LA-14121-MS

Hydrologic Tests at Characterization Wells R-9i, R-13, R-19, R-22, and R-31, Revision 1

Los Alamos
NATIONAL LABORATORY
EST. 1943

The World's Greatest Science Protecting America

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

Edited by Marvin A. Wetovsky, Weirich and Associates, for Group IM-1

LA-12121-MS
Issued: June 2004

Hydrologic Tests at Characterization Wells R-9i, R-13, R-19, R-22, and R-31, Revision 1

Stephen G. McLin
William J. Stone

Los Alamos NATIONAL LABORATORY EST. 1943

The World's Greatest Science Protecting America

TABLE OF CONTENTS

Appendices

List of Figures

List of Tables

ABBREVIATIONS, ACRONYMS, AND NOTATION

ASTM	American Society for Testing and Materials
bgs	below ground surface
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	feet squared per day (transmissivity unit)
FY	fiscal year
gpd/ft^2	gallons per day per square foot (hydraulic conductivity unit)
gpm	gallons per min (discharge unit)
hp	horse power
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
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	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 WELLS R-9i, R-13, R-19, R-22, AND R-31, REVISION 1

by
Stephen G. McLin and William J. Stone

ABSTRACT

Hydrologic information is essential for environmental efforts at Los Alamos National Laboratory. Testing at new characterization wells being drilled to the regional aquifer ("R wells") to improve the conceptual hydrogeologic model of the Pajarito Plateau is providing such information. Field tests were conducted on various zones of saturation penetrated by the R wells to collect data needed for determining hydraulic properties. This document provides details of the design and execution of testing as well as an analysis of data for five new wells: R-9i, R-13, R-19, R-22, and R-31. One well (R-13) was evaluated by a pumping test and the rest (R-9i, R-19, R-22, and R-31) were evaluated by injection tests.

Characterization well R-9i is located in Los Alamos Canyon approximately 0.3 mi west of the Route 4/Route 502 intersection. It was completed at a depth of 322 ft below ground surface (bgs) in March 2000. This well was constructed with two screens positioned below the regional water table. Both screens were tested. Screen 1 is completed at about 189–200 ft bgs in fractured basalt, and screen 2 is completed at about 270–280 ft bgs in massive basalt. Specific capacity analysis of the screen 1 data suggests that the fractured basalt has a transmissivity (T) of 589 ft^2/day and corresponds to a hydraulic conductivity (K) of 7.1 ft/day based on a saturated thickness of 83 ft. The injection test data from the massive basalt near screen 2 were analyzed by the Bouwer-Rice slug test methodology and suggest that K is 0.11 ft/day, corresponding to a T of about 2.8 ft^2/day based on a saturated thickness of 25 ft.

Characterization well R-13 is located in Mortandad Canyon just west of the eastern Laboratory boundary. It was completed at a depth of 1029 ft bgs in February 2002. This well was constructed with one 60-ft long screen positioned about 125 ft below the regional water table. This screen is completed at about 958–1019 ft bgs and straddles the geologic contact between the Puye fanglomerate and unassigned pumiceous units. The specific capacity analysis of a 12 minute pumping test indicates that the Puye fanglomerates near the R-13 screen have a T of 5269 ft^2/day and correspond to a hydraulic conductivity (K) of 17.6 ft/day based on a saturated thickness of 300 ft.

Characterization well R-19 is located east of firing site IJ in Technical Area (TA) 36 on the mesa between Three-mile and Potrillo Canyons. It was completed at a depth of 1885 ft bgs in April 2000. This well was constructed with two screens positioned above the regional water table and five screens positioned below the regional water table. Only the bottom two screens were tested. Screen 6 is completed at about 1727-1734 ft bgs in Puye fanglomerate, and screen 7 is completed at about 1832–1849 ft bgs in Puye fanglomerate. Specific capacity analysis of the screen 6 data suggests that T is about 6923 ft^2/day and corresponds to a K of 18.6 ft/day based on a saturated thickness of 373 ft. Specific capacity analysis of the screen 7 data suggests that T is about 8179 ft^2/day and corresponds to a K of 22.0 ft/day based on a saturated thickness of 373 ft.

Characterization well R-22 is located on Mesita del Buey between Cañada del Buey and Pajarito Canyons immediately east of Material Disposal Area (MDA) G in TA-54. It was completed at a depth of 1489 ft bgs in October 2000. This well was constructed with five screens positioned at or below the regional water table; however, only screens 2–5 were tested. Screen 1 is completed at the regional water table at about 872–914 ft bgs in Cerros del Rio basalt. Screen 2 is completed at about 947–989 ft bgs in Cerros del Rio basalt. Screen 3 is completed at about 1272–1279 ft bgs in Puye fanglomerate. Screen 4

is completed at about 1378–1452 ft bgs in older basalt. Screen 5 is completed at about 1447–1452 ft bgs in older fanglomerate. Bouwer-Rice analyses of the injection-test recovery data suggest K values of 0.04, 0.32, 0.54, and 0.27 ft/day for screens 2, 3, 4, and 5, respectively. These values correspond to T values of 2.8, 15.8, 26.5, and 11.6 ft^2/day, respectively, for screens 2, 3, 4, and 5. These analyses are based on saturated thicknesses of 69.5 ft, 49.4 ft, 49.0 ft, and 43.0 ft, respectively.

Characterization well R-31 is located at TA-39 in the north fork of lower Ancho Canyon. It was completed at a depth of 1103 ft bgs in April 2000. This well was constructed with one screen positioned above the regional water table, and four screens position at or below the regional water table. Only screens 3–5 were tested. Screen 3 is completed at about 666–676 ft bgs in Cerros del Rio basalt. Screen 4 is completed at about 827–837 ft bgs in the Totavi Lentil. Screen 5 is completed at about 1007–1017 ft bgs in Puye fanglomerate. Bouwer-Rice analyses of the injection-test recovery data at screen 3 suggest a K value of 0.48 ft/day, and correspond to a T of 90 ft^2/day. Specific capacity analysis of the screen 4 data suggests that T is about 1332 ft^2/day and corresponds to a K of 11.1 ft/day, based on a saturated thickness of 120 ft. Specific capacity analysis of the screen 5 data suggests that T is about 1388 ft^2/day and corresponds to a K of 8.3 ft/day, based on a saturated thickness of 168 ft.

INTRODUCTION

Hydrologic information is essential for surveillance efforts, environmental restoration activities, as well as numerical modeling of groundwater flow and transport at Los Alamos National Laboratory (LANL or the Laboratory). Various kinds of hydrologic observations at new wells being drilled across the Pajarito Plateau under the Hydrogeologic Workplan (LANL 1998, 59599) provide this information. Saturated zones are identified and characterized as to water level, stratigraphic unit, hydraulic condition (unconfined or confined), and scale (perched or regional). Head measurements at different depths within the regional zone of saturation and in the same or adjacent wells indicate the direction of vertical or horizontal hydraulic gradient, respectively. Field hydrologic tests provide data for determining hydraulic properties of the saturated media. Together, these field observations can be used to locally validate large-scale numerical simulations. As the new wells penetrate the regional water table and are completed there, they are identified by an “R” prefix and are commonly referred to as “R wells.”

This document reports on the collection of hydraulic-property data from five of the new deep R wells (Figure 1). These wells include R-9i, R-13, R-19, R-22, and R-31. The well-completion reports for these wells present only brief summaries and preliminary results of hydrologic testing. By contrast, this report describes the design, execution, and final analysis of hydrogeologic tests, and discusses the quality of the data and results obtained.

Information presented below for the hydrogeology and construction comes from completion reports: R-9i (Broxton et al. 2001, 66600), R-13 (LANL 2003, 76060), R-19 (Broxton et al. 2001, 71253), R-22 (Ball et al. 2001, 71471), and R-31 (Vaniman et al. 2001, 72615). The stratigraphy shown for most of the wells differs slightly from that in the completion reports as a result of additional analysis since the reports were published.

Some conventions were adopted to enhance the clarity, usefulness, and consistency of this report. Reference citations for the analytical methods used are only given under Data Analysis to avoid repetition in the text. Tables summarizing tests in the text are placed in boxes for quick identification and reference. Labels given within the analytical plots serve the same purpose; these are based on the well and screen number. For example, R-9i-1 refers to well R-9i, screen 1. Graphs and raw field data for water level versus time as well as additional analytical data for the selected tests are given in the appendices.

OVERVIEW OF WELLS

Deep wells to the regional zone of saturation are being installed at the Laboratory as part of a program to improve the conceptual hydrogeologic model for the Pajarito Plateau (LANL 1998, 59599). Although some of these wells may become part of the groundwater surveillance network, they are essentially characterization wells. That is, each provides geologic, hydrologic, and hydrochemical observations in an area where there are historical data gaps. The information obtained will eventually be used to design a sound groundwater-monitoring network.

The drilling, construction, and development of the wells are briefly outlined below. Complete details can be found in the well-completion reports listed above. Methods used in drilling, constructing and developing the wells are compatible with Environmental Protection Agency (EPA) guidelines (Aller et al. 1991, 70112).

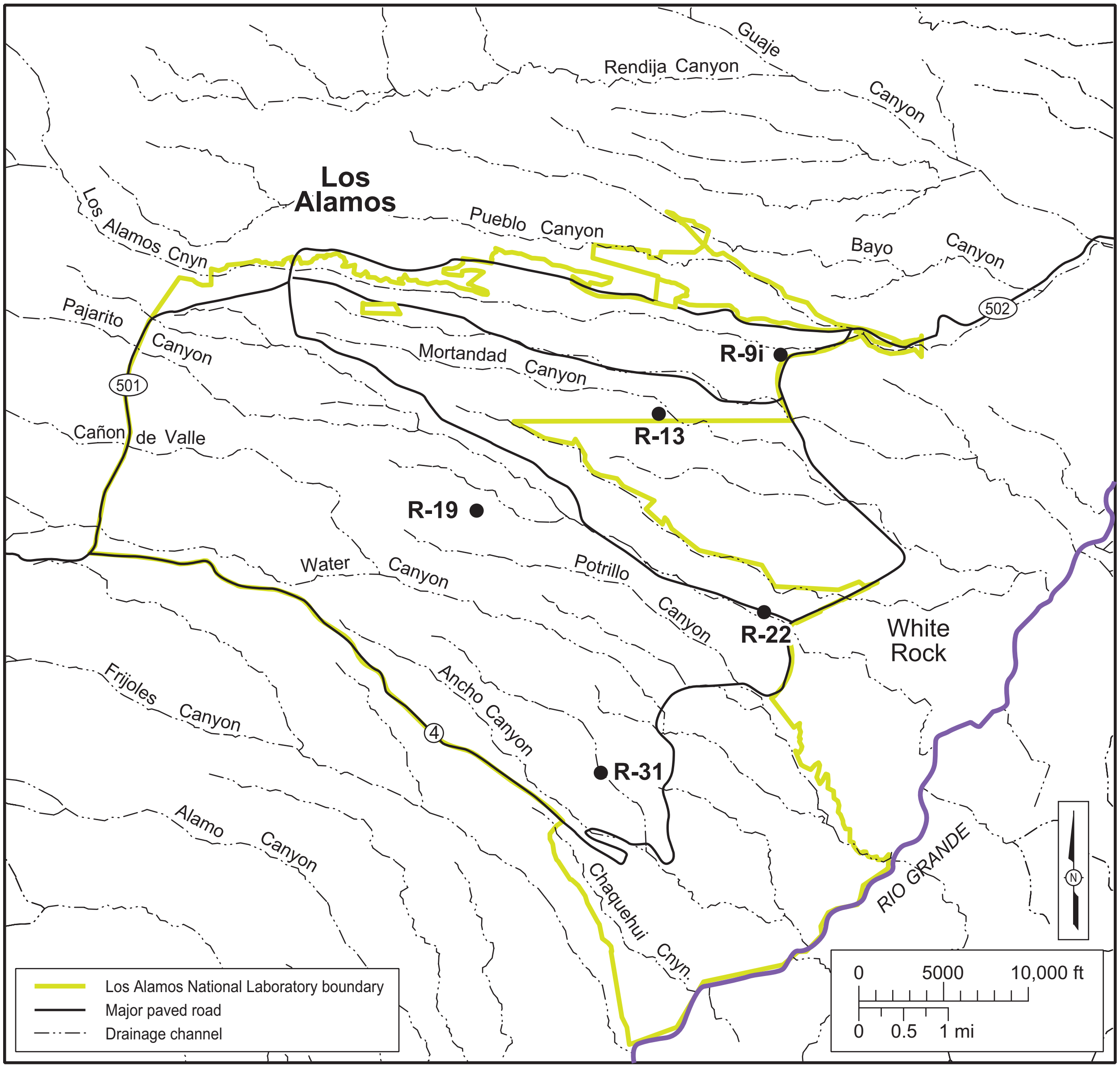


Figure 1. Location of wells tested

Drilling Methods

Drilling methods have changed throughout the deep-well program (Table 1). Initially, wells were drilled by air-rotary casing-advance and coring methods. More recently, drilling has been by open-hole methods, and geophysical logging has replaced coring as the means of supplementing both geologic and hydrologic observations. The holes have been drilled essentially dry so that saturated zones can be more easily recognized. However, water and minor amounts of various drilling fluids have been added at times to enhance lubricity during casing-advance operations or formation stability during open-hole operations.

Table 1
Drilling and Completion of Wells Tested

Well	Drilling Method	Circulation Fluid[a]	No. of Screens	Screen Type[b]	Open Area (%)[c]
R-9i	Air-rotary, open-hole	Air	2	Rod-based, wire-wrapped	7.90
R-13	Air-rotary, open-hole/ casing advance	Air and water (EZ-MUD plus QUIK FOAM)	1	Pipe-based, wire-wrapped	8.75
R-19	Air-rotary, casing-advance	Air and water (EZ-MUD plus QUIK FOAM, Torkease)	7	Pipe-based, wire-wrapped	8.75
R-22	Air-rotary, open-hole/ casing advance	Air and water (EZ-MUD plus QUIK FOAM)	5	Pipe-based, wire-wrapped	8.75
R-31	Air-rotary, open-hole/ casing advance	Air and water (Torkease, EZ-Mud plus)	5	Rod-based, wire-wrapped	7.90

[a] Air and water were the primary fluids; others listed were added only as deemed necessary.
[b] Wire-wrap in all screens is 10-slot stainless steel.
[c] For pipe-based screen, value given is that for drilled pipe.

Well Construction

Construction varied slightly from well to well. Diagrams, provided for each well in the sections that follow, give the basic well-completion details. Nonetheless, some generalizations are offered here as background.

Borehole diameter depends on the size of the bit used. This decreased as casing size was stepped down to accommodate telescoping with increasing depth.

Well casing and screen with an inside diameter (I.D.) of 4.5 in. has generally been used in the R wells. However, slightly larger I.D. casing was used in the earlier wells (R-9i and R-31). The summary tables for the tests give specific sizes.

Most of the wells are completed with multiple screens placed within perched and regional zones of saturation (Table 2). All screens are constructed of stainless steel and have a 0.010-in. slot size. Rod-based, wire-wrapped screens were used in wells R-9i and R-31. That is the more common type of wire-wrapped screen. These screens were fabricated with 32 rods and have an open area of 7.9%. Pipe-based, wire-wrapped screens were used in the other three wells. In that type of screen, a wire-wrapped jacket is placed around a pipe in which round holes have been drilled. In the screens used, the holes are 0.5 in. in diameter, and their density is up to 84 holes/ft. Open area for the drilled pipe is 8.75%. The New Mexico Environment Department (NMED) has required that the uppermost screens be positioned so that the upper 5 ft lie above the water table. Most screens are 10 ft long, except those straddling the regional water table, which are longer in anticipation of the water level declining with time.

Annular fill consists of primary and secondary filter packs as well as seals. Filter-pack material consists of sand in all wells described in this report. The primary filter pack is coarser (usually 20/40 sand) to ensure that water flows easily to the screen. The secondary filter pack is finer (usually 30/70 sand). It is placed between the primary filter pack and the seal to prevent bentonite from reaching the screen. These different sizes of sand are not distinguished on the construction diagrams for the wells tested. Rather, the total length of filter pack (sand) is illustrated. Screened intervals are isolated from each other by seals in the annulus between filter packs. Annular-seal material generally consists of bentonite, but in some places additional cement seals were emplaced.

Table 2
Hydrogeology and Construction of Wells Tested

Well	TD (ft)	Ground Elevation[a] (ft)	Saturated Zone/Unit[b]	Saturated Interval (ft)[c]	Screen Number	Screened Interval (ft)[d]	Head (ft)[e]
R-9i	322	6383.2	UP/Tb	142–225	1	189.1–199.5	6243.03
			LP/Tb	264–290	2	269.6–280.3	6130.54
R-13	1133	6660.0	R/Tpf	833–TD	1	958.3–1018.7	5827 **c**
R-19	1885	7066.3	UP/Qbof	834–840	1	827.2–843.6	6337 **d**
	Sloughed		LP/Tpf	894–912	2	893.3–909.6	6241 **d**
	From 1902		R/Tpf	1178–TD	3	1171.4–1215.4	5888 **d**
					4	1410.2–1417.4	NA[f]
					5	1582.6–1589.8	NA
					6	1726.8–1733.9	5889 **t**
					7	1832.4–1839.5	5892 **t**
R-22	1489	6650.5	R/Tb	883–TD	1	872.3–914.2	5766.27
					2	947.0–988.9	5760.17
					3	1272.2–1278.9	5703.21
					4	1378.2–1384.9	5697.54
					5	1447.3–1452.3	5697.91
R-31	1103	6362.5	P/Tb	439–455	1	439.1–454.4	5910.62 (dry)
			R/Tb	523–TD	2	515.0–545.7	5842.31
					3	666.3–676.3	5830.68
					4	826.6–836.6	5833.26
					5	1007.1–1017.1	5840.04

[a] Surveyed elevation (ft above mean sea level) of brass monument in concrete pad.
[b] Zone: U = upper, M = middle, L = lower; P = perched, R = regional; Unit: Qbof = Otowi Member ash flow, Bandelier Tuff, Tb = Cerros del Rio basalt, Tpf = Puye Formation, fanglomerate, Tsfb = Santa Fe Group basalt.
[c] Depth (ft) below ground surface; based on observations during drilling or geophysical logs.
[d] Top and bottom of open interval, not screen joints.
[e] Water level determined from Westbay transducer after testing; **c** indicates a composite value taken prior to testing; **d** indicates value obtained during drilling; **t** indicates value from packed off interval prior to testing.
[f] NA = not available.

Well Development

After the wells were constructed, they were developed to (1) remove fines and drilling fluid from both the formation and filter pack behind the screen; (2) create a stable zone of filtration between the screen and formation; and (3) re-establish effective hydraulic conductivity near the well. In most cases, development followed a multiphase protocol (Table 3). Preliminary development involved various combinations of wire-brushing, bailing, airlifting, surging, or jetting. Screens were first wire-brushed to remove particles that might have settled in the larger openings of the pipe-based screen. Next, the sump and screens were bailed to remove the more turbid water from the well and thus protect the pump. Where deemed beneficial, surging, swabbing, or jetting followed bailing. Final development was by pumping.

Table 3
Methods Used to Develop Wells Tested

Well[a]	Preliminary Development					Final Development	
	Wire-Brushing	Surging[b]	Swabbing[c]	Airlifting	Jetting[d]	Bailing	Pumping
R-9i (m)	X					X	X
R-13 (s)	X	X	X			X	X
R-19 (m)	X			X	X	X	X
R-22 (m)	X					X	X
R-31 (m)	X	X		X		X	X

[a] (m) = multiscreen completion; (s) = single-screen completion
[b] Done with surge block attached to wireline (not to rod)
[c] Involves flowing water out through screen from between two surge blocks
[d] Done with perforated pipe (not conventional jetting tool)

Development of pipe-based screen is difficult because there are two layers of openings. The effectiveness of well development was evaluated by means of several field parameters (pH, specific conductance, temperature, and turbidity). These were monitored at the outset of bailing and at regular intervals during pumping. When turbidity was < 5 nephelometric turbidity units (NTU) or could not be improved, the pump was turned off, and the well was allowed to rest for a short interval. Then pumping was resumed briefly and field parameters were monitored at regular intervals to see if the previously obtained turbidity value could be reproduced. This process (pump off/on) was repeated three times. When the turbidity value could be reproduced, a sample was usually collected and analyzed for total organic carbon (TOC), a good indicator of the presence of drilling fluid. If the analytical result approximated the background value for the Pajarito Plateau, development was halted. If it did not, physical development continued until TOC content was at background level or could not be improved. Video logs were an invaluable aid in development. These were made (1) before development to determine target intervals for more intense wire-brushing, (2) at various stages during development if field parameters did not improve, and (3) after development to confirm that the well was ready for Westbay™ installation.

CONSTRAINTS ON TESTING

As discussed below, hydrologic testing of the R wells has been constrained by the hydrogeologic setting and well construction that limited the testing methods that could be applied.

Hydrogeologic Constraints

Stratigraphy and depth to water are the main hydrogeologic constraints on testing. The stratigraphic sequence underlying the Pajarito Plateau is complex. Interbedded igneous and sedimentary deposits characterize the geologic column. Furthermore, the column varies considerably from place to place (Stone et al. 2001, 69830). The variation between hard and soft materials gives rise to irregularities in borehole diameter. Although washouts have been fairly common in the Puye Formation, screens have not been placed in such intervals.

In addition to stratigraphic constraints, the regional water table lies at great depth: as much as 1178 ft below ground surface (bgs) for the wells covered by this report (Table 2). Most R wells are greater than 1000 ft in depth. This depth impacts testing in different ways, depending on test method. In the case of injection tests, introduced water falls a long way before reaching the static water level for a given screen. In the case of pumping tests, pumps used must be able to lift water from such depths at a rate that stresses the saturated medium.

Well-Design Constraints

The main testing constraints associated with well design are small-diameter production casings, multiple screened intervals, screens spanning contacts between geologic units, pipe-based screens, and long filter packs. The R wells are commonly constructed with a 4.5-in. I.D. production casing. Thus, there is little room to accommodate a slugger and transducer for traditional slug tests. This small diameter also limits the size of pump that can be used, which in turn limits the pump capacity. Such limitations impact both well development and evaluation by pumping tests.

Most R wells are completed with multiple screens (Table 2). Each screen must be isolated both for development and testing. Straddle packers are readily available for shutting in individual screened intervals. However, conducting traditional slug or pumping tests in conjunction with straddle packers is difficult. No testing apparatus is readily available that permits interchanging transducers and pumping from considerable depth at a rate sufficient to stress a productive saturated zone, especially in the small-diameter production casing used in the R wells.

If a screen straddles a geologic contact, testing yields an average result for the two materials involved, or a result biased by the response of the more permeable material, rather than a representative hydraulic property for a single saturated material. Only one of the tests reported here involved a screen that straddles a geologic contact. R-13 was completed with a single screen set in the Puye Formation. However, the screen spanned the contact between the pumiceous and overlying fanglomerate units of the Puye. Presumably, the results of testing at R-13 represent the more permeable of the materials behind the screen, but only tests of screens dedicated to each of the units would reveal conclusively which is more permeable.

In most of the R wells, including four of the five reported on here, the uppermost screen was placed across the water table at the request of the NMED. In these cases, the upper 5 ft or so of screen is in the vadose zone, thus hindering development and ruling out testing of saturated aquifer properties. Any turbid water raised in the well during development or testing simply drains into the unsaturated material lying behind the upper portion of the screen. Furthermore, injection testing is not appropriate as these methods assume the screen is below static water level. If the water level is below the top of the screen, “water [drains] from the well into the vadose zone as well as the saturated aquifer” (Fetter 1994, 70942). Thus, testing of screens straddling the water table overestimates permeability because the unsaturated material takes up water faster than the saturated material.

The use of pipe-based screen introduces another constraint to testing. Injected or pumped water must move through the tortuous path presented by two layers of screen: the perforated pipe and the wire-wrap envelope. If one layer has a smaller open area than the other, it limits the rate at which water is delivered or extracted, thus hindering well development and yielding low test results.

Usually, the primary filter pack extends 5 ft above and below the screen and the intervals of secondary filter pack are generally also 5 ft long. Where the screen is 10 ft long, the length of filter pack is usually 30 ft or three times that of the screen. In seven of the twelve intervals tested, however, the length of filter pack has exceeded three times the length of associated screens. In some of the wells, the length of some filter packs is many times the length of the associated screen (Table 4).

Table 4
Filter-Pack Length vs. Screen Length in Wells Tested

Well (Screen)	Screen Length (ft)[a]	Filter-Pack Length (ft)[b]	Filter-Pack Length/Screen Length
R-9i (1)	10.4	20.7	2.0
(2)	10.7	18.5	1.7
R-13 [c]	60.4	87.5	1.4
R-19(6)	7.1	103.9	14.6
(7)	7.1	20.2	2.8
R-22(2)	41.9	69.5	1.7
(3)	6.7	49.5	7.4
(4)	6.7	22.0	3.3
(5)	5.0	43.0	8.6
R-31(3)	10.0	18.0	1.8
(4)	10.0	76.7	7.7
(5)	10.0	198.9	19.9

[a] Length of openings, not joints.
[b] Total; more than one sand size generally used.
[c] Only one screen in this well.

OVERVIEW OF TESTS

In view of the constraints described above, the aquifer properties of the saturated materials penetrated by the R wells were investigated by straddle-packer/injection and/or pumping tests (Table 5). Three of the five wells were investigated by injection tests alone (R-19, R-22, and R-31). One well was tested both by injection and pumping methods (R-9i). One well was tested by the pumping method alone (R-13).

Field and testing methods used are compatible with those recommended by the American Society for Testing and Materials (ASTM 1994, 70099, and 1996, 70100). Furthermore, the use of pressure transducers and collection of water-level measurements in both types of tests followed procedures given in Environmental Restoration (ER) Project Standard Operating Procedures (SOPs) ER-SOP-07.01 and -07.02, respectively. Test data were analyzed by means of commercially available software.

For a given type of test, essentially the same field procedures were employed. To avoid repetition in the sections that follow, those methods are summarized once at the outset.

Table 5
Overview of Hydrologic Testing

Well (screen)[a]	Saturated Zone[b]	Geologic Unit[c]	Type of Test[d]	Analytical Method[e]	T (ft^2/d)	K (ft/d)
R-9i (1)	U. perched	Tb	Injection	Specific Capacity	588.8	7.1
(2)	L. perched	Tb	Injection	Bouwer-Rice	-	0.11
R-13	Regional	Tpf-Tpp	Pumping	Specific Capacity	5,268.6	17.6
R-19 (6)	Regional	Tpp	Injection	Specific Capacity	6,922.7	18.6
(7)	Regional	Tpp	Injection	Specific Capacity	8,179.1	22.0
R-22 (2)	Regional	Tb	Injection	Bouwer-Rice	-	0.04
(3)	Regional	Tpf	Injection	Bouwer-Rice	-	0.32
(4)	Regional	Tbo	Injection	Bouwer-Rice	-	0.54
(5)	Regional	Tfo	Injection	Bouwer-Rice	-	0.27
R-31 (3)	Regional	Tb	Injection	Bouwer-Rice	-	0.48
(4)	Regional	Tpt	Injection	Specific Capacity	1,332.4	11.1
(5)	Regional	Tpt	Injection	Specific Capacity	1,387.7	8.3

[a] See hydrogeology and construction diagrams for depths of screened intervals; R-13 has only 1 screen.
[b] U. = upper, L. = lower; see hydrogeology and construction diagrams.
[c] Tb = Cerros del Rio basalt; Tpf = Puye Formation (fanglomerate); Tpp = Puye Formation (pumiceous); Tpt = Puye Formation, Totavi Lentil; Tbo = older basalt: Tfo = older fanglomerate.
[d] See appendices for field-data plots.
[e] Specific Capacity (McLin 2004, 82834) and Bouwer and Rice (1976, 64056); Table 13 gives major assumptions of methods used.

Injection-Test Procedures

Hydraulic properties of saturated materials at four of the five wells (R-9i, R-19, R-22, and R-31) were investigated by means of injection tests. First, we isolated a target screen by deploying straddle packers inside the well casing. Then, a finite amount of water was introduced at a constant rate by means of a hose inserted into the open end of the drill rod connected to the injection assembly (Figure 2). The water moved by gravity down the rod, through the upper packer, out of the perforated pipe in the injection assembly, through the screen, and into the saturated medium.

These are not slug tests, as the water is not introduced instantaneously. Rather, they are a hybrid type of test, necessitated by the constraints described above. The tests are very similar to drill-stem tests used in oil and gas wells (Earlougher 1977, 73478). Procedures used were those outlined in ER SOP ER-SOP-07.03.

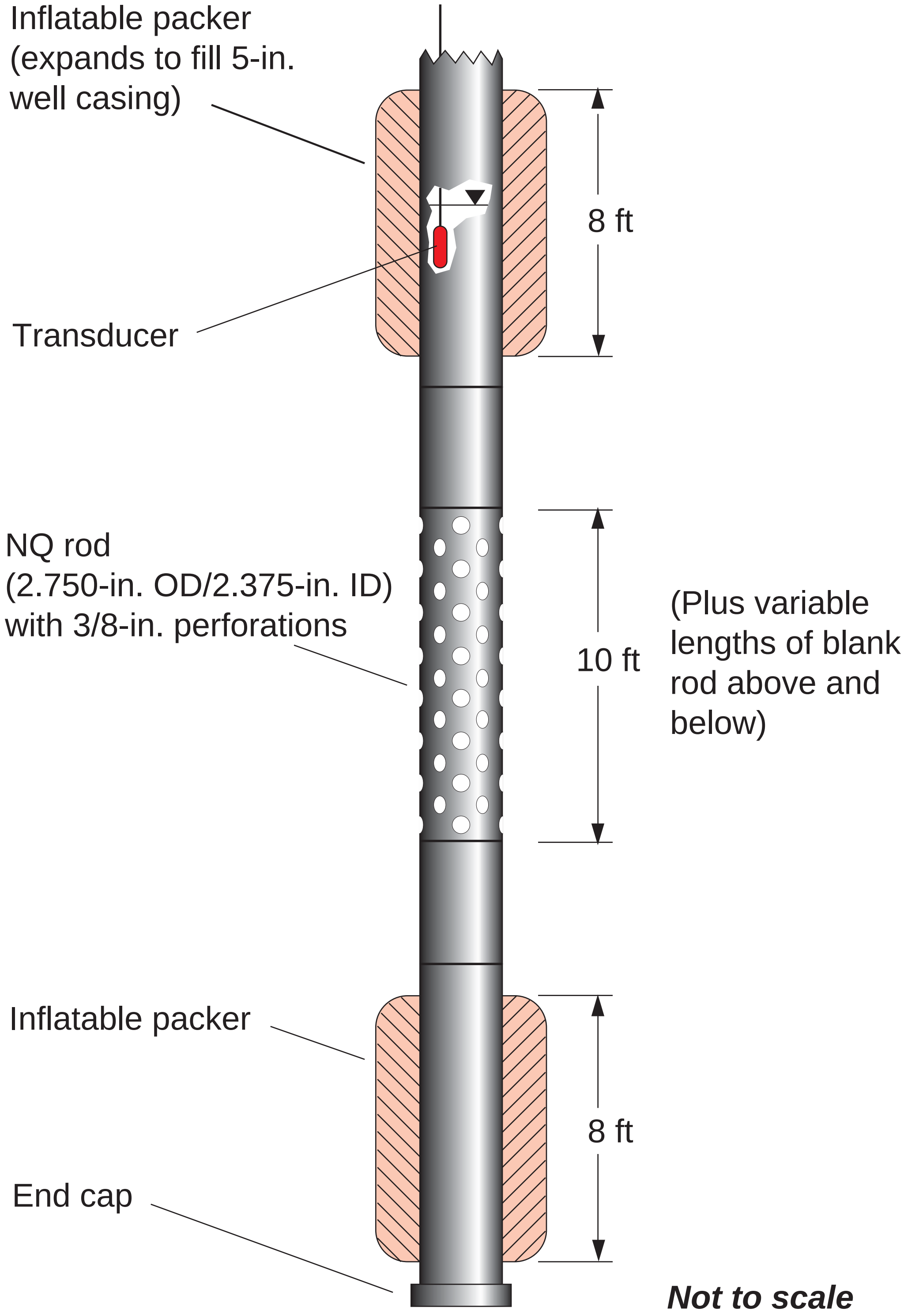


Figure 2. Straddle-packer/injection assembly

Water introduced into the wells during injection testing does not impact water quality for three reasons: (1) the water injected is drinking water from the Los Alamos municipal supply and, therefore, does not introduce contaminants; (2) the volume of water injected is small, especially when compared with the volumes added in other stages of the well installation (Table 6), so there is little dilution of natural groundwater; and (3) following testing, five times the volume of water introduced is pumped from each screened interval where there was injection to remove the foreign water. NMED's Ground-Water Quality Bureau approved the injection of municipal water for these tests without requiring the Lab to file a discharge permit.

Table 6
Water Introduced and Extracted at Wells Tested by Injection

Well	Water Added in Drilling (gal.)	Water Added in Construction (gal.)	Water Removed in Development (gal.)	Water Injected in Testing (gal.)
R-9i	Minimal[a]	Unknown[b]	4,465	728[c]
R-19	Minimal	Unknown[b]	~50,000	807
R-22	Minimal	42,000	34,803	526
R-31	Minimal	39,000	14,930	589

[a] Drilled by air-rotary methods.

[b] Value not given in well-completion report.

[c] Includes 120 gal. injected in unsuccessful initial test at screen 1; pumping test following injection tests produced 6,485 gal.

Straddle-packer/injection testing involved several steps:

1. Pertinent pre-test information was compiled and recorded.
2. The straddle-packer/injection assembly (Figure 2) was emplaced and inflated. Gauges on the nitrogen tank were checked frequently to ensure that the packers were holding pressure.
3. Water level was measured with an electric probe and the static position was recorded.
4. A transducer was emplaced and its position recorded. Its operation and communication with the datalogger were checked by connection to a laptop computer.
5. Water for injection was placed in a large open stock tank. The water was taken up by means of a hose connected to the Bean pump on the drilling rig. A hose was used to gravity-flow water into the well through drill rods connected to the injection assembly. Only municipal water was used.
6. Prior to testing, the rate of discharge from the injection hose was evaluated and adjusted to an appropriate value, based on yield during development.
7. A fixed volume of water was injected down the rod connected to the straddle-packer assembly, or water was injected over a fixed time interval.
8. The variation in flow rate during injection and total volume injected were evaluated using a flow meter (in-line between the water supply tank and the pump) and a stopwatch or watch with a second hand.
9. Water-level rise during injection was monitored by transducer and recorded by a datalogger. If the material behind a screen does not readily take up the injected water, the water level can quickly rise above the rated depth of the transducer, rendering it inoperable. If water-level threatened to surpass the depth capacity of the transducer, injection was halted.
10. Recovery to pre-test static water level was monitored on a laptop. When water level returned to the static position, the test was halted.
11. Post-test data (duration of test, volume injected, final water level, etc.) were recorded.

Following the tests, up to five times the volume of water injected was pumped out of the well to minimize the impact of introducing foreign water.

Pumping-Test Procedures

Pumping tests were conducted at two of the five wells (R-9i and R-13). Procedures used were those given in various standard texts (e.g., Driscoll 1986, 70111, or Kruseman and de Ridder 2000, 70110) and as outlined in ER-SOP-07.04.

The pumping tests involved several steps:

1. A submersible pump was installed.
2. An initial static water-level condition in the well was ensured by monitoring for an extended period after the pump was installed but prior to testing.
3. Pertinent pre-test information (pump type, pump depth, static water level) was recorded.
4. A pressure transducer was emplaced and the position recorded. Its operation and communication with the datalogger were checked by connection to a laptop computer.
5. Barometric pressure was recorded during the test period using the transducer.
6. The pump was turned on and the discharge rate was monitored by means of an in-line flow meter and stopwatch or watch with a second hand.
7. Drawdown observations were monitored with a laptop and recorded by a data logger.
8. When the drawdown seemed to be leveling off, the pump was turned off.
9. Recovery of the water level was then monitored.
10. When the pre-test static level was reached or nearly so, the test was halted.
11. Post-test data (duration of test, total volume pumped, final water level, etc.) were recorded.

Produced water was not allowed to re-enter the aquifer being tested. Rather, well discharge was collected in a large-capacity tank.

DATA ANALYSIS

Data collected in the injection and pumping tests were analyzed by various standard methods to obtain hydraulic properties. Plots were made showing the fit of the test data to appropriate theoretical curves. AQTESOLV^{TM} for Windows (professional version 3.50) was used to produce these plots and analyze the data from all tests. Several parameters are required as input for these analyses. Typical well configurations and definitions are shown in Figure 3. These include:

D = saturated thickness (ft)

d = distance (ft) between water table or aquifer top (if confined) and top of screen

l = distance (ft) between water table or aquifer top (if confined) and bottom of screen

r_c = radius (ft) of casing (1/2 the I.D. of riser pipe from injection assembly)

r_w = radius (ft) of wellbore (1/2 the borehole diameter)

For consistency throughout the analyses, standard assumptions were made for some input parameters required by the software:

Anisotropy ratio = 1,
Filter-pack porosity = 0.25, and
Well-skin radius = well-bore radius.

