



Standard Test Method (Analytical Procedure) for Tests of Anisotropic Unconfined Aquifers by Neuman Method¹

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1. Scope*

1.1 This test method covers an analytical procedure for determining the transmissivity, storage coefficient, specific yield, and horizontal-to-vertical hydraulic conductivity ratio of an unconfined aquifer. It is used to analyze the drawdown of water levels in piezometers and partially or fully penetrating observation wells during pumping from a control well at a constant rate.

1.2 The analytical procedure given in this test method is used in conjunction with Guide [D4043](#) and Test Method [D4050](#).

1.3 The valid use of the Neuman method is limited to determination of transmissivities for aquifers in hydrogeologic settings with reasonable correspondence to the assumptions of the theory.

1.4 The values stated in SI units are to be regarded as standard.

1.5 *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](#)

[D4050](#) Test Method for (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems

[D4105](#) Test Method for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Non-leaky Confined Aquifers by the Modified Theis Nonequilibrium Method

[D4106](#) Test Method for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Non-leaky Confined Aquifers by the Theis Nonequilibrium Method

[D6026](#) Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions*—For definitions of general technical terms used within this guide, refer to Terminology [D653](#).

3.2 Symbols and Dimensions:

3.2.1 b [L]—initial saturated thickness of the aquifer.

3.2.2 d [L]—vertical distance between top of screen in pumping well and initial position of the water table.

3.2.3 d_D [nd]—dimensionless d , equal to d/b .

3.2.4 $J_0(x)$ —zero-order Bessel function of the first kind.

3.2.5 K_r [LT^{-1}]—hydraulic conductivity in the plane of the aquifer, radially from the control well.

3.2.6 K_z [LT^{-1}]—hydraulic conductivity normal to the plane of the aquifer.

3.2.6.1 *Discussion*—The use of the symbol K for the hydraulic conductivity is the predominant usage in groundwater literature by hydrogeologists, whereas, the symbol k is commonly used for this term in soil and rock mechanics and soil science.

3.2.7 l [L]—vertical distance between bottom of screen in control well and initial position of water table.

3.2.8 l_D [nd]—dimensionless l , equal to l/b .

3.2.9 Q [L^3T^{-1}]—discharge rate.

3.2.10 r [L]—radial distance from control well.

3.2.11 s [L]—drawdown.

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.

- 3.2.12 $s_c [L]$ —corrected drawdown.
- 3.2.13 $s_D [nd]$ —dimensionless drawdown, equal to $4\pi Ts/Q$.
- 3.2.14 $s_{wt} [L]$ —drawdown of the water table.
- 3.2.15 $S [nd]$ —storage coefficient, equal to $S_s b$.
- 3.2.16 $S_s [L^{-1}]$ —specific storage.
- 3.2.17 $S_y [nd]$ —specific yield.
- 3.2.18 $t [T]$ —time since pumping started.
- 3.2.19 $t_r [T]$ —time since recovery started.
- 3.2.20 $t_s [nd]$ —dimensionless time with respect to S_s , equal to Tt/Sr^2 .
- 3.2.21 $t_y [nd]$ —dimensionless time with respect to S_y , equal to $Tt/S_y r^2$.
- 3.2.22 $t_\beta [T]$ —time, t , corresponding to intersection of a horizontal line through the intermediate data with an inclined line through late data on semilogarithmic paper.
- 3.2.23 $t_{y\beta} [nd]$ —dimensionless time, t_y , corresponding to the intersection of a horizontal line through intermediate data with an inclined line through late data in Fig. 1.
- 3.2.24 $(t/r^2)_e [T]$ — t/r^2 corresponding to the intersection of a straight line through the early data with $s = 0$ on semilogarithmic paper $[TL^{-2}]$.
- 3.2.25 $(t/r^2)_l [T]$ — t/r^2 corresponding to the intersection of a straight line through the late data with $s = 0$ on semilogarithmic paper.
- 3.2.26 $T [L^2 T^{-1}]$ —transmissivity, $K_r b$.
- 3.2.27 $z [L]$ —vertical distance above the bottom of the aquifer.
- 3.2.28 $z_l [L]$ —vertical distance of the bottom of the observation well screen above the bottom of the aquifer.

