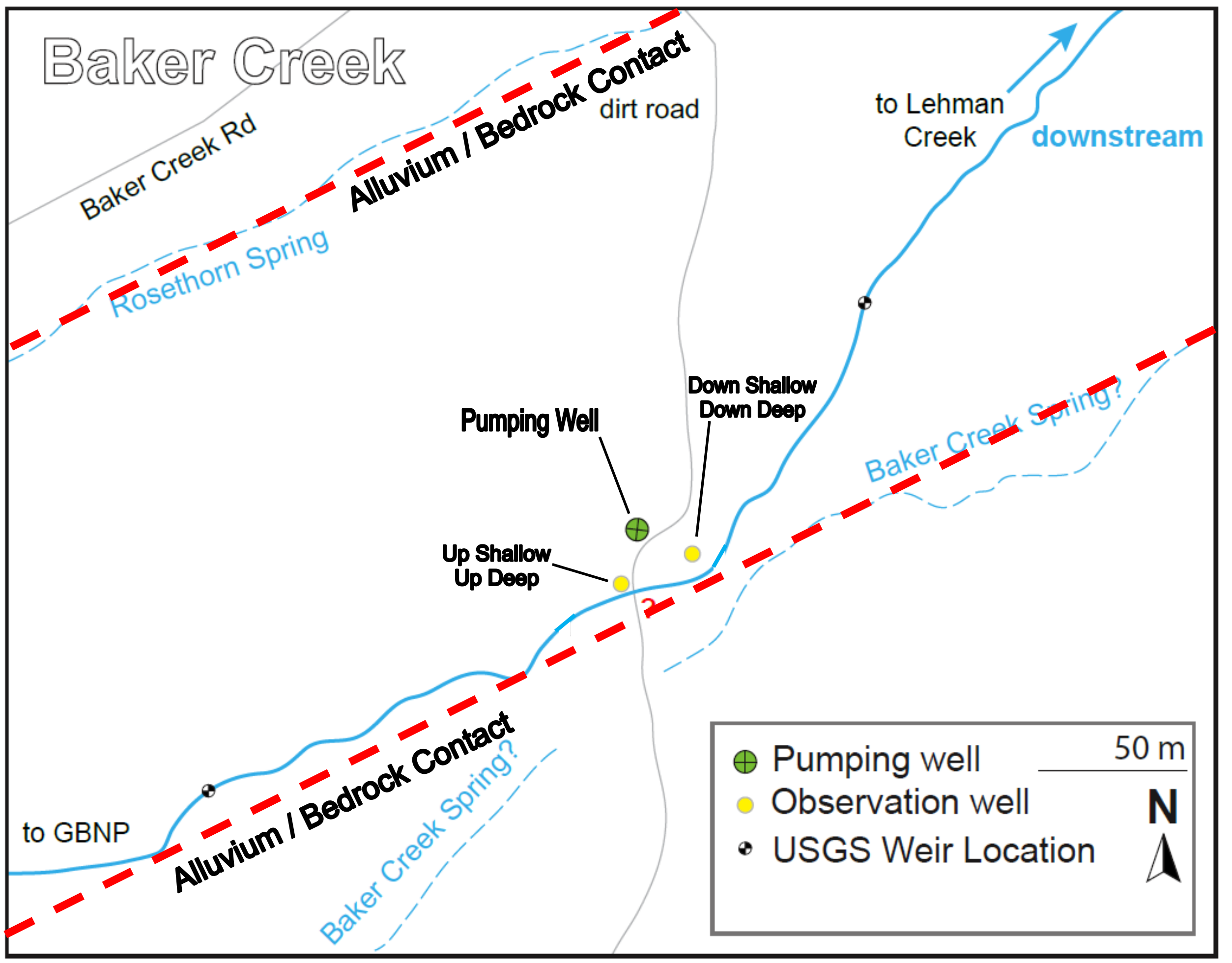

Figure 2—Configuration of Baker Creek multiple-well aquifer test.

Miocene uplifting of the Snake Range (Asch and Sweetkind, 2010). This geologic unit is consolidated and typically conglomeratic. The Miocene deposits include brecciated megablocks and typically are overlain by coarser fluvial, glacio-fluvial, alluvial, and debris-flow deposits. The brecciated megablocks are composed of Paleozoic rocks originally present in the western Snake Range. Some megablocks are monolithologic, whereas other megablocks have varying lithologies.