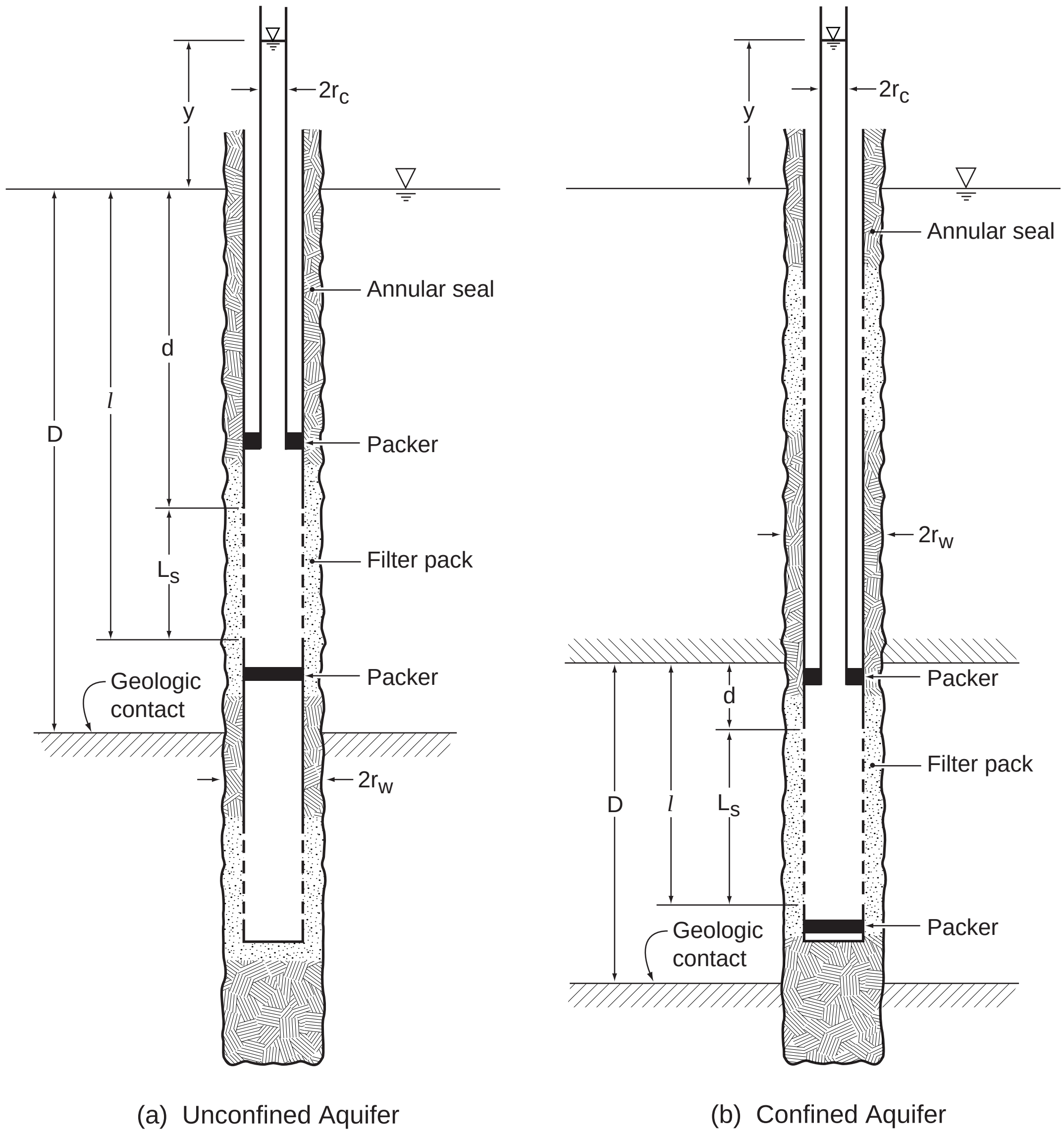


Figure 3. Typical well configurations and definitions

It should be noted that in all applications presented in this report, none of these latter parameters were actually used in the data analyses. In addition, the software accounts for the effects of partial aquifer penetration in many analyses when specified. As noted below, the effects of partial penetration often play a dominant role in data analyses.

Saturated aquifer thickness (D) can play a role at two different times in the test analysis. First, the software requires that a value for D must be specified before data can be analyzed. Obviously, this value depends on the stratigraphic sequences penetrated by the well. However, a representative value for this parameter is not always straightforward. The analytical method used to estimate aquifer transmissivity can be relatively sensitive to this parameter. For example, the Theis method as developed in the AQTESOLV™ program will analyze pumping test data from confined or unconfined aquifers with fully or partially penetrating well screens. However, the Cooper-Jacob technique (an equivalent method of analysis) will only analyze pumping test data from confined or unconfined aquifers with fully penetrating well screens. Second, many R wells encounter partial well penetration in a thick aquifer. In these situations, D should be represented by the thickness of the cone of depression (or impression in the case of injection). Hence, when these partially penetrating wells are tested, the cone of depression 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 depth of the cone at any time is unknown unless an observation well is available. Hence, it is often not possible to know D exactly. This condition makes test analyses difficult because there are no analytical methods that specifically apply to these complex test conditions. When we compute hydraulic conductivity (K) using the relationship K = T/D, where T is transmissivity and D is effective aquifer thickness, an error is introduced. When this situation is encountered, we are forced to interpret a value for D. Hence, additional details may appear under the “Discussion” section for individual tests to fully address this issue.

Our approach to test analysis was to obtain the best curve-match possible and then evaluate the resulting values for hydraulic parameters. Results are treated in the “Discussion” sections of this report. To avoid repetition in the text, parenthetical reference citations for the various analytical methods (that is, the years of publication and ER ID numbers) are only given in the sections below.

Analysis of Casing Storage Effects

Casing storage was first recognized by Schafer (1978, 73449) when he suggested that early-time pumping test data might not fit the theoretical Cooper-Jacob non-equilibrium aquifer response. Instead, these early data might reflect the removal of water in the well casing. When pumping first begins, casing waters are initially removed. The water level in the well drops in response to this pumping. However, water also starts to enter the well screen from the surrounding aquifer. Gradually, a larger and larger percentage of the pumping rate is derived from the aquifer, and a smaller and smaller percentage is from casing storage. A similar phenomenon will also occur during injection except that the processes are theoretically reversed. The duration of casing storage can be calculated using the following equation (Schafer 1978, 73449):

$$t_c = \frac{0.6\left(D_c{}^2 - d_p{}^2\right)}{Q/s}$$

where t_c is the duration of casing storage (minutes), D_c is inside diameter of the well casing (inches), d_p is the outside diameter of the production pipe (inches), Q is the pumping or injection rate (gpm), and s (ft) is the drawdown (or head buildup) *at time* t_c. The casing storage formula should be used to estimate the time at which the data become valid for analysis. In the application to injection tests, D_c will be the inside diameter of the injection tubing holding the straddle-packer assembly, and d_p will be zero.

Analysis of Short Injection Tests

Short injection tests were conducted in screen 2 at R-9i, in all screens at R-22, and in screen 3 at R-31. All of these tests were characterized by a rapid rise in water levels so that injection was prematurely terminated. The water level responses in these tests immediately began a slow exponential decline back toward their respective static equilibrium values. This response is characteristic of a tight formation that is resistant to water injection. In most instances, data obtained from short injection tests should not be analyzed by conventional slug test procedures because the slug input is not delivered instantaneously. In other words, injection water starts to immediately flow into the formation as it is made available. This condition violates important model assumptions and produces erroneous results. For example, if T is relatively high and a slug test procedure is used to analyze the data, the resulting T estimates will be too low. These estimates are often an order of magnitude below comparable estimates obtained by conventional pumping test methods of analysis. However, if T is relatively low, water does not flow into the formation very fast and the wellbore becomes filled with injection water. In this case, injection waters behave like an instantaneous slug input and we can use conventional slug test methods of analysis. Although the injection test procedure described earlier is not a true slug test because water is not introduced instantaneously, the water level response is very similar to that in traditional slug tests. That is, water levels rise abruptly when injection starts and gradually fall after injection stops. The falling limbs of the well hydrograph are identical to those for traditional slug tests. Therefore, analysis of the recovery (or falling limb) data by well-established slug test methods is reasonable.

Bouwer-Rice Method (Bouwer and Rice 1976, 64056). We analyzed the short injection tests mentioned above by the Bouwer-Rice slug-test technique. This method applies to both partially and completely penetrating wells, unconfined or confined conditions, and application of stress by addition or withdrawal of water.

Analysis of Longer Injection Tests and Pumping Tests

We analyzed the longer duration tests (at R-19 and screens 4 and 5 in R-31) and the pumping test (at R-13) by standard pumping-test methods. Analysis included data from both the injection/pumping and recovery portions of the test data.

Theis-Recovery Method (Theis 1935, 70102). We analyzed longer injection tests and the pumping tests by the Theis-recovery method. In this method, a straight line is drawn through a semi-logarithmic plot of residual drawdown versus the ratio of t/t'. Residual drawdown is the difference between the original static water level and the depth of water at any given instant during recovery. In the ratio, t/t', t is the time since pumping started and t' is the time since pumping stopped. The method assumes that the well is fully penetrating, the hydraulic condition of the aquifer is confined or unconfined, and application of stress is by either injection or pumping. The method does not correct for partial penetration.

Specific-Capacity Method (McLin 2004, 82834). For comparison, we also analyzed test data by the specific-capacity method as developed by McLin (2004, 82834). This technique is a modification of the method presented by Bradbury and Rothschild (1985, 76040). Specific capacity may be defined as discharge (Q) divided by drawdown (or change in water level, s). This method uses an iterative technique 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 obtained from the relationship K = T/D, where D is saturated thickness. Bradbury and Rothschild demonstrated that T values from the specific-capacity technique are rather insensitive to changes in storativity (S). However, McLin (2004, 82834) suggested that well efficiency and partial penetration effects can dramatically influence T values. Hence, McLin (2004, 82834) modified the original program of Bradbury and Rothschild so that it uses a single S value while allowing well efficiency and partial penetration to vary over an expected range of values. McLin converted their original BASIC program into the MATLAB™ language (Appendix A). This modified program computes and plots a range of possible T values for a particular application.

WELL R-9i

R-9i is located beside regional well R-9 on the south bank of Los Alamos (LA) Canyon, 0.3 mi west of the White Rock "Y" (Figure 1). During the drilling of regional well R-9 by the casing-advance method, two perched zones of saturation were encountered in separate interflow zones within the Cerros del Rio basalt (Broxton et al. 2001, 66600). The first zone was located between 180-236 ft bgs while the second zone was located at 275-282 ft bgs (Broxton et al 2001, 71251, p. 7). These zones were sealed off to protect the regional aquifer from wellbore leakage and R-9 drilling continued to TD. Later, R-9i was installed beside R-9 to monitor the quality of these perched waters (Broxton et al. 2001, 66600). Well R-9i was drilled by air-rotary casing-advance methods to a total depth (TD) of 322 ft. The well was completed with two screened intervals in the Cerros del Rio basalt (Figure 4).

Hydrogeology

Geologic units penetrated by well R-9i are shown in Figure 4. The same perched zones of saturation seen in well R-9 were encountered in R-9i. Water was first recognized in the R-9i borehole at a depth of about 180–186 ft in fractured basalt (Broxton et al. 2001, 66600, p. 7). Within minutes, the water level quickly rose to a depth of 162 ft bgs. After several hours, the water level had stabilized at 142 ft bgs (Broxton, personal communication, January 14, 2004). This water level rise can be interpreted several different ways, including an origin from either a fracture-dominated confined or unconfined system. A close examination of available core shows that the upper screen and filter pack cross two separate breccia zones at 183.0–184.3 ft bgs and 191.5–192.5 ft bgs, respectively. Massive basalts located below the screen at about 225 ft bgs act as the perching layer. In addition, massive basalts located above the screened interval suggest that the upper perched system must be confined. However, the core also reveals that these fractures are nearly vertical so hydraulic communication between the surface and the breccia zones is not obvious from core examinations. A close examination of available water level records collected between March 1, 2002, and July 24, 2002, from the Westbay transducer system at R-9i confirms that these upper perched zones behave like a single, unconfined aquifer because they are in clear communication with the atmosphere. Hence, we have interpreted the upper perched horizon as a fracture-dominated, unconfined aquifer that is located between about 142 and 225 ft bgs. These same water level records also seem to suggest that at least some stream infiltration from LA Canyon reaches this upper perched system. As revealed by the R-9i core, the lower screen and filter pack cross a third small breccia zone at 279.0–282.4 ft bgs. A dense marl deposit below this depth acts as the lower perching horizon. The Westbay transducer data from this zone suggests that the lower perched zone is almost completely isolated from the atmosphere and appears to behave like a confined aquifer system. This behavior may simply be associated with the low permeability associated with the basalts at this lower zone. Hence, we have interpreted this lower zone to also be phreatic, and to be located between about 264 and 290 ft bgs. Finally, both of these units are characterized by highly fractured basalts with vertical cooling fractures. However, hydraulic communication between the two perched systems has not been confirmed.

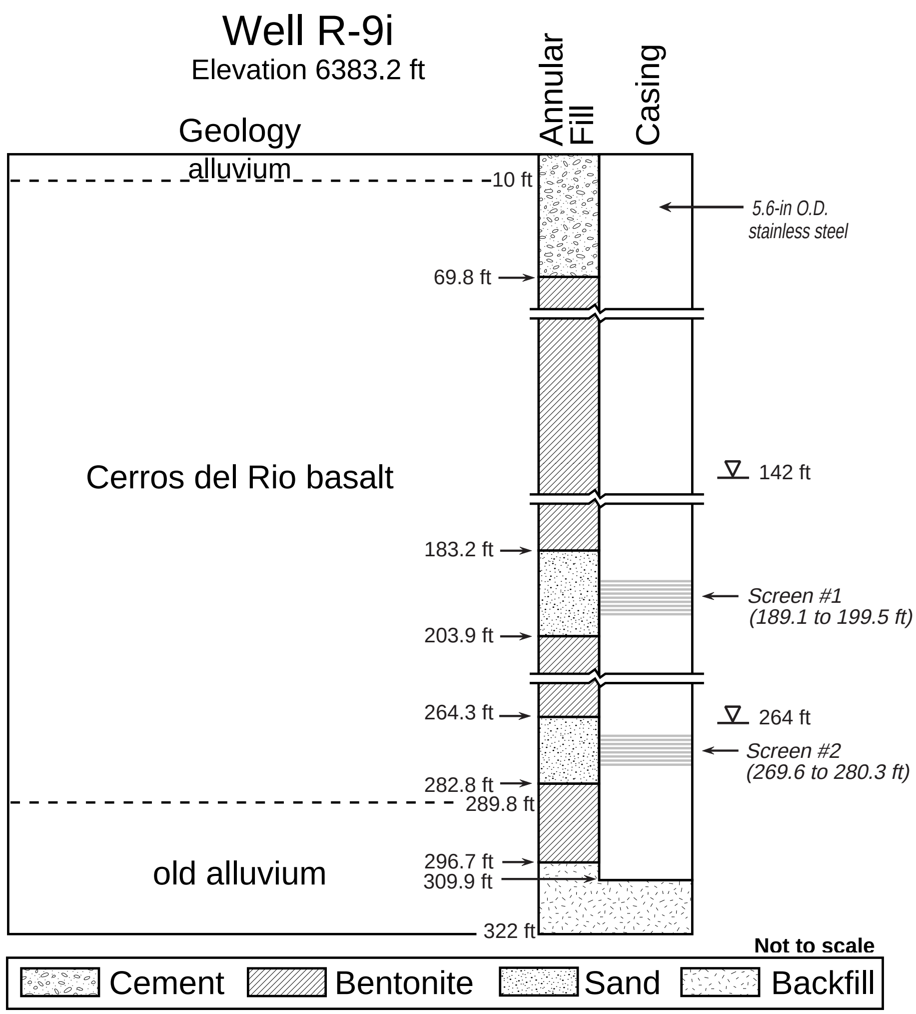


Figure 4. Hydrogeology and construction of R-9i

Injection and Pumping Tests

Injection tests were attempted for both screened intervals in well R-9i. The lower interval (screen 2) was tested first using the procedure described above under "Injection Test Procedures." However, this zone was so tight that within 2 minutes injected water came out of the top of the rod connected to the packer assembly. Injection was halted and recovery data were collected. Next, the packers were moved to the upper interval and injection testing was conducted at screen 1. Test design and results are summarized in Table 7. Analyses of injection-test data from R-9i are shown in Figures 5 and 6. In addition, a 421-minute pumping test was later conducted by inserting a submersible pump into the well. These data are summarized in Table 8. This pumping test configuration was open to both screens. However, nearly all of the water production came from screen 1 because the injection tests indicated that there is a relatively permeable system of fractures near this screen. In addition, the injection test at screen 2 indicated relatively low permeability there. Field and analytical data for all tests are given in Appendix B.

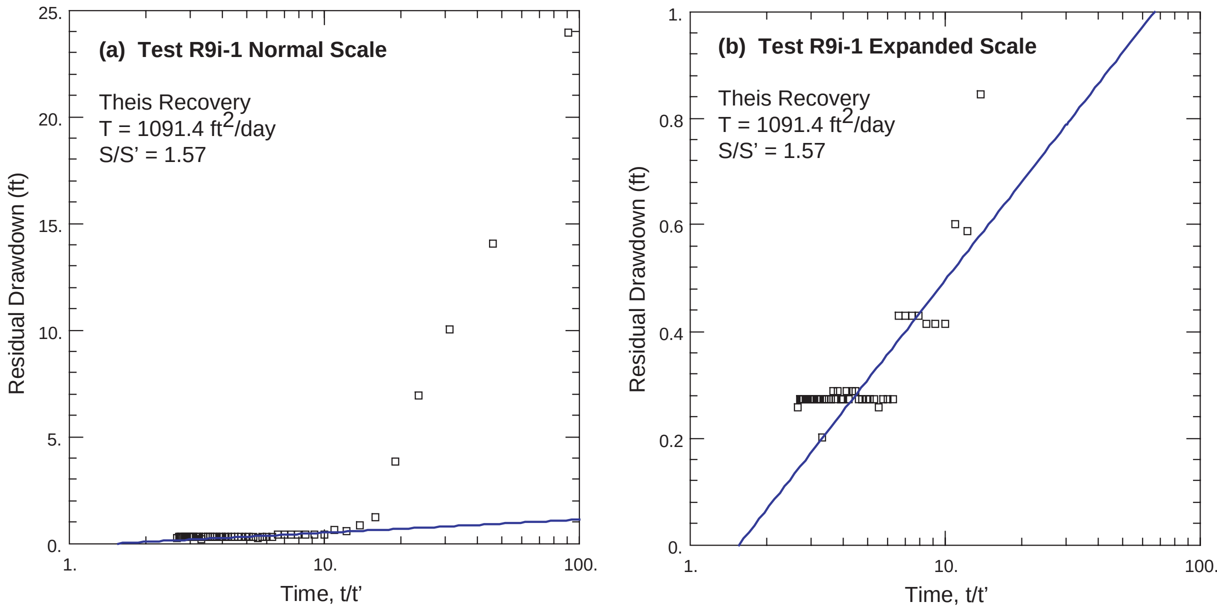


Figure 5. Theis recovery analysis of test data for R-9i, screen 1

Table 7
Summary of Injection Testing at R- 9i

Screen #	**1**	**2**
Geologic Unit[a]	Tb	Tb
Screened Interval (ft)[b]	189.1–199.5	269.6–280.3
Screen Length (ft)[b]	10.4	10.7
Borehole Diameter (in.)	12.25	12.25
Well Casing I.D. (in.)	5	5
Test Design		
Riser Pipe I.D. (in)	2.375	2.375
Pre-Test Water Level (ft)[c]	141	141
Average Injection Rate (gpm)[d]	19	19
Injection-Rate Variation (%)	<3	<3
Injection Period (min)	30	2
Volume Injected (gal.)	570	38
Conducted by[e]	SM/WS	SM/WS
Date	4/10/00	4/10/00
Comments:	Assumed fractured, phreatic aquifer between 142-225 ft bgs	Assumed phreatic aquifer between 264-289.8 ft bgs
Test Results		
D (ft)[f]	83.0	25.2
d (ft)[f]	47.1	5.6
l (ft)[f]	57.5	18.8
r_c (ft)[f]	0.099	0.099
r_w (ft)[f]	0.5104	0.5104
t_c (min)	4.6	49
t/t' (dimensionless)	7.5	1
Transmissivity (ft^2/d)	Theis-Recovery: 1091.4 Specific-Capacity: 588.8	NA
Hydraulic Conductivity (ft/d)	Theis-Recovery:13.1–104.9 Specific-Capacity: 7.1	Bouwer-Rice: 0.11
Analyzed by[e]	SM	SM
Comments:	Two breccia zones	One breccia zone

[a] Tb = Cerros del Rio basalt.
[b] For open interval, not screen joints.
[c] Depth bgs for packed-off interval, not well.
[d] Determined by flow meter and watch with second hand.
[e] SM = S. McLin.; WS = W. Stone,
[f] See Figure 3 for definitions.

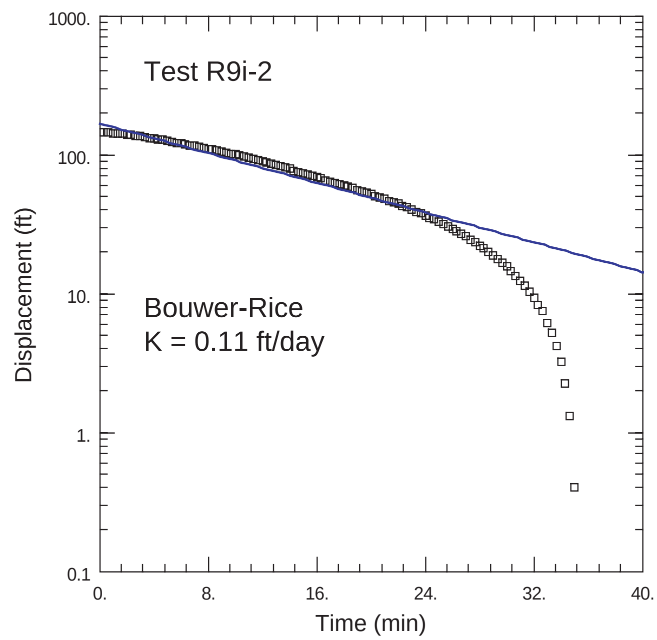


Figure 6. Bouwer-Rice analysis of test data for R-9i, screen 2

Table 8
Summary of Single-Well Pumping Test at R- 9i

Screen #	**1 & 2**
Geologic Unit[a]	Tb
Screened Interval (ft)[b]	189.1–199.5 & 269.6-280.3
Screen Length (ft)[b]	10.4 & 10.7
Borehole Diameter (in.)	12.25
Well Casing I.D. (in.)	5
Test Design	
Riser Pipe I.D. (in.)	2.375
Pre-Test Water Level (ft)[c]	141
Average Pumping Rate (gpm)[d]	15.4
Pumping-Rate Variation (%)	<1
Pumping Period (min)	421
Volume pumped (gal)	6,485
Conducted by[e]	SM/WS
Date	4/11/00
Comments:	Well open to both screens but test evaluated only the higher permeability material behind screen 1
Test Results	
D (ft)[f]	83.0
d (ft)[f]	47.1
l (ft)[f]	57.5
r_c (ft)[f]	0.2083
r_w (ft)[f]	0.5104
t_c (min)	6
Transmissivity (ft^2/d)	Specific-Capacity 529.5
Hydraulic Conductivity (ft/d)	Specific-Capacity 6.4
Analyzed by[e]	SM
Comments:	Recovery data anomalous due to back-siphoning at shut-down

[a] Tb = Cerros del Rio basalt.
[b] For open interval, not screen joints.
[c] Depth bgs for packed-off interval, not well.
[d] Determined by flow meter and watch with second hand.
[e] SM = S. McLin.; WS = W. Stone,
[f] See Fig. 3 for definitions.

Discussion

R9i-1 Injection Test. A field plot of this injection test is shown in Appendix B-1. Tabulated data are contained in Appendix B-2, and results of a specific capacity analysis are given in Appendix B-3 using the program listing contained in Appendix A.

Data analysis using the Theis recovery technique is shown in Figure 5. The casing storage formula was applied to this test to estimate the time at which the data become valid for analysis. Using Q = 19 gpm, s = 25.72 ft, and an injection tube inside-diameter of 2.375 inches, yields a t_c value of 4.6 minutes. The corresponding value of *t/t'* for the recovery event is about 7.5 [i.e., from Table 7, t/t' = (30+4.6)/4.6 = 7.5]. Thus, when applying the Theis recovery method, data collected prior to this time (i.e., t/t'>7.5) is omitted from the analysis. Figure 5a shows results from the Theis recovery analysis using a normal scale, while Figure 5b shows an expanded scale. Most of the response shown in Figure 5 is influenced by casing storage affects. When these casing storage data are excluded from the analysis, a transmissivity (T) of 1091.4 ft^2/day is obtained. This T value is based on the remaining data between about 0.0-0.3 ft.

Using the reported saturated thickness of 83 ft for the fractured basalt, an average hydraulic conductivity of 13.1 ft per day (fpd) is obtained. However as indicated earlier, the actual saturated thickness of the permeable formation may be more or less than this amount. As indicated in the R-9 completion report (Broxton et al. 2001, 66600), when the well was drilled, no water could be detected entering the borehole between 142 ft and 180 ft, possibly indicating that the formation materials there are tight in this interval. If only the screened interval (10.4 ft) were permeable, the calculated hydraulic conductivity for the screened zone would be 104.9 fpd. Hence in Table 7, a range of K values is reported for this well screen using the Theis-recovery analytical procedure. Resolving the question as to the actual thickness of the permeable formation will require additional geologic information that is not currently available.

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Hence, using the modified Matlab program listing in Appendix A and the data shown in Appendix B-3, we obtained a T=588.8 ft^2/day. The resulting K value is 7.1 fpd using a saturated thickness of 83 ft. This value represents a lower limit for both T and K, and is not much different than that obtained by applying the Bouwer-Rice slug test method of analysis to the recovery data. This latter method yielded a K of about 4.9 fpd; however, these results are not shown here. The specific capacity T value shown here is almost identical to a similar analysis of the 421 minute pumping test that is reported below. Hence, we favor this value as the most representative for K for the fractured basalt.

R9i-2 Injection Test. The water injected at screen 2 quickly rose to the surface. Figure 4 shows a static water level for the lower perched zone of 264 ft bgs. This water level was measured shortly after well completion. However, an incorrect water-level depth of only 141 ft was measured with the packers set on that zone immediately prior to testing. This discrepancy occurred because the wellbore remained open from the time of well development to the time of well testing. When the test packer assembly was set at the lower screen, the water level did not drop to a static position appropriate for the lower zone because of its low permeability. Thus, water remained at the composite level and a rise of only 141 ft was sufficient to cause water to overflow the rod connected to the injection assembly.

Data from the R9i-2 injection test were analyzed by the Bouwer-Rice slug test method even though the injected water was not added instantaneously. A field plot is shown in Appendix B-4, and all test data are giving in Appendix B-5. Results are shown in Figure 6 and yielded an estimate for K of 0.11 fpd.

R9i-2 Pumping Test. A 7-hour (i.e., 421 minutes) pumping test was also conducted at well R-9i using a submersible pump open to both screens 1 and 2. A field plot and test data are contained in Appendices B-6 and B-7, respectively. Appendix B-8 contains a specific capacity analysis using the program listing in

Appendix A. These data only contain the pumping response. Recovery data were not collected because there was no check valve in the riser pipe. Specific capacity analyses of these pumping data were used to see what the predicted lower-bound transmissivity estimate is. Hence, using the modified Matlab program listing in Appendix A and the data shown in Appendix B-8, we obtained a T=529.5 ft^2/day. The resulting K value is 6.4 fpd using a saturated thickness of 83 ft. This value represents a lower limit for both T and K, and is not very different than that obtained in the R9i-1 injection test analysis.

The specific capacity results shown in Tables 7 and 8 provide that most reliable T and K estimates for the fractured basalt surrounding screen 1. Independent specific capacity analyses for the injection and pumping tests yielded similar results. Recall that the injection test at R9i-1 lasted about 30 minutes and yielded a T = 588.8 ft^2/day (or a K = 7.1 ft/day). The pumping test extended for 421 minutes and yielded a T = 529.5 ft^2/day (or 6.4 ft/day). Likewise, the Bouwer-Rice analysis yielded satisfactory results with K = 0.11 ft/day for the basalt surrounding screen 2.

WELL R-13

R-13 is located in Mortandad Canyon, just west of the eastern Laboratory boundary (Figure 1). Well R-13 was drilled to a TD of 1133 ft within the Puye Formation and completed at the same depth with a single 60-ft-long screen placed 125 ft below the regional water table (Figure 7).

Hydrogeology

Geologic units penetrated by well R-13 are shown in Figure 7. No perched water was detected. The regional water table was encountered at a depth of 833 ft within the Puye Formation. The single screen straddles the contact between the Puye fanglomerate and the underlying pumiceous Puye (Figure 7).

Pumping Test

A short single-well pumping test was conducted at R-13 using a submersible pump inside the well casing. Test design and results are summarized in Table 9. A plot of time versus drawdown is shown in Appendix C-1, and all test data are listed in Appendix C-2. Analyses of the test data by the Theis-recovery method are shown in Figure 8. Finally, a summary of the specific capacity analysis is shown in Appendix C-3.

Discussion

R13 Pumping Test. Because R-13 was constructed with a single screen situated below the water table, it provided an opportunity for evaluating aquifer properties by means of a traditional single-well pumping test. After an initial drawdown of about 2.5 ft, the water level started to gradually decline (Appendix C-1). The test was terminated after about 12 minutes of pumping so conclusions from the analyses are limited. Still, representative values for T and K were determined.

The casing storage formula was applied to this test to estimate the time at which the data become valid for analysis. Using Q = 19.1 gpm, s = 2.20 ft, an inside well diameter of 4.5 inches, and an outside diameter of the production casing of 2.675 inches, the t_c value is about 60 seconds. The corresponding value of *t/t'* for the recovery event is about 12.5 [i.e., from Table 9, t/t' = (690+60)/60 = 12.5]. Thus, when applying the Theis recovery method, one should avoid including data earlier than this (i.e., t/t'>12.5) in the analysis. Figure 8 shows results from the Theis Recovery analysis. Figure 8a shows a normal scale, while Figure 8b shows an expanded scale using only data below the t/t' limit of 12.5 for the linear fit. Some of the response shown in Figure 8 is influenced by casing storage affects. When these casing storage data are excluded from the analysis, a T value between 2,400 and 5,300 ft^2/day is obtained, depending on how the straight-line fit passes through the remaining data points. Note that Table 9 shows T = 2,403.3 ft^2/day, while Figure 8 shows T = 5390.6 ft^2/day. All of these T values are based on drawdown data between 0.0 and 0.2 ft., so the slope of the linear fit must be determined by very small changes in water level. If the reported saturated thickness of 300 ft for the Puye fanglomerate and pumiceous zone is reliable, then the hydraulic conductivity ranges from a minimum of about 8.0 to 39.7 fpd as seen in Table 9**.**

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Hence, using the modified Matlab program listing in Appendix A and the data shown in Appendix C-3, T=5,268.6 ft^2/day. The resulting K value is 17.6 fpd based on the saturated thickness of 300 ft. This value may be more reliable than the Theis recovery method presented above because of the test duration.

Since the screen straddles the contact between the pumiceous and fanglomerate units of the Puye Formation, the test result cannot be assigned to either one of these materials. The test yielded an average result that probably overestimates the permeability of the fanglomerate and underestimates the permeability of the pumiceous Puye.

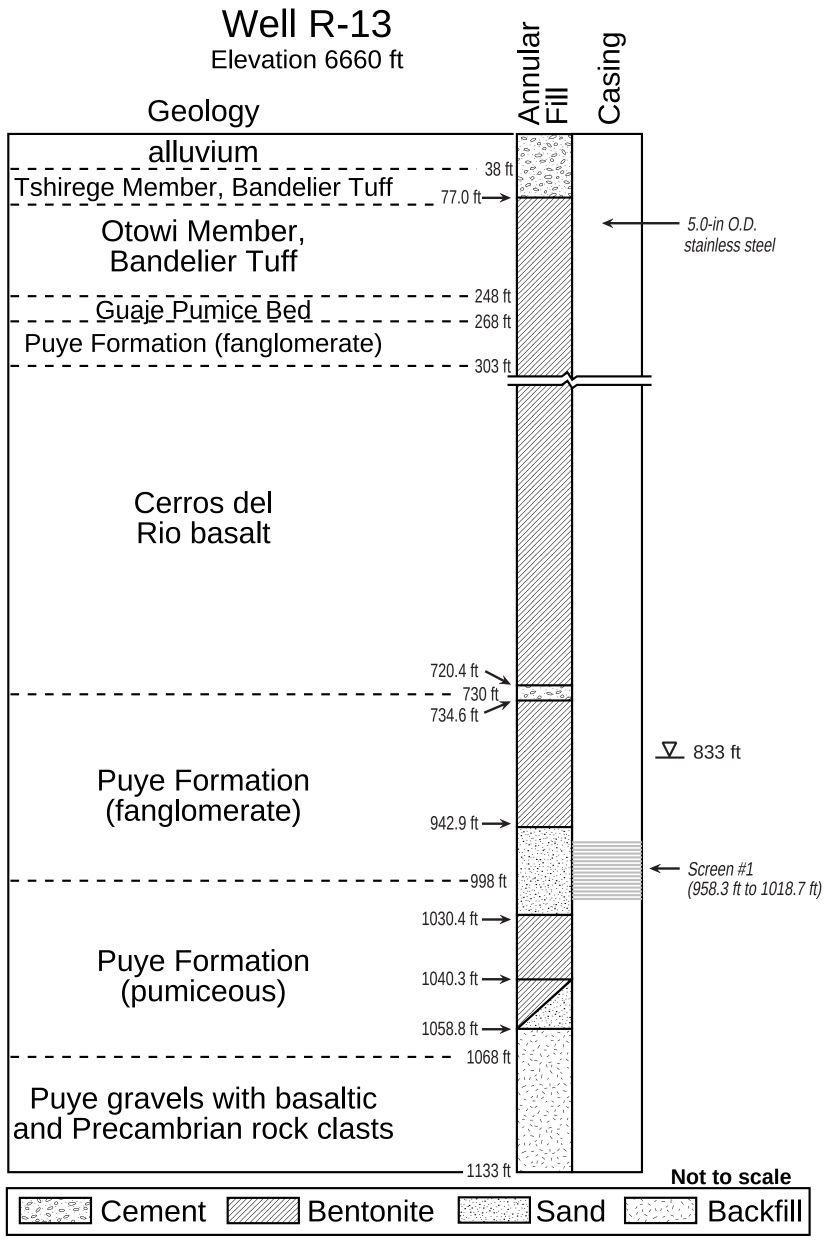


Figure 7. Hydrogeology and construction of R-13

Table 9
Summary of Single-Well Pumping Tests at R-13

Geologic Unit[a]	Tpf/Tpp	
Screened Interval (ft)[b]	958.3–1018.7	
Screen Length (ft)[b]	60.4	
Borehole Diameter (in.)	12.75	
Well Casing I.D. (in.)	4.5	
Test Design		
Riser pipe I.D. (in.)	1.25	
Pre-Test Water Level (ft)	833	
Pump Type	10 hp submersible	
Depth of Pump Intake (ft)	931	
Average Pumping Rate (gpm)[c]	19.1	
Pumping Rate Variation (%)	<1	
Pumping Period (min)	12	
Volume Pumped (gal.)	229	
Conducted by[d]	WS	
Date	10/31/01	
Comments: Pumping rate apparently not enough to stress aquifer		
Test Results		
D (ft)[e]	300	
d (ft)[e]	125.3	
l (ft)[e]	185.7	
r_c (ft)[e]	0.1875	
r_w (ft)[e]	0.5104	
t_c (min)	1	
Transmissivity (ft^2/d)	Theis recovery	2,403.3
	Specific-Capacity	5,268.6
Hydraulic Conductivity (ft/d)	Theis-recovery	8.0-39.8
	Specific-Capacity	17.6
Analyzed by[d]	SM	
Comments:		

[a] Tpf = Puye Formation, fanglomerate; Tpp = Puye Formation, pumiceous unit
[b] Length of open interval, not screen joints.
[c] Determined by flow meter and stopwatch.
[d] WS = William Stone, SM = Stephen McLin.
[e] See Figure 3 for definitions

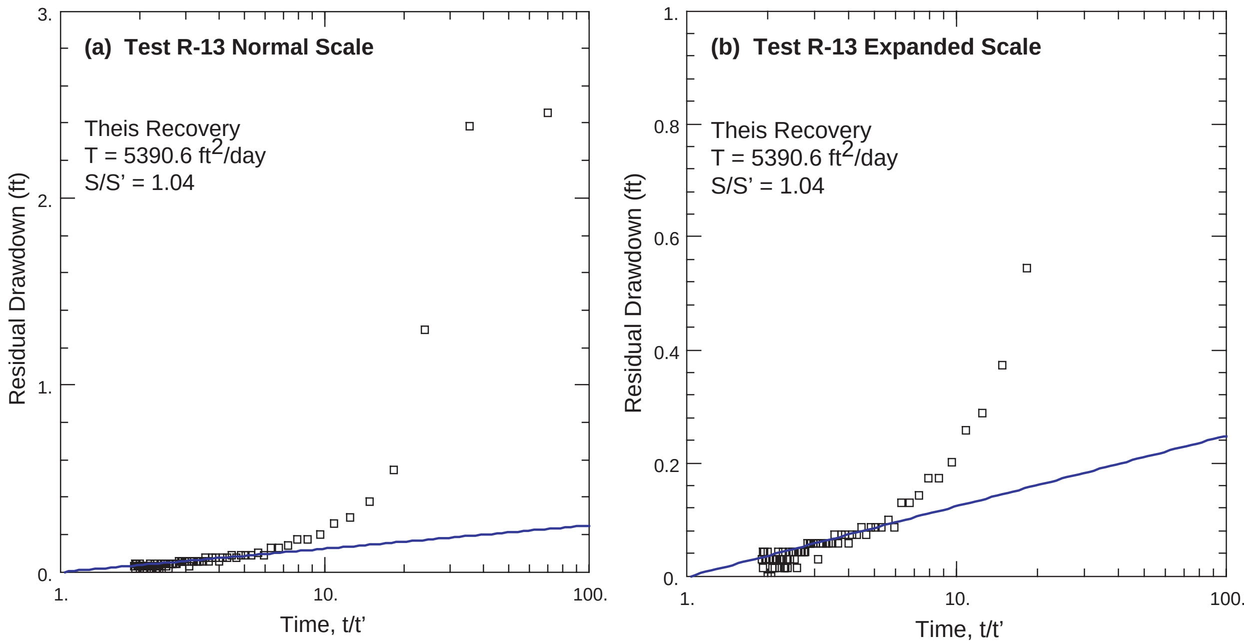


Figure 8. Theis-recovery analysis of pumping-test data for R-13

WELL R-19

Well R-19 is located on the mesa between Three-mile and Pajarito Canyons in TA-36 (Figure 1). It was drilled to a TD of 1902 ft, but the final depth is 1885 ft in the Puye Formation because of sloughing in of the borehole (Broxton et al. 2001, 66603). It was completed with seven screens: two in possible perched zones, one across the water table, and four within the regional zone of saturation (Figure 9).

Hydrogeology

Geologic units penetrated by well R-19 are shown in Figure 9. Two possible zones of perched saturation were encountered at depths of 830-840 ft bgs in the Guaje Pumice Bed and at 894-912 ft bgs in the Puye Formation. The regional water table was encountered at a depth of 1178 ft within the Puye Formation. Two head measurements made during testing indicate that a downward vertical gradient exists in the regional zone of saturation at well R-19.

