Aquifer-Test Report for Test Well U-20a-2

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INTRODUCTION

Numerous aquifer tests have been conducted in and around the Nevada Test Site. Many of these tests have been completed in a fractured rock medium. Methods used to analyze these aquifer tests have included the Theis and Cooper-Jacob solutions. Although both methods are used to estimate aquifer characteristics in fracture media, the results may be qualified because both methods were developed for porous rock media. Recently, GeoTrans Inc., working in cooperation with the U.S. Department of Energy (DOE), evaluated time/drawdown data collected in wells drilled for DOE in the Oasis Valley area (ER-EC wells, completed in fractured volcanic rock) using a fractured-rock, double-porosity model (Moench, 1984). Based on this evaluation, it was thought that analyzing aquifer-test results from these wells with a dual-porosity solution would yield a better transmissivity estimate in these wells. Subsequently, individuals from GeoTrans Inc. identified approximately 62 wells in the vicinity of the Nevada Test Site with aquifer test data that could potentially be reevaluated with a fractured-rock, double-porosity model. Transmissivity estimates from these aquifer tests will support ground-water flow models being developed for DOE.

The U.S. Geological Survey (USGS) proposed to DOE to work in cooperation with GeoTrans Inc. to review these aquifer tests for the availability of aquifer-test data that might be suitable for reevaluation. Well U-20a-2 was one of the wells selected by the USGS for reevaluation. Transmissivity in well U-20a-2 has been estimated to be 2,400 ft^2/d by Blankennagel and Weir (1973, p. B12, table 3), from an aquifer test conducted on February 10 – 11, 1965. The aquifer-test data from this test were reanalyzed using the Cooper-Jacob solution (Cooper and Jacob, 1946) and Moench's dual-porosity spherical-shaped block and slab-shaped block solutions (Moench, 1984). Transmissivity estimates from each solution were compared.

TEST DESCRIPTION

Well U-20a-2 is located in Area 20 of the Nevada Test Site (fig. 1). On February 10, 1965, at 12:02 pm (Pacific Standard Time, PST) the USGS began a single-well aquifer test on well U-20a-2 which lasted approximately 29 hours (pump off at 5:02 pm, PST, on February 11, 1965) (Blankennagel and Weir, 1965, p. 16). Average discharge during the test was 186 gallons per minute.

Blankennagel and Weir, (1965, p. 17, footnotes a/, b/, and c/) report that:

- this well was used as a general supply well and had not been pumped for about 24 hours prior to starting the test;
- at approximately 900 minutes questionable measurements were made due to a short circuit in the measuring device;

- the measuring device was changed and the measurements shown were converted to the terms of the original measuring device based on differences in calibration of the two cables.

Drawdown data collected at 900 minutes of pumping was removed from the data set used to estimate transmissivity for this report. No adjustments to the drawdown data due to barometric, tidal, or temperature effects were made.

On page 5, Blankennagel and Weir (1965) reported that:

> *"Water levels were measured with a deep-well electrical line capable of detecting relative changes in water level as small as 0.02 foot. The static-level measurements have not been corrected to a steel tape secondary standard and should not be used for water-level contouring.*
>
> *A Reda submersible pump was used in the test on hole U-20a-2. A positive displacement check value was placed immediately above the pump. Discharge measurements were made using Sparling water meters. In most tests the meter accuracy was checked with a 44 gallon oil drum or a 10,000 gallon tank."*

TEST SITE

Well U-20a-2 is located at 37 ° 14’ 34” N.; 116 ° 25’ 16” W., in Area 20 of the Nevada Test Site (fig. 1).