The pumping and down-deep monitoring wells encountered only unconsolidated Quaternary alluvium, whereas the up-deep monitoring well encountered a megablock of brecciated Pioche Shale embedded in Miocene deposits at a depth of 12 m. The megablock continued to a depth of at least 18 m, the total depth of the well. The megablock of brecciated Pioche Shale encountered in the upstream monitoring well may be one of many blocks within the study area. Megablocks of quartzite or shale restrict the movement of groundwater flow through them. The drill cuttings also showed that a confining layer does not exist between the land surface and the water table, which was less than 3 m below land surface at the time of the aquifer test indicating the Quaternary alluvium is unconfined.

AQUIFER TEST CONFIGURATION

All wells (Table 1) were drilled using the ODEX-type drilling system. An annular fill of medium aquarium Monterey sand was used across the screen intervals and bentonite chips were used above and below the screened intervals. The pumped well was drilled about 16 m north of the stream to a depth of 12 m and is screened over much of its saturated interval (from 6 to 12 m) (Figure 2). Two dual completion monitoring wells were drilled near the edge of Baker Creek at an upstream and downstream location. The upstream monitoring well is 1 m north of the stream in the center of the jeep trail, whereas the downstream monitoring well is 6 m north of the stream and 7.5 m downstream of the upstream monitoring well. Both monitoring wells have a shallow piezometer screened 4.5 to 6 m below the stream. The deeper piezometer in the upstream monitoring well is screened from 15 to 18 m below the stream and the deeper piezometer in the downstream monitoring well is screened from 9 to 10.5 m below the stream. The deeper piezometer in the upstream monitoring well was screened in a large block of Pioche Shale embedded in Miocene deposits.

Table 1—Location and construction of wells used in Baker Creek aquifer test.

[Latitude and longitude are in degrees, minutes, and seconds and referenced to North American Datum of 1983 (NAD 83); m amsl, meters above North American Vertical Datum of 1929 (NAVD 29); m bgs, meters below ground surface; na, not available.]

Local Identifier	SITE IDENTIFIER	Latitude	Longitude	Ground surface elevation, m amsl	Depth to Static Water Level, m bgs	Diameter Screen, in inches	Top Screen, m bgs	Bottom Screen, m bgs
Pumped	385947114113201	38°59'47"	114°11'32"	1,947.7	2.79	6	6.10	12.19
Up Shallow	385946114113201	38°59'46"	114°11'32"	1,947.7	2.04	2	4.88	6.40
Up Deep	385946114113202	38°59'46"	114°11'32"	1,947.7	2.58	2	14.94	17.98
Down Shallow	385946114113101	38°59'47"	114°11'31"	1,948.0	2.32	2	3.66	5.49
Down Deep	na	38°59'47"	114°11'31"	1,948.0	2.46	2	9.14	10.67

MEASUREMENTS

Pressure transducers simultaneously measured water levels at 3 minute intervals between September 12, 2009 and November 1, 2009, which is about 2 weeks before the test, during the 94-hr aquifer test, and 2 weeks after the test. The pressure transducers have a pressure resolution of 0.2 cm of water with an accuracy of ± 0.5 cm of water within a temperature range of 0° C to 40°C (Schlumberger, 2008). Water levels also were measured routinely in all wells during and immediately after the test using an electric tape with a resolution of 0.3 cm. Periodic streamflow measurements were made at the upstream and downstream pressure transducers in the stream, however, flow and stage in the stream did not change during the aquifer test.

The pumping rate at the pumped well was a constant 1.64 L/s and was determined from a totalizing flow meter at the pumped well and by periodically timing the filling of a 200 L barrel. The discharge rate could not be increased beyond 1.64 L/s during the test or water levels in the pumped well would have fallen below the top of the screened interval and pump intake.

MEASURED DRAWDOWN

The upstream monitoring well screened over the deeper interval (UpDeep) showed the least amount of drawdown (Figure 3). It is completely screened within the lower permeability megablock of brecciated Pioche Shale. The downstream monitoring wells screened in the deeper and shallow intervals (DownDeep and DownShallow) had greater drawdown than the upstream well screened in the shallow interval (UpShallow). They are closer to the pumped well by about 4 m. The DownDeep well had more drawdown than the DownShallow well. This may be due to the coupled effects of (1) having the screened interval of DownDeep closer to the screened interval of the pumped well than the DownShallow well; and (2) vertical heterogeneity in the Quaternary alluvium.

