Designation: D 5855 – 95 (Reapproved 2000)

Standard Test Method for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of a Confined Nonleaky or Leaky Aquifer by Constant Drawdown Method in a Flowing Well[1]

This standard is issued under the fixed designation D 5855; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers an analytical solution for determining transmissivity and storage coefficient of a leaky or nonleaky confined aquifer. It is used to analyze data on the flow rate from a control well while a constant head is maintained in the well.

1.2 This analytical procedure is used in conjunction with the field procedure in Practice D 5786.

1.3 *Limitations*—The limitations of this technique for the determination of hydraulic properties of aquifers are primarily related to the correspondence between field situation and the simplifying assumption of the solution.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 4043 Guide for Selection of Aquifer-Test Method in Determining of Hydraulic Properties by Well Techniques[2]

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[2]

D 5786 Practice (Field Procedure) for Constant Drawdown Tests in Flowing Wells for Determining Hydraulic Properties of Aquifer Systems[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method see Terminology D 653.

3.2 *Symbols:Symbols and Dimensions:*

3.2.1 T—transmissivity [L^2T^{-1}].

3.2.2 K_1— modified Bessel function of the second kind, first order [*nd*].

3.2.3 K_2— modified Bessel function of the second kind, zero order [*nd*].

3.2.4 J_0— Bessel function of the first kind, zero order [*nd*].

3.2.5 Y_0— Bessel function of the second kind, zero order [*nd*].

3.2.6 $W(u)$—w (well) function of u [*nd*].

3.2.7 u—variable of integration [*nd*].

3.2.8 t—elapsed time test [T].

3.2.9 Q—discharge rate [L^3T^{-1}].

3.2.10 s_W—constant drawdown in control well [L].

3.2.11 S—storage coefficient [*nd*].

3.2.12 r_W—radius of control well.

4. Summary of Test Method

4.1 This test method describes the analytical procedure for analyzing data collected during a constant drawdown aquifer test. This test method is usually performed on a flowing well. After the well has been shut-in for a period of time, the well is opened and the discharge rate is measured over a period of time after allowing the well to flow. The water level in the control well while the well is flowing is the elevation of the opening of the control well through which the water is allowed to flow. Data are analyzed by plotting the discharge rate versus time.

NOTE 1—This test method involves the withdrawal of water from a control well that is fully screened through the confined aquifer. The withdrawal rate is varied to cause the water level within the well to remain constant. The field procedure involved in conducting a constant drawdown test is given in Practice D 5786. Methods used to develop a conceptual model of the site and for initially selecting an analytical procedure are described in Guide D 4043.

4.2 *Leaky Aquifer Solution*—The solution is given by Hantush.[4] Transmissivity is calculated as follows:

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

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This practice is presently under development in Section D18.21.04 and may be obtained by contacting the Committee D-18 Staff Manager.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

[4] Hantush, M. S., "Nonsteady Flow to Flowing Wells in Leaky Aquifer," *Journal of Geophysical Research*, Vol 64, No. 8, 1959, pp. 1043–1052.

NOTE 2—These are Eq (93) through (97) of Lohman.[5]

$$T = \frac{Q}{2\pi s_W\, G\,(\alpha, r_W/\,B)}\,[L^2T^{-1}] \quad (1)$$

where:

$$\alpha = \frac{Tt}{Sr_W^{\;2}}\,[nd] \quad (2)$$

$$r_W/B = r_W[T/(K'\,/b')]^{-0.5}\,[L^2] \quad (3)$$

and:

$$G\left[\frac{r_W}{B}\right] = \left[\frac{r_W}{B}\right]\left[\frac{K_1(r_w\,/b)}{K_0(r_W/b)}\right] + \frac{r}{\pi^2}\exp\left[-\alpha\left(\frac{r_W}{B}\right)^2\right]. \quad (4)$$

$$\int_o^\infty \frac{u\,exp(-\alpha u^2)}{J_0^{\;2}(u) + Y_0^{\;2}(u)}\cdot\frac{du}{u^2 + (r_W/B)^2}\,[nd]$$

