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Aquifer Test Analysis for Well R-15

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Aquifer Test Analysis for Well R-15

by
Stephen G. McLin

Abstract

A 46-hour aquifer pumping test was conducted at well R-15 on February 19–21, 2000. Water levels were recorded in the pumping well while water was produced at a constant rate of 11.7 gallons per minute. Maximum observed drawdown near the end of the test was 16.1 ft. This well is completed into the regional aquifer and has a 60-foot screen. The screened interval is located between 960 and 1020 ft below ground surface (bgs). This screen straddles the contact between lower Puye fanglomerates and deeper, unassigned pumiceous deposits at 973 ft bgs. At the start of the aquifer test, the static water level was also located in the screened interval at approximately 964 ft bgs (or about 5856 ft above mean sea level). Drawdown data were analyzed to determine characteristic values for transmissivity (T) and hydraulic conductivity (K). These results demonstrate that the regional aquifer near well R-15 behaves like a phreatic aquifer. Test results were adjusted to simultaneously consider the effects of partial screen penetration and flow-zone thinning. Methods of analyses included Theis, Moench, Neuman, and specific capacity techniques, and suggest a relatively narrow range of T between 277 and 318 square ft per day. However, the most reliable results come from those techniques developed specifically for phreatic aquifers (Moench and Neuman). Overall, an average T value of about 302 square ft per day was obtained for the regional aquifer from this pumping test, and primarily represents aquifer transmissivity for the unassigned pumiceous deposits. The corresponding average horizontal K value is about 2.2 ft per day and is based on a total saturated thickness of 136 ft.

I. INTRODUCTION

Characterization well R-15 is located on the south side of Mortandad Canyon, as seen in Figure 1 (i.e., at New Mexico State Plane coordinates 1768272 North, 1635309 East). This location is south-southeast of the lowest sediment trap. Well R-15 was drilled and completed in several phases between September 1998 and June 1999 as part of the Laboratory's Groundwater Protection Management Program as specified in the Hydrogeologic Workplan (LANL 1998, 59599). Figure 2 summarizes important geology, hydrology, and well construction details for R-15. Table 1 summarizes the stratigraphic log for this well. This report contains analytical results from a 46-hour aquifer pumping test that was conducted from February 19 to 21, 2000. In addition, data from a 33-hour recovery period that immediately followed this pumping interval were also collected. All of the drawdown and residual recovery information used in these analyses are contained in Appendix A of this report. The original R-15 completion report (Longmire et al. 2001, 70103) contains additional detailed descriptions of site geology, hydrology, and analytical chemistry results from water samples recovered during drilling operations. Hydrogeologic conditions within the alluvial portions of Mortandad Canyon were previously reported in McLin et al. (1997).

As seen in Figure 2, well R-15 contains a single screen that is completed into the regional aquifer within the lower portion of the Puye fanglomerate, which extends from about 747 to 973 ft below ground surface (bgs), and then into unassigned pumiceous deposits from 973 to 1100 ft bgs. Current data suggests that these unassigned deposits contain pumice that may be related to the Peralta Tuff, typically seen to the south in outcrops, and lavas of the Kerns Group that may have moved here from the west (D. Vaniman, 2004, personal communication). The well screen actually straddles the contact between the Puye fanglomerate and the unassigned pumiceous deposits at 973 ft bgs. The screened interval is located between 958.6 and 1020.3 ft bgs, and also straddles the regional water table that is located at about 964 ft bgs. During well drilling, an unsaturated upper portion of the Puye fanglomerate was also identified between 472 and 494 ft bgs. The interval between the two sequences of Puye fanglomerate was identified as Cerros del Rio basalt. A perched water body was encountered in the lower portions of the Cerros del Rio basalt between about 646 and 747 ft bgs. This perched zone was hydraulically isolated from the regional water table because a cement-bentonite annular borehole seal and solid steel casing were placed around this interval. Hence, it had no influence on the pumping test reported here. Furthermore, this water body was obviously perched in the basalt because the upper portions of the Puye located immediately below the basalt were clearly unsaturated (Longmire et al. 2001, 70103).

Table 1
Stratigraphic Log for Well R-15

Depth[1]	Thickness (ft)	Geologic Unit	Comments
0–16.5	16.5	Alluvium	unsaturated
16.5–66	49.5	Upper Bandelier Tuff	unsaturated
66–120	54	Cerro Toledo interval	unsaturated
120–420	300	Lower Bandelier Tuff	unsaturated
420–472	52	Guaje Pumice Bed	unsaturated
472–492	20	Puye Fm (fanglomerate)	unsaturated
492–747	255	Cerros del Rio basalt	perched water: 646–747 ft
747–973	226	Puye Fm (fanglomerate)	regional water table: 964 ft
973–1100	127	Unassigned pumiceous deposits	screen interval: 960–1020 ft
1100–1107	7	Totavi Lentil	total depth drilled: 1107 ft

[1] All depths are in ft bgs.

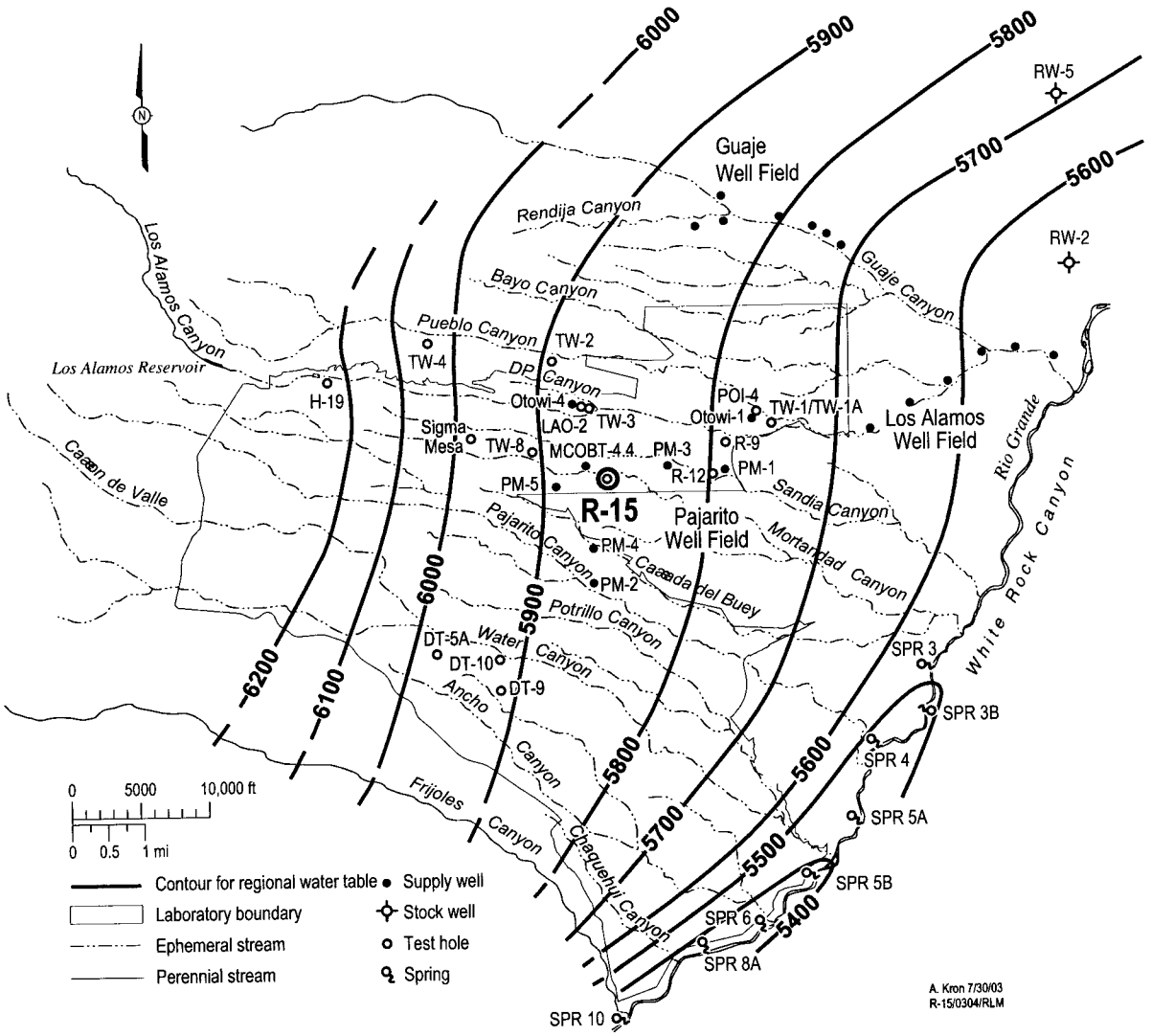

Figure 1. General location of R-15 well.

