Designation: D5473/D5473M – 20

Standard Practice for (Analytical Procedures) Analyzing the Effects of Partial Penetration of Control Well and Determining the Horizontal and Vertical Hydraulic Conductivity in a Nonleaky Confined Aquifer[1]

This standard is issued under the fixed designation D5473/D5473M; 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 solution for determining the horizontal and vertical hydraulic conductivity of an aquifer by analysis of the response of water levels in the aquifer to the discharge from a well that partially penetrates the aquifer. This standard uses data derived from Test Method D4050.

1.2 *Limitations*—The limitations of the technique for determination of the horizontal and vertical hydraulic conductivity of aquifers are primarily related to the correspondence between the field situation and the simplifying assumption of this practice.

1.3 *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 results in units other than SI shall not be regarded as nonconformance with this standard.

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

1.4.1 The procedures used to specify how data are collected/recorded or calculated, in this 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 analytical methods for engineering design

1.5 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 he ASTM consensus process.

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

1.7 *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

D4050 Test Method for (Field Procedure) for Withdrawal and Injection Well Testing for Determining Hydraulic

[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.

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[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**

Properties of Aquifer Systems
D4105/D4105M Practice for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method
D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *unconfined aquifer*—an aquifer that has a water table.

3.3 *Symbols and Dimensions:*

3.3.1 a [nd]—$(K_z/K_r)^{1/2}$.

3.3.2 b [L]—thickness of aquifer.

3.3.3 d [L]—distance from top of aquifer to top of screened interval of control well.

3.3.4 d' [L]—distance from top of aquifer to top of screened interval of observation well.

3.3.5 f_s [nd]—dimensionless drawdown factor.

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

3.3.7 K_r [LT^{-1}]—hydraulic conductivity in the plane of the aquifer, radially from the control well.

3.3.8 K_z [LT^{-1}]—hydraulic conductivity normal to the plane of the aquifer.

3.3.9 K_0—modified Bessel function of the second kind and zero order.

3.3.10 l [L]—distance from top of aquifer to bottom of screened interval of control well.

3.3.11 l' [L]—distance from top of aquifer to bottom of screened interval of observation well.

3.3.12 Q [L^{3}T^{-1}]—discharge.

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

3.3.14 r_c—distance from pumped well at which an observed drawdown deviation, δs, would occur in the equivalent isotropic aquifer.

3.3.15 S [nd]—storage coefficient.

3.3.16 s [L]—drawdown.

3.3.17 S_s[L^{-1}]—specific storage.

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

3.3.19 u [nd]—$(r^2S)/(4\ Tt)$.

3.3.20 $W(u)$ [nd]—an exponential integral known in hydrology as the well function of u.

3.3.21 $W(u, f_s)$—partial-penetration control well function.

3.3.22 δs [L]—drawdown deviation due to partial penetration from that given by equations for purely radial flow.

3.3.23 z [L]—distance from top of aquifer to bottom of piezometer.

4. Summary of Practice

4.1 This practice uses the deviations in drawdown near a partially penetrating control well from those that would occur near a control well fully penetrating the aquifer. These deviations occur when a well partially penetrating the aquifer is pumped because water levels are drawn down more near the level of the screen, and less at levels somewhat above or below the screened interval, than they would be if the pumped well fully penetrated the aquifer. These effects are shown in Fig. 1 by comparing drawdown and flow lines for fully penetrating and partially penetrating control wells in an isotropic aquifer. Drawdown deviations due to partial penetration are amplified when the vertical permeability is less than the horizontal permeability, as often occurs in stratified sediments (**1**).[3] Hantush (**2**) has shown that at a distance, r, from the control well the drawdown deviation due to pumping a partially penetrating well at a constant rate is the same as that at a distance $r(K_z/K_r)^{1/2}$ if the aquifers were transformed into an equivalent isotropic aquifer.