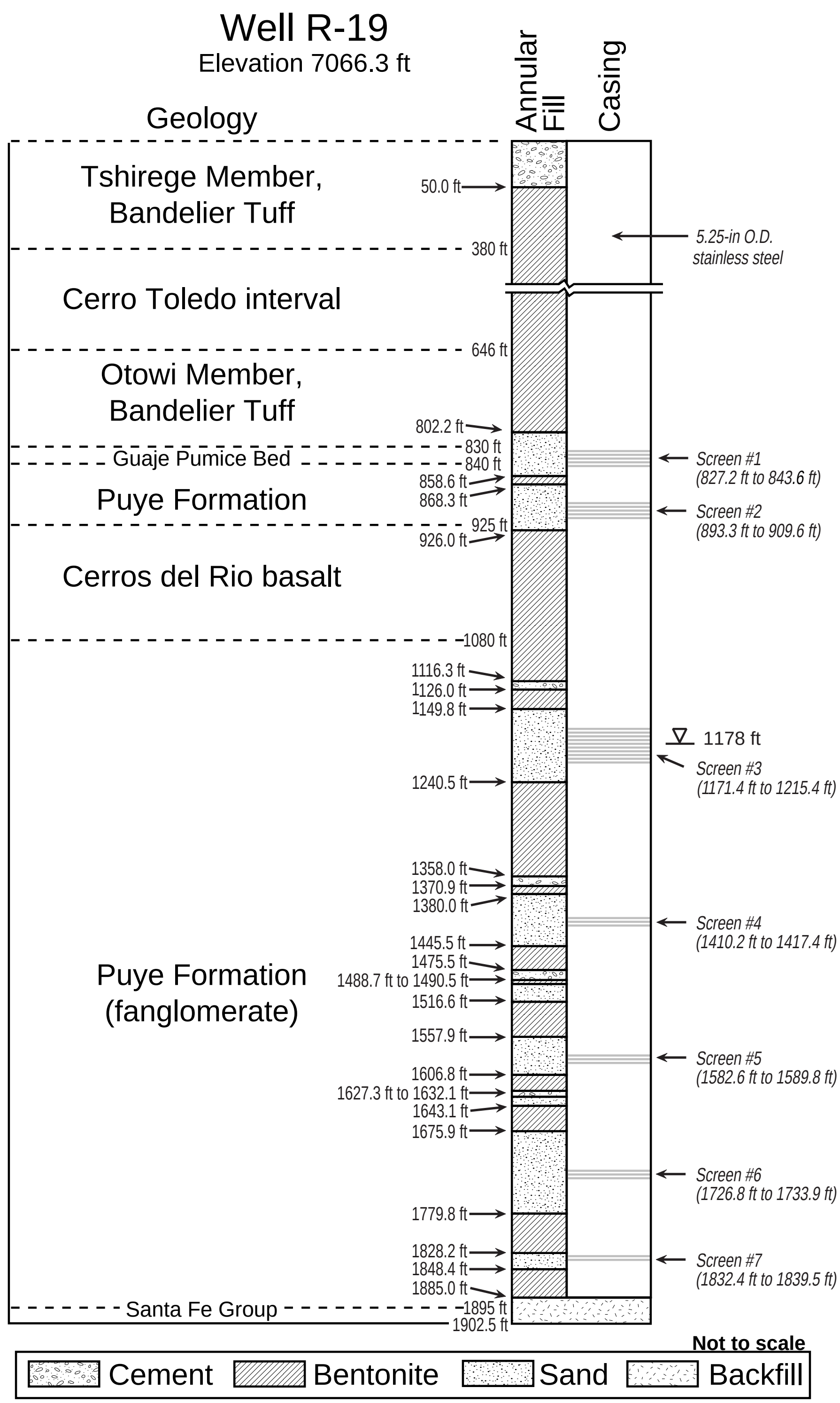


Figure 9. Hydrogeology and construction of R-19

Injection Tests

The lowermost two screened intervals (screens 6 and 7) were tested at well R-19. Test design and results are summarized in Table 10. Analyses of injection-test data are shown in Figures 10 and 11. Field and analytical test data are given in Appendix D.

Table 10
Summary of Injection Testing at R-19

Screen #	6	7
Geologic Unit[a]	Tpp	Tpp
Screened Interval (ft)[b]	1726.8-1733.9	1832.4-1839.5
Screen Length (ft)[b]	7.1	7.1
Borehole Diameter (in.)	12.25	12.25
Well Casing I.D. (in.)	4.5	4.5
Test Design		
Riser Pipe I.D. (in.)	2.375	2.375
Pre-Test Water Level (ft)[c]	1177	1174
Average Injection Rate (gpm)[d]	11.8	14.6
Injection-Rate Variation (%)	<3	<3
Injection Period (min)	30	31
Volume Injected (gal)	354	453
Conducted by[e]	NT	NT
Date	7/27/00	7/27/00
Comments		
Test Results		
D (ft)[f]	372.5	372.5
d (ft)[f]	196.8	302.4
l (ft)[f]	203.9	309.5
r_c (ft)[f]	0.099	0.099
r_w (ft)[f]	0.5104	0.5104
t_c (min)	2.4	<1
Transmissivity (ft^2/d)	Theis-Recovery 1775.4 Specific-Capacity 6922.7	Theis-Recovery 932.0 Specific-Capacity 8179.1
Hydraulic Conductivity (ft/d)	Theis-Recovery 4.8 – 250.1 Specific-Capacity 18.6	Theis-Recovery 2.5 – 131.3 Specific-Capacity 22.0
Analyzed by[e]	SM	SM
Comments		

[a] Tp = Puye Formation, pumiceous unit.
[b] For open interval, not screen joints.
[c] Depth below ground surface for packed-off interval, not well (composite static water-level depth for well = 1179 ft).
[d] Determined by flow meter and stopwatch or watch with second hand.
[e] NT = Neal Tapia, SM = S. McLin.
[f] See Figure 3 for definitions.

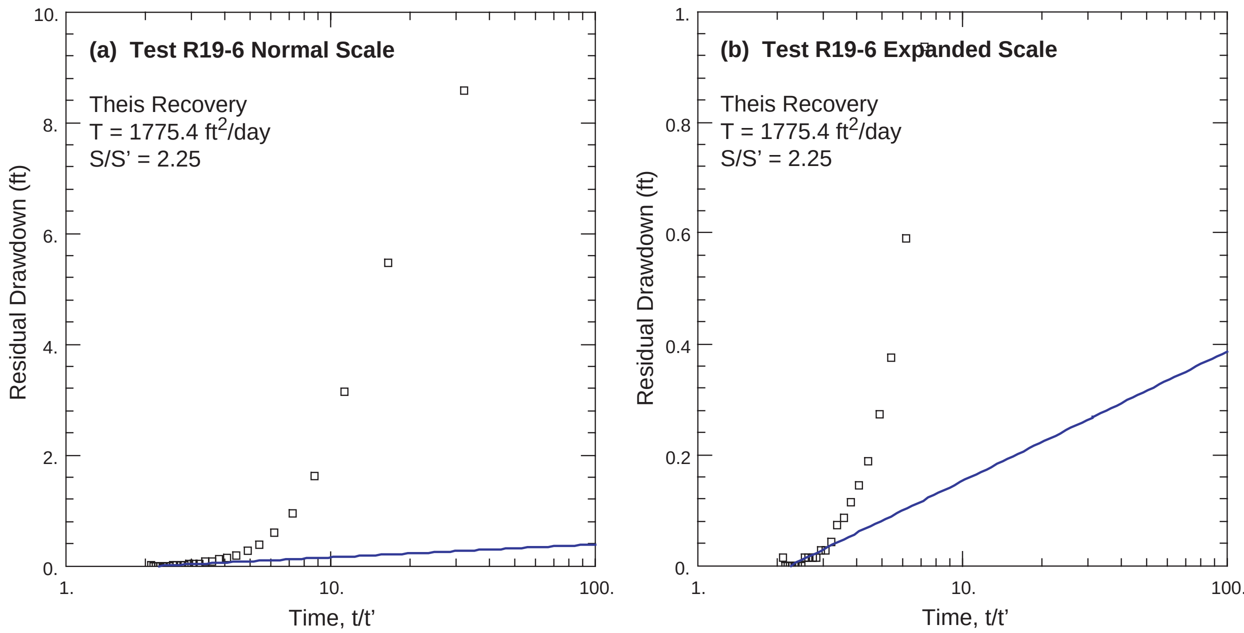


Figure 10. Theis-recovery for injection-test at R-19, screen 6; (a) normal scale and (b) expanded scale.

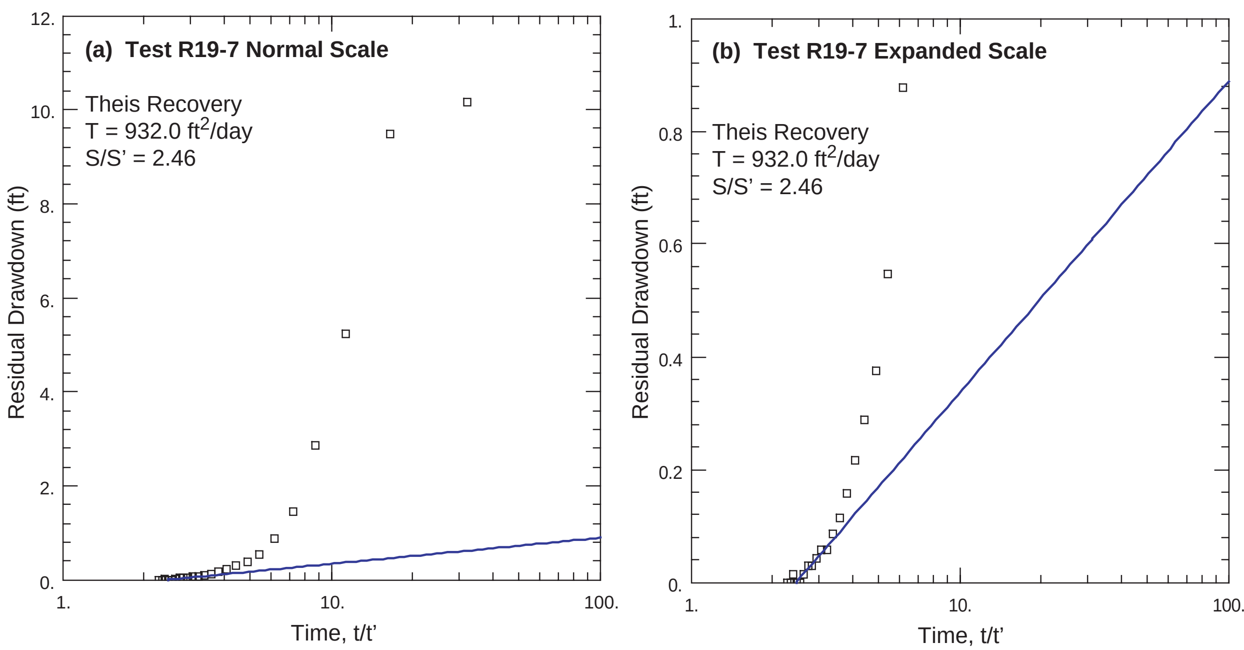


Figure 11. Theis-recovery for injection-test at R-19, screen 7; (a) normal scale and (b) expanded scale.

Discussion

Screens 1 and 2 at R-19 are located above the regional water table and no tests were conducted in these upper screens. Since screen 3 straddles the water table, it was feared that injection testing would affect future water sampling efforts. Therefore, hydrologic testing was not conducted at screen 3. Screen 4 is in the Puye fanglomerate and screen 5 is in the newly recognized pumiceous unit of the Puye Formation. Screen 4 was not tested. The test at screen 5 proved unsuccessful because after 30 gal. of water were injected, the water level in the straddle-packer/injection apparatus and drill rods rose rapidly and the capacity of the transducer was exceeded. This observation implies that the transmissivity near screen 5 is relatively low. Finally, testing at well R-19 successfully characterized the newly recognized lower pumiceous unit in the Puye Formation that was accessible in screens 6 and 7.

R19-6 Injection Test. A plot of water levels versus time for this test is shown in Appendix D-1. Appendix D-2 contains the tabulated data for this test, while Appendix D-3 contains results of a specific capacity analysis. A close examination of water levels versus time (Appendix D-1) shows that the water level initially rose very rapidly in response to injection. However, as time progressed, the rate of rise slowed and eventually began to decrease toward the end of the injection phase of the test. Since the injection rate was held constant, entrained air probably entered the injection water stream and interfered with the smooth, uninterrupted water entry into well screen 6. In effect, this entrained air probably changed the well efficiency in an unpredictable manner. The recovery portion of the test was smooth.

Data analysis using the Theis recovery technique is shown in Figure 10. The casing storage formula previously discussed was applied to this test to estimate the time at which the data become valid for analysis. Using Q = 11.8 gpm, s = 8.79 ft at t = 3.0 min (see Appendix D-2), and an injection tube I.D. of 2.375 in., t_c is about 2.4 min. The corresponding value of *t/t'* for the recovery event is about 13.5 [i.e., from Table 10, t/t' = (30+2.4)/2.4 = 13.5]. Thus, when applying the Theis recovery method, one should exclude data earlier (i.e., t/t'>13.5) than this in the analysis. Figure 10a shows a normal scale, while Figure 10b shows an expanded scale for the linear fit. Most of the response data shown in Figure 10 are not influenced by casing storage affects. A transmissivity (T) of 1,775.4 ft^2/day is obtained using this method but is based on data between 0.0 and 0.1 ft., so the slope of the linear fit was determined by very small changes in water level. This implies that the cone of impression in response to injection continued to expand both vertically and horizontally during the test. Thus the curve shown in Figure 10 continues to flatten out as time increases. If the test were longer, the curve would probably have asymptotically approached a constant slope.

If the reported saturated thickness of 372.5 ft for the pumiceous Puye is reliable, then the average hydraulic conductivity is 4.8 fpd. As indicated earlier, the actual saturated thickness of the permeable formation that was affected by injection may be less than 372.5 ft. If only the screened interval (7.1 ft) were affected, then the calculated hydraulic conductivity for the screened zone would be 250.1 fpd. Table 10 reports a range of K values for this well screen using the Theis-recovery procedure. Resolving the question as to the actual thickness of the permeable formation affected requires either a long test or an observation well located near screen 6.

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Using the modified Matlab program listing in Appendix A and the data shown in Appendix D-3, T = 6,922.7 ft^2/day. The resulting K value is 18.6 fpd using a saturated thickness of 372.5 ft. These values represent a lower limit for both T and K.

R19-7 Injection Test. A plot of water levels versus time for this test is shown in Appendix D-4. Appendix D-5 contains the tabulated data for this test, while Appendix D-6 contains results of a specific capacity analysis. A close examination of water levels versus time (Appendix D-4) shows that this test was similar to that presented above. Hence, the water level initially rose very rapidly in response to injection. However, as time progressed, the rate of rise slowed and eventually began to decrease toward the end of the injection phase of the test. Since the injection rate was held constant, it is likely that entrained air entered the injected water stream and interfered with the uninterrupted water entry into well screen 7. This entrained air probably changed the well efficiency in an unpredictable manner. The recovery portion of the test was smooth.

The casing storage formula was applied to this test to estimate the time at which the data become valid for analysis. Using Q = 14.6 gpm, s = 5.73 ft at t = 3.0 min (Appendix D-5), and an injection tube I.D. of 2.375 in., t_c equals less than 1 min. The corresponding value of *t/t'* for the recovery event is about 32 [i.e., from Table 10, t/t' = (31+1)/1 = 32]. Thus, when applying the Theis recovery method, one should avoid including data prior to t/t'>32 in the analysis. Figure 11 shows results from the Theis Recovery analysis. Note that Figure 11a shows a normal scale, while Figure 11b shows an expanded scale for the linear fit, so most of the response shown in Figure 11 is not influenced by casing storage affects. A transmissivity (T) of 932.0 ft^2/day is obtained, and is based on limited data between about 0.0-0.1 ft. The slope of the linear fit was determined by very small changes in water level. As reported above for screen 6, this situation results because the cone of impression in response to injection continues to expand both vertically and horizontally during the test. Hence, the curve shown in Figure 11 continues to flatten out as time increases. If the test were much longer, then the curve would asymptotically approach a constant slope.

Based on the reported saturated thickness of 372.5 ft for the pumiceous Puye, the average hydraulic conductivity is 2.5 fpd. However, as indicated earlier, the actual saturated thickness of the permeable formation affected by injection may be less than 372.5 ft. If only the screened interval (7.1 ft) were affected, then the calculated hydraulic conductivity for the screened zone would be 131.3 fpd. Hence in Table 10, a range of K values is reported for this well screen using the Theis-recovery analytical procedure. Resolving the question as to the actual thickness of the permeable formation affected requires either a very long test interval or an observation well located near screen 7.

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Using the modified Matlab program listing in Appendix A and the data shown in Appendix D-6, we obtained a T = 8,179.1 ft^2/day. The resulting K value is 22.0 fpd using a saturated thickness of 372.5 ft. These values represent a lower limit for both T and K.

The specific capacity results shown in Table 10 provide the most reliable T and K estimates for the pumiceous Puye surrounding screens 6 and 7. Generally, the Theis recovery method provides a more reliable estimate for T. However, in this test, very small changes in slope result in large charges in the estimated T value. Hence, a range for T based on this method is reported in Table 10.

WELL R-22

Well R-22 is located east of MDA-G in Technical Area (TA)-54 on the mesa between Cañada del Buey and Pajarito Canyons (Figure 1). It was drilled by open-hole methods to a TD of 1489 ft in the Santa Fe Group (Ball et al. 2001, 71471). The well was completed with five screens: one at the water table and four within the regional zone of saturation (Figure 12).

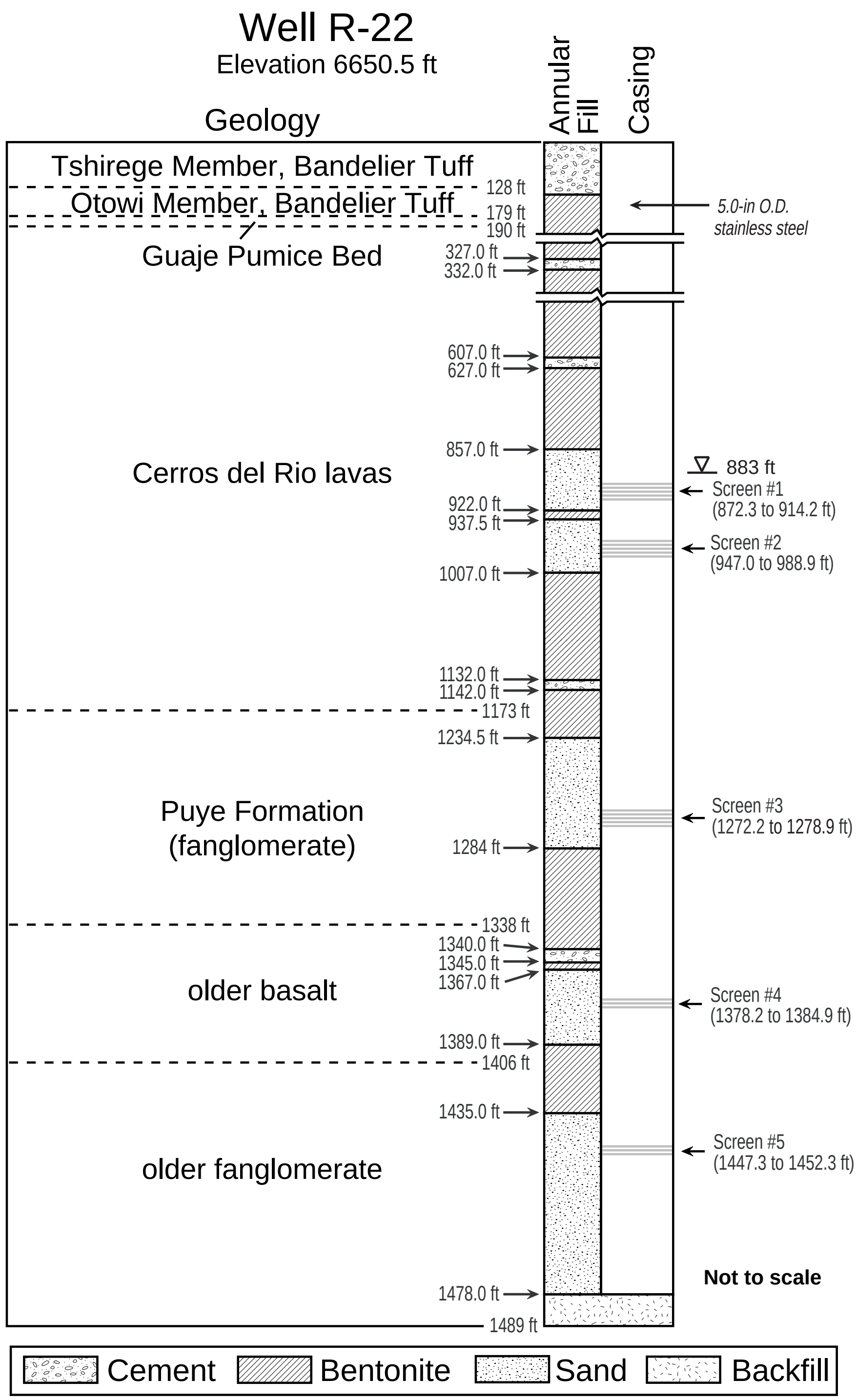


Figure 12. **Hydrogeology and construction of R-22**

Hydrogeology

Geologic units penetrated by well R-22 are shown in Figure 12. No perched water was encountered at this location. The regional water table was penetrated at a depth of 883 ft in the Cerros del Rio basalt (Ball et al. 2001, 71471). Of the four screens below water table, two provide access to basalt, one is situated in Puye Formation fanglomerate, and one targets older fanglomerate. Head measurements for each screened interval during testing indicate the vertical gradient is downward at R-22.

Injection Tests

Straddle-packer/injection tests were attempted at each of the screened intervals below the water table, that is, screens 2 through 5. During the test at screen 3, the rod to which the packer assembly was attached dropped 4.8 in. and stripped the coating off the transducer cable, so the test had to be halted. To make the best use of rig time while the cable was being repaired at the drilling yard, the packer assembly was moved down to screen 4 and a static water level was determined. When the cable had been repaired and returned to the site, testing resumed with screen 4. A repeat test of screen 4 (R-22-4b) with the same injection rate and time was also run for comparison; results from both tests were comparable as seen in Table 11. Finally, screen 5 was tested. Test design and results for all tests are summarized in Table 11. Analyses of injection-test data are shown in Figures 13 through 16. Field and analytical data are given in Appendix E.

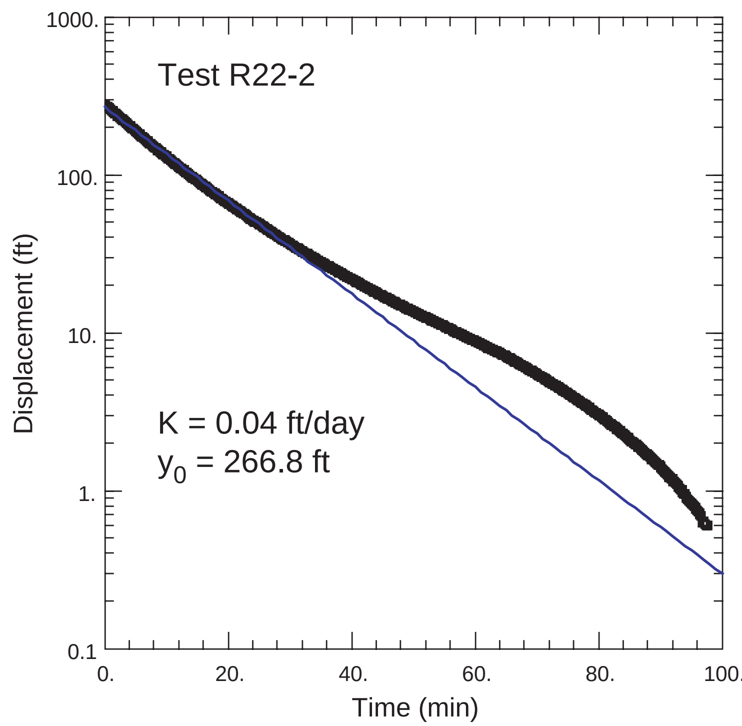


Figure 13. Bouwer-Rice analysis of injection-test recovery data for R-22, screen 2

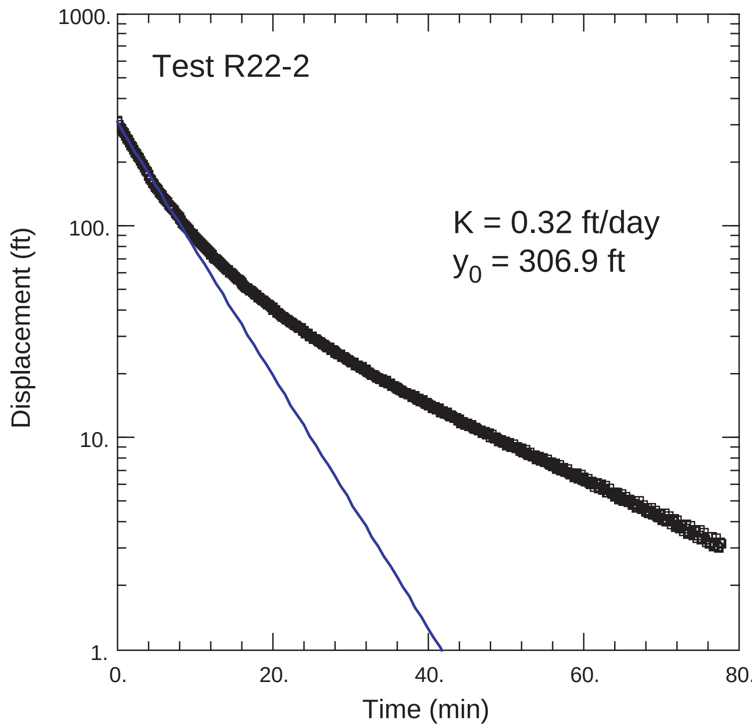


Figure 14. Bouwer-Rice analysis of injection-test recovery data for R-22, screen 3

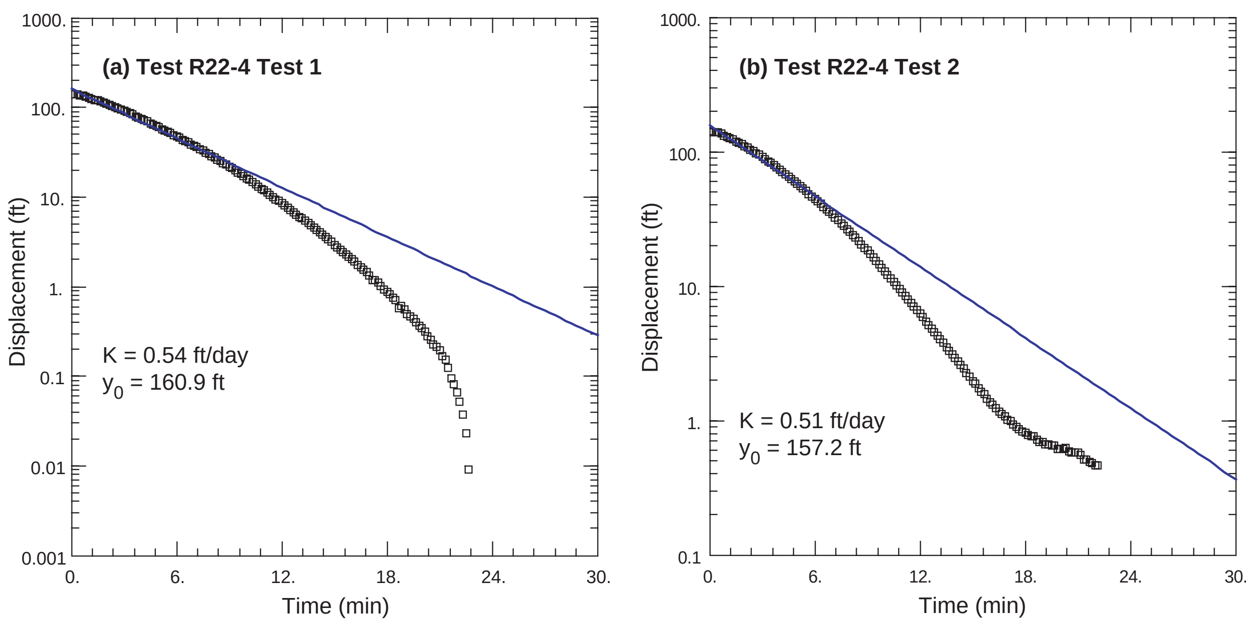


Figure 15. Bouwer-Rice analysis of injection-test recovery data for R-22, screen 4

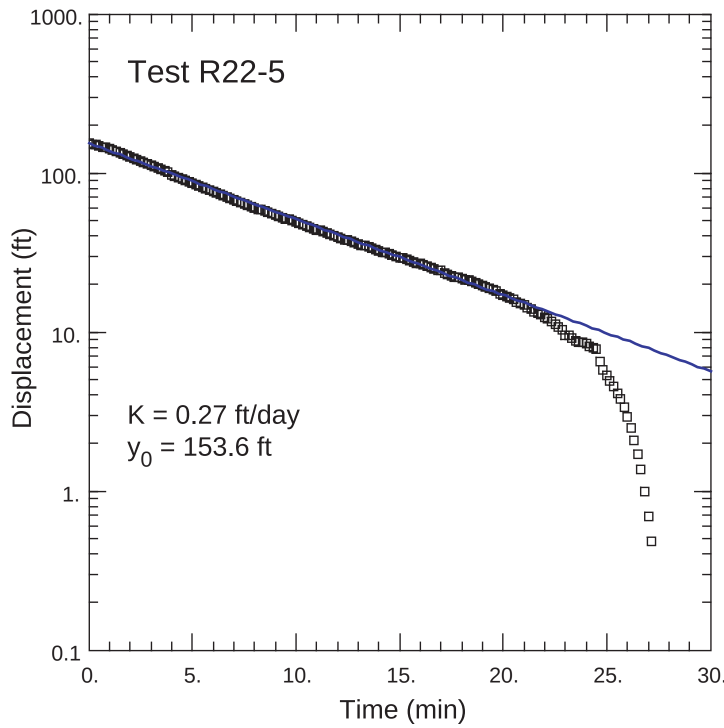


Figure 16. Bouwer-Rice analysis of injection-test recovery data for R-22, screen 5

Discussion

R22-2 Injection Test. A plot of water level versus time for this test is shown in Appendix E-1. Appendix E-2 contains the tabulated data for this test. A close examination of water levels versus time (Appendix E-1) shows that the water level initially rose rapidly in response to injection. After 19 min, injection stopped and water levels started to slowly fall in response. Recovery took about 100 min before the initial static water level was achieved. This slow response suggests that the formation opposite to screen 2 is relatively tight. Analysis by conventional pumping techniques proved unsuccessful. Hence, this test was analyzed using the Bouwer-Rice slug test procedure even though the injected waters were not instantaneously introduced into the wellbore. Results are shown in Figure 13, and indicate that hydraulic conductivity (K) is about 0.04 fpd.

R22-3 Injection Test. A plot of water levels versus time for this test is shown in Appendix E-3. Appendix E-4 contains the tabulated data for this test. A close examination of water levels versus time (Appendix E-3) shows that the water level initially rose rapidly in response to injection. After about 9 min, injection stopped and water levels started to slowly fall in response. Recovery took almost 69 min before the initial static water level was achieved. This slow response suggests that the formation opposite to screen 3 is relatively tight. Analysis by conventional pumping techniques proved unsuccessful. Hence, this test was analyzed using the Bouwer-Rice slug test procedure even though the injected waters were not instantaneously introduced into the wellbore. Results are shown in Figure 14, and indicate that K is about 0.32 fpd.

R22-4 Injection Test. A plot of water levels versus time for this test is shown in Appendix E-5. Appendix E-6 contains the tabulated data for this test. A close examination of water levels versus time (Appendix E-5) shows that the water level initially rose rapidly in response to injection. After 5 min, injection stopped and water levels started to slowly fall in response. Recovery took about 25 min before the initial static water level was achieved. This slow response suggests that the formation opposite to screen 4 is relatively tight. Analysis by conventional pumping techniques proved unsuccessful. Hence, this test was analyzed using the Bouwer-Rice slug test procedure even though the injected waters were not instantaneously introduced into the wellbore. Results are shown in Figure 15a, and indicate that K is about 0.54 fpd. A repeat test at screen 4 using nearly identical inputs showed a nearly identical response, as seen in Figure 15b, and indicated K = 0.51 fpd.

R22-5 Injection Test. A plot of water levels versus time for this test is shown in Appendix E-7. Appendix E-8 contains the tabulated data for this test. A close examination of water levels versus time (Appendix E-7) shows that the water level initially rose rapidly in response to injection. After 5 min, injection stopped and water levels started to slowly fall in response. Recovery took about 27 min before the initial static water level was achieved. This slow response suggests that the formation opposite to screen 5 is relatively tight. Analysis by conventional pumping techniques proved unsuccessful. Hence, this test was analyzed using the Bouwer-Rice slug test procedure even though the injected waters were not instantaneously introduced into the wellbore. Results are shown in Figure 16, and indicate that K is about 0.27 fpd.

Table 11
Summary of Injection Testing at R-22

Screen #	**2**	**3**	**4[a]**	**5**
Geologic Unit[b]	Tb	Tpt	Tbo	Tfo
Screened Interval (ft)[c]	947–988.9	1272.2–1278.9	1378.2–1384.9	1447.3–1452.3
Screen Length (ft)	41.9	6.7	6.7	5.0
Saturated Thickness (ft)	69.5	49.4	49.0	43.0
Borehole Diameter (in.)	12.25	12.25	10.5	10.5
Casing I.D. (in.)	4.5	4.5	4.5	4.5
Test Design				
Riser Pipe I.D. (jn.)	2.375	2.375	2.375	2.375
Pre-Test Water Level (ft)[d]	899.6	948.0	955.5	955.5
Average Injection Rate (gpm)[e]	9.12	12.0	a) 16 16	17
Injection-Rate Variation (%)	<3	<3	<3	<3
Injection Period (min)	19	9	a) 5 5	5
Volume Injected (gal.)	173	108	a) 80 80	85
Conducted by[f]	WS	WS	WS	WS
Date	11/15/00	11/16/00	11/17/00	11/17/00
Comments:		Drill rod slipped 4.8 in. during test and stripped transducer cable	Two tests run with identical parameters	
Test Results				
Hydraulic Conductivity (ft/d), Bouwer-Rice method	0.04	0.32	a) .54 b) 0.51	0.27
Analyzed by[f]	SM	SM	SM	SM
Comments:	Data could not be analyzed by pumping-test methods; screen 4 results similar in repeat test			

[a] Two tests were conducted for this screen to check reproducibility of results.
[b] Tb = Cerros del Rio basalt; Tpt = Puye Formation, Totavi Lentil; Tbo = older basalt; Tfo = older fanglomerate.
[c] For open interval, not screen joints.
[d] Depth bgs for packed-off interval, not well (composite static water-level depth for well = 890 ft).
[e] Determined by flow meter and watch with second hand.
[f] WS = W. Stone, SM = S. McLin.

WELL R-31

Well R-31 is located in TA-39 in lower Ancho Canyon (Figure 1). It was drilled by the air-rotary casing-advance method (Table 1) to a TD of 1103 ft in the Totavi Lentil (Vaniman et al. 2001, 72615). The well was completed with five screens: one in a possible perched zone of saturation, one across the water table, and three in the regional zone of saturation (Figure 17).

Hydrogeology

Geologic units penetrated by R-31 are shown in Figure 17. A possible zone of perched water was encountered in the Cerros del Rio basalt at a depth of 440 ft. The regional water table was encountered at a depth of 523 ft, also in the Cerros del Rio basalt. Preliminary head measurements from transducers in the Westbay™ monitoring system suggest that well R-31 was drilled nearly parallel to an isopotential. In other words, groundwater flow at this location appears to be essentially horizontal.

Injection Tests

Injection tests were conducted for screens 3, 4, and 5. Screen 5 results are from a test conducted before final development was completed. However, tests for screens 3 and 4 were conducted after 9 days of additional development. Test design and results are summarized in Table 12. Analyses of injection-test data are shown in Figures 18 through 20. Field and analytical data are given in Appendix F.

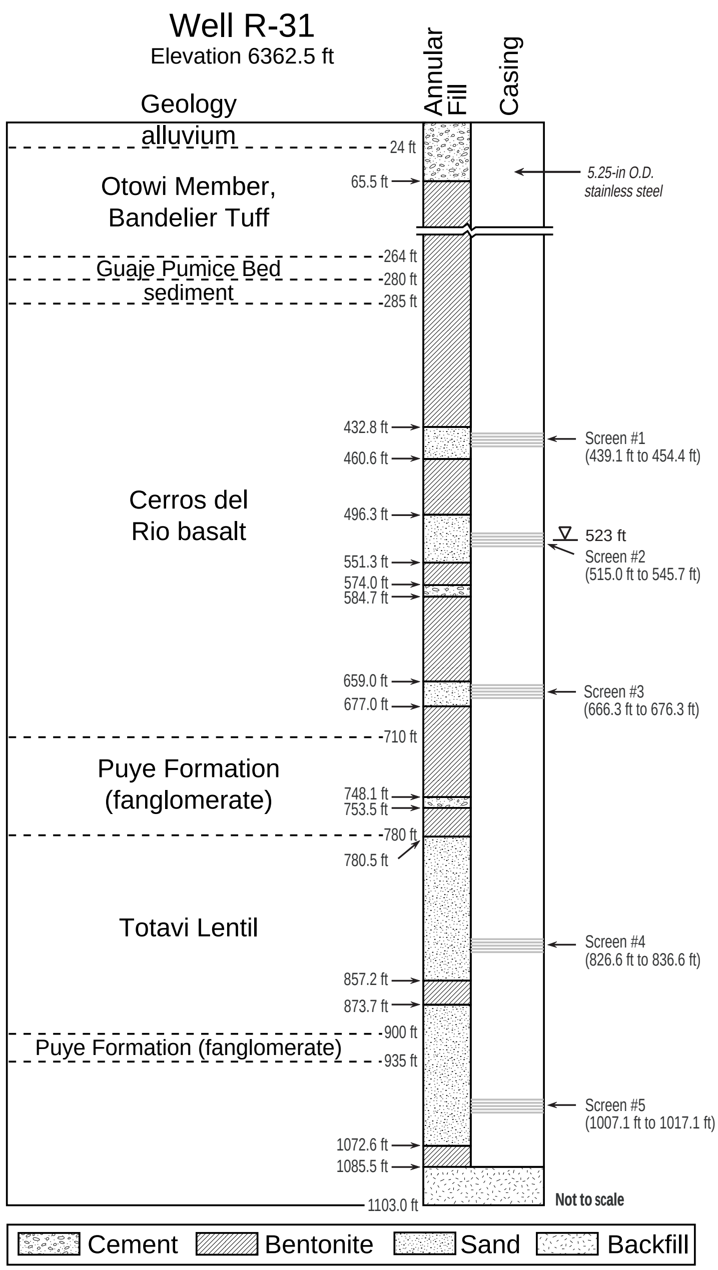


Figure 17. Hydrogeology and construction of R-31

Table 12
Summary of Injection Testing at R-31

Screen #	**3**	**4**	**5**
Geologic Unit[a]	Tb	Tpt	Tpt
Screened Interval (ft)[b]	666.3–676.3	826.6–836.6	1007.1–1017.1
Screen length (ft)[b]	10.0	10.0	10.0
Borehole Diameter (in.)	13 1/8	10 3/4	10 ¾
Well Casing I.D. (in.)	4.75	4.75	4.75
Test Design			
Riser Pipe I.D. (in.)	2.375	2.375	2.375
Pre-Test Water Level (ft)[c]	522.9	520.6	524.0
Average Injection Rate (gpm)[d]	10.9	9.8	9.0
Injection-Rate Variation (%)	<3	<3	<3
Injection Period (min)	2	30	30
Volume Injected (gal.)	21.8	294	273
Conducted by[e]	SM/WS	SM/WS	SM/WS
Date	3/28/00	3/28/00	3/10/00
Comments:	Test conducted after second round of well development	Test conducted after second round of well development	Test conducted before second round of well development
Test Results			
D (ft)[f]	187.0	120	168
d (ft)[f]	NA	46.6	72.1
l (ft)[f]	153.3	56.6	82.1
r_c[f]	1.19	1.19	1.19
r_w[f]	6.13	3.2	2.7
t_c	20	10.4	12.2
Transmissivity (ft^2/d)		Theis-Recovery 576.2 Specific-Capacity 1332.4	Theis-Recovery 159.7 Specific Capacity 1387.7
Hydraulic Conductivity (ft/d)	Bouwer-Rice 0.48	Theis-Recovery 4.8-57.6 Specific Capacity 11.1	Theis-Recovery 1.0-16.0 Specific Capacity 8.3
Analyzed by[e]	SM	SM	SM
Comments:			

[a] Tb = Cerros del Rio basalt;Tpt = Puye Formation, Totavi Lentil.
[b] Length of open interval, not screen joints.
[c] Depth bgs for packed-off interval, not well (composite static water-level depth for well = 522.8 ft).
[d] Determined by flow meter and stopwatch or watch with second hand.
[e] SM = S. McLin, WS = W. Stone.
[f] See Figure 3 for definitions.

