Designation: D5855/D5855M – 15

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

This standard is issued under the fixed designation D5855/D5855M; 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 D5786.

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 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values in each system may not be exact equivalents; therefore each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.6 *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:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4043 Guide for Selection of Aquifer Test Method in Determining Hydraulic Properties by Well Techniques

D5786 Practice for (Field Procedure) for Constant Drawdown Tests in Flowing Wells for Determining Hydraulic Properties of Aquifer Systems

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Derfinitions:*

3.1.1 For definitions of terms used in this test method, see Terminology D653.

3.2 *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*].

[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 Groundwater and Vadose Zone Investigations.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

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 D5786. Methods used to develop a conceptual model of the site and for initially selecting an analytical procedure are described in Guide D4043.

4.2 *Leaky Aquifer Solution*—The solution is given by Hantush.[3] Transmissivity is calculated as follows:

NOTE 2—These are Eq (93) through (97) of Lohman.[4]

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

where:

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

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

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.[4]

NOTE 3—These equations are Eq (66) through (69) of Lohman.[4]

4.3.1.1 Transmissivity is calculated as follows:

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

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.[5]

NOTE 4—Jacob and Lohman[5] 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 $log_{10}\, 2.25Tt/r_W{}^2S$. 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.[4]

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

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

NOTE 7—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

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,

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

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

[5] 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.

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 D5786) 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 D5786.

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 D5786.

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.[3]

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.[4]

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).

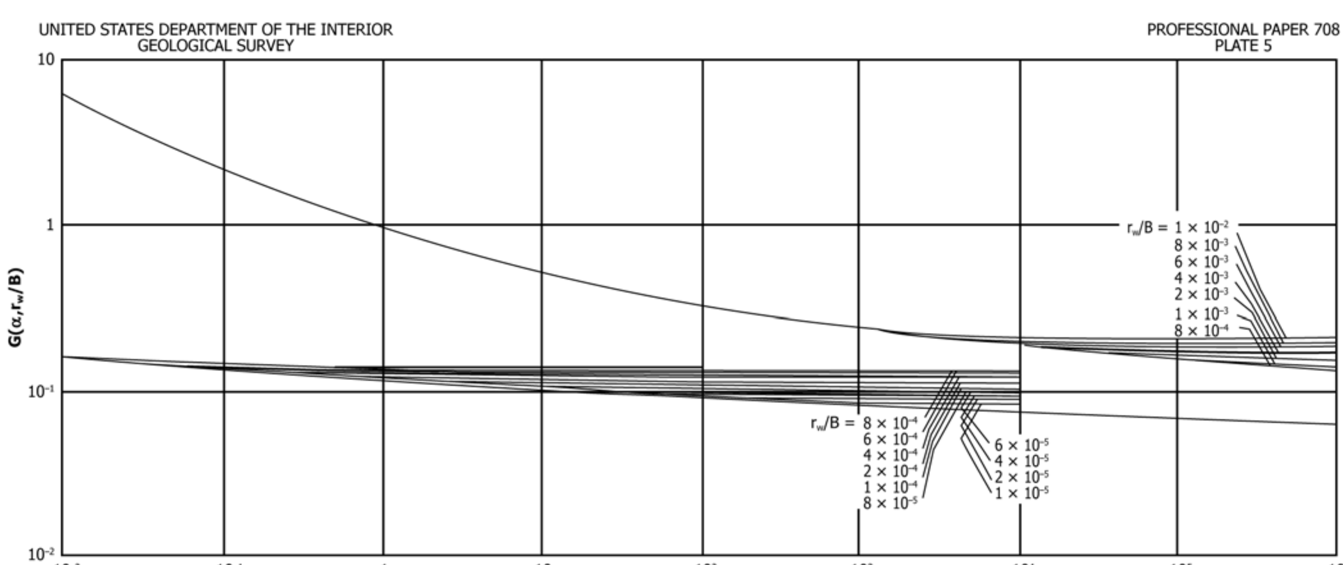
8.2 *Non-Leaky Aquifer Solution—Log-Log Solution:*

8.2.1 (Eq 8) cannot be integrated directly but has been evaluated numerically and the values are given in Table 7 of Lohman.[4]

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

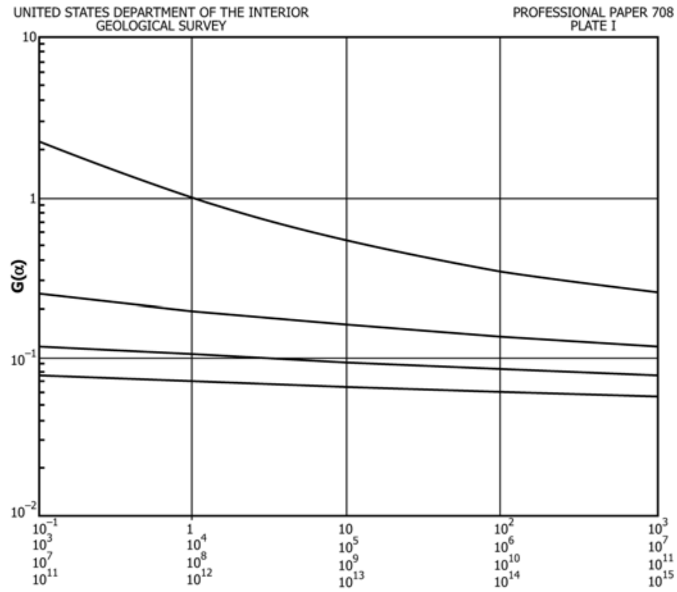
8.2.2.1 Plot values $G(\alpha)$ versus α at a logarithmic scale. This plot is referred to as the type curve plot. An example of this type curve is given in Fig. 2, that is after Plate 1 of Lohman.[4]

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.



