Designation: D6028 – 96 (Reapproved 2010)$^{\varepsilon 1}$

Standard Test Method (Analytical Procedure) for Determining Hydraulic Properties of a Confined Aquifer Taking into Consideration Storage of Water in Leaky Confining Beds by Modified Hantush Method[1]

This standard is issued under the fixed designation D6028; 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.

ε[1] NOTE—The units statement in 1.4 was revised editorially in August 2010.

1. Scope

1.1 This test method covers an analytical procedure for determining the transmissivity and storage coefficient of a confined aquifer taking into consideration the change in storage of water in overlying or underlying confining beds, or both. This test method is used to analyze water-level or head data collected from one or more observation wells or piezometers during the pumping of water from a control well 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 This analytical procedure is used in conjunction with Test Method D4050.

1.3 *Limitations*—The valid use of the modified Hantush method (**1**)[2] is limited to the determination of hydraulic properties for aquifers in hydrogeologic settings with reasonable correspondence to the assumptions of the Hantush-Jacob method (Test Method D6029) with the exception that in this case the gain or loss of water in storage in the confining beds is taken into consideration (see 5.1). All possible combinations of impermeable beds and source beds (for example, beds in which the head remains uniform) are considered on the distal side of the leaky beds that confine the aquifer of interest (see Fig. 1).

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D4050 Test Method for (Field Procedure) for Withdrawal and Injection Well Testing for Determining Hydraulic Properties of Aquifer Systems

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

D6029 Test Method (Analytical Procedure) for Determining Hydraulic Properties of a Confined Aquifer and a Leaky Confining Bed with Negligible Storage by the Hantush-Jacob Method

3. Terminology

3.1 *Definitions:*

3.1.1 *aquifer, confined, n*—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, n*—an aquifer is unconfined where it has a water table.

3.1.3 *coefficient of leakage, n*—see *leakance*.

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

3.1.5 *control well, n*—well by which the head and flow in the aquifer is changed, for example, by pumping, injection, or change of head.

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

[1] This test method is under the jurisdiction of Committee D18 on Soil and Rockand is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

Current edition approved Aug. 1, 2010. Published September 2010. Originally approved in 1996. Last previou edition approved in 2004 as D6028–96(2004). DOI: 10.1520/D6028-96R10E01.

[2] The boldface numbers in parentheses refer to a list of references at the end of this test method.

[3] 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.

