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Hydrologic Tests at Characterization Well R-16

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The World's Greatest Science Protecting America

Produced by the Groundwater Protection Program,
Risk Reduction and Environmental Stewardship-Remediation Services

Edited by Faith J. Harp, Comforce, for Group IM-1. Composition support provided by Jolene Catron, Group IM-1.

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Hydrologic Tests at Characterization Well R-16

Stephen G. McLin

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ABBREVIATIONS, ACRONYMS, AND NOTATION

ASTM	American Society for Testing and Materials
bgs	below ground surface
D	saturated thickness
EES	Earth and Environmental Sciences (Division)
EPA	Environmental Protection Agency
ER	Environmental Restoration (Project)
fpd	feet per day
ft/d	feet per day (hydraulic conductivity unit)
ft^2/d	square feet per day (transmissivity unit)
FY	fiscal year
gpd/ft^2	gallons per day per square foot (hydraulic conductivity unit)
gpm	gallons per minute (discharge unit)
hp	horse power
I	injection (data)
I.D.	inside diameter
IM	Information Management (Division)
K	hydraulic conductivity
LANL	Los Alamos National Laboratory
MDA	Material Disposal Area
O.D.	outside diameter
NMED	New Mexico Environment Department
NTU	nephelometric turbidity units
Q	discharge
R	recovery (data)
RR	residual-recovery (data)
RRES	Risk Reduction and Environmental Stewardship (Division)
s	water-level change relative to static position (drawdown)
S	storativity
SAIC	Science Applications International Corporation
SOP	standard operating procedure
t	time since testing began
t^1	time since testing stopped
T	transmissivity
TA	Technical Area

TD	total depth
TOC	total organic carbon
UDR	underground drill rig
y	displacement of water level in slug testing

HYDROLOGIC TESTS AT CHARACTERIZATION WELL R-16

by
Stephen G. McLin

ABSTRACT

Well R-16 is on the south rim of Cañada del Buey near Overlook Park, White Rock, New Mexico. It was completed at a depth of 1277 ft below ground surface (ft bgs) in September 2002. The well was constructed with four screens positioned at or below the regional water table. Screen 1 is at about 641–649 ft bgs. However, it is hydraulically isolated inside the abandoned 11.75-in. drill casing that is between 0 and 729 ft bgs and is unusable. Screen 2 is set into Santa Fe Group sediments at about 863–871 ft bgs. Screen 3 is also within Santa Fe Group sediments at about 1015–1022 ft bgs. Finally, screen 4 is also set into Santa Fe Group sediments at about 1237–1245 ft bgs. Individual static piezometric surfaces measured on 10 December 2002 for screens 2, 3, and 4 were 5643 ft, 5562 ft, and 5548 ft, respectively, suggesting a vertically downward component to the hydraulic gradient at this time. The measurements were made after the Westbay™ monitoring system was installed. Water levels were measured again on several occasions and were almost identical to the December measurements. Hence, these levels probably represent near-static conditions. In all probability, this vertical gradient component at well R-16 is in response to municipal pumping in the Buckman well field by the city of Santa Fe. Normally, a vertically upward component to the hydraulic gradient at well R-16 would be anticipated in response to a theoretical regional discharge boundary along the Rio Grande.

Constant-rate, straddle-packer, injection tests were conducted at all usable screens and typically included two short tests and one long test. The short tests were 1 min each but at different injection rates. The short tests were used for selecting an appropriate injection rate for the long tests. Both injection and recovery data from the long tests were analyzed using the Theis, Theis recovery, Theis residual-recovery, and specific-capacity techniques. The Theis injection, Theis recovery, and specific-capacity methods correct for partial screen penetration; however, the Theis residual-recovery method does not.

The long tests at screens 2, 3, and 4 were all conducted at similar injection rates, injection times, and recovery times. The individual responses to injection in all zones were typical of partially penetrating well screens in a massively thick, confined aquifer. The Theis simple recovery method yielded the most reliable values for transmissivity (T) for all three tests. These results suggest that the 559-ft-thick Santa Fe Group sediments near screens 2, 3, and 4 have individual T values of 879, 1092, and 916 ft^2/day, respectively. In addition, the horizontal-to-vertical anisotropy ratio for hydraulic conductivity (K_h/K_v) is about 1000:1 for all three zones.

1.0 INTRODUCTION

Characterization well R-16 was completed on the south rim of Cañada del Buey (Figure 1) near Overlook Park, White Rock, New Mexico, on 7 September 2002, at a depth of 1277 ft below ground surface (ft bgs). This well is immediately upstream of Los Alamos County's White Rock municipal sewage treatment plant. Well R-16 was installed as part of the Hydrogeologic Workplan (LANL 1998, 59599) in support of the Groundwater Protection Management Program Plan (LANL 1996, 70215). Geologic units penetrated by well R-16 are shown in Figure 2. This section includes (in descending order) 5 ft of surficial soil, 79 ft of the Otowi Member of the Bandelier Tuff, 8 ft of basaltic sediments, 55 ft of diatomaceous lake beds, 65 ft of the Cerros del Rio basalt, 15 ft of lake beds with basaltic detritus, 115 ft of older alluvium, 35 ft of Cerros del Rio basalts, 250 ft of river gravels, 30 ft of the Puye Formation (fanglomerate), 20 ft of river gravels, 51 ft of the Puye Formation (fanglomerate), and 559 ft of Santa Fe Group sediments. The Totavi Lentil mentioned by Griggs (1964, 8795) was reached in well R-16 between 377 and 627 ft bgs and between 657 and 677 ft bgs. Both of these units are listed as "river gravels" in Figure 2. Both units are also located above the regional water table.

No alluvial water was encountered at the start of drilling operations. In addition, no intermediate perched saturation was encountered during the remainder of drilling activities at well R-16. On 27 August 2002, the regional water table was first encountered during drilling in relatively coarse-grained sediments within the Santa Fe Group at 867 ft bgs. However, this water level quickly rose and stabilized within the Puye Formation (fanglomerate) at about 621 ft bgs. A static water-level depth of 642 ft bgs was later measured on 13 November 2002 during the video logging of the completed well. Since all screens were open to the entire wellbore, this measurement represents a composite depth-to-water. A Westbay™ monitoring system was deployed in well R-16 in early December 2002. Hence, subsequent water-level measurements are from individual well screens that are isolated from the wellbore. These water-level data, summarized in Table 1, show a consistent and stable pattern of individual static water levels throughout the Santa Fe Group sediments penetrated by screens 2, 3, and 4. Piezometric heads in screens 2, 3, and 4 on 10 December 2002 were 5643 ft, 5562 ft, and 5548 ft, respectively. This pattern clearly suggests a vertically downward component to the hydraulic gradient within Santa Fe Group sediments near well R-16. Normally, a vertically upward component to the hydraulic gradient would be expected at this location because the Rio Grande represents a theoretical, regional groundwater discharge boundary. In all probability, this gradient has been reversed (i.e., from upward to downward) by municipal water pumpage from the city of Santa Fe's Buckman well field (Vesselinov and Keating 2002).

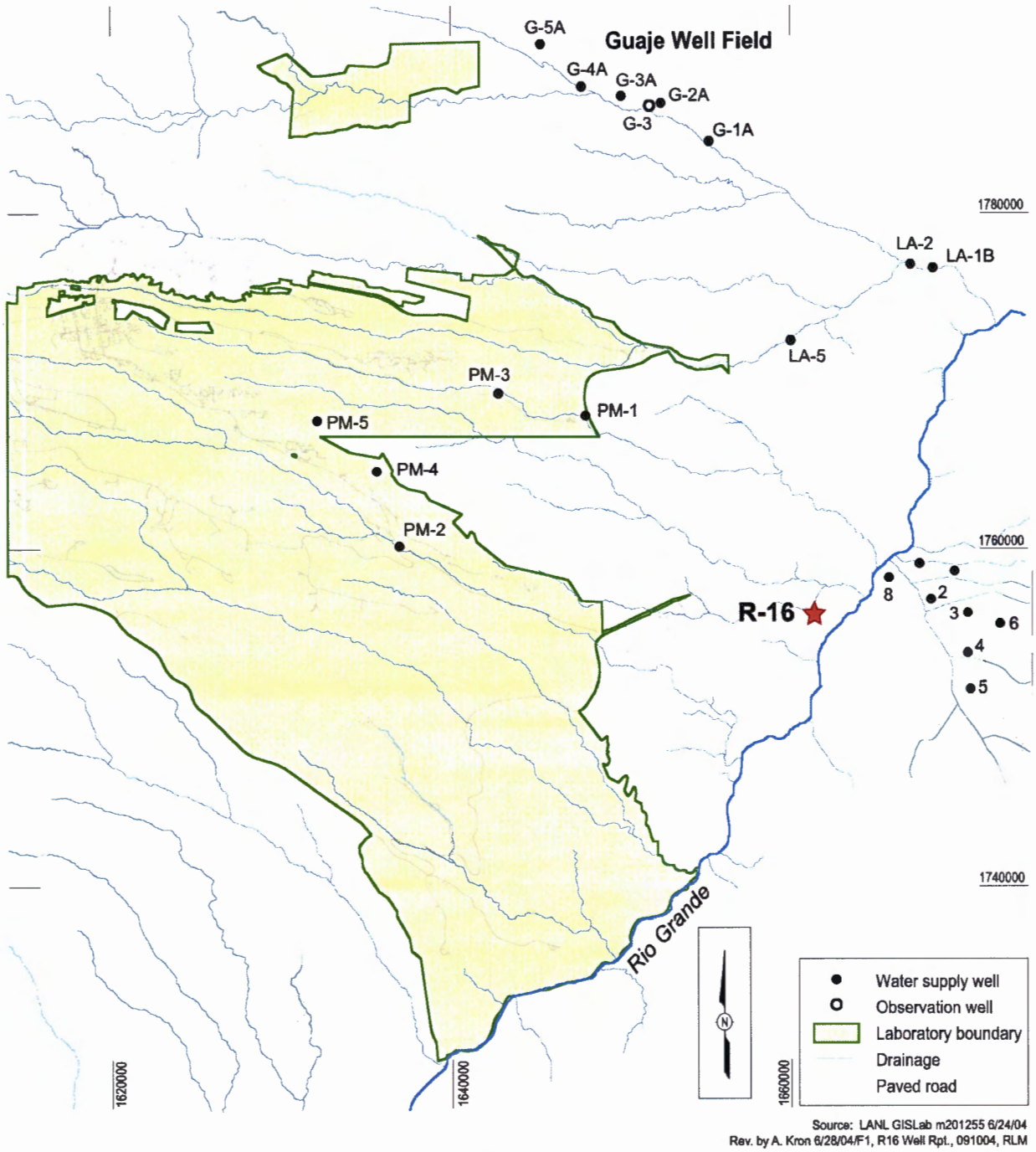

Figure 1. Location of characterization well R-16

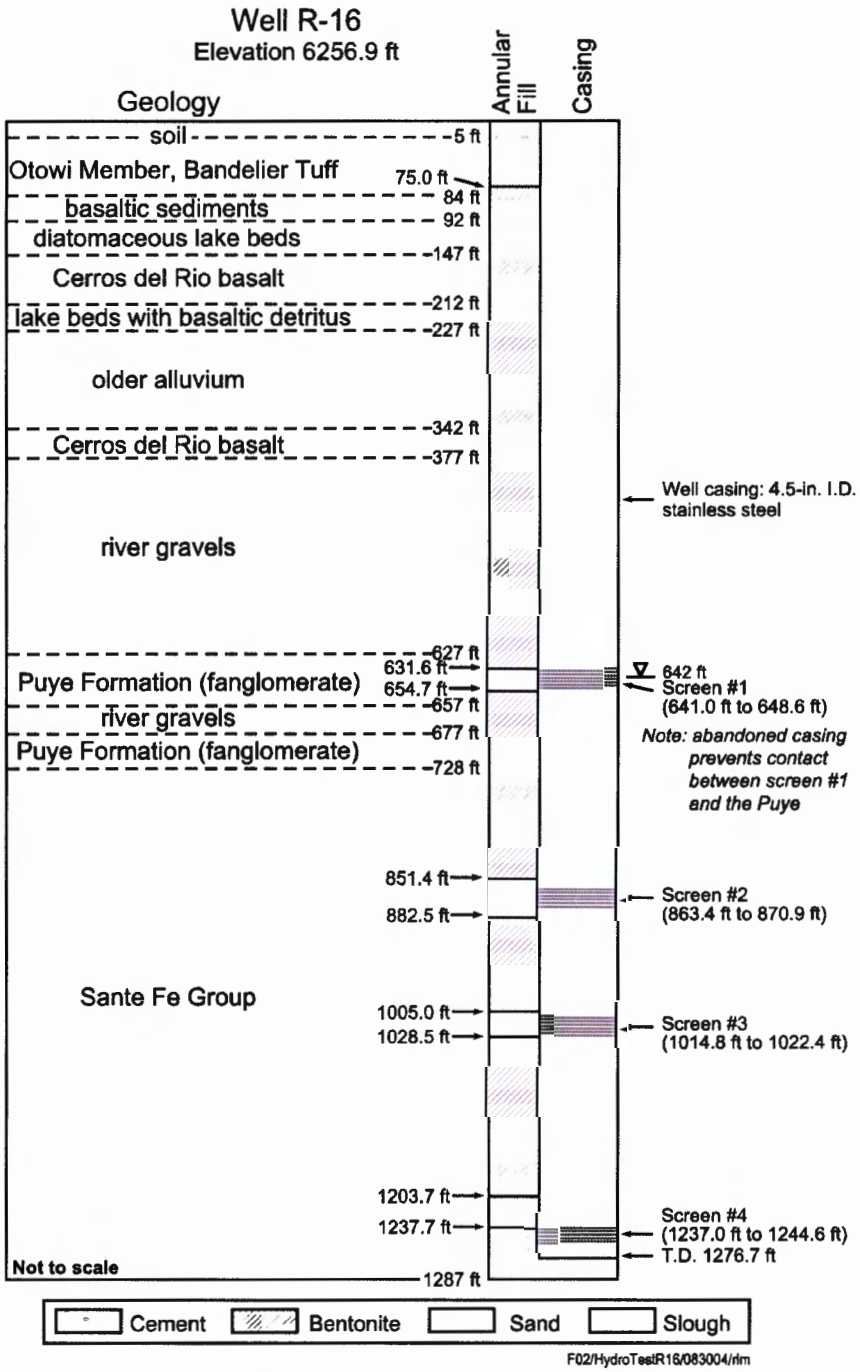

Figure 2. Hydrogeology and construction of well R-16

Table 1
Water-Level Measurements and Elevations in Well R-16

Date	Water Level	Remarks
27 August 2002	867 ft bgs (composite)	First observed level while drilling
27 August 2002	621 ft bgs (composite)	Stabilized level with no drilling
25 November 2002	642 ft bgs (composite)	After well development
10 December 2002	5642.9 ft (or 614.0 ft bgs)[a]	Screen 2 water-level elevation
10 December 2002	5561.7 ft (or 695.2 ft bgs)[a]	Screen 3 water-level elevation
10 December 2002	5547.6 ft (or 709.3 ft bgs)[a]	Screen 4 water-level elevation
14 December 2002	5643.0 ft (or 613.9 ft bgs)[a]	Screen 2 water-level elevation
14 December 2002	5560.4 ft (or 696.5 ft bgs)[a]	Screen 3 water-level elevation
14 December 2002	5547.7 ft (or 709.2 ft bgs)[a]	Screen 4 water-level elevation
10 September 2003	5643.1 ft (or 613.8 ft bgs)[a]	Screen 2 water-level elevation
10 September 2003	5558.4 ft (or 698.5 ft bgs)[a]	Screen 3 water-level elevation
10 September 2003	5547.2 ft (or 709.7 ft bgs)[a]	Screen 4 water-level elevation

[a]Individual water-level elevations were recorded by the Westbay monitoring system.

Well R-16 was constructed with four screens that are all located at or below the water table (Figure 2). Screen positions were selected to correspond to zones of high porosity and permeability on the basis of geologic and geophysical observations collected during well drilling. Screen 1 is located at about 641–649 ft bgs. However, it is hydraulically isolated from the Puye Formation (fanglomerate) because the screen is inside an abandoned 11.75-in. drill casing that is located between 0 and 729 ft bgs. Hence, this screen is unusable. Screen 2 is 7.5 ft long and is between 863.4 and 870.9 ft bgs within the Santa Fe Group deposits. Screen 3 has 7.6 ft of screened openings and is between 1014.8 and 1022.4 ft bgs within the Santa Fe Group deposits. Screen 4 also has 7.6 ft of screened openings and is between 1237.0 and 1244.6 ft bgs within the Santa Fe Group deposits. After construction, the well was developed by wire-brushing, bailing, chemical treatments, surging, and simultaneous jetting and pumping.

Well R-16 was drilled by fluid-assisted air-rotary and conventional mud-rotary methods to a total depth of 1287 ft bgs within the Santa Fe Group deposits. Because of sloughing near the bottom of the borehole, the completed well has a slightly shallower depth: 1276.7 ft bgs. The sloughing suggests a relatively high hydraulic conductivity at this depth.

Methods used in drilling, construction, and developing well R-16 are compatible with Environmental Protection Agency guidelines (Aller et al. 1991, 70112). Complete installation details are given in the well-completion report (LANL 2003, 76061).

2.0 AQUIFER TEST PROCEDURE

Testing at well R-16 was accomplished on all usable screens on 25–27 November 2002. Neither traditional slug tests nor pumping tests could be conducted in well R-16 because of its multiple-screen construction. However, the slug-test procedure was modified to one that is very similar to a drill-stem test commonly used in oil and gas wells (Earlougher 1977, 73478). Initially, a screen is hydraulically isolated by means of the straddle-packer assembly (Figure 3). Water is then injected by gravity into the well screen at a constant rate. The water level inside the packer assembly (Figure 3) initially rises very fast; however, the rate of rise eventually decreases, and the water level approaches a new quasi-static equilibrium in response to the constant inflow rate. The new quasi-static level is located some distance above the initial static water level. When injection is abruptly halted, the water level in the well immediately starts to fall and gradually returns to the original static position.

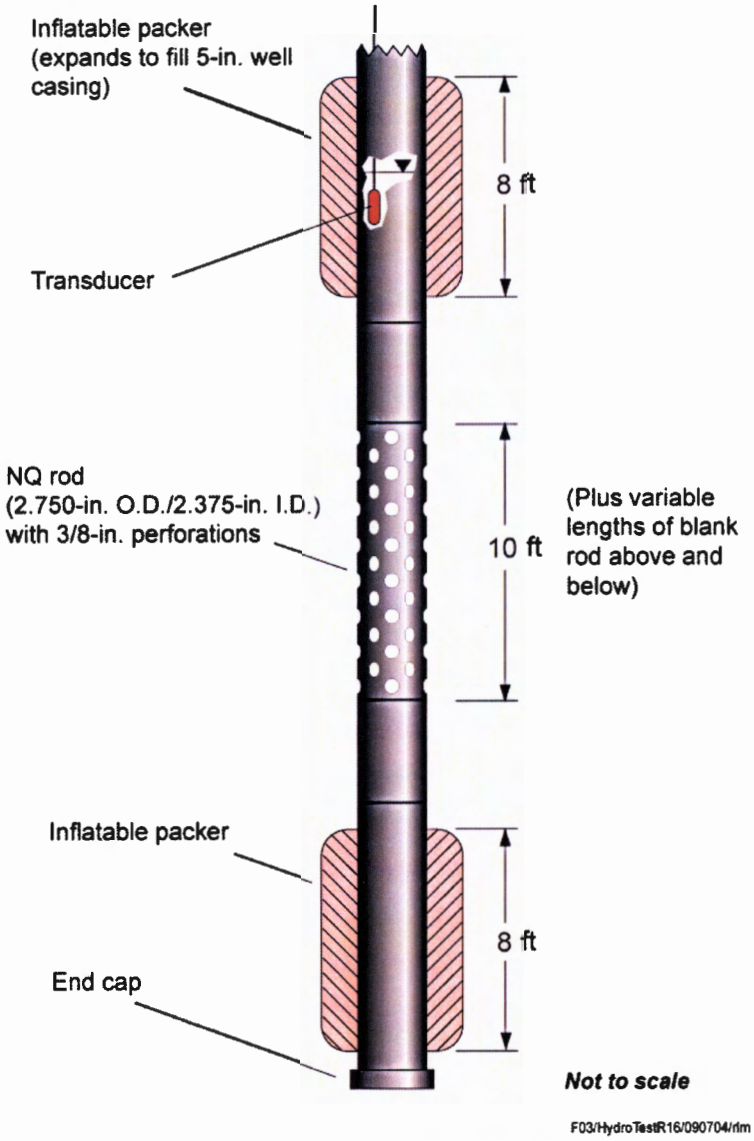

Figure 3. Straddle-packer/injection assembly used in R-16 tests

Field Procedure. A standardized procedure was followed for each test. First, the target screen was isolated by straddle packers deployed inside the well casing, and the static water-level condition was reestablished. Then, a finite amount of water was introduced at a constant rate for a finite period of time. Water was injected by means of a hose terminating in a short length of galvanized pipe that was inserted into the open end of the riser (or connector) pipe attached to the packer/injection assembly (Figure 3). Water moved by gravity down the riser pipe, through the upper packer, out of the perforated pipe in the injection assembly, through the screen, and finally into the saturated porous media. This riser pipe had a different diameter from that indicated on the straddle-packer assembly shown in Figure 3. Hence, the straddle-packer assembly had an inside diameter (I.D.) of 2.375 in.; however, the riser pipe for the testing reported here had an I.D. of only 1.375 in. The water level always remained inside the smaller-diameter riser pipe throughout all testing at well R-16. Generally, there were three tests at each screen (i.e., tests a, b, and c). The first two were short; the third was long.

The field-testing methods used are compatible with those recommended by the American Society for Testing and Materials (ASTM 1994, 70099; 1996, 70100). Testing procedures used were those outlined in Environmental Restoration Project (ER) Standard Operating Procedure (SOP) 07.03. Furthermore, the use of pressure transducers and collection of water-level measurements followed procedures given in ER SOPs 07.01 and 07.02, respectively.

Water introduced into the wells during injection testing did not affect water quality for three reasons: (1) the water injected was drinking water from the Los Alamos municipal supply and, therefore, did not introduce contaminants; (2) the volume of water injected was small, especially when compared with the volumes added in other stages of the well installation, so there was little dilution of natural groundwater; and (3) following testing, approximately seven times the volume of water introduced by testing was pumped from the well to remove the foreign water. The Ground Water Quality Bureau of the New Mexico Environment Department approved the injection of municipal water for these tests without requiring the Laboratory to apply for a special discharge permit.

Straddle-packer/injection testing involved various steps.

1. The straddle-packer/injection assembly (Figure 3) was emplaced around a screen, and packers were inflated from the surface. Gauges on the nitrogen tank were checked frequently to ensure that the packers were holding inflation pressure.
2. Water-level depth was measured with an electric water-level probe until readings stabilized and the static position was recorded. The target transducer depth was determined from this water-level depth measurement.
3. A transducer was emplaced and its position was recorded. Its operation and communication with the data-logger were checked by connection to a laptop computer.
4. Water for injection was placed in a large open stock tank. The water was taken up by means of a hose connected to a Bean pump mounted on a trailer. A hose was used to gravity-flow water into the well through a riser pipe connected to the injection assembly. Only municipal water was used for injection.
5. Before testing, the rate of discharge from the injection hose was measured, adjusted as required, and allowed to stabilize to a constant value by circulating water from the stock tank to the Bean pump and back to the stock tank. The initial injection rate for each test was based on the sustained yield established during well development.
6. A fixed volume of water was injected down the riser pipe connected to the straddle-packer assembly, or water was injected at a constant rate over a fixed time interval.
7. The variation in flow rate during injection and the total volume injected were evaluated by means of a flow meter (in-line between the pump and the water supply tank) and a stopwatch or a watch with a second hand.
8. Water-level rise during injection and recovery after injection ceased were measured by a transducer, recorded by a data-logger, and monitored by a laptop computer. The transducer pressure-head was checked periodically so as not to exceed its rated capacity.
9. When the water level returned to the pretest static position, the test was halted.
10. Posttest data (duration of test, final water level, volume injected, and volume to be purged) were compiled and recorded.

Following testing at well R-16, approximately seven times the total volume of water injected was purged from the well.

Comparison to Slug Tests. Traditional slug tests could not be performed because it was feared that the line on any bailer or slugger could become entangled with the transducer cable. The actual injection tests that were performed did not introduce instantaneously. That is, the peak water level does not occur at time zero in these injection tests. Instead, the peak resulting from injection occurs some time later, depending on the injection rate, the length of the injection period, the depth to water, and the hydraulic conductivity of the porous media outside the well screen.