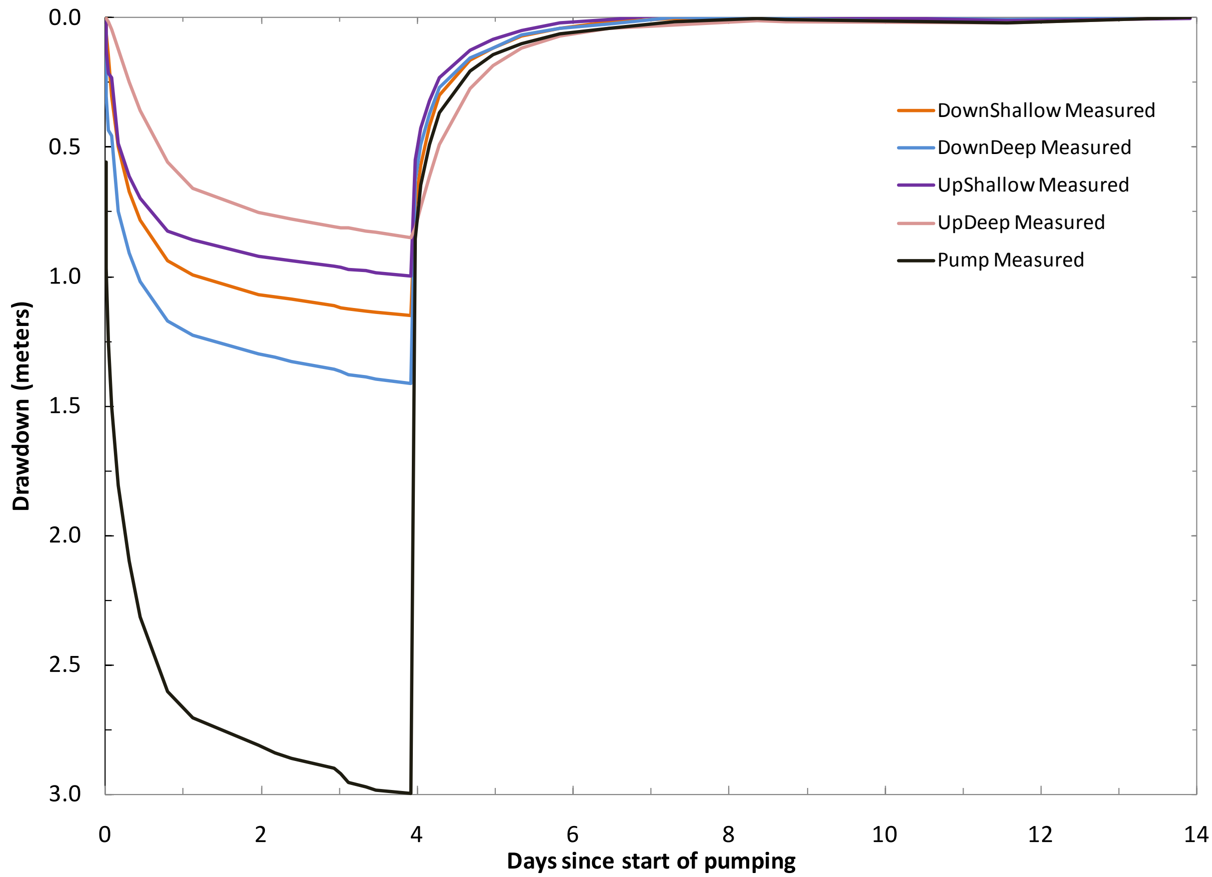

Figure 3—Test and monitoring well measured drawdown during the 94-hour aquifer test. The DownShallow and DownDeep lines represent the shallow and deeper screened intervals of the downstream monitoring well, respectively, and the UpShallow and UpDeep lines represent the shallow and deeper screened intervals of the upstream monitoring well, respectively.

NUMERICAL MODEL

Data from the multiple-well aquifer test was analyzed using a three-dimensional groundwater flow model, MODFLOW-2005 (Harbaugh, 2005). The aquifer hydraulic properties were calibrated first by trial-and-error and then with PEST (Doherty, 1999; Doherty, 2009) by reducing the residuals between simulated and measured drawdown. Table 2 lists the constant model input parameters. The modeled domain was 300 m wide by 400 m long by 18 m thick. Eighteen, uniformly spaced 1-m thick layers were used because, during the drilling process, the deepest well drilled was the upstream monitoring well at 18 m. Furthermore, it was assumed that the low discharge rate from the test well, which was drilled to a depth of 12 m, did not pull water from great depth. This grid discretization had a finer grid embedded in a coarser grid to provide more detail around the pumping well. The grid was oriented parallel to and in the direction of streamflow for the section of Baker Creek that was adjacent to the test site.