Discussion

Testing before and after complete well development provided an opportunity to evaluate the impact of this process on hydraulic properties. The K for the material behind screen 3 increased slightly from 0.27 ft/d to 0.48 ft/d with further development (or increased by a factor of 1.78). The T value for the material behind screen 4 increased from 315.3 ft^2/d to 576.2 ft^2/d according to the Theis recovery method (or increased by a factor of 1.83). Apparently, additional development at these screens showed some measurable improvement.

R31-3 Injection Test. A plot of water levels versus time for this test is shown in Appendix F-1. Appendix F-2 contains the tabulated data for this test. A close examination of water levels versus time (Appendix F-1) shows that the water level initially rose very rapidly in response to injection. After 2 min, injection stopped and water levels started to slowly fall in response. Recovery took another 20 min before the initial static water level was achieved. This relatively slow response suggests that the formation opposite screen 3 is relatively tight. Analysis by conventional pumping techniques proved unsuccessful. This test was analyzed using the Bouwer-Rice slug test procedure even though the injected waters were not instantaneously introduced into the wellbore. Results are shown in Figure 18, and indicate that hydraulic conductivity (K) is about 0.48 fpd.

R31-4 Injection Test. A plot of water levels versus time for this test is shown in Appendix F-3. Appendix F-4 contains the tabulated data for this test, while Appendix F-5 contains results of a specific capacity analysis. A close examination of water levels versus time (Appendix F-3) shows that the water level initially rose very rapidly in response to injection. However, as time progressed, the rate of rise slowed and eventually began to decrease toward the end of the injection phase of the test. Since the injection rate was held constant, it is likely that entrained air entered the injection water stream and may have interfered with the smooth, uninterrupted water entry into well screen 4. In effect, this entrained air changed the well efficiency in an unpredictable manner. The recovery portion of the test was smooth as expected.

Data analysis using the Theis recovery technique is shown in Figure 19. The casing storage formula previously discussed was applied to this test to estimate the time at which the data become valid for analysis. Starting with Q = 9.8 gpm, s = 9.11 ft at t = 3.0 min (see Appendix F-4), and an injection tube I.D. of 2.375 inches, t_c equals about 3.2 min. The corresponding value of *t/t'* for the recovery event is about 10.4 [i.e., from Table 12, t/t' = (30+3.2)/3.2 = 10.4]. Thus, when applying the Theis recovery method, one should avoid including data prior to t/t'>10.4 in the analysis. Note that Figure 19a shows a normal scale, while Figure 19b shows an expanded scale for the linear fit. Most of the response data shown in Figure 19 are not influenced by casing storage affects. A transmissivity (T) of 576.2 ft^2/day is obtained using this method, and is based on residual drawdown data between about 0.0–0.3 ft, indicating that the slope of the linear fit was determined by small changes in water level. This situation results because the cone of impression in response to injection continues to expand both vertically and horizontally during the test. However, the curve shown in Figure 19 has flattened out and appears to asymptotically approach a constant slope. Hence, the test is reliable.

If the reported saturated thickness of 120.0 ft for the pumiceous Puye indicates the vertical thickness affected by injection, then the average hydraulic conductivity is 4.8 fpd. However as indicated earlier, the actual saturated thickness of the permeable formation that was affected by injection may be less than 120.0 ft. If only the screened interval (10.0 ft) were permeable, the calculated hydraulic conductivity for the screened zone would be 57.6 fpd. Since we do not know exactly how much of the pumiceous Puye near screen 4 was affected by this test, we report an upper and lower limit. Hence in Table 12, a range of K values is reported for this well screen using the Theis-recovery analytical procedure. Resolving the question as to the actual thickness of the permeable formation affected requires either a very long test interval or an observation well located near screen 4.

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Using the modified Matlab program listing in Appendix A and the data shown in Appendix F-5, T = 1,332 ft^2/day. The resulting K value is 11.1 fpd using a saturated thickness of 120.0 ft. These values represent a lower limit for both T and K.

R31-5 Injection Test. A plot of water levels versus time for this test is shown in Appendix F-6. Appendix F-75 contains the tabulated data for this test, while Appendix F-8 contains results of a specific capacity analysis. A close examination of water levels versus time (Appendix F-6) shows that this test was similar to that presented above for screen 4. Hence, the water level initially rose rapidly in response to injection. However, as time progressed, the rate of rise slowed and eventually approached a constant toward the end of the injection phase of the test. Since the injection rate was held constant, it is likely that entrained air did not enter the injected water stream and did not interfere with the smooth, uninterrupted water entry into well screen 5. The recovery portion of the test was also smooth.

The casing storage formula was applied to this test to estimate the time at which the data become valid for analysis. Starting with Q = 9.0 gpm, s = 7.00 ft at t = 3.0 minutes (Appendix D-5), and an injection tube inside-diameter of 2.375 in., t_c equals 2.7 min. The corresponding value of *t/t'* for the recovery event is about 12.2 [i.e., from Table 12, t/t' = (30.33+2.7)/2.7 = 12.2]. Thus, when applying the Theis recovery method, one should avoid including data prior to t/t'>12.2 in the analysis. Figure 20 shows results from the Theis Recovery analysis. Note that Figure 20a shows a normal scale, while Figure 20b shows an expanded scale for the linear fit, so most of the response shown in Figure 20 is not influenced by casing storage affects. A transmissivity (T) of 159.7 ft^2/day is obtained using this method, and is based on residual drawdown data between about 0.0-0.6 ft. The slope of the linear fit was determined by small changes in water level. This situation results because the cone of impression in response to injection continues to expand both vertically and horizontally during the test. However, the curve shown in Figure 20 has flattened out and appears to asymptotically approach a constant slope. Hence, the test appears reliable.

If the saturated thickness of the pumiceous Puye is 168.0 ft, then the average hydraulic conductivity is 1.0 fpd. However as indicated earlier, the actual saturated thickness of the permeable formation may be less than 168 ft. If only the screened interval (10.0 ft) were permeable, the calculated hydraulic conductivity for the screened zone would be 16.0 fpd. Hence in Table 12, a range of K values is reported for this well screen using the Theis-recovery analytical procedure. Resolving the question as to the actual thickness of the permeable formation affected requires either a very long test interval or an observation well located near screen 7.

As a check, the specific capacity approach was also used to see what the predicted lower-bound transmissivity estimate is. Using the modified Matlab program listing in Appendix A and the data shown in Appendix D-7, T = 1,388 ft^2/day. The resulting K value is 8.3 fpd using a saturated thickness of 168.0 ft. These values represent a lower limit for both T and K.

The Theis recovery results for screen 4 and 5 provide a valid range of reliable T and K estimates for the pumiceous Puye surrounding these screens. Generally, the Theis recovery method provides a more reliable estimate for T than the specific capacity approach. However, the specific capacity method does correct for partial penetration and provides a minimum theoretical estimate for T and K.

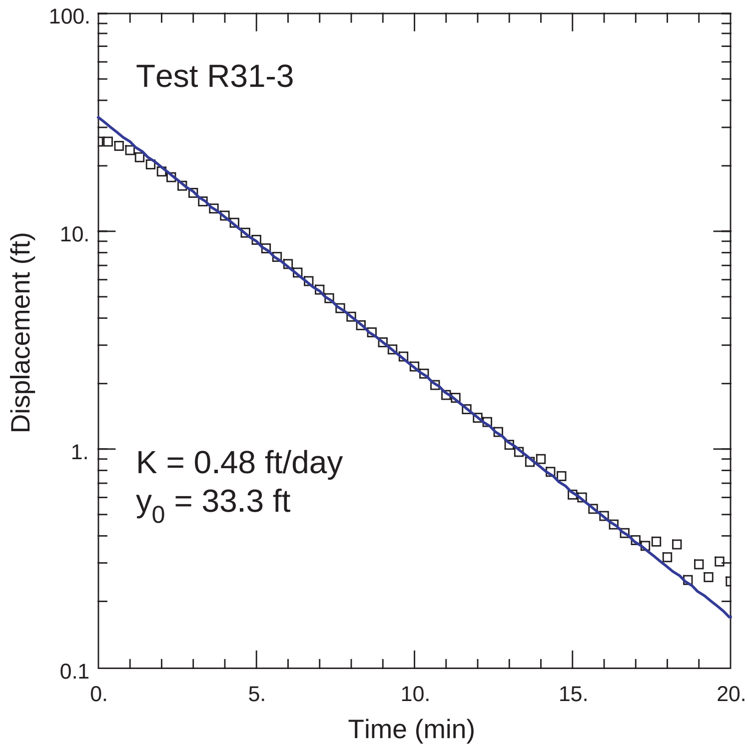


Figure 18. Bouwer-Rice analysis of injection-test recovery data for R-31, screen 3

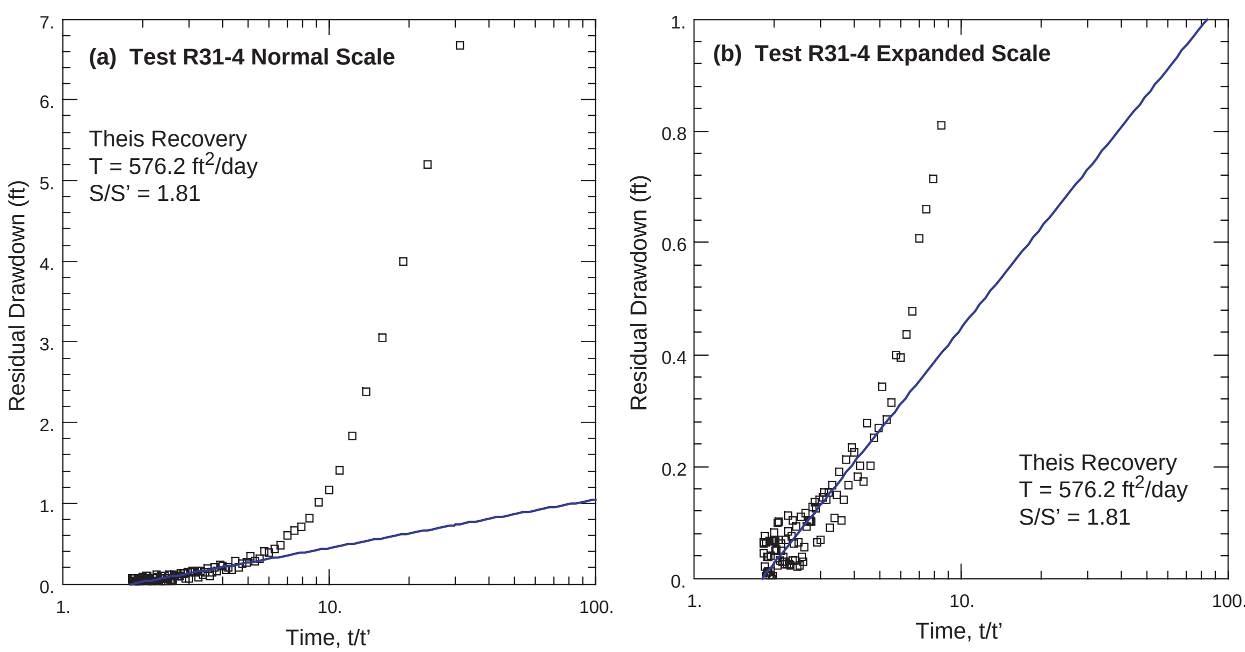


Figure 19. Theis-recovery analysis of injection-test data for R-31, screen 4

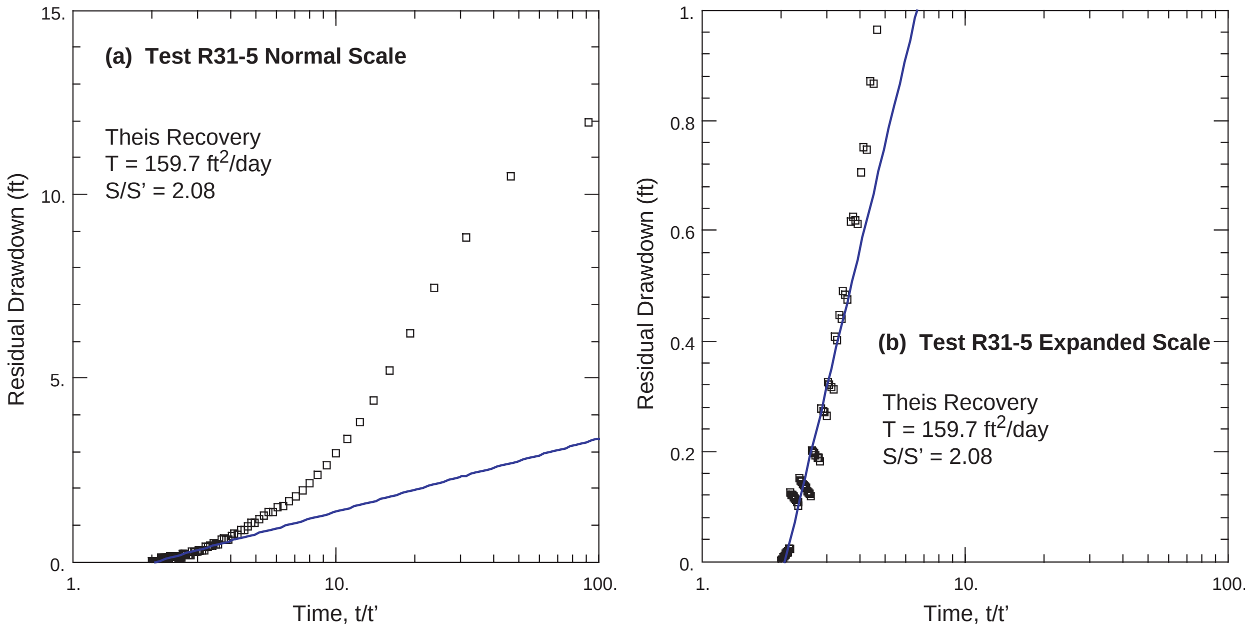


Figure 20. Theis-recovery analysis of injection-test data for R-31, screen 5

QUALITY OF TEST RESULTS

This report not only presents the results of testing five of the R wells but also provides the details of test design, execution, and analysis necessary for users to judge the quality of test results for the R wells. Quality of test results depends on the reliability of the field data collected and the validity of the methods used to analyze those data. Addressing a few basic questions about the tests permits a general evaluation of the results.

Reliability of Test Data

The type of test conducted is an important consideration. With one exception (well R-13), testing was limited to a straddle-packer/injection method, a hybrid form of test. It is not strictly a slug test as water is not injected instantaneously. Rather, the introduction of a volume of water takes a number of minutes. Thus, the plots of water level versus time for the injection tests differ slightly from those for traditional slug tests: the slope of the initial water-level rise on the plots is not always vertical.

The reliability of hydrologic-test data depends on the uniformity of the stress applied during testing and the reliable operation of test equipment. Stress during the test, that is, the rate of water injection or withdrawal, must not vary significantly. The pump and flow meter must operate correctly.

Data reliability also depends on the correct functioning of all the equipment involved in measurements. Water-level measurements depend on the proper functioning of water-depth probes, transducers, and data loggers. In multiscreened wells, screens must be isolated by packers during injection tests. Thus, packers must hold inflation throughout the tests.

Overall, stress was applied uniformly and the testing equipment employed functioned reliably. Any exceptions are noted in the summary tables and discussion sections for the tests described herein.

Validity of Analytical Methods

Hydraulic properties are derived by analysis of test data using any of various established methods. These methods vary with hydrologic condition or aquifer type: unconfined, leaky confined, and confined. Software permits plotting data against type curves for the various methods. The type curve yielding the best fit presumably identifies the hydrologic condition prevailing for the material tested and gives the most representative result. However, the results should not be accepted uncritically but should be evaluated in view of what is known of the hydrogeology of the area.

As many analytical methods are graphical (they involve curve-matching), there will always be some variation in the results. However, slight differences in curve-matching yield only slight differences in results.

More important, however, is the suitability of the method used to analyze the data. Suitability is determined by the similarity of both the site and test conditions to those specified for the method. In other words, assumptions made for the method must be met. Table 13 summarizes the basic conditions assumed for the analytical methods used in this report.

Table 13
Major Assumptions for Analytical Methods Used

Method	Well Penetration of Aquifer	Hydraulic Condition	Application of Stress
Bouwer-Rice	Partial or complete	Unconfined or confined	Addition or withdrawal
Theis Recovery	Complete	Confined	Addition or withdrawal
Specific Capacity	Partial or complete	Confined	Addition or withdrawal

Evaluating Test Results

It is beyond the scope of this report to review the field of well hydraulics. Excellent coverage can be found in standard hydrology textbooks (for example, Driscoll 1986, 70111, and Fetter 1994, 70942). However, for a quick quality-assurance check of hydrologic tests, one can ask a few basic questions:

1. *How much did flow rate vary during the test?* All analytical methods assume it was constant. However, maintaining a constant flow rate is difficult. For the test to be valid, flow rate should not have varied by more than 10%; less variation is desirable (Fetter 1994, 70942). The Bean pumps used provided remarkably constant flow rates. In all the tests reported on here, flow-rate variation was much less than 10% (typically 2-4%).
2. *Are there indications that any equipment was unreliable?* Did drill rod slip, packers deflate, the flow meter behave erratically, etc.? Obviously, unreliable equipment produces unreliable data. Whenever equipment problems occurred, testing was halted until they could be resolved.
3. *Were the assumptions for the analytical method used actually met at the site?* Unrealistic or erroneous hydraulic properties are often attributed to the inadequacy of the analytical equation used. It is more likely that any of several field conditions did not match those on which the equation is based:

   Screen Position. Tests for screens straddling the water table are not ideal, as discussed under "Constraints." Although a few methods specifically state that they apply only to tests of screens below the water table, that assumption is inherent for all methods.

Well Penetration of Aquifer. Ideally, a well to be tested fully penetrates the thickness of an aquifer. Some methods are suitable for partially penetrating wells, others require fully penetrating wells, and some apply to either case, especially if certain conditions are met. If a screen covers less than 70% of the total thickness of the saturated material, the well is considered to be partially penetrating (Kruseman and de Ridder 2000, 70110). The multiscreen completion of most of the wells epitomizes partial penetration. Short single-screen completions also represent only partial penetration.

Hydraulic Condition. Some methods apply only to confined conditions, others apply only to unconfined conditions, while still others apply to leaky-confined conditions. Some apply to either confined or unconfined conditions, if certain provisions apply. If an analytical plot looks good for a given condition, one should consider whether that condition is likely for the location and material behind the screen.

Flow Conditions. Each analytical method corresponds to a specific flow condition. Flow to the well is assumed to be radial. For pumping tests, flow may also be further described as steady (in equilibrium) or nonsteady (not in equilibrium). In steady flow, the cone of depression continues to grow with time. In nonsteady flow, the cone of depression has reached a recharge boundary and stopped growing.

Method of Applying Stress. Some methods evaluate the response to removal of water (as by pumping), while others address the response to addition of water (as by injection). Most methods also apply to the recovery of water level after such stresses.

Major assumptions for the methods used to analyze data from the five wells tested are summarized in Table 13.

4. *Do the test results for the various geologic units compare favorably with those obtained previously?* Figure 21 permits a comparison of the results of the injection testing described herein and those obtained for tests of the same geologic unit by various other methods. In most cases, injection-test results fall within the distribution of values. In fact, all of the hydraulic conductivity values are log-normally distributed as seen in Figure 22. Supporting data are listed in Appendix G.
5. *Do the results seem reasonable for the geologic materials tested?* That is, are the hydraulic properties within the range commonly reported for the rock types tested? Table 14 gives the lithology of the material tested, the results obtained from testing (K), and the range of textbook K values for the same or most similar material. All of the test results fall within reported ranges of K for the geologic materials tested.

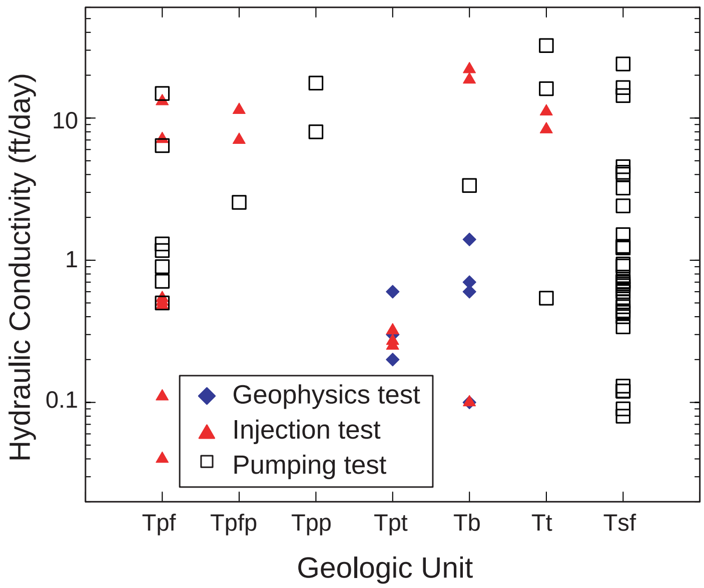


Figure 21. Comparison of results for various test methods. Tpf = Puye Formation (fanglomerate); Tpfp = Puye Formation (fanglomerate and pumiceous); Tpp = Puye Formation (pumiceous); Tpt = Puye Formation, Totavi Lentil; Tb = Cerros del Rio basalt; Tt = Tschicoma Formation; and Tsf = Santa Fe Group.

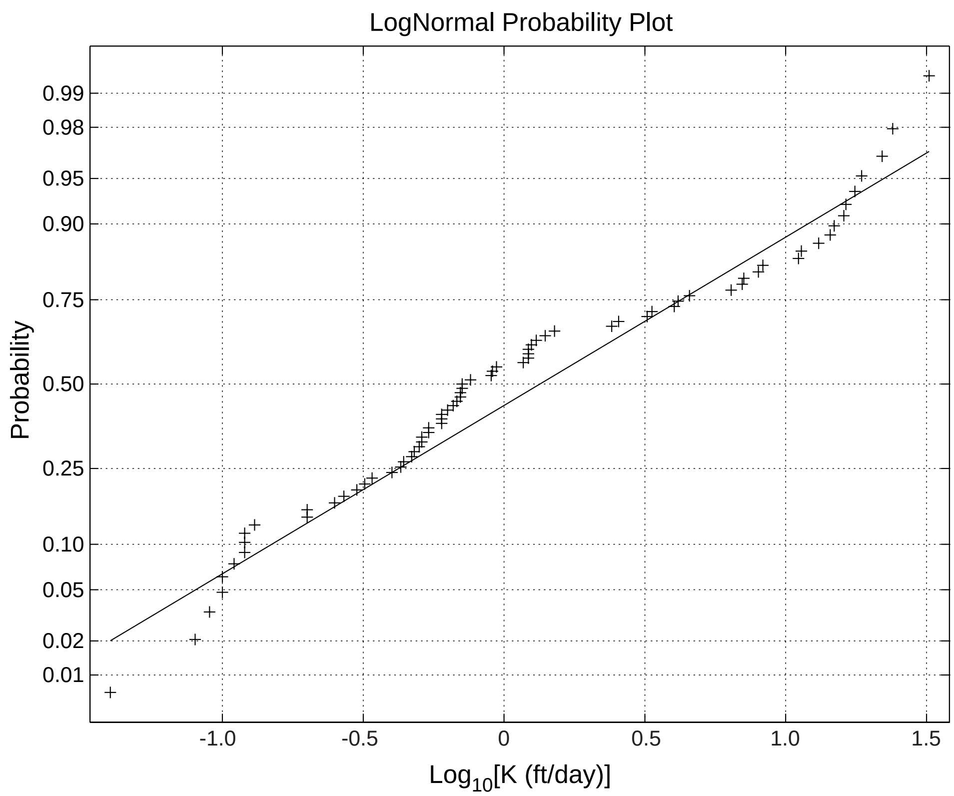


Figure 22 Log-normal probability plot of hydraulic conductivity values

Table 14
Hydraulic Properties vs. Geology

Material Tested (well-screen/test)[a]	Test Results K (ft/d)	(gpd/ft^2)[b]	Comparable Textbook Material[c]	Textbook K Range (gpd/ft^2)[c]
Clayey flow base (R-9i-2)	0.11	0.82	Glacial till	10^{-5} to 10
Massive/somewhat fractured basalt			Fractured igneous and metamorphic rock	10^{-1} to 10^{3}
(R-22-2)	0.04	0.30		
(R-31-3)	0.48	3.59		
(R-22-4a)	0.54	4.04		
(R-22-4b)	0.51	3.81		
Highly fractured basalt			Permeable basalt	1 to10^{5}
(R-9i-1a)	7.1	53.1		
(R-9i-1)*	6.4	47.9		
Fanglomerate and axial gravel			Silty sand	1 to 10^{3}
(R-22-3)	0.32	2.39		
(R-22-5)	0.27	2.02		
(R-19-7)p	22.0	164.6		
(R-31-5)g	8.3	62.1		
(R-19-6)p	18.6	139.1		
(R-31-4)g	11.1	83.0		
(R-13b)*	17.6	131.6		

[a] * = pumping test and K = T/saturated thickness; p = pumiceous fanglomerate (Puye Formation), g = gravel (Totavi Lentil).

[b] Calculated as ft/d value (Table 5) x 7.48.

[c] From Freeze and Cherry (1979, 64057) Table 2.2.

Despite the care taken in the design, execution, and analysis of tests, results obtained are not unique. Kruseman and DeRidder (2000, 70110, p. 13) summed up the reason succinctly:

> Analyzing and evaluating pumping test data…is as much an art as a science. It is science because it is based on theoretical models that the geologist or engineer must understand and on thorough investigations that he [/she] must conduct into the geologic formations in the area of interest. It is an art because different types of aquifers can exhibit similar drawdown behaviors, which demand interpretation…on the part of the geologist or engineer.

This dual nature of hydrologic testing should be kept in mind when evaluating or using test results.

RECOMMENDATIONS

As noted in the “Constraints” section above, the R wells present several challenges to hydrologic testing. The following are suggestions for optimizing hydrologic characterization in the R wells, recognizing however, that the R wells are not constructed strictly for hydrologic characterization. Therefore some recommendations may not be practical or deemed necessary in the overall program.

Avoid Placing Screens Across Water Table. Designing wells with testing in mind maximizes both testing opportunities and results. Most analytical methods assume the screen is below the water table. NMED has specified that the uppermost screen must straddle the water table to facilitate detection of organic contaminants floating at the top of the saturated zone, despite the fact that organics are not the principal contaminants at LANL. Furthermore, such a well design hinders development of the uppermost screen. Thus, screens should not be placed across the water table, unless there is a reason to suspect organic contaminants in the area.

Avoid Placing Screens Across Geologic Contacts. Hydrologic testing is usually conducted to learn the properties of a single geologic unit or type of material within a geologic unit. When screens are placed across contacts between geologic units, the test result is an average that is not representative of either unit. Thus, placing screens across geologic contacts or contacts between material types within units should be avoided wherever hydraulic properties are of interest.

Avoid Oversized Filter Packs. Oversized filter packs should be avoided as they hinder both focused hydrologic testing and water-quality sampling. One usually assumes that the interval of geologic material targeted by a screen is similar to the length of the screen. Thus, it is not only misleading but also counterproductive to have a 7-ft screen and a 100-ft filter pack (as at R-19, screen 6; Table 4). Results of testing such a screen installation are biased by the amount of permeable material in such a long interval. Furthermore, many of the R wells are destined to become monitoring wells. Such wells usually target certain intervals in the saturated zone. Oversized filter packs permit the mixing of water over long intervals. It is not possible to characterize the quality of water associated with material behind a 7-ft screen if the water sample actually came from a bracketing 100-ft interval.

Employ Alternative Test Methods. Ideally, a given saturated material would be tested by as many methods as possible and the results compared. For example, injection tests, slug tests, and pumping tests could be conducted in the same well. Testing of the multiscreened R wells has been by a straddle-packer/injection method. Slug and pumping tests between straddle packers should also be performed. However, equipment for such testing was not available for wells discussed in this report. The added expense of applying multiple methods would be minimal as equipment is already at the well site. Costs would also be minimized by employing multiple methods only until the relationship of results is determined.

Tests employing a solid slugger would not only be simpler but would have the advantage of eliminating the need to introduce foreign water. As equipment is not readily available, an assembly must be fabricated to permit such testing between straddle packers. A major design challenge, however, is accommodating a transducer and a solid slugger in the small production casing, without tangling/damaging the transducer cable or compromising the seal provided by the packer.

One possible alternative approach to traditional slug testing in the multiscreened wells would be to add a valve to the straddle-packer/injection assembly currently used that could be tripped from the surface. In this case one would add a known volume of water to the rods above the valve and then trip it for instantaneous delivery to the screened interval, as assumed in slug testing. Another alternative is to use a pulse of air as the “slug.” In these and the solid-slugger cases, analytical methods intended for slug tests would be directly applicable.

Screen-specific pumping tests, in which water is withdrawn from between a pair of packers isolating screens, would also be ideal. Such tests would provide additional hydraulic-property results for comparison with those from straddle-packer/injection or slug tests. For such tests, a pump must (1) fit inside a 4.5-in. production casing, (2) lift water against the heads involved in these deep wells, and (3) discharge at a rate great enough to stress the saturated zones. Where hydrologic data are an objective, larger diameter wells should be installed.

Hydraulic properties can also be evaluated by means of water-level time-series analysis, especially with respect to the response to atmospheric pressure and earth tides (Ritzi et al. 1991, 73645; McLin 2000, 73735). The water levels collected to date by LANL's transducer network are a valuable source of data for such analysis. Results would complement and provide a further check of field-test results.

If funding permits only two-well tests, they could be most economically accomplished by locating selected R wells near existing water-supply wells. In such an arrangement, the supply well could be the pumping well and the R well could be the observation well. The use of a municipal well solves the problem of disposal of produced water: it would go into the supply line. However, the construction of supply wells is not always ideal for hydrologic testing. That is, screens may be long and extend over multiple hydrostratigraphic units.

If no supply well exists where a test is needed or if the construction of existing supply wells is not appropriate, an R well can be installed to be either the pumping well or an observation well. If the R well is completed with a single screen and used as the pumping well, the observation well(s) can be a small-diameter piezometer(s). The piezometer(s) must be constructed so as to be compatible with the pumping well (same unit screened, etc.) or with the test objective.

Repeat Tests When Practical. Conducting more than one test using the same method on the same screen and comparing results is instructive and should be done where feasible. Some repeat tests were made for the wells reported here but not consistently. Retesting should become routine practice, at least until it is shown that results are reproducible. In the case of injection or pumping tests, a second test can be run after water level has returned to the pre-test static position. In the second round of testing, flow rate and duration can be kept the same or changed.

Verify Development With Testing. Hydrologic testing assumes the well has been completely developed. Even if field parameters reach acceptable levels, the two-layer screen (as currently in use), the filter pack or the adjacent formation may not be completely open. A series of tests can be performed to verify that well development has completely removed all drilling fluids or that borehole skin effects do not dominate the flow regime (Butler 1997, 73641). Ideally, at least three tests are employed sequentially: slug withdrawal first, slug injection next, and finally slug withdrawal. The resulting impact on the well is much like surging during well development. Generally, during the final test, the maximum slug-injection head is about twice the initial slug-injection head. This series gives results for flow both into and out of the formation. If these tests replicate one another, then one has high confidence that well development was adequate, and that the reported hydraulic conductivity values represent the undisturbed formation surrounding the well screen.

Even if the exact series of tests described above cannot be performed, repeat tests can tell something about development. For example, if the recovery curve for the initial falling-head test is rough but that for subsequent tests is smooth, one may conclude that the initial injection accomplished some development.

Target Selected Hydrostratigraphic Units. Figure 25 shows that the injection tests reported here have not included the deeper geologic units (Tt, Tsfuv, and Tsf). This can be explained by the fact that the R wells do not usually penetrate these units. Results of recent numerical modeling of the groundwater system beneath the Pajarito Plateau suggest that existing data adequately characterize the hydraulic properties for the Santa Fe Group. Thus, future testing in the deep wells should focus on other units for which aquifer properties are poorly constrained, namely, the Cerros del Rio basalt and the Puye Formation. Hydraulic conductivity data obtained from testing to date vary considerably for both of these units (Stone et al. 2001, 70090).

Testing every screen in every well may not be necessary or economical. As noted above, testing screens straddling the water table is not appropriate. Additionally, if a given unit has been fairly well characterized by previous testing or if several screens are set in the same unit in the well, testing may be limited to selected screens.

SUMMARY AND CONCLUSIONS

The key findings of the tests and conclusions based on them are summarized below.

1. Eleven straddle-packer/injection tests and one pumping test have been conducted at five wells: R-9i, R-13, R-19, R-22, R-31.
2. Although testing by injection between straddle packers is a hybrid method, it was the only one available for the deep, multiscreened wells being installed on the Pajarito Plateau.
3. Four of the eleven injection tests evaluated the Cerros del Rio basalt. K values for the basalt range from 0.04 to 4.87 ft/d. Such a range of values is expected given the variability of porosity and permeability within basalts.
4. Two of the eleven injection tests involved the Puye Formation, pumiceous unit, in the same well (R-19). Results of the tests are very similar: 0.73 and 1.10 ft/d, no doubt a result of similar depositional conditions, and thus similar porosity and permeability, for this unit of the Puye lying behind the two screens tested.
5. Two other tests involve the Totavi Lentil of the Puye Formation, in the same well (R-31). K values determined from these tests are 1.23 ft/d (screen 4) and 0.75 ft/d (screen 5).
6. The remaining three injection tests each targeted a different geologic unit. K for the Puye Formation at R-22, screen 3 = 0.21 ft/d; K for older basalt at R-22, screen 4 = 0.54 ft/d; and K for older fanglomerate at R-22, screen 5 = 0.27 ft/d.
7. Hydraulic properties at R-13 were evaluated by a pumping test. Discharge was too low with the pump available to significantly stress the regional aquifer at R-13 and the test was cut short. For the Puye Formation at R-13, T is at least 829.7 ft^2/d (K = 13.7 ft/d). As the screen straddles the contact between fanglomerate and pumiceous Puye, this is a composite value.
8. Tests characterized by extended periods of injection, analyzed by pumping-test methods, seems the best approach to evaluating hydraulic properties in the multiscreened R wells.
9. In spite of constraints imposed by hydrogeology and well design, hydrologic testing yielded reasonable order-of-magnitude results when compared both with those of previous testing on the Pajarito Plateau and with values commonly reported for similar materials outside the area.
10. Several recommendations should be considered in constructing and testing R wells in which determining hydraulic properties is the major objective.

Although major saturated materials beneath the Pajarito Plateau have been previously tested, especially in the water-supply wells, details of some such tests have not been preserved, and those for others are incomplete or not readily available. Thus, the validity of many of the previous tests cannot be determined. It is hoped that since this document not only presents results of testing at five of the new R wells but also captures and preserves information about the test design, implementation, and analysis needed to evaluate the quality of these results, it will be even more useful to readers.

ACKNOWLEDGEMENTS

Prior to his retirement, William J. Stone conducted the testing program for the wells reported here. He was assisted with testing by Chad Johannsen (S.M. Stoller Corp.) at well R-13, Neal Tapia (RRES-WQH) at well R-19, Paula Schuh (Daniel B. Stephens and Associates) at well R-22, and Richard Koch (SAIC) at well R-31. Personnel of Dynatec Drilling, Inc., supported testing operations at all the wells. Review comments by Roy Bohn (RRES), Ellen Louderbough (Legal), Steve Pearson (RRES), David Rogers (RRES), Dave Schafer (David Schafer & Associates), Kelly Summers (retired groundwater scientist), as well as Tom Whitacre and Bob Enz (both DOE) are gratefully acknowledged.

