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Designation: D5920/D5920M – 20

Standard Practice for (Analytical Procedure) Tests of Anisotropic Unconfined Aquifers by Neuman Method[1]

This standard is issued under the fixed designation D5920/D5920M; 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 practice 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 practice 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 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated 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 result in units other than SI shall not be regarded as nonconformance with this standard.

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

1.5.1 The procedures used to specify how data are collected/recorded or calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering data.

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of the practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without the consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 Testing for Determining Hydraulic Properties of Aquifer Systems

[1] This practice 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.

Current edition approved May 15, 2020. Published May 2020. Originally approved in 1996. Last previous edition approved in 2014 as D5920-14. DOI: 10.1520/D5920_D5920M-20.

[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

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D4105/D4105M Practice for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method

D4106 Practice for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions*—For definitions of common technical terms used within this standard, 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.

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_β *[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 $(t/r^2)_1$ *[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^2T^{-1}]*—transmissivity, $K_r b$.

3.2.27 z *[L]*—vertical distance above the bottom of the aquifer.

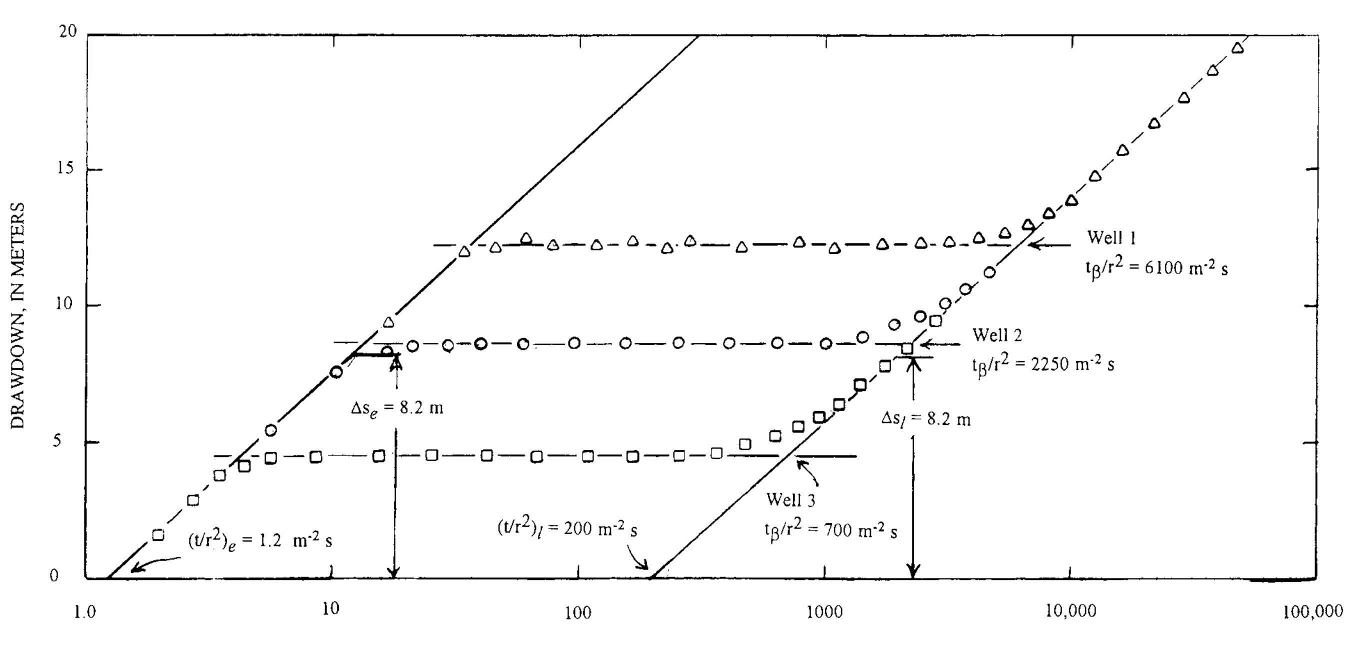

FIG. 1 Aquifer-Test Analysis, Example Two

3.2.28 z_1 *[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 β *[nd]*—dimensionless parameter $\alpha\, r^2/b^2$.

3.2.35 Δs_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 Δs_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 σ *[nd]*—dimensionless parameter S/S_y.

4. Summary of Practice

4.1 *Procedure*—This practice describes a procedure for analyzing data collected during a withdrawal well test. This practice 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 practice 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, 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:

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

and:

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

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:

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

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

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

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