The pumping well and monitoring wells were situated in the center of the model domain. Baker Creek, which flowed through the center of the model in layer 1, was simulated in the River Package (Harbaugh, 2005). Rosethorn spring and its associated stream was the northern boundary in layer 1 and was simulated in the River Package. The spring and associated stream flows along the surface contact between the Quaternary alluvium to the south and Miocene deposits to the north (Miller et al., 1995).

The principal directions of the hydraulic conductivity tensor were aligned with the Cartesian coordinate axes x, y, and z and groundwater within the model domain flows from the left to the right side (or from the southwest to the northeast) at the test site. The groundwater flow direction is nearly parallel to Baker Creek and was determined from calculating a hydraulic gradient using water levels in the wells. The hydraulic gradient also was used to calculate the top elevation of model cells in layer 1, which represented the approximate elevation of the water table. The bottom elevation of layer 1 was calculated by subtracting 1 m from the top elevation of layer 1. Because all model layers had a uniform thickness of 1 m, the bottom elevation for each cell in subsequent layers was calculated by subtracting 1 m from the bottom elevation of the overlying layer. The top elevation of layer 1 also was used as the initial heads for all cells in a vertical column within the model domain. These initial heads were used in the steady-state simulation to calculate the starting heads for the transient simulation. The boundary heads at the left (upstream) and right (downstream) head-dependent flow boundaries coincide with the initial heads and layer elevations calculated from the hydraulic gradient. No-flow boundaries were specified for the top (north), bottom (south), and base of the model.

Table 2—Constant input parameters for model.

	Input Parameter	Value	Units	Comments
Periods and Time Steps	**Steady State stress period**			
	Time steps	1	-	Assigned
	Total time of stress period	1.0	days	Assigned
	Multiplier	1.0	-	Assigned
	Transient pumping stress period			
	Time steps	12	-	Assigned
	Total time of stress period	3.9125	days	Assigned
	Multiplier	1.5	-	Assigned
	Transient recovery stress period			
	Time steps	15	-	Assigned
	Total time of stress period	10.0	days	Assigned
	Multiplier	1.3	-	Assigned
Boundary Conditions	**Left (West) general head boundary**			Layers 1-18; Rows 1-108; Column 1
	Boundary head	1956.7	m	
	Conductance	5-20	m^2/day	Fine to coarse grid
	Right (East) general head boundary			Layers 1-18; Rows 1-108; Column 135
	Boundary head	1930.2	m	
	Conductance	5-20	m^2/day	Fine to coarse grid
Wells	Pumped well	4-10	m	Assigned; Screened Interval Layers
	Upstream shallow well	3-5	m	Assigned; Screened Interval Layers
	Upstream deeper well	14-17	m	Assigned; Screened Interval Layers
	Downstream shallow well	2-4	m	Assigned; Screened Interval Layers
	Downstream deeper well	7-9	m	Assigned; Screened Interval Layers
Hydrologic Features	**Baker Creek**			River Package; Layer 1
	Streambed hydraulic conductivity	0.5	m/day	Assigned
	Conductance	0.1-5.3	m^2/day	Assigned; Fine-coarse grid
	Stream stage	0.1	m	Assigned; 0.1 m above top elevation of cells
	River bottom	-1	m	Assigned; 1 m below stream stage
	Rosethorn Spring			River Package; Layer 1
	Streambed hydraulic conductivity	0.3	m/day	Assigned
	Conductance	0.9-3.6	m^2/day	Assigned; Fine-coarse grid
	Stream Stage	0.1	m	Assigned; 0.1 m above top elevation of cells
	River bottom	-1	m	Assigned; 1 m below stream stage

The hydraulic properties of Baker Creek's underlying geologic material were specified in the Layer Property Flow (LPF) Package (Harbaugh, 2005) and were characterized by the following: horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and a horizontal anisotropy ratio—the ratio of hydraulic conductivity in the y-direction (along a column) to hydraulic conductivity in the x-direction (along a row). The contact between the Quaternary alluvium and Miocene deposits dipped from the northwest and southeast into the alluvium within the model domain (Figure 4). A brecciated megablock is centered to the south of Baker Creek and the well. The hydraulic properties of these geologic units were specified within zones in the model grid that were defined by the zone array.

