Designation: D 5270 – 96 (Reapproved 2002)

Standard Test Method for Determining Transmissivity and Storage Coefficient of Bounded, Nonleaky, Confined Aquifers[1]

This standard is issued under the fixed designation D 5270; 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 the transmissivity, storage coefficient, and possible location of boundaries for a confined aquifer with a linear boundary. This test method is used to analyze water-level or head data from one or more observation wells or piezometers during the pumping of water from a control well at a constant rate. This test method also applies to flowing artesian wells discharging at a constant rate. With appropriate changes in sign, this test method also can be used to analyze the effects of injecting water into a control well at a constant rate.

1.2 The analytical procedure in this test method is used in conjunction with the field procedure in Test Method D 4050.

1.3 *Limitations*—The valid use of this test method is limited to determination of transmissivities and storage coefficients for aquifers in hydrogeologic settings with reasonable correspondence to the assumptions of the Theis nonequilibrium method (see Test Method D 4106) (see 5.1), except that the aquifer is limited in areal extent by a linear boundary that fully penetrates the aquifer. The boundary is assumed to be either a constant-head boundary (equivalent to a stream or lake that hydraulically fully penetrates the aquifer) or a no-flow (impermeable) boundary (equivalent to a contact with a significantly less permeable rock unit). The Theis nonequilibrium method is described in Test Methods D 4105 and D 4106.

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 4105 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method[2]

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

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *constant-head boundary*—the conceptual representation of a natural feature such as a lake or river that effectively fully penetrates the aquifer and prevents water-level change in the aquifer at that location.

3.1.2 *equipotential line*—a line connecting points of equal hydraulic head. A set of such lines provides a contour map of a potentiometric surface.

3.1.3 *image well*—an imaginary well located opposite a control well such that a boundary is the perpendicular bisector of a straight line connecting the control and image wells; used to simulate the effect of a boundary on water-level changes.

3.1.4 *impermeable boundary*—the conceptual representation of a natural feature such as a fault or depositional contact that places a boundary of significantly less-permeable material laterally adjacent to an aquifer.

3.1.5 See Terminology D 653 for other terms.

3.2 *Symbols and Dimensions*:

3.2.1 K_l *[nd]*—constant of proportionality, r_i / r_r.

3.2.2 Q $[L^3T^{-1}]$—discharge.

[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 Ground Water and Vadose Zone Investigations.

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

3.2.3 r [L]—radial distance from control well.
3.2.4 r_i [L]—distance from observation well to image well.
3.2.5 r_r [L]—distance from observation well to control well.
3.2.6 S [nd]—storage coefficient.
3.2.7 s [L]—drawdown.
3.2.8 s_i [L]—component of drawdown due to image well.
3.2.9 s_o [L]—drawdown at an observation well.
3.2.10 s_r [L]—component of drawdown due to control well.
3.2.11 T [L^2T^{-1}]—transmissivity.
3.2.12 t [T]—time since pumping or injection began.
3.2.13 t_o [T]—time at projection of zero drawdown.

4. Summary of Test Method

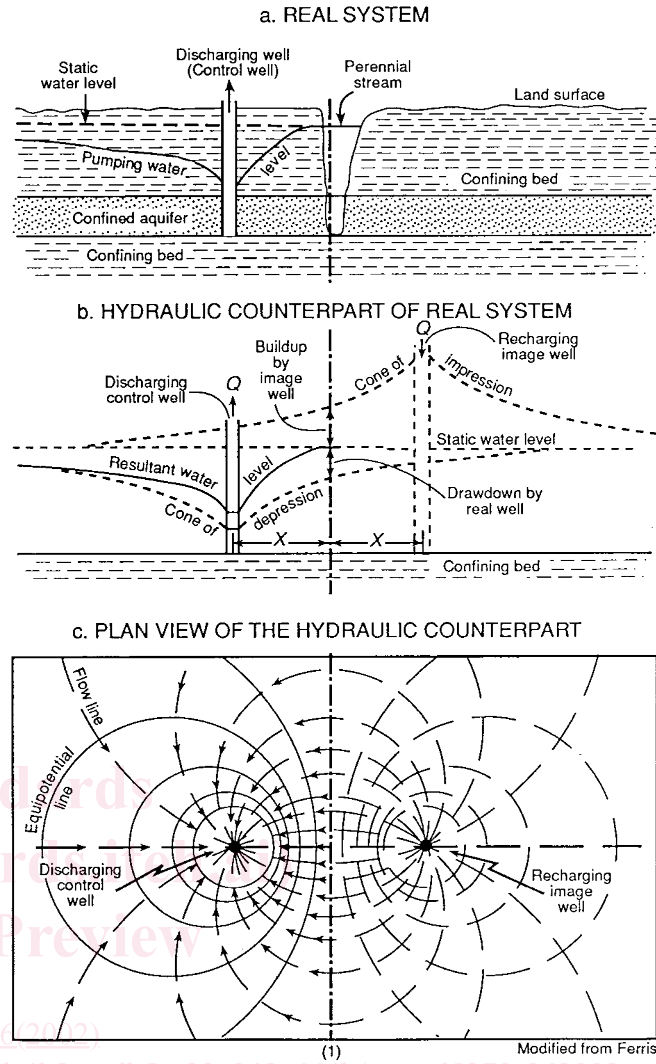
4.1 This test method prescribes two analytical procedures for analysis of a field test. This test method requires pumping water from, or injecting water into, a control well that is open to the entire thickness of a confined bounded aquifer at a constant rate and measuring the water-level response in one or more observation wells or piezometers. The water-level response in the aquifer is a function of the transmissivity and storage coefficient of the aquifer, and the location and nature of the aquifer boundary or boundaries. Drawdown or build up of the water level is analyzed as a departure from the type curve defined by the Theis nonequilibrium method (see Test Method D 4106) or from straight-line segments defined by the modified Theis nonequilibrium method (see Test Method D 4105).

