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Hydrologic Tests at Characterization Well R-14

Los Alamos
NATIONAL LABORATORY
EST. 1943

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Stephen G. McLin
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HYDROLOGIC TESTS AT CHARACTERIZATION WELL R-14

by
Stephen G. McLin and William J. Stone

ABSTRACT

Well R-14 is located in Ten Site Canyon and was completed at a depth of 1316 ft below ground surface (bgs) in August 2002 within unassigned pumiceous deposits located below the Puye Formation (fanglomerate). The well was constructed with two screens positioned below the regional water table. Individual static depths measured for each isolated screen after the Westbay™ transducer monitoring system was installed in mid-December 2002 were nearly identical at 1177 ft bgs, suggesting only horizontal subsurface flow at this time, location, and depth. Screen 1 straddles the geologic contact between the Puye fanglomerate and unassigned pumiceous deposits. Screen 2 is located about 50 ft deeper than screen 1 and is only within the unassigned pumiceous deposits.

Constant-rate, straddle-packer, injection tests were conducted at screen 2, including two short tests and one long test. The short tests were 1 minute each but at different injection rates. These short tests were used to select an appropriate injection rate for the long test. We analyzed both injection and recovery data from the long test using the Theis, Theis recovery, Theis residual-recovery, and specific capacity techniques. The Theis injection, Theis recovery, and specific capacity methods correct for partial screen penetration; however, the Theis residual-recovery method does not.

The long test at screen 2 involved injection at a rate of 10.1 gallons per minute (gpm) for 68 minutes and recovery for the next 85 minutes. The Theis analysis for screen 2 gave the best fit to residual recovery data. These results suggest that the 158-ft thick deposits opposite screen 2 have a transmissivity (T) equal to or greater than 143 ft^2/day, and correspond to a horizontal hydraulic conductivity (K) of at least 0.9 ft/day. The specific capacity method yielded a T value equal to or greater than 177 ft^2/day, and a horizontal K of at least 1.1 ft/day. Results from the injection and recovery phases of the test at screen 2 were similar to those from the residual-recovery portion of the test, but were lower by a factor of about two. The response to injection was typical for a partially penetrating well screen in a very thick aquifer.

I. INTRODUCTION

Characterization well R-14 was completed in Ten Site Canyon, immediately southeast of the former Technical Area (TA) 35 liquid-wastewater treatment facility (Figure 1) during August 2002. The well lies on the north side of the channel approximately 1 mi upstream from the confluence of Ten Site and Mortandad Canyons. Geologic units penetrated by R-14 are shown in Figure 2. The section includes (in descending order) 3 ft of soil and fill, 217 ft of Tshirege Member of the Bandelier Tuff, 24 ft of Cerro Toledo interval, 278 ft of Otowi Member, Bandelier Tuff, 12 ft of Guaje Pumice Bed, Otowi Member, Bandelier Tuff, 86 ft of the Puye Formation (fanglomerate), 148 ft of dacitic volcanic rocks referred to as the Cerros del Rio basalt (an informal local name), another 442 ft of Puye Formation (fanglomerate), and 117 ft of unassigned pumiceous deposits. Current data suggests that these unassigned deposits contain pumice that may be related to the Peralta Tuff, typically seen in outcrops to the south (D. Vaniman, personal communication, 2004). The contact with the Totavi Lentil was never reached in R-14. However, it should be located at approximately 1340 ft bgs based on the PM-5 drilling log. According to the Laboratory's geologic model (G. Cole, personal communication, 2004), this contact is located at about 1423 ft bgs according to R-well data through 2002.

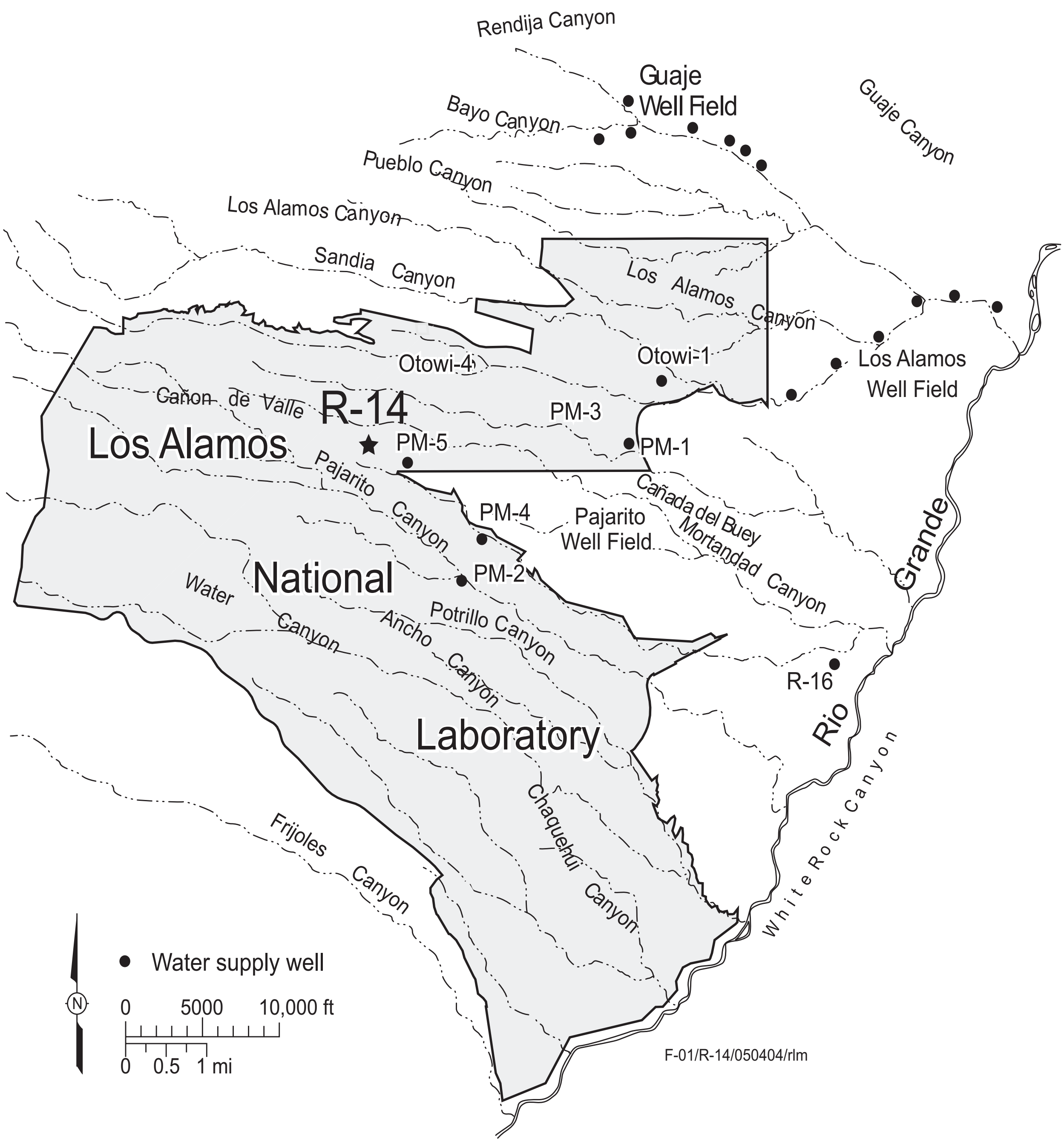


Figure 1. Location of characterization well R-14

No perched saturation was encountered during drilling at R-14. The regional water table lies in the lower of the two penetrated intervals of Puye fanglomerate. A precise water-level measurement was not made at the time of testing (November 12, 2002) because the electrical water-level sounder probe wire stuck to the sidewalls of the small-diameter pipe connected to the packer assembly. However, when we lowered the transducer approximately 1200 ft (based on a surface-mounted cable counter) into the well with screen 2 isolated, it registered 40.18 ft of water above the instrument. These observations suggest that the static water level for screen 2 was about 1160 ft bgs if there was no error in the cable counter (unlikely). A composite water-level measurement of 1182 ft bgs was measured when the well was open to both screens prior to installation of the Westbay™ monitoring system on November 25, 2002. By mid-December 2002, and after the Westbay™ system was installed and operational, more accurate and representative water levels for screens 1 and 2 were 1176.6 ft and 1176.5 ft bgs, respectively. These values translate into piezometric water levels of 5885.5 and 5885.6 ft above mean sea level, respectively. Since screens 1 and 2 are separated by more than 50 ft of saturated sediments, we conclude that these water level measurements reflect essentially horizontal groundwater flow at this time, location, and depth. This interpretation is reasonable considering the limited information that is currently available. However, as longer Westbay™ water-level time series data become available at R-14, this picture may start to resemble the regional setting where seasonal municipal water production is affecting deeper units (e.g., the Totavi Lentil) where downward vertical gradients are prevalent.

R-14 was drilled by fluid-assisted air-rotary and conventional mud-rotary methods to a total depth of 1327 ft bgs within the unassigned pumiceous deposits located below the Puye. Because of sloughing near the bottom of the borehole, the completed well has a slightly shallower depth: 1315.6 ft bgs.

R-14 was constructed with two screens that are both located below the water table (Figure 2). Screen positions were selected to correspond to zones of high porosity and permeability, based on geologic and geophysical observations collected during well drilling. Screen 1 has 32.5 ft of screened openings and straddles the geologic contact between the Puye fanglomerate and unassigned pumiceous deposits. The top of screen 1 is about 19 ft below the top of the regional aquifer. Screen 2 is 6.6 ft long and lies within the unassigned pumiceous deposits. It was placed so that its top is about 104 ft below the composite regional water–table depth. After construction, the well was developed by wire-brushing, bailing, surging, and pumping.

Methods used in drilling, construction, and developing R-14 are compatible with Environmental Protection Agency guidelines (Aller et al. 1991, 70112). Complete details of the installation of R-14 are given in the well-completion report (LANL 2003, 76062).

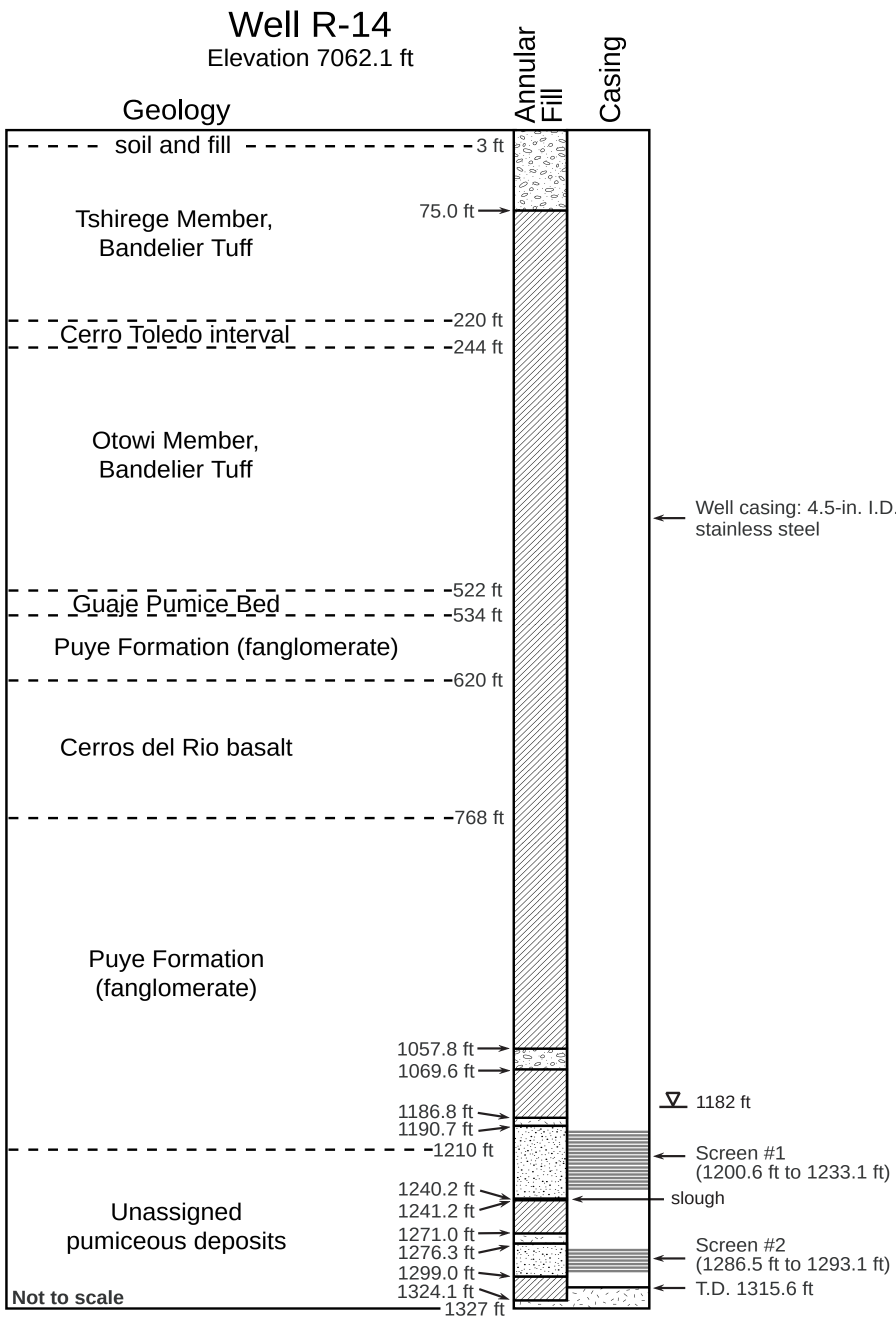


Figure 2. Hydrogeology and construction of well R-14

II. AQUIFER TEST PROCEDURE

Testing at R-14 focused on screen 2. Neither traditional slug tests nor pumping tests could be conducted in R-14 because of its multi-screen construction. However, the slug-test procedure was modified to one that is very similar to a drill-stem test commonly used in oil and gas wells (Earlougher 1977, 73478). Initially, a screen is hydraulically isolated using the straddle-packer assembly shown in Figure 3. Water is then injected by gravity into the well-screen at a constant rate. The water level initially rises very fast; however, the rate of rise eventually decreases, and the water level approaches a new quasi-static equilibrium in response to the constant inflow rate. This new quasi-static level is located some distance above the initial static water level. When injection is abruptly halted, the water level in the well immediately starts to fall and gradually returns to the original static position.