4.2 *Solutions*—Solutions are given by Hantush (**2**) for the drawdown near a partially penetrating control well being pumped at a constant rate and tapping a homogeneous, isotropic artesian aquifer:

$$s = \frac{Q}{4\pi T}\left[W(u)+f_s\right] \quad (1)$$

where:

$$W(u) = \int_u^\infty \frac{e^{-y}}{y}\,dy \quad (2)$$

and f_s is the dimensionless drawdown correction factor. The function $[\,W(u)+f_s]$ in Eq 1 can be referred to as the partial penetration well function.

4.2.1 The dimensionless drawdown correction factor for a piezometer is given by:

$$f_s = f\left(u, \frac{ar}{b}, \frac{l}{b}, \frac{d}{b}, \frac{z}{b}\right) \quad (3)$$

$$= \frac{2b}{\pi(l-d)}\sum_{n=1}^{\infty}\frac{1}{n}\left(\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b}\right)\cos\frac{n\pi z}{b}\,W\left(u, \frac{n\pi ar}{b}\right)$$

and the solution for the dimensionless drawdown correction factor for an observation well is given by:

$$f_s = f\left(u, \frac{ar}{b}, \frac{l}{b}, \frac{d}{b}, \frac{l'}{b}, \frac{d'}{b}\right) \quad (4)$$

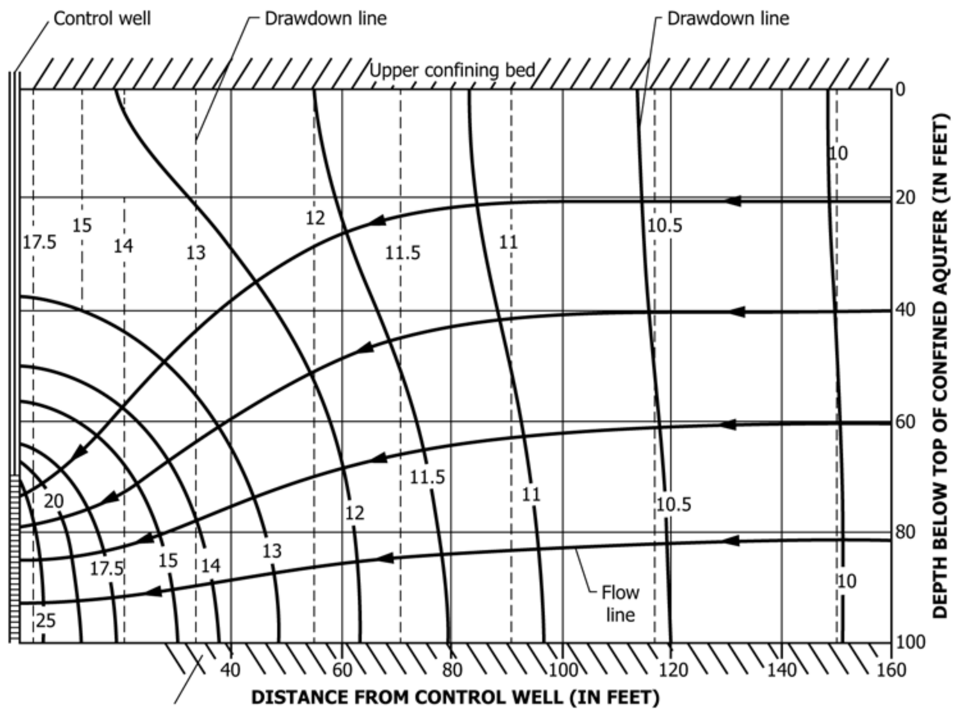
$$= \frac{2b^2}{\pi^2(l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}\left(\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b}\right)$$

$$\left(\sin\frac{n\pi l'}{b} - \sin\frac{n\pi d'}{b}\right)W\left(u, \frac{n\pi ar}{b}\right)$$

where:

$$W(m, x) = \int_u^\infty \frac{\exp\left(-y - \frac{x^2}{4y}\right)}{y}\,dy \quad (5)$$

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



NOTE 1—Solid lines are for a well screened in the bottom three tenths of the aquifer; dashed lines are for a well screened the full thickness.

