United States Department of the Interior

U. S. GEOLOGICAL SURVEY

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August 25, 2003

MEMORANDUM

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

From: Keith J. Halford, Ground-Water Specialist, Nevada District, WRD

Subject: AQUIFER TESTS—Analysis of multiple-well, multiple-stress, aquifer test, Dry Valley, Nevada

Two aquifer tests were conducted in Dry Valley, Nevada (Figure 1) to define the hydraulic characteristics of the alluvial fill. The primary aquifer test was 24 hours in duration and started at 0921 on May 5, 2003 and ended at 0931 on May 6, 2003. The second aquifer test was about 4 hours in duration and started at 0758 on July 10, 2003 and ended at 1215 on July 10, 2003. Results from these tests were used to estimate subsurface discharge from Dry Valley. The primary hydraulic characteristics to be quantified by these tests are the lateral and vertical hydraulic conductivity of the alluvial fill.

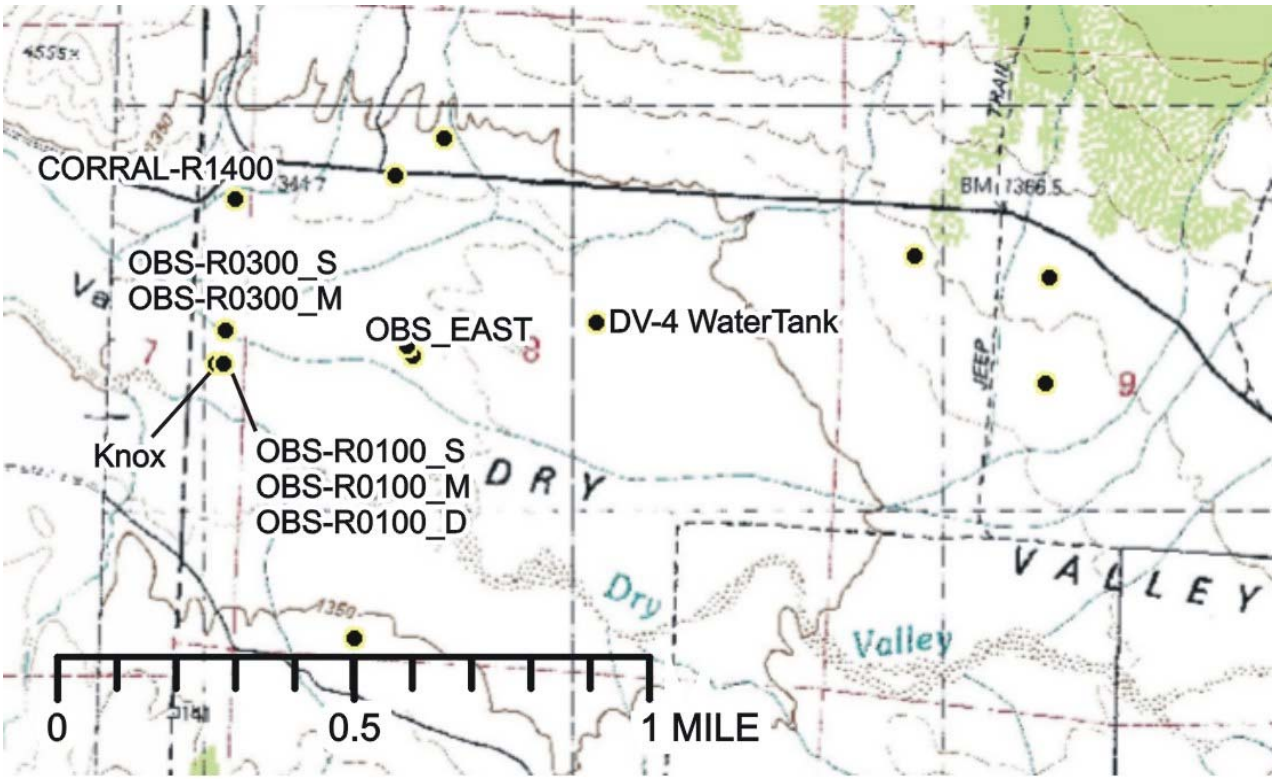

Figure 1.—Location of wells for aquifer tests in Dry Valley, Nevada.