Axial deposits of the ancestral Rio Grande were also encountered at the base of the unassigned pumiceous deposits below 1100 ft bgs (i.e., the Totavi Lentil of Griggs 1964, 8795). However, this well did not penetrate into the Totavi Lentil because of caving (i.e., "flowing sand") problems encountered during drilling. It is worth mentioning that this caving suggests a relatively high K value within the upper portions of the Totavi Lentil. Hence, these K values are probably larger than those reported here for overlying unassigned pumiceous deposits.

The R-15 casing materials consist of mild carbon steel between the surface and 929 ft bgs. From 929 to 1031 ft bgs, well materials consist of stainless steel including the bottom end-cap. This lower stainless-steel interval straddles the regional water table. Materials in the lower interval are constructed from 5.0-in. I.D. (or 5.56-in. O.D.), Schedule-40, 304-stainless steel with a 0.010-in. continuous-slotted screen (or wire-wrap screen), as seen in Figure 2. The borehole diameter between 750 and 1107 ft bgs is 12.75 in.; the wellbore annulus from about 942 to 1031 ft bgs is filled with a medium quartz sand filter-pack. Annular seals are located above 942 ft bgs and below 1031 ft bgs; these seals consist of a mixture of bentonite and fine sand.

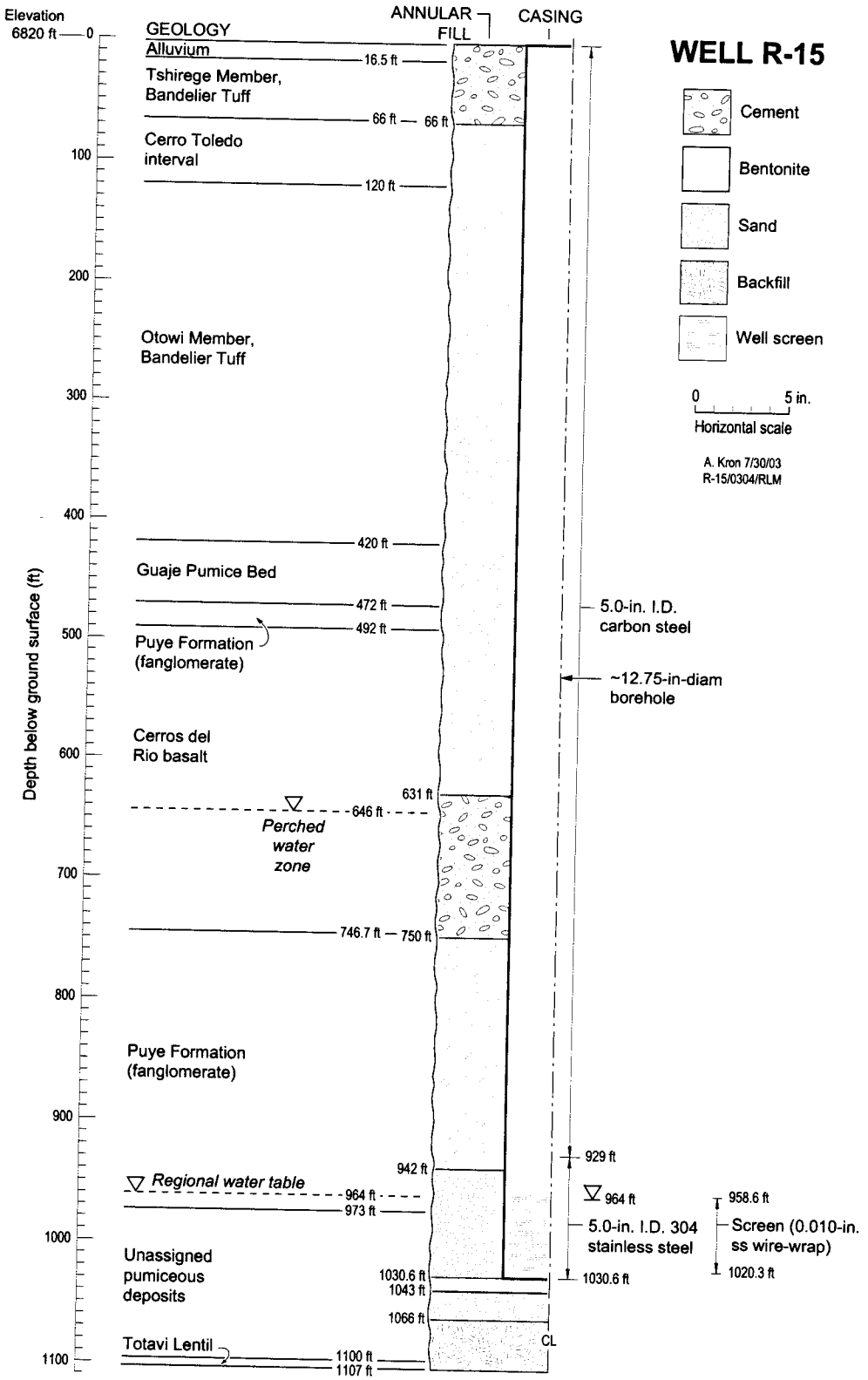

Figure 2. Hydrogeology and well construction details for well R-15.

At the start of the aquifer test, the water level in the regional aquifer was located about 964 ft bgs (i.e., within the screened portion of the well). A simple determination of the R-15 water elevation relative to mean sea level (MSL) suggests that the static water level is located at about 5856 ft MSL (i.e., the R-15 surface elevation of 6820 ft MSL minus the depth to water of 964 ft bgs). This static value for R-15 is consistent with the water table contour map of the regional aquifer shown in Figure 1. The water table contours seen in Figure 1 were originally developed by Purtymun (Purtymun and Johansen 1974, 11835), but have changed since then in response to municipal water production (Rogers et al. 1996, 54714).

Because the static water level was located within the screened portion of well R-15, the test pump was set at the base of this interval at approximately 1020 ft bgs. The inside diameter of the water production casing was 2.375 in.; this casing was attached to the submersible pump used during the aquifer test. The test pump and production casing were removed at the end of the test. During this pump removal process, it was discovered that the pump's water production casing did not have a one-way check value located above the pump. Hence, when the pump was turned off at the end of the aquifer test, approximately 226 gal. of water contained in the production casing immediately flowed back into the well. As a result, recovery data are considered suspect and no recovery-based results are presented here. Additional well construction details are listed in the R-15 well completion report (Longmire et al. 2001, 70103).

The most reliable hydraulic parameters characterizing aquifer behavior come from long-term pumping tests where multiple observation wells are used to record both drawdown and recovery data (Kruseman and de Ridder 1990, 70110). Drawdown values in observation wells are preferable to similar data collected in pumping wells because numerous complexities are avoided. Some of these complexities include (1) localized wellbore turbulence effects associated with elevated entrance velocities within the filter pack and/or well screen; (2) changes in well efficiency over time resulting from a redistribution of formation and filter pack materials during pumping and/or recovery; (3) wellbore storage effects; and (4) flow-zone thinning near the pumping screen for phreatic aquifer conditions. While data from observation wells generally do not contain these complexities, these extra observation wells are expensive to install. Instead, the pumping well is typically used to record water-level declines in response to pumping and water-level recovery once the pump is shut down. Suitably modified test procedures provide reliable estimates for T; however, estimates for S are not valid under these test conditions. Hence, only T values are reported here.

II. AQUIFER TEST PROCEDURE

The aquifer test at well R-15 was performed in accordance with the recommended test procedures outlined in Kruseman and de Ridder (1990, 70110) and Driscoll (1986). Static conditions were established several weeks prior to the start of the aquifer test. The discharge rate was frequently measured during the test using an in-line flow meter and stopwatch. As seen in Table 2, these measurements indicate that the discharge fluctuated less than 1.9% during the aquifer test. A total of 32,310 gal. of water were pumped during the 46-hr test at an average rate of 11.7 gallons per minute (gpm). Pumped waters were piped approximately one-quarter mile down-canyon where they were discharged by a sprinkler irrigation system into the lower portions of Mortandad Canyon. This test discharge procedure was approved by the New Mexico Environmental Department's Ground Water Quality Bureau. Drawdown and recovery in the pumping well were automatically recorded using a pressure transducer attached to the outside portion of the production casing and located several feet above the pump intake. These test data are tabulated in Appendix A and graphically shown in Figure 3. As seen in Figure 4, pumping and recovery data do not replicate one another as they should. In fact, the recovery data rise considerably faster than drawdown data. This situation resulted from the absence of a check value to prevent back-flow when the pump was turned off. This situation makes the drawdown data more reliable than recovery data; normally when a check valve is present, this situation is reversed.

Hence, no recovery analyses are presented in this report. However, residual recovery data are still preserved in Appendix A, along with drawdown (or pumping) data. In addition, K is obtained from transmissivity using the relationship K = T/D, where D is the aquifer saturated thickness.