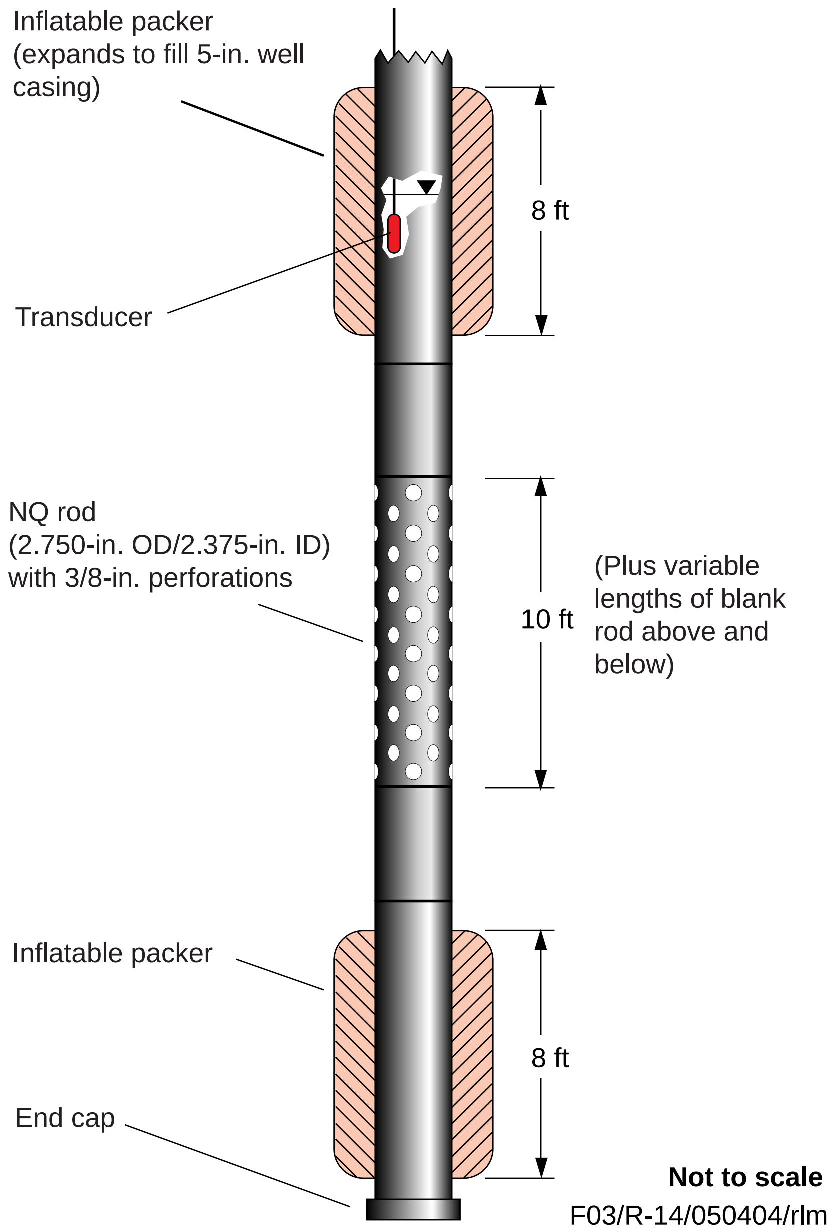


Figure 3. Straddle-packer/injection assembly used in R-14 tests

Field Procedure. A standardized procedure was followed for each test. First, the target screen was isolated by straddle packers deployed inside the well casing and the static water-level condition was re-established. Then, a finite amount of water was introduced at a constant rate for a finite period of time. Water was injected by means of a hose terminating in a short length of galvanized pipe that was inserted into the open end of the riser pipe connected to the packer/injection assembly (Figure 3). Water moved by gravity down the riser pipe, through the upper packer, out of the perforated pipe in the injection assembly, through the screen, and finally into the saturated porous media. Note that this riser pipe had a different diameter from that indicated on the straddle-packer assembly shown in Figure 3. Hence, the straddle-packer assembly had an inside diameter of 2.375 in.; however, the riser pipe for the testing reported here had an inside diameter of only 1.375 in.

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

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

Straddle-packer/injection testing involved several steps:

1. The straddle-packer/injection assembly (Figure 3) was emplaced and packers were inflated from the surface. Gauges on the nitrogen tank were checked frequently to ensure that the packers were holding inflation pressure.

2. Water-level depth was measured with an electric water-level probe until readings stabilized and the static position was recorded. The target transducer depth was determined from this water-level depth measurement.

3. A transducer was emplaced and its position recorded. Its operation and communication with the data-logger were checked by connection to a laptop computer.

4. Water for injection was placed in a large open stock tank. The water was taken up by means of a hose connected to a Bean pump mounted on a trailer. A hose was used to gravity-flow water into the well through a riser pipe connected to the injection assembly. Only municipal water was used for injection.

5. Prior to testing, the rate of discharge from the injection hose was measured, adjusted as required, and allowed to stabilize to a constant value by circulating water from the stock tank to the Bean pump and back to the stock tank. The initial injection rate for each test was based on the sustained yield established during well development.

6. A fixed volume of water was injected down the pipe connected to the straddle-packer assembly, or water was injected at a constant rate over a fixed time interval.

7. The variation in flow rate during injection and total volume injected were evaluated using a flow meter (in-line between the pump and the water supply tank) and a stopwatch or watch with a second hand.

8. Water-level rise during injection and recovery after injection ceased were measured by transducer, recorded by a data-logger, and monitored by a laptop computer. Transducer pressure-head was checked periodically so as not to exceed its rated capacity.

9. When water level returned to the pre-test static position, the test was halted.

10. Post-test data (duration of test, final water level, volume injected, and volume to be purged) were compiled and recorded.

Following testing at screen 2, approximately five times the total volume of water injected was purged from the well.

Comparison to Slug Tests. Traditional slug tests could not be performed because the line on any bailer or slugger could become entangled with the transducer cable. The actual injection tests performed differ from traditional slug tests in that water is not introduced instantaneously. That is, the peak water level does not occur at time zero in these injection tests. Instead, the peak resulting from injection occurs some time later, depending on the length of the injection period, the injection rate, and the depth to water.

Comparison to Pumping Tests. We also could not perform a traditional pumping test because a pump of sufficient size would not fit in the 4.5-in. inside diameter (I.D.) well casing and still have the capacity to stress the aquifer given the lift involved (approximately 1175 ft at R-14). However, injection over an extended period of time mirrors pumping over that same interval. In other words, the response to injection is theoretically the opposite to that of pumping. When a well is pumped, water level drops until pumping ceases and then rises back to the pre-test static level. By contrast, when water is injected into a well, water level rises until injection ceases and then falls back to the pre-test static position. However, this comparison is not perfect. For example, injection and formation waters are not at the same temperature so dissolved air may unintentionally come out of solution during injection and partially clog the well-screen. In addition, entrained air may be mixed with the free-falling injection waters. This temporary well clogging by entrained air may cause well efficiency to become a function of time when it is typically considered a constant. Hence, the results presented here probably underestimate transmissivity by a small but undetermined amount.

A new protocol was also adopted for testing R-14 and other wells installed in fiscal year 2002. This involved multiple tests, in which injection rates and test durations were varied. We conducted three injection tests at each screen selected for study: two short tests and one of prolonged duration. In both short tests, injection lasted only 1 minute. The short tests helped us determine an appropriate injection rate for the longer test. In the third or longer test, injection rate was adjusted based on water-level response in the short tests and the injection time was extended to a period of up to 2 hours. In some cases, where permeability was low, the period of injection in the longer test was shortened to avoid exceeding the depth capacity of the transducer.

III. DATA ANALYSIS

For analysis, we used commercially available software. That is, test data were fitted to appropriate theoretical type-curve models using Aqtesolv™ for Windows (version 3.50, professional). For consistency throughout the analyses, the anisotropy ratio was set at 1. Although Aqtesolv™ automatically provides a storativity (S) value for any analysis by pumping-test methods, such a determination is not valid for single-well tests as reported here. Therefore, no results are listed for this parameter in the summary table.

Tests are assigned a unique number based on the screen number (e.g., 2 for screen 2). Analytical plots are identified by this number and an abbreviation for the data used: (I) tests used injection data, (R) tests used recovery data, and (RR) tests used residual-recovery data. Both of these recovery terms are defined below. Thus, an analytical plot labeled R14-2(R) is for the long test at screen 2 using recovery data. The analytical method and results are also given on the plot for reader convenience.

Response to Injection. Initially, we collected water level responses to injection over time. According to image-well theory, these data can be treated like drawdown data in response to pumping. Hence these data are analyzed by classical pumping techniques.

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

Residual Recovery. We also determined recovery by subtracting observed water levels after injection ceased from the static equilibrium value established prior to injection. Results of this operation are referred to as residual-recovery data. The advantage of this type of recovery data is that it is not potentially biased by a trend line fitted to the observed data as in the simple recovery method mentioned above. However, the disadvantage is that the effects of partial penetration are not taken into consideration when using Aqtesolv™.

We analyzed data collected during the long injection tests at R-14 by various standard pumping-test methods because injection over an extended period of time is analogous to pumping over that same interval. Analyses included data from both the injection and recovery portions of the test. We analyzed test data by four methods for comparison, including Theis injection, Theis recovery, Theis residual-recovery, and specific capacity techniques. To avoid repetition in the text, parenthetical reference citations for the various methods (that is, the years of publication and ER ID number) are given here.

Theis Method (Theis 1935, 70102). The long tests were initially analyzed by the Theis method. Analyses include both injection and simple-recovery data (as defined above). In this classical method, a log-log plot of injection data versus time is fitted to a Theis type-curve. The method assumes that the well is fully penetrating, the hydraulic condition of the aquifer is confined, and application of stress is by prolonged withdrawal or injection of water. The method has been extended to include partial penetration effects in confined aquifers, and to unconfined aquifer conditions by application of the Jacob correction to observed water levels (Walton, 1970, 76044). Theoretically, both techniques should replicate one another. However, when they do not, we might infer that wellbore clogging or other phenomena were present during some phase of the test.

Theis-Residual Recovery Method (Theis 1935, 70102). We also analyzed the test data by the Theis-residual recovery method. This traditional method differs from the Theis analysis of recovery data described above in that it uses residual-recovery data. In this method, a straight line is drawn through a semi-logarithmic plot of residual recovery data versus the dimensionless ratio of t/t'. Residual recovery is the difference between the original static water level and the depth of water at a given instant during recovery. In addition, t is the time since injection started and t' is the time since injection stopped. This method is probably more widely used than the simple Theis-recovery method mentioned above; however, corrections for partial penetration can not be made with this technique. Some readers may wonder why two different recovery methods were employed here. The answer is simple: when using the pumping (or injection) well as the observation well, many hydrologists consider recovery data to be more reliable than pumping (or injection) data because wellbore turbulence is minimized. As previously mentioned, all three approaches should replicate one another exactly. When they do not, we simply have additional information to make inferences about dominant effects during certain phases of the test procedure. These inferences can influence our interpretation as to which method is more reliable.

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

Regardless of the method used, our general approach was to obtain the best curve-match possible and then evaluate the resulting hydraulic-parameter values. Data from each test were analyzed by multiple methods and results compared. Interpretation of these results is treated in the discussion section for each test.

IV. TEST DATA ANALYSES

The top of screen 2 lies at a depth of 1286.5 ft bgs and approximately 104.5 ft below the composite water-table depth (Figure 2). We did not test Screen 1 because it straddles the geologic contact between the Puye fanglomerate and unassigned pumiceous deposits that are below it. Instead we only test screen 2. We performed three injection tests at screen 2: two of short duration and one of prolonged duration. Again, the purpose of the first two short injection tests was to establish an optimal injection rate for the long test. The design and results for the long test are given in Table 1 and field data are given in Appendices A through C.

Test 2a. In the first short test at screen 2, water was injected between packers at a rate of 8.25 gallons per minute (gpm) for 1 min. Initially, water rose in response to injection. Although injection stopped after 1 min, the water level continued to rise for a short time. Then the water level rapidly dropped below the initial static position before rapidly rising again to a second, higher peak value. The water level then began a slow, exponential decline back to the initial static position. Although oscillatory data cannot presently be analyzed because available slug-test methods assume instantaneous delivery of water, test 2a helped us determine the appropriate injection rate for the long test (2c). The data for test 2a are given in appendix A.

Table 1
Summary of Injection Testing at Well R-14

Parameter	Screen 1	Screen 2
Geologic unit	Puye fanglomerate & unassigned pumiceous deposits	Unassigned pumiceous deposits
Screened Interval (ft)[a]	1200.6-1233.1	1286.5–1293.1
Screen Length (ft)	32.5	6.6
Filter-Pack Length (ft)	53.4	22.7
Saturated Thickness (ft)	28.0	≥ 158
Static Water Level (ft)	about 1,182	about 1182
Average Injection Rate (gpm)	not tested	10.1
Injection rate variation (%)		< 1
Injection Period (min)		69
Total Volume Injected (gal)		720
Volume Purged after Test (gal)	4750	
Transmissivity or T (ft^2/day)[b]		Theis (I) = 72.4 Theis (R) = 68.9 Theis (RR) ≥ 142.5 Specific Capacity ≥ 177.2
Hydraulic Conductivity or K (ft/day)		Theis (I) = 0.5 Theis (R) = 0.4 Theis (RR) ≥ 0.9 Specific Capacity ≥ 1.1
Recommended T & K values		Use Theis (RR) or SC

[a] All depths are in feet below ground surface

[b] Injection (I), recovery (R), and residual-recovery (RR) data used in test analysis

Test 2b. In the second short test, water was injected between packers at a rate of 14.75 gpm for 1 min. As in the first test, the water-level response was oscillatory. Initially, water rose to an initial peak value, dropped almost back to the static position, and then rose again to a second but lower peak value. From there, the water level declined exponentially back to static equilibrium. In contrast to the first test, the second peak in test 2b was lower than in test 2a. This test could not be analyzed by available slug-test methods because water was not injected instantaneously. The data for test 2b are given in Appendix B.