Comparison to Pumping Tests. Traditional pumping tests also could not be performed because a modified packer assembly with a pump of sufficient size would not fit in the 4.5-in.-I.D. well casing and still have the capacity to stress the aquifer given the lift involved (an average of about 642 ft at well R-16). However, injection over an extended period of time is analogous to pumping over that same interval. In other words, the response to injection is theoretically the exact opposite to that of pumping. When a well is pumped, the water level drops until pumping ceases and then rises back to the pretest static level. By contrast, when water is injected into a well, the water level rises until injection ceases and then falls back to the pretest static position. However, this analogy is not perfect. For example, injection and formation waters are not at the same temperature, so dissolved air may come out of solution, unintended, during injection and partially clog the well screen. If present, this temporary well clogging by air bubbles may cause well efficiency to become a function of time when it is typically considered a constant. In addition, entrained air may be mixed with the free-falling injection waters and cause wellbore turbulence near the water surface. If the transducer is initially located immediately below this free surface, turbulence associated with air entrainment may cause water-level measurement errors in the injection test data. These errors typically appear as high-frequency water-level oscillations during the injection phase of a test, but the errors are usually absent during the recovery phase. Thus, the results from the injection phase of a test may tend to over- or underestimate transmissivity (T) by a small, but undetermined, amount.

Indication of Anisotropy. According to the water-level depths shown in Table 1, there is a downward vertical component to the hydraulic gradient between screens 2 and 3 and between screens 3 and 4. Here, hydraulic gradient is defined as the change in water level divided by the change in distance between the two points where the water levels are measured. Hence, using the midpoints of screens 2 and 3, the hydraulic gradient on 10 December 2002 was 0.536 (i.e., 695.2 ft – 614.0 ft ÷ 1018.6 ft – 867.2 ft). Since the computed gradient is positive, there is a component of groundwater flow moving from screen 2 toward screen 3. However, there appears to be a relatively strong resistance to vertical flow between screens 2 and 3 because the vertical component of hydraulic gradient is so large. Likewise, the vertical hydraulic gradient between screens 3 and 4 is 0.063 (i.e., 709.3 ft – 695.2 ft ÷ 1240.8 ft – 1018.6 ft). This value is more typical of that encountered in the field and suggests that the resistance to vertical flow is either much lower here (less likely) or that most of the groundwater flow is moving horizontally (more likely) toward the Buckman wells and under the Rio Grande. Again, since the gradient is positive, a small component of groundwater flow still moves from screen 3 toward screen 4. The respective screen midpoints are simply the top and bottom screen depths divided by 2. It is apparent that the hydraulic gradient between screens 2 and 3 is much larger than that between screens 3 and 4. This difference suggests that a significant portion of the water produced by the Buckman well field is being drawn from elevations at or near screens 3 and 4 in well R-16. The upper screened portions of most Buckman wells are also located near these same elevations. In addition, water near screens 3 and 4 is probably moving horizontally toward the Buckman wells and under the Rio Grande because the vertical gradient is relatively low.

Finally, these vertical gradients also suggest that at least some water near screen 2 is moving vertically downward to replace this Buckman production water. In other words, the Santa Fe Group sediments near screen 2 are acting like a leaky, confined source bed to underlying sediments. In addition, the sediments near screens 3 and 4 are the primary horizons that yield water to the Buckman wells. Vesselinov and Keating (2002) provide additional supporting data and numerical simulations for this conclusion. Hence, continuous water-level measurements from screens 3 and 4 will probably slowly oscillate in response to pumping patterns in the Buckman well field. It would be instructive to measure the temporal change in vertical hydraulic gradients in well R-16 at hourly intervals to verify these observations.

There is also a relatively strong contrast in hydraulic conductivity between screens 2, 3, and 4 as suggested by these vertical hydraulic gradients. This variation in hydraulic conductivity can be expressed as the ratio K_h/K_v, where K_h is the horizontal hydraulic conductivity and K_v is the vertical hydraulic conductivity. The methodology used for exploring this variation in the anisotropy ratio is explained in the next section, and individual test analyses are highlighted under the Discussion sections for each screen.

In addition, a new protocol was adopted for testing well R-16 and other wells installed in fiscal year (FY) 2002. The protocol involved multiple tests, in which injection rates and test durations were varied. Three injection tests were conducted at each screen selected for study: two short tests and one of prolonged duration. In both short tests (i.e., tests a and b), injection lasted only 1 min. The short tests helped in determining an appropriate injection rate for the longer test (or test c). In the third or longer test, the injection rate was adjusted on the basis of water-level response in the short tests, and the injection time was extended to a period of up to 2 hours. In some cases, where hydraulic conductivity was low, the period of injection in the longer test was shortened to avoid exceeding the depth capacity of the transducer.

3.0 DATA ANALYSIS

Data collected during the long injection tests at well R-16 were analyzed by various standard pumping-test methods because injection over an extended period of time is analogous to pumping over that same interval. Analyses included data from both the injection and recovery portions of the long test (i.e., test c). Test data were analyzed by four methods for comparison, including specific capacity, Theis residual-recovery, Theis injection, and Theis recovery techniques.

Tests are assigned a unique number based on the screen number (e.g., 2 for screen 2). Analytical plots are identified by this number and an abbreviation for the data used: (I), tests used injection data; (R), tests used recovery data; and (RR), tests used residual-recovery data. These recovery terms are defined below. Thus, an analytical plot labeled R-16-2c(R) is for the long, or third, test at screen 2 using recovery data. The analytical method and results are also given on individual plots for reader convenience.

Response to Injection. Initially, water-level responses to injection were collected over time. According to image-well theory, these data can be treated exactly like drawdown data in response to pumping. Hence, the response to injection was measured by subtracting the static equilibrium value established before injection from the water level at any time during injection. These data were treated like drawdown data and analyzed by classical pumping techniques.

Residual Recovery. Next, recovery was determined by subtracting the static level determined before injection from the observed water levels after injection ceased. Results of this operation are called residual-recovery data to differentiate from data obtained by the simple-recovery procedure described below. The advantage of this type of recovery data is that it is not potentially biased by a trend line fitted

to the observed data as in the simple-recovery method. However, the disadvantage is that the effects of partial penetration are not taken into consideration when commercially available software is used.

Simple Recovery. Finally, a procedure described by Driscoll (1986, 70111, pp. 252–260) was employed for recovery data collected after injection ceased. In this method, a trend line is extended through the data collected from the latter portions of the injection phase and into the recovery period, as illustrated in Figure 9.37 of Driscoll. Recovery was then computed as the difference between values on this trend line and the observed water levels measured at the same time. Results of this process are simply called recovery data, and the analysis is identical to that for pumping (or injection) data. The advantage of using this type of recovery data is that the effects of partial penetration can be taken into consideration when commercially available software is used.

Data Analysis Rationale. For analysis, commercially available aquifer testing software was used for determining aquifer T. That is, test data were fitted to appropriate theoretical type-curve models using Aqtesolv™ for Windows (Version 3.50, Professional). The software automatically provides a storativity (S) value for any analysis by pumping-test methods. However, because such a determination is not valid for single-well tests, S values are not reported here. The software allows the horizontal-to-vertical anisotropy ratio for hydraulic conductivity (K_h/K_v) to vary for some methods of analyses but keeps the ratio fixed at 1 for other methods. Hence for consistency, this ratio was initially set at 1 in all techniques so that results from different methods could be compared. The specific-capacity analysis was performed first because this method is viewed as providing a lower-bound estimate for T. Next, the traditional Theis residual-recovery method was applied because this technique uses recovery data that generally have fewer disturbances than do injection data. The K_h/K_v ratio cannot be varied with either of these techniques. However, it can be changed in the Theis method. According to the discussion presented earlier, the K_h/K_v ratio is probably larger than 1 according to the vertical hydraulic gradient information. Hence, a Theis sensitivity analysis was performed where the K_h/K_v ratio was systematically varied between 1 and 10,000. The best estimate for T was selected from these latter analyses according to the following criteria: a single Theis T value and the corresponding K_h/K_v ratio using simple recovery data were considered best when this T value matched or just exceeded the specific-capacity T value. Finally, all recommended T values are summarized in Table 2. Specific details for individual test analyses are presented under the Discussion section for each screen.

Specific-Capacity Method (McLin 2004, 82834). As an initial comparison, injection test data were analyzed by the specific-capacity method to determine T. This technique was modified by McLin from a procedure originally developed by Bradbury and Rothschild (1985, 76040). Here, specific capacity is defined as discharge (Q) divided by drawdown or injection (s), and has units of gallons per minute per foot. Strictly speaking, this method is valid only for confined aquifers and is typically used for estimating a minimum value for T. However, it is also used for unconfined aquifers as a basis of comparing alternative techniques. This method uses an iterative approach to solve for T, using the Cooper-Jacob approximation for the Theis well-function. It also corrects specific-capacity data for partial penetration and well losses in arriving at an estimate for T. As before, K is then obtained from the relationship $K = T/D$, where D is saturated thickness. Numerous authors (e.g., Walton 1970, 76044) have demonstrated that T values from the specific-capacity technique are rather insensitive to changes in S. McLin has also suggested that well efficiency and partial penetration effects can dramatically influence these T values. Hence, the original program of Bradbury and Rothschild was modified by McLin so that it uses a single S value while allowing well efficiency and partial penetration to vary over an expected range of values. The original Basic program was adapted to the Matlab™ language, and it computes and plots a range of T values. This range in T values demonstrates that the specific-capacity method is relatively sensitive to variations in these latter parameters. Hence, the analyses should be viewed as representing a lower limit for possible T values. As previously mentioned, the K_h/K_v ratio is fixed at 1 with this method.

Table 2
Summary of Injection Testing at Well R-16

Parameter	Screen 2	Screen 3	Screen 4
Geologic Unit	Santa Fe Group sediments	Santa Fe Group sediments	Santa Fe Group sediments
Screened interval (ft)[a]	863.4–870.9	1014.8–1022.4	1237.0–1244.6
Screen length (ft)	7.5	7.6	7.6
Filter-pack length (ft)	31.1	23.5	83.3
Saturated thickness (ft)	559	559	559
Westbay static depth to water (ft) on 10 December 2002	614.0	695.2	709.3
Hydraulic gradient to next lower screen midpoint (ft/ft); see Figure 2	0.536	0.063	—
Average injection rate (gpm)	8.45	9.74	8.04
Injection rate variation (%)	<1	<1	<1
Injection period (min)	120	120	105
Total volume injected (gal.)	1032	1185	858
Volume purged after test (gal.)		22,800	
Transmissivity (ft^2/day) from specific capacity	849	1058	900
Transmissivity (ft^2/day) from Theis recovery (best estimate)	879	1092	916
Hydraulic conductivity (ft/day) from Theis recovery (best estimate)	1.6	2.0	1.6
Anisotropy (K_h/K_v) ratio from Theis recovery (best estimate)	1000:1	1000:1	1000:1

[a]All depths are in ft bgs.

Theis Residual-Recovery Method (Theis 1935, 70102). Test data were also analyzed by the Theis residual-recovery method. This traditional method differs from the Theis analysis of recovery data described below in that it uses residual-recovery data. Residual recovery is the difference between the original static water level and the depth of water at a given instant during recovery. In this method, a straight line is drawn through a semilogarithmic plot of residual recovery versus the dimensionless ratio t/t′, where t is the time since injection started and t′ is the time since injection stopped. This method is probably more widely used than the simple Theis recovery method; however, corrections for partial penetration cannot be made with this technique. The reason that two different recovery methods were employed is simple: when using the pumping (or injection) well as the observation well, many hydrologists consider recovery data to be more reliable than pumping (or injection) data because wellbore turbulence is minimized. As previously mentioned, all approaches should replicate one another exactly unless specific model assumptions are violated. When they do not, one simply has additional information to make inferences about dominant effects during certain phases of the test procedure. These inferences can affect the final interpretation as to which method is more reliable. As with the previous method, the K_h/K_v ratio is fixed at 1 with this technique.

Theis Method (Theis 1935, 70102). Finally, the long tests were analyzed by the Theis method using a K_h/K_v ratio of 1. Analyses include both injection and simple recovery data (as defined above). In this

classical method, a log-log plot of injection or simple recovery data versus time is fitted to a Theis type-curve. The method assumes that the well is fully penetrating, the hydraulic condition of the aquifer is confined, and application of stress is by prolonged withdrawal or injection of water. The method has been extended to include partial penetration effects in confined aquifers, and to unconfined aquifer conditions by application of the Jacob correction to observed water levels (Walton 1970, 76044). Theoretically, both injection and recovery techniques should replicate one another. However, when they do not, one might infer that wellbore clogging, turbulence, or other phenomena were present during some phase of the test (usually during the injection phase). Finally, the K_h/K_v ratio was systematically varied between 1 and 10,000 using simple recovery data. A single best estimate for T was selected from these latter values by comparing them with the specific-capacity T value. The resulting best estimate for T equaled or exceeded the specific capacity value. This best estimate and its corresponding K_h/K_v ratio from the Theis simple recovery method are reported in Table 2.

All usable screens at well R-16 were tested. Two short tests and one long test were conducted in screens 2 and 3; however, only one short test and one long test were conducted in screen 4. Analytical test results are presented below. Regardless of the method used, our general approach was to obtain the best curve-match possible and then evaluate the resulting hydraulic parameter values. Interpretation of these results is treated in the Discussion section for each test.

4.0 SCREEN 2 ANALYSES

The top of screen 2 lies at a depth of 863.4 ft bgs, approximately 221 ft below the composite water-table depth (Figure 2) and about 249 ft below the isolated static piezometric surface for screen 2 (Table 1). As Figure 4 shows, three injection tests were performed at screen 2: two of short duration and one of prolonged duration. Again, the purpose of the first two short injection tests was to establish an optimal injection rate for the long test. The design and results for the long test at screen 2 are given in Table 2; field data are plotted in Appendix A-1 and tabulated in Appendix A-2.

Test 2a. In the first short test at screen 2, water was injected between packers at a rate of 6.29 gallons per minute (gpm) for 1 min. Initially, water rose more than 21 ft in response to injection. Although injection stopped after 1 min, the water level continued to rise for a short time. Then the water level exponentially declined back toward the initial static position in about 10 min. Although these data cannot currently be analyzed because available slug-test methods assume instantaneous delivery of water, test 2a helped in the determination of the appropriate injection rate for the long test (test 2c).

Test 2b. In the second short test, water was injected between packers at a rate of 11.46 gpm for 1 min. In a response similar to that in the first test, the water level rose to an initial peak value of almost 52 ft above static in slightly less than 2 min. From there, the water level declined exponentially back toward static equilibrium in about 13 min. This test could not be analyzed by available slug-test methods because water was not injected instantaneously.

Test 2c. The third or long test at screen 2 involved injection at a rate of 8.45 gpm for 120 min. Injection was then stopped, and water-level recovery was monitored for the next 46 min. The water-level response (see Figure 4 and Appendix A-1) was clearly oscillatory in response to continuous injection. After rising rapidly to an initial peak, water levels began to gently oscillate around a gradually rising trend until injection was halted. This small but significant oscillatory behavior cannot be attributed to fluctuations in injection rate since this rate was essentially constant (i.e., less than 1% variation). In addition, the observed small, high-frequency oscillations are not associated with low-frequency barometric pressure fluctuations. In all probability, these oscillations are due to wellbore turbulence caused by entrained air captured during the free-fall injection test procedure. The turbulence was apparently recorded by the

transducer because it was inadvertently located too close to the initial static water level. These oscillations may also have resulted from well-screen clogging as dissolved air came out of solution because the injection and formation waters were at different temperatures. However, this explanation seems less likely because the well screen is generally located relatively far from the initial static water level, and waters of different temperatures probably had time to mix sufficiently. In any event, when injection ceased, the water level immediately began to decline smoothly toward the pretest static position because neither effect was present during recovery. Water-level data for both injection and recovery portions of the test are given in Appendix A-2. Design parameters and test results are summarized in Table 2.

Field data for all tests in screen 2 are shown in Figure 4. Curves for injection and simple recovery data are compared in Figure 5. These two curves are somewhat different; normally, one expects them to resemble one another closely. These differences between injection and simple recovery are most likely due either to turbulence caused by entrained air captured during the free-fall injection or to well-screen clogging related to water temperature differences. In other words, the polynomial extrapolation from the injection phase into the recovery phase of the test was probably biased somewhat by a less than perfectly defined least-squares fit of the oscillatory water-level data obtained during injection. A test configuration diagram (Figure 6) lists important test configuration parameters for the Aqtesolv software.

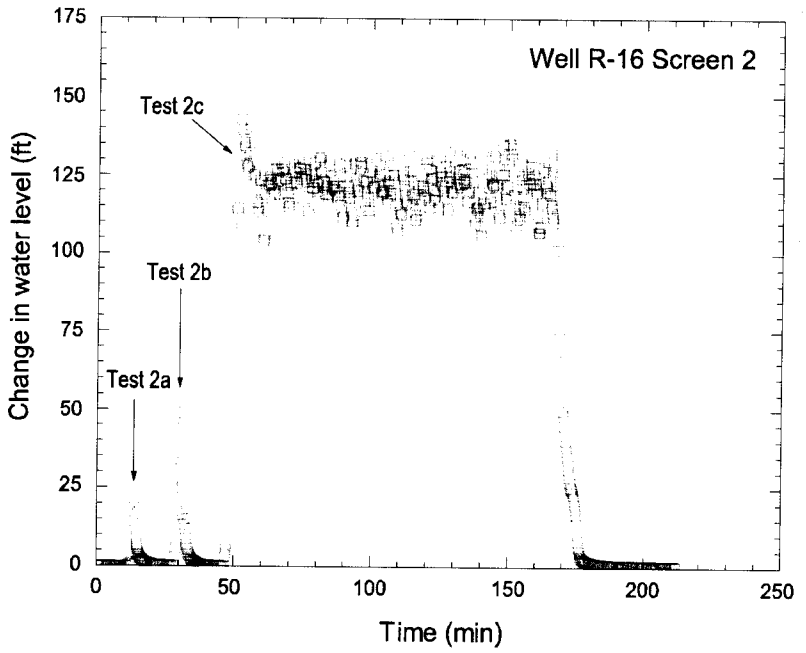

Figure 4. Field plot for the three tests at well R-16, screen 2

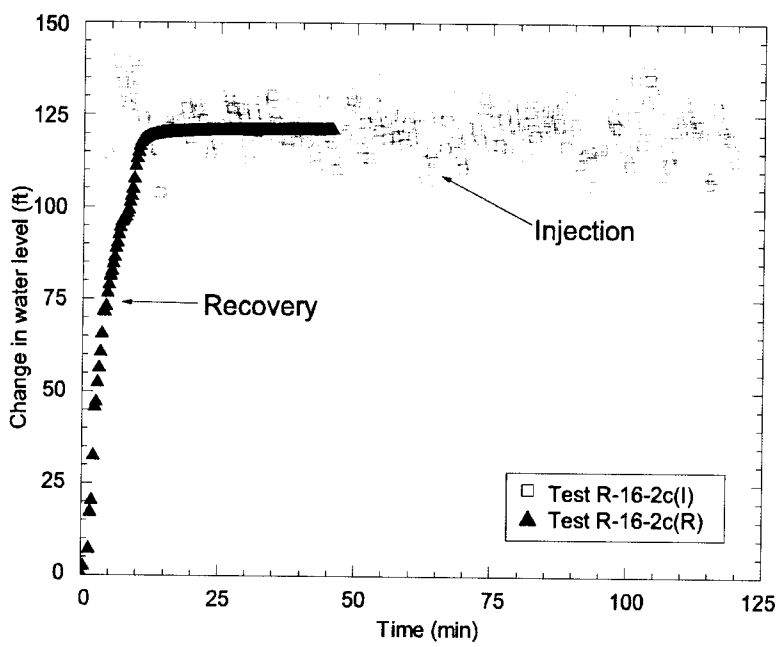

Figure 5. Comparison of injection and recovery data for test R-16, screen 2

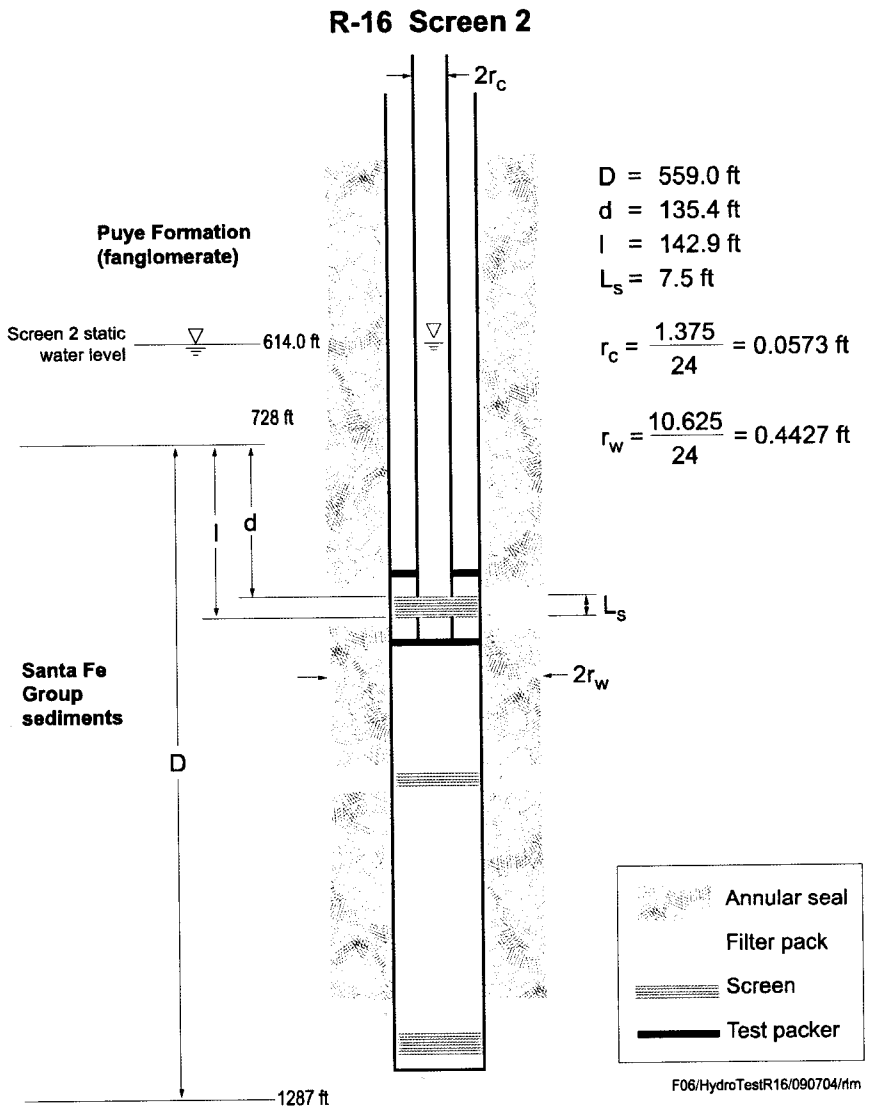

Figure 6. Test configuration parameters for the analysis of the R-16-2c aquifer test

Specific-Capacity Analysis. Initially, a modified version (McLin 2004, 82834) of the specific-capacity method of Bradbury and Rothschild (1985, 76040) was used for computing a range of values for *T*. Results from test 2c are summarized in Appendix A-3 using input values listed there. The range in *T* values demonstrates that the specific-capacity method is relatively sensitive to variations in partial penetration and well losses for test 2c over an expected range of values for these parameters, and represents a lower limit for the actual *T* value. For optimum conditions at screen 2 (i.e., assuming 100% well efficiency, 100% aquifer penetration, and a formation storativity of 0.003), a *T* of 7 ft^2/day is obtained (Appendix A-3). For more realistic conditions when well efficiency is 80% (estimated) and partial penetration is 1.34% (observed), a *T* of 849 ft^2/day (Appendix A-3) is obtained. Dividing this *T* by a saturated thickness of 559 ft gives a *K* of 1.5 ft/day. These values represent a lower limit for both *T* and *K* when the K_h/K_v ratio is 1. However, this ratio is probably larger than 1, and the associated *T* and *K* values are also probably larger.