4.2.1 Storage coefficient is given by:

$$S = \frac{Tt}{r_W^{\;2}\alpha}\,[nd] \quad (5)$$

4.3 *Non-Leaky Aquifer*:

4.3.1 *Log-Log*—The solution is given by Lohman.[5]

NOTE 3—These equations are Eq (66) through (69) of Lohman.[5]

4.3.1.1 Transmissivity is calculated as follows:

$$T = \frac{Q}{2\pi G(\alpha)s_W}\,[L^2T^{-1}] \quad (6)$$

where:

$$\alpha = \frac{Tt}{Sr_W^{\;2}}\,[nd] \quad (7)$$

and:

$$G(a) = \frac{4\alpha}{\pi}\int_o^\infty xe^{-\alpha x^2}\left[\frac{\pi}{2} + \tan^{-1}\left(\frac{Y_o(x)}{J_o(x)}\right)\right]dx\,[nd] \quad (8)$$

4.3.1.2 Storage coefficient is given by:

$$S = \frac{Tt}{\alpha r_W^{\;2}}\,[nd] \quad (9)$$

4.3.2 *Semi-Log*—The solution is given by Jacob and Lohman.[6]

NOTE 4—Jacob and Lohman[6] showed that for all but extremely small values of *t*, the function of *G(a)* shown above can be approximated very closely by 2/ *W(u)*. For sufficiently small values of *u*, *W(u)* are further approximated by 2.30 $log_{10}\, 2.25Tt/r_W^{\;2}S$. The use of this semi-logarithmic method will produce values of transmissivity that are slightly elevated. Examples of this error are shown below:

u	*W (u)*	Estimated Error, %
0.25000	1.044283	25
0.00625	4.504198	10
0.000833	6.513694	5
1.25E-05	10.71258	2

4.3.2.1 Transmissivity is calculated as follows:

NOTE 5—These equations are Eqs (71) and (73) of Lohman.[5]

$$T = \frac{2.30}{4\pi\Delta(s_W/Q)/\Delta\log_{10}(t/r_W^{\;2})}\,[L^2T^{-1}] \quad (10)$$

by extrapolating the straight line to $s_W/Q = 0$ (the point of zero drawdown), storage coefficient is given by:

$$S = 2.25\,T\frac{t}{r_W^{\;2}}\,[nd] \quad (11)$$

NOTE 6—In (Eq 10) and (Eq 11), *Q* is in cubic feet per day, *t* is in days.

5. Significance and Use

5.1 *Assumptions—Leaky Aquifer*:

5.1.1 Drawdown (s_W) in the control well is constant,

5.1.2 Well is infinitesimal diameter and fully penetrates aquifer,

5.1.3 The aquifer is homogeneous, isotropic, and areally extensive, and

5.1.4 The control well is 100 % efficient.

5.2 *Assumptions—Nonleaky Aquifer*:

5.2.1 Drawdown (s_W) in the control well is constant,

5.2.2 Well is infinitesimal diameter and fully penetrates aquifer,

5.2.3 The aquifer is homogeneous, isotropic, and areally extensive,

5.2.4 Discharge from the well is derived exclusively from storage in the nonleaky aquifer, and

5.2.5 The control well is 100 % efficient.

5.3 *Implications of Assumptions*:

5.3.1 The assumptions are applicable to confined aquifers and fully penetrating control wells. However, this test method may be applied to partially penetrating wells where the method may provide an estimate of hydraulic conductivity for the aquifer adjacent to the open interval of the well if the horizontal hydraulic conductivity is significantly greater than the vertical hydraulic conductivity.

5.3.2 Values obtained for storage coefficient are less reliable than the values calculated for transmissivity. Storage coefficient values calculated from control well data are not reliable.

6. Apparatus

6.1 Analysis of data from the field procedure (see Practice D 5786) by the methods specified in this procedure requires that the control well and observation wells meet the specifications given in the apparatus section of Practice D 5786.