SITE

The aquifer tests occurred along the California-Nevada state line in Dry Valley (Figure 1). The alluvial fill was comprised of poorly sorted intervals of silt and gravel, sands, and clays from 0 to 780 ft below land surface. Much of the geohydrologic column could not be differentiated from the driller's log or geophysical logs (Figure 2). The contact between alluvial fill and bedrock was estimated to be 2,000 ft below land surface from geophysical surveys and was assumed to be the base of the aquifer. Clay and silt were assumed to be the dominant materials from 800 to 2,000 ft below land surface.

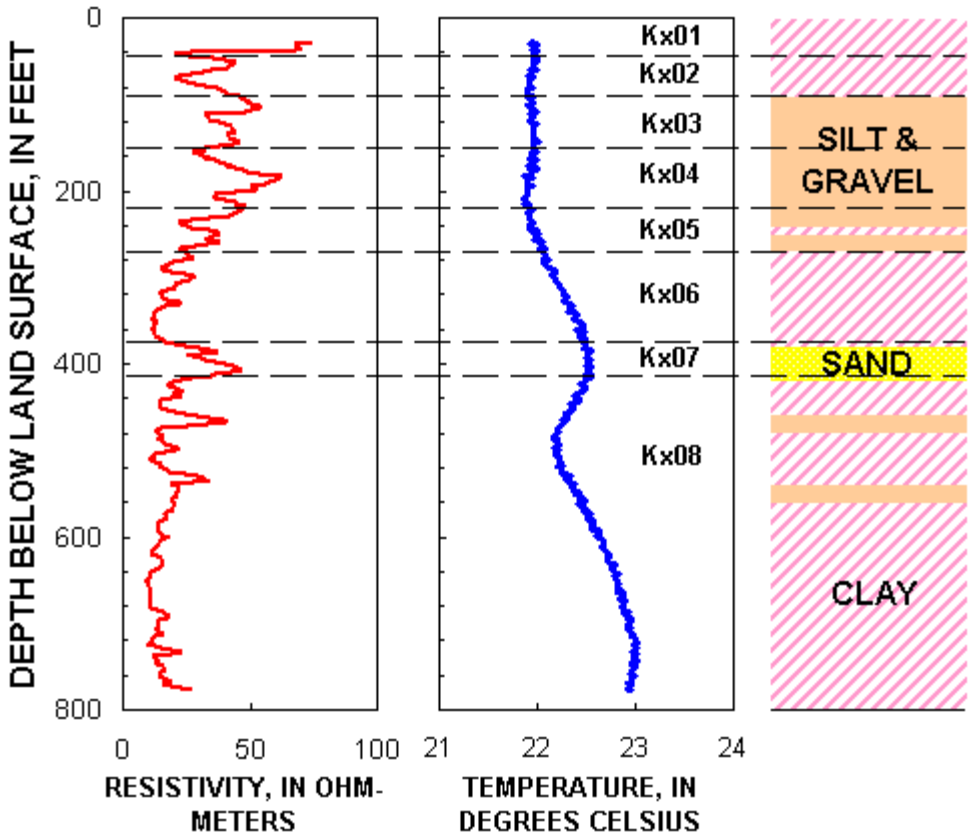

Figure 2.—Geophysical and Driller's logs from well OBS-R0100_D.

Observation wells were screened across what appeared to be more permeable zones as inferred from geophysical and Driller's logs. Four permeable intervals were identified and the geohydrologic column was divided into 8 intervals. More permeable zones were assigned odd number and less permeable zones were assigned even numbers (Figure 2). The uppermost interval, Kx01, was assumed to be more permeable based on the resistivity log rather than the Driller's log.

PROCEDURES

Two production wells and seven observation wells were used for the two aquifer tests (Table 1, Figure 1). Water levels were monitored continuously in all of the observation wells for 4 days or more prior to the primary test and throughout the duration of the primary test. Water levels were measured periodically in the pumped Knox well during the primary test. Water levels were monitored continuously in the CORRAL-R1400 and OBS-R0300_S wells for a day prior to the secondary test and throughout the duration of the secondary test.

Table 1.—Location and construction of wells used in Dry Valley aquifer tests.