Theis Residual-Recovery Analysis. For further comparison, test 2c data were analyzed by the Theis residual-recovery method (Figure 7). Aqtesolv does not correct for partial penetration with this technique even though the screen 2 penetration is less than 2% of the total thickness of the Santa Fe Group sediments (i.e., 7.5/559). Residual-recovery is defined as the difference between the pretest static water level and the observed water level during recovery (Driscoll 1986, 70111, pp. 252–260). The advantage of this approach is that a trend in injection water levels through the recovery period is not required to compute recovery. Unfortunately, the recovery period was somewhat short. Note, however, that a *T* of 178 ft^2/day was obtained, and corresponds to a *K* of only 0.3 ft/day. In Figure 7, t is defined as time since injection began, and t′ is time since injection stopped. Hence, the lower end of the dimensionless time axis (i.e., between 1 and 10) actually represents late time, while the upper end of the dimensionless time axis (i.e., about 50 to 1000) represents early time. Likewise, in Figure 7-a, *S* is defined as storativity during injection, and *S′* is storativity during recovery. Theoretically, the *S/S′* ratio should approach 1 if no boundary is present (Driscoll 1986, pp. 246–247; Walton 1970, pp. 158–167). However, if a barrier (or no-flow) boundary is present, then *S/S′* is <1. If a recharge boundary is present, then *S/S′* is >1. An *S/S′* value of 2.44 for test 2c suggests that a recharge boundary might have been encountered at late time. However, no such boundary is suggested in the Theis analyses presented below. The *S/S′* ratio can also be affected by atmospheric-pressure effects near the end of the test (unlikely in this test). Alternatively, one might also conclude that the expanding three-dimensional (3-D) cone of impression has caused a flattening slope change (more likely). These flattening changes are generally associated with recharge, leakage, or an increasing *T* value going away from the well screen, rather than a traditional boundary effect. Hence, no conclusive statement can be made about the boundary type, or even that one really exists. Such effects are best confirmed using a separate observation well and test of even longer duration than test 2c, where changes in barometric pressure can be taken into account. Interestingly, the *T* value obtained from the Theis residual-recovery analysis shown in the expanded scale of Figure 7-b strongly suggests a flattening slope over increasing time. This type of behavior is typical for a partially penetrating well in a very thick, confined aquifer or when the *T* value increases laterally away from the well screen. Also note that the *T* value obtained with the specific-capacity analysis presented above is more than 4.8 times larger than that obtained with the Theis residual-recovery method (i.e., 849/178). This discrepancy is quite unusual because the specific-capacity technique is supposed to provide a lower limit to *T*. Since the specific-capacity method accounts for partial penetration and the Theis residual-recovery method does not, the effects of partial screen penetration appear significant and should be taken into account.

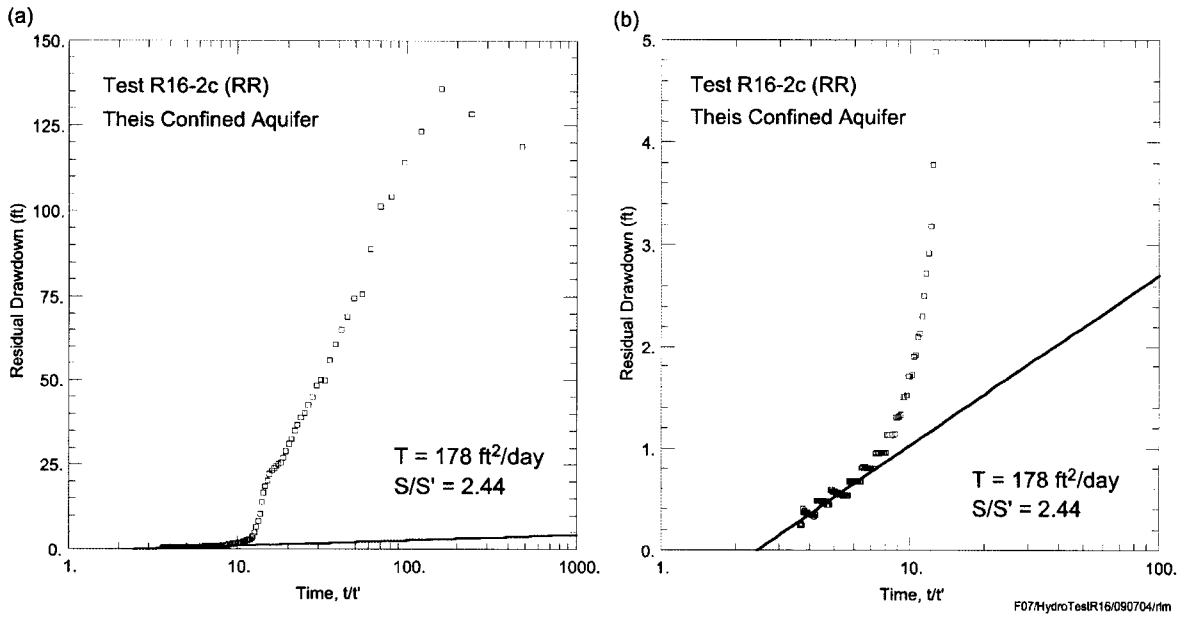

Figure 7. Theis confined aquifer analysis for R-16-2c residual-recovery data: (a) a normal scale and (b) an expanded scale

Theis Analysis. Both injection (Figure 8) and recovery (Figure 9) data from test 2c were analyzed by the Theis method for confined-aquifer conditions. The Aqtesolv program corrects the Theis method for partial aquifer penetration. As Figure 8 shows for the injection phase, a *T* value of 396 ft^2/day was obtained. Dividing this *T* by a saturated thickness of 559 ft gives a *K* of 0.7 ft/day. As Figure 9 shows for the recovery phase, a *T* value of 400 ft^2/day and a *K* of 0.7 ft/day were obtained. Considering the differences between injection and recovery responses (i.e., Figure 5), it is encouraging that the results for the Theis analyses (Figures 8 and 9) are essentially the same. However, the curve-fitting procedure required to obtain recovery data is subjective in nature. At the same time, recovery is much smoother than injection because these data do not contain significant wellbore turbulence effects associated with injected waters free-falling about 614 ft before exiting the well screen and filter pack. Nor do these analyses consider temperature differences between injection and formation waters that might cause dissolved air to come out of solution and clog the well screen. Finally, the *T* value obtained with the specific-capacity analysis presented above is more than 2.1 times larger than that obtained with the Theis recovery method (i.e., 849/400). This discrepancy is also unusual and suggests that the anisotropy ratio is larger than 1.

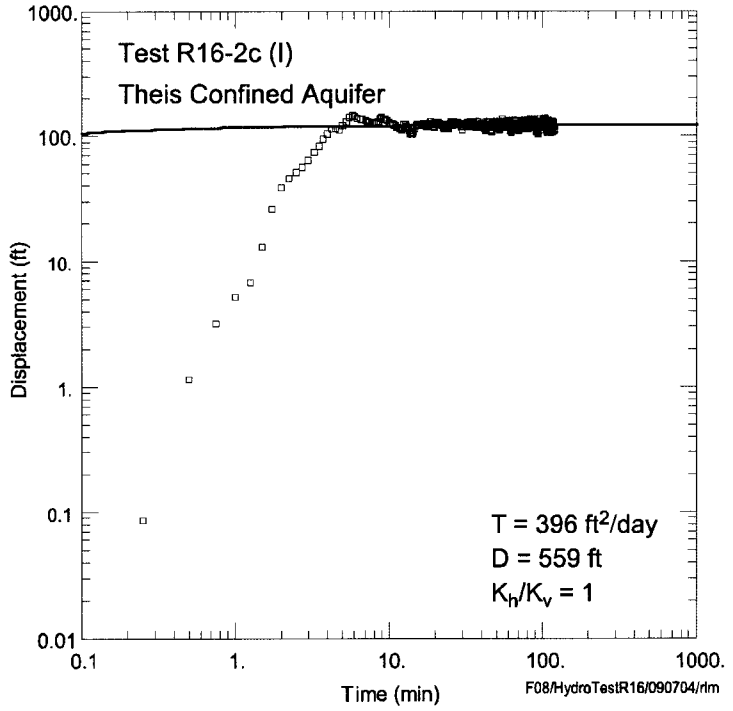

Figure 8. Theis confined aquifer analysis for R-16-2c injection data

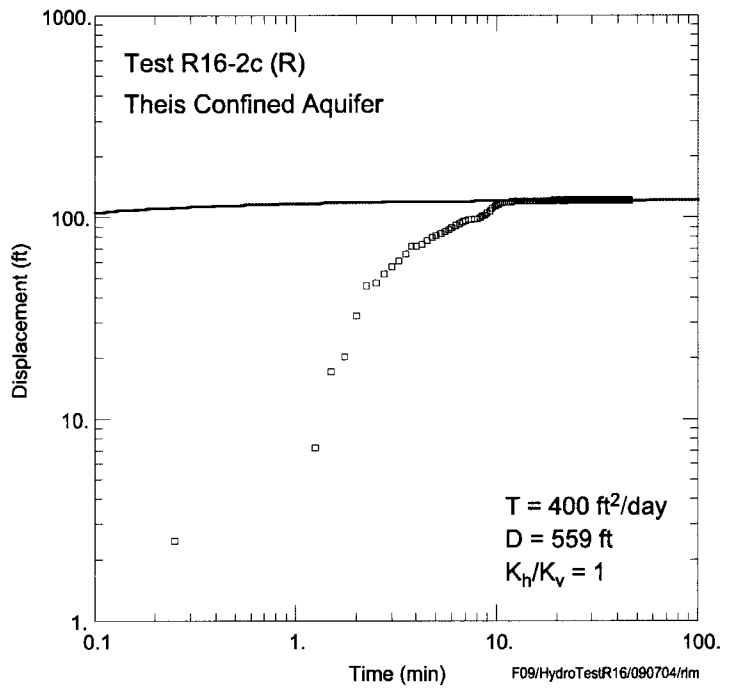

Figure 9. Theis confined aquifer analysis for R-16-2c recovery data

Anisotropy Effects. The Theis analysis for simple recovery was repeated, and the anisotropy ratio (K_h/K_v) was allowed to vary between 1 and 10,000. These results did not significantly change the shape of the Theis type-curve fit shown in Figure 9. However, as Figure 10 shows, T values were significantly increased. The value for T from Figure 10 that just exceeds the specific-capacity value of 849 ft^2/day found earlier occurs at K_h/K_v = 1000. With this criterion, the best estimate for T at screen 2 is obtained from the Theis simple recovery analysis with T = 879 ft^2/day and K_h/K_v = 1000. These values are shown in Figure 11 and listed in Table 2.

Discussion. The static water level obtained before the start of test 2a was reestablished after each of the three injection periods (Figure 4 and Appendix A-2). However, the dilemma encountered in testing R-wells on Pajarito Plateau is that many of these wells are subjected to a severe case of partial well penetration in a massively thick, anisotropic, confined aquifer. Well R-16 is no exception. Hence, when these wells are tested, the cone of depression (or impression in the case of injection) expands both horizontally and vertically throughout the test unless a sufficiently tight aquitard is encountered at depth to limit the growth of the cone in the vertical direction. The problem is that the depth of the cone at any time is not known unless an observation well is available. Hence, it is often not possible to know what aquifer thickness to use when calculating hydraulic conductivity (K), using the relationship $K = T/D$, where T is transmissivity and D is saturated thickness. Hence, T may increase as the cone expands because D is increasing in an unknown fashion. This condition makes test analyses extremely difficult because there is no analytical method that exactly applies to these complex test conditions. Furthermore, there is some additional uncertainty associated with the test results that cannot be eliminated (i.e., either well-screen clogging or water-level turbulence resulting from injection).

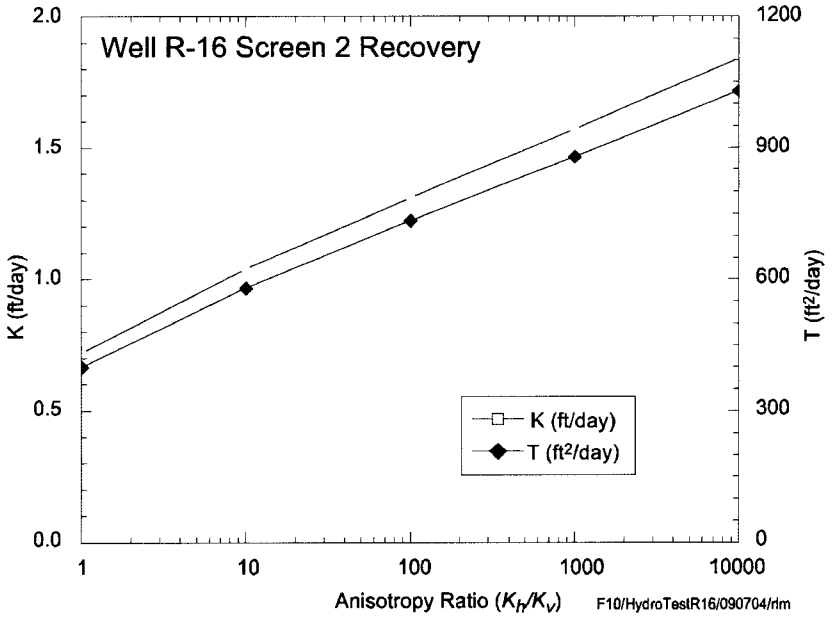

Figure 10. Effect of anisotropy ratio (K_h/K_v) on transmissivity (T) during test R-16-2c(R)

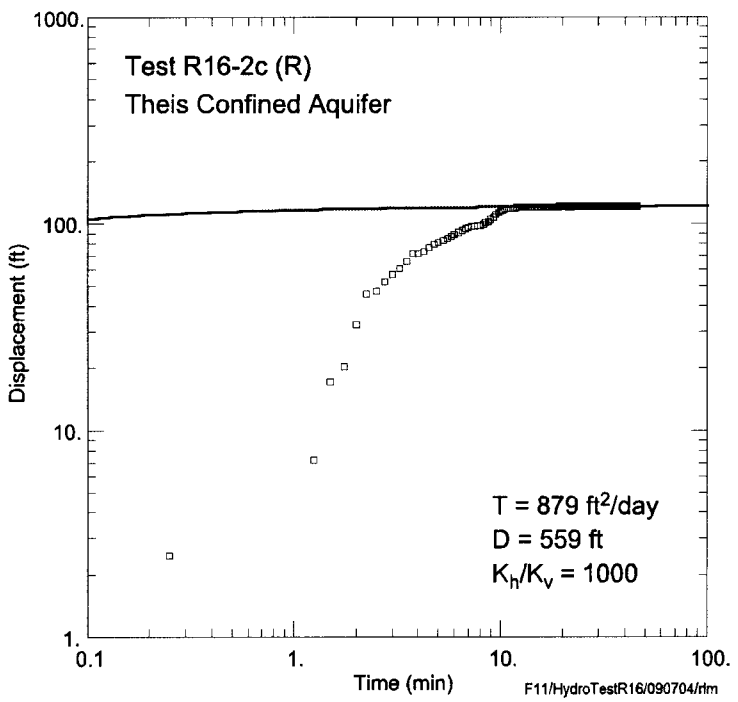

Figure 11. Theis confined aquifer analysis for R-16-2c recovery data with K_h/K_v = 1000

Figure 5 shows injection and recovery data versus time from screen 2. On the plot, the effect of casing storage is apparent (i.e., the steep portion of each plot before the slope changes at about 5–10 min). The theoretical duration of casing storage can be calculated from the following equation (Schafer 1979, 73449):

$$t_c = \frac{0.6\left(D^2 - d^2\right)}{Q/s}, \tag{1}$$

where t_c is the duration of casing storage (minutes), D is the I.D. of the well casing (1.375 in. here), d is the outside diameter (O.D.) of column pipe (0 inches for the injection tests here), Q is the discharge rate (gallons per minute), and s is drawdown (or recovery in feet) at time t_c. The data from the R-16 test of screen 2 produced theoretical casing storage duration of about 16 min for both the injection and recovery test phases. In other words, the injection and recovery data should describe a steep curve for about 16 min. This curve should gradually transition to the correct theoretical slope after these effects have dissipated. This formula usually produces a conservative t_c estimate. In many tests, the observed effects of casing storage can be as little as half the theoretical value because the asymptotic approach of the data to the theoretical drawdown curve has been largely achieved by then. Thus, a calculated value of 16 min might imply that observed casing storage effects would be observed for at least 8 min.

According to Equation (1) and the calculations made above, the time-recovery graph in Figure 7 should reveal an abrupt slope change at about $t/t' = 8.5$ [i.e., (120 + 16)/16] since the injection phase was 120 total min and casing storage effects theoretically lasted about 16 min into the recovery phase. In other words, casing storage effects are theoretically in effect for $t/t' > 8.5$. This behavior should be clearly apparent in Figure 7-b as t/t' becomes smaller and smaller. However, a gradually flattening curve is visually apparent out to about $t/t' = 13$ and implies that casing storage was observed during recovery for only 10 min instead of 16 min (i.e., $t/t' = (120 + 10)/10$]. Regardless, the linear fit in Figure 7-b uses only data beyond the theoretical time (i.e., $t/t' < 8.5$). This behavior also reflects an increase in T farther away from the well caused by the ever-expanding cone of impression. This behavior is typical of a partially penetrating well in a very thick, confined aquifer. Unfortunately, the Theis residual-recovery method assumes full penetration.

Inspection of the time-injection graph on Figure 8 and the time-recovery plot in Figure 9 suggests that the observed duration of casing storage effects were visually apparent for about 4 min during injection and about 10 min during recovery. Hence, the Theis curve fits use-only data beyond these times. These times are different from theoretical time presented above because of the logarithmic scales in Figures 8 and 9 and because the injection data are inherently more noisy than recovery data.

Which analytical method gives the most representative hydraulic properties for the formation opposite screen 2 in well R-16? On the surface, the specific-capacity technique appears to be the least accurate of all techniques presented because it uses only one value for injection at one time during the entire test. This technique is in stark contrast to a conventional aquifer test in which numerous s and t values are matched to an appropriate theoretical type-curve. However, according to Walton (1970, 76044, pp. 314–321), the specific-capacity method gives minimum values for T because the effects of partial penetration, well losses, and hydrogeologic boundaries are taken into consideration. This is also the case with the Theis method, which also allows K_h/K_v to vary.

Ultimately, the Theis simple recovery data (Figure 11) provide the best estimate of T for the aquifer materials near screen 2 when $K_h/K_v = 1000$ because this analysis is not affected by water-level data collected during injection. Furthermore, this technique replicates the specific-capacity analysis while accounting for anisotropy. Finally, the residual-recovery analysis is not as reliable as are the other

methods presented here because it does not account for partial penetration effects and does not consider variations in the K_h/K_v ratio.

5.0 SCREEN 3 ANALYSES

The tests and analyses for screen 3 are very similar to those from screen 2. Hence, results are only briefly presented and many comments are omitted since they closely replicate those for screen 2. Results are summarized in Table 2.

The top of screen 3 lies at a depth of 1014.8 ft bgs, approximately 373 ft below the composite water-table depth (Figure 2) and approximately 320 ft below the isolated static piezometric surface for screen 3 (Table 1). As Figure 12 shows, three injection tests were performed at screen 3: two of short duration and one of prolonged duration. The design and results for the long test at screen 3 are given in Table 2; field data are also plotted in Appendix B-1 and tabulated in Appendix B-2.

Test 3a. In the first short test at screen 3, water was injected between packers at a rate of 5.54 gpm for 1 min. Although injection stopped after 1 min, the water level continued to rise for a very short time. Ultimately, the water rose about 2.1 ft in response to injection. Then the water level declined toward the initial static position in about 20 min. Although these data cannot currently be analyzed because available slug-test methods assume instantaneous delivery of water, test 3a helped in the determination of the appropriate injection rate for the long test (test 3c).

Test 3b. In the second short test, water was injected between packers at a rate of 10.90 gpm for 1 min. As in the first test, the water level rose to an initial peak value of about 40 ft above static in slightly under 2 min. From there, the water level declined exponentially toward static equilibrium in about 28 min. This test behavior could not be analyzed by available slug-test methods because the water was not injected instantaneously.

Test 3c. The third or long test at screen 3 involved injection at a rate of 9.74 gpm for 120 min. Injection was then stopped and water-level recovery was monitored for an additional 75 min. The water-level response was oscillatory, as Figures 12 and 13 show. After rising rapidly to an initial peak, water levels began to gently oscillate around a gradually rising trend until injection was halted. This small but significant oscillatory behavior cannot be attributed to fluctuations in injection rate because this rate was essentially constant (i.e., less than 1% variation). In addition, the observed small, high-frequency oscillations are not associated with low-frequency barometric pressure fluctuations. In all probability, these oscillations are due to wellbore turbulence or well-screen clogging as previously discussed for screen 2. When injection ceased, the water level immediately began to decline smoothly toward the pretest static position. Water-level data for both injection and recovery portions of the test are given in Appendix B-2. Design parameters and test results are summarized in Table 2.

Field data for all tests in screen 3 are shown in Figure 12. Curves for injection and simple recovery data are compared in Figure 13. These two curves are somewhat different; normally, one can reasonably expect that these two curves will closely resemble each other. These differences between injection and simple recovery are most likely due either to turbulence caused by entrained air captured during the free-fall injection or to well-screen clogging related to water temperature differences. In other words, the polynomial extrapolation from the injection phase into the recovery phase of the test was probably biased by a less than perfectly defined least-squares fit of oscillatory water-level data collected during injection. A test configuration diagram (Figure 14) lists important test configuration parameters for the Aqtesolv software.

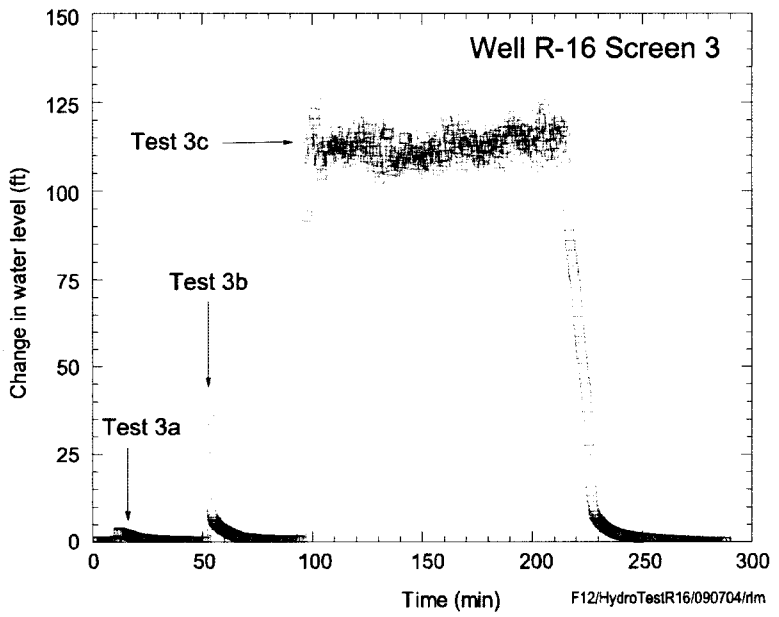

Figure 12. Field plot for the three tests at well R-16, screen 3

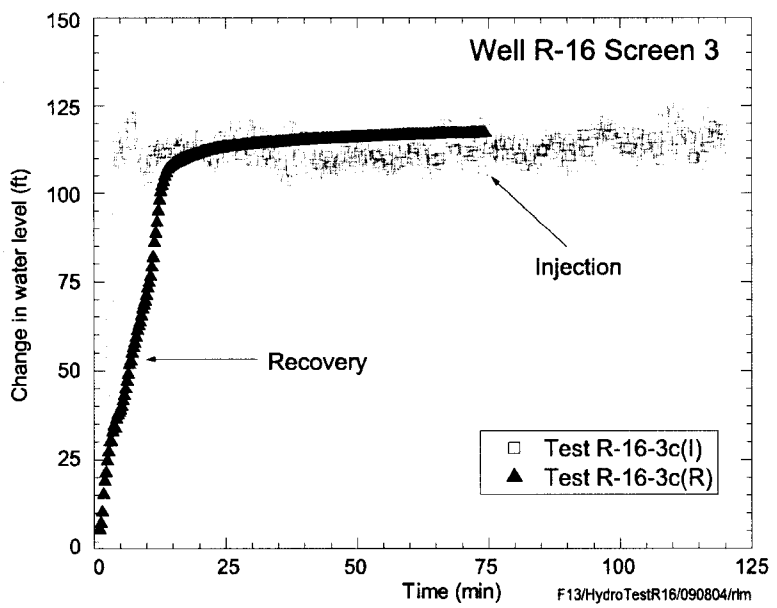

Figure 13. Comparison of injection and recovery tests at screen 3

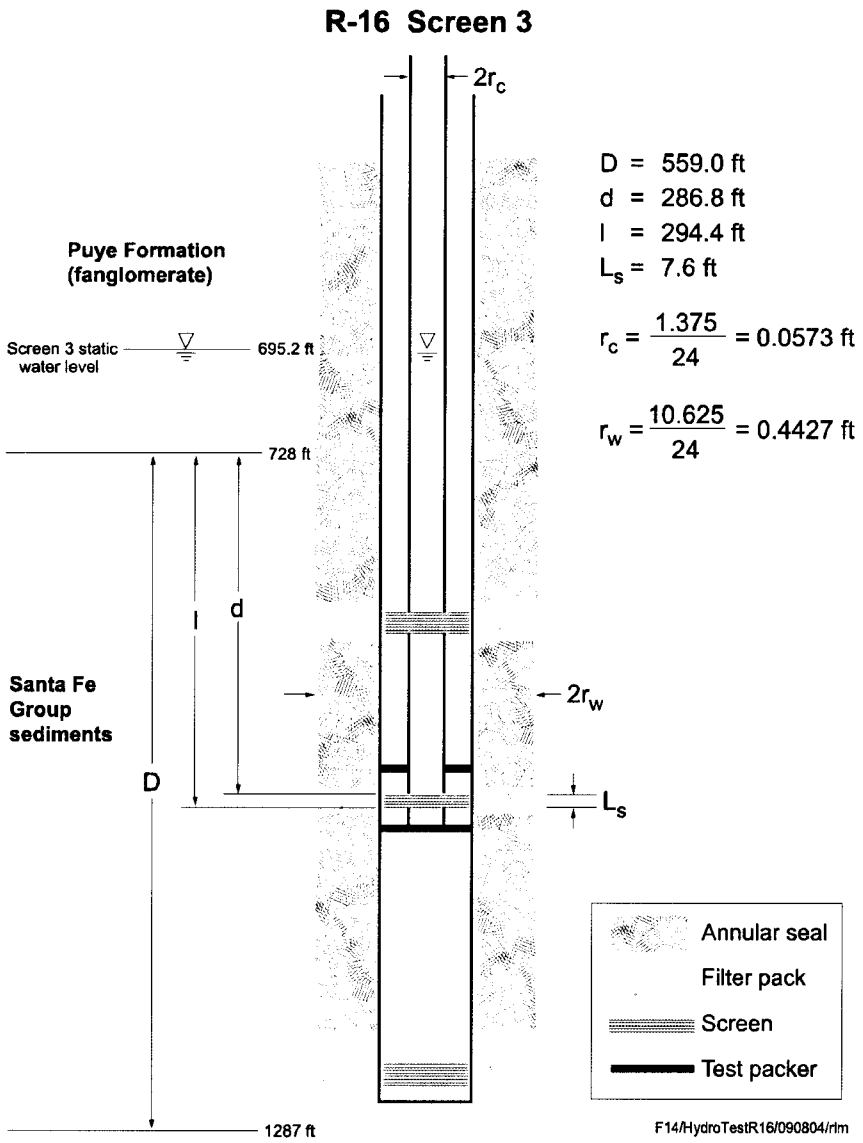

Figure 14. Test configuration parameters for the R-16-3 aquifer test

Specific-Capacity Analysis. Initially, a modified version (McLin 2004, 82834) of the specific-capacity method of Bradbury and Rothschild (1985, 76040) was used for computing a value for *T*. Results from test 3c are shown in Appendix B-3 along with the input values listed there. Again, analysis and results are similar to those from screen 2 that were presented earlier and are not repeated in detail here. For optimum conditions at screen 3 (i.e., assuming 100% well efficiency, 100% aquifer penetration, and a formation storativity of 0.003), a *T* of 10 ft^2/day is obtained (Appendix B-3). For more realistic conditions when well efficiency is 80% (estimated) and a partial penetration is 1.36% (observed), a *T* of 1058 ft^2/day (Appendix B-3) was found. Dividing this *T* by a saturated thickness of 559 ft gives a *K* of 1.9 ft/day. These values represent a lower limit for *T* and *K* when the K_h/K_v ratio is 1. As previously noted, this ratio is undoubtedly larger than 1. In addition, the best estimates for *T* and *K* are also probably larger than 1.