7. Procedure

7.1 *Data Collection*—Procedures to collect the field data used by the analytical procedures described in this test method are given in Practice D 5786.

7.2 *Data Calculation and Interpretation*—Perform the procedures for calculation and interpretation of test data as given in Section 8.

7.3 *Report*—Prepare a report as given in Section 9.

8. Calculation and Interpretation of Results

8.1 *Leaky Aquifer Solution*:

8.1.1 (Eq 4) cannot be integrated directly but has been evaluated numerically and the values are given in Table 1 of Hantush.[4]

[5] Lohman, S. W., "Ground-Water Hydraulics," *Professional Paper 708, U.S. Geological Survey*, 1972.

[6] Jacob, C. E. and Lohman, S. W., "Nonsteady Flow to a Well of Constant Drawdown in an Extensive Aquifer," *American Geophysical Union Transactions*, Vol 33, No. 4, 1952, pp. 552–569.

8.1.2 *Procedure*—The graphical procedure is based on the functional relations between $G(\alpha,r_W/B)$ and α.

8.1.2.1 Plot values of $G(\alpha,r_W/B)$ versus α at a logarithmic scale. This plot is referred to as the type curve plot. An example of this type curve is given in Fig. 1. This plot is after Plate 5 of Lohman.[5]

8.1.2.2 On logarithmic tracing paper of the same scale as the type curve plot values of Q on the vertical coordinate against t on the horizontal coordinate.

8.1.2.3 Overlay the data plot on the type curve plot and, while the coordinate axes of the two plots are held parallel, shift the data plot to align with the type curve.

8.1.2.4 Select and record the values of an arbitrary point, referred to as the match point, anywhere on the overlapping part of the plots. Record the values of $G(\alpha,r_W/B)$, α, Q, and t. For convenience the point may be selected where $G(\alpha,r_W/B)$ and α are integer values.

8.1.2.5 Using the coordinates of the match point, determine the transmissivity and storage coefficient from (Eq 1) and (Eq 5).

8.2 *Non-Leaky Aquifer Solution—Log-Log Solution*:

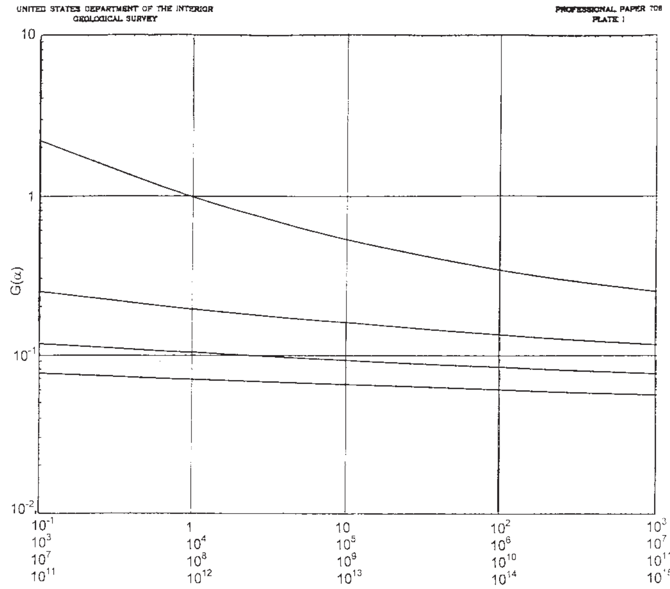
8.2.1 (Eq 8) cannot be integrated directly but has been evaluated numerically and the values are given in Table 7 of Lohman.[5]

8.2.2 *Procedure*—The graphical procedure is based on relationships of Q/s_W and t/r_W^2.

8.2.2.1 Plot values $G(\alpha)$ versus α at a logarithmic scale. This plot is referred to as the type curve plot. An example of this type curve is given in Fig. 2, that is after Plate 1 of Lohman.[5]

8.2.2.2 On logarithmic tracing paper of the same scale as the type curve, plot values of Q/s_W versus t/r_W^2. Alternatively, plot values of Q versus t.