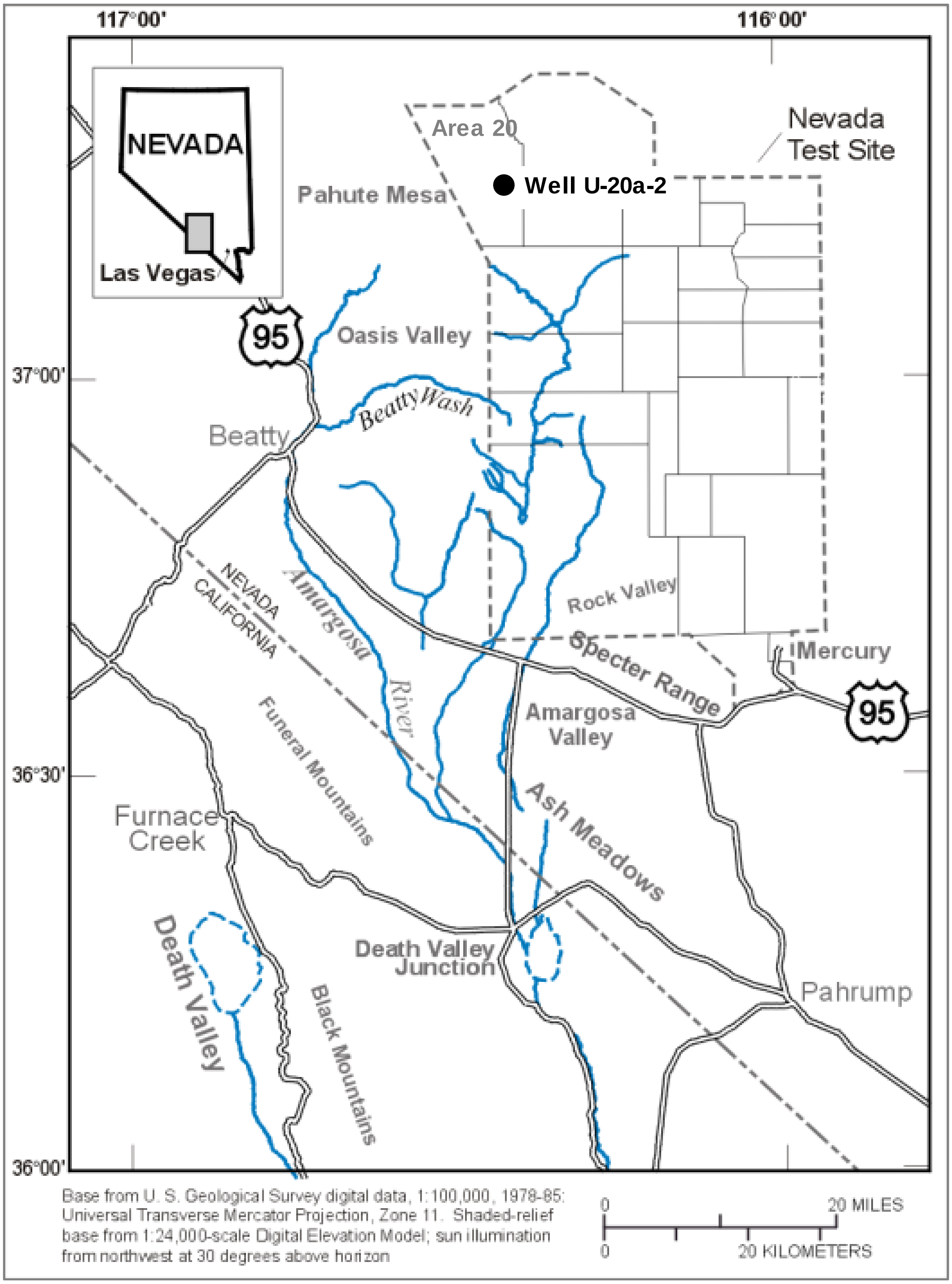

Figure 1 Location of well U-20a-2 on the Nevada Test Site.

CONSTRUCTION

Well U-20a-2 was completed as a water-supply well in the Pahute Mesa area (Blankennagel and Weir, 1965, p. 2). Well U-20a-2 was drilled to a depth of 4,500 feet below land surface and was completed with a 13 3/8-inch outside diameter casing from land surface to 860 feet below land surface. The well is open hole from 860 to 4,500 feet below land surface with a hole diameter of 10 5/8-inch (fig. 2). The major production zones were reported to be in Rhyolite from 2,404 to 2,682; 2,895 to 3,085; and 3,648 to 3,838 feet below land surface (Blankennagel and Weir, 1965, p. 16). The saturated thickness of aquifer tested is about 2,411 feet.