Theis Residual-Recovery Analysis. For further comparison, test 3c data were analyzed by the Theis residual-recovery method (Figure 15). Recall that Aqtesolv does not correct for partial penetration with this technique. A *T* of 59 ft^2/day was obtained, which corresponds to a *K* of 0.1 ft/day. An *S/S'* value of 2.79 for test 3c suggests that a recharge boundary might have been encountered at late time. However, no such boundary is suggested in the Theis analysis presented below. Hence, the expanding 3-D cone of impression has probably caused the flattening slope change. These flattening changes are generally associated with recharge, leakage, or an increasing *T* value going away from the well screen, rather than a traditional boundary effect. Hence, no conclusive statement can be made about the boundary type or even that one really exists. Interestingly, the *T* value obtained from the Theis residual-recovery analysis shown in the expanded scale of Figure 15-b strongly suggests a flattening slope over increasing time. This type of behavior is typical for a partially penetrating well in a very thick aquifer or when *T* increases laterally away from the well screen. The *T* value from the specific-capacity analysis is more than 17 times larger than the *T* from the Theis residual-recovery analysis (i.e., 1058/59). This observation implies that the effects of partial penetration are significant.

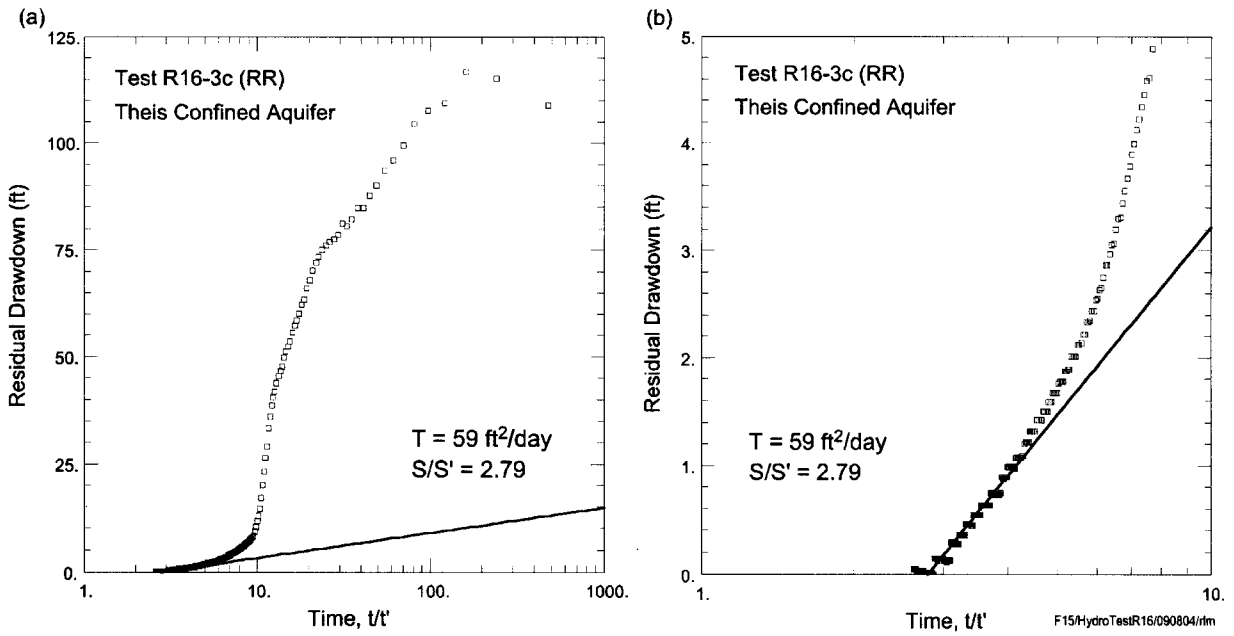

Figure 15. Theis confined aquifer analysis for R-16-3 residual-recovery data: (a) a normal dimensionless time (t/t') scale and (b) an expanded scale

Theis Analysis. Both injection (Figure 16) and recovery (Figure 17) data from test 3c were analyzed by the Theis method for confined-aquifer conditions. The Aqtesolv program corrects the Theis method for partial aquifer penetration. As Figure 16 shows for the injection phase, a *T* value of 486 ft^2/day was obtained. Dividing this *T* by a saturated thickness of 559 ft gives a *K* of 0.9 ft/day. As Figure 17 shows for the recovery phase, a *T* value of 491 ft^2/day and a *K* of 0.9 ft/day were found. These effects are essentially the same. Again, the *T* value from the specific-capacity analysis is more than twice as large as the *T* from the Theis simple recovery analysis (i.e., 1058/491). These results suggest that the K_h/K_v ratio is larger than 1.

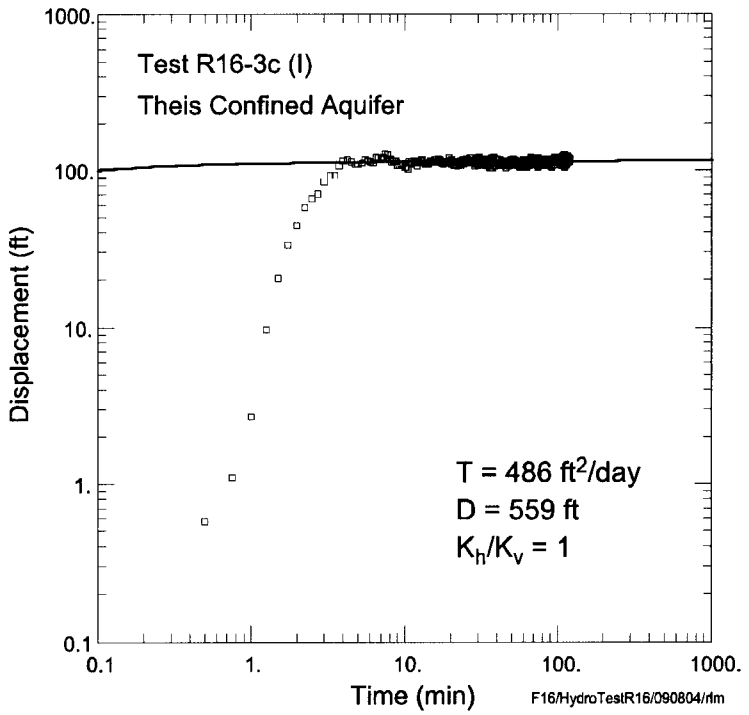

Figure 16. Theis confined aquifer analysis for R-16-3 injection data

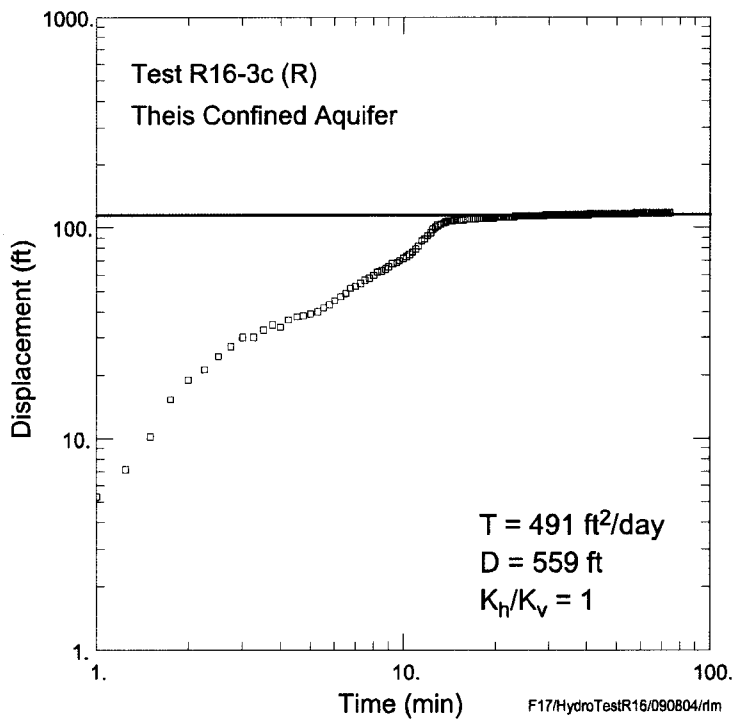

Figure 17. Theis confined aquifer analysis for R-16-3 recovery data

Anisotropy Effects. The Theis analysis for simple recovery was repeated, and the anisotropy ratio (K_h/K_v) was allowed to vary between 1 and 10,000. These results did not significantly change the Theis type-curve fit shown in Figure 17. However, as Figure 18 shows, T values were significantly increased. The Figure 19 value for T that just exceeds the specific-capacity value of 1058 ft^2/day found earlier occurs at K_h/K_v = 1000. Here, the Theis analysis of simple recovery data suggests that T = 1092 ft^2/day. Hence, this value is shown in Figure 19 and listed in Table 2.

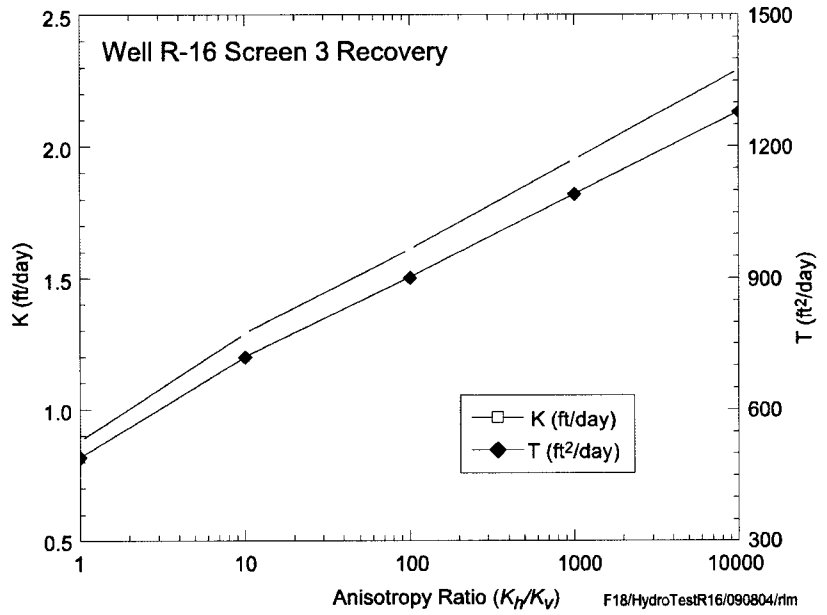

Figure 18. Effect of anisotropy ratio (K_h/K_v) on transmissivity (T) during test R-16-3c (R)

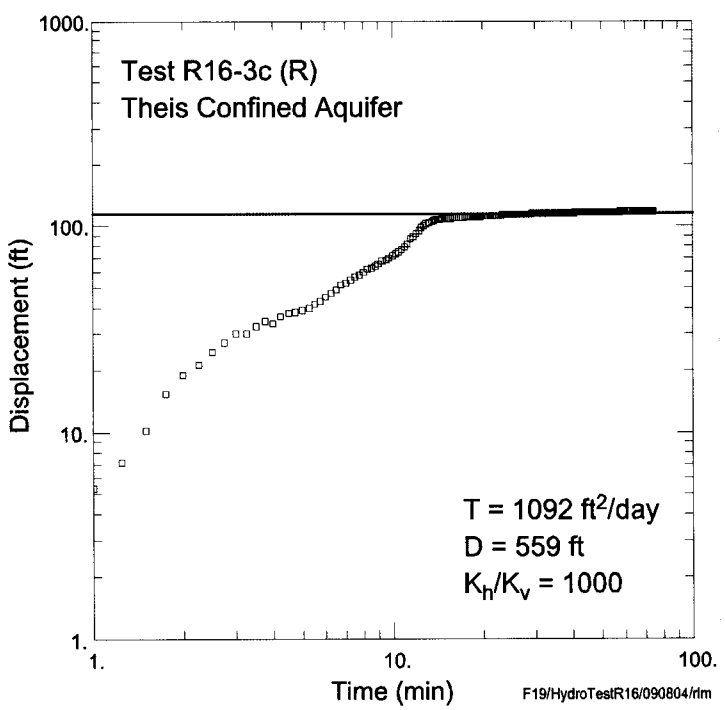

Figure 19. Theis confined aquifer analysis for R-16-3 recovery data with K_h/K_v = 1000

Discussion. The static water level obtained before the start of test 3a was reestablished after each of the three injection periods (Figure 12 and Appendix B-2). Results for screen 3 are very similar to those presented earlier for screen 2. Hence, many of these earlier comments also apply here but are not repeated. Figure 13 shows injection and recovery data versus time from screen 3. On the plot, the effect of casing storage is apparent (i.e., the steep portion of each plot before the slope changes at about 5–15 min). Once again, the theoretical duration of casing storage can be calculated from Equation (1). The data from the R-16 test at screen 3 produced a theoretical casing storage duration of about 13 min for the injection test phase and only about 4 min for the recovery phase. These differences are most likely related to the differences between injection and recovery as Figure 13 shows. Some of these differences are due to the noisy injection data that undoubtedly affected the calculation of simple recovery. This curve should gradually transition to the correct theoretical slope after these effects have dissipated. This formula usually produces a conservative t_c estimate. In many tests, the observed effects of casing storage can be as little as half the theoretical value because the asymptotic approach of the data to the theoretical drawdown curve has been largely achieved by then. Hence, the injection data should show wellbore storage effects for at least 6–7 min, whereas the recovery data should show these effects for at least 2 min. The more conservative time from injection casing storage effects are used below.

According to Equation (1) and the calculations mentioned above, Figure 15-a should show casing storage effects for $t/t' > 10.3$ [i.e., (120 + 13)/13]. However, in Figure 15-b these effects appear to be active until $t/t' = 9$, when a gradual flattening of the curve becomes apparent and corresponds to a time of 15 min [i.e., (120 + 15)/15]. This flattening behavior is more clearly seen in Figure 15-b as t/t' becomes smaller and smaller. This behavior reflects an increase in T farther away from the well caused by the ever-expanding cone of impression. The behavior is typical of a partially penetrating well in a very thick, confined aquifer.

Inspection of the time-injection plot (Figure 16) and the time-recovery plot (Figure 17) also shows that the observed duration of casing storage effects were about 4 min for injection and about 15 min for recovery, respectively. These times differ from those presented above because of the logarithmic time scales in Figures 16 and 17 and because of the noisy injection data.

Which analytical method gives the most representative hydraulic properties for the formation opposite screen 3 in well R-16? Ultimately, the Theis simple recovery method (Figure 19) provides the best estimate of T for the aquifer materials near screen 3 when $K_h/K_v = 1000$ because this analysis is not affected by water-level data collected during injection. Furthermore, this technique replicates the specific-capacity analysis while accounting for anisotropy. Finally, the residual-recovery analysis is not as reliable as the other methods presented here because it does not account for partial penetration effects and does not consider variations in the K_h/K_v ratio.

6.0 SCREEN 4 ANALYSES

The tests and analyses for screen 4 are very similar to those from screen 2. Hence, results are only briefly presented, and many comments are omitted because they closely replicate those for screen 2.

The top of screen 4 lies at a depth of 1237.0 ft bgs, approximately 595 ft below the composite static water level (Figure 2) and about 528 ft below the isolated static piezometric surface for screen 4 (Table 1). As Figure 20 shows, only one short and one long injection test were performed at screen 4 because this screen is completed in the same interval as are screens 2 and 3. The design and results for the long test at screen 4 are given in Table 2; field data are also plotted in Appendix C-1 and tabulated in Appendix C-2.

Test 4a. In the first short test at screen 4, water was injected between packers at a rate of 5.58 gpm for 1 min. Although injection stopped after 1 min, the water level continued to rise for about 4 min. Ultimately, the water rose about 2.4 ft in response to injection. Then the water level declined toward the initial static position in about 35 min. Although these data cannot currently be analyzed because available slug-test methods assume instantaneous delivery of water, test 4a helped in determining the appropriate injection rate for the long test (test 4c).

Test 4b. There was no second short injection test at screen 4.

Test 4c. The long test at screen 4 involved injection at a rate of 8.04 gpm for 105 min. Injection was then stopped, and water-level recovery was monitored for an additional 39 min. The water-level response was oscillatory, as Figure 21 shows. After rising rapidly to an initial peak, water levels began to oscillate gently around a gradually rising trend until injection was halted. This small but significant oscillatory behavior cannot be attributed to fluctuations in injection rate because this rate was essentially constant (i.e., less than 1% variation). In addition, the observed small, high-frequency oscillations are not associated with low-frequency barometric pressure fluctuations. In all probability, these oscillations are due to wellbore turbulence or well-screen clogging as previously discussed for screen 2. When injection ceased, the water level immediately began to decline smoothly toward the pretest static position. Water-level data for both injection and recovery portions of the test are given in Appendix C-2. Design parameters and test results are summarized in Table 2.

Field data for the long test in screen 4 are shown in Figure 20. Curves for injection and simple recovery data are compared in Figure 21. These two curves are somewhat different; normally, one can reasonably expect that these two curves will closely resemble each other. These differences between injection and simple recovery are most likely due to either turbulence caused by entrained air captured during the free-fall injection or to well-screen clogging related to water temperature differences. In other words, the polynomial extrapolation from the injection phase into the recovery phase of the test was probably biased by a less than perfectly defined least-squares fit of oscillatory water-level data obtained during injection. A test configuration diagram (Figure 22) lists important test configuration parameters for the Aqtesolv software.

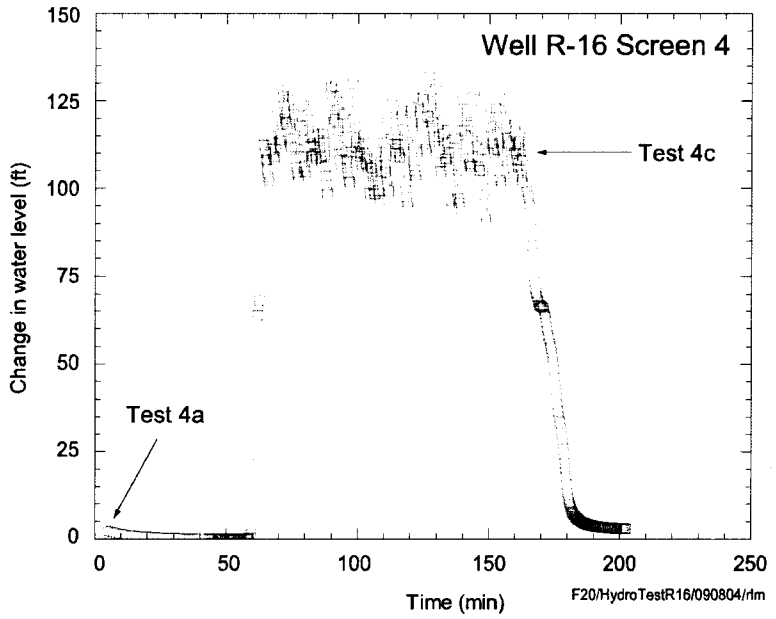

Figure 20. Field plot for the three tests at well R-16, screen 4

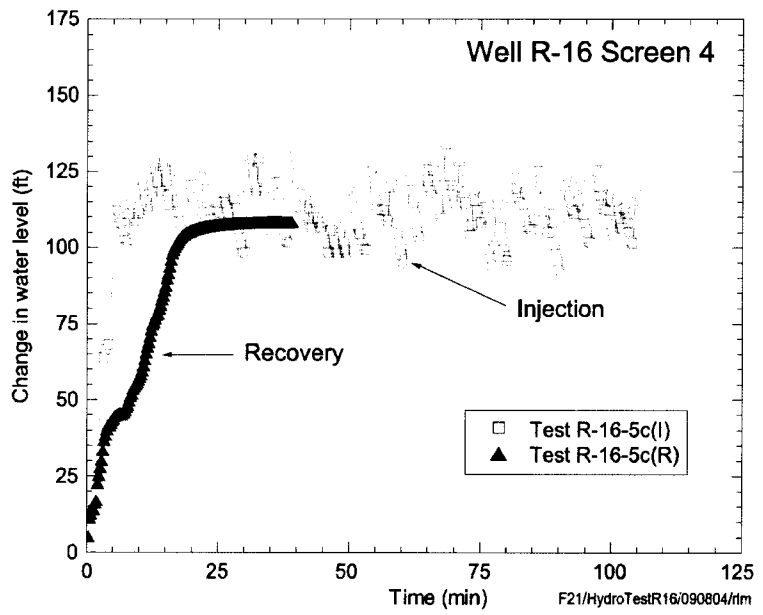

Figure 21. Comparison of injection and recovery tests at screen 4

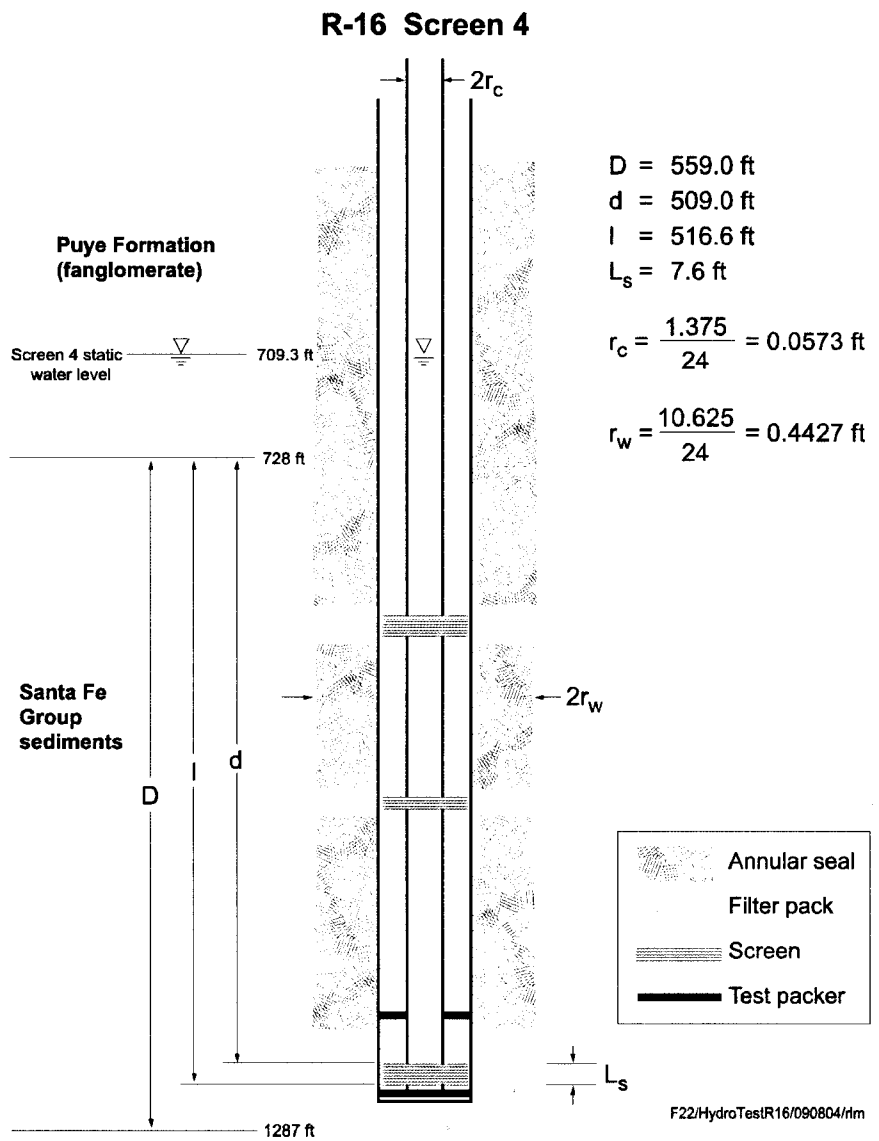

Figure 22. Test configuration parameters for the R-16-4 aquifer test

Specific-Capacity Analysis. Initially, a modified version (McLin 2004, 82834) of the specific-capacity method of Bradbury and Rothschild (1985, 76040) was used for computing a value for *T*. Results from test 4c are shown in Appendix C-3 along with the input values listed there. Analysis and results for screen 4 are similar to those from screens 2 and 3 presented earlier. Hence, many of the same comments also apply but are not repeated here. For optimum conditions at screen 4 (i.e., assuming 100% well efficiency, 100% aquifer penetration, and a formation storativity of 0.003), a *T* of 8 ft^2/day (Appendix C-3) is obtained. For more realistic conditions when well efficiency is 80% (estimated) and a partial penetration is 1.36% (observed), a *T* of 900 ft^2/day is found (Appendix C-3). Dividing this *T* by a saturated thickness of 559 ft gives a *K* of 1.6 ft/day. Again, these results represent a lower limit for *T* and *K* when the K_h/K_v ratio is 1. Because it was previously suggested that this ratio is larger than 1 for screens 2 and 3, one can safely assume that the final *T* and *K* values near screen 4 will also be larger than the specific-capacity results presented here.