Table 2
Discharge Rate and Elapsed Time in Well R-15

Instantaneous Volume Pumped (gal.)	Instantaneous Pumping Time (min)	Discharge Rate (gpm)	Total Elapsed Time (min)
60	5.16	11.63	3
70	6.02	11.63	23
60	5.17	11.61	38
60	5.16	11.63	53
60	5.15	11.65	68
250	21.19	11.80	458
60	5.07	11.83	498
120	10.17	11.80	1393
60	5.11	11.74	1433
60	5.14	11.67	2728
60	5.15	11.65	2743
32310 (total volume)	2760 (total time)	11.71 (average)[a]	2760 (total time)

[a] Represents an overall average pumping rate for the aquifer test.

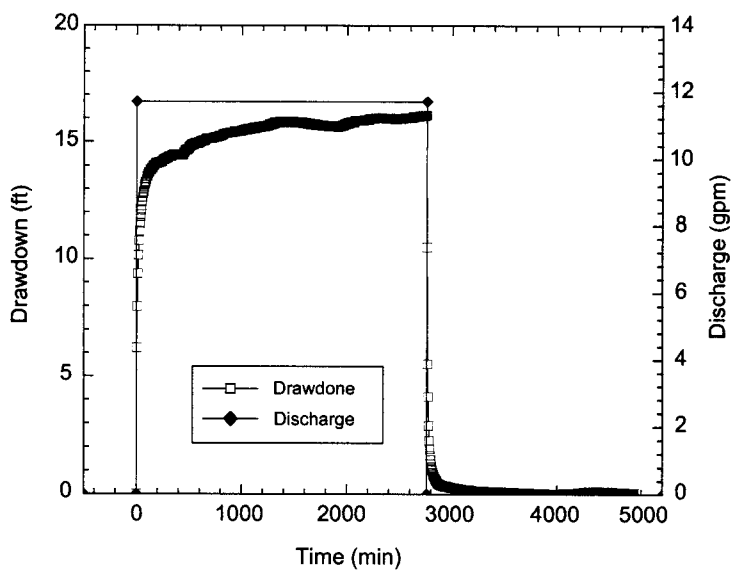

Figure 3. Observed time-drawdown, recovery, and discharge for the R-15 aquifer test.

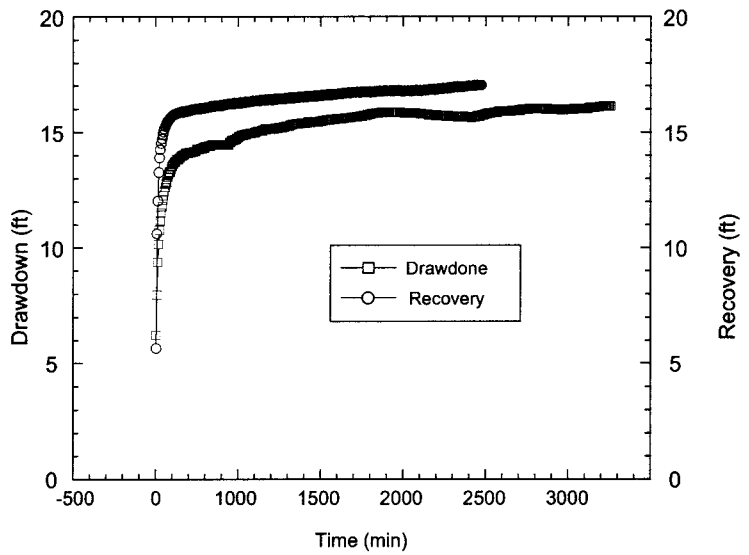

Figure 4. Comparison of drawdown and recovery data for the R-15 aquifer test.

III. DATA ANALYSIS

In thick unconfined aquifers that are screened at the water table, such as R-15, there are both partial penetration and flow-zone thinning (or dewatering) effects that must be taken into consideration while analyzing data from a pumping test. A close examination of Figure 2 shows that the R-15 well screen penetrates only the upper 41% of the aquifer (i.e., primarily the unassigned pumiceous deposits located above the Totavi Lentil). In other words, 56.3 ft of the formation are screened out of a total of 136 ft. Hence, the screen is partially penetrating. In addition, the static water level is located within the screened interval. Therefore, we also know that we will be required to deal with flow-zone thinning effects. These dewatering effects commonly occur in phreatic aquifers as the cone of depression propagates radially outward from the well screen. As mentioned above, most of the screened aquifer materials at R-15 are in the unassigned pumiceous deposits. However, the upper nine ft of submerged screen are within the Puye fanglomerate. These saturated Puye fanglomerate deposits near the top of the submerged well screen were dewatered during the aquifer test. Regardless, the final transmissivity value from any analysis should be assigned to both the lower nine feet of the Puye fanglomerate and the entire thickness of the pumiceous deposits that are below the Puye. In other words, the T and K values presented here represent a weighted average of both the Puye fanglomerate and unassigned pumiceous deposits. Strictly speaking, these weights are unknown; however, an initial estimate of these weights could be assigned according to the screened intervals. Hence, about 6.5% (i.e., 9 ft out of 136 ft) of T comes from the Puye, while about 93.5% comes from the unassigned pumiceous unit.

Drawdown data were analyzed using the software package Aqtesolv™ for Windows™ (version 3.50 professional). This package plots both test data and selected theoretical aquifer type-curves on the same figure. Unfortunately, there is no available solution within Aqtesolv™ that takes both partial penetration and flow-zone thinning effects into account simultaneously. As it turns out, the Theis method in this package will account for partial penetration effects in the pumping well only if the aquifer is confined. However, when we have an unconfined aquifer like R-15, Aqtesolv™ will not correct for partial penetration effects. But the program will correct for flow-zone thinning in this situation. We can combine these features into our final solution using the following procedure. First, we can manually apply the Jacob correction (Walton 1970, 76044, pp. 222–225) to the time-drawdown data. This correction will automatically account for flow-zone thinning effects that typically occur in phreatic aquifers. Second, we

can now select the aquifer type within Aqtesolv™ as "Theis confined" so that partial penetration effects will also be taken into consideration. It is worth repeating that dewatering effects in the phreatic aquifer were incorporated into the data before using the software. Now our analysis will take both partial penetration and flow-zone thinning effects into consideration simultaneously, and will be valid for phreatic aquifer conditions at R-15. Note that this procedure must be carefully applied and will not work with all available solutions in Aqtesolv™. For example, we can not manually apply the Jacob-corrected time-drawdown data and then use the Cooper-Jacob solution for a confined aquifer because partial penetration effects will not be taken into consideration. Recall that the Jacob correction is given by Walton (1970, 76044, pp. 222-225):

$$s = s_a - \frac{s_a^2}{2b} \qquad (1)$$

where s is the corrected drawdown that would have occurred in an equivalent non-leaky, confined aquifer with a fully penetrating well screen, s_a is the observed drawdown under phreatic aquifer conditions, and $b=D$ is the initial saturated aquifer thickness as seen in Figure 5. For partially penetrating systems, however, there is no "good way" to apply a dewatering correction because an applicable theoretical equation does not exist. Nevertheless, we assume that equation (1) will adequately correct for flow-zone thinning effects in a partially penetrating well if we use the screen length, L, substituted for aquifer thickness, D. For example, if calculations for the dewatering corrections were made in R-15 using the aquifer thickness of 136 ft rather than the screen length of 56.3 ft, the magnitude of the correction would be substantially less than if the screen length were used. Actual degradation of well performance associated with dewatering the screen is probably more closely tied to the amount of dewatering as a percentage of the screen length rather than the total aquifer thickness. Hence, we have chosen to use screen length rather than aquifer thickness for this correction. The resulting correction in (1) is larger and the associated corrected drawdown (s) is smaller. Hence, the resulting transmissivity obtained with the corrected drawdown data will be higher than if we had simply used aquifer thickness in (1). Finally, a hydraulic conductivity value was obtained by dividing this transmissivity by the true aquifer thickness of 136 ft.

Experienced Aqtesolv™ users will recognize that we have simply tricked the program by making a manual flow-zone thinning correction to the data. Now when we select the Theis confined aquifer solution in Aqtesolv™, the program will make the appropriate correction for partial penetration. Finally, we note that the data reported in Appendix A is observed data without the dewatering correction applied.

As a check, a similar procedure can also be followed using the Moench or Neuman solutions in Aqtesolv™ for a phreatic aquifer. In other words, the dewatering correction is applied to the data before using Aqtesolv™. Now Aqtesolv™ will simultaneously correct for partial penetration and flow-zone thinning effects when either the Moench or Neuman solutions are used. Finally, a hydraulic conductivity value for these techniques is obtained by dividing transmissivity by the true aquifer thickness of 136 ft.

It turns out that failure to account for dewatering is often unimportant, particularly in submerged screens and in observation wells. However, dewatering of the pumped well screen is normally considered significant. When this occurs, it is important to correct the drawdown measurements for dewatering to minimize errors that could otherwise occur in parameter calculations.