[Geographic coordinates (latitude and longitude) are given in degrees, minutes, and seconds and referenced to North American Datum of 1983]

WELL NAME	LATITUDE	LONGITUDE	Altitude, Feet Above Sea Level	Depth to Top of Screen, ft	Depth to Bottom of Screen, ft	Diameter, in
KNOX-PUMPING	39°57'34.1"	119°59'56.1"	4,406	100	400	14
OBS-R0100_D	39°57'34.2"	119°59'55.0"	4,406	532	542	2
OBS-R0100_M	39°57'34.2"	119°59'55.0"	4,406	235	245	2
OBS-R0100_S	39°57'34.2"	119°59'55.0"	4,406	30	40	2
OBS-R0300_M	39°57'36.9"	119°59'54.9"	4,403	370	380	2
OBS-R0300_S	39°57'36.9"	119°59'54.9"	4,403	135	145	2
CORRAL-R1400	39°57'47.4"	119°59'54.3"	4,406	90	141	6
OBS-EAST	39°57'35.4"	119°59'34.3"	4,408	31	41	2
DV-4_WaterTruck	39°57'38.6"	119°59'14.1"	4,418	10	20	2

Volumes of produced water were monitored with an in-line, totalizing flow meter and an acoustic, instantaneous flow meter. Both meters were measured periodically to estimate flow rates. Measurements from the two meters agreed to within a percent. The Knox well was pumped at an average discharge of 415 gpm and discharges ranged from 400 to 430 gpm during the first aquifer test. The corral well was pumped at an average discharge of 43 gpm and discharges ranged from 40 to 45 gpm during the second aquifer test.

Drawdowns from the primary aquifer test were estimated by subtracting surrogate water levels from measured water levels in each observation well. Surrogate water levels were estimated by fitting a summation of background, barometric, earth-tide, and linear trends to antecedent water levels in each observation well. Water-level recoveries from a 1-hour pretest, May 1, 2003 caused the linear trends observed prior to the primary aquifer test (Figure 3). Linear trends were estimated only in wells Knox, OBS-R0100_M, OBS-R0100_S, OBS-R0300_M, and OBS-R0300_S which were all within 300 ft of the Knox production well.

Drawdowns from the secondary aquifer test were estimated by subtracting the water level just prior to pumping from water levels. Surrogate water levels were not estimated because the only detectable response to pumping occurred in the production well where drawdowns were more than 40 ft.

The "Noordbergum effect" (Verruijt, 1969, p. 368; Wolf, 1970) was observed in well OBS-R0100_S where water levels initially rose 0.2 ft during the first hour of pumping and then declined (Figure 3). Aquifer deformation primarily changed pore pressure between the Knox and OBS-R0100_S wells for the first hour of the test. A reverse water-level response suggests relatively low permeability materials occur between 40 and 100 ft below land surface.