- 3.2.29 $z_2 [L]$ —vertical distance of the top of the observation well screen above the bottom of the aquifer.
- 3.2.30 $z_D [nd]$ —dimensionless elevation, equal to z/b .
- 3.2.31 $z_{1D} [nd]$ —dimensionless elevation of base of screen, equal to z_1/b .
- 3.2.32 $z_{2D} [nd]$ —dimensionless elevation of top of screen, equal to z_2/b .
- 3.2.33 α —degree of anisotropy, equal to K_z/K_r .
- 3.2.34 $\beta [nd]$ —dimensionless parameter $\alpha r^2/b^2$.
- 3.2.35 $\Delta s_e [L]$ —the difference in drawdown over one log cycle of time along a straight line through early data on semilogarithmic paper.
- 3.2.36 $\Delta s_l [L]$ —the difference in drawdown over one log cycle of time along a straight line through late data on semilogarithmic paper.
- 3.2.37 $\sigma [nd]$ —dimensionless parameter S/S_y .

4. Summary of Test Method

4.1 *Procedure*—This test method describes a procedure for analyzing data collected during a withdrawal well test. This test method should have been selected using Guide D4043 on the basis of the hydrologic characteristics of the site. The field test (Test Method D4050) requires pumping a control well that is open to all or part of an unconfined aquifer at a constant rate for a specified period and observing the drawdown in piezometers or observation wells that either partly or fully penetrate the aquifer. This test method may also be used to analyze an injection test with the appropriate change in sign. The rate of drawdown of water levels in the aquifer is a function of the location and depths of screened open intervals of the control well, observation wells, and piezometers. The drawdown may be analyzed to determine the transmissivity, storage coefficient,