FIG. 1 Vertical Section Showing Drawdown Lines and Approximate Flow Paths Near a Pumped Well in an Ideal Artesian Aquifer

The hydrogeologic conditions and symbols used in connection with piezometer and well geometries are shown in Fig. 2.

4.2.2 For large values of time, that is, for $t > b^2S/(2a^2T)$ or $t > bS/(2K_z)$, the effects of partial penetration are constant in time, and $W(u, (n\pi ar)/b))$ can be approximated by $2K_0((n\pi ar)/b)$ (**2**). K_0 is the modified Bessel function of the second kind of order zero.

4.2.3 Eq 1 can be written

$$s = \frac{Q}{4\pi T} W(u) + \frac{Q}{4\pi T} f_s \quad (6)$$

The first term in Eq 6 is the drawdown in an isotropic homogeneous confined aquifer under radial flow, as given by Theis (**3**). The second term is deviation from the Theis drawdown caused by partial penetration of the control well. This term is designated as the drawdown deviation by Weeks (**1**) and is given by:

$$\delta s = \frac{Q}{4\pi T} f_s \quad (7)$$

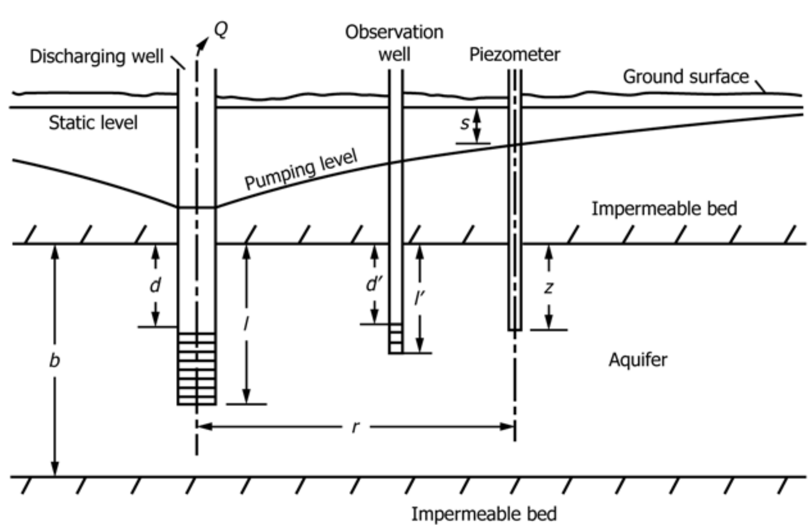


FIG. 2 Cross Section Through a Discharging Well That is Screened in a Part of a Nonleaky Aquifer

4.2.4 The effects of partial penetration need to be considered for *ar/b* < 1.5. There is a response curve for each value of *ar/b, d/b, l/b*, and either *z/b* for piezometers, or *l'/ b* and *d'/b* for observation wells. A table of dimensionless drawdown factors for piezometers from Weeks (**1**) is given in Table 1 covering 56 different partial-penetration situations. A graph of one of the many families of curves showing the dimensionless drawdown factor f_s versus *ar/b* for a control well screened, or open, from $z = 0.6b$ to $z = 0.9b$ for various values of piezometer penetration, *z/b*, is shown in Fig. 3. Because of the even greater number of possible drawdown factors for observation wells, drawdown correction factors for wells are not tabulated.

5. Significance and Use

5.1 *Assumptions:*

5.1.1 Control well discharges at a constant rate, *Q*.

5.1.2 Control well is of infinitesimal diameter and partially penetrates the aquifer.

5.1.3 The nonleaky artesian aquifer is homogeneous, and aerially extensive. The aquifer may also be anisotropic and, if so, the directions of maximum and minimum hydraulic conductivity are horizontal and vertical, respectively. The methods may be used to analyze tests on unconfined aquifers under conditions described in a following section.

NOTE 1—Slug and pumping tests implicitly assume a porous medium. Fractured rock and carbonate settings may not provide meaningful data and information.

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. 2.