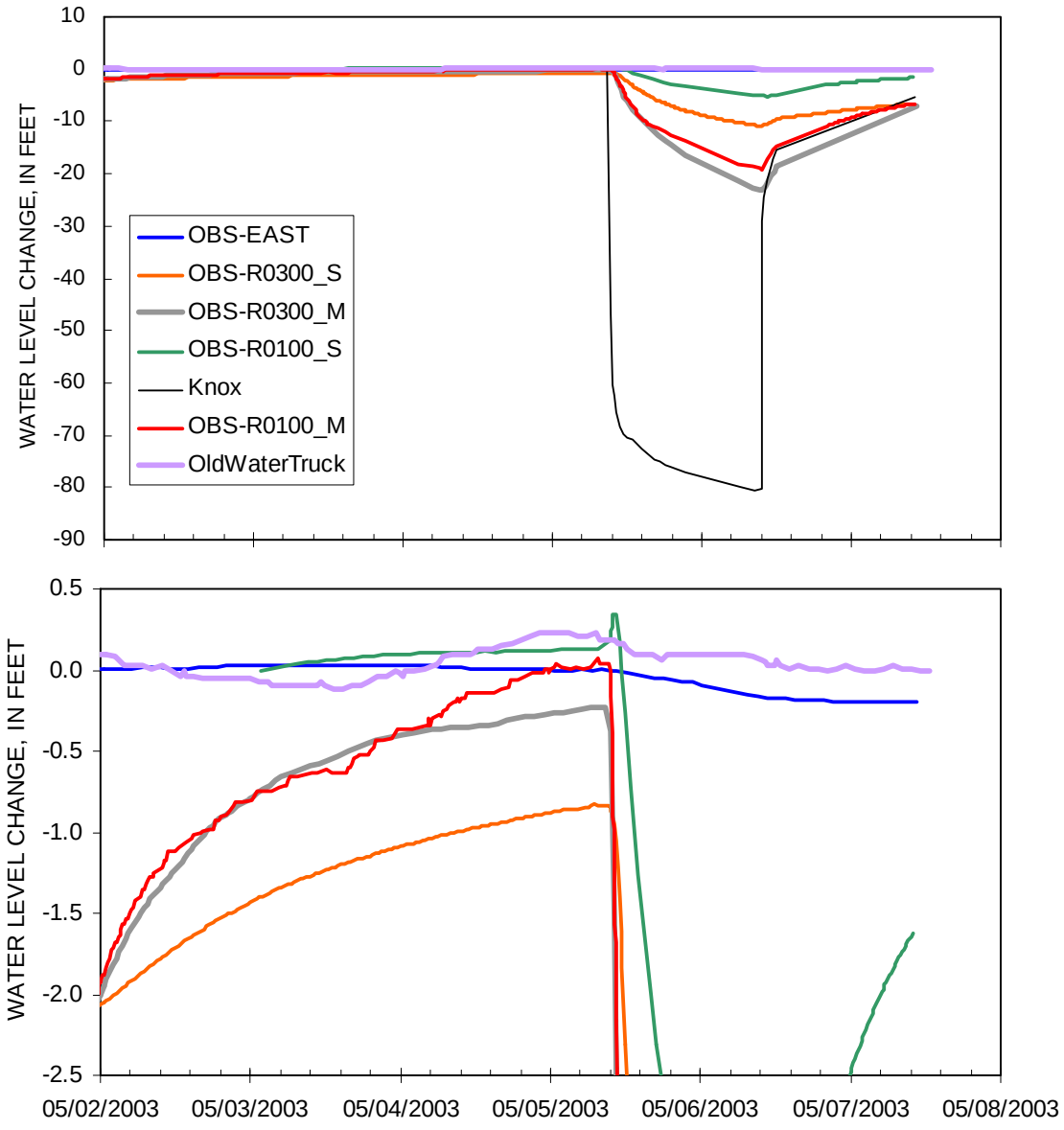

Figure 3.—Water-level changes in selected wells during the primary aquifer test.

Drawdowns from wells OBS-R0100_M and OBS-R0100_D were discounted in the analysis because these wells did not develop well. Hydraulic conductivity estimates of 0.02 and 0.05 ft/d were estimated from slug tests in wells OBS-R0100_M and OBS-R0100_D. A hydraulic conductivity estimate of 0.02 ft/d, a delayed drawdown response to pumping, and a final drawdown of almost 20 ft suggested that the screen was plugged in well OBS-R0100_M. Erratic water-level responses and a drawdown decline of 1.2 ft during the primary aquifer test suggested that the casing was cracked and leaking in well OBS-R0100_D. Drawdowns in well OBS-R0100_D were not used to estimate hydraulic properties.

Simulated and measured drawdown changes in the Knox and OBS-R0100_M wells were compared 20 and 100 min, respectively, after the primary test commenced. Significant differences between simulated and measured drawdown resulted from not simulating wellbore storage effects in these two wells. These effects are not important for characterizing the geohydrologic column and were ignored by fitting to drawdown changes after wellbore storage effects had dissipated in each well.

Estimation of drawdowns with surrogate water levels was necessary only in wells OBS-EAST and Corral-R1400 which experienced drawdowns of less than 0.2 ft (Figure 4). Surrogate water levels in wells OBS-EAST and Corral-R1400 were estimated by fitting to measured water levels from 2 d prior to pumping the Knox irrigation well. Drawdown estimates were not improved materially from simply subtracting the water level just prior to pumping. Although the surrogate water level analysis increased the confidence that drawdowns were observed.