Test 2c. The third or long test at screen 2 involved injection at a rate of 10.1 gpm for about 69 min. Injection was then stopped and water level recovery was monitored for the next 85 min. The water level response was much less oscillatory than for the first two tests. After rising rapidly to an initial peak, water levels began to gently oscillate around a gradually rising trend until injection was halted. This small but significant oscillatory behavior cannot be attributed to fluctuations in injection rate since this rate was essentially constant (i.e., less than 1% variation). In addition, the observed small, high-frequency oscillations are not associated with low frequency barometric pressure fluctuations. In all probability, these oscillations are due to well screen clogging as dissolved air came out of solution because the injection and formation waters were at different temperatures. These oscillations may also have resulted from entrained air captured during the free-fall injection test procedure. When injection ceased, the water level immediately began to decline smoothly back toward the pre-test static position. Water-level data for both injection and recovery portions of the test are given in Appendix C. Design parameters and test results are summarized in Table 1.

Field data are shown in Figure 4. Curves for injection and simple recovery data are compared in Figure 5. These two curves are dramatically different; normally we expect these two curves to resemble one another. These differences between injection and simple recovery are most likely due to well screen clogging during injection. This clogging is probably related to dissolved air coming out of solution because the injection and formation waters are at different temperatures, or because of entrained air captured by injection waters during its 1175-ft free-fall. A test configuration diagram is shown in Figure 6 listing important test parameters.

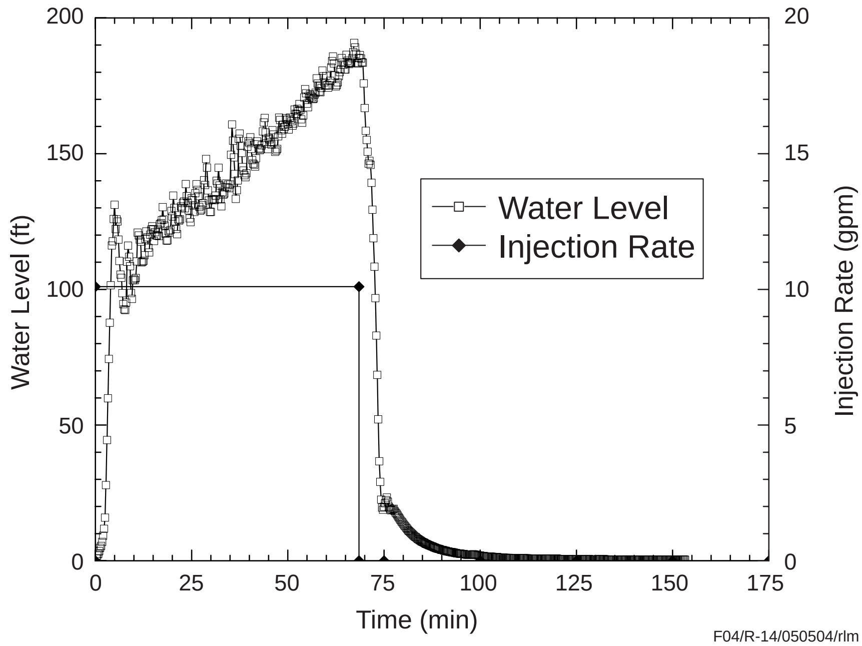


Figure 4. Field plot for the three tests at R-14, screen 2

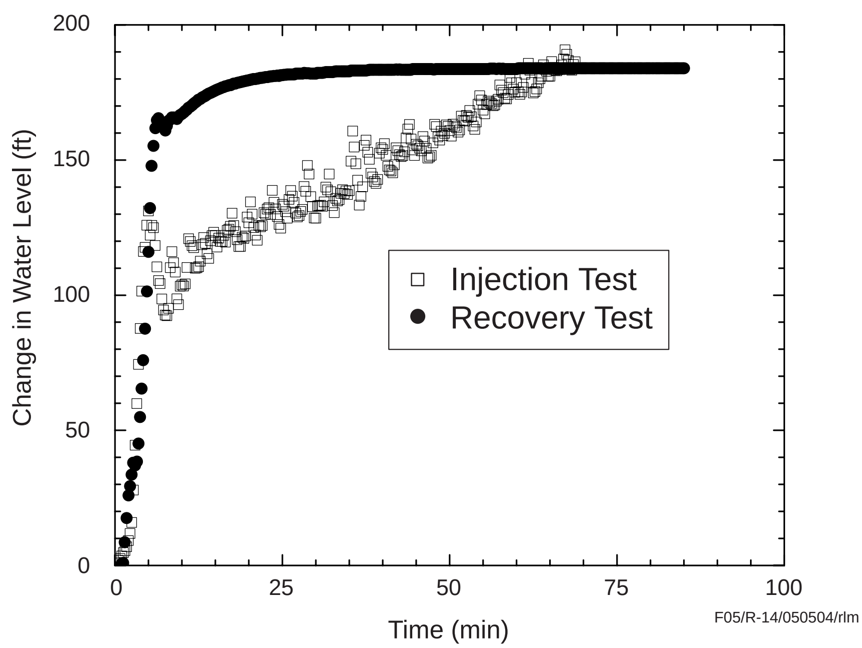
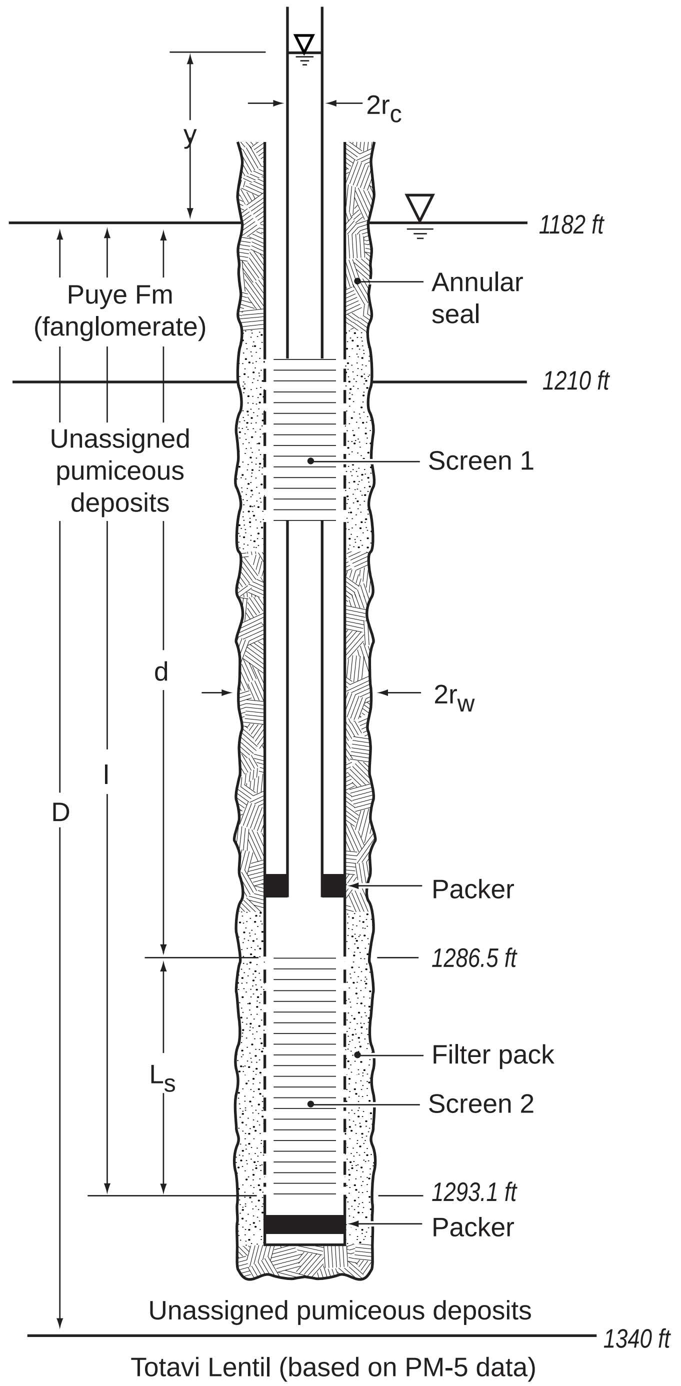


Figure 5. Comparison of injection and recovery data for test R-14, screen 2



$D = 158.0$ ft

$d = 104.5$ ft

$l = 111.1$ ft

$L_s = 6.6$ ft

$$r_c = \frac{1.375}{24} = 0.0573 \text{ ft}$$

$$r_w = \frac{12.75}{24} = 0.5313 \text{ ft}$$

Figure 6. Test configuration parameters for the R14-2 aquifer test

Theis Analysis. We analyzed both injection (Figure 7) and recovery (Figure 8) data from test 2c by the Theis method for confined-aquifer conditions even though the aquifer is phreatic at this location. The Jacob correction for phreatic aquifer conditions was not applied since the well screen was not dewatered during the test. This correction would make water levels higher in response to injection (i.e., the opposite of pumping), and would result in an under-estimated T value. The Aqtesolve™ program corrects the Theis method for partial aquifer penetration. As seen in Figure 7 for the injection phase, we obtained a T value of 72.4 ft^2/day. Dividing this T by a saturated thickness of 158 ft gives a K of 0.5 ft/day. However, as seen in Figure 8 for the recovery phase, we obtained a T value of 68.9 ft^2/day and a K of 0.4 ft/day. Considering the differences between injection and recovery responses (i.e. Figure 5), it is encouraging that the results for the Theis analyses (Figures 7 and 8) differ only by a factor of 1.1. We are cognizant, however, of the subjective nature of the curve-fitting procedure required to obtain recovery data. At the same time, we also recognize that recovery is much smoother than injection because these data do not contain significant wellbore turbulence effects associated with injected waters free-falling nearly 1175 ft before exiting the well screen and filter pack. These analyses also do not consider temperature differences between injection and formation waters that might cause dissolved air to come out of solution and clog the well screen.