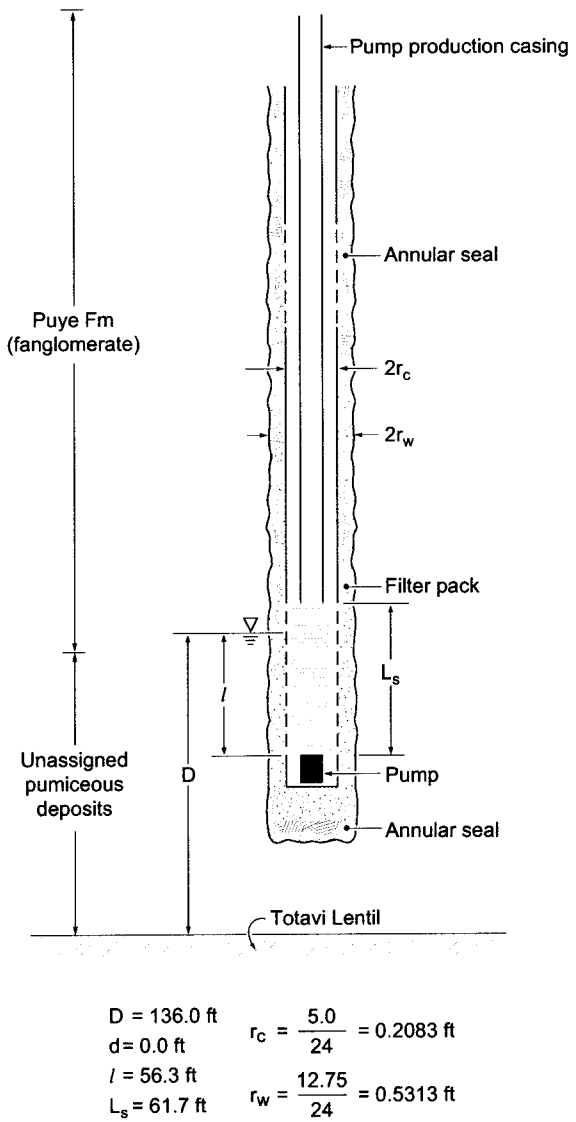

Figure 5. Test configuration parameters for the R-15 aquifer test.

Results for the pumping portion of the test analyses are summarized in Table 3. All of these type-curve solutions are shown in Figures 6–9. These figures depict an appropriate type curve as a solid or dashed line, and the observed field data as points. In addition, these figures show that late-time agreement between the respective type curves and data points are reasonably good, whereas, the early-time agreement is not. These early-time data are commonly difficult to analyze because of many factors, including wellbore turbulence. Regardless, the late-time data are generally considered more reliable and our analyses are consistent with this interpretation. Overall, these results suggest an average value for aquifer transmissivity (T) is about 300 square ft per day (ft^2/day). However, as seen below, there are some minor variations between different test analyses. In addition, Table 3 also shows several other solutions that are intended for comparison only. These latter analyses account for partial penetration but not dewatering. Hence, they give some indication of the effects of flow-zone thinning if we compare these results to other techniques that simultaneously consider both effects. These comparison T values are not intended to be representative of the pumiceous deposits and should not be used for that purpose.

Table 3
Comparison of Aquifer Test Type-Curve Analyses for Well R-15

Method	Aquifer Type	T (ft^2/day)	K (ft/day)[c]	Reference
Theis	confined[a]	232	1.7	see Figure 6
Theis	(un)confined[b]	277	2.0	see Figure 7
Moench	unconfined[b]	306	2.2	see Figure 8
Neuman	unconfined[b]	299	2.2	see Figure 9
Specific Capacity	confined[a]	271	2.0	not listed
Specific Capacity	(un)confined[b]	318	2.3	see Appendix B-1
Average Value	all tests[b]	300	2.2	
Recommended	Moench or Neuman	302	2.2	

[a] For comparison only; no Jacob correction applied. This value is not recommended for use.
[b] Jacob correction (Eq. 1) applied to data with b=56.3 ft; see text for discussion.
[c] $K=T/b$, where b is the saturated aquifer thickness of 136 ft.; see D in Fig. 5.

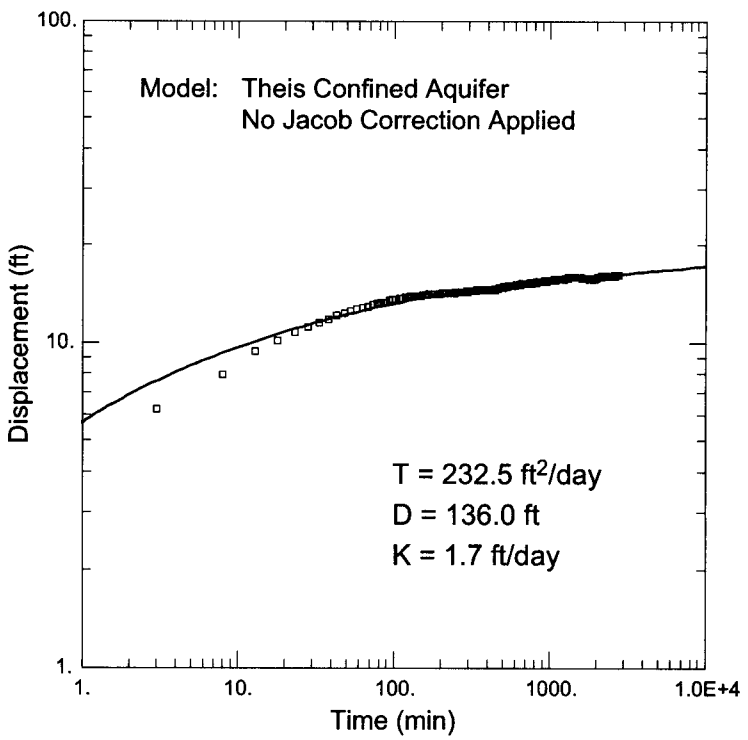

Figure 6. Theis confined aquifer analysis for R-15 drawdown data.

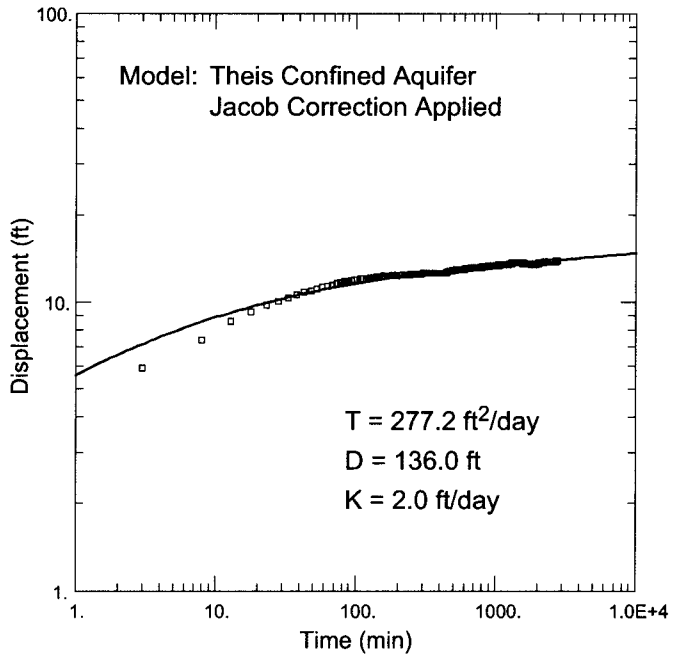

Figure 7. Theis confined aquifer analysis for R-15 drawdown data. The data were corrected for dewatering effects using the Jacob correction prior to analysis.

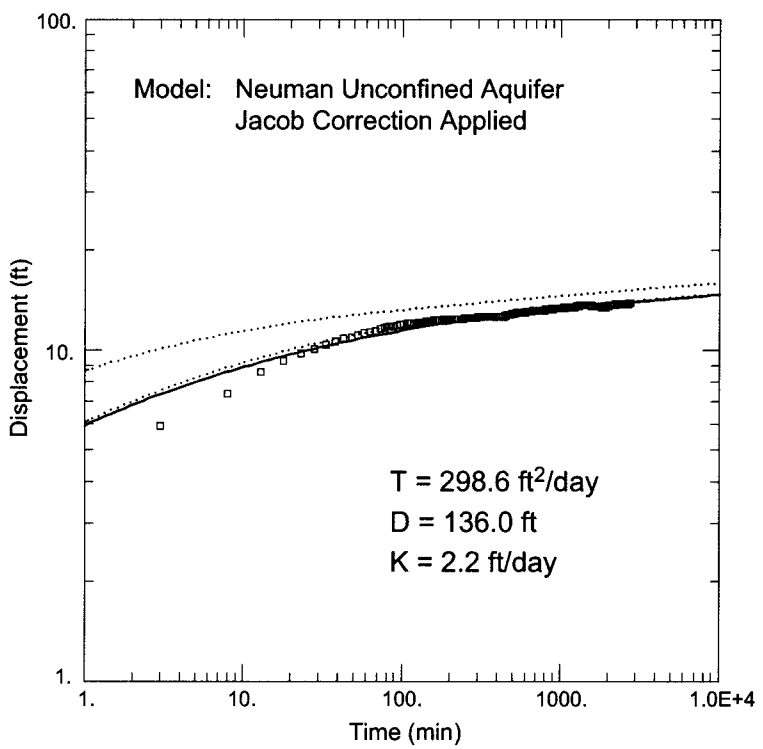

Figure 8. Neuman analysis for R-15 drawdown data. The data were corrected for dewatering effects using the Jacob correction prior to analysis.