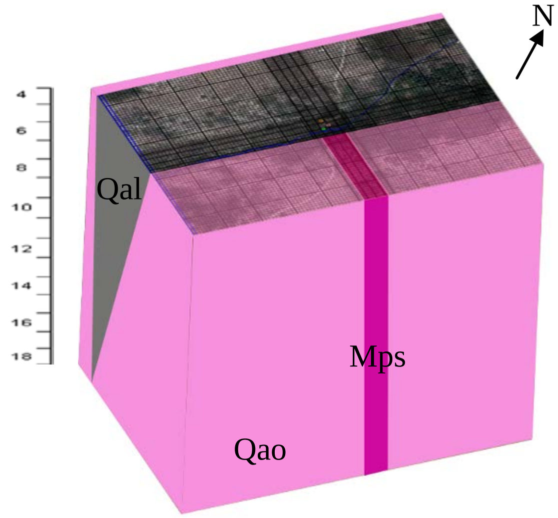

Figure 4—Geology block diagram of model. Quaternary alluvium (Qal) bounded on the north and south by Miocene deposits (Qao). A megablock of brecciated Pioche Shale (Mps) is situated within Miocene deposits to south. Vertical exaggeration is 10:1. Upper face is the top of pumped interval.

MODEL CALIBRATION

The Quaternary alluvium is highly heterogeneous. Therefore, the alluvium was divided into five units with different hydraulic properties to provide a match between measured and simulated drawdown. The Quaternary alluvium was homogeneous and anisotropic within each of its five units and the hydraulic properties of the Miocene deposits and megablock(s) were the same (Table 3). Unit 1 corresponded to model layer 1 and represented the water table. During manual calibration, this layer needed lower horizontal and vertical hydraulic conductivities compared with deeper layers. Unit 2 included model layers 2 through 5, which corresponded to the screened intervals of the shallow monitoring wells and the upper part of the screened interval in the pumped well. A horizontal anisotropy ratio of 0.6 was used to produce a greater separation between the drawdown in the shallow upstream and downstream monitoring wells. When the horizontal anisotropy was 1.0, the simulated drawdowns for the shallow wells were identical. Unit 3 corresponded to model layer 6. This unit was added to produce greater separation in the drawdown between the shallow and deeper downstream monitoring wells. Unit 4 included model layers 7-10, which corresponded to the screened interval of the deeper downstream monitoring well. Unit 4 was separated from unit 2 by a lower permeability unit (unit 3) because a higher horizontal hydraulic conductivity was needed to match the drawdown in the deeper downstream monitoring well while still producing the measured drawdowns in the shallow upstream and downstream monitoring wells. Unit 5 included model layers 11-18 and represented alluvium below the screened interval of the pumped well. This unit was important for simulating drawdown in the pumped well while producing less drawdown in the deeper downstream monitoring well.

Table 3—Constant input values and estimated parameters for model.

Input Parameter	Value	Units	Comments
Quaternary Alluvium (unit 1):			Layer 1
Horizontal hydraulic conductivity	1.0	m/day	Assigned
Vertical hydraulic conductivity	0.05	m/day	Assigned
Horizontal anisotropy ratio	0.60	-	Assigned
Specific Yield	0.01	-	Assigned
Quaternary Alluvium (unit 2):			Layers 2-5
Horizontal hydraulic conductivity	3.7	m/day	PEST estimated
Vertical hydraulic conductivity	0.3	m/day	PEST estimated
Horizontal anisotropy ratio	0.60	-	Assigned
Specific Storage	5.0×10^{-6}	m^{-1}	PEST estimated
Quaternary Alluvium (unit 3):			Layer 6
Horizontal hydraulic conductivity	0.1	m/day	PEST estimated
Vertical hydraulic conductivity	0.18	m/day	PEST estimated
Horizontal anisotropy ratio	1.0	-	Assigned
Specific Storage	5.0×10^{-5}	m^{-1}	PEST estimated
Quaternary Alluvium (unit 4):			Layers 7-10
Horizontal hydraulic conductivity	10.2	m/day	PEST estimated
Vertical hydraulic conductivity	0.9	m/day	PEST estimated
Horizontal anisotropy ratio	1.0	-	Assigned
Specific Storage	5.0×10^{-5}	m^{-1}	PEST estimated
Quaternary Alluvium (unit 5):			Layers 11-18
Horizontal hydraulic conductivity	11.5	m/day	PEST estimated
Vertical hydraulic conductivity	0.26	m/day	PEST estimated
Horizontal anisotropy ratio	1.0	-	Assigned
Specific Storage	3.7×10^{-5}	m^{-1}	PEST estimated
Miocene Deposits			Layers 1-18
Horizontal hydraulic conductivity	7.0×10^{-3}	m/day	Assigned
Vertical hydraulic conductivity	6.0×10^{-3}	m/day	Assigned
Horizontal anisotropy ratio	1.0	-	Assigned
Specific Storage	7.0×10^{-5}	m^{-1}	Assigned
Megablock of Pioche Shale			Layers 1-18
Horizontal hydraulic conductivity	7.0×10^{-3}	m/day	Assigned
Vertical hydraulic conductivity	6.0×10^{-3}	m/day	Assigned
Horizontal anisotropy ratio	1.0	-	Assigned
Specific Storage	7.0×10^{-5}	m^{-1}	Assigned