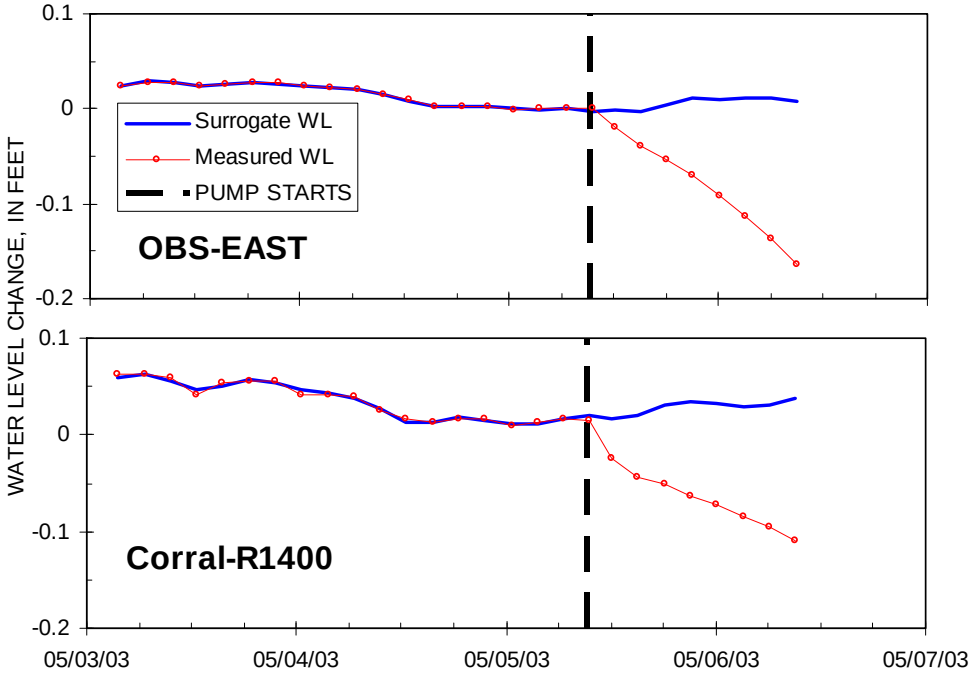

Figure 4.—Surrogate and measured water levels in well OBS-EAST and Corral-R1400 from 5/3/03 to 5/6/03.

Recovery data was collected but not analyzed. Aquifer response and measurement problems were qualitatively judged from water levels that were measured during recovery. Drawdowns during recovery were not estimated or analyzed because errors in surrogate water levels increase as elapsed time from the beginning of a test increases. Drawdown magnitude also is decreasing as surrogate water-level error is increasing.

ANALYSIS

The hydraulic properties of the geohydrologic column were estimated for 8 intervals (Figure 2) by fitting simulated drawdowns to measured drawdowns from both aquifer tests. Drawdowns were simulated with a two-dimensional, radial MODFLOW model (McDonald and Harbaugh 1988; Harbaugh and McDonald, 1996). Parameter estimation was performed by minimizing a weighted sum-of-squares objective function with an optimization routine (Halford, 1992) coupled to MODFLOW.

Wells and aquifer flow system were simulated with an axisymmetric, radial geometry in a single MODFLOW layer. Radial distance increased with increasing column indices and depth increased with increasing row indices. Hydraulic conductivities and storages of the ith column were multiplied by $2\pi r_i$ to simulate radial flow where r_i was the distance from the outer edge of the first column to the center of the ith column.

The model extended from a production well to more than 200,000 ft away and from the water table to 2,000 ft below land surface. The model domain was discretized into a layer of 90 rows of 89 columns (Figure 5). Cell widths ranged from 0.2 ft adjacent to the production well to 25,000 ft in the farthest column. Vertical discretization also was variable and finer across less permeable units. All external boundaries were specified as 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 tests were simulated with two 10-d stress periods. The primary aquifer test was simulated during the first stress period with initial heads of 0. The secondary aquifer test was simulated during the second stress period and heads were reset to 0 between stress periods 1 and 2. Stress periods of 10 days were specified for convenience so drawdown observation time would be equivalent to elapsed time during the secondary test plus 10 d.

Production wells were simulated as a high conductivity zone with vertical conductances multiplied by 10^7. Water was removed from the uppermost node in a well and MODFLOW was allowed to apportion inflow to the well. Wellbore storage associated with the production well was not simulated and was addressed by discounting the first 15 minutes of drawdowns during a test.