Theis Analysis. Drawdown data were initially analyzed by the Theis method (Bouwer 1978, 73678) for a confined aquifer using the test configuration shown in Figure 5. Initially, only the uncorrected data were used and these results are intended for comparison only. This analysis is shown in Figure 6 and Table 3 and only accounts for partial penetration. Still, the observed data fit the theoretical Theis type-curve rather nicely after about 20 min. When the time-drawdown data are corrected for flow-zone thinning effects using equation (1) with b = 56.3 ft, the Theis confined aquifer solution simultaneously corrects for partial penetration and dewatering. This analysis is shown in Figure 7 and Table 3 and indicates that T is about 277 ft^2/day. The corresponding value for hydraulic conductivity is 2.0 ft/day and was obtained after dividing T by the initial saturated thickness of 136 ft. We conclude that T is increased by about 45 ft^2/day (or a relative increase of 19%) when dewatering effects are taken into account. In addition, using the analysis of Schafer (1978, 73449), it can be shown that the effects of wellbore storage were dissipated within about 7 minutes after pumping started. Hence, these effects are not considered further in this report.

Neuman Analysis. For comparison, drawdown data were also analyzed by the Neuman method (Neuman, 1974) for an unconfined aquifer with partial penetration using the test configuration shown in Figure 5. When the time-drawdown data are manually corrected for flow-zone thinning effects using equation (1) with b = 56.3 ft, the Neuman unconfined aquifer solution simultaneously corrects for partial penetration and dewatering. As seen in Figure 8, the corrected data also fit the theoretical type curve very well after about 20 min. This analysis indicates that T is about 299 ft^2/day. The corresponding K value is 2.2 ft/day and was obtained with a saturated thickness of 136 ft.

Moench Analysis. For comparison, drawdown data were also analyzed by the Moench method (Moench, 1993, 1996, and 1997) for an unconfined aquifer using the test configuration shown in Figure 5. This method automatically corrects for partial penetration effects. When the time-drawdown data are manually corrected for flow-zone thinning effects using equation (1) with b = 56.3 ft, the Moench unconfined aquifer solution simultaneously corrects for partial penetration and dewatering. As seen in Figure 9, the observed data fit the theoretical type-curve very nicely after about 25 min. This analysis indicates that T is about 306 ft^2/day. The corresponding K value is 2.2 ft/day, and was obtained with a saturated thickness of 136 ft.

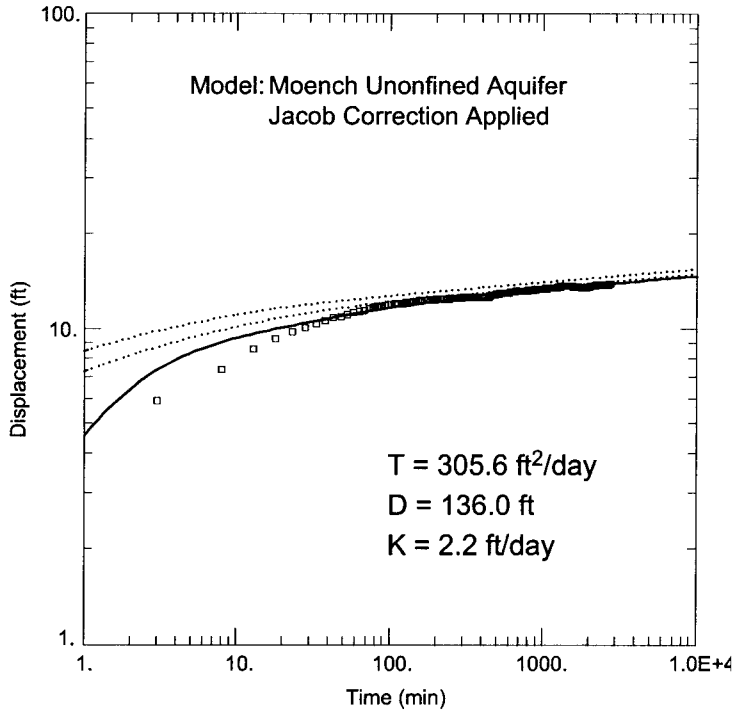

Figure 9. Moench analysis for R-15 drawdown data. The data were corrected for dewatering effects using the Jacob correction prior to analysis.

Specific Capacity Analysis. As a final comparison, drawdown 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 (s), and has units of gpm/ft. Strictly speaking, this method is 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 $K = T/b$, where b is saturated thickness (or D in Figure 5). 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 the resulting script file is listed in Appendix B-2. This Matlab program computes and plots a range of T values. Results from the aquifer test at R-15 are shown in Figure 10 using input values listed in Appendix B-1. These results list the estimated output range in T values as a function of well efficiency and partial penetration. This analysis demonstrates that the specific capacity method is relatively sensitive to variations in these parameters. Hence, the curve in Figure 10 is viewed by many to represent a lower limit for a very wide range of possible T values. However, if we restrict ourselves to the observed aquifer penetration value of 41.4%, and assume a reasonable range of possible well efficiencies, then our analysis yields a much narrower band of possible T values. For example, if we assume that the screen at R-15 has a 100% well efficiency, 41.4% aquifer penetration (i.e., 56.3*100/136 from Figure 5), and the formation has an S = 0.01, we obtain a minimum T value of 277 ft^2/day. However, if we apply the Jacob correction to the observed data with b = 56.3 ft as previously described, we obtain a single T value of 318 ft^2/day. As seen in Table 3, this latter T value is very similar to that obtained with the Theis, Moench, or

Neuman techniques using Jacob-corrected drawdown data. Dividing these T values by a saturated thickness of 136 ft gives a K value of between 2.0 and 2.3 ft/day.

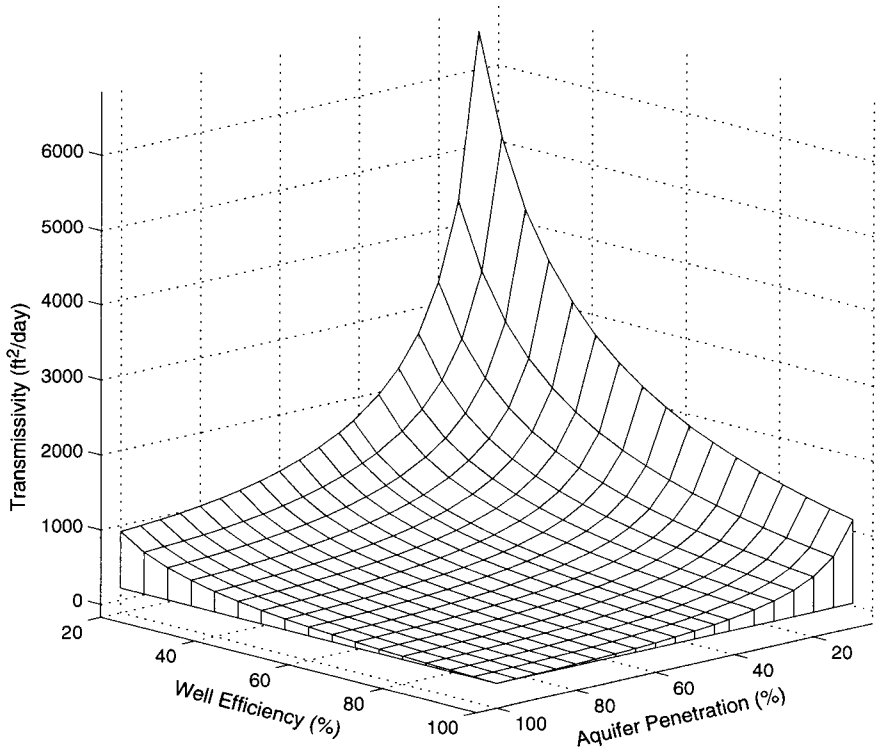

Figure 10. Specific capacity analysis for R-15 test data. The data were corrected for dewatering effects using the Jacob correction prior to analysis.

IV. DISCUSSION AND CONCLUSIONS

Results from all of the R-15 aquifer test analyses are summarized in Table 3. Review of these results shows that T values vary from a low of 277 to a high of 318 ft^2/day, and average about 300 ft^2/day. This relatively small range suggests remarkably good agreement between all of the methods used here. However, either the Moench or Neuman type-curve analyses probably represent the unconfined T values in the regional aquifer better than the other methods since these solutions were specifically developed for unconfined aquifers. Hence, in Table 3, the recommended T value actually represents an average of T values from only the Moench and Neuman methods. Finally, as explained below, the specific capacity method also provides us with another estimate for the variability of T that is much broader than that implied in Table 3.