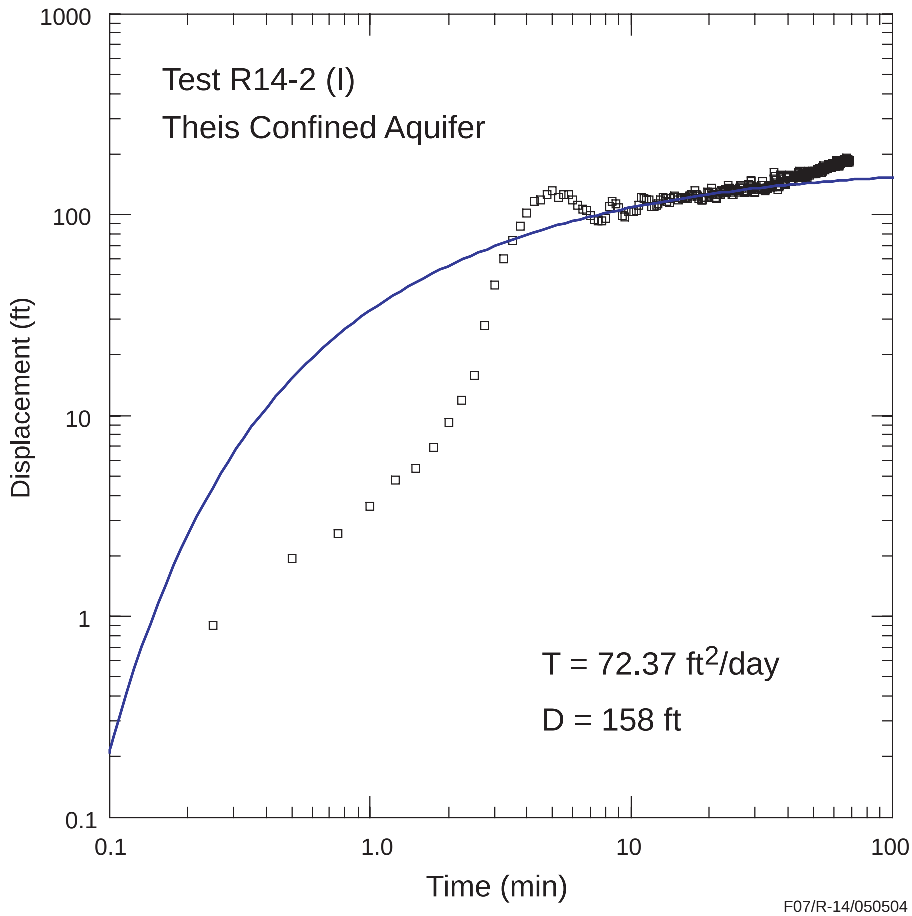


Figure 7. Theis confined aquifer analysis for R14-2 injection data

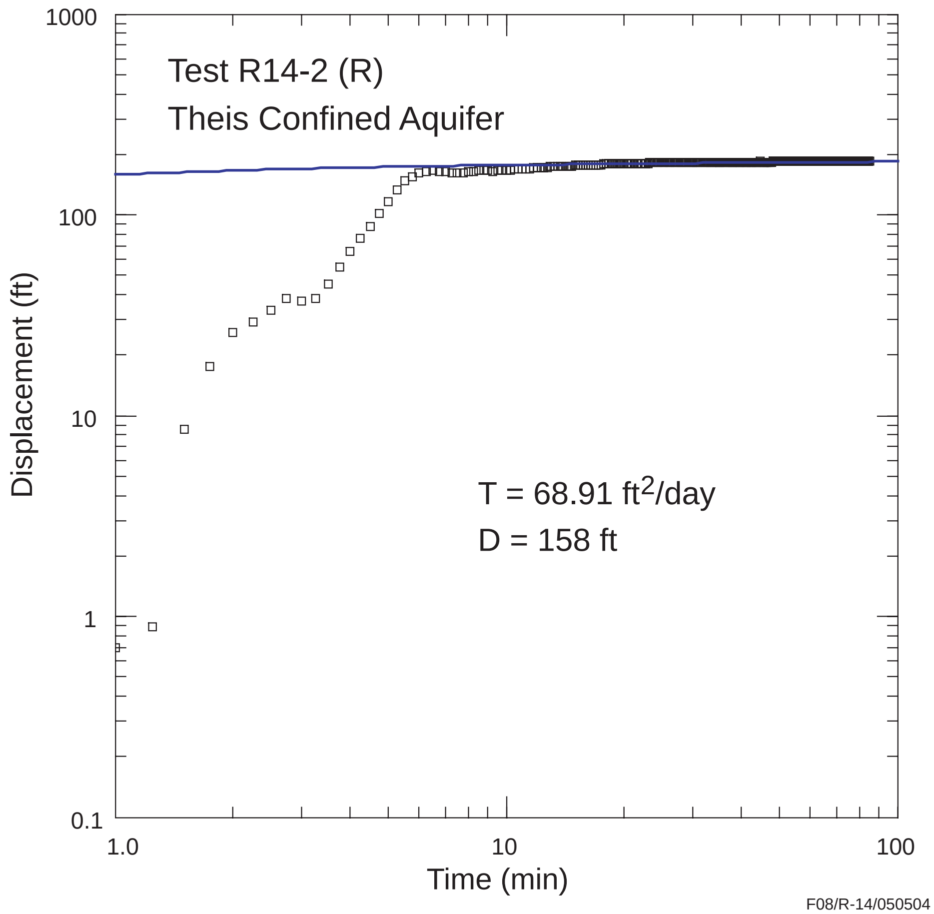


Figure 8. Theis confined aquifer analysis for R14-2 recovery data

Theis-Residual Recovery Analysis. For further comparison, we also analyzed test 2c data by the Theis-recovery method (Figure 9). Note that Aqutesolv™ does not correct for partial penetration with this technique. In addition, this method differs from that used in the Theis recovery analysis (Figure 8) because it uses residual-recovery data. Recall that residual-recovery is defined as the difference between the pre-test static water level and the observed water level during recovery (Driscoll, 1986, 70111, pp. 252–260). The advantage of this approach is that a trend in injection water levels through the recovery period is not required to compute recovery. Note that a T of 142.5 ft^2/day was obtained, and corresponds to a K of 0.9 ft/day. In Figure 9, t is defined as time since injection began and t' is time since injection stopped. Hence, the lower end of the dimensionless time axis (i.e., between 1 and 10) actually represents late time, while the upper end of the dimensionless time axis (i.e., about 50 to 1000) represents early time. Likewise in Figure 9, S is defined as storativity during injection, and S' is storativity during recovery. Theoretically, the S/S' ratio should approach 1 if no boundary is present. However, if a barrier (or no-flow) boundary is present, then S/S' is < 1. If a recharge boundary is present, then S/S' is > 1. An S/S' value of 1.28 for test 2c suggests that a recharge boundary might have been encountered at late time. This is exactly the opposite of implications of the Theis analysis presented in Figure 7. However, the S/S' ratio can also be affected by atmospheric-pressure effects near the end of the test (unlikely in this test). Alternately, we might also conclude that the expanding 3-D cone of impression has caused a flattening slope change. These flattening changes are generally associated with recharge, leakage, or an increasing T value going away from the well screen, rather than a boundary. Hence, no conclusive statement can be made about the boundary type, or even if one really exists. We subjectively conclude that boundary effects are not present. Such effects are best confirmed using a separate observation well and tests of even longer duration than 2c, where changes in barometric pressure can be taken into account. Interestingly, the T value obtained from the Theis-residual recovery analysis shown in the expanded scale of Figure 10 suggests a flattening slope over increasing time. This type of behavior is typical for a partially penetrating well in a very thick aquifer or when T increases laterally away from the well screen.

Specific-Capacity Analysis. Finally, we utilized a modified version (McLin, 2004, 82834) of the specific-capacity method of Bradbury and Rothschild (1985, 76040) to compute a value for T (Appendix D-1). Results from test 2c are shown in Figure 11 and in Appendix D-3 using input values listed in D-2. This range in T values demonstrates that the specific capacity method is relatively sensitive to variations in partial penetration and well losses for test 2c over an expected range of values for these parameters, and probably represents a lower limit for the actual T value. For optimum conditions at screen 2 (i.e., assuming 100% well efficiency, 100% aquifer penetration, and a formation storativity of 0.01), we obtain a T of 5.4 ft^2/day (see Appendix D-3). For more realistic conditions when well efficiency is 100% (estimated) and a partial penetration is 4.2% (observed), we obtain a T of 177.2 ft^2/day (Appendix D-3). Dividing this T by a saturated thickness of 158 ft gives a K of 1.1 ft/day. Note that this latter T value closely corresponds with the value for T obtained for the analyses of residual-recovery data.

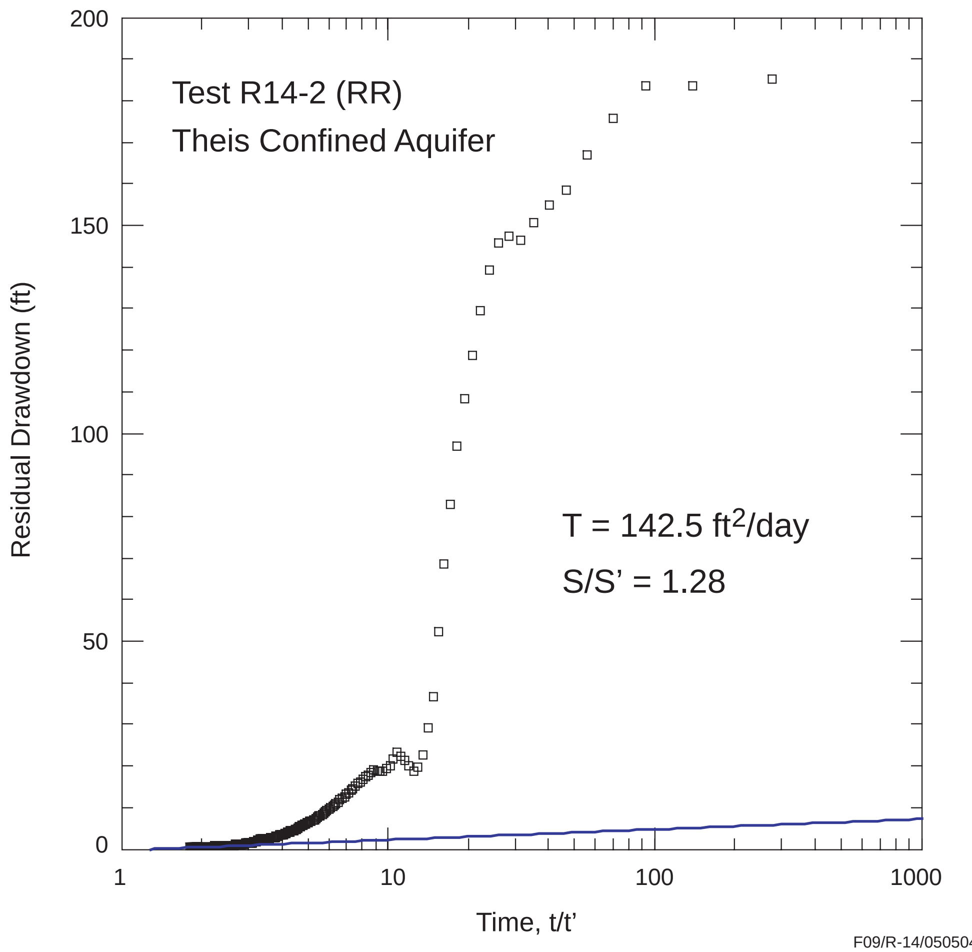


Figure 9. Theis confined aquifer analysis for R14-2 residual recovery data

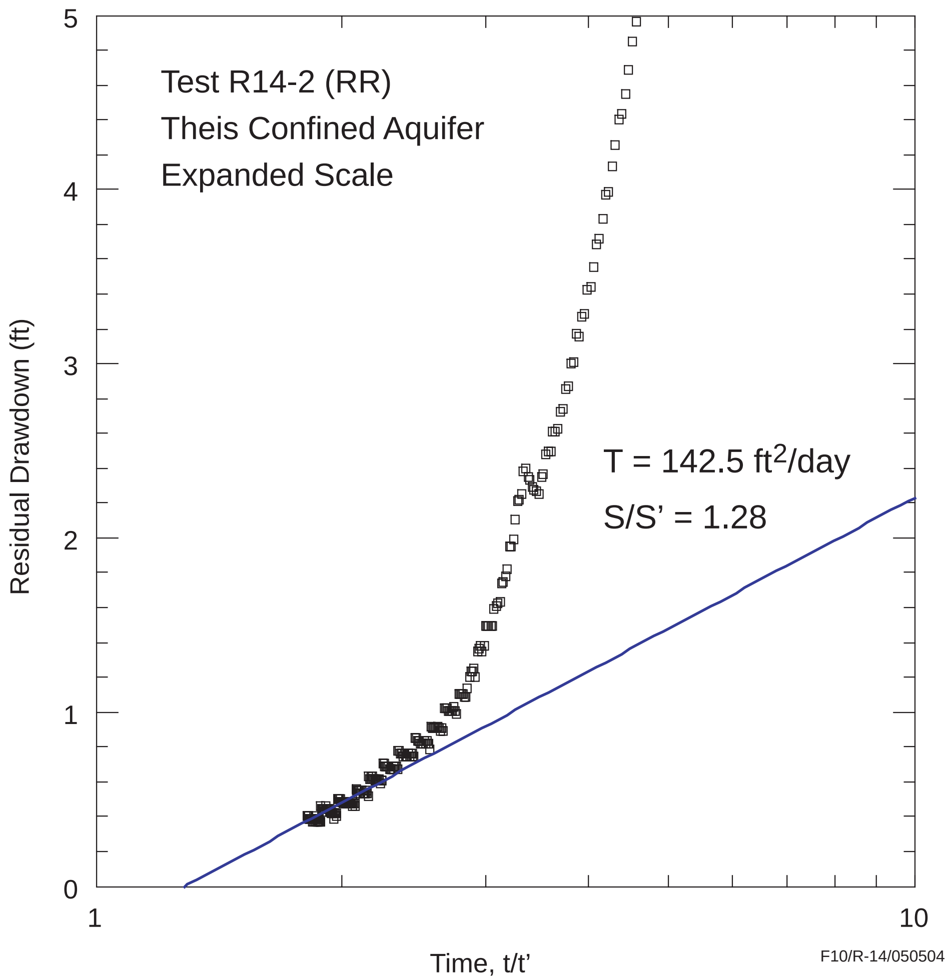


Figure 10. Expanded scale for Theis confined aquifer analysis for R14-2 residual recovery data

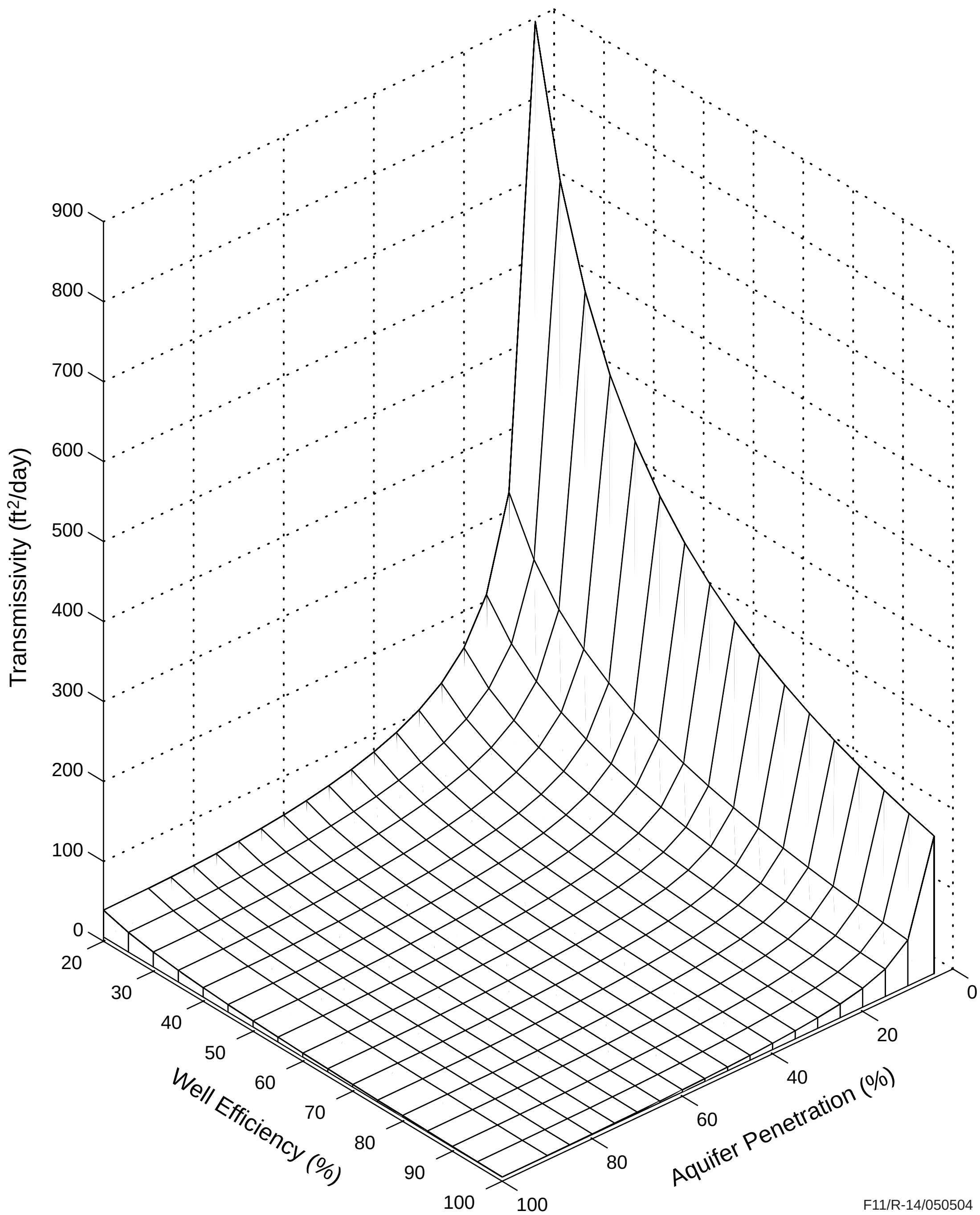


Figure 11. Impact of well efficiency and aquifer penetration on T values for R14-2 test

Discussion. The static water level obtained before the start of test 2a was reestablished after each of the three injection tests at screen 2 (see Appendices A-1, B-1, and Figure 4). However, the dilemma encountered in testing R-wells on Pajarito Plateau is that many of these wells encounter a severe case of partial well penetration in a massively thick aquifer. Well R-14 was no exception. Hence, when these wells are tested, the cone of depression (or impression in the case of injection) expands both horizontally and vertically throughout the test unless a sufficiently tight aquitard is encountered at depth to limit the growth of the cone in the vertical direction. The problem is that the depth of the cone is not known unless an observation well is available. Hence, it is often not possible to know what aquifer thickness to use when calculating hydraulic conductivity (*K*), using the relationship $K = T/D$, where *T* is transmissivity and *D* is saturated thickness. Hence, T may increase as the cone expands because D is increasing in an unknown fashion. This condition makes test analyses extremely difficult because there is no analytical method that exactly applies to these complex test conditions. In addition, there is some additional uncertainty associated with the test results than can not be eliminated.