Well U-20a-2

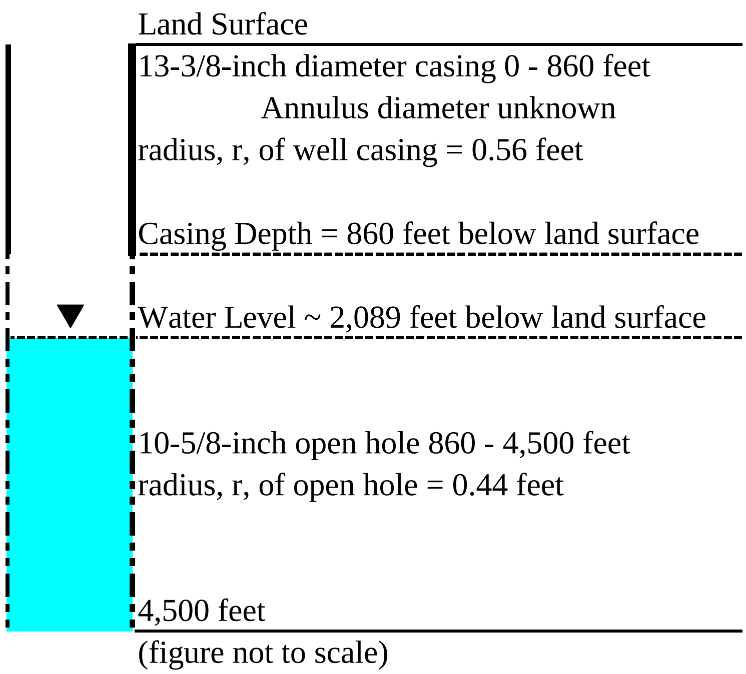

Figure 2 Construction of well U-20a-2..

HYDROGEOLOGIC CHARACTERISTICS

Blankennagel and Weir (1965, p. 2), report that well U-20a-2 is completed in Rhyolite. Belcher and Elliott, (2001, Appendix A: Hydraulic-Properties Database, worksheet Tertiary Volcanics) report the well was completed in Rhyolite lava flows with bedded tuff of the Calico Hills Formation. Orkild and Jenkins, (1978, p. 58) present a detailed description of rock type and stratigraphic units for well U-20a-2 (table 1).

Table 1 Rock type in well U-20a-2 from 0 to 4,580 feet below land surface (adapted from Orkild and Jenkins (1978, p. 58))

Depth interval, in feet below land surface	**Rock type**
0 - 50	Nonwelded to partially welded ash-flow tuff
50 - 70	Vitric bedded tuff
70 - 240	Nonwelded to moderately welded ash-flow tuff
240 - 300	Vitric bedded tuff
300 - 510	Nonwelded to moderately welded ash-flow tuff
510 - 560	Vitric bedded tuff
560 - 1,190	Nonwelded to moderately welded ash-flow tuff
1,190 - 1,210	Vitric bedded tuff
1,210 - 1,770	Rhyolitic lava flow
1,770 - 1,815	Rhyolitic lava-flow breccia
1,815 - 2,010	Zeolitized bedded tuff
2,010 - 2,210	Rhyolitic lava flow
2,210 - 2,310	Zeolitized bedded tuff
2,310 - 4,350	Rhyolitic lava flow
4,350 - 4,500	Rhyolitic lava flow breccia (crystal rich)

COOPER-JACOB ANALYSIS

The Cooper-Jacob method (Cooper and Jacob, 1946), commonly referred to as the straight-line method, is a simplification of the Theis (1935) solution for flow to a fully penetrating well in a confined aquifer. Using the Cooper-Jacob method, a transmissivity was estimated to be 2,400 ft^2/d by fitting a straight line to late-time drawdown data (fig. 3). Lohman (1979, p. 22) states that the Cooper-Jacob method is only valid when the well function of *u* is less than or equal to 0.01 (*u* = r2 S/4 T t, where r = distance to observation well, S = aquifer storage, T = aquifer transmissivity and t = time of pumpage). Assuming an r of 1 foot and S of 0.001, the criteria of a value of *u* less than or equal to 0.01 was met after the first second of pumping.