From a cursory review, the specific capacity technique appears to be the least accurate of all techniques presented because it only uses one value for drawdown at one time occurring near the end of the test. In fact, this criticism is perhaps the biggest limitation associated with this particular method. However, according to Walton (1970, 76044, pp. 314–321), because of the effects of partial penetration, well losses, and hydrogeologic boundaries, actual T values can be expected to be larger than those determined by the specific capacity approach. The analyses presented here corrected for these effects and appears to confirm our expectation that T is probably larger than an estimated minimum 277 ft^2/day. By extension, the K value of 2.0 ft/day associated with the specific capacity method should also represent

a minimum. In addition, the modified methods of McLin (2004, 82834) and Bradbury and Rothschild (1985, 76040) demonstrate that the effects of well efficiency, partial penetration, and dewatering can potentially increase the value of T by a relatively large amount as seen in Figure 10. On the other hand, when we restrict these parameters to observed or realistic values, a much narrower range of possible T values is obtained from the specific capacity technique. In fact, final T values from this technique are nearly identical to those obtained in either the Moench and Neuman methods if reasonable values for well efficiency, partial penetration (actual value used), and S can be estimated. Ultimately, T values obtained from these latter methods probably represent the best estimate because they are derived specifically for phreatic aquifer conditions. Finally, the specific capacity method produces a range of T values that gives us some qualitative measure of potential uncertainty. It should also be remembered that the analyses presented here implicitly assume that T values are representative of the horizontal direction since flow is assumed to be radially (i.e., horizontally) toward the well screen during pumping.

V. ACKNOWLEDGEMENTS

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Appendix A

R-15 Aquifer Test Data

A-1
Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test

T (min)	S (ft)	Q (gpm)
3	6.228	11.63
8	7.972	—
13	9.370	—
18	10.149	—
23	10.768	11.63
28	11.186	—
33	11.518	—
38	11.792	11.61
43	12.080	—
48	12.267	—
53	12.469	11.63
58	12.627	—
63	12.786	—
68	12.858	11.65
73	13.074	—
78	13.189	—
83	13.276	—
88	13.290	—
93	13.406	—
98	13.521	—
103	13.550	—
108	13.622	—
113	13.694	—
118	13.708	—

T (min)	S (ft)	Q (gpm)
123	13.737	—
128	13.838	—
133	13.838	—
138	13.824	—
143	13.881	—
148	13.896	—
153	13.939	—
158	13.996	—
163	13.982	—
168	14.025	—
173	14.025	—
178	14.083	—
183	14.112	—
188	14.097	—
193	14.097	—
198	14.097	—
203	14.126	—
208	14.126	—
213	14.126	—
218	14.141	—
223	14.141	—
228	14.141	—
233	14.169	—
238	14.169	—

T (min)	S (ft)	Q (gpm)
243	14.169	—
248	14.256	—
253	14.256	—
258	14.256	—
263	14.256	—
268	14.285	—
273	14.285	—
278	14.314	—
283	14.299	—
288	14.328	—
293	14.342	—
298	14.328	—
303	14.386	—
308	14.386	—
313	14.386	—
318	14.400	—
323	14.386	—
328	14.400	—
333	14.429	—
338	14.443	—
343	14.458	—
348	14.472	—
353	14.472	—
358	14.472	—

T (min)	S (ft)	Q (gpm)
363	14.458	—
368	14.472	—
373	14.458	—
378	14.472	—
383	14.472	—
388	14.472	—
393	14.472	—
398	14.458	—
403	14.458	—
408	14.443	—
413	14.443	—
418	14.458	—
423	14.443	—
428	14.458	—
433	14.443	—
438	14.443	—
443	14.458	—
448	14.559	—
453	14.573	—
458	14.616	11.80
463	14.659	—
468	14.659	—
473	14.674	—
478	14.674	—

T (min)	S (ft)	Q (gpm)
483	14.688	—
488	14.688	—
493	14.760	—
498	14.746	11.83
503	14.803	—
508	14.832	—
513	14.847	—
518	14.861	—
523	14.876	—
528	14.876	—
533	14.876	—
538	14.904	—
543	14.919	—
548	14.904	—
553	14.948	—
558	14.948	—
563	14.948	—
568	14.948	—
573	14.962	—
578	14.948	—
583	14.962	—
588	14.976	—
593	14.962	—
598	14.976	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
603	14.991	—
608	15.034	—
613	15.034	—
618	15.048	—
623	15.048	—
628	15.063	—
633	15.063	—
638	15.063	—
643	15.077	—
648	15.063	—
653	15.121	—
658	15.121	—
663	15.149	—
668	15.135	—
673	15.135	—
678	15.135	—
683	15.135	—
688	15.135	—
693	15.149	—
698	15.135	—
703	15.135	—
708	15.149	—
713	15.149	—
718	15.149	—

T (min)	S (ft)	Q (gpm)
723	15.178	—
728	15.193	—
733	15.178	—
738	15.193	—
743	15.193	—
748	15.221	—
753	15.221	—
758	15.207	—
763	15.221	—
768	15.207	—
773	15.236	—
778	15.236	—
783	15.236	—
788	15.265	—
793	15.265	—
798	15.279	—
803	15.265	—
808	15.279	—
813	15.279	—
818	15.322	—
823	15.322	—
828	15.351	—
833	15.351	—
838	15.365	—

T (min)	S (ft)	Q (gpm)
843	15.365	—
848	15.365	—
853	15.380	—
858	15.365	—
863	15.380	—
868	15.380	—
873	15.380	—
878	15.380	—
883	15.409	—
888	15.394	—
893	15.394	—
898	15.409	—
903	15.394	—
908	15.409	—
913	15.409	—
918	15.409	—
923	15.438	—
928	15.452	—
933	15.438	—
938	15.452	—
943	15.452	—
948	15.452	—
953	15.438	—
958	15.452	—

T (min)	S (ft)	Q (gpm)
963	15.466	—
968	15.466	—
973	15.466	—
978	15.452	—
983	15.466	—
988	15.466	—
993	15.466	—
998	15.481	—
1003	15.481	—
1008	15.495	—
1013	15.510	—
1018	15.510	—
1023	15.510	—
1028	15.524	—
1033	15.538	—
1038	15.538	—
1043	15.553	—
1048	15.524	—
1053	15.524	—
1058	15.538	—
1063	15.567	—
1068	15.553	—
1073	15.567	—
1078	15.553	—

T (min)	S (ft)	Q (gpm)
1083	15.553	—
1088	15.567	—
1093	15.567	—
1098	15.596	—
1103	15.596	—
1108	15.596	—
1113	15.610	—
1118	15.610	—
1123	15.582	—
1128	15.596	—
1133	15.596	—
1138	15.596	—
1143	15.596	—
1148	15.625	—
1153	15.639	—
1158	15.639	—
1163	15.639	—
1168	15.625	—
1173	15.639	—
1178	15.639	—
1183	15.639	—
1188	15.654	—
1193	15.654	—
1198	15.668	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
1203	15.668	—
1208	15.668	—
1213	15.668	—
1218	15.682	—
1223	15.668	—
1228	15.682	—
1233	15.682	—
1238	15.682	—
1243	15.697	—
1248	15.697	—
1253	15.697	—
1258	15.740	—
1263	15.740	—
1268	15.740	—
1273	15.740	—
1278	15.740	—
1283	15.769	—
1288	15.769	—
1293	15.769	—
1298	15.783	—
1303	15.783	—
1308	15.827	—
1313	15.827	—
1318	15.812	—

T (min)	S (ft)	Q (gpm)
1323	15.827	—
1328	15.827	—
1333	15.827	—
1338	15.827	—
1343	15.827	—
1348	15.827	—
1353	15.841	—
1358	15.855	—
1363	15.855	—
1368	15.870	—
1373	15.841	—
1378	15.841	—
1383	15.841	—
1388	15.855	—
1393	15.841	11.80
1398	15.855	—
1403	15.855	—
1408	15.870	—
1413	15.841	—
1418	15.855	—
1423	15.855	—
1428	15.870	—
1433	15.855	11.74
1438	15.855	—

T (min)	S (ft)	Q (gpm)
1443	15.855	—
1448	15.855	—
1453	15.870	—
1458	15.870	—
1463	15.855	—
1468	15.870	—
1473	15.855	—
1478	15.855	—
1483	15.855	—
1488	15.855	—
1493	15.855	—
1498	15.841	—
1503	15.841	—
1508	15.827	—
1513	15.827	—
1518	15.841	—
1523	15.841	—
1528	15.841	—
1533	15.841	—
1538	15.841	—
1543	15.841	—
1548	15.841	—
1553	15.827	—
1558	15.841	—

T (min)	S (ft)	Q (gpm)
1563	15.841	—
1568	15.827	—
1573	15.812	—
1578	15.827	—
1583	15.812	—
1588	15.812	—
1593	15.812	—
1598	15.812	—
1603	15.812	—
1608	15.798	—
1613	15.798	—
1618	15.783	—
1623	15.783	—
1628	15.783	—
1633	15.783	—
1638	15.783	—
1643	15.783	—
1648	15.783	—
1653	15.755	—
1658	15.755	—
1663	15.755	—
1668	15.740	—
1673	15.755	—
1678	15.755	—

