



Designation: **D5269 – 96 (Reapproved 2008) D5269 – 15**

## Standard Test Method for Determining Transmissivity of Nonleaky Confined Aquifers by the Theis Recovery Method<sup>1</sup>

This standard is issued under the fixed designation D5269; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This test method covers an analytical procedure for determining the transmissivity of a confined aquifer. This test method is used to analyze data from the recovery of water levels following pumping or injection of water to or from a control well at a constant rate.

1.2 The analytical procedure given in this test ~~method~~ method, along with several others, is used in conjunction with the field procedure in Test Method [D4050](#). Guide [D4043](#) provides information for determining hydraulic properties.

1.3 *Limitations*—The valid use of the Theis recovery method is limited to determination of transmissivities for aquifers in hydrogeologic settings ~~with reasonable correspondence~~ reasonably corresponding to the assumptions of the Theis theory (see [5-15.2](#)).

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 non-conformance 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](#). All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice [D6026](#), unless otherwise superseded by this standard.

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*:<sup>2</sup>

[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](#)

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

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

~~[D4750](#)~~[D6026 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well \(Observation Well\)](#)[Practice for Using Significant Digits in Geotechnical Data](#) (~~Withdrawn 2010~~)

<sup>1</sup> 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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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

### 3. Terminology

#### 3.1 Definitions:

3.1.1 For definitions of common Terminology terms used within this guide refer to Terminology [D653](#).

#### 3.2 Definitions: Definitions of Terms Specific to This Standard:

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

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

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

3.1.5 *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.

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

3.1.7 *piezometer*—a device used to measure head at a point in the subsurface.

3.1.8 *residual drawdown*—The difference between the projected prepumping water-level trend and the water level in a well or piezometer after pumping or injection has stopped.

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 *step-drawdown test*—a test in which a control well is pumped at constant rates in “steps” of increasing discharge. Each step is approximately equal in duration, although the last step may be prolonged.

3.1.11 *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.

3.1.12 *transmissivity*—the volume of water of the prevailing kinematic viscosity transmitted in a unit time through a unit width of the aquifer under a unit hydraulic gradient.

#### 3.3 Symbols and Dimensions:

3.3.1  $b$  [L]—aquifer thickness.

3.3.2  $K$  [ $L T^{-1}$ ]—hydraulic conductivity.

#### 3.3.2.1 Discussion—

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<https://standards.iteh.ai/catalog/standards/sist/52c8d93e-5190-4b56-87b6-60029ac0a8e5/astm-d5269-15>

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

3.3.3  $K_r$ —hydraulic conductivity in the plane of the aquifer, radially from the control well.

3.3.4  $K_z$ —hydraulic conductivity in the vertical direction.

3.3.5  $\ln$ —natural logarithm.

3.3.6  $\log_{10}$ —logarithm to the base 10.

3.3.7  $Q$  [ $L^3 T^{-1}$ ]—discharge.

3.3.8  $r$  [L]—radial distance from control well.

3.3.9  $r_c$  [L]—equivalent inside radius of control well.

3.3.10  $S$  [nd]—storage coefficient.

3.3.11  $s$  [L]—drawdown.

3.3.12  $s_c$  [L]—drawdown corrected for the effects of reduction in saturated thickness.

3.3.13  $S_y$  [nd]—specific yield.

3.3.14  $s' [L]$ —residual drawdown.

3.2.15  $\Delta s' [L]$ —change in residual drawdown over one log cycle of  $t/t'$ .

3.3.15  $\Delta s' [L]$ —change in residual drawdown over one log cycle of  $t/t'$ .

3.3.16  $T$  [ $L^2 T^{-1}$ ]—transmissivity.

3.3.17  $t$  [T]—time since pumping or injection began.

3.3.18  $t'$  [T]—time since pumping or injection stopped.

3.3.19  $u$ —dimensionless parameter, equal to  $r^2S/4Tt$ .

3.3.20  $u'$ —dimensionless parameter, equal to  $r^2S/4Tt'$ .

#### 4. Summary of Test Method

4.1 This test method describes an analytical procedure for determining transmissivity using data collected during the recovery phase of a withdrawal or injection well test. The field test (see Test Method **D4050**) requires pumping or injecting a control well that is open to the entire thickness of a confined aquifer at a constant rate for a specified period. The water-levels in the control well, observation wells, or piezometers are measured after pumping is stopped and used to calculate the transmissivity of the aquifer using the procedures in this test method. Alternatively, this test method can be performed by injecting water into the control well at a constant rate. With some modification, this test method can also be used to analyze the residual drawdown following a step test. This test method is used by plotting residual drawdown against either a function of time or a function of time and discharge and determining the slope of a straight line fitted to the points. The solution calculations are shown in Section 8.

4.2 *Solution*—The solution given by Theis (**1**)<sup>4</sup> can be expressed as follows:

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

and:

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

4.3 At a control well, observation well, or piezometer, for large values of time,  $t$ , and small values of radius,  $r$ , the Theis equation reduces, as shown by Cooper and Jacob (**2**) and Jacob (**3**) to the following:

$$s' = \frac{Q}{4\pi T} \ln(t/t') \quad (3)$$

where:

$t$  = the time after pumping began and

$t'$  = the time after pumping ceases. From which it can be shown that:

$$T = \frac{2.3Q}{4\pi \Delta s'} \quad (4)$$

where:

$\Delta s'$  = the measured or projected residual drawdown over one  $\log_{10}$  cycle of  $t/t'$ .