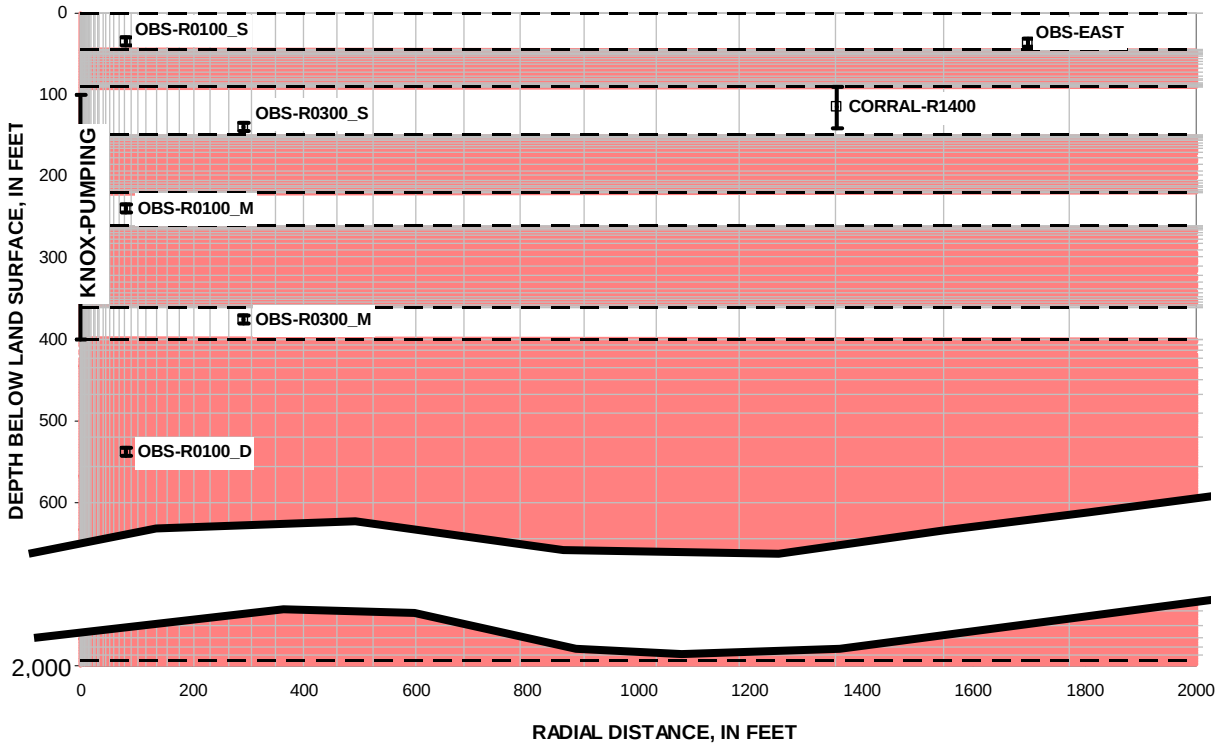

Figure 5.—Radial cross-section about the Knox well that shows model grid.

The configuration of the production well was changed from that of the Knox well to that of the CORRAL-R1400 between stress periods 1 and 2. The hydraulic properties of the well were modified with the Time-Variant Hydraulic-Property Package, VAR1 (Halford, 1998). The VAR1 package allows hydraulic properties to be modified step-wise from one stress period to the next by either being multiplied or replaced. The simulated location of an observation well also differs between stress periods because radial distances change as the production well changes. Depth of observation does not change between stress periods.

HYDRAULIC PROPERTY ESTIMATES

The hydraulic properties of the geohydrologic column were defined with ten parameters, the lateral hydraulic conductivity of each of the 8 zones, specific storage, and specific yield. Specific storage was assumed to be uniform throughout the geohydrologic column and was defined with a single parameter. Lateral-to-vertical anisotropy was unknown and assigned a value of 1 for simplicity.

Simulated drawdowns matched measured drawdowns reasonably well during both aquifer tests (Figure 6, Figure 7). The RMS error was 0.15 ft relative to measured drawdowns of more than 20 ft after a day of pumping. Simulated and measured drawdowns in OBS-R0300_S compared poorly and differed by about 2 ft relative to measured drawdowns of more than 5 ft (Figure 6). No drawdown was observed in well OBS-R0300_S during the second test and simulated drawdowns were less than 0.01 ft.

Transmissivity of the geohydrologic column was 1,200 ft^2/d which differed little from a transmissivity estimate of 1,500 ft^2/d from a Cooper-Jacob analysis of the Knox well (Cooper and Jacob, 1946). Hydraulic conductivity was not distributed uniformly throughout the geohydrologic column (Figure 8). Hydraulic conductivity estimates of the 8 zones ranged from 0.01 to 20 ft/d in zones Kx08 and Kx05, respectively (Table 2). Unconstrained hydraulic conductivity estimate for zone Kx08 were less than 0.0005 ft/d but the estimate was constrained to 0.01 ft/d by slug test results.