T (min)	S (ft)	Q (gpm)
1683	15.740	—
1688	15.755	—
1693	15.740	—
1698	15.726	—
1703	15.740	—
1708	15.726	—
1713	15.726	—
1718	15.726	—
1723	15.726	—
1728	15.711	—
1733	15.711	—
1738	15.711	—
1743	15.711	—
1748	15.711	—
1753	15.711	—
1758	15.697	—
1763	15.711	—
1768	15.697	—
1773	15.711	—
1778	15.697	—
1783	15.682	—
1788	15.697	—
1793	15.697	—
1798	15.697	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
1803	15.682	—
1808	15.682	—
1813	15.682	—
1818	15.682	—
1823	15.682	—
1828	15.668	—
1833	15.682	—
1838	15.668	—
1843	15.668	—
1848	15.668	—
1853	15.654	—
1858	15.682	—
1863	15.682	—
1868	15.682	—
1873	15.668	—
1878	15.668	—
1883	15.668	—
1888	15.654	—
1893	15.654	—
1898	15.654	—
1903	15.654	—
1908	15.654	—
1913	15.639	—
1918	15.654	—

T (min)	S (ft)	Q (gpm)
1923	15.654	—
1928	15.668	—
1933	15.668	—
1938	15.668	—
1943	15.697	—
1948	15.697	—
1953	15.711	—
1958	15.697	—
1963	15.697	—
1968	15.711	—
1973	15.740	—
1978	15.740	—
1983	15.755	—
1988	15.755	—
1993	15.769	—
1998	15.783	—
2003	15.798	—
2008	15.783	—
2013	15.827	—
2018	15.827	—
2023	15.812	—
2028	15.827	—
2033	15.841	—
2038	15.841	—

T (min)	S (ft)	Q (gpm)
2043	15.841	—
2048	15.855	—
2053	15.855	—
2058	15.841	—
2063	15.855	—
2068	15.841	—
2073	15.884	—
2078	15.899	—
2083	15.913	—
2088	15.913	—
2093	15.899	—
2098	15.899	—
2103	15.899	—
2108	15.899	—
2113	15.899	—
2118	15.913	—
2123	15.913	—
2128	15.913	—
2133	15.899	—
2138	15.899	—
2143	15.899	—
2148	15.899	—
2153	15.913	—
2158	15.927	—

T (min)	S (ft)	Q (gpm)
2163	15.942	—
2168	15.927	—
2173	15.927	—
2178	15.927	—
2183	15.942	—
2188	15.927	—
2193	15.927	—
2198	15.927	—
2203	15.956	—
2208	15.927	—
2213	15.971	—
2218	15.985	—
2223	15.985	—
2228	15.985	—
2233	15.985	—
2238	15.985	—
2243	15.985	—
2248	15.985	—
2253	15.985	—
2258	15.985	—
2263	16.014	—
2268	16.014	—
2273	16.014	—
2278	16.014	—

T (min)	S (ft)	Q (gpm)
2283	16.014	—
2288	16.014	—
2293	16.014	—
2298	16.028	—
2303	16.028	—
2308	16.028	—
2313	16.028	—
2318	16.014	—
2323	16.014	—
2328	16.028	—
2333	16.014	—
2338	16.014	—
2343	16.014	—
2348	16.014	—
2353	16.014	—
2358	16.014	—
2363	16.000	—
2368	16.000	—
2373	16.014	—
2378	15.985	—
2383	16.000	—
2388	16.000	—
2393	16.000	—
2398	16.000	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
2403	16.000	—
2408	16.000	—
2413	15.985	—
2418	16.000	—
2423	16.000	—
2428	15.985	—
2433	16.000	—
2438	16.000	—
2443	15.985	—
2448	16.000	—
2453	15.985	—
2458	15.971	—
2463	15.985	—
2468	15.985	—
2473	15.971	—
2478	15.985	—
2483	16.000	—
2488	15.985	—
2493	16.000	—
2498	16.000	—
2503	16.000	—
2508	16.000	—
2513	16.000	—
2518	16.000	—

T (min)	S (ft)	Q (gpm)
2523	16.000	—
2528	16.000	—
2533	15.985	—
2538	16.014	—
2543	16.014	—
2548	16.014	—
2553	16.028	—
2558	16.028	—
2563	16.028	—
2568	16.028	—
2573	16.014	—
2578	16.014	—
2583	16.028	—
2588	16.028	—
2593	16.014	—
2598	16.028	—
2603	16.028	—
2608	16.028	—
2613	16.028	—
2618	16.028	—
2623	16.043	—
2628	16.072	—
2633	16.057	—
2638	16.057	—

T (min)	S (ft)	Q (gpm)
2643	16.086	—
2648	16.072	—
2653	16.086	—
2658	16.072	—
2663	16.086	—
2668	16.086	—
2673	16.086	—
2678	16.086	—
2683	16.086	—
2688	16.100	—
2693	16.115	—
2698	16.115	—
2703	16.115	—
2708	16.115	—
2713	16.129	—
2718	16.115	—
2723	16.115	—
2728	16.115	11.67
2733	16.115	—
2738	16.115	—
2743	16.129	11.65
2748	16.129	—
2753	16.129	—
2758	16.129	Pump off at 2760

T (min)	S (ft)	Q (gpm)
2763	10.494	—
2768	5.536	—
2773	4.123	—
2778	2.898	—
2783	2.263	—
2788	1.917	—
2793	1.643	—
2798	1.456	—
2803	1.283	—
2808	1.153	—
2813	1.038	—
2818	0.922	—
2823	0.850	—
2828	0.778	—
2833	0.721	—
2838	0.663	—
2843	0.620	—
2848	0.591	—
2853	0.562	—
2858	0.519	—
2863	0.475	—
2868	0.461	—
2873	0.447	—
2878	0.432	—

T (min)	S (ft)	Q (gpm)
2883	0.418	—
2888	0.403	—
2893	0.389	—
2898	0.389	—
2903	0.375	—
2908	0.360	—
2913	0.360	—
2918	0.346	—
2923	0.360	—
2928	0.331	—
2933	0.331	—
2938	0.331	—
2943	0.346	—
2948	0.331	—
2953	0.331	—
2958	0.331	—
2963	0.317	—
2968	0.302	—
2973	0.302	—
2978	0.288	—
2983	0.288	—
2988	0.288	—
2993	0.274	—
2998	0.274	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
3003	0.274	—
3008	0.274	—
3013	0.274	—
3018	0.274	—
3023	0.274	—
3028	0.274	—
3033	0.259	—
3038	0.259	—
3043	0.259	—
3048	0.245	—
3053	0.245	—
3058	0.245	—
3063	0.245	—
3068	0.230	—
3073	0.230	—
3078	0.230	—
3083	0.230	—
3088	0.216	—
3093	0.216	—
3098	0.202	—
3103	0.202	—
3108	0.202	—
3113	0.202	—
3118	0.202	—

T (min)	S (ft)	Q (gpm)
3123	0.187	—
3128	0.187	—
3133	0.187	—
3138	0.187	—
3143	0.187	—
3148	0.173	—
3153	0.187	—
3158	0.173	—
3163	0.202	—
3168	0.187	—
3173	0.158	—
3178	0.158	—
3183	0.158	—
3188	0.144	—
3193	0.158	—
3198	0.144	—
3203	0.144	—
3208	0.144	—
3213	0.144	—
3218	0.144	—
3223	0.144	—
3228	0.144	—
3233	0.144	—
3238	0.129	—

T (min)	S (ft)	Q (gpm)
3243	0.129	—
3248	0.129	—
3253	0.129	—
3258	0.129	—
3263	0.129	—
3268	0.129	—
3273	0.129	—
3278	0.115	—
3283	0.129	—
3288	0.129	—
3293	0.129	—
3298	0.129	—
3303	0.129	—
3308	0.101	—
3313	0.115	—
3318	0.115	—
3323	0.101	—
3328	0.101	—
3333	0.101	—
3338	0.101	—
3343	0.101	—
3348	0.086	—
3353	0.086	—
3358	0.086	—

T (min)	S (ft)	Q (gpm)
3363	0.101	—
3368	0.086	—
3373	0.101	—
3378	0.086	—
3383	0.086	—
3388	0.101	—
3393	0.086	—
3398	0.086	—
3403	0.086	—
3408	0.086	—
3413	0.086	—
3418	0.086	—
3423	0.072	—
3428	0.086	—
3433	0.086	—
3438	0.072	—
3443	0.072	—
3448	0.072	—
3453	0.086	—
3458	0.072	—
3463	0.072	—
3468	0.101	—
3473	0.072	—
3478	0.072	—