Theis Residual-Recovery Analysis. For further comparison, test 4c data were analyzed by the Theis residual-recovery method (Figure 23). Recall that Aqtesolv does not correct for partial penetration with this technique. A T of 55 ft^2/day was obtained, which corresponds to a K of 0.1 ft/day. An S/S' value of 1.00 for test 4c was obtained and suggests that no boundary was encountered at late time. Furthermore, no boundaries were suggested in the Theis method presented below. In all likelihood, the expanding 3-D cone of impression has caused the flattening-slope change. These flattening changes are generally associated with recharge, leakage, or an increasing T value going away from the well screen, rather than a traditional boundary effect. Interestingly, the T value obtained from the Theis residual-recovery analysis shown in the expanded scale of Figure 23-b strongly suggests a flattening slope over increasing time. This type of behavior is typical for a partially penetrating well in a very thick aquifer or when T increases laterally away from the well screen. As in the screen 2 analysis, the T value from the specific-capacity analysis is more than 16 times larger than the T from the Theis residual-recovery analysis (i.e., 900/55). This observation implies that the effect of partial penetration is significant.

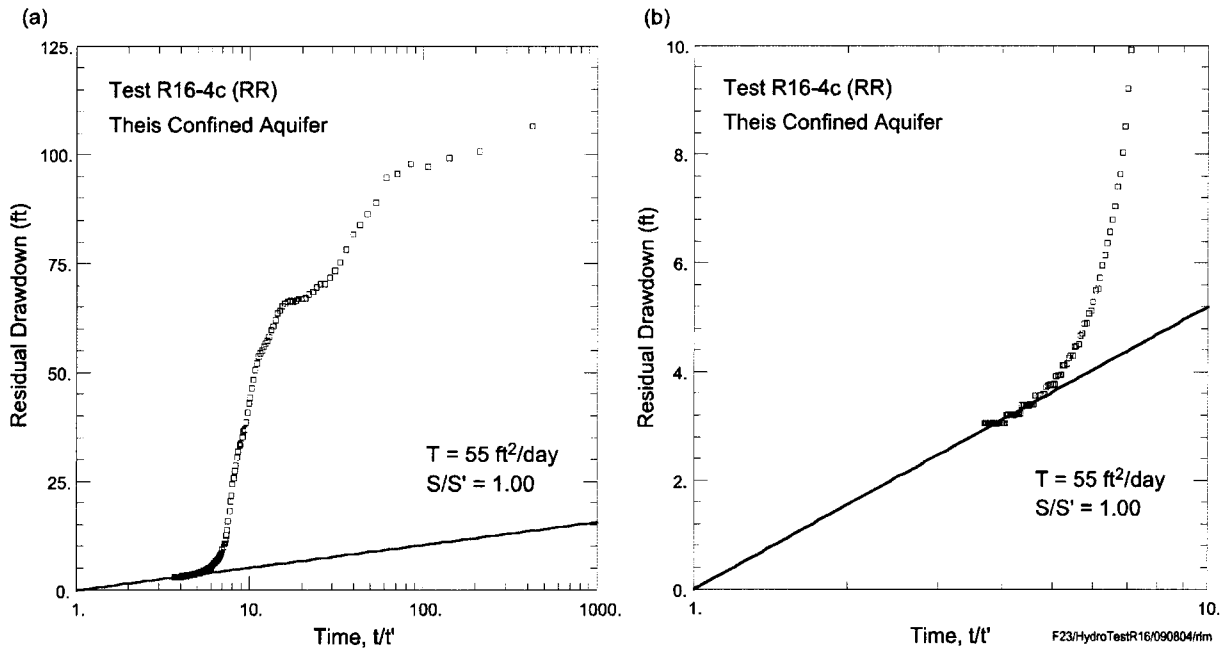

Figure 23. Theis confined aquifer analysis for R-16-4 residual-recovery data: (a) a normal dimensionless time (t/t') scale and (b) an expanded scale

Theis Analysis. Both injection (Figure 24) and recovery (Figure 25) data from test 4c were analyzed by the Theis method for confined-aquifer conditions. The Aqtesolv program corrects the Theis method for partial aquifer penetration. As Figure 24 shows for the injection phase, a T value of 408 ft^2/day was obtained. Dividing this T by a saturated thickness of 559 ft gives a K of 0.7 ft/day. As Figure 25 shows for the recovery phase, a T value of 408 ft^2/day and a K of 0.7 ft/day were found. As before, at screens 2 and 3, the T value from the specific-capacity analysis is more than twice as large as the T from the Theis simple recovery method (i.e., 900/408). These results suggest that the K_h/K_v ratio is larger than 1.

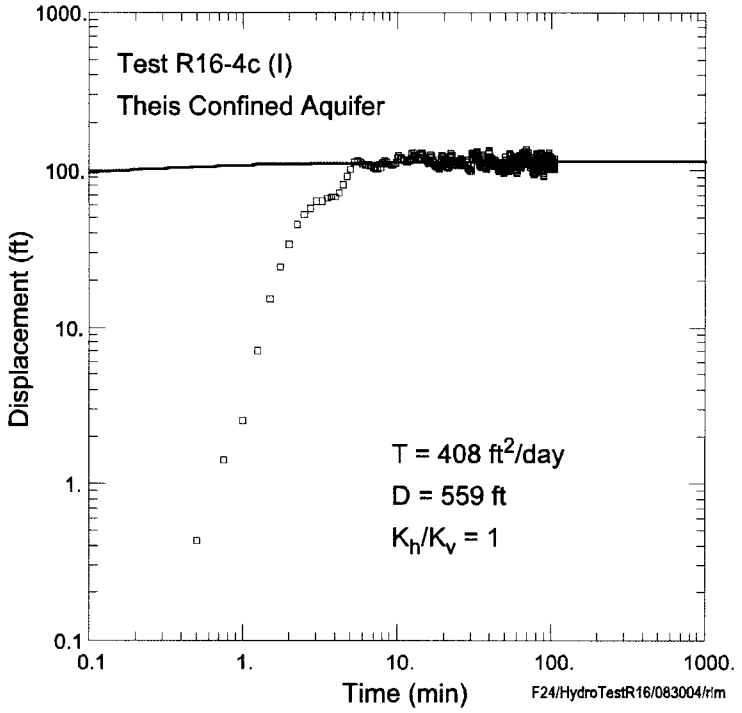

Figure 24. Theis confined aquifer analysis for R-16-4c injection data

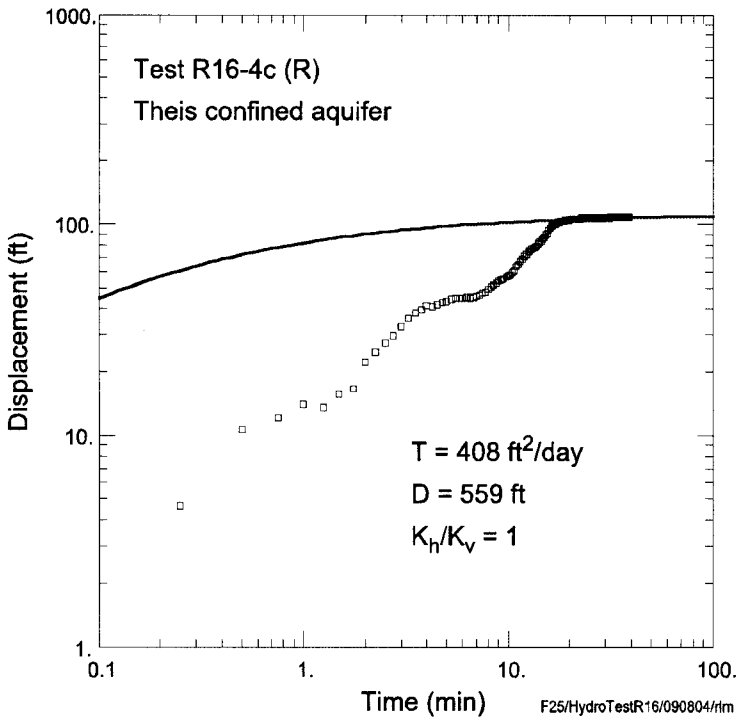

Figure 25. Theis confined aquifer analysis for R-16-4c recovery data

Anisotropy Effects. The Theis analysis for simple recovery was repeated, and the anisotropy ratio (K_h/K_v) was allowed to vary between 1 and 10,000. These results did not significantly change the Theis type-curve fit shown in Figure 25. However, as Figure 26 shows, T values were significantly increased. The Figure 26 value for T that just exceeds the specific-capacity value of 900 ft^2/day found earlier occurs at K_h/K_v = 1000. Here, the Theis analysis of simple recovery data suggests that T = 916 ft^2/day. Hence, this value is shown in Figure 27 and listed in Table 2.

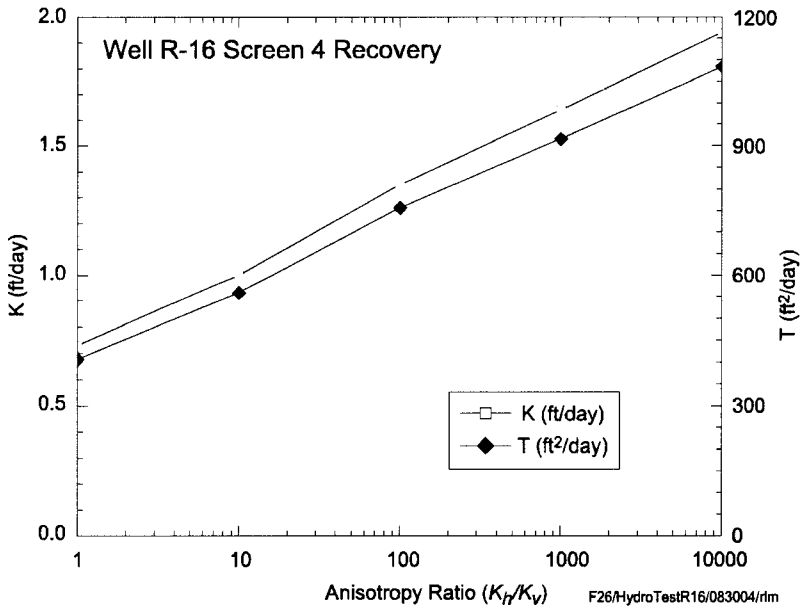

Figure 26. Effect of anisotropy ratio (K_h/K_v) on transmissivity (T) during test R-16-4c(R)

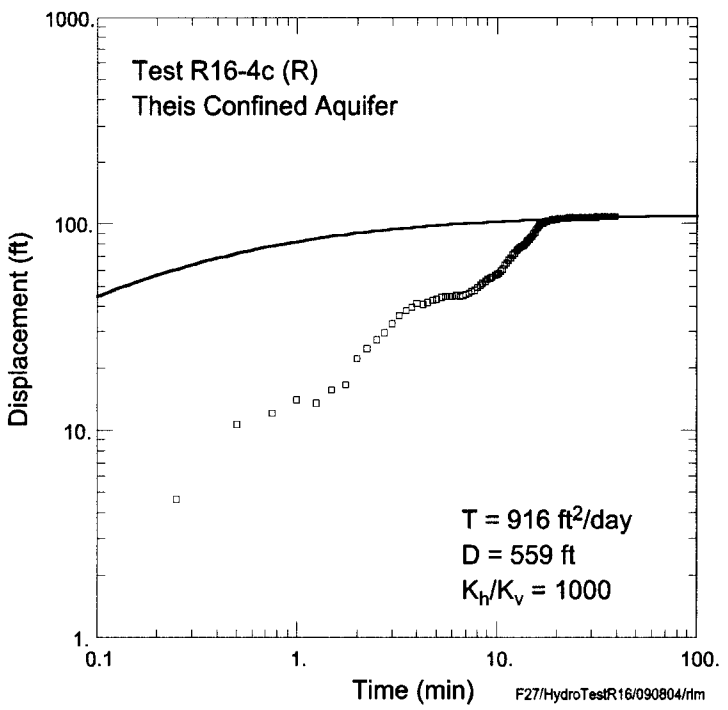

Figure 27. Theis confined aquifer analysis for R-16-4c recovery data with K_h/K_v = 1000

Discussion. The static water level obtained before the start of test 4c was only partially reestablished after the long test at screen 4 (Figure 21 and Appendix C-2) because the recovery period was shortened. Hence, about 3 ft of recovery data were not collected. Results for screen 4 are still very similar to those presented earlier for screens 2 and 3. Thus, many earlier comments still apply here but are not repeated. Figure 21 shows injection and recovery data versus time from screen 4. On the plot, the effect of casing storage is apparent (i.e., the steep portion of each plot before the slope changes at about 5–20 min). Recall that the theoretical duration of casing storage can be calculated from Equation (1). The data from the R-16 test produced a theoretical casing storage duration of about 16 min for the injection phase of the test and about 6 min for the recovery phase. This response is unusual and is most likely related to the extrapolation line used for generating the simple recovery data. This curve should gradually transition to the correct theoretical slope after these effects have dissipated. This formula usually produces a conservative t_c estimate. In many tests, the observed effects of casing storage can be as little as half the theoretical value because the asymptotic approach of the data to the theoretical drawdown curve has been largely achieved by then. Thus, the injection data should show casing storage effects for at least 8 min, whereas the smoother recovery data should show these effects for at least 3 min. Again, these differences are probably due to the noisy injection data that affected the extrapolated line used for computing simple recovery data. Hence, the more conservative time is used below.

According to Equation (1) and the calculations made above, Figure 23-a should show casing storage effects at least until $t/t' = 7.6$ [i.e., (105 + 16)/16]. Instead, these effects appear to be active for values of $t/t' > 5$. Here a gradual flattening of the curve becomes apparent and corresponds to a time of 26.3 min [i.e., (105 + 26.3)/26.3]. This flattening behavior is more clearly seen in Figure 23-b as t/t' becomes smaller. This behavior reflects an increase in T farther away from the well, caused by the ever-expanding cone of impression. This behavior is typical of a partially penetrating well in a very thick aquifer.

Inspection of the time-injection plot (Figure 24), and the time-recovery plot (Figure 25), shows that the observed duration of casing storage effects were apparently about 8 and 16 min for the injection and recovery phases, respectively. These times are different from those presented above because of the logarithmic scales in Figures 24 and 25 and because the injection data are inherently more noisy than recovery data.

Which analytical method gives the most representative hydraulic properties for the formation opposite screen 4 in well R-16? Ultimately, the Theis simple recovery method (Figure 27) provides the best estimate of T for the aquifer material near screen 4 when $K_h/K_v = 1000$ because this analysis is not affected by water-level data collected during injection. Furthermore, this technique replicates the specific-capacity analysis while accounting for anisotropy. Finally, the residual-recovery analysis is not as reliable as the other methods used here because it does not account for partial penetration effects and does not consider variations in the K_h/K_v ratio.

7.0 SUMMARY AND CONCLUSIONS

The downward vertical gradients observed in well R-16 before testing imply a downward vertical component of groundwater flow between screens 2, 3, and 4. They also suggest a gradient reversal in response to pumping in the Buckman well field. Normally, one would expect to see a vertically upward hydraulic gradient near a groundwater discharge boundary like the Rio Grande. Hence, the sediments near screens 3 and 4 probably yield water to the Buckman wells. Water in these lower zones probably moves horizontally toward the Buckman wells and under the Rio Grande. However, a component of groundwater flow near screen 2 is moving downward toward screen 3 to replace this production water. These observations imply that the Santa Fe Group sediments near screens 3 and 4 behave like a confined aquifer and that the sediments near screen 2 behave like a leaky source bed. In addition, the

hydraulic gradients near well R-16 reflect a pronounced anisotropy effect. Hence, water flows more easily in the horizontal direction than in the vertical direction. A similar behavior was also suggested in numerical simulations of the regional groundwater system near the Buckman well field (Vesselinov and Keating 2002).

Reasonable results were obtained for sediment hydraulic properties near screens 2, 3, and 4 at well R-16 from injection tests using a straddle-packer assembly that directs injected waters horizontally into the target medium opposite the isolated screen. All of these screens are completed in Santa Fe Group sediments.

The multiple-test approach employed at well R-16 used two short tests with different injection rates and one long test at a constant injection rate at screens 2 and 3. However, at screen 4, only one short test and one long test were run. The purpose of the short tests was to determine an appropriate injection rate for the long test. Interestingly, the short tests were characterized by oscillatory water-level responses. In addition, the long test showed a normal injection response at screens 2, 3, and 4 for partial penetrating wells in a very thick, confined aquifer. This response was characterized by an ever-flattening curvature on the residual-recovery plots. Both injection and recovery data from the long test were analyzed by the Theis, Theis recovery, Theis residual-recovery, and specific-capacity methods for comparison. The specific-capacity method provides a lower bound estimate for T. This lower specific-capacity T value was replicated in the Theis simple recovery method when the anisotropy ratio (K_h/K_v) was increased to 1000 and provides the best estimates for this parameter at screens 2, 3, and 4. This interpretative procedure was possible because water-level measurements had been previously recorded in individual screens before testing and allowed vertical hydraulic gradients to be computed.

During the long test at screen 2, water was injected at a constant rate of 8.45 gpm for 120 min and recovery data were monitored for an additional 46 min. The 7.5-ft screen is located within a 559-ft-thick saturated section of Santa Fe Group sediments. Hence, the well screen covers only about 1.34% of the total formation thickness. This condition represents an extreme case of partial penetration in a very thick, confined aquifer. Furthermore, injection data were very noisy compared with recovery data. This situation apparently developed because the transducer was located immediately below the static water level. Hence, entrained air probably mixed with free-falling injection waters and caused wellbore turbulence near the water surface. This entrained air problem is related to the test design, because injection waters must free-fall about 614 ft before reaching the static piezometric surface for screen 2. The resulting turbulence was recorded as high-frequency water-level oscillations during the injection phase but not in the recovery phase. Consequently, the recovery data are considered more reliable than injection data. Furthermore, simple recovery data are more reliable than residual-recovery data because partial penetration effects were shown to be important. Similar comments also apply to the other screens. Finally, the specific-capacity method yields a minimum value for the estimated T. This minimum T was replicated in the Theis simple recovery method when the K_h/K_v ratio was increased to 1000:1. Hence, the most reliable results for screen 2 are from the latter technique, which yielded T = 879 ft^2/day, K = 1.6 ft/day, and K_h/K_v = 1000.

Water was injected at a constant rate of 9.74 gpm for 120 min during the long test at screen 3, and recovery was monitored for an additional 75 min. This 7.6-ft screen is also located within the 559-ft-thick saturated section of Santa Fe Group sediments. Once again, this situation represents an extreme case of partial penetration in a thick, confined aquifer sequence. Since these effects were shown to be important at screen 3, the Theis analysis of injection and simple recovery data are considered more reliable than the residual-recovery analysis. In addition, the specific-capacity method yields a minimum value for the estimated T. This minimum T was replicated in the Theis simple recovery method when the K_h/K_v value was increased to 1000. Hence, the most reliable results for screen 3 yielded T = 1092 ft^2/day, K = 2.0 ft/day, and K_h/K_v = 1000.

Water was injected at a constant rate of 8.04 gpm for 105 min during the long test at screen 4, and recovery was monitored for an additional 39 min. This 7.6-ft screen is also located within the 559-ft-thick saturated section of Santa Fe Group sediments and represents an extreme case of partial penetration in a thick, confined aquifer. Not surprisingly, similar conclusions and results were also obtained from the screen 4 test. Hence, the specific-capacity method provides another minimum T estimate. In addition, this minimum T was replicated in the Theis simple recovery analysis when the K_h/K_v ratio was fixed at 1000. This latter result is considered the most reliable and yielded T = 916 ft^2/day, K = 1.6 ft/day, and K_h/K_v = 1000.