DRAWDOWN AND RESIDUAL DRAWDOWN RESULTS

The early time drawdown was over-predicted at the pumping well and the early time residual drawdown during recovery was under-predicted (Figure 5). Greater simulated drawdown at early time could have been caused by having a zone of higher hydraulic conductivity in the vicinity of the pumped well that was not simulated in the model and less simulated drawdown at later time could have been the result of a slightly lower hydraulic conductivity in the alluvium that contributed water to the well, which reduced the response of the well after turning off the pump.

Simulated drawdown and recovery at the upstream and downstream monitoring wells showed a consistent trend between drawdown and residual drawdown (Figure 5). The simulated drawdown at the shallow and deeper piezometers of each well matched their respective measured drawdowns, but the measured residual drawdown recovered more quickly than the simulated drawdown for both wells. The reason for the more rapid measured recovery could have been that either the sediments around the monitoring wells had higher hydraulic conductivities than simulated or that the leakage through the streambed was higher than that simulated in the model. The simplified geometry of the underlying geology could have led to these small errors in the estimation of the Quaternary alluvium, Miocene deposits, and Baker Creek streambed hydraulic properties.

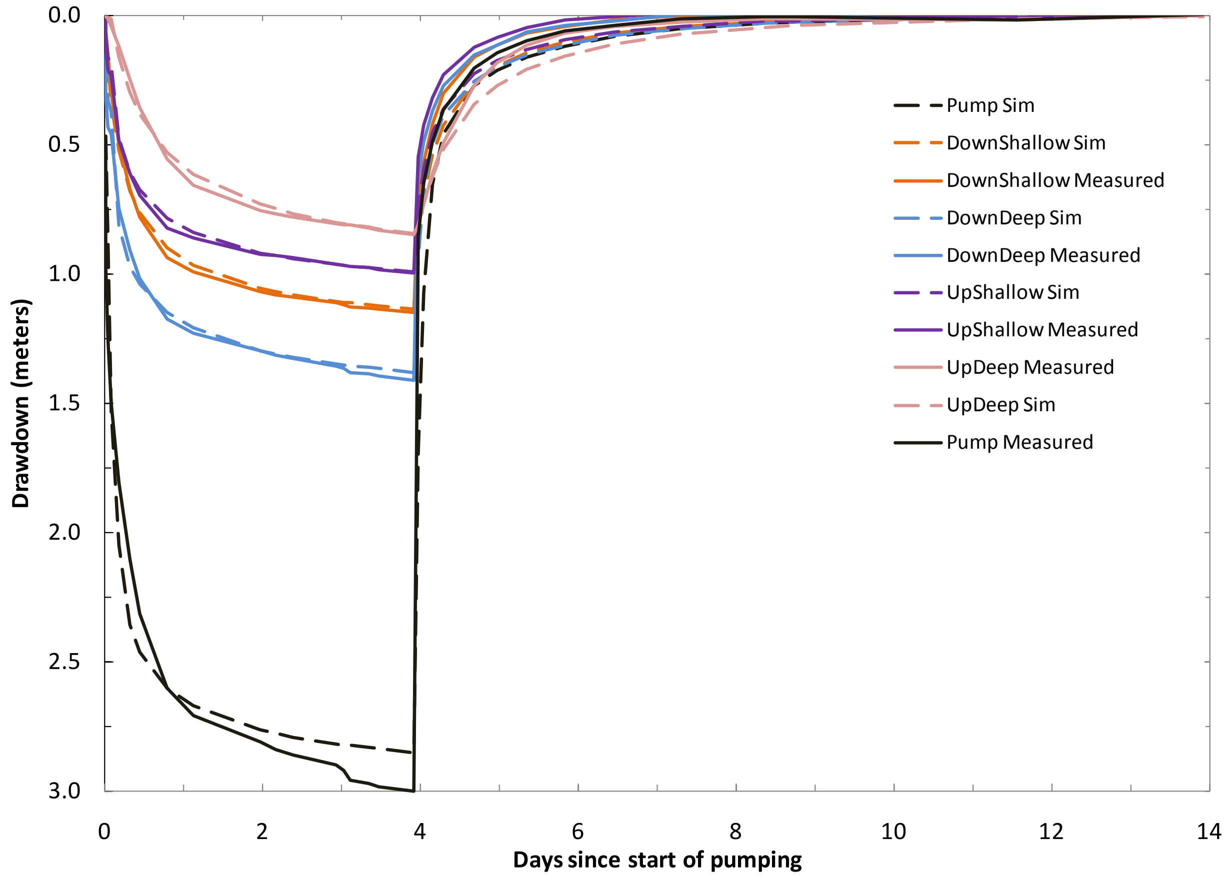

Figure 5—Simulated (dashed line) versus measured (solid line) pumping and recovery drawdown.

DISCUSSION

Partitioning of the Quaternary alluvium into five units with differing hydraulic properties was needed to simulate measured drawdown in the pumped and monitoring wells. The results suggest a highly heterogeneous alluvial aquifer, which is reasonable given that the alluvium is a poorly-sorted mixture of boulders, cobbles, gravels, sands, silts, and clays that was deposited in a steeply sloping high energy environment (Table 3). The Quaternary alluvium may have stratified layers of finer material, such as simulated in model layer 6, between coarser materials, such as simulated in model layers 2 through 5 and 7 through 18, due to fluvial processes. The arithmetic mean of the horizontal hydraulic conductivities from these five units in the direction of streamflow (west to east) and transverse to the direction of streamflow (north to south) were 8.3 and 7.9 m/d, respectively. The harmonic mean of the vertical hydraulic conductivities for the

Quaternary alluvium was 0.15 m/d. Slug tests on monitoring wells indicated that the monitoring wells were in good communication with the alluvial aquifer.

The Miocene deposits and megablock had the same hydraulic properties (Table 3). Brecciated megablocks within Miocene deposits along the eastern flank of the southern Snake Range restrict groundwater flow. However, Miocene deposits are not that dissimilar to the alluvium in their depositional environment and thus are also heterogeneous in their aquifer properties. The geometry of the Miocene deposits and brecciated megablock was simplified in the numerical model and the actual geometry of these geologic units is more complex. The