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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method[1]

This standard is issued under the fixed designation D 4105; 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 procedure for determining transmissivity and storage coefficient of a nonleaky confined aquifer under conditions of radial flow to a fully penetrating well of constant flux. This test method is a shortcut procedure used to apply the Theis nonequilibrium method. The Theis method is described in Test Method D 4106.

1.2 This test method is used in conjunction with the field procedure given in Test Method D 4050.

1.3 *Limitations*—The limitations of this test method are primarily related to the correspondence between the field situation and the simplifying assumptions of this test method (see 5.1). Furthermore, application is valid only for values of u less than 0.01 (u is defined in Eq 2, in 8.6).

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:*

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

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

D 4050 Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems[2]

D 4106 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *aquifer, confined*—an aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.

3.1.2 *aquifer, unconfined*—an aquifer that has a water table.

3.1.3 *confining bed*—a hydrogeologic unit of less permeable material bounding one or more aquifers.

3.1.4 *control well*—well by which the aquifer is stressed, for example, by pumping, injection, or change of head.

3.1.5 *drawdown*—vertical distance the static head is lowered due to the removal of water.

3.1.6 *hydraulic conductivity—(field aquifer tests)*, the volume of water at the existing kinematic viscosity that will move in a unit time under unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

3.1.7 *observation well*—a well open to all or part of an aquifer.

3.1.8 *piezometer*—use to measure static head at a point in the subsurface.

3.1.9 *specific storage*—the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head.

3.1.10 *storage coefficient*—the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. For a confined aquifer, it is equal to the product of specific storage and aquifer thickness. For an unconfined aquifer, the storage coefficient is approximately equal to the specific yield.

3.1.11 *transmissivity*—the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit width of the aquifer.

3.1.12 For definitions of other terms used in this test method, see Terminology D 653.

3.2 *Symbols:Symbols and Dimensions:*

3.2.1 K [LT^{-1}]—hydraulic conductivity.

3.2.2 K_{xy}—hydraulic conductivity in the horizontal direction.

3.2.3 K_z—hydraulic conductivity in the vertical direction.

3.2.4 T [L^2T^{-1}]—transmissivity.

3.2.5 S [nd]—storage coefficient.

3.2.6 Ss [L^{-1}]—specific storage.

3.2.7 s [L]—drawdown.

3.2.8 Q [L^3T^{-1}]—discharge.

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

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

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

3.2.10 t [T]—time.
3.2.11 b [L]—thickness of the aquifer.

4. Summary of Test Method

4.1 This test method describes an analytical procedure for analyzing data collected during a withdrawal or injection well test. The field procedure (see Test Method D 4050) involves pumping a control well at a constant rate and measuring the water level response in one or more observation wells or piezometers. The water-level response in the aquifer is a function of the transmissivity and coefficient of storage of the aquifer. Alternatively, the test can be performed by injecting water at a constant rate into the aquifer through the control well. Analysis of buildup of water level in response to injection is similar to analysis of drawdown of water level in response to withdrawal in a confined aquifer. Drawdown of water level is analyzed by plotting drawdown against factors incorporating either time or distance from the control well, or both, and matching the drawdown response with a straight line.

4.2 *Solution*—The solution given by Theis **(1)**[3] can be expressed as follows:

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y}\,dy \quad (1)$$

where:

$$u = \frac{r^2 S}{4Tt} \quad (2)$$

and:

$$\int_u^\infty \frac{e^{-y}}{y}\,dy = W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2!2} + \frac{u^3}{3!3} - \frac{u^4}{4!4} + \ldots \quad (3)$$

4.3 The sum of the terms to the right of $\log_e u$ in the series of Eq 3 is not significant when u becomes small.

NOTE 1—The errors for small values of u, from Kruseman and DeRidder **(1)** are as follows:

Error less than, %:	1	2	5	10
For u smaller than:	0.03	0.05	0.1	0.15

The value of u decreases with increasing time, t, and decreases as the radial distance, r, decreases. Therefore, for large values of t and reasonably small values of r, the terms to the right of $\log_e u$ in Eq 3 may be neglected as recognized by Theis **(2)** and Jacob **(3)**. The Theis equation can then be written as follows:

$$s = \frac{Q}{4\pi T}\left[-0.577216 - \ln\left(r^2 \frac{S}{4Tt}\right)\right] \quad (4)$$

from which it has been shown by Lohman **(4)** that

$$T = \frac{2.3Q}{4\pi \Delta s/\Delta \log_{10} t} \quad (5)$$

and:

$$T = -\frac{2.3Q}{2\pi \Delta s/\Delta \log_{10} r} \quad (6)$$

where:

$\Delta s/\Delta \log_{10} t$ = the drawdown (measured or projected) over one log cycle of time, and
$\Delta s/\Delta \log_{10} r$ = the drawdown (measured or projected) over one log cycle of radial distance from the control well.

5. Significance and Use

5.1 *Assumptions*:
5.1.1 Well discharges at a constant rate, Q.
5.1.2 Well is of infinitesimal diameter and fully penetrates the aquifer, that is, the well is open to the full thickness of the aquifer.
5.1.3 The nonleaky aquifer is homogeneous, isotropic, and areally extensive. A nonleaky aquifer receives insignificant contribution of water from confining beds.
5.1.4 Discharge from the well is derived exclusively from storage in the aquifer.
5.1.5 The geometry of the assumed aquifer and well conditions are shown in Fig. 1.

5.2 *Implications of Assumptions*:
5.2.1 Implicit in the assumptions are the conditions of radial flow. Vertical flow components are induced by a control well that partially penetrates the aquifer, that is, not open to the aquifer through its full thickness. If the control well does not fully penetrate the aquifer, the nearest piezometer or partially penetrating observation well should be located at a distance, r, beyond which vertical flow components are negligible, where according to Reed **(5)**

$$r = \frac{1.5b}{\sqrt{\frac{K_z}{K_{xy}}}} \quad (7)$$

This section applies to distance-drawdown calculations of transmissivity and storage coefficient and time-drawdown calculations of storage coefficient. If possible, compute transmissivity from time-drawdown data from wells located within a distance, r, of the pumped well using data measured after the effects of partial penetration have become constant. The time at which this occurs is given by Hantush **(6)** by:

$$t = b^2 s/2T\,(K_z/K_r) \quad (8)$$

Fully penetrating observation wells may be placed at less than distance r from the control well. Observation wells may

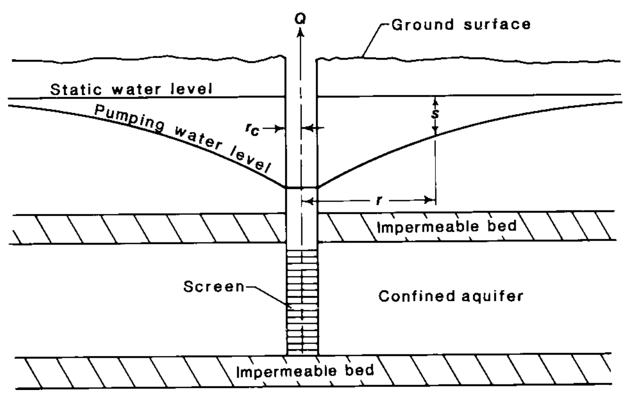

FIG. 1 Cross Section Through a Discharging Well in a Nonleaky Confined Aquifer

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