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, 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, 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)

Ball, T., M. Everett, P. Longmire, D. Vaniman, W. Stone, D. Larssen, K. Greene, N. Clayton, and S. McLin, February 2001. "Characterization Well R-22 Completion Report," Los Alamos National Laboratory report LA-13893-MS, Los Alamos, New Mexico. (Ball et al. 2001, 71471)

Bouwer, H., and R. C. Rice, 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," *Water Resources Research*, Vol. 12, pp. 423-428. (Bouwer and Rice 1976, 64056)

Broxton, D., R. Gilkeson, P. Longmire, J. Marin, R. Warren, D. Vaniman, A Crowder, B. Newman, B. Lowry, D. Rogers, W. Stone, S. McLin, G. WoldeGabriel, D. Daymon, and D. Wycoff, May 2001. "Characterization Well R-9 Completion Report," Los Alamos National Laboratory report LA-13742-MS, Los Alamos, New Mexico. (Broxton et al. 2001, 66599)

Broxton, D., D. Vaniman, W. Stone, S. McLin, M. Everett and A. Crowder, September 2000. "Characterization Well R-9i Completion Report," Los Alamos National Laboratory report LA-13821-MS, Los Alamos, New Mexico. (Broxton et al. 2001, 66600)

Broxton, D., D. Vaniman, W. Stone, S. McLin, J. Marin, R. Koch, R. Warren, P. Longmire, D. Rogers, and N. Tapia, May 2001. "Characterization Well R-19 Completion Report," Los Alamos National Laboratory report LA-13823-MS, Los Alamos, New Mexico. (Broxton et al. 2001, 71253)

Butler, J.J., 1997. *The Design, Performance, and Analysis of Slug Tests*, Lewis Publishers, New York. (Butler 1997, 73641)

Driscoll, F.G., 1986. *Groundwater and Wells*, Johnson Division, St. Paul, Minnesota. (Driscoll 1986, 70111)

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

Fetter, C. W., 1994. *Applied Hydrogeology*, 3rd edition, Prentice Hall, Upper Saddle River, New Jersey. (Fetter 1994, 70942)

Freeze, R. A. and J. A. Cherry, 1979. *Groundwater*, Prentice Hall, Englewood Cliffs, New Jersey. (Freeze and Cherry 1979, 64057)

Kruseman, G. P. and N. A. de Ridder, 2000. *Analysis and Evaluation of Pumping Test Data*, International Institute for Land Reclamation and Improvement, Publication 47, Wageningen, The Netherlands. (Kruseman and de Ridder 2000, 70110)

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

LANL (Los Alamos National Laboratory), June 2003. “Characterization Well R-13 Completion Report,” Los Alamos National Laboratory document LA-UR-03-1373, Los Alamos, New Mexico. (LANL 2003, 76060)

McLin, S.G., April 2000. “Estimating Hydraulic Parameters from Water-Level Fluctuations (abstract),” New Mexico Geological Society, Proceedings of Annual Spring Meeting, Socorro, New Mexico. (McLin 2000, 73735)

McLin, S.G., 2004. “Estimating Aquifer Transmissivity from Specific Capacity Using Matlab” *Ground Water*, in press. **(**McLin 2004, 82834**)**

Ritzi, R.W., P.A. Hsieh, and S. Sorooshian, 1991. “The Estimation of Fluid Flow Properties from the Response of Water Levels in Wells to the Combined Atmospheric and Earth Tide Forces,” *Water Resources Research*, Vol. 27, No. 5, pp. 883-893. (Ritzi et al. 1991, 73645)

Schafer, D., January 1978. “Casing Storage Can Affect Pumping Test Data,” article excerpt, *Johnson Drillers Journal*, (Schafer 1978, 73449)

Stone, W., G. Cole, W. Carey, and M. Jones, 2001. “Expanded Hydrogeologic Atlas for Los Alamos National Laboratory,” Los Alamos National Laboratory document LA-UR-01-70, Los Alamos, New Mexico. (Stone et al. 2001, 69830)

Stone, W., S. McLin, and D. Vaniman, April 2001. “Hydraulic Conductivity vs Geology in New Los Alamos Wells” (abstract), New Mexico Geological Society, Proceedings of Annual Spring Meeting, Socorro, New Mexico. (Stone et al. 2001, 70090)

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. 519–52. (Theis 1935, 70102)

Vaniman, D., J. Marin, W. Stone, B. Newman, P. Longmire, N. Clayton, R. Lewis, R. Koch, S. McLin, G. WoldeGabriel, D. Counce, R. Rogers, R. Warren, E. Kluk, S. Chipera, D. Larssen, and W. Kopp, March 2002. “Characterization Well R-31 Completion Report,” Los Alamos National Laboratory report, LA-13910-MS, Los Alamos, New Mexico. (Vaniman et al. 2001, 72615)

Appendix A

MATLAB^{TM} Script File for Specific-Capacity Analysis

APPENDIX A. MATLAB™ SCRIPT FILE FOR SPECIFIC-CAPACITY ANALYSIS

The following computer note was accepted for publication in *Ground Water* on 5 December 2003.

Estimating Aquifer Transmissivity from Specific Capacity Using Matlab

Stephen G. McLin

Los Alamos National Laboratory, PO Box 1663 MS-K497, Los Alamos, NM 87544, U.S.A; sgm@lanl.gov

Abstract

Historically, specific capacity information has been used to calculate aquifer transmissivity when pumping test data are unavailable. This paper presents a simple computer program written in the Matlab programming language that estimates transmissivity from specific capacity data while correcting for aquifer partial penetration and well efficiency. The program graphically plots transmissivity as a function of these factors so that the user can visually estimate their relative importance in a particular application. The program is compatible with any computer operating system running Matlab, including Windows, Macintosh OS, Linux, and Unix. Two simple examples illustrate program usage.

INTRODUCTION

A computer technique for estimating transmissivity from specific capacity data is currently available (Bradbury and Rothschild 1985). However, it is written in Basic and does not graphically display results. This paper presents a modified version of the Bradbury-Rothschild iterative solution technique that is written in the Matlab language and listed in the Appendix. A useful new feature includes a 3-D graphical display of results so that the user can quickly estimate the relative importance of aquifer penetration and well efficiency. Potential users should be aware that Matlab must be installed on their computers before the program will function. Alternately, users may convert either the original or revised code to any convenient programming language (e.g., C++, Fortran, Excel, or MathCad). However, Matlab is a powerful tool with numerous capabilities that are not readily found in other languages.

Recall that total drawdown (s_t) observed in a production well can be written (Bouwer 1978) as the sum of drawdown due to formation loss (s_f) and drawdown due to well loss (s_w), or:

$$s_t = s_f + s_w = BQ + CQ^n \quad (1)$$

where $B =$ formation loss coefficient (T/L^2),

$C =$ well loss coefficient (T^2/L^5 if n = 2),

$Q =$ well discharge (L^3/T), and

$n =$ an exponent related to wellbore turbulence (typically $1.5 \le n \le 3.5$).

When well efficiency (E) is defined as $E = 100\, s_f/s_t$ and n = 2, then C is related to E by:

$$C = \left(\frac{s_t}{Q^2}\right)\left(1 - \frac{E}{100}\right) \quad (2)$$

When s_f is given by the Jacob approximation for the Theis solution, then *B* can be found from (Sternberg 1973):

$$s_f = BQ = \frac{Q}{4\pi T}\left[\ln\left(\frac{2.25Tt}{r_w^2 S}\right) + 2s_p\right] \tag{3}$$

where T = aquifer transmissivity (L^2/T),

S = aquifer storage coefficient (dimensionless),

t = time since pumping began (T),

r_w = effective wellbore radius (L), and

s_p = a partial penetration factor (dimensionless).

In (3), the effect of partial penetration may be represented by (Brons and Marting 1961):

$$s_p = \left(\frac{D-L}{L}\right)\left[\ln\left(\frac{D}{r_w}\right) - G\left\{\frac{L}{D}\right\}\right] \tag{4}$$

where D = aquifer thickness (L),

L = well screen length (L), and

G = a function of the L/D ratio (dimensionless).

Using available data, Bradbury and Rothschild (1985) expressed *G* as the polynomial $G = a + b(L/D) + c(L/D)^2 + d(L/D)^3$, where the fitting coefficients were *a* = 2.948, *b* = -7.363, *c* = 11.447, and *d* = -4.675. Substituting (1) into (3) yields:

$$T = \frac{Q}{4\pi(s_t - s_w)}\left[\ln\left(\frac{2.25Tt}{r_w^2 S}\right) + 2s_p\right] \tag{5}$$

Well efficiency is embedded in (5) since $s_w = CQ^2$, and *C* is defined by (2). Hence, a step drawdown test is not required if *E* can be estimated. In addition, the effect of partial penetration is represented by (4) using the Bradbury-Rothschild polynomial for *G*. In (5), *T* appears on both sides of the equation; hence, an iterative solution is required (Bradbury and Rothschild 1985). Initially, a guess is made for *T* (Tguess in the program) on the right-hand side of (5) and an updated solution for *T* (Tcalc in the program) is obtained from the left-hand side. This updated solution is again used on the right-hand side of (5) and a new *T* is again computed. This iterative process continues until some suitable tolerance criterion for error (Err in the program) is reached. For the Matlab program shown in the Appendix, either metric or customary U.S. units may be employed.

PROGRAM USAGE

The program is executed from the Matlab command line by typing in the m-file program name (i.e., [A, T]=TQs). The user is prompted to select a system of units and then enter input values for *Q*, s_t, *t*, *L*, r_w, *S*, *D* (optional), and *C* (optional). Walton (1970) showed that *T* is relatively insensitive to variations in *S*; hence this value may be estimated. Tabulated and graphed output consists of a range of *T* values that correspond to a range of expected well efficiencies and aquifer penetration values. The two original examples shown in Bradbury and Rothschild (1985) are used as illustrations. Input data for these tests are summarized in Table 1. The Matlab program is executed once for each test and the user is prompted to enter appropriate data from Table 1. Properties for well 1 (metric) were used in the Matlab program to generate Figure 1. A similar figure can be generated with well 2 data. Figure 1 is a graphical representation of the tabulated output for well 1. Output for well 2 was omitted because it is similar to Figure 1. If known values for *D* and *C* are entered, then single best estimates for *T* and *E* are also obtained. Using well 1 metric units from Table 1, we find T = 46.6 m^2/day at E = 99.9% and L/D = 23%; for well 2, T = 36.2 m^2/day at E = 99.9% and L/D = 59%. Bradbury and Rothschild originally reported *T* values of 47.6 and 36.7 m^2/day for wells 1 and 2, respectively. Well efficiencies were determined from (2) using their *C* value.

Table 1.

Parameter (units)	Well 1 (m)	Well 1 (US)	Well 2 (m)	Well 2 (US)
Q (lpm or gpm)	37.853	10	37.853	10
s_t (m or ft)	4.572	15	2.743	9
t (min)	480	480	480	480
L (m or ft)	14.326	47	20.726	68
r_w (cm or in)	7.62	3	7.62	3
S (dimensionless)	0.0002	0.0002	0.0002	0.0002
D (m or ft)	62.484	205	35.052	115
C (min^2/m^5 or sec^2/ft^5)	3.453	32.7	3.453	32.7

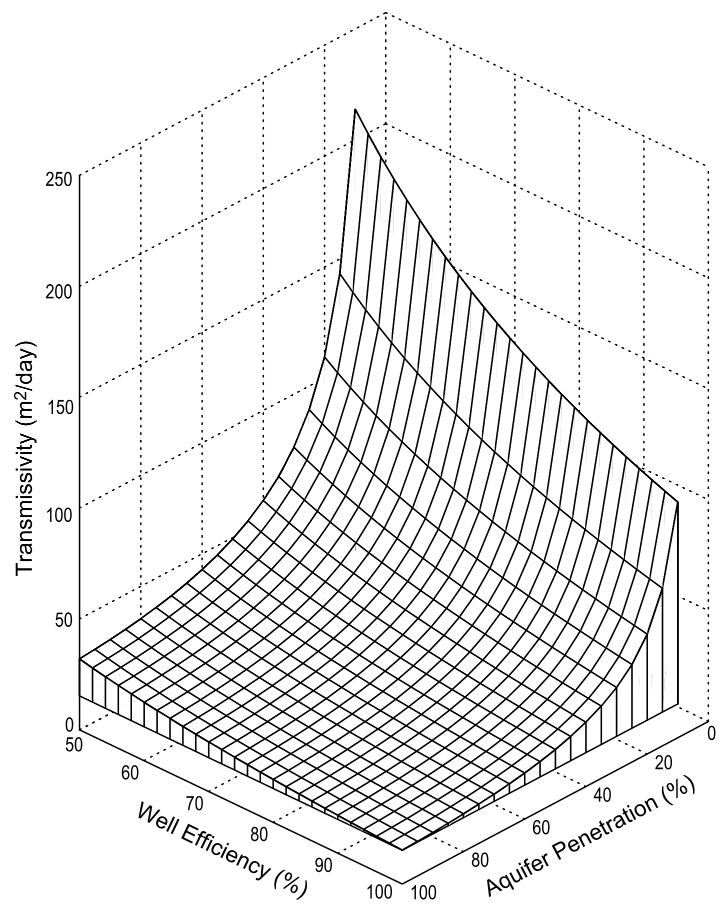


Figure A-1. Graphical representation of the tabulated output for well 1

One may question the choice of having partial penetration as a variable in Figure 1 since a single value for this parameter should be known from the driller's log. However, we often have difficulty actually deciding where aquifer boundaries are located. This is especially true in horizontally stratified aquifers where vertical changes in hydraulic conductivity may not be obvious. In addition, step-drawdown tests that determine *C* are the exception rather than the rule, especially in monitoring well applications. This program simply provides a range of estimated *T* values that can assist us in overcoming these difficulties. As seen above, we can narrow the range of possible *T* values to a single best estimate if we know partial penetration and well efficiency. Alternately, we may determine partial penetration from Figure 1 if we have independent estimates for *T* and *E*. The real value of this exercise, however, may be the recognition of uncertainty in the estimation process.

CONCLUSIONS

Specific capacity data are often used in hydrogeological studies to estimate *T*. The major criticism of this method is that it assumes a quasi-steady state condition has been established. This is in contrast to a conventional aquifer test where transient *s* and *t* values are matched to an appropriate theoretical type-curve. However, the Matlab program presented here is really a parameter sensitivity analysis because it translates specific capacity into a range of *T* values that reflect the combined influence of the formation, aquifer penetration, and well efficiency. This type of analysis simply gives us another way to determine *T*. These *T* estimates can be valuable in those situations where conventional aquifer tests are unavailable.

ACKNOWLEDGEMENTS

This work was supported by the Groundwater Protection Program at Los Alamos National Laboratory (LANL). LANL is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. Special thanks are extended to David Schafer for fruitful discussions during this effort. Review comments by Ken Bradbury and Mary Anderson are especially appreciated. The LANL document number for this computer note is LA-UR-03-6116.

REFERENCES

Bouwer, H. 1978. *Groundwater Hydrology*. New York, McGraw-Hill.

Bradbury, K.R., and E.R. Rothschild. 1985. A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data. *Ground Water* 23, no. 2: 240-246.

Brons, F., and V.E. Marting. 1961. The effect of restricted fluid entry on well productivity. *Journal of Petroleum Technology* 13, no. 2: 172-174.

Sternberg, Y.M. 1973. "Efficiency of partially penetrating wells," *Ground Water* 11, no. 3: 5-7, New York, McGraw-Hill.

Walton, W.C. 1970. *Groundwater Resource Evaluation*, New York, McGraw-Hill.

APPENDIX

```
function [A, T]=TQs
%TQs  computes Transmissivity (T) from Specific Capacity (Q/s) data.
%
%       This m-file was written in the Matlab language by:
%       Stephen G. McLin, 8 May 2003, e-mail: sgm@lanl.gov
%
%       A = a matrix of T values as a function of R and E.
%       Note that R is the last row of A and E is the last column of A
%       T = transmissivity (sq m/day or sq ft/day).
%       Q = well pump rate (lps or gpm).
%       s = wellbore drawdown (m or ft).
%       t = time (minutes).
%       D = aquifer thickness (m or ft).
%       L = well screen length (m or ft).
%       R = L/D (dimensionless penetration).
%       r = wellbore radius (cm or in).
%       S = aquifer storage coefficient (or specific yield).
%       E = well efficiency (%).
%       C = well loss coefficient (min^2/m^5 or sec^2/ft^5).
%
format short e;
Units=input('Enter 1 for metric units and 2 for US units.......');
if Units==1
   Q=input('Enter Q (lpm) now.......'); conv=1000;
   s=input('Enter drawdown (m) now.......');
   t=input('Enter time (minutes) now.......');
   L=input('Enter well screen length (m) now.......');
   r=input('Enter wellbore radius (cm) now.......'); r=r/100;
   S=input('Enter storage coefficient S now.......');
   Do=input('Enter observed aquifer thickness (m) now (enter 1 if unknown).......');
   Co=input('Enter step-test C (min^2/m^5) now (enter 1 if unknown).......');
   if Co~=1; Co=Co*3600; end; str='Transmissivity (sq m/day)';
elseif Units==2
   Q=input('Enter Q (gpm) now.......'); conv=7.48;
   s=input('Enter drawdown (ft) now.......');
   t=input('Enter time (minutes) now.......');
   L=input('Enter well screen length (ft) now.......');
   r=input('Enter wellbore radius (in) now.......'); r=r/12;
   S=input('Enter storage coefficient S now.......');
   Do=input('Enter observed aquifer thickness (ft) now (enter 1 if unknown).......');
   Co=input('Enter step-test C (sec^2/ft^5) now (enter 1 if unknown).......');
   str='Transmissivity (sq ft/day)';
else
   error('You have entered an incorrect response.   Please start again.');
end
E=[50:2:100]'; [n1,m1]=size(E);
R=[0.1:0.05:1.0]'; [n2,m2]=size(R); D=L./R;
```

```
A=zeros(n1+1,n2+1); err=0.000001; Tguess=1.0;
a=2.948; b=-7.363; c=11.447; d=-4.675;
C=(1-E./100).*(s/Q^2); sw=C.*Q^2;
G=(a+b*(L./D)+c*(L./D).^2+d*(L./D).^3);
sp=((D-L)./L.*(log(D./r)-G));
for j=1:n2; for i=1:n1;
   Tcalc(i,j)=1440*Q*(log(2.25*Tguess*t/(1440*r^2*S))+2*sp(j))/(4*conv*pi*(s-sw(i)));
   diff=abs(Tcalc(i,j)-Tguess); test=diff;
   while test>err
      Tcalc(i,j)=1440*Q*(log(2.25*Tguess*t/(1440*r^2*S))+2*sp(j))/(4*conv*pi*(s-sw(i)));
      diff=abs(Tcalc(i,j)-Tguess); Tguess=Tcalc(i,j); test=diff;
   end; A(i,j)=Tcalc(i,j);
end; end
A(1:n1,(n2+1))=E; A((n1+1),1:n2)=100.*R';
z=A(1:n1,1:n2); x=100.*R; y=E; h=figure;
set(h,'PaperPosition',[0.25,0.25,8.00,10.50]);
meshz(x,y,z); zlabel(str);
ylabel('Well Efficiency (%)'); xlabel('Aquifer Penetration (%)');
if Do==1; T=1; return;
elseif Co==1; T=1; return;
else
fac=60*60*conv*conv; Tguess=1.0;
Eo=100*(1-Co*Q^2/(s*fac)); swo=Co*Q^2/fac;
Go=a+b*(L/Do)+c*(L/Do)^2+d*(L/Do)^3;
spo=(Do-L)/L*(log(Do/r)-Go);
Tcalco=1440*Q*(log(2.25*Tguess*t/(1440*r^2*S))+2*spo)/(4*conv*pi*(s-swo));
   diff=abs(Tcalco-Tguess); test=diff;
   while test>err
      Tcalco=1440*Q*(log(2.25*Tguess*t/(1440*r^2*S))+2*spo)/(4*conv*pi*(s-swo));
      diff=abs(Tcalc-Tguess); Tguess=Tcalco; test=diff;
   end; T=[Tcalco Eo L*100/Do]; end;
% Tcalco = best single estimate for transmissivity;
% Eo = well efficiency; 100L/Do = aquifer penetration;
```

Appendix B

Well R-9i Test Data

APPENDIX B. WELL R-9i TEST DATA

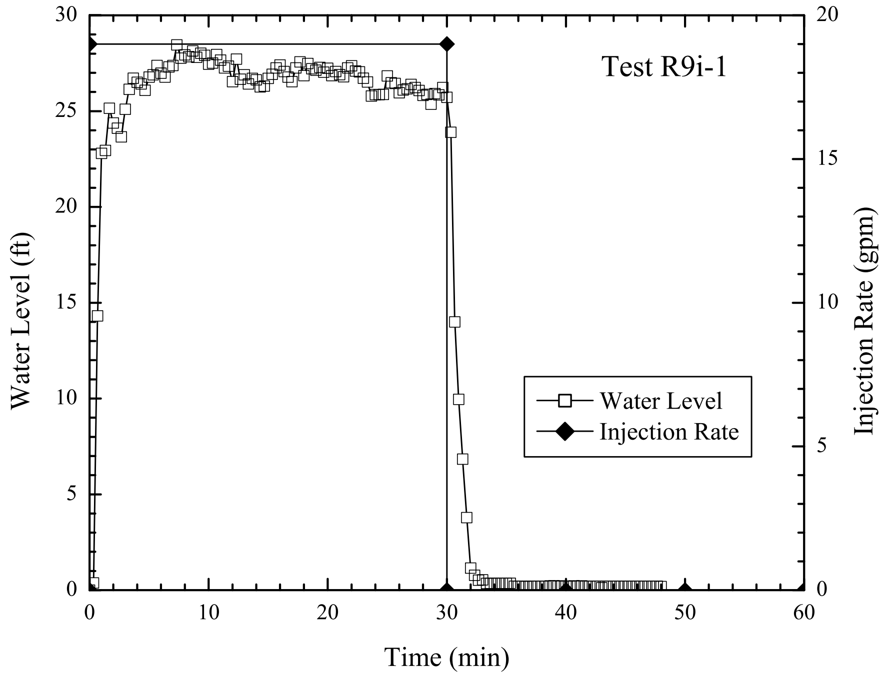


Figure B-1. Injection test R9i-1

B-2
Data for Injection Test R9i-1

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.000	19.00
0.333	0.375	19.00
0.667	14.313	19.00
1.000	22.795	19.00
1.333	22.953	19.00
1.667	25.145	19.00
2.000	24.386	19.00
2.333	24.113	19.00
2.667	23.655	19.00
3.000	25.102	19.00
3.333	26.134	19.00
3.667	26.722	19.00
4.000	26.507	19.00
4.333	26.421	19.00
4.667	26.091	19.00
5.000	26.779	19.00
5.333	26.894	19.00
5.667	27.381	19.00
6.000	26.980	19.00
6.333	26.779	19.00
6.667	27.309	19.00
7.000	27.381	19.00
7.333	28.456	19.00
7.667	27.768	19.00
8.000	27.940	19.00
8.333	27.840	19.00
8.667	28.140	19.00
9.000	27.811	19.00
9.333	28.026	19.00
9.667	27.911	19.00
10.000	27.453	19.00
10.333	27.510	19.00
10.667	27.954	19.00
11.000	27.668	19.00
11.333	27.252	19.00
11.667	27.352	19.00
12.000	26.535	19.00
12.333	27.711	19.00
12.667	26.664	19.00
13.000	26.894	19.00
13.333	26.421	19.00
13.667	26.707	19.00
14.000	26.636	19.00
14.333	26.263	19.00
14.667	26.306	19.00
15.000	26.707	19.00
15.333	26.922	19.00
15.667	27.252	19.00
16.000	27.410	19.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
16.333	27.066	19.00
16.667	26.779	19.00
17.000	26.535	19.00
17.333	27.252	19.00
17.667	27.567	19.00
18.000	26.851	19.00
18.333	27.481	19.00
18.667	27.209	19.00
19.000	27.137	19.00
19.333	27.281	19.00
19.667	27.037	19.00
20.000	27.238	19.00
20.333	26.851	19.00
20.667	27.066	19.00
21.000	26.908	19.00
21.333	26.793	19.00
21.667	27.252	19.00
22.000	27.367	19.00
22.333	27.094	19.00
22.667	27.051	19.00
23.000	26.722	19.00
23.333	26.521	19.00
23.667	25.790	19.00
24.000	25.862	19.00
24.333	25.862	19.00
24.667	25.876	19.00
25.000	26.836	19.00
25.333	26.478	19.00
25.667	26.449	19.00
26.000	25.962	19.00
26.333	26.105	19.00
26.667	26.163	19.00
27.000	26.392	19.00
27.333	26.234	19.00
27.667	26.077	19.00
28.000	25.819	19.00
28.333	25.876	19.00
28.667	25.360	19.00
29.000	25.919	19.00
29.333	25.847	19.00
29.667	26.234	19.00
30.000	25.718	19.00
30.333	23.898	0.00
30.667	13.997	0.00
31.000	9.957	0.00
31.333	6.835	0.00
31.667	3.784	0.00
32.000	1.148	0.00
32.333	0.776	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
32.667	0.518	0.00
33.000	0.533	0.00
33.333	0.346	0.00
33.667	0.346	0.00
34.000	0.346	0.00
34.333	0.361	0.00
34.667	0.361	0.00
35.000	0.361	0.00
35.333	0.361	0.00
35.667	0.203	0.00
36.000	0.203	0.00
36.333	0.203	0.00
36.667	0.189	0.00
37.000	0.203	0.00
37.333	0.203	0.00
37.667	0.203	0.00
38.000	0.203	0.00
38.333	0.203	0.00
38.667	0.218	0.00
39.000	0.218	0.00
39.333	0.203	0.00
39.667	0.218	0.00
40.000	0.203	0.00
40.333	0.203	0.00
40.667	0.218	0.00
41.000	0.203	0.00
41.333	0.218	0.00
41.667	0.203	0.00
42.000	0.203	0.00
42.333	0.203	0.00
42.667	0.203	0.00
43.000	0.132	0.00
43.333	0.203	0.00
43.667	0.203	0.00
44.000	0.203	0.00
44.333	0.203	0.00
44.667	0.203	0.00
45.000	0.203	0.00
45.333	0.203	0.00
45.667	0.203	0.00
46.000	0.203	0.00
46.333	0.203	0.00
46.667	0.203	0.00
47.000	0.203	0.00
47.333	0.203	0.00
47.667	0.203	0.00
48.000	0.189	0.00

B-3
Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration from Specific Capacity for Injection Test R-9i-1[a]

Well Eff (%)	Aquifer Penetration (%)																		
	10	**12.5**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	3811	3035	1958	1612	1383	1220	1097	1001	925	864	815	776	744	719	700	685	674	666	661
25	3039	2418	1556	1279	1096	965	867	790	729	681	641	610	584	564	549	537	528	522	518
30	2525	2008	1289	1059	906	797	715	651	600	560	527	501	480	463	450	440	433	428	424
35	2160	1716	1100	902	771	678	608	553	509	475	446	424	406	391	380	372	365	361	358
40	1886	1498	959	786	671	589	528	480	442	411	387	367	351	338	328	321	316	312	309
45	1673	1328	849	695	593	521	466	423	389	362	340	323	309	297	289	282	277	274	272
50	1503	1193	762	623	532	466	417	378	348	323	304	288	275	265	257	251	247	244	242
55	1365	1082	690	565	481	422	377	342	314	292	274	260	248	239	232	226	222	219	218
60	1249	991	631	516	439	385	344	312	286	266	249	236	226	217	211	206	202	199	198
65	1152	913	581	475	404	354	316	286	263	244	229	216	207	199	193	188	185	183	181
70	1068	846	538	439	374	327	292	264	243	225	211	200	191	183	178	174	170	168	167
75	996	789	501	409	348	304	271	246	225	209	196	185	177	170	165	161	158	156	154
80	933	739	469	383	325	284	253	229	210	195	183	173	165	158	153	150	147	145	144
85	877	694	441	359	305	267	238	215	197	183	171	162	154	148	144	140	137	136	134
90	828	655	416	339	288	251	224	202	185	172	161	152	145	139	135	131	129	127	126
95	784	620	393	320	272	237	211	191	175	162	152	143	136	131	127	124	122	120	119
100	744	**588**[b]	373	303	258	225	200	181	166	153	143	135	129	124	120	117	115	113	112

[a] Input data: Q = 19.0 gpm; s = 25.72 ft at t = 30 min; screen length = 10.4 ft; dw = 12.25 in; S = 0.001; aquifer thickness = 83.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 12.5%, T = 588.4 ft^2/day.

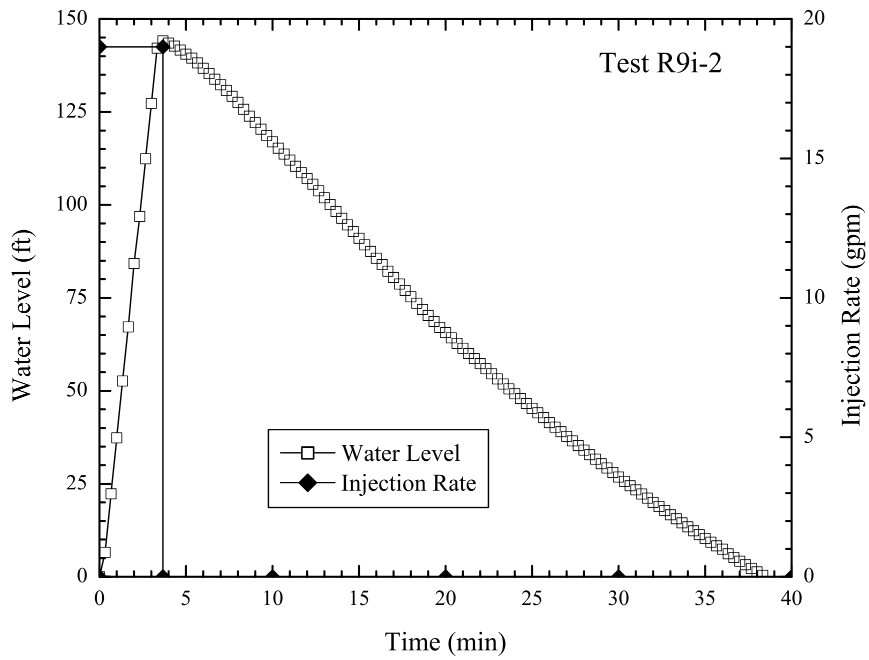


Figure 4. Injection test R9i-2

B-5
Data for Injection Test R9i-2

Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)
0.330	144.130	8.000	110.380	15.670	70.290	23.330	39.010
0.670	143.530	8.330	108.640	16.000	68.650	23.670	37.780
1.000	142.730	8.670	107.090	16.330	67.090	24.000	36.520
1.330	141.650	9.000	105.570	16.670	65.640	24.330	35.300
1.670	140.550	9.330	103.810	17.000	64.220	24.670	34.070
2.000	139.460	9.670	101.940	17.330	62.800	25.000	32.830
2.330	138.210	10.000	100.100	17.670	61.450	25.330	31.630
2.670	136.760	10.330	98.260	18.000	60.030	25.670	30.410
3.000	135.340	10.670	96.430	18.330	58.670	26.000	29.220
3.330	133.810	11.000	94.620	18.670	57.290	26.330	28.050
3.670	132.290	11.330	92.820	19.000	55.920	26.670	26.830
4.000	130.780	11.670	91.060	19.330	54.540	27.000	25.660
4.330	129.220	12.000	89.280	19.670	53.180	27.330	24.480
4.670	127.590	12.330	87.500	20.000	51.830	27.670	23.360
5.000	125.700	12.670	85.690	20.330	50.500	28.000	22.260
5.330	123.870	13.000	83.950	20.670	49.180	28.330	21.130
5.670	122.100	13.330	82.200	21.000	47.930	28.670	20.010
6.000	120.370	13.670	80.480	21.330	46.610	29.000	18.910
6.330	118.610	14.000	78.740	21.670	45.320	29.330	17.820
6.670	116.950	14.330	77.020	22.000	44.060	29.670	16.660
7.000	115.280	14.670	75.270	22.330	42.800	30.000	15.580
7.330	113.700	15.000	73.590	22.670	41.450	30.330	14.490
7.670	112.060	15.330	71.910	23.000	40.250	30.670	13.420

Data for Injection Test R9i-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)
31.000	12.340
31.330	11.330
31.670	10.330
32.000	9.310

Elapsed Time (min)	Change in Water Level (ft)
32.330	8.290
32.670	7.430
33.000	6.170

Elapsed Time (min)	Change in Water Level (ft)
33.330	5.180
33.670	4.180
34.000	3.220

Elapsed Time (min)	Change in Water Level (ft)
34.330	2.250
34.670	1.300
35.000	0.400

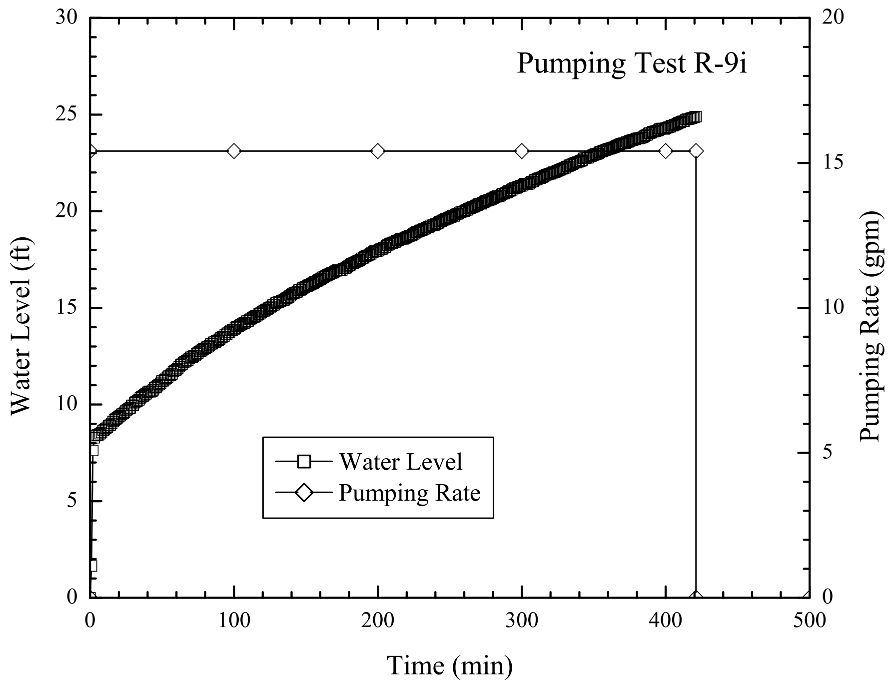


Figure B-6. Pumping test R-9i

Table B-7
Data for Pumping Test R-9i

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
0	0.000	15.4
1	1.643	15.4
2	7.619	15.4
3	8.278	15.4
4	8.392	15.4
5	8.421	15.4
6	8.435	15.4
7	8.493	15.4
8	8.550	15.4
9	8.665	15.4
10	8.693	15.4
11	8.765	15.4
12	8.822	15.4
13	8.908	15.4
14	8.937	15.4
15	9.023	15.4
16	9.123	15.4
17	9.195	15.4
18	9.252	15.4
19	9.309	15.4
20	9.367	15.4
21	9.424	15.4
22	9.496	15.4
23	9.539	15.4
24	9.596	15.4
25	9.682	15.4
26	9.739	15.4
27	9.797	15.4
28	9.825	15.4
29	9.954	15.4
30	9.954	15.4
31	10.098	15.4
32	10.141	15.4
33	10.184	15.4
34	10.241	15.4
35	10.341	15.4
36	10.398	15.4
37	10.441	15.4
38	10.499	15.4
39	10.556	15.4
40	10.628	15.4
41	10.685	15.4
42	10.656	15.4
43	10.685	15.4
44	10.757	15.4
45	10.871	15.4
46	10.900	15.4
47	10.972	15.4
48	11.029	15.4
49	11.101	15.4
50	11.215	15.4
51	11.229	15.4
52	11.287	15.4
53	11.358	15.4
54	11.416	15.4
55	11.502	15.4
56	11.516	15.4

Data for Pumping Test R-9i (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
57	11.573	15.4	99	13.851	15.4	141	15.743	15.4
58	11.702	15.4	100	13.880	15.4	142	15.771	15.4
59	11.760	15.4	101	13.952	15.4	143	15.800	15.4
60	11.803	15.4	102	14.023	15.4	144	15.828	15.4
61	11.860	15.4	103	14.038	15.4	145	15.914	15.4
62	11.960	15.4	104	14.095	15.4	146	15.929	15.4
63	12.046	15.4	105	14.138	15.4	147	15.957	15.4
64	12.089	15.4	106	14.181	15.4	148	16.029	15.4
65	12.175	15.4	107	14.210	15.4	149	16.058	15.4
66	12.204	15.4	108	14.238	15.4	150	16.101	15.4
67	12.261	15.4	109	14.310	15.4	151	16.129	15.4
68	12.290	15.4	110	14.324	15.4	152	16.172	15.4
69	12.376	15.4	111	14.396	15.4	153	16.201	15.4
70	12.447	15.4	112	14.453	15.4	154	16.244	15.4
71	12.447	15.4	113	14.496	15.4	155	16.287	15.4
72	12.505	15.4	114	14.525	15.4	156	16.330	15.4
73	12.533	15.4	115	14.582	15.4	157	16.359	15.4
74	12.619	15.4	116	14.596	15.4	158	16.402	15.4
75	12.662	15.4	117	14.668	15.4	159	16.444	15.4
76	12.734	15.4	118	14.697	15.4	160	16.487	15.4
77	12.763	15.4	119	14.754	15.4	161	16.530	15.4
78	12.834	15.4	120	14.811	15.4	162	16.588	15.4
79	12.877	15.4	121	14.840	15.4	163	16.616	15.4
80	12.906	15.4	122	14.897	15.4	164	16.659	15.4
81	12.963	15.4	123	14.926	15.4	165	16.702	15.4
82	12.992	15.4	124	14.983	15.4	166	16.731	15.4
83	13.049	15.4	125	15.012	15.4	167	16.774	15.4
84	13.135	15.4	126	15.069	15.4	168	16.803	15.4
85	13.149	15.4	127	15.141	15.4	169	16.817	15.4
86	13.221	15.4	128	15.155	15.4	170	16.874	15.4
87	13.235	15.4	129	15.241	15.4	171	16.917	15.4
88	13.293	15.4	130	15.284	15.4	172	16.960	15.4
89	13.321	15.4	131	15.298	15.4	173	16.946	15.4
90	13.379	15.4	132	15.327	15.4	174	16.932	15.4
91	13.450	15.4	133	15.370	15.4	175	16.960	15.4
92	13.493	15.4	134	15.384	15.4	176	17.032	15.4
93	13.522	15.4	135	15.413	15.4	177	17.032	15.4
94	13.622	15.4	136	15.470	15.4	178	17.075	15.4
95	13.637	15.4	137	15.513	15.4	179	17.132	15.4
96	13.722	15.4	138	15.556	15.4	180	17.189	15.4
97	13.751	15.4	139	15.628	15.4	181	17.232	15.4
98	13.837	15.4	140	15.685	15.4	182	17.290	15.4