Figure 5 shows time-injection and time-recovery data from R-14. On each plot, the effect of casing storage is apparent (i.e., the steep portion of each plot before the slope changes at about 6–12 minutes). Recall that the duration of casing storage can be calculated from the following equation (Schafer 1979, 73449):

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

where t_c is the duration of casing storage (minutes), *D* is the inside diameter of the well casing (1.375 in. here), *d* is the outside diameter of column pipe (zero inches for the injection tests here), *Q* discharge rate (gpm), and *s* is drawdown (or recovery in ft) at time t_c. The data from the R-14 test produced a casing storage duration of about 12 min for both the injection and recovery test phases. In other words, the injection and recovery data describe a steep curve for about 12 min. This curve gradually transitions to the correct theoretical slope after these effects have dissipated. This formula usually produces a conservative t_c estimate. In many tests, the observed effects of casing storage can be as little as half the theoretical value because the asymptotic approach of the data to the theoretical drawdown curve have been largely achieved by then. Thus, a calculated value of 12 min. might imply that observed casing storage effects are completed in about 6 min. Inspection of the time-injection graph on Figures 7, and the time-recovery plot in Figure 8, shows that the observed duration of casing storage effects were about midway between these times for both injection and recovery. Depending on exactly how one fits the theoretical type-curves and field data in these figures, these observed casing storage times can vary anywhere from about 6–12 min. for injection and recovery.

These effects are dramatically apparent in Figures 9 and 10. Once casing storage effects have stopped at about 9 min (i.e., where t/t' is about 10 in Figure 9), a gradually flattening of the curve becomes apparent. This flattening behavior is readily apparent in Figure 10 as t/t' becomes smaller and smaller. This behavior reflects an increase in transmissivity farther away from the well caused by the ever-expanding cone of impression. The behavior is typical of a partially penetrating well in a very thick aquifer.

Which analytical method gives the most representative hydraulic properties for the formation opposite screen 2 in R-14? On the surface, the specific-capacity technique appears to be the least accurate of all techniques presented because it only uses one value for injection at one time during the entire test. This is in stark contrast to a conventional aquifer test in which numerous s and t values are matched to an appropriate theoretical type-curve. However, according to Walton (1970, 76044, pp. 314–321), the specific-capacity method gives minimum values for T because the effects of partial penetration, well losses, and hydrogeologic boundaries are taken into consideration. This is not the case with the other methods available for analysis.

Ultimately, we feel that the Theis analysis of residual-recovery data (Figures 9 and 10) and the specific capacity methods provide the best estimates of T for the material behind screen 2 because these values are not based on water level data collected during injection.

V. SUMMARY AND CONCLUSIONS

We obtained reasonable results for hydraulic properties for sediments near screen 2 at well R-14 from injection tests using a straddle-packer assembly that directs injected waters horizontally into the target medium opposite the isolated screen. Screen 1 was not tested because it straddles the geologic contact between the Puye fanglomerate and the unassigned pumiceous deposits. Instead, testing at screen 2 focused on evaluating these unassigned pumiceous deposits.

The multiple-test approach employed at screen 2 used two short tests with different injection rates and one long test at a constant injection rate. The purpose of the short tests was to determine an appropriate injection rate for the long test. Interestingly, the short tests were characterized by oscillatory water-level responses. In addition, the long test showed a normal injection response at screen 2 for a partial penetrating well in a very thick aquifer. This response was characterized by an ever-flattening curvature on the residual-recovery plot. We analyzed both injection and recovery data from the long test by the Theis, Theis-recovery, Theis-residual recovery, and specific-capacity methods for comparison. However, the latter two methods provide the best estimates for transmissivity at this location.

During the long test at screen 2, water was injected at a constant rate of 10.1 gpm for 69 min and recovery data were monitored for an additional 85 min. The 6.6 ft screen is located within the 158-ft thick unassigned pumiceous deposits located below the Puye fanglomerate. Hence, the well screen only covers 4.2% of the total formation thickness. This condition represents an extreme case of partial penetration in a very thick aquifer. Furthermore, well screen clogging caused by dissolved or entrained air coming out of solution makes the injection data suspect. Dissolved air coming out of solution is associated with temperature differences between injection and formation waters. The entrained air problem is related to the test design since injection waters must free-fall about 1175 ft before reaching the regional water table. Consequently, the Theis analysis of injection and simple recovery data are not considered reliable. In addition, the Theis analysis of residual-recovery data and the specific capacity methods yield minimum values for the estimated transmissivity. These techniques yielded a minimum T value of 142.5 and 177.2 ft^2/day, respectively. The corresponding minimum horizontal K values are 0.9 and 1.1 ft/day, respectively, and are based on a saturated thickness of 158 ft.

VI. ACKNOWLEDGEMENTS

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Appendix A

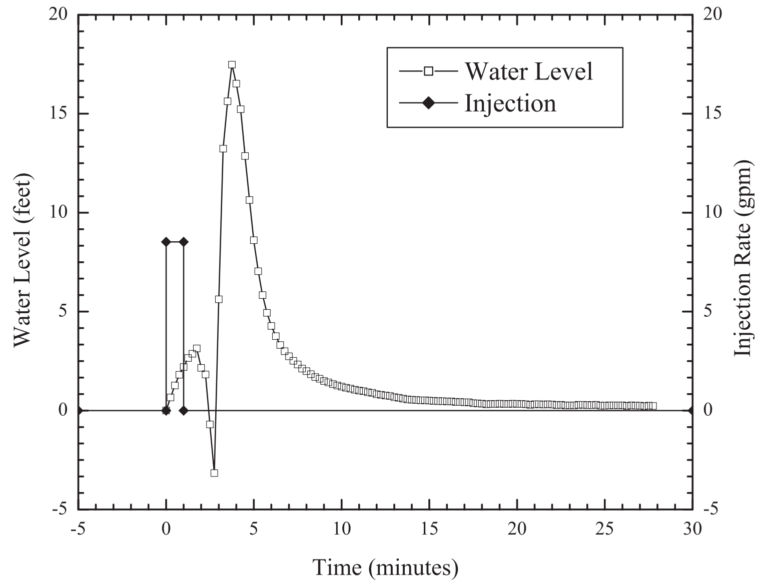
Well R-14, Screen 2, Test a

Contents

A-1 Field Plot for Injection Test 2a

A-2 Data for Injection Test 2a

A-1. Field Plot for R-14, Screen 2, Test a



A-2. Data for R-14, Screen 2, Injection Test a

t (min)	s (ft)	Q (gpm)
0.000	0.003	8.52
0.250	0.663	8.52
0.500	1.265	8.52
0.750	1.810	8.52
1.000	2.197	8.52
1.250	2.655	0.00
1.500	2.870	0.00
1.750	3.143	0.00
2.000	2.154	0.00
2.250	1.824	0.00
2.500	-0.699	0.00
2.750	-3.164	0.00
3.000	5.623	0.00
3.250	13.236	0.00
3.500	15.631	0.00
3.750	17.481	0.00
4.000	16.520	0.00
4.250	15.230	0.00
4.500	12.864	0.00
4.750	10.641	0.00
5.000	8.605	0.00
5.250	7.042	0.00
5.500	5.838	0.00
5.750	4.935	0.00
6.000	4.275	0.00
6.250	3.759	0.00
6.500	3.315	0.00
6.750	2.999	0.00
7.000	2.741	0.00
7.250	2.512	0.00
7.500	2.326	0.00
7.750	2.125	0.00
8.000	1.996	0.00
8.250	1.838	0.00
8.500	1.695	0.00
8.750	1.609	0.00
9.000	1.494	0.00
9.250	1.423	0.00
9.500	1.337	0.00
9.750	1.265	0.00
10.000	1.208	0.00
10.250	1.150	0.00
10.500	1.107	0.00
10.750	1.050	0.00
11.000	1.007	0.00
11.250	0.978	0.00
11.500	0.921	0.00
11.750	0.892	0.00
12.000	0.821	0.00
12.250	0.792	0.00
12.500	0.763	0.00
12.750	0.735	0.00
13.000	0.677	0.00
13.250	0.649	0.00
13.500	0.606	0.00
13.750	0.563	0.00
14.000	0.548	0.00
14.250	0.534	0.00
14.500	0.520	0.00
14.750	0.520	0.00
15.000	0.505	0.00
15.250	0.491	0.00
15.500	0.477	0.00

Data for R-14, Screen 2, Injection Test a (continued)

t (min)	s (ft)	Q (gpm)
15.750	0.477	0.00
16.000	0.462	0.00
16.250	0.462	0.00
16.500	0.434	0.00
16.750	0.434	0.00
17.000	0.419	0.00
17.250	0.419	0.00
17.500	0.376	0.00
17.750	0.362	0.00
18.000	0.348	0.00
18.250	0.319	0.00
18.500	0.333	0.00
18.750	0.333	0.00
19.000	0.348	0.00
19.250	0.333	0.00
19.500	0.333	0.00
19.750	0.348	0.00

t (min)	s (ft)	Q (gpm)
20.000	0.333	0.00
20.250	0.333	0.00
20.500	0.319	0.00
20.750	0.290	0.00
21.000	0.319	0.00
21.250	0.319	0.00
21.500	0.304	0.00
21.750	0.319	0.00
22.000	0.304	0.00
22.250	0.276	0.00
22.500	0.290	0.00
22.750	0.261	0.00
23.000	0.261	0.00
23.250	0.261	0.00
23.500	0.290	0.00
23.750	0.290	0.00

t (min)	s (ft)	Q (gpm)
24.000	0.276	0.00
24.250	0.276	0.00
24.500	0.290	0.00
24.750	0.247	0.00
25.000	0.247	0.00
25.250	0.261	0.00
25.500	0.261	0.00
25.750	0.261	0.00
26.000	0.261	0.00
26.250	0.233	0.00
26.500	0.261	0.00
26.750	0.247	0.00
27.000	0.247	0.00
27.250	0.218	0.00
27.500	0.247	0.00
27.750	0.233	0.00

Appendix B

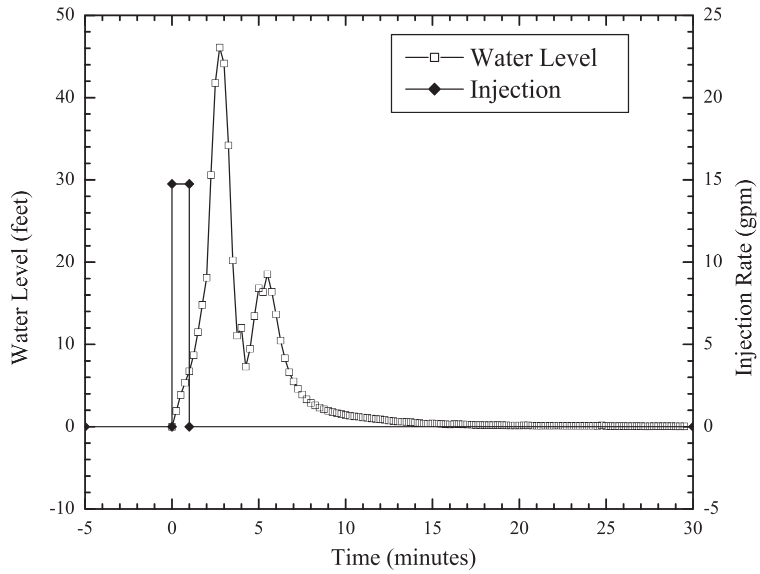
Well R-14, Screen 2, Test b

Contents

B-1 Field Plot for Injection Test 2b

B-2 Data for Injection Test 2b

B-1. Field Plot for R-14, Screen 2, Test b



B-2. Data for R-14, Screen 2, Injection Test b

t (min)	s (ft)	Q (gpm)
0.000	-0.025	14.75
0.250	1.910	14.75
0.500	3.845	14.75
0.750	5.351	14.75
1.000	6.727	14.75
1.250	8.677	0.00
1.500	11.487	0.00
1.750	14.800	0.00
2.000	18.112	0.00
2.250	30.577	0.00
2.500	41.769	0.00
2.750	46.088	0.00
3.000	44.151	0.00
3.250	34.192	0.00
3.500	20.206	0.00
3.750	11.071	0.00
4.000	12.003	0.00
4.250	7.300	0.00
4.500	9.465	0.00
4.750	13.437	0.00
5.000	16.822	0.00
5.250	16.363	0.00

t (min)	s (ft)	Q (gpm)
5.500	18.528	0.00
5.750	16.406	0.00
6.000	13.652	0.00
6.250	10.469	0.00
6.500	8.318	0.00
6.750	6.612	0.00
7.000	5.494	0.00
7.250	4.605	0.00
7.500	3.917	0.00
7.750	3.329	0.00
8.000	2.899	0.00
8.250	2.584	0.00
8.500	2.326	0.00
8.750	2.111	0.00
9.000	1.924	0.00
9.250	1.767	0.00
9.500	1.638	0.00
9.750	1.523	0.00
10.000	1.408	0.00
10.250	1.322	0.00
10.500	1.265	0.00
10.750	1.208	0.00

t (min)	s (ft)	Q (gpm)
11.000	1.122	0.00
11.250	1.064	0.00
11.500	1.007	0.00
11.750	0.935	0.00
12.000	0.892	0.00
12.250	0.835	0.00
12.500	0.749	0.00
12.750	0.677	0.00
13.000	0.620	0.00
13.250	0.606	0.00
13.500	0.577	0.00
13.750	0.548	0.00
14.000	0.491	0.00
14.250	0.434	0.00
14.500	0.376	0.00
14.750	0.376	0.00
15.000	0.405	0.00
15.250	0.362	0.00
15.500	0.333	0.00
15.750	0.305	0.00
16.000	0.262	0.00
16.250	0.319	0.00