8.0 ACKNOWLEDGMENTS

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9.0 REFERENCES

Aller, L., T. W. Bennett, G. Hackett, R. J. Petty, J. H. Lehr, H. Sedoris, D. M. Nielsen, and J. E. Denne, 1991. "Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells," US Environmental Protection Agency report EPA 160014-891034. (Aller et al. 1991, 70112)

ASTM (American Society for Testing and Materials), 1994. "Standards on Ground Water and Vadose Zone Investigations," sponsored by Committee D-18 on Soil and Rock (2nd edition), ASTM Publication Code Number 03-418094-38. (ASTM 1994, 70099)

ASTM (American Society for Testing and Materials), 1996. "Standards on Analysis of Hydrologic Parameters and Ground Water Modeling," sponsored by Committee D-18 on Soil and Rock, ASTM Publication Code Number 03-41096-38. (ASTM 1996, 70100)

Bradbury, K. R., and E. R. Rothschild, 1985. "A Computerized Technique for Estimating Hydraulic Conductivity of Aquifers from Specific-Capacity Data," in *Ground Water*, Vol. 23, No. 2, pp. 240–246. (Bradbury and Rothschild 1985, 76040)

Driscoll, F. G., 1986. *Groundwater and Wells*, 2nd ed., Johnson Filtration Systems, H. M. Smythe Co., St. Paul, Minnesota. (Driscoll 1986, 70111)

Earlougher, R. C., 1977. *Advances in Well Test Analysis*, Society of Petroleum Engineers of AIME, New York. (Earlougher 1977, 73478)

Griggs, R. L., 1964. "Geology and Groundwater Resources of the Los Alamos Area, New Mexico," US Geological Survey, Water Supply Paper 1753. (Griggs 1964, 8795)

LANL (Los Alamos National Laboratory), January 1996. "Groundwater Protection Management Program Plan," Los Alamos, New Mexico. (LANL 1996, 70215)

LANL (Los Alamos National Laboratory), September 1998. "Hydrogeologic Workplan," Los Alamos, New Mexico. (LANL 1998, 59599)

LANL (Los Alamos National Laboratory), 2003. "Characterization Well R-16 Completion Report," Los Alamos National Laboratory document LA-UR-03-1841, Los Alamos National Laboratory, Los Alamos, New Mexico (Thompson et al. 2003, 76061)

McLin, S. G., 2004. "Estimating Transmissivity from Specific Capacity Using Matlab" (to be published in *Ground Water*). (McLin 2004, 82834)

Schafer, D. C., 1979. "Casing Storage Can Affect Pumping Test Data," *Johnson Driller's Journal*, January–February 1979. (Schafer 1979, 73449)

Theis, C. V., 1935. "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage," *American Geophysical Union Transactions*, Vol. 16, pp. 519–524. (Theis 1935, 70102)

Vesselinov, V. V., and E. H. Keating, 2002. "Analysis of Capture Zones of the Buckman Well Field and a Proposed Horizontal Collector Well North of the Otowi Bridge," Los Alamos National Laboratory document LA-UR-02-2750, Los Alamos National Laboratory, Los Alamos, New Mexico. (Vasselinov and Keating 2002)

Walton, W. C., 1970. *Groundwater Resource Evaluation*, McGraw-Hill Book Company, New York. (Walton 1970, 76044)

Appendix A

Data for Injection and Recovery, Test R-16-2c

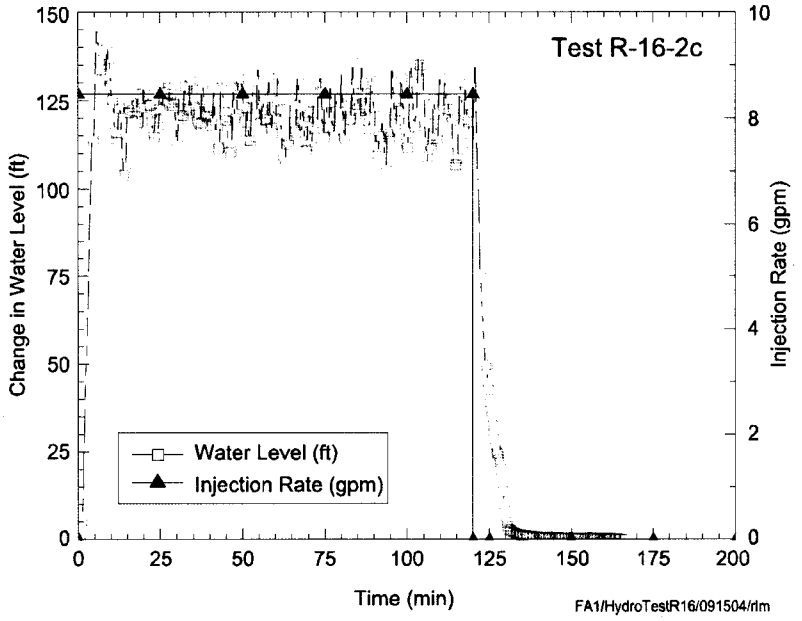
Contents

A-1 Field Plot for R-16, Screen 2, Test c

A-2 Data for Injection and Recovery Test R-16-2c

A-3 Transmissivity (ft^2/day) for Injection Test R-16-2c as a Function of Well Efficiency and Aquifer Penetration

A-1. Field Plot for R-16, Screen 2, Test c



A-2. Data for Injection and Recovery Test R-16-2c

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.000	8.45
0.250	0.086	8.45
0.500	1.146	8.45
0.750	3.194	8.45
1.000	5.199	8.45
1.250	6.818	8.45
1.500	13.079	8.45
1.750	26.305	8.45
2.000	38.532	8.45
2.250	45.558	8.45
2.500	51.150	8.45
2.750	56.644	8.45
3.000	64.519	8.45
3.250	75.022	8.45
3.500	84.079	8.45
3.750	94.372	8.45
4.000	103.749	8.45
4.250	114.421	8.45
4.500	114.019	8.45
4.750	113.516	8.45
5.000	120.958	8.45
5.250	131.074	8.45
5.500	139.856	8.45
5.750	145.779	8.45
6.000	142.645	8.45
6.250	139.267	8.45
6.500	136.306	8.45
6.750	135.271	8.45
7.000	133.733	8.45
7.250	131.189	8.45
7.500	128.502	8.45
7.750	127.352	8.45
8.000	127.036	8.45
8.250	127.783	8.45
8.500	131.908	8.45
8.750	139.411	8.45
9.000	140.906	8.45
9.250	135.199	8.45
9.500	136.953	8.45
9.750	132.641	8.45
10.000	129.278	8.45
10.250	124.809	8.45
10.500	125.197	8.45
10.750	124.234	8.45
11.000	120.182	8.45
11.250	116.173	8.45
11.500	116.001	8.45
11.750	114.148	8.45
12.000	113.171	8.45
12.250	115.398	8.45
12.500	122.926	8.45
12.750	123.573	8.45
13.000	120.024	8.45
13.250	115.599	8.45
13.500	109.997	8.45
13.750	103.907	8.45
14.000	103.993	8.45
14.250	104.639	8.45
14.500	106.104	8.45
14.750	114.450	8.45
15.000	121.590	8.45
15.250	123.257	8.45
15.500	121.791	8.45
15.750	121.432	8.45
16.000	124.277	8.45
16.250	122.294	8.45
16.500	122.351	8.45
16.750	126.389	8.45
17.000	123.429	8.45
17.250	120.670	8.45
17.500	119.392	8.45
17.750	118.443	8.45
18.000	121.906	8.45
18.250	126.720	8.45
18.500	129.651	8.45
18.750	127.036	8.45
19.000	125.585	8.45
19.250	122.941	8.45
19.500	118.846	8.45
19.750	116.044	8.45
20.000	123.084	8.45
20.250	128.947	8.45
20.500	126.461	8.45
20.750	126.001	8.45
21.000	127.539	8.45
21.250	126.734	8.45
21.500	123.774	8.45
21.750	123.573	8.45
22.000	123.645	8.45
22.250	121.576	8.45
22.500	119.248	8.45
22.750	115.972	8.45
23.000	114.737	8.45
23.250	114.924	8.45
23.500	122.452	8.45
23.750	121.662	8.45
24.000	119.277	8.45
24.250	117.294	8.45
24.500	115.699	8.45
24.750	122.696	8.45
25.000	130.140	8.45
25.250	125.958	8.45
25.500	122.366	8.45
25.750	122.265	8.45
26.000	127.295	8.45
26.250	131.419	8.45
26.500	129.062	8.45
26.750	127.481	8.45
27.000	126.921	8.45
27.250	126.878	8.45
27.500	124.550	8.45
27.750	123.558	8.45
28.000	128.674	8.45
28.250	126.835	8.45
28.500	123.731	8.45
28.750	126.705	8.45
29.000	125.426	8.45

A-2. Data for Injection and Recovery, Test R-16-2c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
29.250	124.521	8.45	39.000	121.130	8.45	48.750	131.175	8.45
29.500	122.998	8.45	39.250	122.495	8.45	49.000	129.235	8.45
29.750	118.027	8.45	39.500	120.656	8.45	49.250	127.941	8.45
30.000	113.387	8.45	39.750	120.196	8.45	49.500	128.933	8.45
30.250	112.338	8.45	40.000	123.257	8.45	49.750	131.017	8.45
30.500	119.578	8.45	40.250	121.489	8.45	50.000	127.438	8.45
30.750	126.634	8.45	40.500	119.492	8.45	50.250	123.041	8.45
31.000	124.952	8.45	40.750	117.754	8.45	50.500	119.032	8.45
31.250	122.941	8.45	41.000	118.501	8.45	50.750	116.245	8.45
31.500	120.728	8.45	41.250	128.430	8.45	51.000	113.760	8.45
31.750	120.757	8.45	41.500	124.593	8.45	51.250	122.912	8.45
32.000	120.800	8.45	41.750	119.578	8.45	51.500	123.314	8.45
32.250	128.775	8.45	42.000	115.369	8.45	51.750	117.840	8.45
32.500	129.177	8.45	42.250	113.659	8.45	52.000	113.717	8.45
32.750	125.326	8.45	42.500	111.332	8.45	52.250	112.122	8.45
33.000	122.783	8.45	42.750	111.505	8.45	52.500	113.501	8.45
33.250	119.794	8.45	43.000	111.936	8.45	52.750	125.786	8.45
33.500	121.691	8.45	43.250	118.357	8.45	53.000	128.617	8.45
33.750	122.251	8.45	43.500	128.847	8.45	53.250	124.852	8.45
34.000	130.557	8.45	43.750	131.247	8.45	53.500	122.783	8.45
34.250	129.781	8.45	44.000	128.099	8.45	53.750	121.130	8.45
34.500	130.499	8.45	44.250	124.435	8.45	54.000	120.915	8.45
34.750	126.001	8.45	44.500	121.489	8.45	54.250	121.331	8.45
35.000	123.515	8.45	44.750	119.435	8.45	54.500	130.614	8.45
35.250	125.728	8.45	45.000	119.521	8.45	54.750	134.940	8.45
35.500	122.998	8.45	45.250	117.739	8.45	55.000	129.594	8.45
35.750	122.639	8.45	45.500	117.610	8.45	55.250	123.573	8.45
36.000	121.030	8.45	45.750	113.042	8.45	55.500	118.860	8.45
36.250	119.219	8.45	46.000	110.327	8.45	55.750	116.763	8.45
36.500	118.759	8.45	46.250	109.092	8.45	56.000	124.708	8.45
36.750	121.619	8.45	46.500	110.557	8.45	56.250	125.340	8.45
37.000	118.314	8.45	46.750	112.410	8.45	56.500	121.647	8.45
37.250	117.308	8.45	47.000	121.705	8.45	56.750	119.478	8.45
37.500	118.759	8.45	47.250	128.660	8.45	57.000	118.889	8.45
37.750	128.099	8.45	47.500	123.831	8.45	57.250	119.693	8.45
38.000	129.968	8.45	47.750	119.866	8.45	57.500	119.722	8.45
38.250	124.636	8.45	48.000	120.110	8.45	57.750	125.225	8.45
38.500	120.627	8.45	48.250	121.188	8.45	58.000	131.333	8.45
38.750	118.084	8.45	48.500	126.619	8.45	58.250	125.972	8.45

A-2. Data for Injection and Recovery, Test R-16-2c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
58.500	120.081	8.45
58.750	117.366	8.45
59.000	115.987	8.45
59.250	122.222	8.45
59.500	123.228	8.45
59.750	120.139	8.45
60.000	118.357	8.45
60.250	119.277	8.45
60.500	124.895	8.45
60.750	132.511	8.45
61.000	128.272	8.45
61.250	125.168	8.45
61.500	122.538	8.45
61.750	119.147	8.45
62.000	115.484	8.45
62.250	109.781	8.45
62.500	108.388	8.45
62.750	106.492	8.45
63.000	107.655	8.45
63.250	113.099	8.45
63.500	115.125	8.45
63.750	113.588	8.45
64.000	112.568	8.45
64.250	112.582	8.45
64.500	125.010	8.45
64.750	126.102	8.45
65.000	123.745	8.45
65.250	121.532	8.45
65.500	118.731	8.45
65.750	117.194	8.45
66.000	116.001	8.45
66.250	116.590	8.45
66.500	123.745	8.45
66.750	132.526	8.45
67.000	130.629	8.45
67.250	126.432	8.45
67.500	122.897	8.45
67.750	118.156	8.45
68.000	115.398	8.45

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
68.250	119.018	8.45
68.500	123.257	8.45
68.750	117.711	8.45
69.000	113.329	8.45
69.250	110.830	8.45
69.500	110.973	8.45
69.750	112.482	8.45
70.000	119.004	8.45
70.250	122.007	8.45
70.500	117.639	8.45
70.750	114.162	8.45
71.000	112.036	8.45
71.250	117.122	8.45
71.500	124.708	8.45
71.750	121.691	8.45
72.000	121.116	8.45
72.250	120.139	8.45
72.500	118.803	8.45
72.750	118.084	8.45
73.000	127.151	8.45
73.250	130.269	8.45
73.500	128.947	8.45
73.750	132.454	8.45
74.000	127.136	8.45
74.250	120.943	8.45
74.500	117.150	8.45
74.750	114.751	8.45
75.000	123.760	8.45
75.250	126.533	8.45
75.500	124.306	8.45
75.750	120.182	8.45
76.000	117.452	8.45
76.250	117.194	8.45
76.500	118.788	8.45
76.750	129.809	8.45
77.000	124.435	8.45
77.250	120.455	8.45
77.500	116.590	8.45
77.750	114.134	8.45

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
78.000	115.010	8.45
78.250	127.927	8.45
78.500	126.016	8.45
78.750	122.524	8.45
79.000	124.708	8.45
79.250	121.964	8.45
79.500	120.139	8.45
79.750	121.259	8.45
80.000	133.661	8.45
80.250	127.984	8.45
80.500	123.099	8.45
80.750	117.826	8.45
81.000	114.277	8.45
81.250	113.746	8.45
81.500	123.314	8.45
81.750	126.303	8.45
82.000	124.291	8.45
82.250	121.475	8.45
82.500	119.578	8.45
82.750	119.636	8.45
83.000	120.053	8.45
83.250	127.898	8.45
83.500	135.645	8.45
83.750	129.809	8.45
84.000	125.570	8.45
84.250	122.308	8.45
84.500	121.245	8.45
84.750	124.004	8.45
85.000	126.504	8.45
85.250	122.783	8.45
85.500	122.136	8.45
85.750	121.130	8.45
86.000	126.950	8.45
86.250	135.429	8.45
86.500	129.939	8.45
86.750	126.102	8.45
87.000	123.170	8.45
87.250	122.222	8.45
87.500	127.136	8.45

A-2. Data for Injection and Recovery, Test R-16-2c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
87.750	122.783	8.45
88.000	119.578	8.45
88.250	117.035	8.45
88.500	116.662	8.45
88.750	120.440	8.45
89.000	130.614	8.45
89.250	132.583	8.45
89.500	128.962	8.45
89.750	125.958	8.45
90.000	121.403	8.45
90.250	123.185	8.45
90.500	116.418	8.45
90.750	112.065	8.45
91.000	109.393	8.45
91.250	109.910	8.45
91.500	114.852	8.45
91.750	114.277	8.45
92.000	114.076	8.45
92.250	114.895	8.45
92.500	119.808	8.45
92.750	115.527	8.45
93.000	113.085	8.45
93.250	108.962	8.45
93.500	106.090	8.45
93.750	105.329	8.45
94.000	115.513	8.45
94.250	116.245	8.45
94.500	114.277	8.45
94.750	114.737	8.45
95.000	116.260	8.45
95.250	124.119	8.45
95.500	134.595	8.45
95.750	130.083	8.45
96.000	125.628	8.45
96.250	121.216	8.45
96.500	118.156	8.45
96.750	116.791	8.45
97.000	124.823	8.45
97.250	122.883	8.45
97.500	122.222	8.45
97.750	121.877	8.45
98.000	121.978	8.45
98.250	131.362	8.45
98.500	130.930	8.45
98.750	125.455	8.45
99.000	121.374	8.45
99.250	116.892	8.45
99.500	113.473	8.45
99.750	112.855	8.45
100.000	111.677	8.45
100.250	111.692	8.45
100.500	115.886	8.45
100.750	125.340	8.45
101.000	134.567	8.45
101.250	135.415	8.45
101.500	130.284	8.45
101.750	125.484	8.45
102.000	120.943	8.45
102.250	117.682	8.45
102.500	117.538	8.45
102.750	121.992	8.45
103.000	121.561	8.45
103.250	128.559	8.45
103.500	137.815	8.45
103.750	134.998	8.45
104.000	135.098	8.45
104.250	132.224	8.45
104.500	130.427	8.45
104.750	137.168	8.45
105.000	133.949	8.45
105.250	126.447	8.45
105.500	118.889	8.45
105.750	113.200	8.45
106.000	109.207	8.45
106.250	106.535	8.45
106.500	111.131	8.45
106.750	118.443	8.45
107.000	114.780	8.45
107.250	112.525	8.45
107.500	111.419	8.45
107.750	114.378	8.45
108.000	123.932	8.45
108.250	125.182	8.45
108.500	121.044	8.45
108.750	118.415	8.45
109.000	115.182	8.45
109.250	114.263	8.45
109.500	113.545	8.45
109.750	122.179	8.45
110.000	132.080	8.45
110.250	128.027	8.45
110.500	126.016	8.45
110.750	124.306	8.45
111.000	122.840	8.45
111.250	122.251	8.45
111.500	131.218	8.45
111.750	128.056	8.45
112.000	124.061	8.45
112.250	122.567	8.45
112.500	121.159	8.45
112.750	125.326	8.45
113.000	122.524	8.45
113.250	118.788	8.45
113.500	120.469	8.45
113.750	119.478	8.45
114.000	112.826	8.45
114.250	108.847	8.45
114.500	106.679	8.45
114.750	106.908	8.45
115.000	106.923	8.45
115.250	108.646	8.45
115.500	108.689	8.45
115.750	116.604	8.45
116.000	127.582	8.45
116.250	130.126	8.45
116.500	126.432	8.45
116.750	122.955	8.45

A-2. Data for Injection and Recovery, Test R-16-2c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
117.000	122.107	8.45
117.250	121.145	8.45
117.500	119.622	8.45
117.750	129.436	8.45
118.000	123.673	8.45
118.250	119.636	8.45
118.500	118.932	8.45
118.750	118.918	8.45
119.000	115.584	8.45
119.250	114.823	8.45
119.500	112.999	8.45
119.750	111.806	8.45
120.000	110.370	8.45
120.250	118.961	0.00
120.500	128.329	0.00
120.750	135.602	0.00
121.000	123.228	0.00
121.250	114.220	0.00
121.500	104.208	0.00
121.750	101.193	0.00
122.000	88.916	0.00
122.250	75.639	0.00
122.500	74.319	0.00
122.750	69.039	0.00
123.000	65.050	0.00
123.250	60.761	0.00
123.500	55.869	0.00
123.750	49.759	0.00
124.000	49.874	0.00
124.250	48.368	0.00
124.500	44.884	0.00
124.750	42.676	0.00
125.000	40.152	0.00
125.250	38.862	0.00
125.500	36.826	0.00
125.750	35.063	0.00
126.000	32.697	0.00
126.250	31.207	0.00
126.500	28.899	0.00
126.750	26.964	0.00
127.000	25.474	0.00
127.250	25.001	0.00
127.500	24.542	0.00
127.750	23.883	0.00
128.000	22.980	0.00
128.250	22.063	0.00
128.500	20.056	0.00
128.750	18.394	0.00
129.000	16.503	0.00
129.250	13.824	0.00
129.500	10.385	0.00
129.750	8.222	0.00
130.000	6.489	0.00
130.250	4.884	0.00
130.500	3.781	0.00
130.750	3.180	0.00
131.000	2.922	0.00
131.250	2.721	0.00
131.500	2.507	0.00
131.750	2.306	0.00
132.000	2.134	0.00
132.250	2.106	0.00
132.500	1.919	0.00
132.750	1.905	0.00
133.000	1.719	0.00
133.250	1.705	0.00
133.500	1.705	0.00
133.750	1.518	0.00
134.000	1.504	0.00
134.250	1.504	0.00
134.500	1.332	0.00
134.750	1.318	0.00
135.000	1.304	0.00
135.250	1.304	0.00
135.500	1.146	0.00
135.750	1.132	0.00
136.000	1.132	0.00
136.250	1.132	0.00
136.500	1.132	0.00
136.750	1.132	0.00
137.000	0.960	0.00
137.250	0.960	0.00
137.500	0.960	0.00
137.750	0.960	0.00
138.000	0.960	0.00
138.250	0.945	0.00
138.500	0.960	0.00
138.750	0.960	0.00
139.000	0.945	0.00
139.250	0.802	0.00
139.500	0.802	0.00
139.750	0.802	0.00
140.000	0.802	0.00
140.250	0.802	0.00
140.500	0.802	0.00
140.750	0.802	0.00
141.000	0.802	0.00
141.250	0.817	0.00
141.500	0.802	0.00
141.750	0.817	0.00
142.000	0.802	0.00
142.250	0.673	0.00
142.500	0.673	0.00
142.750	0.673	0.00
143.000	0.673	0.00
143.250	0.673	0.00
143.500	0.673	0.00
143.750	0.673	0.00
144.000	0.673	0.00
144.250	0.673	0.00
144.500	0.673	0.00
144.750	0.673	0.00
145.000	0.673	0.00
145.250	0.673	0.00
145.500	0.673	0.00
145.750	0.530	0.00
146.000	0.530	0.00

A-2. Data for Injection and Recovery, Test R-16-2c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
146.250	0.530	0.00
146.500	0.530	0.00
146.750	0.530	0.00
147.000	0.530	0.00
147.250	0.544	0.00
147.500	0.559	0.00
147.750	0.544	0.00
148.000	0.544	0.00
148.250	0.559	0.00
148.500	0.559	0.00
148.750	0.559	0.00
149.000	0.559	0.00
149.250	0.559	0.00
149.500	0.559	0.00
149.750	0.573	0.00
150.000	0.573	0.00
150.250	0.573	0.00
150.500	0.573	0.00
150.750	0.587	0.00
151.000	0.587	0.00
151.250	0.587	0.00
151.500	0.587	0.00
151.750	0.444	0.00
152.000	0.444	0.00
152.250	0.444	0.00
152.500	0.444	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
152.750	0.444	0.00
153.000	0.473	0.00
153.250	0.473	0.00
153.500	0.473	0.00
153.750	0.473	0.00
154.000	0.473	0.00
154.250	0.473	0.00
154.500	0.473	0.00
154.750	0.487	0.00
155.000	0.487	0.00
155.250	0.487	0.00
155.500	0.487	0.00
155.750	0.487	0.00
156.000	0.487	0.00
156.250	0.487	0.00
156.500	0.487	0.00
156.750	0.487	0.00
157.000	0.487	0.00
157.250	0.487	0.00
157.500	0.344	0.00
157.750	0.344	0.00
158.000	0.330	0.00
158.250	0.330	0.00
158.500	0.344	0.00
158.750	0.344	0.00
159.000	0.344	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
159.250	0.344	0.00
159.500	0.344	0.00
159.750	0.358	0.00
160.000	0.358	0.00
160.250	0.358	0.00
160.500	0.358	0.00
160.750	0.358	0.00
161.000	0.358	0.00
161.250	0.358	0.00
161.500	0.373	0.00
161.750	0.358	0.00
162.000	0.373	0.00
162.250	0.373	0.00
162.500	0.373	0.00
162.750	0.373	0.00
163.000	0.387	0.00
163.250	0.373	0.00
163.500	0.373	0.00
163.750	0.401	0.00
164.000	0.401	0.00
164.250	0.244	0.00
164.500	0.244	0.00
164.750	0.244	0.00
165.000	0.258	0.00
165.250	0.244	0.00
165.500	0.244	0.00

A-3. Transmissivity (ft^2/day) for Injection Test R-16-2c as a Function of Well Efficiency and Aquifer Penetration[a]

Well Eff. (%)	Aquifer Penetration (%)																		
	1.342	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	80	90	100
20	3404	1611	708	325	213	161	131	111	96	85	77	70	65	60	57	54	50	48	47
25	2722	1288	565	259	170	128	104	88	76	67	61	55	51	47	45	42	39	37	37
30	2268	1072	470	215	141	106	86	72	63	55	50	45	42	39	36	35	32	30	30
35	1943	919	403	184	120	90	73	61	53	47	42	38	35	33	31	29	27	26	25
40	1700	804	352	161	105	79	63	53	46	41	36	33	30	28	26	25	23	22	22
45	1511	714	313	142	93	70	56	47	41	36	32	29	27	25	23	22	20	19	19
50	1360	642	281	128	83	62	50	42	36	32	29	26	24	22	21	20	18	17	17
55	1236	584	255	116	76	57	46	38	33	29	26	23	21	20	19	18	16	15	15
60	1133	535	234	106	69	52	42	35	30	26	24	21	19	18	17	16	15	14	14
65	1045	494	216	98	64	48	38	32	28	24	22	20	18	16	15	15	13	13	12
70	971	458	200	91	59	44	35	30	25	22	20	18	16	15	14	13	12	12	11
75	906	428	187	85	55	41	33	28	24	21	19	17	15	14	13	12	11	11	10
80	**849**[b]	401	175	79	51	38	31	26	22	19	17	16	14	13	12	11	11	10	10
85	799	377	165	75	48	36	29	24	21	18	16	15	13	12	11	11	10	9	9
90	755	356	155	70	46	34	27	23	20	17	15	14	12	11	11	10	9	9	8
95	715	337	147	67	43	32	26	21	18	16	14	13	12	11	10	9	9	8	8
100	679	320	140	63	41	30	24	20	17	15	14	12	11	10	10	9	8	8	7

[a] Input data (McLin 2004, 82834): Q = 8.45 gpm; s = 122.47 ft at t = 60.0 min; screen length = 7.6 ft; dw = 10.625 in.; S = 0.003; aquifer thickness = 559 ft.