Data for Pumping Test R-9i (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
183	17.318	15.4	230	19.023	15.4	273	20.441	15.4
184	17.347	15.4	231	19.037	15.4	274	20.484	15.4
185	17.390	15.4	232	19.080	15.4	275	20.527	15.4
186	17.419	15.4	233	19.095	15.4	276	20.556	15.4
187	17.462	15.4	234	19.152	15.4	277	20.570	15.4
188	17.505	15.4	235	19.181	15.4	278	20.599	15.4
189	17.562	15.4	236	19.209	15.4	279	20.627	15.4
190	17.591	15.4	237	19.267	15.4	280	20.670	15.4
191	17.648	15.4	238	19.267	15.4	281	20.713	15.4
192	17.691	15.4	239	19.281	15.4	282	20.742	15.4
193	17.705	15.4	240	19.338	15.4	283	20.785	15.4
194	17.748	15.4	241	19.353	15.4	284	20.771	15.4
199	17.934	15.4	242	19.396	15.4	285	20.814	15.4
200	17.949	15.4	243	19.453	15.4	286	20.871	15.4
201	18.006	15.4	244	19.481	15.4	287	20.900	15.4
202	18.035	15.4	245	19.524	15.4	288	20.914	15.4
203	18.049	15.4	246	19.553	15.4	289	20.957	15.4
204	18.106	15.4	247	19.596	15.4	290	20.986	15.4
205	18.135	15.4	248	19.610	15.4	291	21.043	15.4
206	18.221	15.4	249	19.653	15.4	292	21.057	15.4
207	18.250	15.4	250	19.682	15.4	293	21.100	15.4
208	18.307	15.4	251	19.711	15.4	294	21.172	15.4
209	18.335	15.4	252	19.782	15.4	295	21.200	15.4
210	18.350	15.4	253	19.754	15.4	296	21.200	15.4
211	18.393	15.4	254	19.825	15.4	297	21.243	15.4
212	18.407	15.4	255	19.854	15.4	298	21.272	15.4
213	18.464	15.4	256	19.883	15.4	299	21.315	15.4
214	18.493	15.4	257	19.940	15.4	300	21.315	15.4
215	18.536	15.4	258	19.969	15.4	301	21.372	15.4
216	18.579	15.4	259	19.983	15.4	302	21.430	15.4
217	18.579	15.4	260	19.997	15.4	303	21.430	15.4
218	18.565	15.4	261	20.040	15.4	304	21.401	15.4
219	18.622	15.4	262	20.069	15.4	305	21.415	15.4
220	18.651	15.4	263	20.126	15.4	306	21.487	15.4
221	18.694	15.4	264	20.155	15.4	307	21.530	15.4
222	18.722	15.4	265	20.198	15.4	308	21.544	15.4
223	18.737	15.4	266	20.212	15.4	309	21.616	15.4
224	18.780	15.4	267	20.241	15.4	310	21.644	15.4
225	18.823	15.4	268	20.284	15.4	311	21.673	15.4
226	18.880	15.4	269	20.312	15.4	312	21.716	15.4
227	18.923	15.4	270	20.370	15.4	313	21.716	15.4
228	18.951	15.4	271	20.398	15.4	314	21.759	15.4
229	18.980	15.4	272	20.384	15.4	315	21.788	15.4

Data for Pumping Test R-9i (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
316	21.831	15.4
317	21.888	15.4
318	21.902	15.4
319	21.931	15.4
320	21.931	15.4
321	21.974	15.4
322	22.017	15.4
323	22.017	15.4
324	22.060	15.4
325	22.089	15.4
326	22.131	15.4
327	22.146	15.4
328	22.189	15.4
329	22.217	15.4
330	22.246	15.4
331	22.303	15.4
332	22.318	15.4
333	22.375	15.4
334	22.389	15.4
335	22.432	15.4
336	22.461	15.4
337	22.518	15.4
338	22.518	15.4
339	22.547	15.4
340	22.576	15.4
341	22.604	15.4
342	22.647	15.4
343	22.733	15.4
344	22.747	15.4
345	22.762	15.4
346	22.762	15.4
347	22.833	15.4
348	22.848	15.4
349	22.891	15.4
350	22.905	15.4
351	22.962	15.4

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
352	22.962	15.4
353	22.991	15.4
354	23.048	15.4
355	23.077	15.4
356	23.105	15.4
357	23.134	15.4
358	23.163	15.4
359	23.191	15.4
360	23.220	15.4
361	23.234	15.4
362	23.263	15.4
363	23.292	15.4
364	23.306	15.4
365	23.349	15.4
366	23.378	15.4
367	23.421	15.4
368	23.449	15.4
369	23.492	15.4
370	23.507	15.4
371	23.521	15.4
372	23.521	15.4
373	23.578	15.4
374	23.592	15.4
375	23.635	15.4
376	23.664	15.4
377	23.678	15.4
378	23.707	15.4
379	23.721	15.4
380	23.764	15.4
381	23.764	15.4
382	23.764	15.4
383	23.807	15.4
384	23.822	15.4
385	23.879	15.4
386	23.922	15.4
387	23.951	15.4

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
388	24.022	15.4
389	24.037	15.4
390	24.065	15.4
391	24.108	15.4
392	24.122	15.4
393	24.137	15.4
394	24.165	15.4
395	24.194	15.4
396	24.251	15.4
397	24.280	15.4
398	24.280	15.4
399	24.251	15.4
400	24.294	15.4
401	24.323	15.4
402	24.352	15.4
403	24.366	15.4
404	24.423	15.4
405	24.423	15.4
406	24.466	15.4
407	24.481	15.4
408	24.523	15.4
409	24.566	15.4
410	24.595	15.4
411	24.638	15.4
412	24.652	15.4
413	24.667	15.4
414	24.738	15.4
415	24.767	15.4
416	24.767	15.4
417	24.796	15.4
418	24.810	15.4
419	24.839	15.4
420	24.867	15.4
421	24.896	15.4

Table B-8
Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration from Specific Capacity for Pumping Test R-9i[a]

Well Eff (%)	Aquifer Penetration (%)																	
	10	**18.6**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	3393	2727	1803	1507	1311	1171	1066	985	920	868	827	793	766	745	729	716	707	701	696
25	2706	2173	1434	1196	1040	928	844	779	727	686	652	625	604	587	574	564	556	551	548
30	2249	1805	1189	991	860	767	697	643	600	565	537	515	497	483	472	463	457	453	450
35	1923	1543	1014	845	733	653	593	546	509	480	456	437	421	409	400	393	387	384	381
40	1680	1346	884	736	638	568	515	475	442	416	395	379	365	355	346	340	335	332	330
45	1490	1194	783	652	564	502	456	419	390	367	349	334	322	312	305	300	295	293	291
50	1339	1073	703	584	506	450	408	375	349	328	312	298	288	279	272	267	264	261	259
55	1216	973	637	529	458	407	369	339	316	297	282	269	260	252	246	241	238	236	234
60	1113	891	583	484	419	372	337	309	288	271	257	245	236	229	224	220	217	214	213
65	1026	821	537	445	385	342	310	284	264	248	236	225	217	210	205	201	199	197	195
70	952	761	497	413	357	316	286	263	244	230	218	208	200	194	190	186	183	181	180
75	888	710	463	384	332	294	266	245	227	213	202	193	186	180	176	173	170	168	167
80	831	665	433	359	310	275	249	228	212	199	189	180	174	168	164	161	159	157	156
85	782	625	407	337	291	258	234	214	199	187	177	169	163	158	154	151	149	147	146
90	738	589	384	318	274	243	220	202	187	176	166	159	153	148	144	142	140	138	137
95	698	558	363	301	259	230	208	191	177	166	157	150	144	140	136	134	132	130	129
100	663	**529**[b]	345	285	246	218	197	180	167	157	149	142	137	132	129	126	125	123	122

[a] Input data: Q = 15.4 gpm; s = 24.90 ft at t = 421 min; screen length = 10.4 ft; dw = 12.25 in; S = 0.001; aquifer thickness = 83.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 12.5%, T = 529.5 ft^2/day.

Appendix C

Well R-13 Test Data

APPENDIX C. WELL R-13 TEST DATA

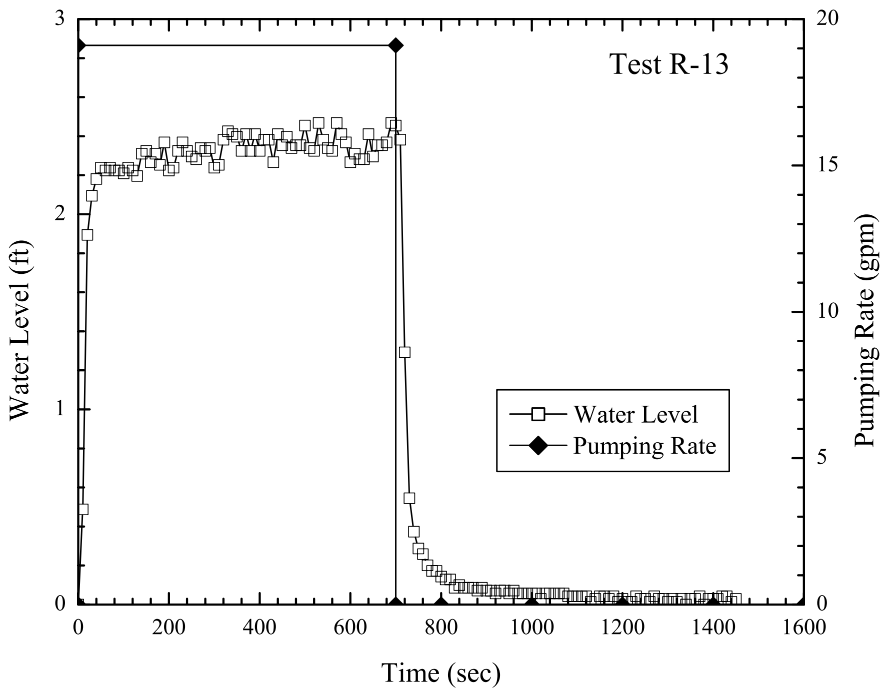


Figure C-1. Pumping test R-13

C-2
Data for Pumping Test R-13

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
0	0.000	19.1
10	0.488	19.1
20	1.894	19.1
30	2.095	19.1
40	2.181	19.1
50	2.239	19.1
60	2.224	19.1
70	2.239	19.1
80	2.224	19.1
90	2.224	19.1
100	2.210	19.1
110	2.239	19.1
120	2.224	19.1
130	2.196	19.1
140	2.310	19.1
150	2.325	19.1
160	2.267	19.1

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
170	2.310	19.1
180	2.253	19.1
190	2.368	19.1
200	2.224	19.1
210	2.239	19.1
220	2.325	19.1
230	2.368	19.1
240	2.325	19.1
250	2.296	19.1
260	2.282	19.1
270	2.339	19.1
280	2.325	19.1
290	2.339	19.1
300	2.239	19.1
310	2.253	19.1
320	2.382	19.1
330	2.425	19.1

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
340	2.411	19.1
350	2.397	19.1
360	2.325	19.1
370	2.411	19.1
380	2.325	19.1
390	2.411	19.1
400	2.325	19.1
410	2.382	19.1
420	2.382	19.1
430	2.267	19.1
440	2.411	19.1
450	2.354	19.1
460	2.397	19.1
470	2.339	19.1
480	2.354	19.1
490	2.354	19.1
500	2.454	19.1

Data for Pumping Test R-13 (continued)

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
510	2.339	19.1
520	2.325	19.1
530	2.468	19.1
540	2.382	19.1
550	2.339	19.1
560	2.325	19.1
570	2.468	19.1
580	2.411	19.1
590	2.368	19.1
600	2.267	19.1
610	2.310	19.1
620	2.282	19.1
630	2.282	19.1
640	2.411	19.1
650	2.296	19.1
660	2.354	19.1
670	2.354	19.1
680	2.368	19.1
690	2.468	19.1
700	2.454	0.0
710	2.382	0.0
720	1.292	0.0
730	0.545	0.0
740	0.373	0.0
750	0.287	0.0
760	0.258	0.0
770	0.201	0.0
780	0.172	0.0
790	0.172	0.0
800	0.143	0.0
810	0.129	0.0
820	0.129	0.0
830	0.086	0.0
840	0.100	0.0
850	0.086	0.0
860	0.086	0.0
870	0.086	0.0
880	0.072	0.0

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
890	0.086	0.0
900	0.072	0.0
910	0.072	0.0
920	0.057	0.0
930	0.072	0.0
940	0.072	0.0
950	0.057	0.0
960	0.072	0.0
970	0.057	0.0
980	0.057	0.0
990	0.057	0.0
1000	0.057	0.0
1010	0.057	0.0
1020	0.029	0.0
1030	0.057	0.0
1040	0.057	0.0
1050	0.057	0.0
1060	0.057	0.0
1070	0.057	0.0
1080	0.043	0.0
1090	0.043	0.0
1100	0.043	0.0
1110	0.043	0.0
1120	0.043	0.0
1130	0.014	0.0
1140	0.029	0.0
1150	0.043	0.0
1160	0.043	0.0
1170	0.029	0.0
1180	0.043	0.0
1190	0.014	0.0
1200	0.029	0.0
1210	0.014	0.0
1220	0.014	0.0
1230	0.043	0.0
1240	0.029	0.0
1250	0.029	0.0
1260	0.014	0.0

Elapsed Time (sec)	Change in Water Level (ft)	Pumping Rate (gpm)
1270	0.043	0.0
1280	0.029	0.0
1290	0.029	0.0
1300	0.014	0.0
1310	0.029	0.0
1320	0.014	0.0
1330	0.029	0.0
1340	0.000	0.0
1350	0.029	0.0
1360	0.029	0.0
1370	0.043	0.0
1380	0.000	0.0
1390	0.029	0.0
1400	0.029	0.0
1410	0.029	0.0
1420	0.043	0.0
1430	0.043	0.0
1440	0.014	0.0
1450	0.029	0.0

C-3
Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration for Pumping Test R-13 from Specific Capacity[a]

Well Eff (%)	Aquifer Penetration (%)																		
	10	**15**	**20.1**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	57373	37205	27318	21781	17974	15247	13193	11591	10311	9273	8421	7719	7137	6656	6259	5932	5664	5445	5266
25	45792	29657	21746	17316	14270	12088	10444	9161	8137	7305	6623	6060	5594	5209	4890	4628	4413	4237	4094
30	38087	24641	18048	14356	11817	9998	8628	7558	6704	6011	5442	4972	4583	4261	3995	3776	3597	3450	3330
35	32593	21068	15416	12251	10075	8516	7340	6423	5691	5096	4608	4205	3871	3595	3367	3178	3024	2898	2795
40	28479	18394	13449	10679	8775	7410	6381	5579	4938	4417	3989	3636	3344	3102	2902	2737	2602	2491	2400
45	25284	16319	11923	9461	7768	6554	5640	4926	4356	3893	3513	3199	2939	2723	2545	2398	2277	2179	2098
50	22730	14661	10705	8489	6965	5873	5050	4407	3894	3477	3134	2852	2617	2423	2262	2130	2021	1933	1860
55	20643	13308	9711	7696	6311	5318	4569	3985	3518	3139	2827	2570	2357	2180	2034	1913	1814	1733	1667
60	18905	12181	8884	7037	5767	4857	4170	3635	3206	2859	2573	2337	2141	1979	1845	1735	1644	1569	1509
65	17436	11229	8186	6481	5308	4468	3834	3340	2944	2623	2359	2141	1961	1811	1687	1585	1501	1432	1376
70	16178	10415	7588	6005	4916	4136	3547	3088	2721	2422	2177	1975	1807	1668	1552	1457	1379	1315	1263
75	15089	9709	7071	5593	4577	3849	3299	2870	2528	2249	2020	1831	1674	1544	1437	1348	1275	1215	1166
80	14136	9093	6620	5234	4281	3598	3083	2681	2359	2098	1884	1706	1559	1437	1336	1253	1184	1128	1082
85	13296	8549	6221	4917	4021	3378	2893	2514	2212	1966	1764	1597	1458	1343	1248	1169	1105	1052	1009
90	12550	8067	5868	4636	3789	3182	2724	2367	2081	1848	1657	1500	1369	1260	1170	1096	1035	985	944
95	11882	7635	5552	4386	3583	3008	2574	2235	1964	1744	1563	1413	1289	1186	1101	1031	973	925	886
100	11282	7247	**5269**[b]	4160	3398	2851	2439	2117	1859	1650	1478	1336	1218	1120	1039	972	917	872	835

[a] Input data: Q = 19.1 gpm; s = 2.47 ft at t = 11.5 min; screen length = 60.4 ft; dw = 12.25 in; S = 0.05; aquifer thickness = 300.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 20.1%, T = 5,268.6 ft^2/day.

Appendix D

Well R-19 Test Data

APPENDIX D. WELL R-19 TEST DATA

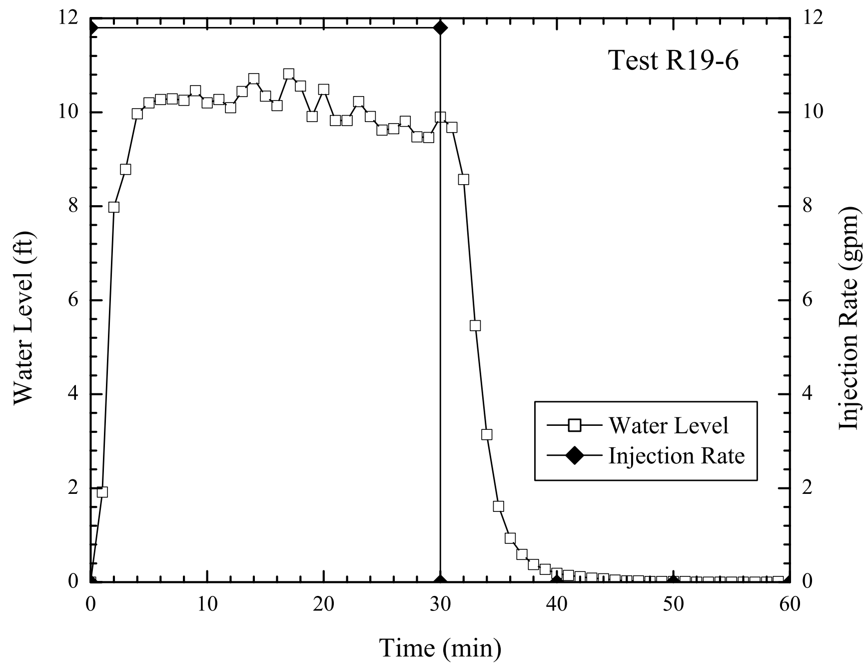


Figure D-1. Injection test R19-6

D-2
Data for Injection Test R19-6

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
0	0.000	11.8	16	10.140	11.8	32	8.570	0.0
1	1.915	11.8	17	10.817	11.8	33	5.458	0.0
2	7.979	11.8	18	10.558	11.8	34	3.139	0.0
3	8.786	11.8	19	9.910	11.8	35	1.613	0.0
4	9.967	11.8	20	10.486	11.8	36	0.936	0.0
5	10.198	11.8	21	9.823	11.8	37	0.590	0.0
6	10.270	11.8	22	9.823	11.8	38	0.374	0.0
7	10.284	11.8	23	10.226	11.8	39	0.273	0.0
8	10.255	11.8	24	9.910	11.8	40	0.187	0.0
9	10.457	11.8	25	9.621	11.8	41	0.144	0.0
10	10.198	11.8	26	9.650	11.8	42	0.115	0.0
11	10.270	11.8	27	9.809	11.8	43	0.086	0.0
12	10.097	11.8	28	9.477	11.8	44	0.072	0.0
13	10.443	11.8	29	9.463	11.8	45	0.043	0.0
14	10.716	11.8	30	9.895	11.8	39	0.273	0.0
15	10.342	11.8	31	9.679	0.0	40	0.187	0.0

Data for Injection Test R19-6 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
41	0.144	0.0
42	0.115	0.0
43	0.086	0.0
44	0.072	0.0
45	0.043	0.0
46	0.028	0.0
47	0.028	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
48	0.014	0.0
49	0.014	0.0
50	0.014	0.0
51	0.014	0.0
52	0.000	0.0
53	0.000	0.0
54	0.000	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
55	0.000	0.0
56	0.000	0.0
57	0.000	0.0
58	0.000	0.0
59	0.014	0.0

D-3
Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration for Injection Test R19-6 from Specific Capacity[a]

Well Eff (%)	Aquifer Penetration (%)																		
	1.9	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	34753	3406	2613	2152	1848	1630	1467	1339	1239	1158	1093	1042	1001	969	945	928	916	908	904
25	27787	2709	2075	1706	1462	1288	1157	1055	974	910	858	817	784	759	739	725	716	710	706
30	23145	2247	1718	1411	1208	1062	953	868	801	747	704	669	642	621	605	593	585	580	577
35	19831	1918	1465	1201	1027	902	809	736	678	632	595	565	542	524	510	500	493	489	486
40	17346	1672	1276	1045	893	784	702	638	587	547	514	488	468	452	440	431	425	421	419
45	15414	1482	1129	924	789	692	619	562	517	481	452	429	411	397	386	378	373	369	367
50	13869	1330	1013	828	706	619	553	502	461	429	403	382	366	353	343	336	331	328	327
55	12606	1206	917	750	639	559	500	453	416	387	363	344	329	318	309	302	298	295	294
60	11553	1103	838	685	583	510	455	413	379	352	330	313	299	288	280	274	270	268	266
65	10662	1016	772	630	536	469	418	379	347	322	302	286	274	264	256	251	247	245	243
70	9898	941	715	583	496	433	386	350	321	297	279	264	252	243	236	231	227	225	224
75	9237	877	665	542	461	403	359	325	298	276	258	244	233	225	218	214	210	208	207
80	8658	821	622	507	431	376	335	303	277	257	241	228	217	209	203	199	196	194	193
85	8148	771	584	476	404	353	314	284	260	241	225	213	203	196	190	186	183	181	180
90	7694	727	551	448	380	332	295	267	244	226	211	200	191	184	178	174	171	170	169
95	7288	688	521	424	359	313	279	252	230	213	199	188	180	173	168	164	161	160	159
100	**6923**[b]	653	494	402	340	297	264	238	218	201	188	178	170	163	158	155	152	151	150

[a] Input data: Q = 11.8 gpm; s = 10.49 ft at t = 20 min; screen length = 7.1 ft; dw = 12.25 in; S = 0.003; aquifer thickness = 372.5 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 1.9%, T = 6,922.7 ft^2/day.

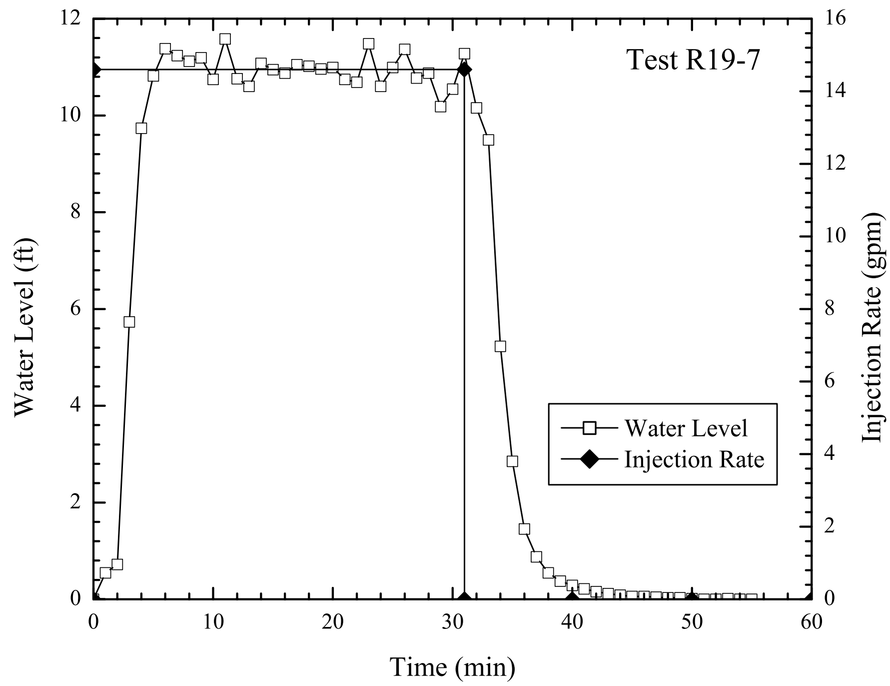


Figure D-4. **Injection Test R19-7.**

D-5
Data for Injection Test R19-7

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
0	0.000	14.6	16	10.875	14.6	32	10.155	0.0
1	0.547	14.6	17	11.048	14.6	33	9.492	0.0
2	0.720	14.6	18	11.019	14.6	34	5.228	0.0
3	5.732	14.6	19	10.961	14.6	35	2.852	0.0
4	9.737	14.6	20	10.990	14.6	36	1.454	0.0
5	10.817	14.6	21	10.745	14.6	37	0.878	0.0
6	11.379	14.6	22	10.688	14.6	38	0.547	0.0
7	11.235	14.6	23	11.480	14.6	39	0.374	0.0
8	11.120	14.6	24	10.601	14.6	40	0.288	0.0
9	11.192	14.6	25	10.990	14.6	41	0.216	0.0
10	10.745	14.6	26	11.365	14.6	42	0.158	0.0
11	11.581	14.6	27	10.774	14.6	43	0.115	0.0
12	10.760	14.6	28	10.875	14.6	44	0.086	0.0
13	10.601	14.6	29	10.183	14.6	45	0.057	0.0
14	11.077	14.6	30	10.544	14.6	46	0.057	0.0
15	10.947	14.6	31	11.278	14.6	47	0.043	0.0

Data for Injection Test R19-7 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
48	0.029	0.0
49	0.029	0.0
50	0.014	0.0
51	0.000	0.0
52	0.000	0.0
53	0.014	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
54	0.000	0.0
55	0.000	0.0
56	-0.015	0.0
57	-0.015	0.0
58	0.000	0.0
59	-0.015	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
60	0.014	0.0
61	0.014	0.0
62	0.000	0.0
63	0.014	0.0

D-6

Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration for Injection Test R19-7 from Specific Capacity[a]

Well	Aquifer Penetration (%)																	
Eff (%)	**1.9**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	41060	4039	3103	2559	2200	1943	1750	1600	1481	1386	1310	1249	1201	1163	1135	1115	1101	1092	1087
25	32830	3213	2464	2029	1741	1535	1381	1260	1165	1089	1028	979	941	911	888	872	860	853	849
30	27346	2665	2041	1678	1438	1266	1137	1037	958	894	843	802	770	745	727	713	703	697	694
35	23430	2275	1740	1429	1223	1076	965	879	811	757	713	678	650	629	613	601	593	588	585
40	20494	1984	1515	1243	1063	934	837	762	702	655	616	586	562	543	529	518	511	507	504
45	18212	1758	1341	1099	939	825	739	672	619	576	542	515	493	477	464	455	449	445	442
50	16386	1577	1203	985	841	738	660	600	552	514	483	459	439	424	413	405	399	395	393
55	14893	1430	1090	892	761	667	597	542	498	463	435	413	396	382	371	364	359	355	354
60	13649	1308	996	814	694	608	544	493	453	422	396	375	359	347	337	330	326	322	321
65	12597	1205	917	749	638	559	499	453	416	386	363	344	329	317	309	302	298	295	293
70	11695	1117	849	693	590	517	461	418	384	356	334	317	303	292	284	278	274	271	270
75	10913	1040	790	645	549	480	428	388	356	331	310	294	281	271	263	257	254	251	250
80	10230	974	739	603	513	449	400	362	332	308	289	274	261	252	245	240	236	234	232
85	9626	915	694	566	481	421	375	339	311	288	270	256	244	235	229	224	220	218	217
90	9090	863	654	533	453	396	353	319	292	271	254	240	229	221	215	210	207	205	204
95	8611	816	619	504	428	374	333	301	276	256	239	226	216	208	202	198	195	193	192
100	**8179[b]**	774	587	478	406	354	315	285	261	242	226	214	204	196	191	187	184	182	181

[a] Input data: Q = 14.6 gpm; s = 10.99 ft at t = 20 min; screen length = 7.1 ft; dw = 12.25 in; S = 0.003; aquifer thickness = 372.5 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 1.9%, T = 8,179.1 ft^2/day.

Appendix E

Well R-22 Test Data

APPENDIX E.   WELL R-22 TEST DATA

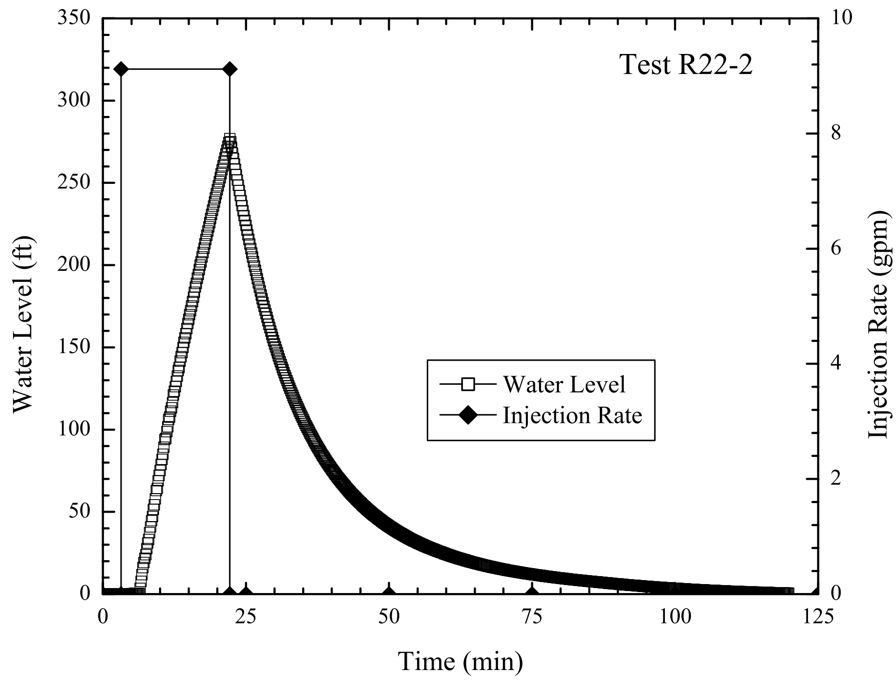


Figure E-1.   Injection test R22-2

E-2
Data for Injection Test R22-2

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.038	0.00
0.167	0.038	0.00
0.333	0.038	0.00
0.500	0.038	0.00
0.667	0.038	0.00
0.833	0.038	0.00
1.000	0.053	0.00
1.167	0.038	0.00
1.333	0.038	0.00
1.500	0.038	0.00
1.667	0.024	0.00
1.833	0.024	0.00
2.000	0.038	0.00
2.167	0.038	0.00
2.333	0.038	0.00
2.500	0.038	0.00
2.667	0.038	0.00
2.833	0.038	0.00
3.000	0.038	0.00
3.167	0.038	9.12
3.333	0.038	9.12
3.500	0.024	9.12
3.667	0.038	9.12
3.833	0.038	9.12
4.000	0.038	9.12
4.167	0.081	9.12
4.333	0.139	9.12
4.500	0.168	9.12
4.667	0.153	9.12
4.833	0.254	9.12
5.000	0.240	9.12
5.167	0.240	9.12
5.333	0.341	9.12
5.500	0.384	9.12
5.667	0.427	9.12
5.833	0.442	9.12
6.000	0.485	9.12
6.167	0.485	9.12
6.333	0.528	9.12
6.500	3.452	9.12
6.667	7.803	9.12
6.833	11.808	9.12
7.000	16.102	9.12
7.167	19.171	9.12
7.333	21.765	9.12
7.500	23.970	9.12
7.667	27.630	9.12
7.833	31.032	9.12

Data for Injection Test R-22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
8.000	33.251	9.12	14.333	155.794	9.12	20.667	255.586	9.12
8.167	37.388	9.12	14.500	158.337	9.12	20.833	257.994	9.12
8.333	40.863	9.12	14.667	161.444	9.12	21.000	260.393	9.12
8.500	44.640	9.12	14.833	164.465	9.12	21.167	262.779	9.12
8.667	47.192	9.12	15.000	167.124	9.12	21.333	265.154	9.12
8.833	51.532	9.12	15.167	169.899	9.12	21.500	267.518	9.12
9.000	54.272	9.12	15.333	172.284	9.12	21.667	269.871	9.12
9.167	57.848	9.12	15.500	175.175	9.12	21.833	272.212	9.12
9.333	62.982	9.12	15.667	177.850	9.12	22.000	274.542	9.12
9.500	64.237	9.12	15.833	180.524	9.12	22.167	276.862	9.12
9.667	68.882	9.12	16.000	183.531	9.12	22.333	275.004	0.00
9.833	72.156	9.12	16.167	186.655	9.12	22.500	271.576	0.00
10.000	75.171	9.12	16.333	188.896	9.12	22.667	268.182	0.00
10.167	78.763	9.12	16.500	192.034	9.12	22.833	264.823	0.00
10.333	81.909	9.12	16.667	194.391	9.12	23.000	261.496	0.00
10.500	85.040	9.12	16.833	197.211	9.12	23.167	258.203	0.00
10.667	89.340	9.12	17.000	200.002	9.12	23.333	254.945	0.00
10.833	94.001	9.12	17.167	202.027	9.12	23.500	251.718	0.00
11.000	94.679	9.12	17.333	204.978	9.12	23.667	248.525	0.00
11.167	98.778	9.12	17.500	207.678	9.12	23.833	245.368	0.00
11.333	101.708	9.12	17.667	210.302	9.12	24.000	242.242	0.00
11.500	106.125	9.12	17.833	212.912	9.12	24.167	239.150	0.00
11.667	107.656	9.12	18.000	215.513	9.12	24.333	236.093	0.00
11.833	111.149	9.12	18.167	218.102	9.12	24.500	233.067	0.00
12.000	113.286	9.12	18.333	220.679	9.12	24.667	230.075	0.00
12.167	116.491	9.12	18.500	223.246	9.12	24.833	227.119	0.00
12.333	121.054	9.12	18.667	225.802	9.12	25.000	224.194	0.00
12.500	123.321	9.12	18.833	228.344	9.12	25.167	221.303	0.00
12.667	126.137	9.12	19.000	230.878	9.12	25.333	218.447	0.00
12.833	129.256	9.12	19.167	233.400	9.12	25.500	215.623	0.00
13.000	132.607	9.12	19.333	235.909	9.12	25.667	212.832	0.00
13.167	136.001	9.12	19.500	238.408	9.12	25.833	210.076	0.00
13.333	137.749	9.12	19.667	240.896	9.12	26.000	207.353	0.00
13.500	141.621	9.12	19.833	243.372	9.12	26.167	204.891	0.00
13.667	144.308	9.12	20.000	245.838	9.12	26.333	202.114	0.00
13.833	146.793	9.12	20.167	248.292	9.12	26.500	199.438	0.00
14.000	150.000	9.12	20.333	250.734	9.12	26.667	196.806	0.00
14.167	153.106	9.12	20.500	253.166	9.12	26.833	194.203	0.00

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
27.000	191.643	0.00
27.167	189.156	0.00
27.333	186.712	0.00
27.500	184.254	0.00
27.667	181.840	0.00
27.833	179.527	0.00
28.000	177.214	0.00
28.167	174.944	0.00
28.333	172.660	0.00
28.500	170.477	0.00
28.667	168.309	0.00
28.833	166.199	0.00
29.000	164.046	0.00
29.167	161.994	0.00
29.333	159.970	0.00
29.500	157.976	0.00
29.667	156.025	0.00
29.833	154.031	0.00
30.000	152.124	0.00
30.167	150.246	0.00
30.333	148.411	0.00
30.500	146.605	0.00
30.667	144.799	0.00
30.833	143.007	0.00
31.000	141.274	0.00
31.167	139.584	0.00
31.333	137.879	0.00
31.500	136.363	0.00
31.667	134.557	0.00
31.833	132.925	0.00
32.000	131.365	0.00
32.167	129.805	0.00
32.333	128.260	0.00
32.500	126.744	0.00
32.667	125.242	0.00
32.833	123.740	0.00
33.000	122.267	0.00
33.167	120.852	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
33.333	119.437	0.00
33.500	118.051	0.00
33.667	116.679	0.00
33.833	115.322	0.00
34.000	113.878	0.00
34.167	112.607	0.00
34.333	111.279	0.00
34.500	109.994	0.00
34.667	108.738	0.00
34.833	107.468	0.00
35.000	106.226	0.00
35.167	104.999	0.00
35.333	103.772	0.00
35.500	102.589	0.00
35.667	101.434	0.00
35.833	100.279	0.00
36.000	99.139	0.00
36.167	98.013	0.00
36.333	96.916	0.00
36.500	95.834	0.00
36.667	94.737	0.00
36.833	93.640	0.00
37.000	92.587	0.00
37.167	91.562	0.00
37.333	90.538	0.00
37.500	89.527	0.00
37.667	88.546	0.00
37.833	87.565	0.00
38.000	86.613	0.00
38.167	85.617	0.00
38.333	84.564	0.00
38.500	83.712	0.00
38.667	82.803	0.00
38.833	81.909	0.00
39.000	81.029	0.00
39.167	80.134	0.00
39.333	79.268	0.00
39.500	78.417	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
39.667	77.580	0.00
39.833	76.744	0.00
40.000	75.907	0.00
40.167	75.084	0.00
40.333	74.248	0.00
40.500	73.454	0.00
40.667	72.675	0.00
40.833	71.911	0.00
41.000	71.146	0.00
41.167	70.396	0.00
41.333	69.660	0.00
41.500	68.925	0.00
41.667	68.218	0.00
41.833	67.497	0.00
42.000	66.804	0.00
42.167	66.112	0.00
42.333	65.405	0.00
42.500	64.713	0.00
42.667	64.021	0.00
42.833	63.357	0.00
43.000	62.708	0.00
43.167	62.059	0.00
43.333	61.410	0.00
43.500	60.776	0.00
43.667	60.170	0.00
43.833	59.535	0.00
44.000	58.944	0.00
44.167	58.338	0.00
44.333	57.761	0.00
44.500	57.170	0.00
44.667	56.593	0.00
44.833	56.017	0.00
45.000	55.454	0.00
45.167	54.863	0.00
45.333	54.300	0.00
45.500	53.738	45.500
45.667	53.205	45.667
45.833	52.685	45.833