8.2.2.3 Overlay the data plot on the type curve plot and, while the coordinate axes of the two plots are held parallel, shift the data plot to align with the type curve.



NOTE 1—After Lohman[5], Plate 1.

FIG. 2 Logarithmic Plot of α Versus G(α)

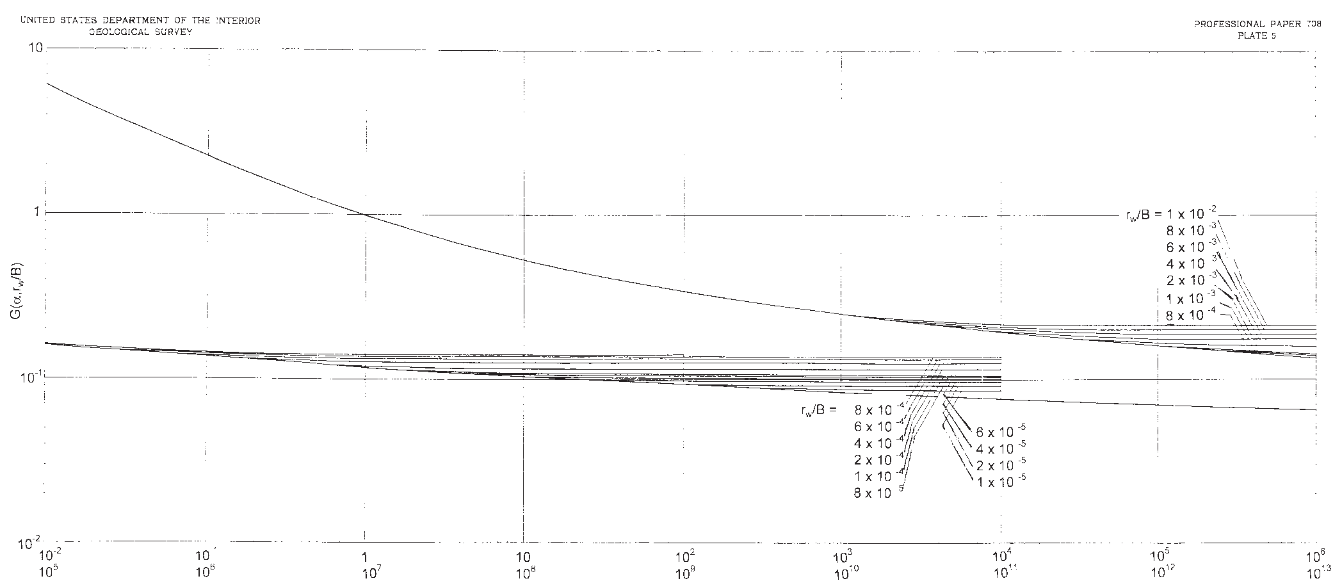
8.2.2.4 Select and record the values of an arbitrary point, referred to as the match point, anywhere on the overlapping part of the plots. Record values of $G(\alpha)$, α, Q/s_W and t/r_W^2, or alternatively $G(\alpha)$, α, Q and t.

8.2.2.5 Using the coordinates of the match point, determine the transmissivity and storage coefficient from (Eq 8) and (Eq 9).

8.3 *Non-Leaky Aquifer Solution—Semi-Log Solution*:

8.3.1 *Procedure*—The graphical procedure is based on the relationships between s_W/Q and t/r_W^2.

8.3.1.1 Plot values of s_W/Q versus t/r_W^2 on a semilogarithmic scale. An example of this plot is given in Fig. 3, that is



NOTE 1—After Lohman[5], Plate 5.