[b] Shaded example shows that for a well efficiency of 80% and aquifer penetration of 1.34%, T = 849 ft^2/day.

Appendix B

Data for Injection and Recovery, Test R-16-3c

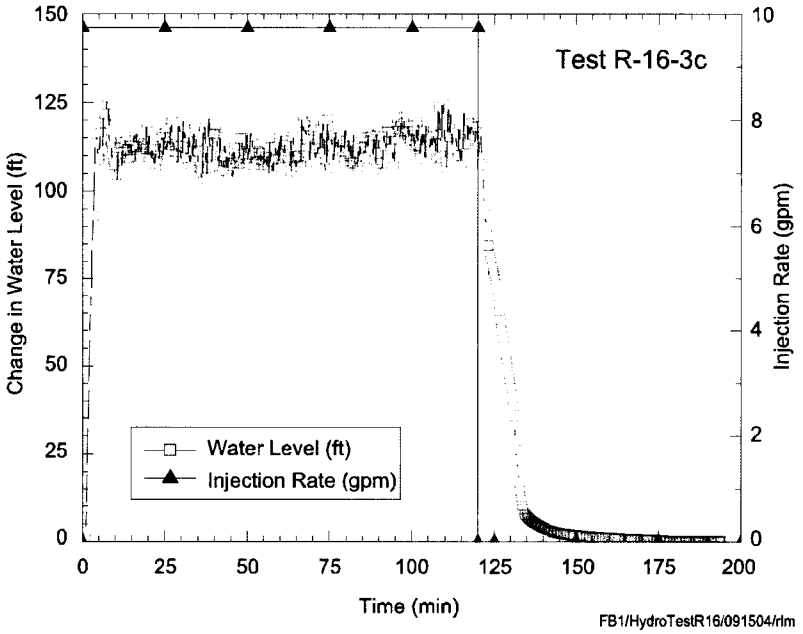
Contents

B-1 Field Plot for R-16, Screen 3, Test c

B-2 Data for Injection and Recovery Test R-16-3

B-3 Transmissivity (ft^2/day) for Injection Test R-16-3c as a Function of Well Efficiency and Aquifer Penetration

B-1. Field Plot for R-16, Screen 3, Test c



B-2. Data for Injection and Recovery Test R-16-3

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.487	9.74
0.250	0.644	9.74
0.500	0.572	9.74
0.750	1.088	9.74
1.000	2.692	9.74
1.250	9.683	9.74
1.500	20.401	9.74
1.750	33.474	9.74
2.000	44.299	9.74
2.250	58.584	9.74
2.500	65.916	9.74
2.750	71.110	9.74
3.000	84.674	9.74
3.250	93.001	9.74
3.500	93.015	9.74
3.750	106.601	9.74
4.000	113.683	9.74
4.250	116.269	9.74
4.500	113.151	9.74
4.750	109.344	9.74
5.000	108.784	9.74
5.250	110.378	9.74
5.500	116.700	9.74
5.750	114.717	9.74
6.000	112.016	9.74
6.250	111.370	9.74
6.500	122.045	9.74
6.750	120.019	9.74
7.000	119.185	9.74
7.250	121.671	9.74
7.500	126.643	9.74
7.750	124.689	9.74
8.000	117.217	9.74
8.250	112.576	9.74
8.500	114.387	9.74
8.750	113.611	9.74
9.000	107.778	9.74
9.250	108.497	9.74
9.500	108.899	9.74
9.750	107.448	9.74
10.000	104.044	9.74
10.250	104.834	9.74
10.500	101.933	9.74
10.750	112.189	9.74
11.000	109.603	9.74
11.250	112.433	9.74
11.500	113.855	9.74
11.750	110.924	9.74
12.000	105.811	9.74
12.250	112.749	9.74
12.500	111.815	9.74
12.750	113.769	9.74
13.000	115.608	9.74
13.250	111.556	9.74
13.500	109.517	9.74
13.750	111.758	9.74
14.000	108.999	9.74
14.250	109.287	9.74
14.500	109.847	9.74
14.750	114.372	9.74
15.000	112.792	9.74
15.250	112.878	9.74
15.500	112.347	9.74
15.750	116.786	9.74
16.000	113.309	9.74
16.250	112.576	9.74
16.500	117.289	9.74
16.750	113.683	9.74
17.000	115.493	9.74
17.250	110.536	9.74
17.500	111.944	9.74
17.750	109.933	9.74
18.000	113.280	9.74
18.250	111.068	9.74
18.500	113.510	9.74
18.750	112.605	9.74
19.000	112.059	9.74
19.250	111.944	9.74
19.500	119.444	9.74
19.750	113.912	9.74
20.000	109.445	9.74
20.250	116.858	9.74
20.500	112.016	9.74
20.750	111.714	9.74
21.000	108.152	9.74
21.250	112.849	9.74
21.500	112.562	9.74
21.750	110.637	9.74
22.000	106.558	9.74
22.250	111.887	9.74
22.500	108.597	9.74
22.750	109.890	9.74
23.000	111.298	9.74
23.250	107.764	9.74
23.500	114.746	9.74
23.750	115.277	9.74
24.000	116.269	9.74
24.250	112.734	9.74
24.500	108.913	9.74
24.750	116.384	9.74
25.000	117.820	9.74
25.250	113.869	9.74
25.500	110.422	9.74
25.750	115.320	9.74
26.000	112.332	9.74
26.250	113.036	9.74
26.500	111.499	9.74
26.750	119.415	9.74
27.000	120.076	9.74
27.250	115.249	9.74
27.500	114.947	9.74
27.750	111.169	9.74
28.000	111.255	9.74
28.250	113.122	9.74
28.500	113.510	9.74
28.750	109.876	9.74
29.000	106.888	9.74

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
29.250	119.573	9.74
29.500	115.464	9.74
29.750	112.691	9.74
30.000	107.822	9.74
30.250	109.545	9.74
30.500	121.010	9.74
30.750	117.691	9.74
31.000	113.539	9.74
31.250	117.404	9.74
31.500	115.277	9.74
31.750	112.145	9.74
32.000	109.201	9.74
32.250	116.427	9.74
32.500	111.226	9.74
32.750	107.003	9.74
33.000	111.427	9.74
33.250	113.927	9.74
33.500	108.813	9.74
33.750	117.375	9.74
34.000	112.246	9.74
34.250	110.637	9.74
34.500	115.881	9.74
34.750	114.099	9.74
35.000	111.384	9.74
35.250	106.845	9.74
35.500	108.497	9.74
35.750	105.581	9.74
36.000	106.299	9.74
36.250	102.493	9.74
36.500	103.785	9.74
36.750	117.705	9.74
37.000	119.458	9.74
37.250	111.987	9.74
37.500	106.716	9.74
37.750	103.484	9.74
38.000	113.898	9.74
38.250	121.714	9.74
38.500	116.269	9.74
38.750	111.226	9.74

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
39.000	110.292	9.74
39.250	106.888	9.74
39.500	116.269	9.74
39.750	115.881	9.74
40.000	116.182	9.74
40.250	117.389	9.74
40.500	116.542	9.74
40.750	115.364	9.74
41.000	111.183	9.74
41.250	107.304	9.74
41.500	105.926	9.74
41.750	116.082	9.74
42.000	110.091	9.74
42.250	105.566	9.74
42.500	108.554	9.74
42.750	106.055	9.74
43.000	109.847	9.74
43.250	114.099	9.74
43.500	109.315	9.74
43.750	110.996	9.74
44.000	105.681	9.74
44.250	110.709	9.74
44.500	107.376	9.74
44.750	109.071	9.74
45.000	107.965	9.74
45.250	106.400	9.74
45.500	102.766	9.74
45.750	107.261	9.74
46.000	112.246	9.74
46.250	107.951	9.74
46.500	108.827	9.74
46.750	106.787	9.74
47.000	110.062	9.74
47.250	110.982	9.74
47.500	108.023	9.74
47.750	114.889	9.74
48.000	114.889	9.74
48.250	115.019	9.74
48.500	110.422	9.74

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
48.750	106.514	9.74
49.000	114.099	9.74
49.250	111.628	9.74
49.500	109.272	9.74
49.750	117.030	9.74
50.000	110.666	9.74
50.250	107.577	9.74
50.500	113.395	9.74
50.750	109.732	9.74
51.000	117.662	9.74
51.250	114.243	9.74
51.500	115.536	9.74
51.750	110.982	9.74
52.000	107.721	9.74
52.250	109.531	9.74
52.500	110.134	9.74
52.750	108.928	9.74
53.000	113.338	9.74
53.250	111.183	9.74
53.500	110.809	9.74
53.750	111.370	9.74
54.000	107.678	9.74
54.250	108.741	9.74
54.500	110.637	9.74
54.750	108.324	9.74
55.000	106.414	9.74
55.250	112.303	9.74
55.500	109.746	9.74
55.750	110.264	9.74
56.000	106.960	9.74
56.250	107.462	9.74
56.500	105.006	9.74
56.750	115.263	9.74
57.000	112.303	9.74
57.250	108.367	9.74
57.500	108.626	9.74
57.750	104.489	9.74
58.000	109.086	9.74
58.250	111.801	9.74

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
58.500	109.330	9.74
58.750	113.553	9.74
59.000	112.734	9.74
59.250	109.129	9.74
59.500	107.376	9.74
59.750	115.119	9.74
60.000	110.493	9.74
60.250	116.872	9.74
60.500	112.921	9.74
60.750	111.528	9.74
61.000	113.165	9.74
61.250	109.488	9.74
61.500	114.372	9.74
61.750	113.180	9.74
62.000	112.519	9.74
62.250	109.703	9.74
62.500	111.111	9.74
62.750	109.071	9.74
63.000	105.897	9.74
63.250	104.460	9.74
63.500	115.407	9.74
63.750	116.441	9.74
64.000	111.686	9.74
64.250	109.818	9.74
64.500	109.631	9.74
64.750	105.724	9.74
65.000	109.962	9.74
65.250	109.459	9.74
65.500	110.134	9.74
65.750	110.106	9.74
66.000	108.367	9.74
66.250	107.060	9.74
66.500	121.470	9.74
66.750	119.774	9.74
67.000	115.766	9.74
67.250	119.387	9.74
67.500	118.625	9.74
67.750	114.789	9.74
68.000	114.976	9.74

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
68.250	113.596	9.74
68.500	112.849	9.74
68.750	112.576	9.74
69.000	107.419	9.74
69.250	115.277	9.74
69.500	117.088	9.74
69.750	117.317	9.74
70.000	118.481	9.74
70.250	113.079	9.74
70.500	112.074	9.74
70.750	108.281	9.74
71.000	112.246	9.74
71.250	109.416	9.74
71.500	113.769	9.74
71.750	111.973	9.74
72.000	110.766	9.74
72.250	117.677	9.74
72.500	113.798	9.74
72.750	111.097	9.74
73.000	120.105	9.74
73.250	115.996	9.74
73.500	108.999	9.74
73.750	104.618	9.74
74.000	106.701	9.74
74.250	120.249	9.74
74.500	118.395	9.74
74.750	112.964	9.74
75.000	112.936	9.74
75.250	115.076	9.74
75.500	115.967	9.74
75.750	111.657	9.74
76.000	111.916	9.74
76.250	107.506	9.74
76.500	116.355	9.74
76.750	111.097	9.74
77.000	113.999	9.74
77.250	115.105	9.74
77.500	111.542	9.74
77.750	115.766	9.74

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
78.000	114.947	9.74
78.250	114.401	9.74
78.500	109.675	9.74
78.750	114.013	9.74
79.000	111.327	9.74
79.250	108.683	9.74
79.500	110.565	9.74
79.750	118.539	9.74
80.000	114.286	9.74
80.250	112.490	9.74
80.500	110.091	9.74
80.750	115.622	9.74
81.000	110.120	9.74
81.250	108.698	9.74
81.500	114.042	9.74
81.750	108.138	9.74
82.000	108.138	9.74
82.250	117.159	9.74
82.500	112.778	9.74
82.750	110.853	9.74
83.000	109.502	9.74
83.250	106.457	9.74
83.500	107.103	9.74
83.750	112.160	9.74
84.000	108.698	9.74
84.250	114.056	9.74
84.500	110.034	9.74
84.750	112.476	9.74
85.000	112.260	9.74
85.250	111.930	9.74
85.500	112.706	9.74
85.750	109.402	9.74
86.000	115.162	9.74
86.250	115.292	9.74
86.500	111.456	9.74
86.750	117.030	9.74
87.000	113.970	9.74
87.250	116.182	9.74
87.500	114.688	9.74

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
87.750	115.766	9.74
88.000	113.180	9.74
88.250	108.956	9.74
88.500	115.823	9.74
88.750	110.881	9.74
89.000	106.529	9.74
89.250	117.303	9.74
89.500	113.912	9.74
89.750	111.140	9.74
90.000	115.550	9.74
90.250	112.620	9.74
90.500	110.924	9.74
90.750	107.922	9.74
91.000	105.222	9.74
91.250	113.022	9.74
91.500	116.757	9.74
91.750	112.361	9.74
92.000	114.602	9.74
92.250	110.953	9.74
92.500	118.266	9.74
92.750	116.757	9.74
93.000	116.657	9.74
93.250	111.987	9.74
93.500	116.829	9.74
93.750	111.959	9.74
94.000	112.289	9.74
94.250	108.051	9.74
94.500	107.046	9.74
94.750	114.861	9.74
95.000	117.016	9.74
95.250	121.226	9.74
95.500	119.631	9.74
95.750	115.579	9.74
96.000	117.145	9.74
96.250	115.953	9.74
96.500	114.990	9.74
96.750	120.593	9.74
97.000	117.030	9.74
97.250	119.157	9.74
97.500	121.096	9.74
97.750	116.441	9.74
98.000	119.559	9.74
98.250	116.944	9.74
98.500	116.815	9.74
98.750	115.105	9.74
99.000	118.625	9.74
99.250	114.545	9.74
99.500	111.600	9.74
99.750	112.892	9.74
100.000	117.576	9.74
100.250	115.665	9.74
100.500	117.246	9.74
100.750	112.131	9.74
101.000	113.137	9.74
101.250	113.410	9.74
101.500	118.625	9.74
101.750	112.964	9.74
102.000	112.706	9.74
102.250	112.964	9.74
102.500	109.330	9.74
102.750	116.958	9.74
103.000	111.743	9.74
103.250	117.562	9.74
103.500	117.217	9.74
103.750	112.433	9.74
104.000	108.209	9.74
104.250	119.616	9.74
104.500	115.550	9.74
104.750	114.071	9.74
105.000	115.407	9.74
105.250	113.223	9.74
105.500	111.355	9.74
105.750	116.125	9.74
106.000	111.700	9.74
106.250	115.766	9.74
106.500	116.815	9.74
106.750	112.174	9.74
107.000	116.096	9.74
107.250	110.034	9.74
107.500	106.802	9.74
107.750	109.631	9.74
108.000	124.013	9.74
108.250	123.539	9.74
108.500	116.297	9.74
108.750	112.792	9.74
109.000	113.711	9.74
109.250	125.781	9.74
109.500	120.507	9.74
109.750	118.740	9.74
110.000	112.792	9.74
110.250	108.382	9.74
110.500	105.365	9.74
110.750	115.378	9.74
111.000	124.488	9.74
111.250	119.430	9.74
111.500	115.478	9.74
111.750	123.036	9.74
112.000	117.576	9.74
112.250	111.887	9.74
112.500	116.714	9.74
112.750	117.203	9.74
113.000	115.708	9.74
113.250	116.182	9.74
113.500	111.283	9.74
113.750	110.106	9.74
114.000	110.249	9.74
114.250	118.740	9.74
114.500	113.137	9.74
114.750	107.462	9.74
115.000	112.648	9.74
115.250	108.209	9.74
115.500	110.680	9.74
115.750	123.295	9.74
116.000	117.447	9.74
116.250	113.323	9.74
116.500	115.780	9.74
116.750	113.352	9.74

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
117.000	119.832	9.74
117.250	119.272	9.74
117.500	114.861	9.74
117.750	119.027	9.74
118.000	119.487	9.74
118.250	116.154	9.74
118.500	118.295	9.74
118.750	114.387	9.74
119.000	112.433	9.74
119.250	118.395	9.74
119.500	116.728	9.74
119.750	118.237	9.74
120.000	112.950	9.74
120.250	108.841	0.00
120.500	115.105	0.00
120.750	116.829	0.00
121.000	109.459	0.00
121.250	107.692	0.00
121.500	104.590	0.00
121.750	99.549	0.00
122.000	95.915	0.00
122.250	93.518	0.00
122.500	90.172	0.00
122.750	87.645	0.00
123.000	84.760	0.00
123.250	84.774	0.00
123.500	82.176	0.00
123.750	80.496	0.00
124.000	81.171	0.00
124.250	78.472	0.00
124.500	77.453	0.00
124.750	76.779	0.00
125.000	76.119	0.00
125.250	75.042	0.00
125.500	73.449	0.00
125.750	71.928	0.00
126.000	70.134	0.00
126.250	67.967	0.00
126.500	65.987	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
126.750	63.333	0.00
127.000	62.257	0.00
127.250	60.148	0.00
127.500	58.441	0.00
127.750	57.265	0.00
128.000	55.615	0.00
128.250	53.635	0.00
128.500	52.373	0.00
128.750	51.283	0.00
129.000	49.734	0.00
129.250	47.841	0.00
129.500	46.636	0.00
129.750	45.546	0.00
130.000	43.869	0.00
130.250	41.875	0.00
130.500	40.356	0.00
130.750	38.621	0.00
131.000	35.954	0.00
131.250	33.216	0.00
131.500	29.087	0.00
131.750	26.392	0.00
132.000	23.368	0.00
132.250	20.115	0.00
132.500	17.005	0.00
132.750	14.626	0.00
133.000	12.936	0.00
133.250	11.746	0.00
133.500	10.256	0.00
133.750	9.225	0.00
134.000	8.251	0.00
134.250	7.835	0.00
134.500	7.563	0.00
134.750	7.319	0.00
135.000	7.062	0.00
135.250	6.818	0.00
135.500	6.675	0.00
135.750	6.431	0.00
136.000	6.173	0.00
136.250	6.059	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
136.500	5.858	0.00
136.750	5.615	0.00
137.000	5.486	0.00
137.250	5.357	0.00
137.500	5.128	0.00
137.750	5.013	0.00
138.000	4.884	0.00
138.250	4.612	0.00
138.500	4.583	0.00
138.750	4.454	0.00
139.000	4.340	0.00
139.250	4.225	0.00
139.500	4.125	0.00
139.750	3.996	0.00
140.000	3.896	0.00
140.250	3.781	0.00
140.500	3.666	0.00
140.750	3.552	0.00
141.000	3.437	0.00
141.250	3.308	0.00
141.500	3.294	0.00
141.750	3.194	0.00
142.000	3.065	0.00
142.250	3.051	0.00
142.500	2.965	0.00
142.750	2.864	0.00
143.000	2.864	0.00
143.250	2.750	0.00
143.500	2.649	0.00
143.750	2.635	0.00
144.000	2.549	0.00
144.250	2.535	0.00
144.500	2.435	0.00
144.750	2.435	0.00
145.000	2.349	0.00
145.250	2.334	0.00
145.500	2.334	0.00
145.750	2.220	0.00
146.000	2.220	0.00

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
146.250	2.134	0.00
146.500	2.119	0.00
146.750	2.119	0.00
147.000	2.019	0.00
147.250	2.019	0.00
147.500	2.019	0.00
147.750	2.019	0.00
148.000	1.890	0.00
148.250	1.890	0.00
148.500	1.876	0.00
148.750	1.876	0.00
149.000	1.776	0.00
149.250	1.776	0.00
149.500	1.776	0.00
149.750	1.761	0.00
150.000	1.675	0.00
150.250	1.675	0.00
150.500	1.675	0.00
150.750	1.675	0.00
151.000	1.589	0.00
151.250	1.589	0.00
151.500	1.589	0.00
151.750	1.504	0.00
152.000	1.504	0.00
152.250	1.504	0.00
152.500	1.504	0.00
152.750	1.418	0.00
153.000	1.418	0.00
153.250	1.418	0.00
153.500	1.418	0.00
153.750	1.418	0.00
154.000	1.317	0.00
154.250	1.317	0.00
154.500	1.317	0.00
154.750	1.317	0.00
155.000	1.317	0.00
155.250	1.217	0.00
155.500	1.217	0.00
155.750	1.217	0.00
156.000	1.217	0.00
156.250	1.203	0.00
156.500	1.088	0.00
156.750	1.088	0.00
157.000	1.074	0.00
157.250	1.074	0.00
157.500	1.074	0.00
157.750	1.074	0.00
158.000	1.074	0.00
158.250	0.974	0.00
158.500	0.988	0.00
158.750	0.988	0.00
159.000	0.988	0.00
159.250	0.988	0.00
159.500	0.988	0.00
159.750	0.988	0.00
160.000	0.988	0.00
160.250	0.888	0.00
160.500	0.888	0.00
160.750	0.888	0.00
161.000	0.873	0.00
161.250	0.888	0.00
161.500	0.888	0.00
161.750	0.744	0.00
162.000	0.730	0.00
162.250	0.730	0.00
162.500	0.730	0.00
162.750	0.730	0.00
163.000	0.730	0.00
163.250	0.730	0.00
163.500	0.730	0.00
163.750	0.744	0.00
164.000	0.730	0.00
164.250	0.744	0.00
164.500	0.630	0.00
164.750	0.630	0.00
165.000	0.630	0.00
165.250	0.630	0.00
165.500	0.630	0.00
165.750	0.630	0.00
166.000	0.630	0.00
166.250	0.630	0.00
166.500	0.630	0.00
166.750	0.630	0.00
167.000	0.630	0.00
167.250	0.630	0.00
167.500	0.544	0.00
167.750	0.544	0.00
168.000	0.544	0.00
168.250	0.544	0.00
168.500	0.544	0.00
168.750	0.544	0.00
169.000	0.544	0.00
169.250	0.544	0.00
169.500	0.544	0.00
169.750	0.444	0.00
170.000	0.444	0.00
170.250	0.444	0.00
170.500	0.458	0.00
170.750	0.458	0.00
171.000	0.458	0.00
171.250	0.458	0.00
171.500	0.458	0.00
171.750	0.458	0.00
172.000	0.358	0.00
172.250	0.358	0.00
172.500	0.358	0.00
172.750	0.358	0.00
173.000	0.358	0.00
173.250	0.358	0.00
173.500	0.358	0.00
173.750	0.358	0.00
174.000	0.358	0.00
174.250	0.358	0.00
174.500	0.272	0.00
174.750	0.272	0.00
175.000	0.272	0.00
175.250	0.272	0.00

B-2. Data for Injection and Recovery Test R-16-3 (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
175.500	0.272	0.00
175.750	0.286	0.00
176.000	0.286	0.00
176.250	0.272	0.00
176.500	0.272	0.00
176.750	0.286	0.00
177.000	0.272	0.00
177.250	0.286	0.00
177.500	0.128	0.00
177.750	0.128	0.00
178.000	0.128	0.00
178.250	0.128	0.00
178.500	0.128	0.00
178.750	0.114	0.00
179.000	0.128	0.00
179.250	0.128	0.00
179.500	0.128	0.00
179.750	0.128	0.00
180.000	0.143	0.00
180.250	0.143	0.00
180.500	0.143	0.00
180.750	0.143	0.00
181.000	0.143	0.00
181.250	0.143	0.00
181.500	0.143	0.00
181.750	0.143	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
182.000	0.143	0.00
182.250	0.143	0.00
182.500	0.128	0.00
182.750	0.143	0.00
183.000	0.143	0.00
183.250	0.143	0.00
183.500	0.143	0.00
183.750	0.143	0.00
184.000	0.143	0.00
184.250	0.000	0.00
184.500	0.000	0.00
184.750	0.000	0.00
185.000	0.014	0.00
185.250	0.014	0.00
185.500	0.014	0.00
185.750	0.014	0.00
186.000	0.014	0.00
186.250	0.014	0.00
186.500	0.014	0.00
186.750	0.000	0.00
187.000	0.014	0.00
187.250	0.014	0.00
187.500	0.014	0.00
187.750	0.014	0.00
188.000	0.014	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
188.250	0.014	0.00
188.500	0.014	0.00
188.750	0.014	0.00
189.000	0.028	0.00
189.250	0.014	0.00
189.500	0.014	0.00
189.750	0.028	0.00
190.000	0.014	0.00
190.250	0.014	0.00
190.500	0.028	0.00
190.750	0.028	0.00
191.000	0.028	0.00
191.250	0.028	0.00
191.500	0.028	0.00
191.750	0.028	0.00
192.000	0.028	0.00
192.250	0.028	0.00
192.500	0.028	0.00
192.750	0.043	0.00
193.000	0.043	0.00
193.250	0.043	0.00
193.500	0.043	0.00
193.750	0.043	0.00
194.000	0.043	0.00
194.250	0.043	0.00

B-3. Transmissivity (ft^2/day) for Injection Test R-16-3c as a Function of Well Efficiency and Aquifer Penetration[a]

Well Eff. (%)	Aquifer Penetration (%)																		
	1.3596	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	80	90	100
20	4240	2040	898	413	272	206	167	142	123	110	99	90	84	78	74	70	65	63	61
25	3391	1631	717	329	216	163	132	112	97	86	78	71	66	61	58	55	51	49	48
30	2825	1358	597	273	179	135	110	93	80	71	64	58	54	50	47	45	41	40	39
35	2421	1164	511	234	153	115	93	79	68	60	54	49	45	42	40	38	35	33	33
40	2118	1018	446	204	133	100	81	68	59	52	47	43	39	37	34	33	30	29	28
45	1882	904	396	181	118	89	72	60	52	46	41	38	35	32	30	29	26	25	25
50	1694	814	357	163	106	80	64	54	47	41	37	34	31	29	27	25	23	22	22
55	1539	739	324	148	96	72	58	49	42	37	33	30	28	26	24	23	21	20	19
60	1411	678	297	135	88	66	53	45	39	34	30	27	25	23	22	21	19	18	18
65	1302	625	274	125	81	61	49	41	35	31	28	25	23	21	20	19	17	17	16
70	1209	580	254	116	75	56	45	38	33	29	26	23	21	20	18	17	16	15	15
75	1128	542	237	108	70	52	42	35	30	27	24	22	20	18	17	16	15	14	14
80	**1058**[b]	508	222	101	66	49	39	33	28	25	22	20	18	17	16	15	14	13	13
85	995	478	209	95	62	46	37	31	27	23	21	19	17	16	15	14	13	12	12
90	940	451	197	89	58	43	35	29	25	22	20	18	16	15	14	13	12	11	11
95	890	427	187	85	55	41	33	28	24	21	18	17	15	14	13	12	11	11	10
100	846	406	177	80	52	39	31	26	22	20	17	16	14	13	12	12	11	10	10

[a] Input data (McLin 2004, 82834): Q = 9.74 gpm; s = 111.92 ft at t = 60.0 min; screen length = 7.6 ft; dw = 10.625 in.; *S* = 0.003; aquifer thickness = 559 ft.