4.4 A similar analysis (see 4.3) may also be used for a step-drawdown test in which a well is pumped at a constant rate for an initial period, and then the pumping rate is increased through several new constant rates in a series of steps. Harrill (**4**) shows that:

$$s' = \frac{2.3\Delta Q_1}{4\pi T} \left( \log_{10} \frac{t_1}{t'} \right) + \frac{2.3\Delta Q_2}{4\pi T} \left( \log_{10} \frac{t_2}{t'} \right) + \dots + \frac{2.3\Delta Q_n}{4\pi T} \left( \log_{10} \frac{t_n}{t'} \right) \quad (5)$$

where:

$t_1, t_2, \dots, t_n$  = the elapsed times since either pumping was begun or the discharge rate was increased,

$Q_1, Q_2, \dots, Q_n$  = the well discharge rates, and

$\Delta Q_1, \Delta Q_2, \dots, \Delta Q_n$  = the incremental increases in discharge.

Eq 5 can be rewritten as follows:

$$T = \frac{2.3Q_n}{4\pi s'} \log_{10} f(t, Q) \quad (6)$$

where:

$$f(t, Q) = \frac{t_1^{\Delta Q_1/Q_n} t_2^{\Delta Q_2/Q_n} t_3^{\Delta Q_3/Q_n} \dots t_n^{\Delta Q_n/Q_n}}{t'} \quad (7)$$

and:

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

<sup>3</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

$$T = \frac{2.3Q_n}{4\pi\Delta s'_n} \tag{8}$$

where:

$\Delta s'_n$  = the residual drawdown over one log cycle of the expression  $f(t, Q)$  in Eq 6.

Eq 8 can also be used to analyze the residual drawdown following a test in which discharge varies significantly, so long as the discharge can be generalized as a series of constant discharge steps.

## 5. Significance and Use

5.1 This test method is useful for analyzing data on the recovery of water levels following pumping or injection of water to or from a control well at a constant rate. The analytical procedure given in this test method along with several others is used in conjunction with the field procedure in Test Method D4050.

### 5.2 Assumptions:

- 5.2.1 The well discharges at a constant rate,  $Q$ , or at steps of constant rate  $Q_1, Q_2 \dots Q_n$ .
- 5.2.2 Well is of infinitesimal diameter and is open through the full thickness of the aquifer.
- 5.2.3 The nonleaky aquifer is homogeneous, isotropic, and areally extensive.
- 5.2.4 Discharge from the well is derived exclusively from storage in the aquifer.
- 5.2.5 The geometry of the assumed aquifer and well are shown in Fig. 1.

### 5.3 Implications of Assumptions—Assumptions:

5.3.1 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 the full thickness of the aquifer. If vertical flow components are significant, the nearest partially penetrating observation well should be located at a distance,  $r$ , beyond which vertical flow components are negligible. See 5.2.25.3.1 of Test Method D4106 for assistance in determining the minimum distance to partially penetrating observation wells and piezometers.

5.3.2 The Theis 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 5.2.25.3.2 of Test Method D4106 for assistance in determining the duration of the effects of well-bore storage on drawdown.

### 5.3.3 Application of Theis Recovery Method for Unconfined Aquifers:

5.3.3.1 Although the assumptions are applicable to artesian or confined conditions, the Theis solution may be applied to unconfined aquifers if (A) drawdown is small compared with the saturated thickness of the aquifer or if the drawdown is corrected for reduction in thickness of the aquifer and (B) the effects of delayed gravity yield are small. See 5.2.35.3.3 of Test Method D4106 for guidance in treating reduction in saturated thickness and delayed gravity drainage in unconfined aquifers.

NOTE 1—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. 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.

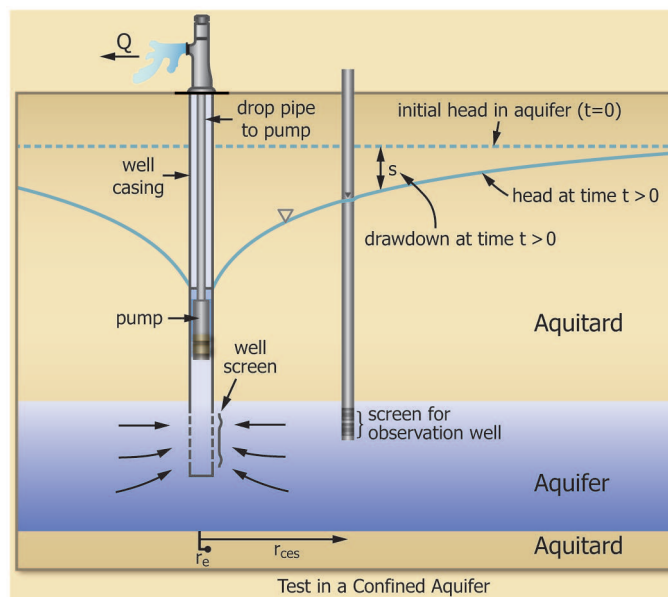


FIG. 1 Cross Section Through a Discharging Well in a Nonleaky Aquifer