A specific yield estimate of 0.0007 resulted from compensating errors, was not reasonable, and should not be considered a good estimate for Dry Valley (Table 2). Zone Kx01 was simplified as a uniform hydraulic conductivity from 0 to 40 ft below land surface while the lithology was clayey silt from 0 to 30 ft below land surface and poorly sorted silt and gravel from 30 to 40 ft below land surface. Specific yield was underestimated to compensate for the lithologic simplification.

Hydraulic conductivity estimates were unique although slight variations in the thicknesses of the estimated intervals would not have affected results. Parameters Kx06 and Kx07 were correlated most (0.97) and remained independent. All other parameter pairs had correlation coefficients less than 0.90. Model error was most sensitive to estimates of Kx05 and least sensitive to estimates of Kx08 (Table 2).

Table 2.—Parameter estimates and relative sensitivities of the 10 hydraulic properties that were estimated for the geohydrologic column at Dry Valley, Nevada.

Hydraulic Property	Parameter Estimate	Relative Sensitivity
Kx01, ft/d	3	0.36
Kx02, ft/d	0.1	0.48
Kx03, ft/d	2	0.93
Kx04, ft/d	0.05	0.24
Kx05, ft/d	16	1.00
Kx06, ft/d	1	0.08
Kx07, ft/d	0.5	0.02
Kx08, ft/d	0.01	0.02
SsAQ, 1/ft	0.000005	0.71
Sy , d'less	0.0007	0.11