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
46.000	52.152	0.00	52.333	36.206	0.00	58.667	26.002	0.00
46.167	51.633	0.00	52.500	35.889	0.00	58.833	25.786	0.00
46.333	51.128	0.00	52.667	35.558	0.00	59.000	25.569	0.00
46.500	50.609	0.00	52.833	35.241	0.00	59.167	25.353	0.00
46.667	50.119	0.00	53.000	34.909	0.00	59.333	25.137	0.00
46.833	49.643	0.00	53.167	34.578	0.00	59.500	24.921	0.00
47.000	49.138	0.00	53.333	34.246	0.00	59.667	24.705	0.00
47.167	48.662	0.00	53.500	33.929	0.00	59.833	24.503	0.00
47.333	48.187	0.00	53.667	33.626	0.00	60.000	24.287	0.00
47.500	47.740	0.00	53.833	33.338	0.00	60.167	24.085	0.00
47.667	47.264	0.00	54.000	33.035	0.00	60.333	23.869	0.00
47.833	46.803	0.00	54.167	32.747	0.00	60.500	23.681	0.00
48.000	46.356	0.00	54.333	32.459	0.00	60.667	23.480	0.00
48.167	45.909	0.00	54.500	32.185	0.00	60.833	23.278	0.00
48.333	45.462	0.00	54.667	31.897	0.00	61.000	23.076	0.00
48.500	45.015	0.00	54.833	31.608	0.00	61.167	22.889	0.00
48.667	44.553	0.00	55.000	31.334	0.00	61.333	22.687	0.00
48.833	44.121	0.00	55.167	31.075	0.00	61.500	22.514	0.00
49.000	43.674	0.00	55.333	30.801	0.00	61.667	22.327	0.00
49.167	43.270	0.00	55.500	30.513	0.00	61.833	22.139	0.00
49.333	42.852	0.00	55.667	30.253	0.00	62.000	21.952	0.00
49.500	42.448	0.00	55.833	30.008	0.00	62.167	21.779	0.00
49.667	42.030	0.00	56.000	29.735	0.00	62.333	21.592	0.00
49.833	41.641	0.00	56.167	29.489	0.00	62.500	21.419	0.00
50.000	41.252	0.00	56.333	29.230	0.00	62.667	21.246	0.00
50.167	40.863	0.00	56.500	28.971	0.00	62.833	21.073	0.00
50.333	40.488	0.00	56.667	28.740	0.00	63.000	20.900	0.00
50.500	40.099	0.00	56.833	28.495	0.00	63.167	20.742	0.00
50.667	39.738	0.00	57.000	28.250	0.00	63.333	20.583	0.00
50.833	39.363	0.00	57.167	28.034	0.00	63.500	20.396	0.00
51.000	39.003	0.00	57.333	27.789	0.00	63.667	20.237	0.00
51.167	38.628	0.00	57.500	27.558	0.00	63.833	20.064	0.00
51.333	38.268	0.00	57.667	27.328	0.00	64.000	19.906	0.00
51.500	37.936	0.00	57.833	27.111	0.00	64.167	19.733	0.00
51.667	37.576	0.00	58.000	26.881	0.00	64.333	19.574	0.00
51.833	37.230	0.00	58.167	26.650	0.00	64.500	19.401	0.00
52.000	36.884	0.00	58.333	26.434	0.00	64.667	19.257	0.00
52.167	36.552	0.00	58.500	26.203	0.00	64.833	19.113	0.00

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
65.000	18.955	0.00
65.167	18.811	0.00
65.333	18.667	0.00
65.500	18.508	0.00
65.667	18.364	0.00
65.833	18.205	0.00
66.000	18.061	0.00
66.167	17.932	0.00
66.333	17.773	0.00
66.500	17.643	0.00
66.667	17.514	0.00
66.833	17.370	0.00
67.000	17.226	0.00
67.167	17.081	0.00
67.333	16.952	0.00
67.500	16.822	0.00
67.667	16.692	0.00
67.833	16.563	0.00
68.000	16.447	0.00
68.167	16.303	0.00
68.333	16.188	0.00
68.500	16.058	0.00
68.667	15.929	0.00
68.833	15.813	0.00
69.000	15.698	0.00
69.167	15.569	0.00
69.333	15.453	0.00
69.500	15.338	0.00
69.667	15.223	0.00
69.833	15.093	0.00
70.000	14.992	0.00
70.167	14.877	0.00
70.333	14.762	0.00
70.500	14.646	0.00
70.667	14.546	0.00
70.833	14.430	0.00
71.000	14.315	0.00
71.167	14.229	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
71.333	14.113	0.00
71.500	14.012	0.00
71.667	13.912	0.00
71.833	13.811	0.00
72.000	13.724	0.00
72.167	13.609	0.00
72.333	13.523	0.00
72.500	13.422	0.00
72.667	13.321	0.00
72.833	13.220	0.00
73.000	13.119	0.00
73.167	13.033	0.00
73.333	12.946	0.00
73.500	12.845	0.00
73.667	12.744	0.00
73.833	12.672	0.00
74.000	12.572	0.00
74.167	12.471	0.00
74.333	12.399	0.00
74.500	12.312	0.00
74.667	12.226	0.00
74.833	12.125	0.00
75.000	12.038	0.00
75.167	11.952	0.00
75.333	11.880	0.00
75.500	11.779	0.00
75.667	11.693	0.00
75.833	11.606	0.00
76.000	11.534	0.00
76.167	11.462	0.00
76.333	11.361	0.00
76.500	11.289	0.00
76.667	11.217	0.00
76.833	11.131	0.00
77.000	11.059	0.00
77.167	10.958	0.00
77.333	10.871	0.00
77.500	10.814	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
77.667	10.742	0.00
77.833	10.641	0.00
78.000	10.569	0.00
78.167	10.497	0.00
78.333	10.425	0.00
78.500	10.353	0.00
78.667	10.266	0.00
78.833	10.194	0.00
79.000	10.122	0.00
79.167	10.065	0.00
79.333	9.964	0.00
79.500	9.921	0.00
79.667	9.849	0.00
79.833	9.762	0.00
80.000	9.704	0.00
80.167	9.632	0.00
80.333	9.560	0.00
80.500	9.488	0.00
80.667	9.416	0.00
80.833	9.359	0.00
81.000	9.287	0.00
81.167	9.229	0.00
81.333	9.143	0.00
81.500	9.085	0.00
81.667	9.013	0.00
81.833	8.955	0.00
82.000	8.898	0.00
82.167	8.840	0.00
82.333	8.754	0.00
82.500	8.696	0.00
82.667	8.624	0.00
82.833	8.581	0.00
83.000	8.523	0.00
83.167	8.451	0.00
83.333	8.379	0.00
83.500	8.321	0.00
83.667	8.264	0.00
83.833	8.206	0.00

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
84.000	8.149	0.00	90.333	6.031	0.00	96.667	4.244	0.00
84.167	8.091	0.00	90.500	5.973	0.00	96.833	4.201	0.00
84.333	8.019	0.00	90.667	5.930	0.00	97.000	4.158	0.00
84.500	7.961	0.00	90.833	5.887	0.00	97.167	4.129	0.00
84.667	7.918	0.00	91.000	5.800	0.00	97.500	4.043	0.00
84.833	7.846	0.00	91.167	5.757	0.00	97.667	4.000	0.00
85.000	7.803	0.00	91.333	5.714	0.00	97.833	3.971	0.00
85.167	7.745	0.00	91.500	5.671	0.00	98.000	3.913	0.00
85.333	7.688	0.00	91.667	5.613	0.00	98.167	3.884	0.00
85.500	7.630	0.00	91.833	5.570	0.00	98.333	3.827	0.00
85.667	7.572	0.00	92.000	5.512	0.00	98.500	3.798	0.00
85.833	7.529	0.00	92.167	5.483	0.00	98.667	3.769	0.00
86.000	7.471	0.00	92.333	5.411	0.00	98.833	3.726	0.00
86.167	7.428	0.00	92.500	5.368	0.00	99.000	3.683	0.00
86.333	7.371	0.00	92.667	5.310	0.00	99.167	3.654	0.00
86.500	7.327	0.00	92.833	5.267	0.00	99.333	3.611	0.00
86.667	7.255	0.00	93.000	5.224	0.00	99.500	3.567	0.00
86.833	7.198	0.00	93.167	5.181	0.00	99.667	3.539	0.00
87.000	7.140	0.00	93.333	5.123	0.00	99.833	3.495	0.00
87.167	7.082	0.00	93.500	5.080	0.00	100.000	3.467	0.00
87.333	7.025	0.00	93.667	5.022	0.00	100.167	3.438	0.00
87.500	6.967	0.00	93.833	4.979	0.00	100.333	3.395	0.00
87.667	6.895	0.00	94.000	4.936	0.00	100.500	3.366	0.00
87.833	6.838	0.00	94.167	4.893	0.00	100.667	3.337	0.00
88.000	6.780	0.00	94.333	4.849	0.00	100.833	3.279	0.00
88.167	6.737	0.00	94.500	4.806	0.00	101.000	3.250	0.00
88.333	6.679	0.00	94.667	4.763	0.00	101.167	3.207	0.00
88.500	6.621	0.00	94.833	4.720	0.00	101.333	3.178	0.00
88.667	6.564	0.00	95.000	4.662	0.00	101.500	3.150	0.00
88.833	6.506	0.00	95.167	4.619	0.00	101.667	3.121	0.00
89.000	6.449	0.00	95.333	4.590	0.00	101.833	3.092	0.00
89.167	6.405	0.00	95.500	4.533	0.00	102.000	3.049	0.00
89.333	6.348	0.00	95.667	4.504	0.00	102.167	3.020	0.00
89.500	6.290	0.00	95.833	4.446	0.00	102.333	2.991	0.00
89.667	6.247	0.00	96.000	4.403	0.00	102.500	2.962	0.00
89.833	6.175	0.00	96.167	4.374	0.00	102.667	2.934	0.00
90.000	6.132	0.00	96.333	4.316	0.00	102.833	2.905	0.00
90.167	6.074	0.00	96.500	4.273	0.00	103.000	2.847	0.00

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
103.167	2.818	0.00
103.333	2.804	0.00
103.500	2.761	0.00
103.667	2.732	0.00
103.833	2.703	0.00
104.000	2.660	0.00
104.167	2.631	0.00
104.333	2.602	0.00
104.500	2.573	0.00
104.667	2.559	0.00
104.833	2.530	0.00
105.000	2.473	0.00
105.167	2.444	0.00
105.333	2.415	0.00
105.500	2.386	0.00
105.667	2.372	0.00
105.833	2.329	0.00
106.000	2.314	0.00
106.167	2.285	0.00
106.333	2.257	0.00
106.500	2.228	0.00
106.667	2.213	0.00
106.833	2.170	0.00
107.000	2.156	0.00
107.167	2.112	0.00
107.333	2.084	0.00
107.500	2.055	0.00
107.667	2.040	0.00
107.833	2.012	0.00
108.000	1.983	0.00
108.167	1.954	0.00
108.333	1.940	0.00
108.500	1.911	0.00
108.667	1.896	0.00
108.833	1.868	0.00
109.000	1.839	0.00
109.167	1.810	0.00
109.333	1.796	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
109.500	1.752	0.00
109.667	1.724	0.00
109.833	1.709	0.00
110.000	1.695	0.00
110.167	1.652	0.00
110.333	1.652	0.00
110.500	1.623	0.00
110.667	1.608	0.00
110.833	1.580	0.00
111.000	1.565	0.00
111.167	1.536	0.00
111.333	1.522	0.00
111.500	1.493	0.00
111.667	1.479	0.00
111.833	1.450	0.00
112.000	1.435	0.00
112.167	1.421	0.00
112.333	1.392	0.00
112.500	1.363	0.00
112.667	1.349	0.00
112.833	1.320	0.00
113.000	1.306	0.00
113.167	1.291	0.00
113.333	1.263	0.00
113.500	1.234	0.00
113.667	1.219	0.00
113.833	1.205	0.00
114.000	1.191	0.00
114.167	1.176	0.00
114.333	1.147	0.00
114.500	1.133	0.00
114.667	1.119	0.00
114.833	1.090	0.00
115.000	1.075	0.00
115.167	1.061	0.00
115.333	1.032	0.00
115.500	1.003	0.00
115.667	1.003	0.00

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
115.833	0.975	0.00
116.000	0.960	0.00
116.167	0.946	0.00
116.333	0.917	0.00
116.500	0.902	0.00
116.667	0.874	0.00
116.833	0.859	0.00
117.000	0.845	0.00
117.167	0.830	0.00
117.333	0.830	0.00
117.500	0.816	0.00
117.667	0.802	0.00
117.833	0.773	0.00
118.000	0.758	0.00
118.167	0.744	0.00
118.333	0.730	0.00
118.500	0.715	0.00
118.667	0.701	0.00
118.833	0.686	0.00
119.000	0.629	0.00
119.167	0.643	0.00
119.333	0.629	0.00
119.500	0.614	0.00
119.667	0.600	0.00
119.833	0.600	0.00

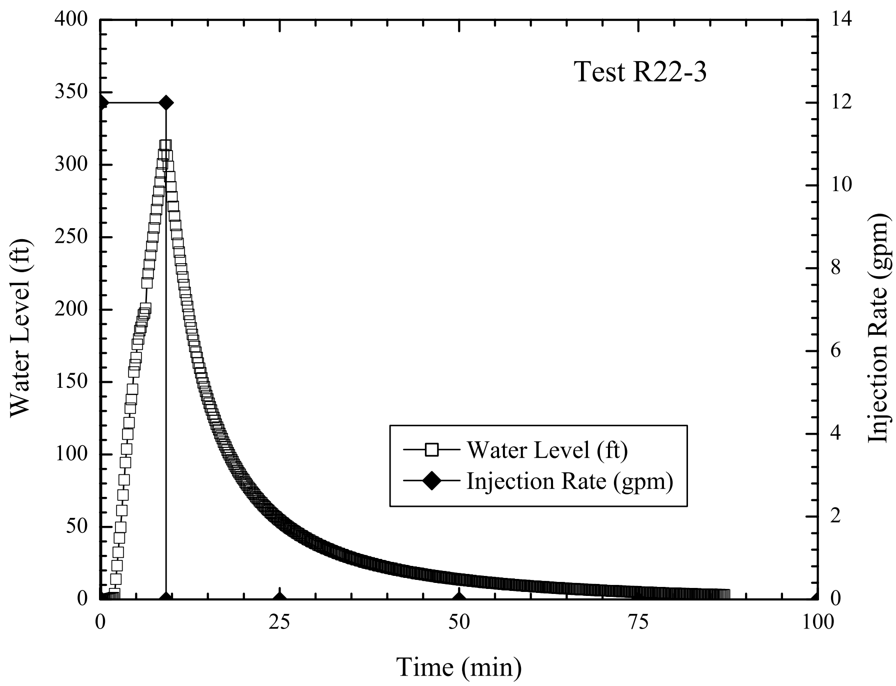


Figure E-3. Injection test R22-3

E-4
Data for Injection Test R22-3

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	-0.827	0.0	2.833	49.833	12.0	5.667	187.795	12.0
0.167	-0.683	12.0	3.000	61.342	12.0	5.833	191.729	12.0
0.333	-0.582	12.0	3.167	72.016	12.0	6.000	196.415	12.0
0.500	-0.381	12.0	3.333	82.577	12.0	6.167	197.601	12.0
0.667	-0.222	12.0	3.500	94.411	12.0	6.333	200.956	12.0
0.833	0.080	12.0	3.667	103.794	12.0	6.500	218.454	12.0
1.000	0.239	12.0	3.833	113.972	12.0	6.667	224.780	12.0
1.167	0.325	12.0	4.000	121.928	12.0	6.833	231.102	12.0
1.333	0.455	12.0	4.167	131.981	12.0	7.000	237.427	12.0
1.500	0.642	12.0	4.333	137.975	12.0	7.167	243.753	12.0
1.667	0.959	12.0	4.500	145.069	12.0	7.333	250.075	12.0
1.833	1.276	12.0	4.667	156.946	12.0	7.500	256.401	12.0
2.000	3.955	12.0	4.833	161.990	12.0	7.667	262.727	12.0
2.167	13.940	12.0	5.000	166.876	12.0	7.833	269.049	12.0
2.333	23.351	12.0	5.167	176.026	12.0	8.000	275.374	12.0
2.500	32.503	12.0	5.333	179.684	12.0	8.167	281.700	12.0
2.667	42.451	12.0	5.500	185.540	12.0	8.333	288.022	12.0

Data for Injection Test R22-3 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
8.500	294.348	12.0
8.667	300.674	12.0
8.833	306.996	12.0
9.000	313.321	12.0
9.167	313.571	12.0
9.333	306.154	0.0
9.500	298.874	0.0
9.667	291.737	0.0
9.833	284.746	0.0
10.000	277.892	0.0
10.167	271.181	0.0
10.333	264.615	0.0
10.500	258.188	0.0
10.667	251.903	0.0
10.833	245.763	0.0
11.000	239.762	0.0
11.167	233.902	0.0
11.333	228.188	0.0
11.500	222.613	0.0
11.667	217.180	0.0
11.833	211.892	0.0
12.000	206.742	0.0
12.167	202.215	0.0
12.333	196.704	0.0
12.500	192.047	0.0
12.667	187.405	0.0
12.833	182.850	0.0
13.000	178.816	0.0
13.167	174.595	0.0
13.333	170.562	0.0
13.500	166.962	0.0
13.667	163.060	0.0
13.833	159.548	0.0
14.000	156.426	0.0
14.167	152.828	0.0
14.333	149.447	0.0
14.500	146.774	0.0
14.667	143.508	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
14.833	140.778	0.0
15.000	138.351	0.0
15.167	135.375	0.0
15.333	132.905	0.0
15.500	130.666	0.0
15.667	127.864	0.0
15.833	125.626	0.0
16.000	123.589	0.0
16.167	120.961	0.0
16.333	118.881	0.0
16.500	117.062	0.0
16.667	114.622	0.0
16.833	112.745	0.0
17.000	110.969	0.0
17.167	108.601	0.0
17.333	106.768	0.0
17.500	105.136	0.0
17.667	102.942	0.0
17.833	101.267	0.0
18.000	99.853	0.0
18.167	97.861	0.0
18.333	96.374	0.0
18.500	95.061	0.0
18.667	93.199	0.0
18.833	91.770	0.0
19.000	90.514	0.0
19.167	88.811	0.0
19.333	87.498	0.0
19.500	86.430	0.0
19.667	84.756	0.0
19.833	83.573	0.0
20.000	82.505	0.0
20.167	80.961	0.0
20.333	79.937	0.0
20.500	78.783	0.0
20.667	77.441	0.0
20.833	76.489	0.0
21.000	75.464	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
21.167	74.137	0.0
21.333	73.228	0.0
21.500	72.305	0.0
21.667	70.977	0.0
21.833	69.982	0.0
22.000	69.362	0.0
22.167	68.063	0.0
22.333	67.212	0.0
22.500	66.563	0.0
22.667	65.323	0.0
22.833	64.515	0.0
23.000	63.938	0.0
23.167	62.784	0.0
23.333	61.919	0.0
23.500	61.370	0.0
23.667	60.289	0.0
23.833	59.524	0.0
24.000	59.048	0.0
24.167	57.981	0.0
24.333	57.274	0.0
24.500	56.798	0.0
24.667	55.875	0.0
24.833	55.125	0.0
25.000	54.693	0.0
25.167	53.871	0.0
25.333	53.092	0.0
25.500	52.659	0.0
25.667	51.866	0.0
25.833	51.131	0.0
26.000	50.727	0.0
26.167	50.064	0.0
26.333	49.314	0.0
26.500	48.896	0.0
26.667	48.377	0.0
26.833	47.584	0.0
27.000	47.165	0.0
27.167	46.762	0.0
27.333	45.954	0.0

Data for Injection Test R22-3 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
27.500	45.565	0.0	33.833	30.788	0.0	40.167	21.953	0.0
27.667	45.204	0.0	34.000	30.139	0.0	40.333	21.434	0.0
27.833	44.383	0.0	34.167	29.909	0.0	40.500	21.362	0.0
28.000	44.008	0.0	34.333	29.909	0.0	40.667	21.463	0.0
28.167	43.719	0.0	34.500	29.332	0.0	40.833	20.915	0.0
28.333	42.912	0.0	34.667	29.044	0.0	41.000	20.800	0.0
28.500	42.551	0.0	34.833	29.029	0.0	41.167	20.901	0.0
28.667	42.278	0.0	35.000	28.582	0.0	41.333	20.483	0.0
28.833	41.456	0.0	35.167	28.237	0.0	41.500	20.281	0.0
29.000	41.110	0.0	35.333	28.237	0.0	41.667	20.353	0.0
29.167	40.937	0.0	35.500	27.819	0.0	41.833	20.079	0.0
29.333	40.115	0.0	35.667	27.444	0.0	42.000	19.762	0.0
29.500	39.769	0.0	35.833	27.372	0.0	42.167	19.805	0.0
29.667	39.639	0.0	36.000	27.156	0.0	42.333	19.647	0.0
29.833	38.846	0.0	36.167	26.694	0.0	42.500	19.272	0.0
30.000	38.515	0.0	36.333	26.579	0.0	42.667	19.258	0.0
30.167	38.385	0.0	36.500	26.550	0.0	42.833	19.258	0.0
30.333	37.678	0.0	36.667	25.959	0.0	43.000	18.796	0.0
30.500	37.289	0.0	36.833	25.844	0.0	43.167	18.768	0.0
30.667	37.188	0.0	37.000	25.887	0.0	43.333	18.869	0.0
30.833	36.568	0.0	37.167	25.282	0.0	43.500	18.364	0.0
31.000	36.150	0.0	37.333	25.152	0.0	43.667	18.307	0.0
31.167	36.035	0.0	37.500	25.239	0.0	43.833	18.451	0.0
31.333	35.502	0.0	37.667	24.633	0.0	44.000	17.961	0.0
31.500	35.040	0.0	37.833	24.504	0.0	44.167	17.874	0.0
31.667	34.882	0.0	38.000	24.590	0.0	44.333	18.033	0.0
31.833	34.507	0.0	38.167	23.999	0.0	44.500	17.572	0.0
32.000	33.959	0.0	38.333	23.869	0.0	44.667	17.442	0.0
32.167	33.757	0.0	38.500	23.941	0.0	44.833	17.572	0.0
32.333	33.555	0.0	38.667	23.437	0.0	45.000	17.226	0.0
32.500	32.936	0.0	38.833	23.235	0.0	45.167	17.024	0.0
32.667	32.734	0.0	39.000	23.307	0.0	45.333	17.125	0.0
32.833	32.604	0.0	39.167	22.947	0.0	45.500	16.909	0.0
33.000	31.941	0.0	39.333	22.630	0.0	45.667	16.635	0.0
33.167	31.710	0.0	39.500	22.616	0.0	45.833	16.721	0.0
33.333	31.682	0.0	39.667	22.443	0.0	46.000	16.563	0.0
33.500	31.004	0.0	39.833	22.010	0.0	46.167	16.231	0.0
33.667	30.773	0.0	40.000	21.938	0.0	46.333	16.303	0.0

Data for Injection Test R22-3 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
46.500	16.260	0.0	52.833	12.283	0.0	59.167	9.618	0.0
46.667	15.871	0.0	53.000	12.024	0.0	59.333	9.229	0.0
46.833	15.871	0.0	53.167	12.110	0.0	59.500	9.257	0.0
47.000	15.958	0.0	53.333	12.081	0.0	59.667	9.473	0.0
47.167	15.496	0.0	53.500	11.736	0.0	59.833	9.084	0.0
47.333	15.482	0.0	53.667	11.779	0.0	60.000	9.056	0.0
47.500	15.655	0.0	53.833	11.909	0.0	60.167	9.257	0.0
47.667	15.165	0.0	54.000	11.476	0.0	60.333	8.984	0.0
47.833	15.136	0.0	54.167	11.491	0.0	60.500	8.854	0.0
48.000	15.309	0.0	54.333	11.707	0.0	60.667	8.984	0.0
48.167	14.891	0.0	54.500	11.246	0.0	60.833	8.926	0.0
48.333	14.776	0.0	54.667	11.231	0.0	61.000	8.652	0.0
48.500	14.935	0.0	54.833	11.447	0.0	61.167	8.710	0.0
48.667	14.603	0.0	55.000	11.087	0.0	61.333	8.840	0.0
48.833	14.445	0.0	55.167	10.986	0.0	61.500	8.451	0.0
49.000	14.560	0.0	55.333	11.130	0.0	61.667	8.494	0.0
49.167	14.373	0.0	55.500	10.972	0.0	61.833	8.724	0.0
49.333	14.113	0.0	55.667	10.741	0.0	62.000	8.321	0.0
49.500	14.171	0.0	55.833	10.799	0.0	62.167	8.306	0.0
49.667	14.128	0.0	56.000	10.871	0.0	62.333	8.508	0.0
49.833	13.782	0.0	56.167	10.482	0.0	62.500	8.263	0.0
50.000	13.811	0.0	56.333	10.540	0.0	62.667	8.119	0.0
50.167	13.883	0.0	56.500	10.713	0.0	62.833	8.263	0.0
50.333	13.465	0.0	56.667	10.280	0.0	63.000	8.206	0.0
50.500	13.494	0.0	56.833	10.280	0.0	63.167	7.932	0.0
50.667	13.652	0.0	57.000	10.525	0.0	63.333	8.004	0.0
50.833	13.177	0.0	57.167	10.093	0.0	63.500	8.119	0.0
51.000	13.177	0.0	57.333	10.064	0.0	63.667	7.759	0.0
51.167	13.378	0.0	57.500	10.280	0.0	63.833	7.831	0.0
51.333	12.903	0.0	57.667	9.992	0.0	64.000	8.018	0.0
51.500	12.903	0.0	57.833	9.848	0.0	64.167	7.615	0.0
51.667	13.090	0.0	58.000	9.978	0.0	64.333	7.644	0.0
51.833	12.672	0.0	58.167	9.863	0.0	64.500	7.860	0.0
52.000	12.600	0.0	58.333	9.646	0.0	64.667	7.543	0.0
52.167	12.787	0.0	58.500	9.747	0.0	64.833	7.471	0.0
52.333	12.470	0.0	58.667	9.704	0.0	65.000	7.629	0.0
52.500	12.312	0.0	58.833	9.430	0.0	65.167	7.500	0.0
52.667	12.456	0.0	59.000	9.473	0.0	65.333	7.283	0.0

Data for Injection Test R22-3 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
65.500	7.356	0.0	71.833	5.670	0.0	78.167	4.301	0.0
65.667	7.485	0.0	72.000	5.900	0.0	78.333	4.301	0.0
65.833	7.125	0.0	72.167	5.526	0.0	78.500	4.546	0.0
66.000	7.168	0.0	72.333	5.526	0.0	78.667	4.287	0.0
66.167	7.384	0.0	72.500	5.742	0.0	78.833	4.186	0.0
66.333	6.981	0.0	72.667	5.483	0.0	79.000	4.316	0.0
66.500	6.995	0.0	72.833	5.396	0.0	79.167	4.359	0.0
66.667	7.240	0.0	73.000	5.511	0.0	79.333	4.071	0.0
66.833	6.866	0.0	73.167	5.497	0.0	79.500	4.143	0.0
67.000	6.851	0.0	73.333	5.266	0.0	79.667	4.359	0.0
67.167	7.082	0.0	73.500	5.353	0.0	79.833	3.999	0.0
67.333	6.822	0.0	73.667	5.483	0.0	80.000	4.013	0.0
67.500	6.707	0.0	73.833	5.122	0.0	80.167	4.258	0.0
67.667	6.808	0.0	74.000	5.194	0.0	80.333	4.056	0.0
67.833	6.822	0.0	74.167	5.425	0.0	80.500	3.898	0.0
68.000	6.534	0.0	74.333	5.050	0.0	80.667	4.028	0.0
68.167	6.606	0.0	74.500	5.050	0.0	80.833	4.143	0.0
68.333	6.779	0.0	74.667	5.295	0.0	81.000	3.783	0.0
68.500	6.390	0.0	74.833	5.036	0.0	81.167	3.840	0.0
68.667	6.448	0.0	75.000	4.950	0.0	81.333	4.100	0.0
68.833	6.664	0.0	75.167	5.094	0.0	81.500	3.768	0.0
69.000	6.275	0.0	75.333	5.007	0.0	81.667	3.739	0.0
69.167	6.304	0.0	75.500	4.820	0.0	81.833	3.898	0.0
69.333	6.534	0.0	75.667	4.906	0.0	82.000	3.855	0.0
69.500	6.203	0.0	75.833	5.036	0.0	82.167	3.610	0.0
69.667	6.160	0.0	76.000	4.690	0.0	82.333	3.711	0.0
69.833	6.361	0.0	76.167	4.748	0.0	82.500	3.898	0.0
70.000	6.145	0.0	76.333	4.993	0.0	82.667	3.523	0.0
70.167	6.030	0.0	76.500	4.633	0.0	82.833	3.566	0.0
70.333	6.174	0.0	76.667	4.618	0.0	83.000	3.826	0.0
70.500	6.073	0.0	76.833	4.834	0.0	83.167	3.566	0.0
70.667	5.872	0.0	77.000	4.647	0.0	83.333	3.466	0.0
70.833	6.001	0.0	77.167	4.474	0.0	83.500	3.595	0.0
71.000	6.073	0.0	77.333	4.532	0.0	83.667	3.639	0.0
71.167	5.742	0.0	77.500	4.690	0.0	83.833	3.365	0.0
71.333	5.800	0.0	77.667	4.359	0.0	84.000	3.437	0.0
71.500	6.016	0.0	77.833	4.431	0.0	84.167	3.667	0.0
71.667	5.627	0.0	78.000	4.661	0.0	84.333	3.293	0.0

Data for Injection Test R22-2 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
84.500	3.336	0.0
84.667	3.581	0.0
84.833	3.307	0.0
85.000	3.221	0.0
85.167	3.394	0.0
85.333	3.394	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
85.500	3.134	0.0
85.667	3.221	0.0
85.833	3.408	0.0
86.000	3.048	0.0
86.167	3.105	0.0
86.333	3.365	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
86.500	3.048	0.0
86.667	3.019	0.0
86.833	3.192	0.0
87.000	3.134	0.0

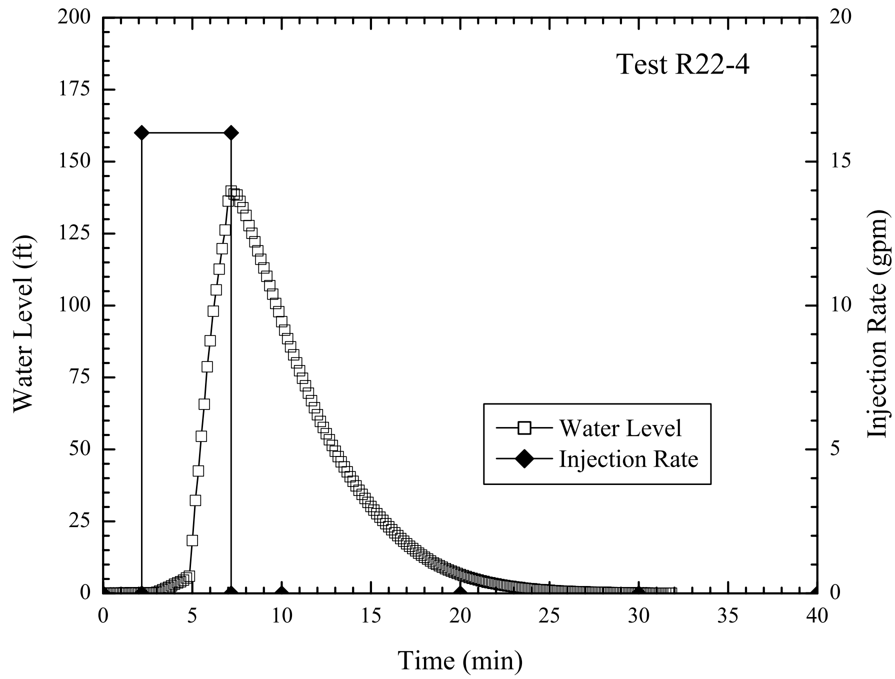


Figure E-5. Injection test R22-4

E-6
Data for Injection Test R22-4

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.043	0.0	3.000	0.375	16.0	6.000	87.761	16.0
0.167	0.115	0.0	3.167	0.778	16.0	6.167	98.038	16.0
0.333	0.086	0.0	3.333	1.239	16.0	6.333	105.444	16.0
0.500	0.000	0.0	3.500	1.714	16.0	6.500	112.649	16.0
0.667	0.115	0.0	3.667	2.118	16.0	6.667	119.725	16.0
0.833	0.130	0.0	3.833	2.608	16.0	6.833	126.225	16.0
1.000	0.130	0.0	4.000	3.184	16.0	7.000	136.265	16.0
1.167	0.130	0.0	4.167	3.645	16.0	7.167	139.776	16.0
1.333	0.130	0.0	4.333	4.020	16.0	7.333	138.706	0.0
1.500	0.144	0.0	4.500	4.582	16.0	7.500	138.417	0.0
1.667	0.144	0.0	4.667	5.331	16.0	7.667	136.178	0.0
1.833	0.144	0.0	4.833	5.979	16.0	7.833	133.982	0.0
2.000	0.072	0.0	5.000	18.373	16.0	8.000	131.310	0.0
2.167	0.144	16.0	5.167	32.254	16.0	8.167	127.771	0.0
2.333	0.158	16.0	5.333	42.520	16.0	8.333	125.069	0.0
2.500	0.158	16.0	5.500	54.533	16.0	8.500	122.137	0.0
2.667	0.158	16.0	5.667	65.697	16.0	8.667	119.003	0.0
2.833	0.173	16.0	5.833	78.741	16.0	8.833	116.057	0.0

Data for Injection Test R22-4 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
9.000	113.039	0.0
9.167	110.137	0.0
9.333	106.917	0.0
9.500	103.971	0.0
9.667	100.709	0.0
9.833	97.879	0.0
10.000	94.400	0.0
10.167	91.441	0.0
10.333	88.497	0.0
10.500	85.639	0.0
10.667	82.868	0.0
10.833	80.068	0.0
11.000	77.355	0.0
11.167	74.715	0.0
11.333	72.118	0.0
11.500	69.550	0.0
11.667	66.967	0.0
11.833	64.486	0.0
12.000	62.077	0.0
12.167	59.740	0.0
12.333	57.619	0.0
12.500	55.456	0.0
12.667	53.393	0.0
12.833	51.374	0.0
13.000	49.398	0.0
13.167	47.509	0.0
13.333	45.692	0.0
13.500	43.947	0.0
13.667	42.246	0.0
13.833	40.530	0.0
14.000	38.915	0.0
14.167	37.343	0.0
14.333	35.829	0.0
14.500	34.373	0.0
14.667	32.960	0.0
14.833	31.591	0.0
15.000	30.207	0.0
15.167	28.909	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
15.333	27.684	0.0
15.500	26.488	0.0
15.667	25.320	0.0
15.833	24.210	0.0
16.000	23.143	0.0
16.167	22.106	0.0
16.333	21.053	0.0
16.500	20.059	0.0
16.667	19.064	0.0
16.833	18.142	0.0
17.000	17.220	0.0
17.167	16.369	0.0
17.333	15.548	0.0
17.500	14.755	0.0
17.667	13.991	0.0
17.833	13.271	0.0
18.000	12.579	0.0
18.167	11.916	0.0
18.333	11.268	0.0
18.500	10.576	0.0
18.667	10.115	0.0
18.833	9.596	0.0
19.000	9.106	0.0
19.167	8.602	0.0
19.333	8.155	0.0
19.500	7.708	0.0
19.667	7.305	0.0
19.833	6.916	0.0
20.000	6.541	0.0
20.167	6.181	0.0
20.333	5.835	0.0
20.500	5.518	0.0
20.667	5.216	0.0
20.833	4.927	0.0
21.000	4.639	0.0
21.167	4.380	0.0
21.333	4.135	0.0
21.500	3.890	0.0

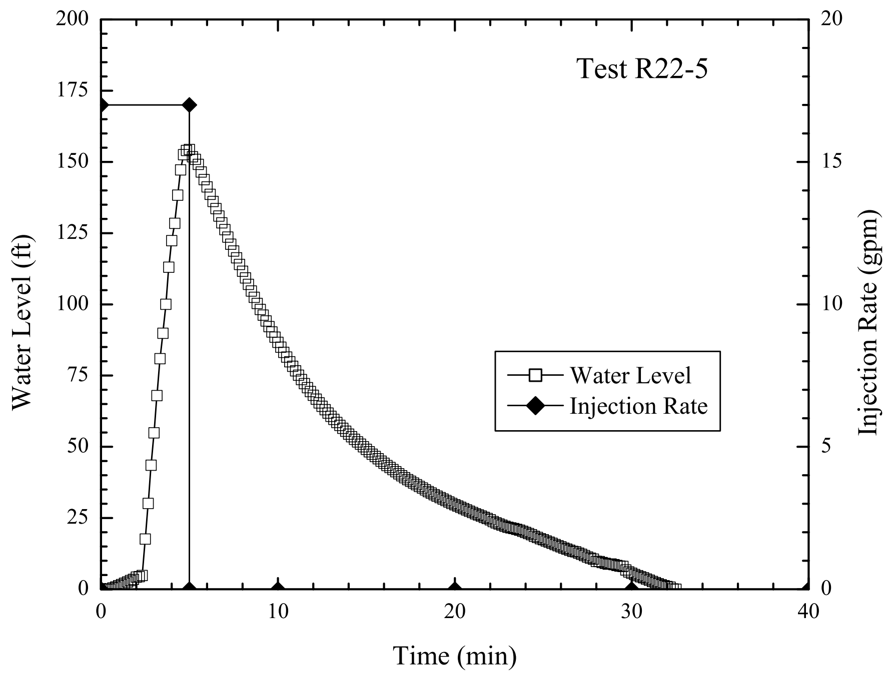
Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
21.667	3.674	0.0
21.833	3.458	0.0
22.000	3.271	0.0
22.167	3.069	0.0
22.333	2.896	0.0
22.500	2.723	0.0
22.667	2.565	0.0
22.833	2.420	0.0
23.000	2.276	0.0
23.167	2.147	0.0
23.333	2.031	0.0
23.500	1.887	0.0
23.667	1.786	0.0
23.833	1.671	0.0
24.000	1.585	0.0
24.167	1.470	0.0
24.333	1.311	0.0
24.500	1.311	0.0
24.667	1.225	0.0
24.833	1.124	0.0
25.000	1.052	0.0
25.167	0.994	0.0
25.333	0.936	0.0
25.500	0.879	0.0
25.667	0.821	0.0
25.833	0.692	0.0
26.000	0.735	0.0
26.167	0.677	0.0
26.333	0.619	0.0
26.500	0.591	0.0
26.667	0.562	0.0
26.833	0.519	0.0
27.000	0.490	0.0
27.167	0.461	0.0
27.333	0.432	0.0
27.500	0.403	0.0
27.667	0.375	0.0
27.833	0.346	0.0

Data for Injection Test R22-4 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
28.000	0.331	0.0
28.167	0.317	0.0
28.333	0.288	0.0
28.500	0.274	0.0
28.667	0.245	0.0
28.833	0.216	0.0
29.000	0.202	0.0
29.167	0.187	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
29.333	0.173	0.0
29.500	0.158	0.0
29.667	0.144	0.0
29.833	0.130	0.0
30.000	0.115	0.0
30.167	0.101	0.0
30.333	0.101	0.0
30.500	0.101	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
30.667	0.086	0.0
30.833	0.072	0.0
31.000	0.072	0.0
31.167	0.058	0.0
31.333	0.058	0.0
31.500	0.043	0.0
31.667	0.043	0.0
31.833	0.029	0.0