FIG. 1 Logarithmic Plot of α Versus $G(\alpha, r_W/B)$

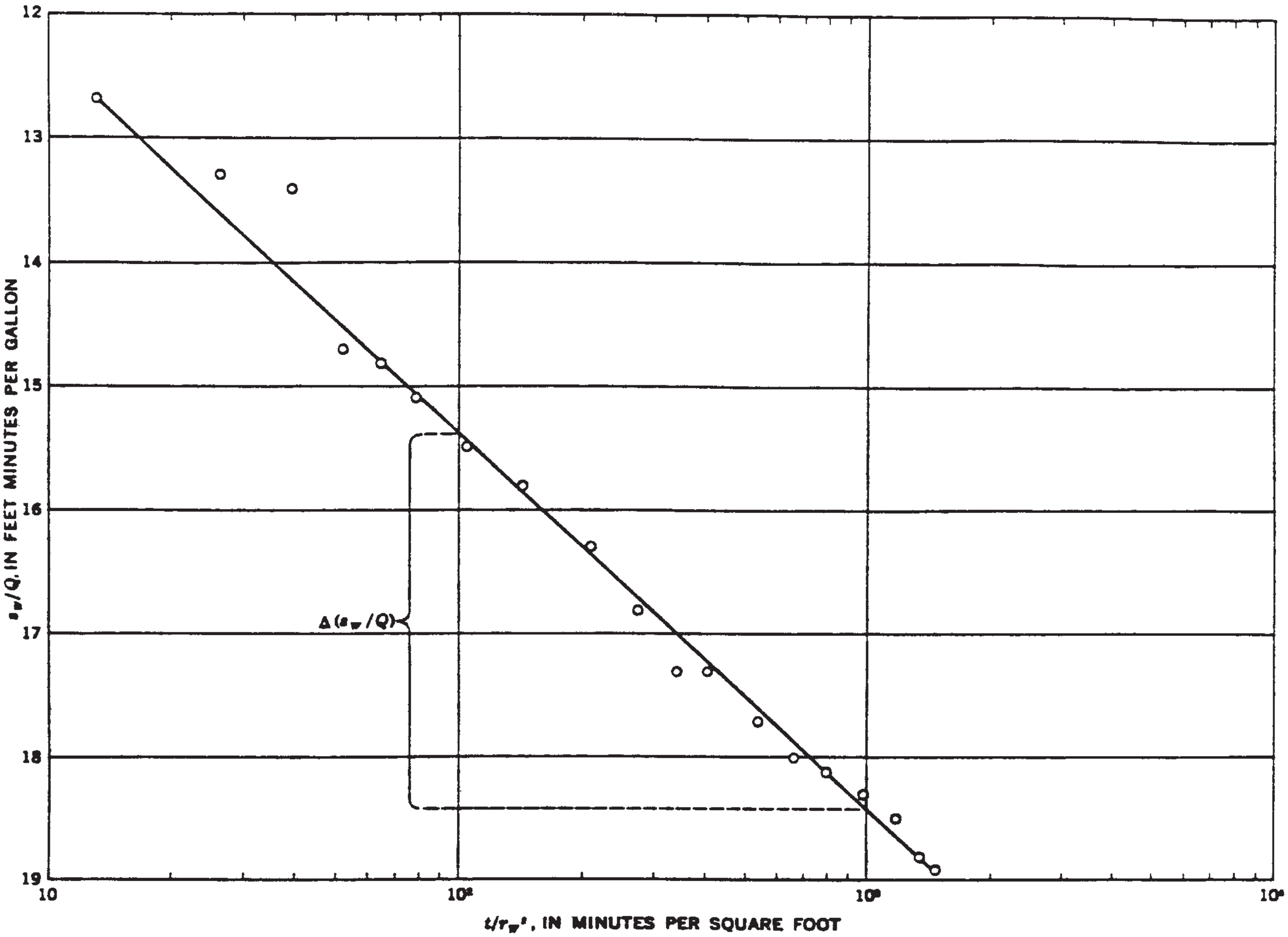


FIG. 3 Semilogarithmic Plot of s_w/Q Versus t/r_w^2

after Fig. 17 of Lohman.[5] The tabulated data used for this plot are shown in Table 1, that is after Table 8 of Lohman.[5]

8.3.1.2 From this semilogarithmic plot, determine s_W/Q, $\Delta(s_W/Q)$ and t/r_W^2.

8.3.1.3 Substitute these values into (Eq 10) and (Eq 11) to determine the transmissivity and storage coefficient.

9. Report

9.1 Report the following information:

9.1.1 *Introduction*—The introductory section is intended to present the scope and purpose of the constant drawdown method for determining transmissivity and storage coefficient in a confined nonleaky aquifer. Summarize the field hydrogeologic conditions and the field equipment and instrumentation including the construction of the control well, the method of measurement of discharge rate, and the duration of the test. Discuss rationale for using the constant drawdown method.