B-2. Data for R-14, Screen 2, Injection Test b (continued)

t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)
16.500	0.305	0.00	21.000	0.118	0.00	25.500	0.061	0.00
16.750	0.290	0.00	21.250	0.118	0.00	25.750	0.075	0.00
17.000	0.262	0.00	21.500	0.133	0.00	26.000	0.075	0.00
17.250	0.233	0.00	21.750	0.118	0.00	26.250	0.061	0.00
17.500	0.204	0.00	22.000	0.133	0.00	26.500	0.061	0.00
17.750	0.190	0.00	22.250	0.133	0.00	26.750	0.075	0.00
18.000	0.176	0.00	22.500	0.104	0.00	27.000	0.061	0.00
18.250	0.176	0.00	22.750	0.104	0.00	27.250	0.046	0.00
18.500	0.176	0.00	23.000	0.118	0.00	27.500	0.046	0.00
18.750	0.190	0.00	23.250	0.104	0.00	27.750	0.061	0.00
19.000	0.176	0.00	23.500	0.118	0.00	28.000	0.061	0.00
19.250	0.161	0.00	23.750	0.118	0.00	28.250	0.061	0.00
19.500	0.147	0.00	24.000	0.104	0.00	28.500	0.061	0.00
19.750	0.147	0.00	24.250	0.104	0.00	28.750	0.061	0.00
20.000	0.147	0.00	24.500	0.090	0.00	29.000	0.046	0.00
20.250	0.161	0.00	24.750	0.161	0.00	29.250	0.046	0.00
20.500	0.161	0.00	25.000	0.075	0.00	29.500	0.046	0.00
20.750	0.133	0.00	25.250	0.075	0.00			

Appendix C

Well R-14, Screen 2, Test c

Contents

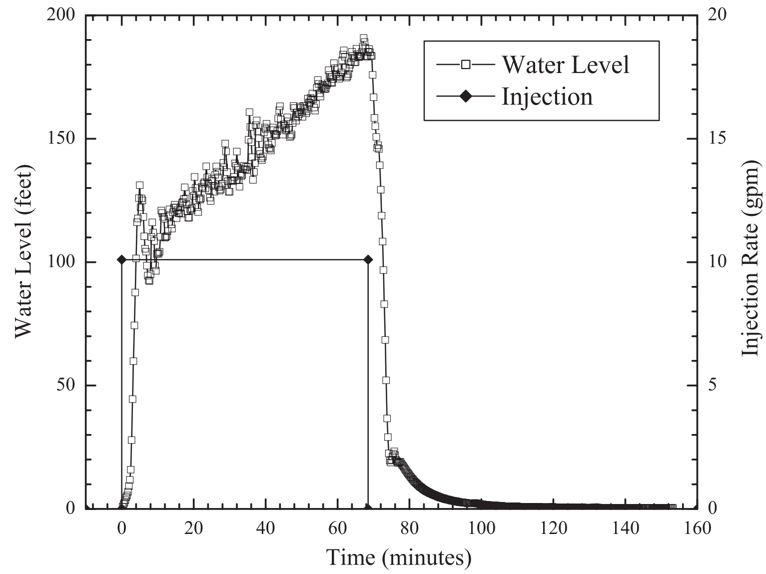
C-1 Field Plot for Injection Test 2c

C-2 Injection Data for Injection Test 2c

C-3 Recovery Data for Injection Test 2c

C-4 Residual-Recovery Data for Injection Test 2c

C-1. Field Plot for Injection Tests, R-14, Screen 2, Test c



C-2. Injection Data for R-14, Screen 2, Injection Test c

t (min)	s (ft)	Q (gpm)
0.250	0.904	10.10
0.500	1.936	10.10
0.750	2.581	10.10
1.000	3.513	10.10
1.250	4.775	10.10
1.500	5.477	10.10
1.750	6.939	10.10
2.000	9.219	10.10
2.250	11.800	10.10
2.500	15.887	10.10
2.750	27.892	10.10
3.000	44.478	10.10
3.250	59.895	10.10
3.500	74.384	10.10
3.750	87.715	10.10
4.000	101.525	10.10
4.250	116.159	10.10
4.500	117.712	10.10
4.750	125.909	10.10
5.000	131.159	10.10
5.250	122.199	10.10
5.500	125.823	10.10

t (min)	s (ft)	Q (gpm)
5.750	125.003	10.10
6.000	118.359	10.10
6.250	110.480	10.10
6.500	105.435	10.10
6.750	104.270	10.10
7.000	98.622	10.10
7.250	94.540	10.10
7.500	92.643	10.10
7.750	92.385	10.10
8.000	95.144	10.10
8.250	110.193	10.10
8.500	116.116	10.10
8.750	112.033	10.10
9.000	108.540	10.10
9.250	98.636	10.10
9.500	96.495	10.10
9.750	103.336	10.10
10.000	103.810	10.10
10.250	103.393	10.10
10.500	104.184	10.10
10.750	110.279	10.10
11.000	120.890	10.10

t (min)	s (ft)	Q (gpm)
11.250	119.869	10.10
11.500	118.345	10.10
11.750	117.569	10.10
12.000	109.977	10.10
12.250	110.164	10.10
12.500	110.538	10.10
12.750	112.594	10.10
13.000	118.647	10.10
13.250	121.365	10.10
13.500	119.165	10.10
13.750	115.340	10.10
14.000	113.629	10.10
14.250	120.157	10.10
14.500	122.041	10.10
14.750	123.263	10.10
15.000	122.156	10.10
15.250	117.799	10.10
15.500	121.092	10.10
15.750	119.869	10.10
16.000	119.869	10.10
16.250	122.113	10.10
16.500	119.625	10.10

C-2. Injection Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)
16.750	123.996	10.10	26.750	134.338	10.10	36.750	136.525	10.10
17.000	124.399	10.10	27.000	130.368	10.10	37.000	140.107	10.10
17.250	125.507	10.10	27.250	128.973	10.10	37.250	155.462	10.10
17.500	130.296	10.10	27.500	129.447	10.10	37.500	157.391	10.10
17.750	125.765	10.10	27.750	131.001	10.10	37.750	152.900	10.10
18.000	123.522	10.10	28.000	131.749	10.10	38.000	150.266	10.10
18.250	120.531	10.10	28.250	140.222	10.10	38.250	145.100	10.10
18.500	118.014	10.10	28.500	138.453	10.10	38.500	143.762	10.10
18.750	118.072	10.10	28.750	148.021	10.10	38.750	142.078	10.10
19.000	121.465	10.10	29.000	144.841	10.10	39.000	141.345	10.10
19.250	120.976	10.10	29.250	136.482	10.10	39.250	142.812	10.10
19.500	121.882	10.10	29.500	132.785	10.10	39.500	152.554	10.10
19.750	128.887	10.10	29.750	128.556	10.10	39.750	154.541	10.10
20.000	126.815	10.10	30.000	128.527	10.10	40.000	153.907	10.10
20.250	134.554	10.10	30.250	133.058	10.10	40.250	156.052	10.10
20.500	130.008	10.10	30.500	133.173	10.10	40.500	151.734	10.10
20.750	125.018	10.10	30.750	133.259	10.10	40.750	147.676	10.10
21.000	122.256	10.10	31.000	132.871	10.10	41.000	146.352	10.10
21.250	120.344	10.10	31.250	134.511	10.10	41.250	145.935	10.10
21.500	125.794	10.10	31.500	140.006	10.10	41.500	145.258	10.10
21.750	125.348	10.10	31.750	138.985	10.10	41.750	148.251	10.10
22.000	125.794	10.10	32.000	144.798	10.10	42.000	154.526	10.10
22.250	130.555	10.10	32.250	138.280	10.10	42.250	153.476	10.10
22.500	129.994	10.10	32.500	133.173	10.10	42.500	151.979	10.10
22.750	131.864	10.10	32.750	130.569	10.10	42.750	151.317	10.10
23.000	132.382	10.10	33.000	135.806	10.10	43.000	151.648	10.10
23.250	129.879	10.10	33.250	134.870	10.10	43.250	153.073	10.10
23.500	138.784	10.10	33.500	135.316	10.10	43.500	158.197	10.10
23.750	134.367	10.10	33.750	137.733	10.10	43.750	161.493	10.10
24.000	131.936	10.10	34.000	138.999	10.10	44.000	163.163	10.10
24.250	129.088	10.10	34.250	137.589	10.10	44.250	157.779	10.10
24.500	126.168	10.10	34.500	138.582	10.10	44.500	153.763	10.10
24.750	124.787	10.10	34.750	137.259	10.10	44.750	151.677	10.10
25.000	133.633	10.10	35.000	138.654	10.10	45.000	155.822	10.10
25.250	132.914	10.10	35.250	149.575	10.10	45.250	155.275	10.10
25.500	130.871	10.10	35.500	160.745	10.10	45.500	154.339	10.10
25.750	128.527	10.10	35.750	154.800	10.10	45.750	153.375	10.10
26.000	135.417	10.10	36.000	148.640	10.10	46.000	158.657	10.10
26.250	138.740	10.10	36.250	142.539	10.10	46.250	157.060	10.10
26.500	136.654	10.10	36.500	133.360	10.10	46.500	154.368	10.10

C-2. Injection Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)
46.750	150.698	10.10	56.750	170.362	10.10	66.750	185.153	10.10
47.000	151.187	10.10	57.000	171.802	10.10	67.000	187.385	10.10
47.250	151.749	10.10	57.250	172.479	10.10	67.250	190.800	10.10
47.500	156.354	10.10	57.500	177.778	10.10	67.500	189.157	10.10
47.750	163.249	10.10	57.750	175.848	10.10	67.750	186.824	10.10
48.000	162.400	10.10	58.000	174.955	10.10	68.000	183.525	10.10
48.250	158.571	10.10	58.250	172.896	10.10	68.250	183.208	10.10
48.500	157.347	10.10	58.500	172.623	10.10	68.500	185.311	10.10
48.750	160.673	10.10	58.750	174.235	10.10	68.750	186.334	10.10
49.000	159.089	10.10	59.000	180.587	10.10	69.000	185.052	0.00
49.250	159.895	10.10	59.250	178.570	10.10	69.250	183.683	0.00
49.500	163.019	10.10	59.500	176.252	10.10	69.500	183.496	0.00
49.750	162.458	10.10	59.750	175.085	10.10	69.750	175.877	0.00
50.000	160.889	10.10	60.000	178.642	10.10	70.000	166.806	0.00
50.250	158.873	10.10	60.250	175.258	10.10	70.250	158.398	0.00
50.500	163.264	10.10	60.500	174.336	10.10	70.500	155.044	0.00
50.750	162.544	10.10	60.750	175.157	10.10	70.750	150.712	0.00
51.000	161.968	10.10	61.000	176.842	10.10	71.000	146.338	0.00
51.250	160.313	10.10	61.250	181.739	10.10	71.250	147.359	0.00
51.500	161.104	10.10	61.500	184.101	10.10	71.500	145.877	0.00
51.750	166.230	10.10	61.750	185.772	10.10	71.750	139.244	0.00
52.000	164.704	10.10	62.000	183.222	10.10	72.000	129.347	0.00
52.250	164.444	10.10	62.250	178.772	10.10	72.250	118.848	0.00
52.500	166.518	10.10	62.500	174.811	10.10	72.500	108.381	0.00
52.750	165.783	10.10	62.750	175.330	10.10	72.750	96.768	0.00
53.000	168.317	10.10	63.000	176.280	10.10	73.000	82.988	0.00
53.250	166.028	10.10	63.250	178.556	10.10	73.250	68.467	0.00
53.500	162.630	10.10	63.500	180.054	10.10	73.500	52.128	0.00
53.750	161.378	10.10	63.750	181.004	10.10	73.750	36.643	0.00
54.000	164.084	10.10	64.000	185.239	10.10	74.000	29.097	0.00
54.250	170.664	10.10	64.250	183.539	10.10	74.250	22.541	0.00
54.500	173.789	10.10	64.500	182.848	10.10	74.500	19.601	0.00
54.750	172.219	10.10	64.750	181.019	10.10	74.750	18.841	0.00
55.000	168.432	10.10	65.000	181.019	10.10	75.000	19.917	0.00
55.250	167.093	10.10	65.250	186.406	10.10	75.250	21.236	0.00
55.500	170.520	10.10	65.500	184.274	10.10	75.500	22.341	0.00
55.750	171.816	10.10	65.750	183.266	10.10	75.750	23.345	0.00
56.000	171.327	10.10	66.000	183.021	10.10	76.000	21.810	0.00
56.250	170.823	10.10	66.250	183.655	10.10	76.250	19.917	0.00
56.500	170.117	10.10	66.500	183.410	10.10	76.500	19.386	0.00

C-2. Injection Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	Q (gpm)
76.750	18.655	0.00
77.000	18.726	0.00
77.250	18.855	0.00
77.500	19.185	0.00
77.750	18.353	0.00
78.000	17.780	0.00
78.250	17.335	0.00
78.500	16.762	0.00
78.750	16.217	0.00
79.000	15.672	0.00
79.250	15.098	0.00
79.500	14.567	0.00
79.750	14.152	0.00
80.000	13.621	0.00
80.250	13.090	0.00
80.500	12.689	0.00
80.750	12.187	0.00
81.000	11.814	0.00
81.250	11.312	0.00
81.500	10.940	0.00
81.750	10.581	0.00
82.000	10.251	0.00
82.250	9.907	0.00
82.500	9.563	0.00
82.750	9.219	0.00
83.000	8.918	0.00
83.250	8.703	0.00
83.500	8.373	0.00
83.750	8.086	0.00
84.000	7.886	0.00
84.250	7.613	0.00
84.500	7.412	0.00
84.750	7.140	0.00
85.000	6.954	0.00
85.250	6.796	0.00
85.500	6.638	0.00
85.750	6.352	0.00
86.000	6.194	0.00
86.250	6.036	0.00
86.500	5.878	0.00
86.750	5.721	0.00
87.000	5.563	0.00
87.250	5.420	0.00
87.500	5.276	0.00
87.750	5.119	0.00
88.000	4.961	0.00
88.250	4.846	0.00
88.500	4.689	0.00
88.750	4.545	0.00
89.000	4.430	0.00
89.250	4.402	0.00
89.500	4.258	0.00
89.750	4.129	0.00
90.000	3.986	0.00
90.250	3.972	0.00
90.500	3.828	0.00
90.750	3.714	0.00
91.000	3.685	0.00
91.250	3.556	0.00
91.500	3.441	0.00
91.750	3.427	0.00
92.000	3.284	0.00
92.250	3.269	0.00
92.500	3.155	0.00
92.750	3.169	0.00
93.000	3.011	0.00
93.250	2.997	0.00
93.500	2.868	0.00
93.750	2.854	0.00
94.000	2.739	0.00
94.250	2.724	0.00
94.500	2.624	0.00
94.750	2.610	0.00
95.000	2.610	0.00
95.250	2.495	0.00
95.500	2.495	0.00
95.750	2.481	0.00
96.000	2.366	0.00
96.250	2.352	0.00
96.500	2.251	0.00
96.750	2.266	0.00
97.000	2.280	0.00
97.250	2.294	0.00
97.500	2.337	0.00
97.750	2.352	0.00
98.000	2.395	0.00
98.250	2.380	0.00
98.500	2.251	0.00
98.750	2.223	0.00
99.000	2.208	0.00
99.250	2.108	0.00
99.500	1.993	0.00
99.750	1.950	0.00
100.000	1.950	0.00
100.250	1.821	0.00
100.500	1.778	0.00
100.750	1.750	0.00
101.000	1.735	0.00
101.250	1.635	0.00
101.500	1.621	0.00
101.750	1.606	0.00
102.000	1.592	0.00
102.250	1.492	0.00
102.500	1.492	0.00
102.750	1.492	0.00
103.000	1.492	0.00
103.250	1.492	0.00
103.500	1.377	0.00
103.750	1.348	0.00
104.000	1.377	0.00
104.250	1.363	0.00
104.500	1.348	0.00
104.750	1.205	0.00
105.000	1.248	0.00
105.250	1.234	0.00
105.500	1.234	0.00
105.750	1.205	0.00
106.000	1.133	0.00
106.250	1.090	0.00
106.500	1.090	0.00