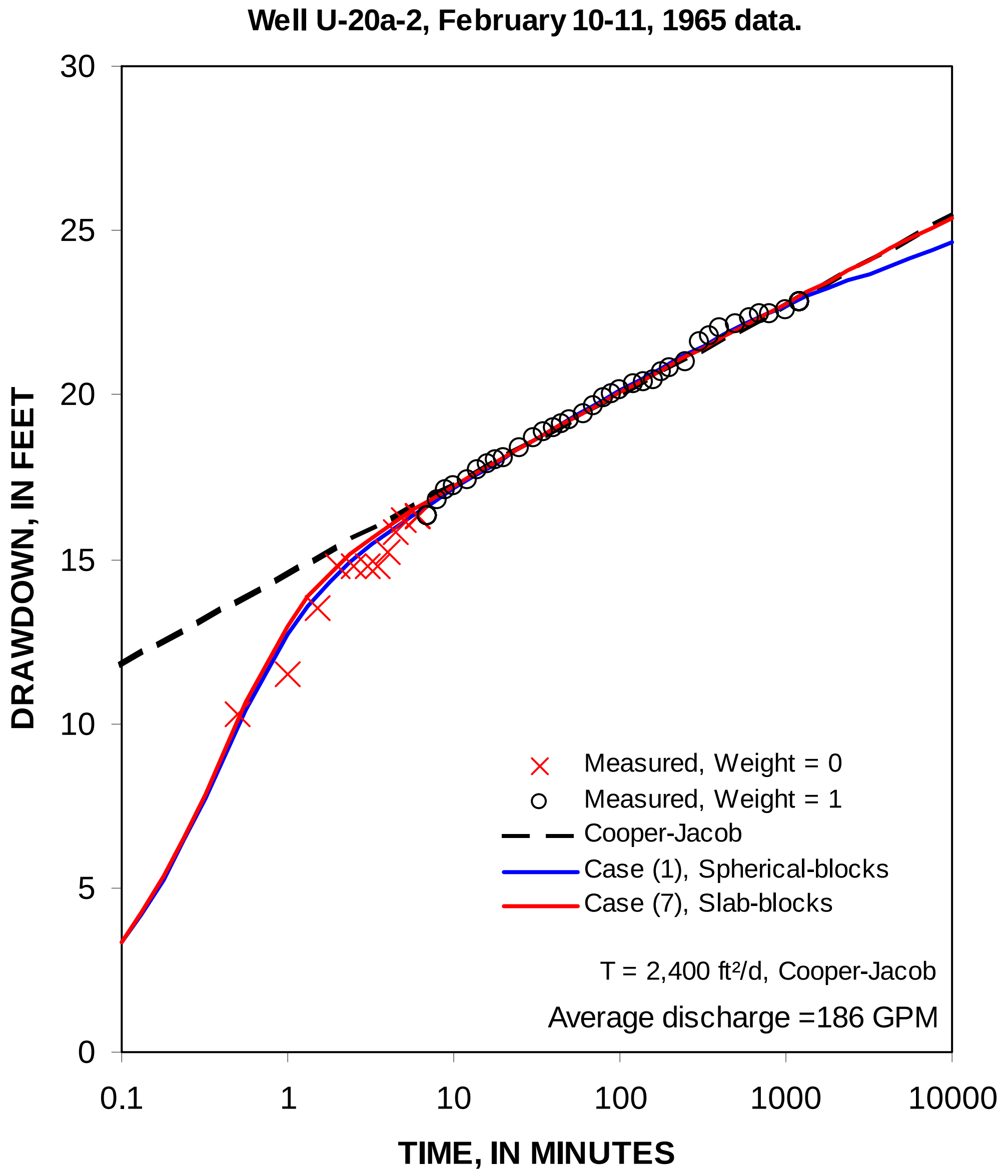

Figure 3 Measured, straight-line approximation, case (1) simulated, and case (7) simulated drawdowns for February 10 – 11, 1965, aquifer test conducted at well U-20a-2.