[b] Shaded example shows that for a well efficiency of 80% and aquifer penetration of 1.36%, *T* = 1058 ft^2/day.

Appendix C

Data for Injection and Recovery, Test R-16-4c

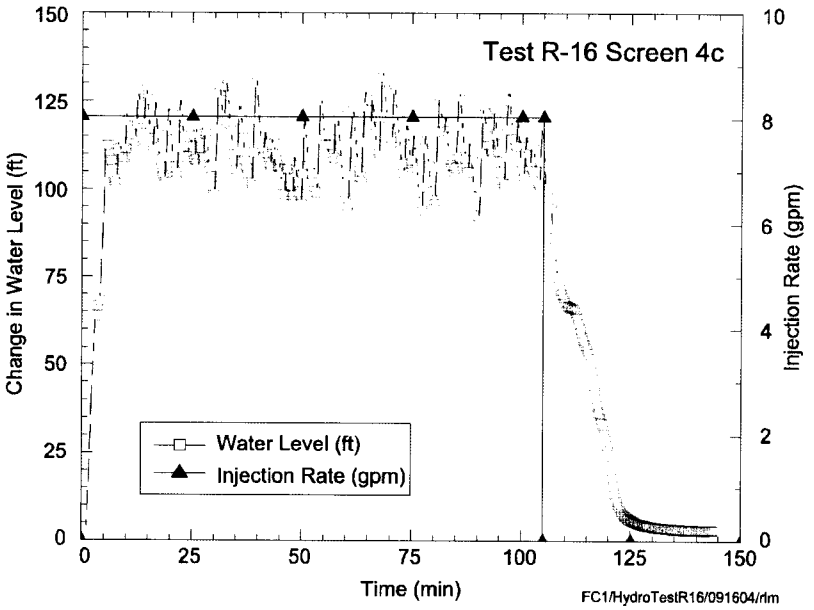
Contents

C-1 Field Plot for R-16, Screen 4, Test c

C-2 Data for Injection and Recovery Test R-16-4c

C-3 Transmissivity (ft^2/day) for Injection Test R-16-4c as a Function of Well Efficiency and Aquifer Penetration

C-1. Field Plot for R-16, Screen 4, Test c



C-2. Data for Injection and Recovery Test R-16-4c

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.071	8.04
0.250	1.074	8.04
0.500	0.430	8.04
0.750	1.418	8.04
1.000	2.522	8.04
1.250	7.007	8.04
1.500	15.221	8.04
1.750	24.325	8.04
2.000	34.133	8.04
2.250	45.250	8.04
2.500	52.109	8.04
2.750	57.260	8.04
3.000	63.877	8.04
3.250	64.049	8.04
3.500	66.604	8.04
3.750	68.212	8.04
4.000	68.025	8.04
4.250	71.629	8.04
4.500	81.335	8.04
4.750	91.604	8.04
5.000	101.890	8.04
5.250	112.409	8.04
5.500	115.039	8.04
5.750	112.481	8.04
6.000	110.224	8.04
6.250	108.198	8.04
6.500	108.112	8.04
6.750	105.726	8.04
7.000	103.226	8.04
7.250	102.249	8.04
7.500	101.559	8.04
7.750	102.680	8.04
8.000	111.202	8.04
8.250	114.435	8.04
8.500	113.242	8.04
8.750	109.865	8.04
9.000	109.132	8.04
9.250	108.284	8.04
9.500	109.017	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
9.750	111.518	8.04
10.000	119.322	8.04
10.250	122.643	8.04
10.500	120.587	8.04
10.750	117.626	8.04
11.000	115.600	8.04
11.250	113.731	8.04
11.500	112.797	8.04
11.750	112.064	8.04
12.000	113.904	8.04
12.250	118.402	8.04
12.500	126.237	8.04
12.750	128.164	8.04
13.000	123.851	8.04
13.250	121.709	8.04
13.500	119.926	8.04
13.750	119.064	8.04
14.000	118.661	8.04
14.250	127.085	8.04
14.500	129.199	8.04
14.750	125.375	8.04
15.000	120.731	8.04
15.250	117.181	8.04
15.500	114.292	8.04
15.750	111.992	8.04
16.000	111.144	8.04
16.250	119.136	8.04
16.500	125.806	8.04
16.750	121.249	8.04
17.000	115.614	8.04
17.250	111.863	8.04
17.500	108.529	8.04
17.750	106.143	8.04
18.000	104.606	8.04
18.250	104.002	8.04
18.500	103.169	8.04
18.750	101.991	8.04
19.000	108.974	8.04
19.250	117.827	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
19.500	123.937	8.04
19.750	120.803	8.04
20.000	116.778	8.04
20.250	113.889	8.04
20.500	109.261	8.04
20.750	106.172	8.04
21.000	104.907	8.04
21.250	103.743	8.04
21.500	104.692	8.04
21.750	111.748	8.04
22.000	120.860	8.04
22.250	126.424	8.04
22.500	122.485	8.04
22.750	119.251	8.04
23.000	114.809	8.04
23.250	112.251	8.04
23.500	109.247	8.04
23.750	108.097	8.04
24.000	109.261	8.04
24.250	112.897	8.04
24.500	115.226	8.04
24.750	111.978	8.04
25.000	109.994	8.04
25.250	108.557	8.04
25.500	108.543	8.04
25.750	114.967	8.04
26.000	118.158	8.04
26.250	115.786	8.04
26.500	113.875	8.04
26.750	111.748	8.04
27.000	108.988	8.04
27.250	107.882	8.04
27.500	109.290	8.04
27.750	116.462	8.04
28.000	115.729	8.04
28.250	113.099	8.04
28.500	109.592	8.04
28.750	106.244	8.04
29.000	103.643	8.04

C-2. Data for Injection and Recovery Test R-16-4c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
29.250	100.999	8.04
29.500	99.031	8.04
29.750	98.356	8.04
30.000	98.614	8.04
30.250	106.488	8.04
30.500	117.008	8.04
30.750	127.215	8.04
31.000	128.868	8.04
31.250	129.415	8.04
31.500	125.087	8.04
31.750	121.033	8.04
32.000	118.977	8.04
32.250	120.012	8.04
32.500	129.127	8.04
32.750	131.255	8.04
33.000	126.367	8.04
33.250	122.629	8.04
33.500	118.719	8.04
33.750	116.649	8.04
34.000	112.466	8.04
34.250	109.966	8.04
34.500	108.040	8.04
34.750	105.827	8.04
35.000	104.433	8.04
35.250	110.972	8.04
35.500	121.177	8.04
35.750	124.800	8.04
36.000	121.407	8.04
36.250	117.396	8.04
36.500	114.680	8.04
36.750	110.512	8.04
37.000	108.155	8.04
37.250	106.129	8.04
37.500	104.519	8.04
37.750	102.551	8.04
38.000	102.034	8.04
38.250	101.186	8.04
38.500	101.818	8.04
38.750	110.483	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
39.000	119.840	8.04
39.250	130.162	8.04
39.500	132.003	8.04
39.750	127.963	8.04
40.000	122.154	8.04
40.250	117.712	8.04
40.500	113.702	8.04
40.750	111.791	8.04
41.000	109.376	8.04
41.250	110.526	8.04
41.500	117.468	8.04
41.750	112.912	8.04
42.000	110.037	8.04
42.250	107.695	8.04
42.500	106.862	8.04
42.750	106.359	8.04
43.000	111.906	8.04
43.250	115.398	8.04
43.500	113.099	8.04
43.750	109.923	8.04
44.000	108.399	8.04
44.250	106.603	8.04
44.500	107.048	8.04
44.750	108.701	8.04
45.000	104.836	8.04
45.250	101.559	8.04
45.500	99.333	8.04
45.750	98.700	8.04
46.000	98.427	8.04
46.250	105.798	8.04
46.500	105.813	8.04
46.750	103.514	8.04
47.000	101.042	8.04
47.250	99.491	8.04
47.500	98.672	8.04
47.750	98.226	8.04
48.000	104.879	8.04
48.250	110.382	8.04
48.500	106.818	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
48.750	102.220	8.04
49.000	99.304	8.04
49.250	98.600	8.04
49.500	96.617	8.04
49.750	95.813	8.04
50.000	104.433	8.04
50.250	115.858	8.04
50.500	121.651	8.04
50.750	116.836	8.04
51.000	113.271	8.04
51.250	109.118	8.04
51.500	106.833	8.04
51.750	104.634	8.04
52.000	104.778	8.04
52.250	102.594	8.04
52.500	100.956	8.04
52.750	99.519	8.04
53.000	99.376	8.04
53.250	99.088	8.04
53.500	103.054	8.04
53.750	114.205	8.04
54.000	125.202	8.04
54.250	126.568	8.04
54.500	123.017	8.04
54.750	118.776	8.04
55.000	115.441	8.04
55.250	112.811	8.04
55.500	110.742	8.04
55.750	109.362	8.04
56.000	112.653	8.04
56.250	114.248	8.04
56.500	112.610	8.04
56.750	110.339	8.04
57.000	109.060	8.04
57.250	108.902	8.04
57.500	119.940	8.04
57.750	122.341	8.04
58.000	120.803	8.04
58.250	116.793	8.04

C-2. Data for Injection and Recovery Test R-16-4c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
58.500	112.495	8.04
58.750	108.299	8.04
59.000	104.850	8.04
59.250	101.746	8.04
59.500	99.577	8.04
59.750	97.637	8.04
60.000	95.698	8.04
60.250	94.951	8.04
60.500	96.114	8.04
60.750	103.945	8.04
61.000	113.257	8.04
61.250	122.169	8.04
61.500	123.290	8.04
61.750	119.064	8.04
62.000	115.312	8.04
62.250	111.647	8.04
62.500	107.925	8.04
62.750	105.310	8.04
63.000	103.873	8.04
63.250	102.335	8.04
63.500	103.542	8.04
63.750	113.429	8.04
64.000	123.462	8.04
64.250	128.883	8.04
64.500	125.662	8.04
64.750	122.284	8.04
65.000	120.170	8.04
65.250	118.733	8.04
65.500	118.115	8.04
65.750	126.712	8.04
66.000	125.403	8.04
66.250	120.530	8.04
66.500	116.505	8.04
66.750	112.869	8.04
67.000	111.446	8.04
67.250	110.641	8.04
67.500	109.764	8.04
67.750	120.659	8.04
68.000	131.787	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
68.250	134.289	8.04
68.500	130.910	8.04
68.750	127.617	8.04
69.000	123.836	8.04
69.250	120.659	8.04
69.500	119.092	8.04
69.750	117.367	8.04
70.000	114.924	8.04
70.250	113.587	8.04
70.500	120.084	8.04
70.750	128.538	8.04
71.000	129.717	8.04
71.250	125.547	8.04
71.500	121.838	8.04
71.750	118.431	8.04
72.000	114.924	8.04
72.250	111.273	8.04
72.500	107.379	8.04
72.750	105.008	8.04
73.000	104.103	8.04
73.250	107.609	8.04
73.500	115.887	8.04
73.750	119.524	8.04
74.000	115.657	8.04
74.250	112.567	8.04
74.500	108.543	8.04
74.750	107.753	8.04
75.000	108.428	8.04
75.250	116.706	8.04
75.500	113.257	8.04
75.750	110.224	8.04
76.000	106.330	8.04
76.250	102.939	8.04
76.500	99.462	8.04
76.750	96.502	8.04
77.000	94.405	8.04
77.250	94.103	8.04
77.500	100.755	8.04
77.750	111.748	8.04

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
78.000	116.634	8.04
78.250	114.435	8.04
78.500	110.224	8.04
78.750	106.732	8.04
79.000	102.537	8.04
79.250	99.476	8.04
79.500	97.264	8.04
79.750	96.028	8.04
80.000	95.827	8.04
80.250	97.249	8.04
80.500	106.474	8.04
80.750	116.433	8.04
81.000	126.927	8.04
81.250	125.734	8.04
81.500	122.873	8.04
81.750	119.380	8.04
82.000	116.807	8.04
82.250	115.197	8.04
82.500	121.752	8.04
82.750	118.043	8.04
83.000	114.579	8.04
83.250	111.230	8.04
83.500	108.873	8.04
83.750	107.063	8.04
84.000	107.178	8.04
84.250	106.445	8.04
84.500	105.267	8.04
84.750	106.229	8.04
85.000	109.319	8.04
85.250	118.072	8.04
85.500	126.554	8.04
85.750	128.480	8.04
86.000	125.274	8.04
86.250	120.156	8.04
86.500	116.448	8.04
86.750	112.179	8.04
87.000	108.945	8.04
87.250	106.445	8.04
87.500	105.252	8.04

C-2. Data for Injection and Recovery Test R-16-4c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
87.750	105.152	8.04
88.000	114.536	8.04
88.250	111.202	8.04
88.500	108.543	8.04
88.750	105.180	8.04
89.000	101.085	8.04
89.250	98.126	8.04
89.500	95.612	8.04
89.750	92.652	8.04
90.000	91.905	8.04
90.250	91.331	8.04
90.500	99.505	8.04
90.750	110.397	8.04
91.000	120.472	8.04
91.250	123.951	8.04
91.500	121.838	8.04
91.750	117.411	8.04
92.000	115.298	8.04
92.250	112.840	8.04
92.500	112.323	8.04
92.750	111.546	8.04
93.000	111.288	8.04
93.250	110.469	8.04
93.500	115.657	8.04
93.750	122.988	8.04
94.000	120.587	8.04
94.250	116.203	8.04
94.500	111.130	8.04
94.750	108.184	8.04
95.000	105.166	8.04
95.250	103.284	8.04
95.500	102.422	8.04
95.750	101.904	8.04
96.000	101.847	8.04
96.250	109.319	8.04
96.500	117.037	8.04
96.750	125.446	8.04
97.000	128.681	8.04
97.250	125.058	8.04
97.500	120.343	8.04
97.750	117.238	8.04
98.000	114.536	8.04
98.250	113.228	8.04
98.500	112.826	8.04
98.750	112.567	8.04
99.000	121.019	8.04
99.250	116.620	8.04
99.500	112.366	8.04
99.750	108.026	8.04
100.000	105.928	8.04
100.250	104.232	8.04
100.500	103.485	8.04
100.750	110.325	8.04
101.000	116.232	8.04
101.250	112.380	8.04
101.500	109.951	8.04
101.750	108.256	8.04
102.000	106.617	8.04
102.250	112.840	8.04
102.500	113.444	8.04
102.750	111.633	8.04
103.000	108.299	8.04
103.250	105.324	8.04
103.500	102.422	8.04
103.750	101.832	8.04
104.000	101.545	8.04
104.250	108.011	8.04
104.500	118.359	8.04
104.750	117.425	8.04
105.000	112.538	8.04
105.250	106.675	0.00
105.500	100.654	0.00
105.750	99.146	0.00
106.000	97.264	0.00
106.250	97.838	0.00
106.500	95.655	0.00
106.750	94.822	0.00
107.000	89.162	0.00
107.250	86.433	0.00
107.500	83.905	0.00
107.750	81.665	0.00
108.000	78.362	0.00
108.250	75.160	0.00
108.500	73.394	0.00
108.750	71.686	0.00
109.000	70.250	0.00
109.250	70.308	0.00
109.500	69.446	0.00
109.750	68.499	0.00
110.000	67.939	0.00
110.250	67.078	0.00
110.500	66.906	0.00
110.750	66.791	0.00
111.000	66.504	0.00
111.250	66.346	0.00
111.500	66.532	0.00
111.750	66.188	0.00
112.000	65.886	0.00
112.250	65.327	0.00
112.500	64.322	0.00
112.750	63.532	0.00
113.000	62.040	0.00
113.250	60.576	0.00
113.500	59.686	0.00
113.750	58.193	0.00
114.000	57.332	0.00
114.250	56.758	0.00
114.500	55.911	0.00
114.750	55.079	0.00
115.000	54.390	0.00
115.250	53.544	0.00
115.500	52.037	0.00
115.750	50.502	0.00
116.000	48.335	0.00
116.250	46.384	0.00
116.500	44.347	0.00
116.750	42.941	0.00

C-2. Data for Injection and Recovery Test R-16-4c (continued)

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
117.000	40.889	0.00
117.250	38.680	0.00
117.500	36.887	0.00
117.750	36.471	0.00
118.000	35.023	0.00
118.250	33.761	0.00
118.500	33.345	0.00
118.750	31.767	0.00
119.000	30.491	0.00
119.250	28.669	0.00
119.500	27.407	0.00
119.750	25.758	0.00
120.000	24.267	0.00
120.250	21.772	0.00
120.500	20.210	0.00
120.750	17.944	0.00
121.000	15.722	0.00
121.250	13.672	0.00
121.500	12.497	0.00
121.750	11.422	0.00
122.000	10.591	0.00
122.250	9.903	0.00
122.500	9.215	0.00
122.750	8.512	0.00
123.000	8.025	0.00
123.250	7.624	0.00
123.500	7.409	0.00
123.750	7.036	0.00
124.000	6.807	0.00
124.250	6.577	0.00
124.500	6.363	0.00
124.750	6.148	0.00
125.000	5.947	0.00
125.250	5.718	0.00
125.500	5.531	0.00
125.750	5.503	0.00
126.000	5.288	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
126.250	5.116	0.00
126.500	5.073	0.00
126.750	4.901	0.00
127.000	4.872	0.00
127.250	4.700	0.00
127.500	4.671	0.00
127.750	4.499	0.00
128.000	4.471	0.00
128.250	4.456	0.00
128.500	4.299	0.00
128.750	4.284	0.00
129.000	4.256	0.00
129.250	4.141	0.00
129.500	4.112	0.00
129.750	4.112	0.00
130.000	3.955	0.00
130.250	3.941	0.00
130.500	3.926	0.00
130.750	3.912	0.00
131.000	3.769	0.00
131.250	3.754	0.00
131.500	3.754	0.00
131.750	3.754	0.00
132.000	3.740	0.00
132.250	3.726	0.00
132.500	3.582	0.00
132.750	3.568	0.00
133.000	3.554	0.00
133.250	3.554	0.00
133.500	3.554	0.00
133.750	3.554	0.00
134.000	3.554	0.00
134.250	3.396	0.00
134.500	3.396	0.00
134.750	3.396	0.00
135.000	3.382	0.00

Ellapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
135.250	3.382	0.00
135.500	3.382	0.00
135.750	3.382	0.00
136.000	3.382	0.00
136.250	3.382	0.00
136.500	3.238	0.00
136.750	3.210	0.00
137.000	3.210	0.00
137.250	3.210	0.00
137.500	3.210	0.00
137.750	3.195	0.00
138.000	3.210	0.00
138.250	3.210	0.00
138.500	3.224	0.00
138.750	3.224	0.00
139.000	3.195	0.00
139.250	3.195	0.00
139.500	3.052	0.00
139.750	3.052	0.00
140.000	3.052	0.00
140.250	3.052	0.00
140.500	3.052	0.00
140.750	3.052	0.00
141.000	3.052	0.00
141.250	3.038	0.00
141.500	3.038	0.00
141.750	3.052	0.00
142.000	3.038	0.00
142.250	3.052	0.00
142.500	3.052	0.00
142.750	3.052	0.00
143.000	3.052	0.00
143.250	3.052	0.00
143.500	3.052	0.00
143.750	3.052	0.00
144.000	3.052	0.00

C-3. Transmissivity (ft^2/day) for Injection Test R-16-4c as a Function of Well Efficiency and Aquifer Penetration[a]

Well Eff. (%)	Aquifer Penetration (%)																		
	1.3596	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	80	90	100
20	3606	1735	763	350	230	174	141	120	104	92	83	76	70	65	62	59	54	52	51
25	2884	1387	609	279	183	138	112	95	82	73	65	60	55	51	48	46	42	41	40
30	2403	1155	507	232	152	114	93	78	68	60	54	49	45	42	39	37	35	33	32
35	2059	989	434	198	130	98	79	66	57	51	46	41	38	35	33	32	29	28	27
40	1801	865	379	173	113	85	69	58	50	44	39	36	33	31	29	27	25	24	23
45	1601	769	337	154	100	75	61	51	44	39	35	32	29	27	25	24	22	21	20
50	1440	692	303	138	90	67	54	46	39	35	31	28	26	24	22	21	19	19	18
55	1309	629	275	125	82	61	49	41	36	31	28	25	23	21	20	19	17	17	16
60	1200	576	252	115	75	56	45	38	32	29	25	23	21	20	18	17	16	15	15
65	1108	532	233	106	69	51	41	35	30	26	23	21	19	18	17	16	14	14	13
70	1028	494	216	98	64	48	38	32	28	24	22	19	18	16	15	14	13	13	12
75	960	461	201	91	59	44	36	30	26	22	20	18	17	15	14	13	12	12	11
80	**900**[b]	432	189	86	56	41	33	28	24	21	19	17	15	14	13	12	11	11	11
85	847	406	178	80	52	39	31	26	22	20	17	16	14	13	12	12	11	10	10
90	800	384	168	76	49	37	29	25	21	18	16	15	14	12	12	11	10	9	9
95	757	363	159	72	47	35	28	23	20	17	16	14	13	12	11	10	9	9	9
100	719	345	151	68	44	33	26	22	19	17	15	13	12	11	10	10	9	8	8

[a] Input data (McLin 2004, 82834): Q = 8.04 gpm; s = 108.59 ft at t = 60.0 min; screen length = 7.6 ft; dw = 10.625 in.; S = 0.003; aquifer thickness = 559 ft.

[b] Shaded example shows that for a well efficiency of 80% and aquifer penetration of 1.36%, T = 900 ft^2/day.

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