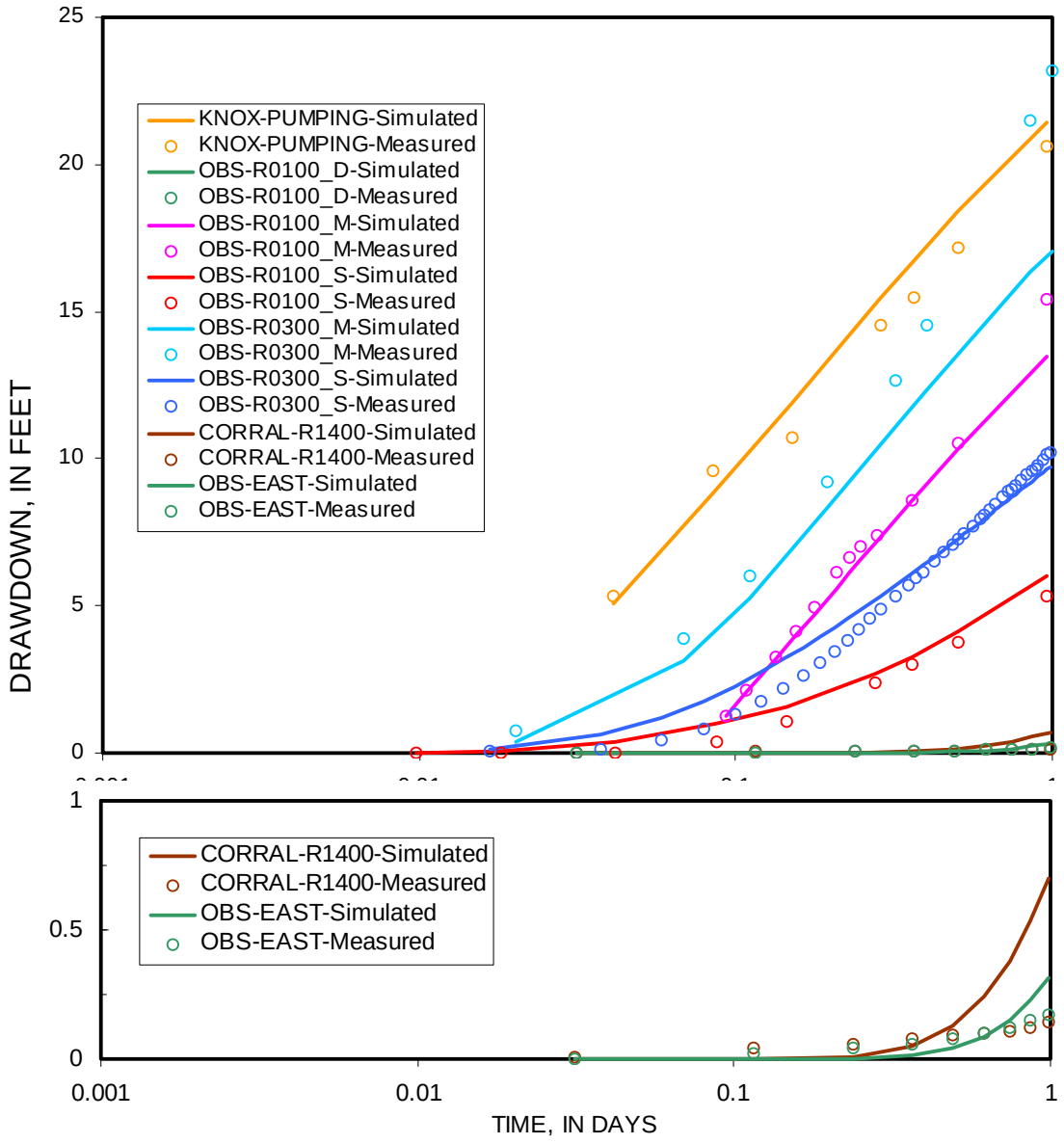

Figure 6.—Measured and simulated drawdowns for the primary aquifer test, May 5, 2003.

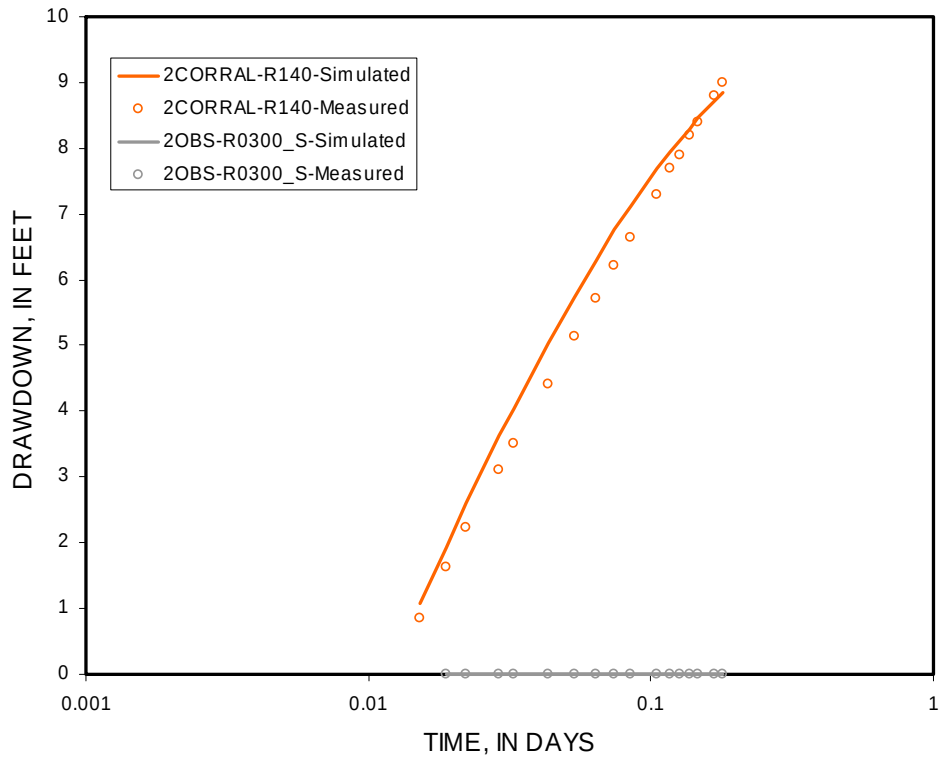

Figure 7.—Measured and simulated drawdowns for the secondary aquifer test, July 10, 2003.

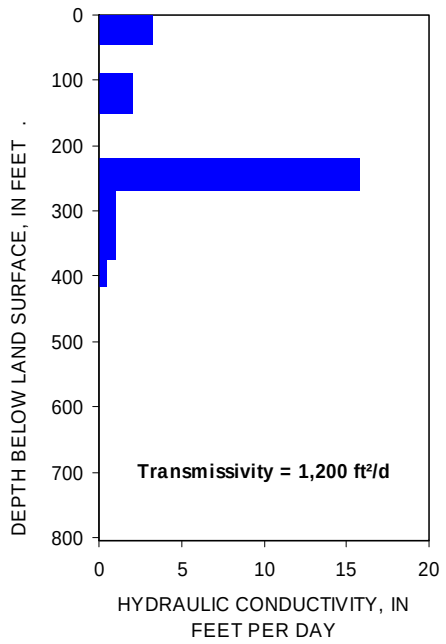

Figure 8.—Estimated hydraulic conductivity distribution of geohydrologic column at Dry Valley, Nevada.

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