simplified geometry of these geologic units and the lack of head observations in the Miocene deposits led to difficulties in differentiating the hydraulic properties of each unit. Because the megablock is embedded within the Miocene deposits and many more megablocks occur within this geologic unit—possibly within the study area along Baker Creek—the megablock and Miocene deposit hydraulic properties estimated were the effective hydraulic properties. The Miocene deposits and brecciated megablock hydraulic conductivities in the direction of stream flow (west to east), transverse to streamflow (north to south), and vertical (z) direction were 7.0×10^{-3}, 7.0×10^{-3}, and 6.0×10^{-3} m/day, respectively. A uniform specific storage of 7.0×10^{-5} m^{-1} was simulated for both the Miocene deposits and the embedded megablock. The model estimated effective hydraulic conductivity was compared to a slug test done on the deeper upstream monitoring well and analyzed using the Cooper-Bredehoeft-Papadopulos slug test method (Cooper et al., 1967). Results of the slug test had an effective horizontal hydraulic conductivity of about 0.03 m/day, which is a reasonable match to the model estimated value.

Simulated drawdown in the one monitoring well completed in the megablock of brecciated Pioche Shale was sensitive to the hydraulic properties assigned to the Miocene deposits and megablock. However, assigning different values for these properties had minimal effect on drawdown in the other wells as long as the values of both horizontal and vertical hydraulic conductivity were between the range of 1.0×10^{-3} and 1.0×10^{-2} m/day and the values of specific storage were between the range of 1.0×10^{-6} and 1.0×10^{-4} m^{-1}. Increasing or decreasing the permeability of the Miocene deposits to the north of the test well by more than one order of magnitude resulted in too much or not enough drawdown for the test well, respectively. Small increases (0.1 m/d) to the permeability or specific storage of the Miocene deposits and megablock to the south of the monitoring wells increased streambed-aquifer interaction because these geologic units underlie Baker Creek at shallow depth near the monitoring wells. An increase in streambed-aquifer interaction along Baker Creek caused less drawdown in the shallow monitoring wells during later time pumping. The estimated streambed vertical hydraulic conductivity along Baker Creek was 0.5 m/day. Even though the pumping rate was insufficient to produce a measureable decrease in streamflow along Baker Creek, water level declines during pumping indicated increased leakage near and downstream of the pumped well. At the end of the 94-hr aquifer test, the simulated streambed leakage increased 6.1 m^3/d. This increase accounted for only about 4 percent of the pumping rate and 0.1 percent of the stream discharge which is not measureable. The estimated streambed hydraulic conductivity along Baker Creek is similar to estimates of streambed hydraulic conductivity along the Trout Creek alluvial fan near Battle Mountain, NV, which was 0.56 m/day (Prudic et al., 2007, p. 332) and Vicee Canyon near Carson City, NV, which was 0.15 m/day (Ronan et al., 1998, p. 2148).