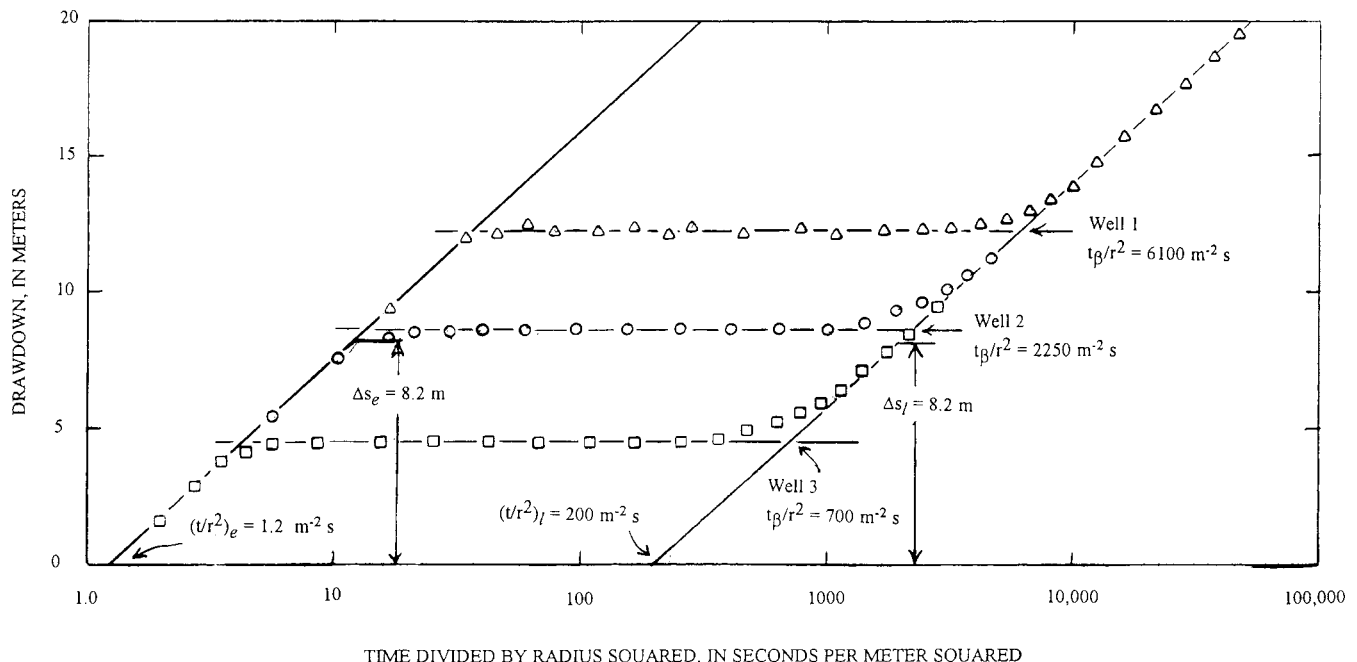


FIG. 1 Aquifer-Test Analysis, Example Two

specific yield, and ratio of vertical to horizontal hydraulic conductivity of the aquifer. The accuracy with which any property can be determined depends on the location and length of the well screen in observation wells and piezometers. Two methods of analysis, a type curve method and a semilogarithmic method, are described.

4.2 *Solution*—The solution given by Neuman (1)³ can be expressed as:

$$s(r, z, t) = \frac{Q}{4\pi T} \int_0^\infty 4yJ_0(y\beta^{1/2}) \left[u_0(y) + \sum_{n=1}^\infty u_n(y) \right] dy \quad (1)$$

where, for piezometers, Neuman's (1) Eqs 27 and 28 are as follows:

$$\frac{\sinh[\gamma_0(1-d_D)] - \sinh[\gamma_0(1-l_D)]}{(l_D - d_D)\sinh(\gamma_0)}$$

and:

$$u_n(y) = \frac{\{1 - \exp[-t_s\beta(y^2 + \gamma_n^2)]\}\cos(\gamma_n z_D)}{\{y^2 - (1+\sigma)\gamma_n^2 - (y^2 + \gamma_n^2)^2/\sigma\}\gamma_n} \quad (3)$$

$$\frac{\sin[\gamma_n(1-d_D)] - \sin[\gamma_n(1-l_D)]}{(l_D - d_D)\sin(\gamma_n)}$$

and the terms γ_0 and γ_n are the roots of the following equations:

$$\sigma\gamma_0 \sinh(\gamma_0) - (y^2 - \gamma_0^2)\cosh(\gamma_0) = 0 \quad (4)$$

$$\gamma_0^2 < y^2$$

$$\sigma\gamma_n \sin(\gamma_n) + (y^2 + \gamma_n^2)\cos(\gamma_n) = 0 \quad (5)$$

$$(2n-1)(\pi/2) < \gamma_n < n\pi \quad n \geq 1$$

4.2.1 The drawdown in an observation well is the average over the screened interval, of which $u_0(y)$ and $u_n(y)$ are described by Neuman's (1) Eqs 29 and 30:

$$u_0(y) = \frac{\{1 - \exp[-t_s\beta(y^2 - \gamma_0^2)]\} [\sinh(\gamma_0 z_{2D}) - \sinh(\gamma_0 z_{1D})]}{\frac{\{\sinh[\gamma_0(1-d_D)] - \sinh[\gamma_0(1-l_D)]\}}{\{y^2 + (1+\sigma)\gamma_0^2 - (y^2 - \gamma_0^2)^2/\sigma\}\cosh(\gamma_0)} \cdot (z_{2D} - z_{1D})\gamma_0(l_D - d_D)\sinh(\gamma_0)} \quad (6)$$

$$u_n(y) = \frac{\{1 - \exp[-t_s\beta(y^2 + \gamma_n^2)]\} [\sin(\gamma_n z_{2D}) - \sin(\gamma_n z_{1D})]}{\frac{\{\sin[\gamma_n(1-d_D)] - \sin[\gamma_n(1-l_D)]\}}{\{y^2 - (1+\sigma)\gamma_n^2 - (y^2 + \gamma_n^2)^2/\sigma\}\cos(\gamma_n)} \cdot (z_{2D} - z_{1D})\gamma_n(l_D - d_D)\sin(\gamma_n)} \quad (7)$$