MOENCH ANALYSIS

General assumptions about aquifer geometry and hydraulic properties are similar for the Theis and Moench solutions. Common assumptions for both solutions are that aquifers are laterally infinite, have homogeneous and isotropic transmissivities, and are bounded by impermeable confining units. Production and observation wells are assumed to be fully penetrating so that all flow is horizontal. Transmissivity (T) and storage (S) are the same parameters in both solutions.

The Theis and Moench solutions differ in how the release of water from storage is simulated. Water is supplied from aquifer and water compressibility in the Theis solution, which is defined by a single parameter (S). Fractures and blocks of unfractured matrix provide two sources of water in the Moench solution. The first source is from fractures, which contribute water from aquifer and water compressibility in direct proportion to drawdown as defined by a single storage term (S). The second source of water is from the blocks of unfractured matrix that can release water at highly variable rates because the blocks are simulated as one-dimensional aquifers. The blocks of unfractured matrix are characterized by four parameters; slab thickness (2b'), (b' in table 2), fracture skin (Sf), matrix hydraulic conductivity (K'), and matrix specific storage (Ss') (fig. 4). The fracture network also can be conceptualized as spheres instead of slabs in the Moench solution where 2b' defines sphere diameter instead of slab thickness.

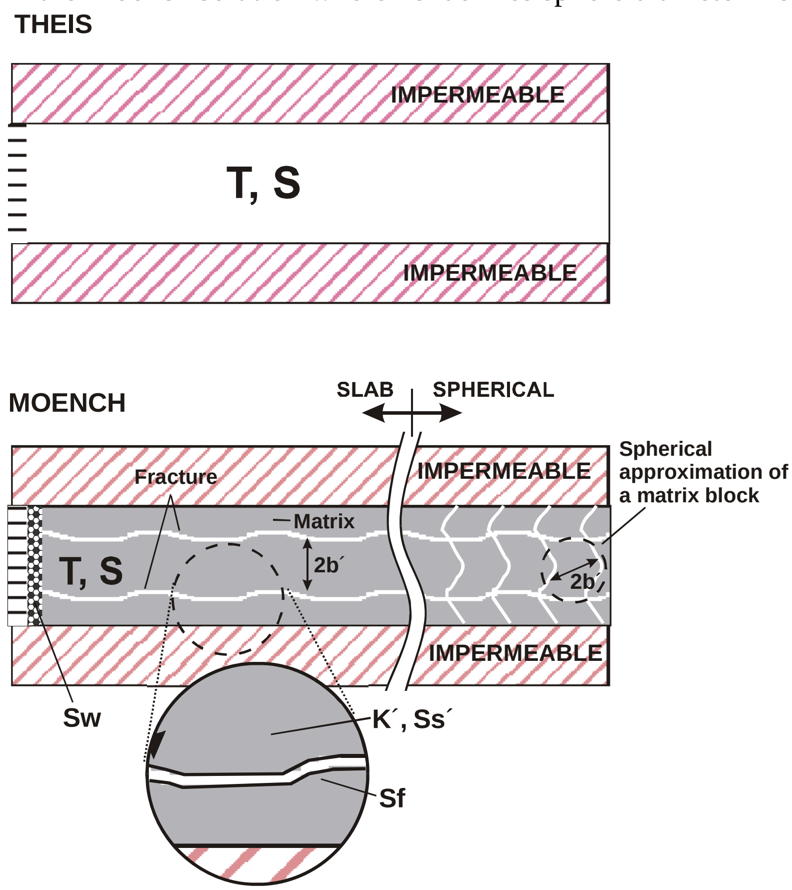

Figure 4 Schematic diagrams of Theis and Moench aquifers.

The range of hydraulic properties that is expected for matrix blocks or slabs is dependent on how the dual-porosity system is conceptualized. Fracture intervals in welded tuffs that are predominantly vertical and recur in intervals of 10 ft or less suggest a spherical approximation of matrix blocks is reasonable. Matrix permeability would be similar to estimates from cores and would have a relatively limited range of expected values if the dual-porosity system were pictured as spheres. Flow logging and packer testing in wells at the Nevada Test Site suggest volcanic interbeds that recur in intervals of 100 to 1,000 ft are the primary permeable zones. This would suggest that the dual-porosity system could be conceptualized as slabs of 100 to 1,000 ft thick. Matrix permeability in the slab conceptualization could be much greater than estimates from cores because the ‘matrix’ also would be fractured, albeit less well connected than the interbeds.