HYDRAULIC PROPERTIES

The transmissivity-width product of the Quaternary alluvium beneath Baker Creek is 12,800 m^3/d (450,000 ft^3/d) regardless of the assumed geometry between fill and underlying Miocene deposits. This is an average transmissivity of 84 m^2/d (900 ft^2/d) assuming a width of 150 m (500 ft). Hydraulic conductivity estimates are dependent on the assumed geometry and lithology distribution within the Quaternary alluvium. Different hydraulic conductivity distributions were estimated with alternative models, but transmissivity-width products were unique.

The Miocene deposits were functionally impermeable in the vicinity of the aquifer test. Hydraulic conductivity estimates consistently were less than 0.01 m/d (0.003 ft/d) regardless of the model.

REFERENCES

Allander, K., and Berger, D., 2009, Seismic velocities and thicknesses of alluvial deposits along Baker Creek in Great Basin National Park, east-central Nevada: U.S. Geological Survey Open-File Report 2009-1174, 14 p.

Asch, T.H., and Sweetkind, D.S., 2010, Geophysical characterization of range-front faults, Snake Valley, Great Basin National Park, Baker, Nevada: U.S. Geological Survey Open-File Report 2010-1016, 226 p.

Cooper, H., Bredehoeft, J., and Papadopulos, I., 1967, Response to a finite diameter well to an instantaneous charge of water: Water Resources Research, v. 3, p. 263–269.

Doherty, John, 1999, Pest—Model Independent Parameter Estimation: Watermark Numerical Computing, Brisbane, Australia, 336 p., Downloadable from www.sspa.com/pest.

Doherty, John, 2009, Addendum to the PEST Manual: Watermark Numerical Computing, Brisbane, Australia, 235 p., Downloadable from www.sspa.com/pest.

Fetter, C.W., 2001,(4th ed.),Applied Hydrogeology: Upper Saddle River, New Jersey, Prentice Hall, 598 p.

Harbaugh, A.W., 2005, MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p.

Jackson, T., 2010, Evaluation of the hydraulic connection between streams and aquifers at Baker and Snake creeks near Great Basin National Park, Snake Valley, White Pine County, Nevada: University of Nevada, Reno, M.S. Thesis, 259 p.

Miller, E.L., Grier, S.P., and Brown, J.L., compiler, 1995, Geologic Map of the Lehman Caves Quadrangle, White Pine County, Nevada: U.S. Geological Survey Geologic Quadrangle Map 1758, scale 1:24,000.

Miller, E., 2007, Geologic map of Great Basin National Park and environs, Southern Snake Range, Nevada: Stanford Geologic Survey Map, scale 1:24,000.

National Park Service, 2009, Digital geologic map of Great Basin National Park and vicinity, Nevada: National Park Service, accessed February 3, 2009 at http://science.nature.nps.gov/nrdata/datastore.cfm?ID=44849.

Prudic, D.E., Niswonger, R.G., Harrill, J.R., and Wood, J.L., 2007, Streambed infiltration and groundwater flow from the Trout Creek drainage, an intermittent tributary to the Humboldt River, north-central, Nevada: U.S. Geological Survey Professional Paper 1703, ch. K, p. 313-351.

Ronan, A.E., Prudic, D.E., Thodal, C.E., and Constantz, Jim, 1998, Field study and simulation of diurnal temperature effects on infiltration and variably saturated flow beneath an ephemeral stream: Water Resources Research, v. 34, no. 9, p. 2137-2154.

Schlumberger, 2008, Groundwater Monitoring Solutions—Diver Brochure: Schlumberger water services, Ontario, Canada.

SNWA, 2008, Southern Nevada Water Authority Clark, Lincoln, and White Pine Counties Groundwater Development Project DRAFT Conceptual Plan of Development: Southern Nevada Water Authority, 100 City Parkway, Suite 700, Las Vegas, Nevada, 88 p, accessed January 1, 2009 at http://www.snwa.com/assets/pdf/gdp_concept_plan.pdf.