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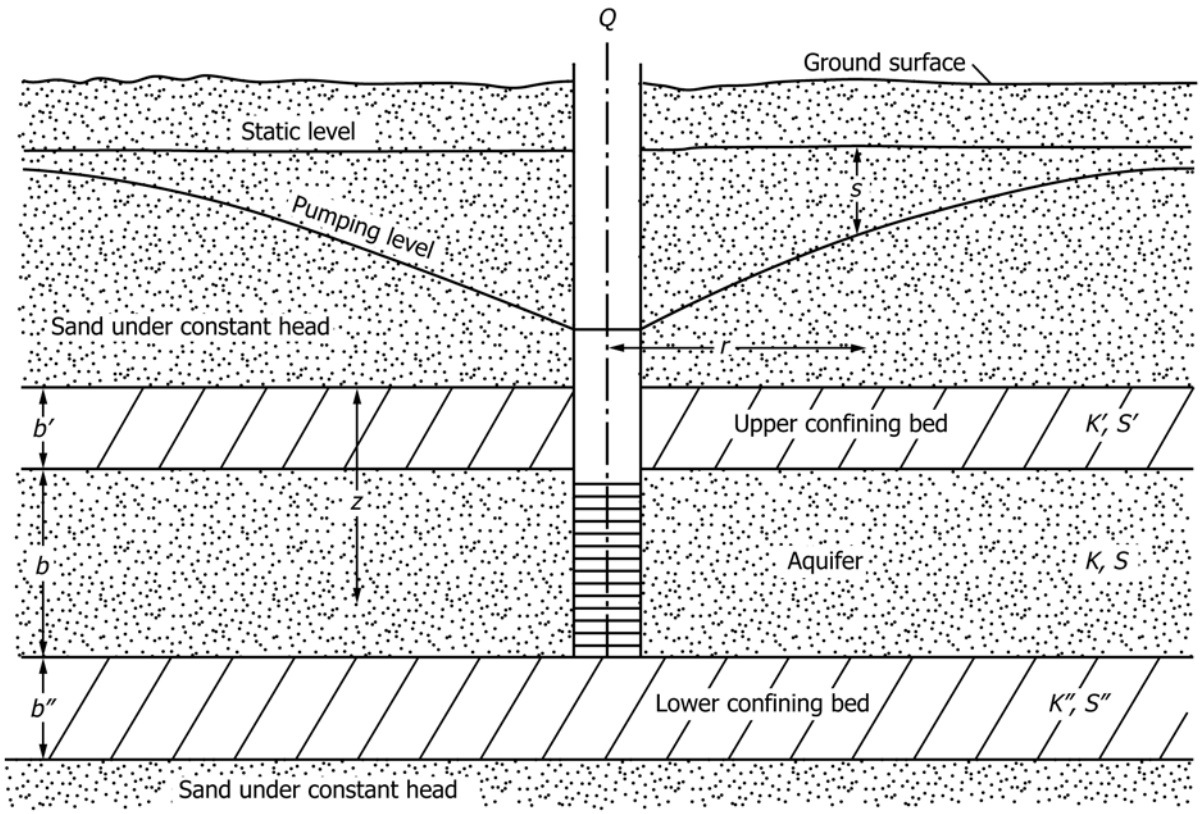
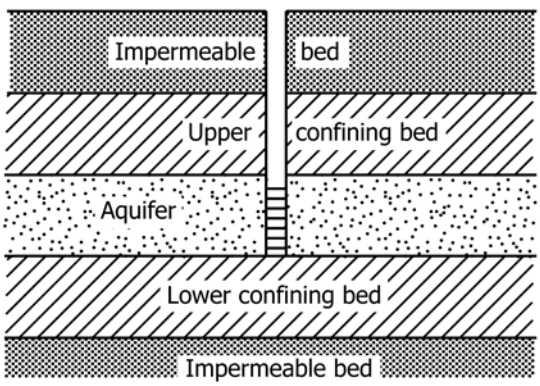


CASE 1



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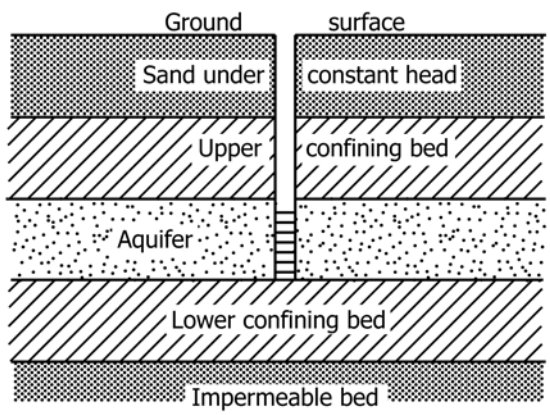

CASE 3

FIG. 1 Cross Sections Through Discharging Wells in Leaky Aquifers with Storage of Water in the Confining Beds, Illustrating Three Different Cases of Boundary Conditions (from Reed (2))

3.1.7 *head, n*—see *head, static*.

3.1.8 *head, static, n*—the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.

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

3.1.10 *leakance, n*—the ratio of the vertical hydraulic conductivity of a confining bed to its thickness.

3.1.11 *observation well, n*—a well open to all or part of an aquifer.

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3.1.12 *piezometer, n*—a device used to measure static head at a point in the subsurface.

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

3.1.14 *storage coefficient, n*—the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

3.1.14.1 *Discussion*—For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. For an unconfined aquifer, the storage coefficient is approximately equal to the specific yield.