NOTE 1—After Lohman,[4] Plate 5.

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



NOTE 1—After Lohman,[4] Plate 1.

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

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.

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(α),* α, Q/s_W and t/r_W^2, or alternatively *G(α),* 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 after Fig. 17 of Lohman.[4] The tabulated data used for this plot are shown in Table 1, that is after Table 8 of Lohman.[4]

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. Records

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.

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 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too

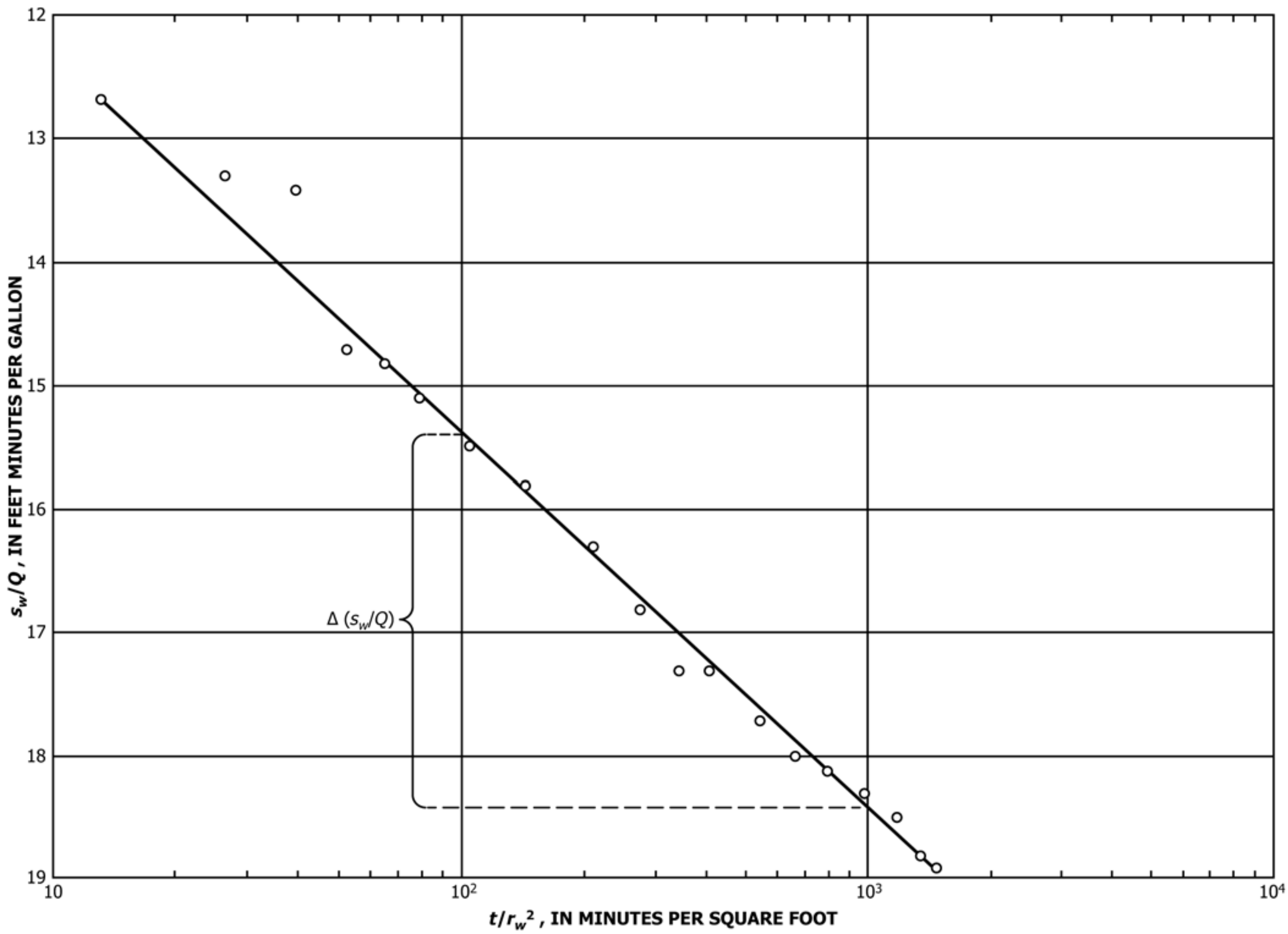


FIG. 3 Semilogarithmic Plot of s_w/Q Versus t/r_w^2

costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

10.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined. The bias caused by the use of the semi-logarithmic method was previously noted.

11. Keywords

11.1 aquifers; aquifer tests; control wells; groundwater; observation wells; storage coefficient; transmissivity

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[4] (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.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1995(Reapproved 2013)) that may impact the use of this standard. (November 1, 2015)

(1) Added Practice D3740 to the Referenced Documents section.

(2) Added Note 7 to Section 5 regarding the use of Practice D3740.