9.1.2 *Conceptual Model*—Review the information available on the hydrogeology of the site; interpret and describe the hydrogeology of the site as it pertains to the selection of this method for conducting and analyzing an aquifer test. Compare the hydrogeologic characteristics of the site as it conforms and differs from the assumptions in the solution of the aquifer test method.

TABLE 1 Field Data for Flow Test on Artesia Heights Well Near Grand Junction, CO., September 22, 1948

NOTE 1—Valve opened at 10:29 a.m. s_w = 92.33 ft; r_w = 0.276 ft. Data from Lohman (1965, Tables 6 and 7, Well 28).

Time of Observation	Rate of Flow (gpm)	Flow Interval (min)	Total Flow During Interval (gal)	Time Since Flow Started (min)	$\frac{s_w}{Q}$ (ft gal^{-1} min)	$\frac{t}{r_w^2}$ (min ft^{-2})
10:30	7.28	1	7.28	1	12.7	13.1
10:31	6.94	1	6.94	2	13.3	26.3
10:32	6.88	1	6.88	3	13.4	39.4
10:33	6.28	1	6.28	4	14.7	52.6
10:34	6.22	1	6.22	5	14.8	65.7
10:35	6.22	1	6.22	6	15.1	78.8
10:37	5.95	2	11.90	8	15.5	105
10:40	5.85	3	17.55	11	15.8	145
10:45	5.66	5	28.30	16	16.3	210
10:50	5.50	5	27.50	21	16.8	276
10:55	5.34	5	26.70	26	17.3	342
11:00	5.34	5	26.70	31	17.3	407
11:10½	5.22	10.5	54.81	41.5	17.7	345
11:20	5.14	9.5	48.83	51	18.0	670
11:30	5.11	10	51.10	61	18.1	802
11:45	5.05	15	75.75	76	18.3	999
12:00 (noon)	5.00	15	75.00	91	18.5	1196
12:12	4.92	12	59.04	103	18.8	1354
12:22	4.88	11	53.68	113	18.9	1485
Total[A]		114	596.98			

[A] 596.98 gal per 114 min = 5.23 gal min^{-1}, weighted average discharge.

9.1.3 *Equipment*—Report the field installation and equipment for the test, including the construction, diameter, depth of screened and gravel packed intervals, and location of the control well and discharge measurement device.

9.1.4 *Instrumentation*—Describe the field instrumentation for observing water levels, discharge rate, barometric changes, and other environmental conditions pertinent to the test. Include a list of measuring devices used during the test, the manufacturers name, model number, and basic specifications for each major item, and the name and date of the last calibration, if applicable.

9.1.5 *Testing Procedures*—State the steps taken in conducting pretest, discharge, and recovery phases of the test. Include the frequency of measurements of discharge rate and other environmental data recorded during the testing procedure.

9.2 *Presentation and Interpretation of Test Results*:

9.2.1 *Data*—Present tables of data collected during the test.

9.2.2 *Data Plots*—Present data plots used in the analysis of data. Show overlays of data plots and type curve with match points and corresponding values of parameters at match points.

9.2.3 Evaluate qualitatively the overall accuracy of the test, accuracy of observations, conformance of the hydrogeologic conditions to the conceptual model assumptions.

10. Precision and Bias

10.1 It is not practicable to specify the precision of this test method because the response of aquifer systems during aquifer tests is dependent upon ambient system stresses. The bias caused by the use of the semi-logarithmic method was previously noted. No other statement can be made about bias because no true reference values exist.

11. Keywords

11.1 aquifers; aquifer tests; control wells; ground water; observation wells; storage coefficient; transmissivity