E-7. Injection test R22-5

E-8
Data for Injection Test R22-5

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.173	0.0	3.000	54.923	17.0	6.000	141.213	0.0
0.167	0.072	0.0	3.167	67.960	17.0	6.167	138.613	0.0
0.333	0.000	0.0	3.333	80.943	17.0	6.333	136.100	0.0
0.500	0.058	0.0	3.500	89.845	17.0	6.500	133.616	0.0
0.667	0.461	17.0	3.667	100.048	17.0	6.667	131.002	0.0
0.833	0.792	17.0	3.833	113.068	17.0	6.833	128.590	0.0
1.000	1.239	17.0	4.000	122.337	17.0	7.000	126.222	0.0
1.167	1.642	17.0	4.167	128.460	17.0	7.167	123.608	0.0
1.333	2.103	17.0	4.333	138.353	17.0	7.333	121.139	0.0
1.500	2.564	17.0	4.500	147.223	17.0	7.500	118.728	0.0
1.667	3.097	17.0	4.667	152.525	17.0	7.667	116.360	0.0
1.833	3.457	17.0	4.833	153.999	17.0	7.833	114.007	0.0
2.000	4.249	17.0	5.000	154.360	17.0	8.000	111.639	0.0
2.167	4.408	17.0	5.167	151.832	0.0	8.167	109.286	0.0
2.333	4.811	17.0	5.333	150.907	0.0	8.333	107.005	0.0
2.500	17.604	17.0	5.500	149.159	0.0	8.500	104.681	0.0
2.667	30.098	17.0	5.667	146.486	0.0	8.667	102.458	0.0
2.833	43.518	17.0	5.833	143.799	0.0	8.833	100.322	0.0

Data for Injection Test R22-5 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
9.000	98.229	0.0	15.333	47.425	0.0	21.667	25.256	0.0
9.167	96.209	0.0	15.500	46.618	0.0	21.833	24.824	0.0
9.333	94.174	0.0	15.667	45.810	0.0	22.000	24.406	0.0
9.500	92.212	0.0	15.833	44.974	0.0	22.167	23.729	0.0
9.667	90.336	0.0	16.000	44.210	0.0	22.333	23.308	0.0
9.833	88.503	0.0	16.167	43.446	0.0	22.500	22.919	0.0
10.000	86.699	0.0	16.333	42.725	0.0	22.667	22.501	0.0
10.167	84.954	0.0	16.500	41.976	0.0	22.833	22.111	0.0
10.333	83.164	0.0	16.667	41.255	0.0	23.000	21.765	0.0
10.500	81.476	0.0	16.833	40.520	0.0	23.167	21.520	0.0
10.667	79.846	0.0	17.000	39.856	0.0	23.333	21.290	0.0
10.833	78.245	0.0	17.167	39.179	0.0	23.500	21.045	0.0
11.000	76.658	0.0	17.333	38.487	0.0	23.667	20.728	0.0
11.167	75.114	0.0	17.500	37.896	0.0	23.833	20.367	0.0
11.333	73.585	0.0	17.667	37.276	0.0	24.000	19.964	0.0
11.500	72.186	0.0	17.833	36.714	0.0	24.167	19.574	0.0
11.667	70.787	0.0	18.000	36.109	0.0	24.333	19.142	0.0
11.833	69.402	0.0	18.167	35.503	0.0	24.500	18.594	0.0
12.000	68.075	0.0	18.333	34.898	0.0	24.667	18.191	0.0
12.167	66.748	0.0	18.500	34.293	0.0	24.833	17.744	0.0
12.333	65.421	0.0	18.667	33.759	0.0	25.000	17.384	0.0
12.500	64.195	0.0	18.833	33.212	0.0	25.167	16.951	0.0
12.667	63.027	0.0	19.000	32.693	0.0	25.333	16.533	0.0
12.833	61.830	0.0	19.167	32.188	0.0	25.500	16.115	0.0
13.000	60.705	0.0	19.333	31.655	0.0	25.667	15.683	0.0
13.167	59.595	0.0	19.500	31.136	0.0	25.833	15.279	0.0
13.333	58.528	0.0	19.667	30.646	0.0	26.000	14.919	0.0
13.500	57.533	0.0	19.833	30.142	0.0	26.167	14.458	0.0
13.667	56.494	0.0	20.000	29.695	0.0	26.333	14.069	0.0
13.833	55.471	0.0	20.167	29.205	0.0	26.500	13.708	0.0
14.000	54.461	0.0	20.333	28.744	0.0	26.667	13.276	0.0
14.167	53.538	0.0	20.500	28.282	0.0	26.833	13.118	0.0
14.333	52.630	0.0	20.667	27.850	0.0	27.000	12.700	0.0
14.500	51.722	0.0	20.833	27.403	0.0	27.167	12.253	0.0
14.667	50.914	0.0	21.000	26.957	0.0	27.333	11.820	0.0
14.833	50.020	0.0	21.167	26.510	0.0	27.500	11.316	0.0
15.000	49.126	0.0	21.333	26.092	0.0	27.667	10.927	0.0
15.167	48.232	0.0	21.500	25.688	0.0	27.833	10.567	0.0

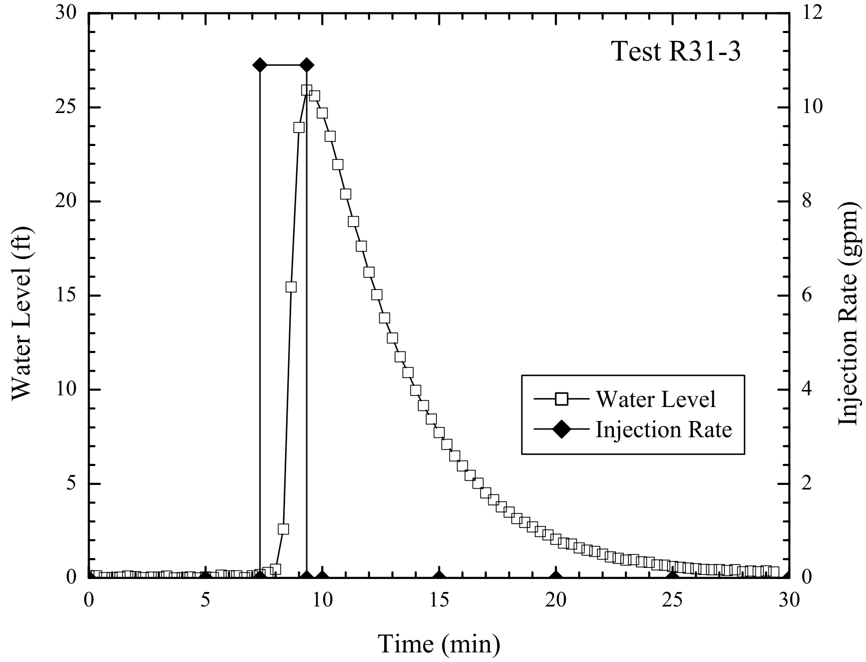
Data for Injection Test R22-5 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
28.000	9.774	0.0	32.500	0.004	0.0	37.000	-5.730	0.0
28.167	9.731	0.0	32.667	-0.212	0.0	37.167	-5.758	0.0
28.333	9.356	0.0	32.833	-0.471	0.0	37.333	-5.802	0.0
28.500	9.097	0.0	33.000	-0.716	0.0	37.500	-5.874	0.0
28.667	8.837	0.0	33.167	-0.975	0.0	37.667	-5.975	0.0
28.833	8.881	0.0	33.333	-1.249	0.0	37.833	-6.061	0.0
29.000	8.636	0.0	33.500	-1.811	0.0	38.000	-6.133	0.0
29.167	8.376	0.0	33.667	-2.099	0.0	38.167	-6.205	0.0
29.333	8.146	0.0	33.833	-2.344	0.0	38.333	-6.320	0.0
29.500	7.987	0.0	34.000	-2.632	0.0	38.500	-6.421	0.0
29.667	6.748	0.0	34.167	-2.863	0.0	38.667	-6.536	0.0
29.833	6.056	0.0	34.333	-3.079	0.0	38.833	-6.680	0.0
30.000	5.609	0.0	34.500	-3.295	0.0	39.000	-6.825	0.0
30.167	5.163	0.0	34.667	-3.482	0.0	39.167	-6.969	0.0
30.333	4.759	0.0	34.833	-3.684	0.0	39.333	-7.098	0.0
30.500	4.356	0.0	35.000	-3.857	0.0	39.500	-7.199	0.0
30.667	4.010	0.0	35.167	-4.058	0.0	39.667	-7.329	0.0
30.833	3.592	0.0	35.333	-4.174	0.0	39.833	-7.415	0.0
31.000	3.174	0.0	35.500	-4.318	0.0	40.000	-7.559	0.0
31.167	2.728	0.0	35.667	-4.476	0.0	40.167	-7.689	0.0
31.333	2.353	0.0	35.833	-4.620	0.0	40.333	-7.790	0.0
31.500	1.950	0.0	36.000	-4.779	0.0	40.500	-7.948	0.0
31.667	1.618	0.0	36.167	-4.923	0.0	40.667	-8.078	0.0
31.833	1.258	0.0	36.333	-5.125	0.0	40.833	-8.164	0.0
32.000	0.955	0.0	36.500	-5.369	0.0	41.000	-8.323	0.0
32.167	0.739	0.0	36.667	-5.557	0.0			
32.333	0.105	0.0	36.833	-5.787	0.0			

Appendix F

Well R-31 Test Data

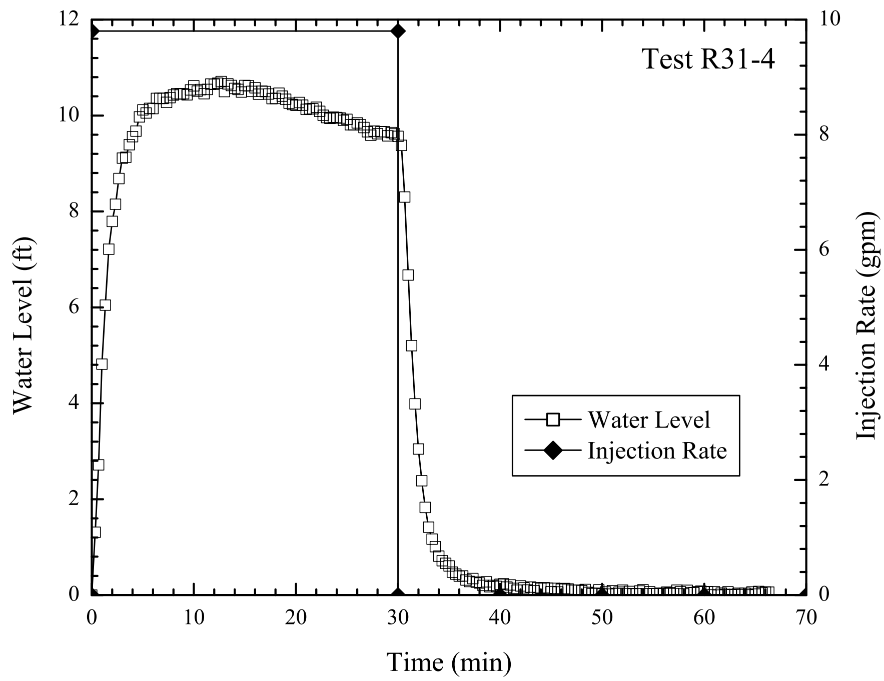
APPENDIX F. WELL R-31-3 TEST DATA



F-1. Injection test R31-3

F-2
Data for Injection Test R31-3

Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)	Elapsed Time (min)	Change in Water Level (ft)
0.000	25.845	5.333	8.368	10.667	1.982	16.000	0.492
0.333	25.537	5.667	7.651	11.000	1.783	16.333	0.454
0.667	24.625	6.000	7.027	11.333	1.729	16.667	0.414
1.000	23.389	6.333	6.412	11.667	1.521	17.000	0.382
1.333	21.888	6.667	5.884	12.000	1.403	17.333	0.362
1.667	20.322	7.000	5.378	12.333	1.336	17.667	0.376
2.000	18.867	7.333	4.960	12.667	1.192	18.000	0.319
2.333	17.548	7.667	4.449	13.000	1.045	18.333	0.365
2.667	16.169	8.000	4.080	13.333	0.967	18.667	0.252
3.000	14.973	8.333	3.704	13.667	0.878	19.000	0.299
3.333	13.743	8.667	3.422	14.000	0.901	19.333	0.258
3.667	12.673	9.000	3.081	14.333	0.783	19.667	0.304
4.000	11.680	9.333	2.882	14.667	0.754	20.000	0.247
4.333	10.845	9.667	2.643	15.000	0.624		
4.667	9.894	10.000	2.392	15.333	0.604		
5.000	9.090	10.333	2.216	15.667	0.532		



F-3. Injection test R31-4

F-4
Data for Injection Test R31-4

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.000	9.8	5.333	10.054	9.8	10.667	10.540	9.8
0.333	1.308	9.8	5.667	10.150	9.8	11.000	10.456	9.8
0.667	2.714	9.8	6.000	10.144	9.8	11.333	10.543	9.8
1.000	4.816	9.8	6.333	10.355	9.8	11.667	10.658	9.8
1.333	6.045	9.8	6.667	10.355	9.8	12.000	10.652	9.8
1.667	7.213	9.8	7.000	10.355	9.8	12.333	10.675	9.8
2.000	7.791	9.8	7.333	10.274	9.8	12.667	10.707	9.8
2.333	8.151	9.8	7.667	10.375	9.8	13.000	10.499	9.8
2.667	8.685	9.8	8.000	10.427	9.8	13.333	10.661	9.8
3.000	9.113	9.8	8.333	10.456	9.8	13.667	10.626	9.8
3.333	9.130	9.8	8.667	10.450	9.8	14.000	10.566	9.8
3.667	9.393	9.8	9.000	10.456	9.8	14.333	10.545	9.8
4.000	9.560	9.8	9.333	10.430	9.8	14.667	10.491	9.8
4.333	9.673	9.8	9.667	10.534	9.8	15.000	10.626	9.8
4.667	9.971	9.8	10.000	10.618	9.8	15.333	10.621	9.8
5.000	10.118	9.8	10.333	10.511	9.8	15.667	10.502	9.8

Data for Injection Test R31-4 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
16.000	10.577	9.8
16.333	10.444	9.8
16.667	10.505	9.8
17.000	10.499	9.8
17.333	10.447	9.8
17.667	10.352	9.8
18.000	10.358	9.8
18.333	10.465	9.8
18.667	10.404	9.8
19.000	10.340	9.8
19.333	10.259	9.8
19.667	10.231	9.8
20.000	10.213	9.8
20.333	10.271	9.8
20.667	10.216	9.8
21.000	10.129	9.8
21.333	10.138	9.8
21.667	10.141	9.8
22.000	10.173	9.8
22.333	10.086	9.8
22.667	10.005	9.8
23.000	9.956	9.8
23.333	9.942	9.8
23.667	9.965	9.8
24.000	9.956	9.8
24.333	9.947	9.8
24.667	9.901	9.8
25.000	9.921	9.8
25.333	9.806	9.8
25.667	9.812	9.8
26.000	9.846	9.8
26.333	9.809	9.8
26.667	9.751	9.8
27.000	9.659	9.8
27.333	9.589	9.8
27.667	9.676	9.8
28.000	9.621	9.8
28.333	9.659	9.8

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
28.667	9.659	9.8
29.000	9.575	9.8
29.333	9.644	9.8
29.667	9.615	9.8
30.000	9.566	9.8
30.333	9.376	0.0
30.667	8.299	0.0
31.000	6.674	0.0
31.333	5.199	0.0
31.667	3.988	0.0
32.000	3.046	0.0
32.333	2.383	0.0
32.667	1.827	0.0
33.000	1.415	0.0
33.333	1.167	0.0
33.667	1.008	0.0
34.000	0.810	0.0
34.333	0.715	0.0
34.667	0.660	0.0
35.000	0.608	0.0
35.333	0.478	0.0
35.667	0.435	0.0
36.000	0.395	0.0
36.333	0.398	0.0
36.667	0.314	0.0
37.000	0.283	0.0
37.333	0.343	0.0
37.667	0.268	0.0
38.000	0.251	0.0
38.333	0.202	0.0
38.667	0.277	0.0
39.000	0.173	0.0
39.333	0.202	0.0
39.667	0.182	0.0
40.000	0.225	0.0
40.333	0.234	0.0
40.667	0.167	0.0
41.000	0.213	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
41.333	0.141	0.0
41.667	0.104	0.0
42.000	0.190	0.0
42.333	0.150	0.0
42.667	0.107	0.0
43.000	0.167	0.0
43.333	0.090	0.0
43.667	0.153	0.0
44.000	0.141	0.0
44.333	0.153	0.0
44.667	0.144	0.0
45.000	0.069	0.0
45.333	0.141	0.0
45.667	0.064	0.0
46.000	0.124	0.0
46.333	0.136	0.0
46.667	0.127	0.0
47.000	0.101	0.0
47.333	0.104	0.0
47.667	0.101	0.0
48.000	0.092	0.0
48.333	0.116	0.0
48.667	0.055	0.0
49.000	0.029	0.0
49.333	0.038	0.0
49.667	0.110	0.0
50.000	0.023	0.0
50.333	0.064	0.0
50.667	0.020	0.0
51.000	0.092	0.0
51.333	0.032	0.0
51.667	0.061	0.0
52.000	0.104	0.0
52.333	0.032	0.0
52.667	0.075	0.0
53.000	0.023	0.0
53.333	0.026	0.0
53.667	0.084	0.0

Data for Injection Test R31-4 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
54.000	0.113	0.0
54.333	0.026	0.0
54.667	0.069	0.0
55.000	0.026	0.0
55.333	0.029	0.0
55.667	0.038	0.0
56.000	0.029	0.0
56.333	0.061	0.0
56.667	0.049	0.0
57.000	0.032	0.0
57.333	0.101	0.0
57.667	0.069	0.0
58.000	0.023	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
58.333	0.098	0.0
58.667	0.052	0.0
59.000	0.049	0.0
59.333	0.067	0.0
59.667	0.081	0.0
60.000	0.069	0.0
60.333	0.067	0.0
60.667	0.003	0.0
61.000	0.067	0.0
61.333	0.000	0.0
61.667	0.041	0.0
62.000	0.012	0.0
62.333	0.067	0.0

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
62.667	0.006	0.0
63.000	0.012	0.0
63.333	0.038	0.0
63.667	0.009	0.0
64.000	0.038	0.0
64.333	0.003	0.0
64.667	0.064	0.0
65.000	0.020	0.0
65.333	0.075	0.0
65.667	0.044	0.0
66.000	0.064	0.0
66.333	0.061	0.0

F-5

Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration for Injection Test R31-4 from Specific Capacity[a]

Well	Aquifer Penetration (%)																	
Eff (%)	**8.33**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	6790	3850	3006	2513	2188	1955	1781	1645	1538	1452	1382	1326	1282	1246	1218	1197	1181	1170	1162
25	5418	3065	2390	1996	1736	1550	1410	1301	1215	1146	1091	1046	1010	982	960	943	930	921	915
30	4505	2545	1982	1654	1437	1281	1165	1075	1003	945	899	862	832	808	789	775	765	757	752
35	3855	2174	1692	1410	1224	1091	991	914	852	803	763	731	706	685	669	657	648	642	637
40	3367	1897	1475	1229	1066	949	862	794	740	697	662	634	612	594	580	569	561	556	552
45	2989	1682	1307	1088	943	840	762	701	654	615	584	559	539	524	511	502	495	490	486
50	2687	1510	1173	976	845	752	682	628	585	550	522	500	482	468	456	448	442	437	434
55	2440	1370	1063	884	766	681	617	568	529	497	472	452	435	422	412	404	399	394	392
60	2234	1254	972	808	699	622	563	518	482	453	430	412	396	385	375	368	363	359	356
65	2060	1155	896	744	644	572	518	476	443	417	395	378	364	353	344	338	333	329	327
70	1912	1071	830	689	596	529	479	441	410	385	365	349	336	326	318	312	307	304	302
75	1783	998	773	642	555	493	446	410	381	358	339	324	312	303	295	290	285	282	280
80	1670	935	724	600	519	460	417	383	356	334	317	303	291	282	275	270	266	263	261
85	1571	879	680	564	487	432	391	359	334	313	297	284	273	265	258	253	249	247	245
90	1482	829	641	531	459	407	368	338	314	295	279	267	257	249	243	238	234	232	230
95	1403	784	606	503	434	385	348	319	297	278	264	252	242	235	229	224	221	219	217
100	**1332**[b]	744	575	477	411	365	330	302	281	264	250	238	229	222	217	212	209	207	205

[a] Input data: Q = 9.8 gpm; s = 9.57 ft at t = 30 min; screen length = 10.0 ft; dw = 10.75 in; S = 0.0001; aquifer thickness = 120.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 8.33%, T = 1,332.4 ft^2/day.

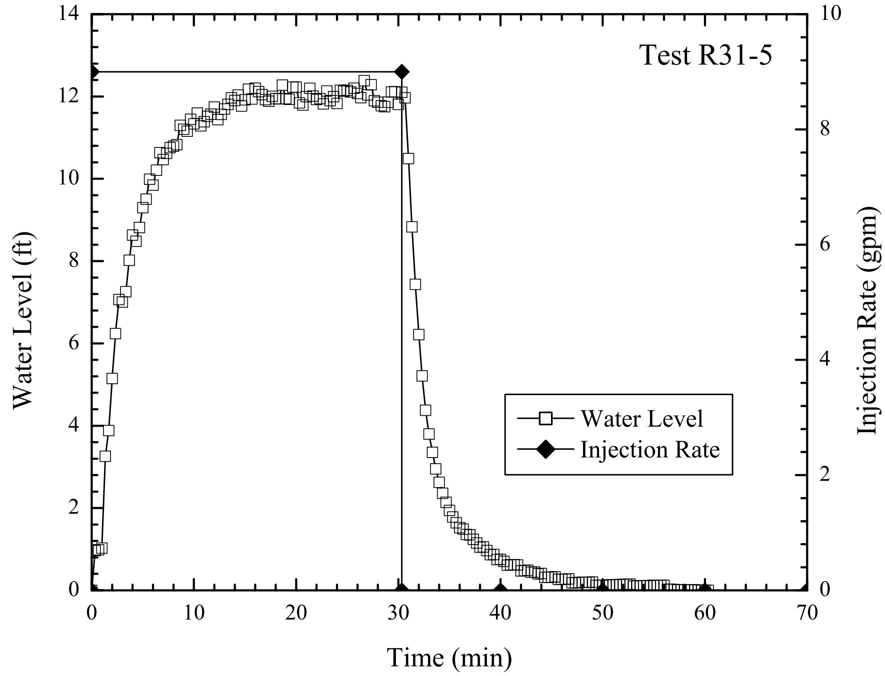


Figure F-6. Injection test R31-5

F-7
Data for Injection Test R31-5

Elapsed Time (min)	Change in Water Level (ft)	Injection Rate (gpm)
0.000	0.000	9.0
0.333	0.968	9.0
0.667	0.985	9.0
1.000	1.028	9.0
1.333	3.258	9.0
1.667	3.883	9.0
2.000	5.148	9.0
2.333	6.239	9.0
2.667	7.064	9.0
3.000	7.004	9.0
3.333	7.258	9.0
3.667	8.020	9.0
4.000	8.635	9.0
4.333	8.482	9.0
4.667	8.818	9.0
5.000	9.296	9.0
5.333	9.504	9.0
5.667	9.988	9.0
6.000	9.846	9.0
6.333	10.209	9.0
6.667	10.636	9.0
7.000	10.467	9.0
7.333	10.620	9.0
7.667	10.757	9.0
8.000	10.793	9.0
8.333	10.831	9.0
8.667	11.297	9.0
9.000	11.205	9.0
9.333	11.156	9.0
9.667	11.445	9.0
10.000	11.335	9.0
10.333	11.598	9.0
10.667	11.286	9.0
11.000	11.387	9.0
11.333	11.518	9.0
11.667	11.570	9.0
12.000	11.745	9.0
12.333	11.436	9.0
12.667	11.564	9.0
13.000	11.696	9.0
13.333	11.807	9.0
13.667	11.966	9.0
14.000	11.902	9.0
14.333	12.035	9.0
14.667	11.768	9.0
15.000	11.921	9.0
15.333	12.177	9.0
15.667	11.940	9.0

Data for Injection Test R31-5 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)	Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
16.000	12.201	9.0	31.333	8.831	0.0	46.667	0.278	0.0
16.333	12.119	9.0	31.667	7.437	0.0	47.000	0.182	0.0
16.667	12.048	9.0	32.000	6.213	0.0	47.333	0.187	0.0
17.000	11.924	9.0	32.333	5.210	0.0	47.667	0.189	0.0
17.333	11.885	9.0	32.667	4.376	0.0	48.000	0.193	0.0
17.667	12.001	9.0	33.000	3.800	0.0	48.333	0.196	0.0
18.000	11.947	9.0	33.333	3.352	0.0	48.667	0.199	0.0
18.333	11.944	9.0	33.667	2.951	0.0	49.000	0.202	0.0
18.667	12.278	9.0	34.000	2.626	0.0	49.333	0.118	0.0
19.000	11.949	9.0	34.333	2.358	0.0	49.667	0.122	0.0
19.333	11.930	9.0	34.667	2.140	0.0	50.000	0.125	0.0
19.667	12.229	9.0	35.000	1.942	0.0	50.333	0.128	0.0
20.000	12.229	9.0	35.333	1.782	0.0	50.667	0.133	0.0
20.333	11.842	9.0	35.667	1.642	0.0	51.000	0.135	0.0
20.667	11.793	9.0	36.000	1.523	0.0	51.333	0.138	0.0
21.000	11.995	9.0	36.333	1.487	0.0	51.667	0.141	0.0
21.333	12.196	9.0	36.667	1.357	0.0	52.000	0.144	0.0
21.667	12.011	9.0	37.000	1.348	0.0	52.333	0.147	0.0
22.000	11.928	9.0	37.333	1.242	0.0	27.333	12.284	9.0
22.333	11.947	9.0	37.667	1.151	0.0	27.667	11.895	9.0
22.667	11.819	9.0	38.000	1.051	0.0	28.000	11.861	9.0
23.000	12.135	9.0	38.333	1.055	0.0	28.333	11.777	9.0
23.333	11.901	9.0	38.667	0.965	0.0	28.667	11.751	9.0
23.667	11.996	9.0	39.000	0.867	0.0	29.000	11.859	9.0
24.000	11.830	9.0	39.333	0.871	0.0	40.000	0.751	0.0
24.333	12.149	9.0	39.667	0.747	0.0	40.333	0.706	0.0
24.667	12.131	9.0	42.667	0.490	0.0	40.667	0.613	0.0
25.000	12.152	9.0	43.000	0.441	0.0	41.000	0.619	0.0
25.333	12.109	9.0	43.333	0.447	0.0	41.333	0.626	0.0
25.667	12.203	9.0	43.667	0.402	0.0	41.667	0.616	0.0
26.000	12.074	9.0	44.000	0.408	0.0	52.667	0.151	0.0
26.333	11.972	9.0	44.333	0.313	0.0	53.000	0.102	0.0
26.667	12.386	9.0	44.667	0.317	0.0	53.333	0.107	0.0
27.000	12.038	9.0	45.000	0.321	0.0	53.667	0.108	0.0
30.000	11.806	9.0	45.333	0.326	0.0	54.000	0.111	0.0
30.333	12.103	9.0	45.667	0.265	0.0	54.333	0.114	0.0
30.667	11.966	0.0	46.000	0.270	0.0	29.333	12.109	9.0
31.000	10.490	0.0	46.333	0.272	0.0	29.667	12.113	9.0

Data for Injection Test R31-5 (continued)

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
55.333	0.120	0.0
55.667	0.121	0.0
56.000	0.124	0.0
56.333	0.023	0.0
56.667	0.022	0.0
57.000	0.019	0.0
42.000	0.474	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
42.333	0.483	0.0
57.333	0.017	0.0
57.667	0.016	0.0
58.000	0.014	0.0
58.333	0.011	0.0
58.667	0.010	0.0
59.000	0.009	0.0

Elapsed Time (min)	Change in Water Level (ft)	Pumping Rate (gpm)
54.667	0.117	0.0
55.000	0.118	0.0
59.333	0.007	0.0
59.667	0.004	0.0
60.000	0.003	0.0
60.333	0.001	0.0

F-8
Transmissivity (ft²/d) as a Function of Well Efficiency and Aquifer Penetration for Injection Test R31-5 from Specific Capacity[a]

Well	Aquifer Penetration (%)																	
Eff (%)	**5.95**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
20	7032	2778	2165	1807	1571	1402	1275	1176	1098	1036	985	945	912	886	866	851	839	831	825
25	5615	2212	1722	1435	1246	1111	1009	930	868	818	777	745	719	698	682	670	660	654	649
30	4672	1836	1428	1189	1031	919	834	768	716	674	641	613	592	574	561	551	543	537	534
35	4000	1569	1218	1014	879	782	709	653	608	573	544	520	502	487	475	466	460	455	452
40	3496	1369	1062	883	765	680	617	567	528	497	472	451	435	422	412	404	398	394	391
45	3104	1214	941	782	677	602	545	501	466	439	416	398	383	372	363	356	351	347	345
50	2792	1090	845	701	607	539	488	449	417	392	372	356	343	332	324	318	313	310	308
55	2536	989	766	636	549	488	442	406	377	354	336	321	309	300	292	287	283	280	277
60	2323	905	700	581	502	446	403	370	344	323	306	293	282	273	266	261	257	254	253
65	2143	834	645	535	462	410	371	340	316	297	281	269	259	251	244	240	236	233	232
70	1988	773	598	495	428	379	343	315	292	274	260	248	239	231	226	221	218	215	214
75	1855	720	557	461	398	353	319	293	272	255	241	230	222	215	209	205	202	200	198
80	1738	674	521	431	372	330	298	273	254	238	225	215	207	200	195	191	189	186	185
85	1635	634	490	405	349	310	280	256	238	223	211	202	194	188	183	179	177	175	173
90	1543	598	462	382	329	292	263	241	224	210	199	190	182	177	172	169	166	164	163
95	1462	566	437	361	311	276	249	228	211	198	188	179	172	167	162	159	157	155	154
100	**1388[b]**	537	414	343	295	261	236	216	200	188	178	169	163	158	153	150	148	146	145

[a] Input data: Q = 9.0 gpm; s = 12.10 ft at t = 30.33 min; screen length = 10.0 ft; dw = 10.75 in; S = 0.0001; aquifer thickness = 168.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 10%, T = 1,387.7 ft²/day..

Appendix G

Summary of Hydraulic Conductivity Values

APPENDIX G. SUMMARY OF HYDRAULIC CONDUCTIVITY VALUES

G-1
Hydraulic Conductivity Estimates in Pajarito Plateau Wells

Well	Dominant Rock Type	Geologic Unit Tested	Unit Symbol	Test Method	K (ft/day)	k[a] (m^2)	Source[b]
PM-5	Bayo Canyon	basalts	Tb	pumping test	0.71	2.56E-13	1
DT-10	Cerros del Rio	basalts	Tb	pumping test	14.87	5.35E-12	1
R22-2	Cerros del Rio	basalts	Tb	injection test	0.04	1.44E-14	2
R31-3	Cerros del Rio	basalts	Tb	injection test	0.48	1.73E-13	2
R9i-1	Cerros del Rio	basalts	Tb	injection test	13.10	4.72E-12	2
R9i-2	Cerros del Rio	basalts	Tb	injection test	0.11	3.96E-14	2
R9i-1	Cerros del Rio	basalts	Tb	injection test	7.10	2.56E-12	2
R9i-1	Cerros del Rio	basalts	Tb	pumping test	6.40	2.30E-12	2
G-5	Older Basalts	basalts	Tb	pumping test	1.17	4.21E-13	1
G-6	Older Basalts	basalts	Tb	pumping test	0.90	3.24E-13	1
GR-1	Older Basalts	basalts	Tb	pumping test	0.50	1.80E-13	3
GR-3	Older Basalts	basalts	Tb	pumping test	1.30	4.68E-13	3
R22-4	Older Basalts	basalts	Tb	injection test	0.54	1.94E-13	2
R22-4	Older Basalts	basalts	Tb	injection test	0.51	1.84E-13	2
CdV-R37-3	Tschicoma	Tschicoma	Tt	injection test	7.01	2.52E-12	4
CdV-R37-4	Tschicoma	Tschicoma	Tt	injection test	11.36	4.09E-12	4
TW-4	Tschicoma	Tschicoma	Tt	pumping test	2.55	9.18E-13	1
CdV-R15	Puye	fanglomerate	Tpf	geophysics	0.60	2.16E-13	5
R-19	Puye	fanglomerate	Tpf	geophysics	0.30	1.08E-13	5
R-13	Puye	fanglomerate+pumpiceous	Tpfp	pumping test	8.00	2.88E-12	2
R-13	Puye	fanglomerate+pumpiceous	Tpfp	pumping test	17.60	6.34E-12	2
CdV-R15-3-4	Puye	fanglomerate	Tpf	geophysics	0.20	7.20E-14	5

Hydraulic Conductivity Estimates in Pajarito Plateau Wells (continued)

Well	Dominant Rock Type	Geologic Unit Tested	Unit Symbol	Test Method	K (ft/day)	k[a] (m^2)	Source[b]
CdV-R15-3-5	Puye	fanglomerate	Tpf	geophysics	0.20	7.20E-14	5
CdV-R15-3-5	Puye	fanglomerate	Tpf	injection test	0.25	9.00E-14	4
R22-3	Puye	fanglomerate	Tpf	injection test	0.32	1.15E-13	2
R22-5	Puye	fanglomerate	Tpf	injection test	0.27	9.72E-14	2
TW-8	Puye	pumiceous	Tpp	pumping test	3.35	1.21E-12	1
CdV-R15-3-6	Puye	pumiceous	Tpp	geophysics	0.70	2.52E-13	5
CdV-R15-3-6	Puye	pumiceous	Tpp	injection test	0.10	3.60E-14	4
R19-6	Puye	pumiceous	Tpp	geophysics	1.40	5.04E-13	5
R19-6	Puye	pumiceous	Tpp	injection test	18.60	6.70E-12	2
R19-7	Puye	pumiceous	Tpp	geophysics	0.60	2.16E-13	5
R19-7	Puye	pumiceous	Tpp	injection test	22.00	7.92E-12	2
R-7	Puye	pumiceous	Tpp	geophysics	0.10	3.60E-14	5
R31-4	Puye	Totavi Lentil	Tpt	injection test	11.10	4.00E-12	2
R31-5	Puye	Totavi Lentil	Tpt	injection test	8.30	2.99E-12	2
TW-1	Puye	Totavi Lentil	Tpt	pumping test	0.54	1.94E-13	1
TW-2	Puye	Totavi Lentil	Tpt	pumping test	32.29	1.16E-11	1
TW-3	Puye	Totavi Lentil	Tpt	pumping test	16.08	5.79E-12	1
O-4	Sante Fe Group	fanglomerate	Tsf	pumping test	4.02	1.45E-12	1
DT-9	Sante Fe Group	sands	Tsf	pumping test	16.35	5.89E-12	1
G-1	Sante Fe Group	sands	Tsf	pumping test	0.94	3.38E-13	1
G-1A	Sante Fe Group	sands	Tsf	pumping test	1.22	4.39E-13	1
G-2	Sante Fe Group	sands	Tsf	pumping test	1.22	4.39E-13	1
G-3	Sante Fe Group	sands	Tsf	pumping test	0.71	2.56E-13	1
G-4	Sante Fe Group	sands	Tsf	pumping test	1.51	5.44E-13	1

Hydraulic Conductivity Estimates in Pajarito Plateau Wells (continued)

Well	Dominant Rock Type	Geologic Unit Tested	Unit Symbol	Test Method	K (ft/day)	k[a] (m²)	Source[b]
GR-2	Sante Fe Group	sands	Tsf	pumping test	0.60	2.16E-13	3
GR-4	Sante Fe Group	sands	Tsf	pumping test	0.70	2.52E-13	3
LA-1B	Sante Fe Group	sands	Tsf	pumping test	1.25	4.50E-13	1
LA-2	Sante Fe Group	sands	Tsf	pumping test	0.47	1.69E-13	1
LA-3	Sante Fe Group	sands	Tsf	pumping test	0.44	1.58E-13	1
LA-4	Sante Fe Group	sands	Tsf	pumping test	0.76	2.74E-13	1
LA-5	Sante Fe Group	sands	Tsf	pumping test	0.40	1.44E-13	1
LA-6	Sante Fe Group	sands	Tsf	pumping test	1.22	4.39E-13	1
O-1	Sante Fe Group	sands	Tsf	pumping test	0.63	2.27E-13	1
PM-1	Sante Fe Group	sands	Tsf	pumping test	4.15	1.49E-12	1
PM-3	Sante Fe Group	sands	Tsf	pumping test	23.99	8.64E-12	1
PM-4	Sante Fe Group	sands	Tsf	pumping test	3.22	1.16E-12	1
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.68	2.45E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.43	1.55E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.12	4.32E-14	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.09	3.24E-14	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.51	1.84E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	4.55	1.64E-12	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.34	1.22E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.66	2.38E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.12	4.32E-14	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	2.41	8.68E-13	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	14.39	5.18E-12	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.91	3.28E-13	6

Hydraulic Conductivity Estimates in Pajarito Plateau Wells (continued)

Well	Dominant Rock Type	Geologic Unit Tested	Unit Symbol	Test Method	K (ft/day)	k[a] (m^2)	Source[b]
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.08	2.88E-14	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.12	4.32E-14	6
Not Reported	Santa Fe Group	undifferentiated	Tsf	not reported	0.13	4.68E-14	6

Notes:

[a] Permeability computed as follows: k (m^2) = K (ft/day) * $3.6*10^{-13}$.

[b] Information Source:

1 = Purtymun (1995, 45344).

2 = McLin and Stone (2004, in preparation).

3 = John Shomaker and Associates (1999).

4 = McLin (2004, in preparation).

5 = Borehole geophysical logs by Schlumberger, Inc.

6 = Daniel B. Stephens and Associates (1994).

This report has been reproduced directly from the best available copy. It is available electronically on the Web (http://www.doe.gov/bridge).

Copies are available for sale to U.S. Department of Energy employees and contractors from:
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(865) 576-8401

Copies are available for sale to the public from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(800) 553-6847

Los Alamos
NATIONAL LABORATORY
EST. 1943