Multiple conceptualizations of the dual-porosity system around well U-20a-2 were tested to determine the uniqueness of hydraulic property estimates. Hydraulic properties were estimated by minimizing the sum-of-squares difference between simulated and observed drawdowns after the first 8 minutes of pumping. Drawdowns from the first 8 minutes of pumping were not used because wellbore storage greatly affected these measurements.

Aquifer geometry was specified and all hydraulic properties except for transmissivity were constrained to reasonable ranges (table 2). Matrix blocks were assumed to have 10-ft diameters for the spherical solutions. Matrix blocks were assumed to have 500-ft thickness for the slab solutions. Matrix specific storage coefficients were limited to range from 10^{-7} to 10^{-5} ft^{-1}. Matrix hydraulic conductivities were limited to range from 10^{-5} to 0.1 ft/d. The skin terms Sf and Sw were estimated, but were constrained to range from 0 to 100.

Estimates of S, b', Sf, K', and Ss' were not unique (table 2). Final estimates of the parameters that were estimated were highly dependent on initial estimates, except for transmissivity. Case 1 and Case 7 had RMS errors of 0.12 to 0.14 ft, respectively, which spans the range of RMS errors for all cases that were tested (table 2). Simulated drawdowns from all cases described the observed drawdowns equally well (fig. 3). Although some simulated drawdowns differed significantly for times later than when measurements existed.

Table 2 Parameter estimates and fitting error for multiple Moench solutions to the observed drawdowns in well U-20a-2.

[Aquifer thickness is 2,411 feet. A total of 38 points were used in the analyses. b' is slab thickness or sphere diameter. K is aquifer hydraulic conductivity. Ss is specific storage of fractures. K' is matrix hydraulic conductivity. Sw is wellbore skin. Sf is fracture skin. T is aquifer transmissivity. S is storage coefficient of aquifer. RMS is Root Mean Square.]

Hydraulic Property	**CASE**							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Slab Geometry[†]	Spherical	Spherical	Slab	Slab	Slab	Slab	Slab	Spherical
Slab, (b'), ft	10 [a]	10 [a]	500 [a]	500 [a]	500 [a]	500 [a]	500 [a]	10 [a]
K, ft/d	0.93	0.99	0.99	0.94	0.95	0.93	1.00 [a]	1.00 [a]
Ss, 1/ft	8.8E-07	2.5E-06	4.1E-08	1.6E-07	7.2E-07	8.8E-07	8.3E-08	6.2E-07
K', ft/d	1.0E-5 [a]	1.0E-1 [a]	1.0E-5 [a]	1.0E-1 [a]	1.0E-5 [a]	1.0E-1 [a]	4.8E-03	1.0E-05
Ss', 1/ft=	2.0E-6 [a]	2.0E-6 [a]	1.0E-7 [a]	1.0E-7 [a]	1.0E-5 [a]	1.0E-5 [a]	1.0E-05	1.0E-05
Sw	1.1	2.4	0.0	0.3	1.1	1.1	0.4	1.5
Sf	2.7	0.0	0.0	19.8	0.0	3.7	55.2	100.0
T, ft^2/d	**2,300**	**2,400**	**2,400**	**2,300**	**2,300**	**2,200**	**2,400 [a]**	**2,400 [a]**
S	2.E-03	6.E-03	1.E-04	4.E-04	2.E-03	2.E-03	2.E-04	2.E-03
RMS error, ft	0.12	0.14	0.14	0.13	0.14	0.12	0.14	0.14

[†] Geometry of matrix in Moench solution which is either slab or sperical.

[a] Values were specified.

CONCLUSIONS

Transmissivity could be reliably estimated around well U-20a-2 with either Cooper-Jacob or a Moench solution from aquifer-test results. Estimate of transmissivity determined for this report using the Cooper-Jacob solution was not improved by using the Moench solution. The best estimate of transmissivity is considered to be 2,400 ft^2/d, but reasonable matches between simulated and measured drawdowns were observed for transmissivity estimates that ranged from 2,200 to 2,400 ft^2/d. The best estimate of transmissivity will be biased above the actual value if the test was of insufficient duration to reach the final limb of a dual-porosity response.