4.2 A constant-head boundary such as a lake or stream that fully penetrates the aquifer prevents drawdown or build up of head at the boundary, as shown in Fig. 1. Likewise, an impermeable boundary provides increased drawdown or build up of head, as shown in Fig. 2. These effects are simulated by treating the aquifer as if it were infinite in extent and introducing an imaginary well or "image well" on the opposite side of the boundary a distance equal to the distance of the control well from the boundary. A line between the control well and the image well is perpendicular to the boundary. If the boundary is a constant-head boundary, the flux from the image well is opposite in sign from that of the control well; for example, the image of a discharging control well is an injection well, whereas the image of an injecting well is a discharging well. If the boundary is an impermeable boundary, the flux from the image well has the same sign as that from the control well. Therefore, the image of a discharging well across an impermeable boundary is a discharging well. Because the effects are symmetrical, only discharging control wells will be described in the remainder of this test method, but this test method is equally applicable, with the appropriate change in sign, to control wells into which water is injected.

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

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

and:



NOTE 1—Modified from Ferris and others (**6**) and Heath (**7**).

FIG. 1 Diagram Showing Constant-Head Boundary

$$u = \frac{r^2S}{4Tt} \tag{2}$$

where:

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

4.4 According to the principle of superposition, the drawdown at any point in the aquifer is the sum of the drawdown due to the real and image wells (**1**) and (**2**):

$$s_o = s_r \pm s_i \tag{4}$$

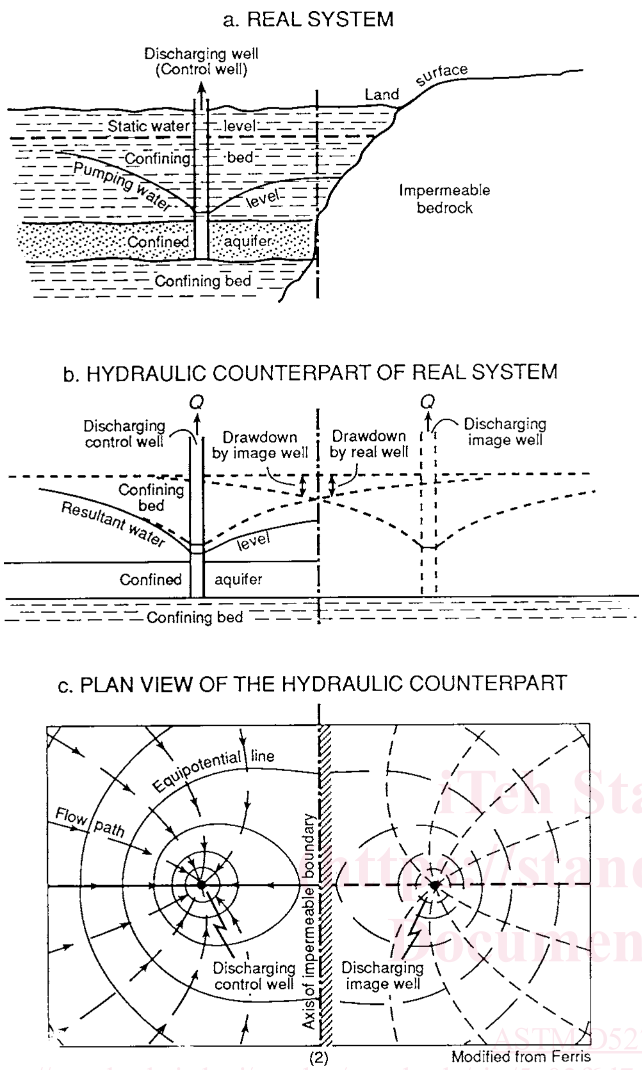
Equation (**4**) can be rewritten as follows:

$$s_o = \frac{Q}{4\pi T}[W(u_r) \pm W(u_i)] = \frac{Q}{4\pi T}\Sigma\, W(u) \tag{5}$$

where:

$$u_r = \frac{r_r^{\,2}S}{4Tt},\; u_i = \frac{r_i^{\,2}S}{4Tt} \tag{6}$$

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



NOTE 1—Modified from Ferris and others **(6)** and Heath **(7)**.

FIG. 2 Diagram Showing Impermeable Boundary

so that:

$$u_i = \left(\frac{r_i}{r_r}\right)^2 u_r, \; u_i = K_l{}^2 u_r \qquad (7)$$

where:

$$K_l = \frac{r_i}{r_r} \qquad (8)$$

NOTE 1—K_l is a constant of proportionality between the radii, not to be confused with hydraulic conductivity.

5. Significance and Use

5.1 *Assumptions*:

5.1.1 The well discharges at a constant rate.

5.1.2 Well is of infinitesimal diameter and is open through the full thickness of the aquifer.

5.1.3 The nonleaky confined aquifer is homogeneous, isotropic, and areally extensive except where limited by linear boundaries.

5.1.4 Discharge from the well is derived initially from storage in the aquifer; later, movement of water may be induced from a constant-head boundary into the aquifer.

5.1.5 The geometry of the assumed aquifer and well are shown in Fig. 1 or Fig. 2.

5.1.6 Boundaries are vertical planes, infinite in length that fully penetrate the aquifer. No water is yielded to the aquifer by impermeable boundaries, whereas recharging boundaries are in perfect hydraulic connection with the aquifer.

5.1.7 Observation wells represent the head in the aquifer; that is, the effects of wellbore storage in the observation wells are negligible.

5.2 *Implications of Assumptions*:

5.2.1 Implicit in the assumptions are the conditions of a fully-penetrating control well and observation wells of infinitesimal diameter in a confined aquifer. Under certain conditions, aquifer tests can be successfully analyzed when the control well is open to only part of the aquifer or contains a significant volume of water or when the test is conducted in an unconfined aquifer. These conditions are discussed in more detail in Test Method D 4105.

5.2.2 In cases in which this test method is used to locate an unknown boundary, a minimum of three observation wells is needed. If only two observation wells are available, two possible locations of the boundary are defined, and if only one observation well is used, a circle describing all possible locations of the image well is defined.

5.2.3 The effects of a constant-head boundary are often indistinguishable from the effects of a leaky, confined aquifer. Therefore, care must be taken to ensure that a correct conceptual model of the system has been created prior to analyzing the test. See Guide D 4043.

6. Apparatus

6.1 Analysis of the data from the field procedure (see Test Method D 4050) by this test method requires that the control well and observation wells meet the requirements specified in the following subsections.

6.2 *Construction of Control Well*—Install the control well in the aquifer and equip with a pump capable of discharging water from the well at a constant rate for the duration of the test. Preferably, the control well should be open throughout the full thickness of the aquifer. If the control well partially penetrates the aquifer, take special precautions in the placement or design of observation wells (see 5.2.1).

6.3 *Construction of Observation Wells and Piezometers*—Construct one or more observation wells or piezometers at specified distances from the control well.

6.4 *Location of Observation Wells and Piezometers*—Wells may be located at any distance from the control well within the area of influence of pumping. However, if vertical flow components are expected to be significant near the control well and if partially penetrating observation wells are to be used, the observation wells should be located at a distance beyond the effect of vertical flow components. If the aquifer is unconfined, constraints are imposed on the distance to partially penetrating observation wells and on the validity of early time measurements (see Test Method D 4106).

NOTE 2—To ensure that the effects of the boundary may be observed during the tests, some of the wells should be located along lines parallel to the suspected boundary, no farther from the boundary than the control well.