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

3.1.16 For definitions of other terms used in this test method, see Terminology D653.

3.2 *Symbols and Dimensions:*

3.2.1 $H(u,\beta)$—well function for leaky systems where water storage in confining beds is important [*nd*].

3.2.2 K—hydraulic conductivity of the aquifer [LT^{-1}].

3.2.2.1 *Discussion*—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 soil and rock mechanics and soil science.

3.2.3 K', K''—vertical hydraulic conductivities of the confining beds through which leakage can occur [LT^{-1}].

3.2.4 Q—discharge [L^3T^{-1}].

3.2.5 $S = bS_s$—storage coefficient of the aquifer [*nd*].

3.2.6 $S' = b'S'_s$, $S'' = b''S''_s$—storage coefficients of the confining beds [*nd*].

3.2.7 S_s—specific storage of the aquifer [L^{-1}].

3.2.8 S'_s, S''_s [L^{-1}]—specific storages of the confining beds.

3.2.9 T—transmissivity [L^2T^{-1}].

3.2.10 $u = \frac{r^2 s}{4Tt}$ [*nd*].

3.2.11 $W(u,r/B)$—well function for leaky aquifer systems with negligible storage changes in confining beds [*nd*].

3.2.12 $W(u)$—well function for nonleaky aquifer systems [*nd*].

3.2.13 b—thickness of aquifer [L].

3.2.14 b', b''—thicknesses of the confining beds through which leakage can occur [L].

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

3.2.16 s—drawdown [L].

3.2.17 $B = \sqrt{\frac{Tb'}{K'}}$ [L] .

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

3.2.19 $\beta = \frac{r}{4b}\left(\sqrt{\frac{K'S'}{b'KS_s}} + \right)\sqrt{\frac{K''S''}{b''KS_s}}$ [*nd*].

4. Summary of Test Method

4.1 This test method involves pumping a control well that is fully screened through the confined aquifer and measuring the water-level response in one or more observation wells or piezometers. The well is pumped at a constant rate. The water-level response in the aquifer is a function of the transmissivity and storage coefficient of the aquifer and the leakance coefficients and storage coefficients of the confining beds. Alternatively, the test method can be performed by injecting water at a constant rate into 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. The water-level response data are analyzed using a set of type curves.

4.2 *Solution*—Hantush (**1**) gave solutions applicable to each of Cases 1, 2, and 3 shown in Fig. 1 for "relatively small" values of time and for "relatively large" values of time. The solution applicable for each case for relatively small values of time can be written as follows

$$s = \frac{Q}{4\pi T} H(u,\beta) \tag{1}$$

where:

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

and

$$\beta = \frac{r}{4b}\left(\frac{K'S'}{b'KS_s} + \frac{K''S''}{b''KS_s}\right) \tag{3}$$

$$H(u,\beta) = \int_u^\infty \frac{e^{-y}}{y}\, erfc\, \frac{\beta\sqrt{u}}{\sqrt{y(y-u)}}\, dy \tag{4}$$

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_u^\infty e^{-y^2}\, dy \tag{5}$$

where y is the variable of integration.

4.2.1 The "relatively small" times when Eq 1 is applicable are when:

$$t < \frac{b'S'}{10K'} \text{ and } t < \frac{b''S''}{10K''} \tag{6}$$

Equation 1 is applicable at early times for each of the cases shown in Fig. 1 even though the conditions on the distal sides of the confining beds are quite different because for early times the solution in the aquifer is essentially independent of conditions on the distal side of the confining beds. The effects of those distant boundary conditions are not felt in the aquifer for a while. Eq 1-5 are the basis for the type curve solution that is described by this test method.

4.2.2 For relatively large values of time the solutions given by Hantush (**1**) can be written as:

4.2.2.1 *Case 1*—Heads in zones on the distal side of the confining beds remain constant and are unaffected by discharge of the pumped well. For times when

$$t > 5\,\frac{b'S'}{K'} \text{ and } t > 5\,\frac{b''S''}{K''} \tag{7}$$

are both satisfied, then

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