Final estimates of parameters b', S, Ss, K', Ss', and Sf were dependent on initial estimates and could not be estimated uniquely. Estimates of matrix hydraulic conductivity (K') and fracture skin (Sf) could range over more than four orders of magnitude for models that matched the observed drawdowns equally well.

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APPENDIX A –TIME/WATER LEVEL/DRAWDOWN RECORDS

Well U-20a-2, February 10 – 11, 1965, time/drawdown data. Source of data, (Blankennagel and Weir, 1965, page 16, table 6). Drawdown data at 900 minutes removed from data set used to estimate transmissivity. Appendix A starts on next page.

DATE TIME	DEPTH TO WATER, IN FEET	ELAPSED TIME, IN MINUTES	DRAWDOWN, IN FEET
02/10/65 12:02:00	2086.50	0.00	0.00
02/10/65 12:02:30	2096.80	0.50	10.30
02/10/65 12:03:00	2098.00	1.00	11.50
02/10/65 12:03:30	2100.00	1.50	13.50
02/10/65 12:04:00	2101.30	2.00	14.80
02/10/65 12:04:30	2101.30	2.50	14.80
02/10/65 12:05:00	2101.30	3.00	14.80
02/10/65 12:05:30	2101.30	3.50	14.80
02/10/65 12:06:00	2101.70	4.00	15.20
02/10/65 12:06:30	2102.30	4.50	15.80
02/10/65 12:07:00	2102.70	5.00	16.20
02/10/65 12:08:00	2102.80	6.00	16.30
02/10/65 12:09:00	2102.80	7.00	16.30
02/10/65 12:10:00	2103.30	8.00	16.80
02/10/65 12:11:00	2103.60	9.00	17.10
02/10/65 12:12:00	2103.70	10.00	17.20
02/10/65 12:14:00	2103.90	12.00	17.40
02/10/65 12:16:00	2104.20	14.00	17.70
02/10/65 12:18:00	2104.40	16.00	17.90
02/10/65 12:20:00	2104.50	18.00	18.00
02/10/65 12:22:00	2104.60	20.00	18.10
02/10/65 12:27:00	2104.90	25.00	18.40
02/10/65 12:32:00	2105.16	30.00	18.66
02/10/65 12:37:00	2105.37	35.00	18.87
02/10/65 12:42:00	2105.49	40.00	18.99
02/10/65 12:47:00	2105.60	45.00	19.10
02/10/65 12:52:00	2105.70	50.00	19.20
02/10/65 13:02:00	2105.94	60.00	19.44
02/10/65 13:12:00	2106.17	70.00	19.67
02/10/65 13:22:00	2106.39	80.00	19.89
02/10/65 13:32:00	2106.52	90.00	20.02
02/10/65 13:42:00	2106.63	100.00	20.13
02/10/65 14:02:00	2106.84	120.00	20.34
02/10/65 14:22:00	2106.90	140.00	20.40
02/10/65 14:42:00	2106.95	160.00	20.45
02/10/65 15:02:00	2107.17	180.00	20.67
02/10/65 15:22:00	2107.29	200.00	20.79
02/10/65 16:12:00	2107.48	250.00	20.98
02/10/65 17:02:00	2108.09	300.00	21.59
02/10/65 17:52:00	2108.31	350.00	21.81
02/10/65 18:42:00	2108.54	400.00	22.04
02/10/65 20:22:00	2108.65	500.00	22.15
02/10/65 22:02:00	2108.85	600.00	22.35
02/10/65 23:42:00	2108.94	700.00	22.44
02/11/65 01:22:00	2108.94	800.00	22.44
02/11/65 03:02:00	2109.10	900.00	22.60
02/11/65 04:42:00	2109.10	1000.00	22.60
02/11/65 08:02:00	2109.31	1200.00	22.81
02/11/65 12:40:00	2109.66	1478.00	23.16
02/11/65 17:00:00	2109.10	1738.00	22.60