4.2.2 In the case in which the control well and observation well fully penetrate the aquifer, the equations reduce to Neuman's (1) Eqs 2 and 3 as follows:

$$u_0(y) = \frac{\{1 - \exp[-t_s\beta(y^2 - \gamma_0^2)]\}\tanh(\gamma_0)}{\{y^2 + (1+\sigma)\gamma_0^2 - [(y^2 - \gamma_0^2)^2/\sigma]\}\gamma_0} \quad (8)$$

and:

$$u_n(y) = \frac{\{1 - \exp[-t_s\beta(y^2 + \gamma_n^2)]\}\tan(\gamma_n)}{\{y^2 - (1+\sigma)\gamma_n^2 - (y^2 + \gamma_n^2)^2/\sigma\}\gamma_n} \quad (9)$$

5. Significance and Use

5.1 Assumptions:

5.1.1 The control well discharges at a constant rate, Q .

5.1.2 The control well, observation wells, and piezometers are of infinitesimal diameter.

5.1.3 The unconfined aquifer is homogeneous and really extensive.

5.1.4 Discharge from the control well is derived initially from elastic storage in the aquifer, and later from gravity drainage from the water table.

5.1.5 The geometry of the aquifer, control well, observation wells, and piezometers is shown in Fig. 2. The geometry of the test wells should be adjusted depending on the parameters of interest.

5.2 Implications of Assumptions:

5.2.1 Use of the Neuman (1) method assumes the control well is of infinitesimal diameter. The storage in the control well may adversely affect drawdown measurements obtained in the early part of the test. See 5.2.2 of Test Method D4106 for assistance in determining the duration of the effects of well-bore storage on drawdown.

5.2.2 If drawdown is large compared with the initial saturated thickness of the aquifer, the late-time drawdown may need to be adjusted for the effect of the reduction in saturated thickness. Section 5.2.3 of Test Method D4106 provides guidance in correcting for the reduction in saturated thickness. According to Neuman (1) such adjustments should be made only for late-time values.

5.3 Practice D3740 provides evaluation factors for the activities in this guide.

NOTE 1—The quality of the result produced by this guide 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 guide are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means

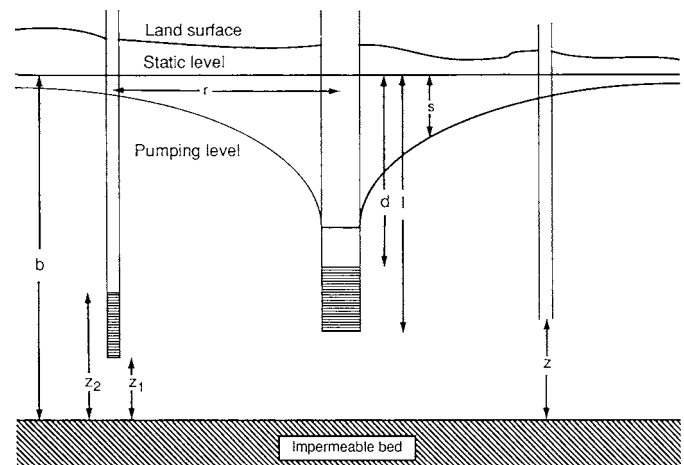


FIG. 2 Cross Section Through a Discharging Well Screened in Part of an Unconfined Aquifer

³ The boldface numbers in parentheses refer to a list of references at the end of the text.