C-2. Injection Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)	t (min)	s (ft)	Q (gpm)
106.750	1.105	0.00	116.750	0.746	0.00	126.750	0.617	0.00
107.000	1.105	0.00	117.000	0.761	0.00	127.000	0.617	0.00
107.250	1.105	0.00	117.250	0.746	0.00	127.250	0.632	0.00
107.500	1.105	0.00	117.500	0.761	0.00	127.500	0.632	0.00
107.750	0.990	0.00	117.750	0.746	0.00	127.750	0.617	0.00
108.000	1.004	0.00	118.000	0.746	0.00	128.000	0.617	0.00
108.250	1.033	0.00	118.250	0.746	0.00	128.250	0.632	0.00
108.500	1.004	0.00	118.500	0.761	0.00	128.500	0.517	0.00
108.750	1.004	0.00	118.750	0.746	0.00	128.750	0.531	0.00
109.000	1.004	0.00	119.000	0.761	0.00	129.000	0.546	0.00
109.250	1.004	0.00	119.250	0.761	0.00	129.250	0.531	0.00
109.500	1.019	0.00	119.500	0.761	0.00	129.500	0.531	0.00
109.750	1.019	0.00	119.750	0.775	0.00	129.750	0.531	0.00
110.000	1.019	0.00	120.000	0.775	0.00	130.000	0.531	0.00
110.250	0.890	0.00	120.250	0.675	0.00	130.250	0.531	0.00
110.500	0.904	0.00	120.500	0.689	0.00	130.500	0.546	0.00
110.750	0.890	0.00	120.750	0.689	0.00	130.750	0.531	0.00
111.000	0.904	0.00	121.000	0.689	0.00	131.000	0.546	0.00
111.250	0.918	0.00	121.250	0.675	0.00	131.250	0.546	0.00
111.500	0.904	0.00	121.500	0.675	0.00	131.500	0.546	0.00
111.750	0.904	0.00	121.750	0.675	0.00	131.750	0.546	0.00
112.000	0.904	0.00	122.000	0.675	0.00	132.000	0.546	0.00
112.250	0.904	0.00	122.250	0.675	0.00	132.250	0.560	0.00
112.500	0.918	0.00	122.500	0.689	0.00	132.500	0.546	0.00
112.750	0.789	0.00	122.750	0.689	0.00	132.750	0.460	0.00
113.000	0.818	0.00	123.000	0.689	0.00	133.000	0.474	0.00
113.250	0.818	0.00	123.250	0.689	0.00	133.250	0.474	0.00
113.500	0.832	0.00	123.500	0.689	0.00	133.500	0.488	0.00
113.750	0.818	0.00	123.750	0.703	0.00	133.750	0.460	0.00
114.000	0.832	0.00	124.000	0.703	0.00	134.000	0.474	0.00
114.250	0.818	0.00	124.250	0.603	0.00	134.250	0.474	0.00
114.500	0.818	0.00	124.500	0.603	0.00	134.500	0.474	0.00
114.750	0.818	0.00	124.750	0.589	0.00	134.750	0.474	0.00
115.000	0.832	0.00	125.000	0.603	0.00	135.000	0.488	0.00
115.250	0.832	0.00	125.250	0.617	0.00	135.250	0.474	0.00
115.500	0.832	0.00	125.500	0.603	0.00	135.500	0.488	0.00
115.750	0.847	0.00	125.750	0.603	0.00	135.750	0.474	0.00
116.000	0.847	0.00	126.000	0.617	0.00	136.000	0.474	0.00
116.250	0.746	0.00	126.250	0.603	0.00	136.250	0.474	0.00
116.500	0.761	0.00	126.500	0.617	0.00	136.500	0.488	0.00

C-2. Injection Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	Q (gpm)
136.750	0.474	0.00
137.000	0.474	0.00
137.250	0.488	0.00
137.500	0.488	0.00
137.750	0.488	0.00
138.000	0.503	0.00
138.250	0.488	0.00
138.500	0.503	0.00
138.750	0.503	0.00
139.000	0.488	0.00
139.250	0.503	0.00
139.500	0.503	0.00
139.750	0.402	0.00
140.000	0.417	0.00
140.250	0.417	0.00
140.500	0.417	0.00
140.750	0.417	0.00
141.000	0.388	0.00
141.250	0.417	0.00
141.500	0.417	0.00
141.750	0.417	0.00
142.000	0.431	0.00
142.250	0.431	0.00

t (min)	s (ft)	Q (gpm)
142.500	0.431	0.00
142.750	0.431	0.00
143.000	0.445	0.00
143.250	0.445	0.00
143.500	0.445	0.00
143.750	0.445	0.00
144.000	0.445	0.00
144.250	0.445	0.00
144.500	0.460	0.00
144.750	0.431	0.00
145.000	0.445	0.00
145.250	0.445	0.00
145.500	0.445	0.00
145.750	0.445	0.00
146.000	0.445	0.00
146.250	0.445	0.00
146.500	0.460	0.00
146.750	0.374	0.00
147.000	0.374	0.00
147.250	0.388	0.00
147.500	0.374	0.00
147.750	0.374	0.00

t (min)	s (ft)	Q (gpm)
148.000	0.388	0.00
148.250	0.374	0.00
148.500	0.388	0.00
148.750	0.388	0.00
149.000	0.374	0.00
149.250	0.374	0.00
149.500	0.388	0.00
149.750	0.402	0.00
150.000	0.374	0.00
150.250	0.388	0.00
150.500	0.374	0.00
150.750	0.388	0.00
151.000	0.388	0.00
151.250	0.388	0.00
151.500	0.388	0.00
151.750	0.388	0.00
152.000	0.388	0.00
152.250	0.388	0.00
152.500	0.388	0.00
152.750	0.402	0.00
153.000	0.402	0.00
153.250	0.402	0.00

C-3. Recovery Data for R-14, Screen 2, Injection Test c

t (min)	s (ft)
1.000	0.701
1.250	0.888
1.500	8.507
1.750	17.578
2.000	25.986
2.250	29.340
2.500	33.672
2.750	38.046
3.000	37.025
3.250	38.507
3.500	45.140
3.750	55.037
4.000	65.536

t (min)	s (ft)
4.250	76.003
4.500	87.616
4.750	101.396
5.000	115.917
5.250	132.256
5.500	147.741
5.750	155.287
6.000	161.843
6.250	164.783
6.500	165.543
6.750	164.467
7.000	163.148
7.250	162.043

t (min)	s (ft)
7.500	161.039
7.750	162.574
8.000	164.467
8.250	164.998
8.500	165.729
8.750	165.658
9.000	165.529
9.250	165.199
9.500	166.031
9.750	166.604
10.000	167.049
10.250	167.622
10.500	168.167

t (min)	s (ft)
10.750	168.712
11.000	169.286
11.250	169.817
11.500	170.232
11.750	170.763
12.000	171.294
12.250	171.695
12.500	172.197
12.750	172.570
13.000	173.072
13.250	173.444
13.500	173.803
13.750	174.133

C-3. Recovery Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)	t (min)	s (ft)	t (min)	s (ft)	t (min)	s (ft)
14.000	174.477	24.000	181.115	34.000	182.892	44.000	183.480
14.250	174.821	24.250	181.229	34.250	182.892	44.250	183.466
14.500	175.165	24.500	181.215	34.500	182.892	44.500	183.595
14.750	175.466	24.750	181.373	34.750	182.892	44.750	183.566
15.000	175.681	25.000	181.387	35.000	182.892	45.000	183.566
15.250	176.011	25.250	181.516	35.250	183.007	45.250	183.552
15.500	176.298	25.500	181.530	35.500	183.036	45.500	183.566
15.750	176.498	25.750	181.645	35.750	183.007	45.750	183.552
16.000	176.771	26.000	181.660	36.000	183.021	46.000	183.566
16.250	176.972	26.250	181.760	36.250	183.036	46.250	183.566
16.500	177.244	26.500	181.774	36.500	183.179	46.500	183.566
16.750	177.430	26.750	181.774	36.750	183.136	46.750	183.552
17.000	177.588	27.000	181.889	37.000	183.150	47.000	183.552
17.250	177.746	27.250	181.889	37.250	183.150	47.250	183.552
17.500	178.032	27.500	181.903	37.500	183.179	47.500	183.537
17.750	178.190	27.750	182.018	37.750	183.251	47.750	183.537
18.000	178.348	28.000	182.032	38.000	183.294	48.000	183.638
18.250	178.506	28.250	182.133	38.250	183.294	48.250	183.623
18.500	178.663	28.500	182.118	38.500	183.279	48.500	183.638
18.750	178.821	28.750	182.104	38.750	183.279	48.750	183.623
19.000	178.964	29.000	182.090	39.000	183.279	49.000	183.638
19.250	179.108	29.250	182.047	39.250	183.279	49.250	183.623
19.500	179.265	29.500	182.032	39.500	183.394	49.500	183.638
19.750	179.423	29.750	181.989	39.750	183.380	49.750	183.638
20.000	179.538	30.000	182.004	40.000	183.351	50.000	183.638
20.250	179.695	30.250	182.133	40.250	183.380	50.250	183.623
20.500	179.839	30.500	182.161	40.500	183.380	50.500	183.638
20.750	179.954	30.750	182.176	40.750	183.380	50.750	183.623
21.000	179.982	31.000	182.276	41.000	183.380	51.000	183.623
21.250	180.126	31.250	182.391	41.250	183.365	51.250	183.623
21.500	180.255	31.500	182.434	41.500	183.365	51.500	183.609
21.750	180.398	31.750	182.434	41.750	183.365	51.750	183.609
22.000	180.412	32.000	182.563	42.000	183.494	52.000	183.709
22.250	180.556	32.250	182.606	42.250	183.480	52.250	183.695
22.500	180.670	32.500	182.634	42.500	183.494	52.500	183.695
22.750	180.699	32.750	182.649	42.750	183.480	52.750	183.695
23.000	180.828	33.000	182.749	43.000	183.466	53.000	183.709
23.250	180.943	33.250	182.763	43.250	183.480	53.250	183.709
23.500	180.957	33.500	182.778	43.500	183.480	53.500	183.709
23.750	181.100	33.750	182.792	43.750	183.480	53.750	183.709

C-3. Recovery Data for R-14, Screen 2, Injection Test c (continued)

t (min)	s (ft)
54.000	183.709
54.250	183.695
54.500	183.695
54.750	183.695
55.000	183.695
55.250	183.695
55.500	183.681
55.750	183.681
56.000	183.781
56.250	183.781
56.500	183.795
56.750	183.781
57.000	183.767
57.250	183.781
57.500	183.781
57.750	183.767
58.000	183.781
58.250	183.767
58.500	183.767
58.750	183.767
59.000	183.752
59.250	183.752
59.500	183.767
59.750	183.767
60.000	183.752
60.250	183.867
60.500	183.853
60.750	183.838
61.000	183.853
61.250	183.853
61.500	183.853
61.750	183.853

t (min)	s (ft)
62.000	183.853
62.250	183.838
62.500	183.853
62.750	183.838
63.000	183.838
63.250	183.838
63.500	183.838
63.750	183.838
64.000	183.824
64.250	183.838
64.500	183.924
64.750	183.910
65.000	183.910
65.250	183.896
65.500	183.924
65.750	183.910
66.000	183.910
66.250	183.910
66.500	183.910
66.750	183.896
67.000	183.910
67.250	183.896
67.500	183.910
67.750	183.910
68.000	183.910
68.250	183.896
68.500	183.910
68.750	183.910
69.000	183.896
69.250	183.896
69.500	183.896

t (min)	s (ft)
69.750	183.881
70.000	183.896
70.250	183.881
70.500	183.881
70.750	183.896
71.000	183.881
71.250	183.881
71.500	183.982
71.750	183.967
72.000	183.967
72.250	183.967
72.500	183.967
72.750	183.996
73.000	183.967
73.250	183.967
73.500	183.967
73.750	183.953
74.000	183.953
74.250	183.953
74.500	183.953
74.750	183.939
75.000	183.939
75.250	183.939
75.500	183.939
75.750	183.939
76.000	183.939
76.250	183.924
76.500	183.953
76.750	183.939
77.000	183.939
77.250	183.939

t (min)	s (ft)
77.500	183.939
77.750	183.939
78.000	183.939
78.250	183.924
78.500	184.010
78.750	184.010
79.000	183.996
79.250	184.010
79.500	184.010
79.750	183.996
80.000	184.010
80.250	183.996
80.500	183.996
80.750	184.010
81.000	184.010
81.250	183.996
81.500	183.982
81.750	184.010
82.000	183.996
82.250	184.010
82.500	183.996
82.750	183.996
83.000	183.996
83.250	183.996
83.500	183.996
83.750	183.996
84.000	183.996
84.250	183.996
84.500	183.982
84.750	183.982
85.000	183.982