T (min)	S (ft)	Q (gpm)
3483	0.072	—
3488	0.086	—
3493	0.072	—
3498	0.072	—
3503	0.072	—
3508	0.072	—
3513	0.072	—
3518	0.072	—
3523	0.086	—
3528	0.086	—
3533	0.086	—
3538	0.086	—
3543	0.086	—
3548	0.072	—
3553	0.072	—
3558	0.072	—
3563	0.072	—
3568	0.072	—
3573	0.057	—
3578	0.072	—
3583	0.072	—
3588	0.057	—
3593	0.072	—
3598	0.072	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
3603	0.057	—
3608	0.057	—
3613	0.072	—
3618	0.072	—
3623	0.072	—
3628	0.057	—
3633	0.057	—
3638	0.057	—
3643	0.057	—
3648	0.057	—
3653	0.057	—
3658	0.057	—
3663	0.057	—
3668	0.057	—
3673	0.043	—
3678	0.057	—
3683	0.057	—
3688	0.043	—
3693	0.057	—
3698	0.057	—
3703	0.043	—
3708	0.057	—
3713	0.057	—
3718	0.057	—

T (min)	S (ft)	Q (gpm)
3723	0.057	—
3728	0.043	—
3733	0.057	—
3738	0.043	—
3743	0.043	—
3748	0.043	—
3753	0.043	—
3758	0.043	—
3763	0.043	—
3768	0.043	—
3773	0.043	—
3778	0.043	—
3783	0.043	—
3788	0.043	—
3793	0.029	—
3798	0.029	—
3803	0.029	—
3808	0.029	—
3813	0.029	—
3818	0.029	—
3823	0.043	—
3828	0.029	—
3833	0.029	—
3838	0.029	—

T (min)	S (ft)	Q (gpm)
3843	0.029	—
3848	0.029	—
3853	0.029	—
3858	0.029	—
3863	0.029	—
3868	0.029	—
3873	0.029	—
3878	0.029	—
3883	0.029	—
3888	0.029	—
3893	0.014	—
3898	0.014	—
3903	0.014	—
3908	0.014	—
3913	0.000	—
3918	0.014	—
3923	0.014	—
3928	0.000	—
3933	0.014	—
3938	0.014	—
3943	0.014	—
3948	0.014	—
3953	0.000	—
3958	0.000	—

T (min)	S (ft)	Q (gpm)
3963	0.014	—
3968	0.000	—
3973	0.000	—
3978	0.014	—
3983	0.000	—
3988	0.014	—
3993	0.014	—
3998	0.014	—
4003	0.014	—
4008	0.014	—
4013	0.014	—
4018	0.014	—
4023	0.014	—
4028	0.014	—
4033	0.014	—
4038	0.014	—
4043	0.014	—
4048	0.014	—
4053	0.014	—
4058	0.029	—
4063	0.043	—
4068	0.029	—
4073	0.029	—
4078	0.029	—

T (min)	S (ft)	Q (gpm)
4083	0.029	—
4088	0.029	—
4093	0.029	—
4098	0.043	—
4103	0.029	—
4108	0.029	—
4113	0.029	—
4118	0.029	—
4123	0.029	—
4128	0.029	—
4133	0.043	—
4138	0.029	—
4143	0.029	—
4148	0.029	—
4153	0.029	—
4158	0.043	—
4163	0.043	—
4168	0.043	—
4173	0.043	—
4178	0.043	—
4183	0.043	—
4188	0.043	—
4193	0.057	—
4198	0.043	—

Observed Time (t), Drawdown (s), and Discharge (Q) Data from the R-15 Aquifer Test (continued)

T (min)	S (ft)	Q (gpm)
4203	0.057	—
4208	0.057	—
4213	0.057	—
4218	0.057	—
4223	0.057	—
4228	0.043	—
4233	0.057	—
4238	0.072	—
4243	0.072	—
4248	0.086	—
4253	0.086	—
4258	0.101	—
4263	0.086	—
4268	0.101	—
4273	0.101	—
4278	0.101	—
4283	0.101	—
4288	0.101	—
4293	0.115	—
4298	0.101	—
4303	0.115	—
4308	0.115	—

T (min)	S (ft)	Q (gpm)
4313	0.115	—
4318	0.115	—
4323	0.101	—
4328	0.086	—
4333	0.101	—
4338	0.101	—
4343	0.101	—
4348	0.101	—
4353	0.115	—
4358	0.115	—
4363	0.115	—
4368	0.129	—
4373	0.129	—
4378	0.115	—
4383	0.115	—
4388	0.115	—
4393	0.115	—
4398	0.115	—
4403	0.115	—
4408	0.115	—
4413	0.115	—
4418	0.115	—

T (min)	S (ft)	Q (gpm)
4423	0.115	—
4428	0.115	—
4433	0.115	—
4438	0.115	—
4443	0.115	—
4448	0.101	—
4453	0.115	—
4458	0.115	—
4463	0.101	—
4468	0.101	—
4473	0.101	—
4478	0.101	—
4483	0.086	—
4488	0.115	—
4493	0.101	—
4498	0.086	—
4503	0.101	—
4508	0.101	—
4513	0.101	—
4518	0.101	—
4523	0.101	—
4528	0.101	—

T (min)	S (ft)	Q (gpm)
4533	0.086	—
4538	0.086	—
4543	0.086	—
4548	0.072	—
4553	0.072	—
4558	0.086	—
4563	0.072	—
4568	0.072	—
4573	0.057	—
4578	0.072	—
4583	0.057	—
4588	0.086	—
4593	0.057	—
4598	0.072	—
4603	0.072	—
4608	0.072	—
4613	0.072	—
4618	0.072	—
4623	0.072	—
4628	0.072	—
4633	0.072	
4638	0.057	

T (min)	S (ft)	Q (gpm)
4643	0.072	—
4648	0.057	—
4653	0.057	—
4658	0.057	—
4663	0.057	—
4668	0.057	—
4673	0.057	—
4678	0.057	—
4683	0.057	—
4688	0.057	—
4693	0.043	—
4698	0.057	—
4703	0.057	—
4708	0.057	—
4713	0.057	—
4718	0.057	—
4723	0.057	—
4728	0.057	—
4733	0.057	—

Appendix B

Results of Specific Capacity Analysis Using Program in B-2

B-1
Transmissivity (ft^2/d) as a Function of Well Efficiency and Aquifer Penetration from Specific Capacity for the R-15 Aquifer Test[a]

Well	Aquifer Penetration (%)																		
Eff (%)	10	15	20	25	30	35	41.4	45	50	55	60	65	70	75	80	85	90	95	100
20	6502	4329	3286	2671	2263	1971	1700	1581	1445	1335	1245	1171	1110	1060	1019	985	958	935	917
25	5190	3452	2617	2125	1798	1565	1348	1253	1144	1056	984	924	876	836	803	776	754	736	721
30	4317	2868	2173	1763	1491	1296	1115	1035	945	871	811	762	721	688	660	638	620	605	593
35	3694	2453	1857	1505	1272	1105	950	882	804	741	689	647	612	583	560	541	525	512	502
40	3228	2142	1620	1312	1108	962	826	767	699	644	599	561	531	506	485	468	455	443	434
45	2866	1900	1437	1163	982	852	731	678	617	568	528	495	468	446	428	413	400	390	382
50	2577	1707	1290	1044	881	764	655	607	553	509	473	443	419	398	382	368	357	348	341
55	2340	1550	1170	947	798	692	593	550	500	460	427	400	378	360	345	332	322	314	308
60	2143	1419	1071	866	730	632	542	502	457	420	390	365	345	328	314	303	294	286	280
65	1977	1308	987	798	672	582	498	462	420	386	358	335	316	301	288	278	269	262	257
70	1834	1213	915	739	623	539	461	427	388	357	331	310	292	278	266	256	248	242	237
75	1711	1131	853	689	580	502	429	398	361	332	308	288	272	258	247	238	231	225	220
80	1603	1059	798	645	542	469	401	372	337	310	287	269	253	241	230	222	215	209	205
85	1507	996	751	606	510	441	377	349	317	291	269	252	238	226	216	208	201	196	192
90	1423	940	708	571	480	415	355	329	298	274	254	237	223	212	203	195	189	184	180
95	1347	890	670	540	454	393	336	310	282	258	239	224	211	200	192	184	179	174	170
100	1279	845	636	513	431	372	318[b]	294	267	245	227	212	200	190	181	174	169	164	161

[a] Input data: Q = 11.7 gpm; s = 13.73 ft (16.00 ft without Jacob correction) at t = 2503 min; screen length = 56.3 ft; dw = 12.25 in; S = 0.01; aquifer thickness = 136.0 ft.

[b] Shaded example shows that for a well efficiency of 100% and aquifer penetration of 41.4%, T = 318.0 ft^2/day.

APPENDIX B-2. MATLAB PROGRAM

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 listed in Bradbury and Rothschild (1985, 76040). This script file was used to generate Figure 10 using the input data listed at the bottom of the table in Appendix B-1. The file requires that Matlab™ be installed in order to run properly.

```
*****************************************************************************

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;
```

```
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;
```

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