C-4. Residual-Recovery Data for R-14, Screen 2, Injection Test c

t/t'	s' (ft)
276.000	185.052
138.500	183.683
92.667	183.496
69.750	175.877
56.000	166.806
46.833	158.398
40.286	155.044
35.375	150.712
31.556	146.338
28.500	147.359
26.000	145.877
23.917	139.244
22.154	129.347
20.643	118.848
19.333	108.381
18.188	96.768
17.176	82.988
16.278	68.467
15.474	52.128
14.750	36.643
14.095	29.097
13.500	22.541
12.957	19.601
12.458	18.841
12.000	19.917
11.577	21.236
11.185	22.341
10.821	23.345
10.483	21.810
10.167	19.917
9.871	19.386
9.594	18.655
9.333	18.726
9.088	18.855
8.857	19.185
8.639	18.353
8.432	17.780

t/t'	s' (ft)
8.237	17.335
8.051	16.762
7.875	16.217
7.707	15.672
7.548	15.098
7.395	14.567
7.250	14.152
7.111	13.621
6.978	13.090
6.851	12.689
6.729	12.187
6.612	11.814
6.500	11.312
6.392	10.940
6.288	10.581
6.189	10.251
6.093	9.907
6.000	9.563
5.911	9.219
5.825	8.918
5.741	8.703
5.661	8.373
5.583	8.086
5.508	7.886
5.435	7.613
5.365	7.412
5.297	7.140
5.231	6.954
5.167	6.796
5.104	6.638
5.044	6.352
4.986	6.194
4.929	6.036
4.873	5.878
4.819	5.721
4.767	5.563
4.716	5.420

t/t'	s' (ft)
4.667	5.276
4.618	5.119
4.571	4.961
4.526	4.846
4.481	4.689
4.438	4.545
4.395	4.430
4.354	4.402
4.313	4.258
4.274	4.129
4.235	3.986
4.198	3.972
4.161	3.828
4.125	3.714
4.090	3.685
4.056	3.556
4.022	3.441
3.989	3.427
3.957	3.284
3.926	3.269
3.895	3.155
3.865	3.169
3.835	3.011
3.806	2.997
3.778	2.868
3.750	2.854
3.723	2.739
3.696	2.724
3.670	2.624
3.644	2.610
3.619	2.610
3.594	2.495
3.570	2.495
3.546	2.481
3.523	2.366
3.500	2.352
3.477	2.251

t/t'	s' (ft)
3.455	2.266
3.434	2.280
3.412	2.294
3.391	2.337
3.371	2.352
3.350	2.395
3.331	2.380
3.311	2.251
3.292	2.223
3.273	2.208
3.254	2.108
3.236	1.993
3.218	1.950
3.200	1.950
3.183	1.821
3.165	1.778
3.148	1.750
3.132	1.735
3.115	1.635
3.099	1.621
3.083	1.606
3.068	1.592
3.052	1.492
3.037	1.492
3.022	1.492
3.007	1.492
2.993	1.492
2.978	1.377
2.964	1.348
2.950	1.377
2.937	1.363
2.923	1.348
2.910	1.205
2.897	1.248
2.884	1.234
2.871	1.234
2.858	1.205

C-4. Residual-Recovery Data for R-14, Screen 2, Injection Test c (continued)

t/t'	s' (ft)
2.846	1.133
2.833	1.090
2.821	1.090
2.809	1.105
2.797	1.105
2.786	1.105
2.774	1.105
2.763	0.990
2.752	1.004
2.741	1.033
2.730	1.004
2.719	1.004
2.708	1.004
2.698	1.004
2.687	1.019
2.677	1.019
2.667	1.019
2.657	0.890
2.647	0.904
2.637	0.890
2.627	0.904
2.618	0.918
2.608	0.904
2.599	0.904
2.590	0.904
2.580	0.904
2.571	0.918
2.563	0.789
2.554	0.818
2.545	0.818
2.536	0.832
2.528	0.818
2.519	0.832
2.511	0.818
2.503	0.818
2.495	0.818
2.486	0.832
2.478	0.832
2.471	0.832
2.463	0.847
2.455	0.847
2.447	0.746
2.440	0.761
2.432	0.746
2.425	0.761
2.418	0.746
2.410	0.761
2.403	0.746
2.396	0.746
2.389	0.746
2.382	0.761
2.375	0.746
2.368	0.761
2.361	0.761
2.355	0.761
2.348	0.775
2.341	0.775
2.335	0.675
2.329	0.689
2.322	0.689
2.316	0.689
2.310	0.675
2.303	0.675
2.297	0.675
2.291	0.675
2.285	0.675
2.279	0.689
2.273	0.689
2.267	0.689
2.261	0.689
2.256	0.689
2.250	0.703
2.244	0.703
2.239	0.603
2.233	0.603
2.228	0.589
2.222	0.603
2.217	0.617
2.211	0.603
2.206	0.603
2.201	0.617
2.196	0.603
2.190	0.617
2.185	0.617
2.180	0.617
2.175	0.632
2.170	0.632
2.165	0.617
2.160	0.617
2.155	0.632
2.151	0.517
2.146	0.531
2.141	0.546
2.136	0.531
2.132	0.531
2.127	0.531
2.122	0.531
2.118	0.531
2.113	0.546
2.109	0.531
2.104	0.546
2.100	0.546
2.096	0.546
2.091	0.546
2.087	0.546
2.083	0.560
2.078	0.546
2.074	0.460
2.070	0.474
2.066	0.474
2.062	0.488
2.058	0.460
2.054	0.474
2.050	0.474
2.046	0.474
2.042	0.474
2.038	0.488
2.034	0.474
2.030	0.488
2.026	0.474
2.022	0.474
2.019	0.474
2.015	0.488
2.011	0.474
2.007	0.474
2.004	0.488
2.000	0.488
1.996	0.488
1.993	0.503
1.989	0.488
1.986	0.503
1.982	0.503
1.979	0.488
1.975	0.503
1.972	0.503
1.968	0.402
1.965	0.417
1.962	0.417
1.958	0.417
1.955	0.417
1.952	0.388
1.948	0.417
1.945	0.417
1.942	0.417
1.939	0.431
1.935	0.431
1.932	0.431
1.929	0.431

C-4. Residual-Recovery Data for R-14, Screen 2, Injection Test c (continued)

t/t'	s' (ft)
1.926	0.445
1.923	0.445
1.920	0.445
1.917	0.445
1.914	0.445
1.911	0.445
1.908	0.460
1.905	0.431
1.902	0.445
1.899	0.445
1.896	0.445

t/t'	s' (ft)
1.893	0.445
1.890	0.445
1.887	0.445
1.884	0.460
1.881	0.374
1.879	0.374
1.876	0.388
1.873	0.374
1.870	0.374
1.868	0.388
1.865	0.374

t/t'	s' (ft)
1.862	0.388
1.859	0.388
1.857	0.374
1.854	0.374
1.851	0.388
1.849	0.402
1.846	0.374
1.844	0.388
1.841	0.374
1.838	0.388

t/t'	s' (ft)
1.836	0.388
1.833	0.388
1.831	0.388
1.828	0.388
1.826	0.388
1.823	0.388
1.821	0.388
1.818	0.402
1.816	0.402
1.814	0.402

Appendix D

Specific-Capacity Analysis, Well R-14, Screen 2, Test c

Contents

D-1 MATLAB^{TM} Script File

D-2 Input Data

D-3 T as a Function of Well Efficiency and Aquifer Penetration

D-1. MATLAB™ Script File for Specific-Capacity Analysis

The following script file is written in the MATLAB™ programming language and was successfully run under MATLAB™ version 6.5 (see http://www.mathworks.com). This program was adapted and modified from the original BASIC program developed by Bradbury and Rothschild (1985, 76040). This script file was used to generate Figure 12 using the input data in D-2.

```
function A=TQs2
%TQs2  computes Transmissivity (T) from Specific Capacity (Q/s) data.
%
%       Yields a 3-D (x,y,z) plot of (T,E,x/l)
%       T(ft^2/day) vs. well efficiency (E) and Partial Penetration (x/l)
%       for a fixed value of Storage Coefficient (S).
%
%       T = transmissivity (ft2/day)
%       Q = well pump rate (gpm)
%       s = wellbore drawdown (ft)
%       t = time (minutes)
%       b = aquifer thickness (ft)
%       L = well screen length (ft)
%       R = L/b (dimensionless penetration)
%       r = well radius (ft)
%       S = aquifer storage coefficient (or specific yield)
%       E = well efficiency (%) = 100/(1+CQ/B) from step drawdown test
%
format short; A=zeros(12,12);
Q=input('Input Q (gpm) now...');
s=input('Input drawdown (ft) now...');
t=input('Input time (minutes) now...');
L=input('Input well screen length (ft) now...');
r=input('Input well radius (ft) now...');
S=input('Input storage coefficient S now...');
E=[50 55 60 65 70 75 80 85 90 95 100]';
R=[0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00]'; b=L./R;
err=0.000001; Tguess=1.0;
C=(1-E./100)/(Q*Q/s);
%       Compute well loss (sw)
sw=C.*Q^2;
%       Correct for well partial penetration effects
for i=1:11
        l=b(i);
        G(i)=2.948-7.363*(L/l)+11.447*(L/l)^2-4.675*(L/l)^3;
        sp(i)=(l-L)/L*(log(l/r)-G(i));
end
sp=sp';
for j=1:11
for i=1:11
    Tcalc(i,j)=1440*Q*(log(2.25*Tguess*t/(1440*r^2*S))+2*sp(j))/(4*7.48*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*7.48*pi*(s-sw(i)));
            diff=abs(Tcalc(i,j)-Tguess); Tguess=Tcalc(i,j); test=diff;
        end
    l=b(j);
    A(i,j)=Tcalc(i,j); Kb(i,j)=Tcalc(i,j)./l; KL(i,j)=Tcalc(i,j)./L;
end
end
A(1:11,12)=E; A(12,1:11)=R'; z=A(1:11,1:11); x=100.*A(12,1:11); y=A(1:11,12);
h=figure;
set(h,'PaperPosition',[0.25,0.25,8.00,10.50]);
surf(x,y,z);
ylabel('Well Efficiency (%)'); xlabel('Aquifer Penetration (%)');
zlabel('Transmissivity (ft2/day)');
*******************************************************************************
%       Stephen G. McLin, 16 May 2003
%       Los Alamos National Laboratory
%       RRES-WQH, MS-K497, 505-665-1721
%       e-mail: sgm@lanl.gov
```

D-2. Input Data for Specific-Capacity Analysis

The following input data was used to generate Figure 12. The user is prompted to enter these values when executing the script file shown above.

```
>> A=TQs2
Input Q (gpm) now...10.10
Input drawdown (ft) now...128.527
Input time (minutes) now...30
Input well screen length (ft) now...6.6
Input well radius (ft) now...0.5313
Input storage coefficient S now...0.0001
```

Upon successful execution of the script file, output similar to that in Table D-3 is generated.

D-3. Transmissivity (ft^2/d) for R-14, Test 2c, as a Function of Well Efficiency and Screen Penetration[a]

Well Efficiency (%)	Aquifer Penetration (%)																		
	4.2	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**100**
20	896.0	322.6	208.1	154.8	123.8	103.3	88.5	77.4	68.7	61.8	56.3	51.8	48.3	45.4	43.3	41.6	40.4	39.7	39.0
25	715.7	257.0	165.4	122.7	97.9	81.5	69.7	60.8	53.8	48.3	43.8	40.2	37.4	35.1	33.4	32.0	31.1	30.5	29.9
30	595.7	213.4	137.0	101.5	80.8	67.1	57.3	49.8	44.0	39.4	35.7	32.7	30.3	28.4	26.9	25.8	25.0	24.5	24.0
35	510.1	182.4	116.9	86.5	68.7	57.0	48.5	42.1	37.2	33.2	30.0	27.4	25.4	23.7	22.5	21.5	20.8	20.4	20.0
40	445.9	159.2	101.9	75.2	59.7	49.4	42.0	36.4	32.1	28.6	25.8	23.5	21.7	20.3	19.2	18.3	17.7	17.3	17.0
45	396.0	141.2	90.2	66.5	52.7	43.6	37.0	32.0	28.2	25.1	22.6	20.6	18.9	17.7	16.7	15.9	15.4	15.0	14.7
50	356.2	126.8	81.0	59.6	47.2	39.0	33.0	28.6	25.1	22.3	20.0	18.2	16.8	15.6	14.7	14.0	13.5	13.2	12.9
55	323.6	115.1	73.4	54.0	42.7	35.2	29.8	25.7	22.6	20.0	18.0	16.3	15.0	13.9	13.1	12.5	12.1	11.8	11.5
60	296.5	105.3	67.1	49.3	38.9	32.1	27.1	23.4	20.5	18.2	16.3	14.8	13.5	12.6	11.8	11.2	10.8	10.6	10.3
65	273.5	97.0	61.8	45.4	35.8	29.5	24.9	21.4	18.7	16.6	14.9	13.4	12.3	11.4	10.7	10.2	9.8	9.6	9.3
70	253.8	90.0	57.2	42.0	33.1	27.2	23.0	19.8	17.3	15.3	13.6	12.3	11.3	10.5	9.8	9.3	9.0	8.7	8.5
75	236.8	83.9	53.3	39.1	30.8	25.3	21.3	18.3	16.0	14.1	12.6	11.4	10.4	9.6	9.0	8.6	8.2	8.0	7.8
80	221.9	78.5	49.9	36.5	28.8	23.6	19.9	17.1	14.9	13.1	11.7	10.6	9.6	8.9	8.3	7.9	7.6	7.4	7.2
85	208.8	73.8	46.8	34.3	27.0	22.1	18.6	16.0	13.9	12.3	10.9	9.8	9.0	8.3	7.7	7.3	7.0	6.8	6.7
90	197.1	69.6	44.2	32.3	25.4	20.8	17.5	15.0	13.1	11.5	10.2	9.2	8.4	7.7	7.2	6.8	6.6	6.4	6.2
95	186.6	65.9	41.8	30.5	24.0	19.6	16.5	14.1	12.3	10.8	9.6	8.6	7.9	7.2	6.8	6.4	6.1	5.9	5.8
100	**177.2**[b]	62.5	39.6	28.9	22.7	18.6	15.6	13.4	11.6	10.2	9.1	8.1	7.4	6.8	6.3	6.0	5.7	5.6	5.4

[a] Input data: Q = 10.1 gpm; s = 128.52 ft at t = 30 min; screen length = 6.6 ft; dw = 12.75 in; S = 0.01; D= 158 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 4.2%, T = 177.2 ft^2/day.

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