5.2 *Implications of Assumptions*—The vertical flow components in the aquifer are induced by a control well that partially penetrates the aquifer, that is, a well that is not open to the aquifer through its full thickness. The effects of vertical flow components are measured in piezometers near the control well, that is, within a distance, *r*, in which vertical flow components are significant, that is:

$$r < 1.5b\sqrt{Kr/Kz} \quad (8)$$

5.3 *Application of Method to Unconfined Aquifers:*

5.3.1 Although the assumptions are applicable to artesian or confined conditions, Weeks (**1**) has pointed out that the solution may be applied to unconfined aquifers if 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 the effects of delayed gravity response are small. The effects of gravity response become negligible after a time as given, for piezometers near the water table, by the equation:

$$t = \frac{bS_y}{K_z} \quad (9)$$

for values of *ar/b* < 0.4 and by the equation:

$$t = \frac{bS_y}{K_z}\left(0.5 + 1.25\,\frac{r}{b}\sqrt{\frac{K_z}{K_r}}\right) \quad (10)$$

for greater values of *ar/b*.

5.3.2 Drawdown in an unconfined aquifer is also affected by curvature of the water table or free surface near the control well, and by the decrease in saturated thickness, that causes the transmissivity to decline toward the control well. This method should be applicable to analysis of tests on water-table aquifers for which the control well is cased to a depth below the pumping level and the drawdown in the control well is less than 0.2*b*. Moreover, little error would be introduced by effects of water-table curvature, even for a greater drawdown in the control well, if the term $(s^2/2b)$ for a given piezometer is small compared to the $\delta\, s$ term.

5.3.3 The transmissivity decreases as a result of decreasing thickness of the unconfined aquifer near the control well. Jacob (**4**) has shown that the effect of decreasing transmissivity on the drawdown may be corrected by the equation:

$$s' = s - \left(s^2/2b\right) \quad (11)$$

where *s* is the observed drawdown and *s'* is the drawdown in an equivalent confined aquifer.

NOTE 2—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/etc. 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.

6. Apparatus

6.1 Apparatus for withdrawal tests is given in Test Method D4050. The apparatus described as follows are those components of the apparatus that require special attributes for Test Method D4050.

6.2 *Construction of Control Well*—Screen the control well through only part of the vertical extent of the aquifer to be tested. The screened interval of the control well must be known as a function of aquifer thickness.

6.3 *Construction and Placement of Piezometers and Observation Wells*—The requirements for observation wells and piezometers are related to the method of analysis to be used. Two methods of analysis are prescribed in Section 8; the observation well and piezometer requirements for each method are given as follows. The piezometers and observation wells may be on the same or various radial lines from the control well.

6.3.1 The type curve fitting methods require one or more piezometers near the control well within the radial distance affected by vertical flow components. This distance is given by $r < 1.5\, b/(K_z/K_r)^{1/2}$. The depth of the piezometer opening must be known as a function of the aquifer thickness. Construction of piezometers or wells for a specific field test shall be identical with respect to distance from the top of the aquifer to the bottom of the piezometers or the screened interval of the wells.

6.3.2 Method 1 of the drawdown deviation methods requires one or more piezometers or wells near the control well within the radial distance affected by vertical flow components. The depth of these piezometers and the screened interval of wells must be known as a function of aquifer thickness. Construction of piezometers or wells for a specific field test

TABLE 1 Tabulated Values of the Dimensionless Drawdown Correction Factor

All values, including those for piezometer depth, are listed for percentages of the aquifer thickness, as measured from the top of the aquifer or from the pumped well.

The *f(s)* values listed are for an isotropic aquifer. For an anisotropic aquifer the value of *f(s)* would be read as the value of $r/b[Kz/Kr)^{1/2}]$, expressed as a percentage, equivalent to the *r* value listed.

Each of the tables listed below may also be used for the situation where values for the bottom and the top of the screen are reversed by reading the *z* value in the table equivalent to (100 *z*) for the field situation. For example, the first table listed could also be used to determine values of *fs* for a well screened from the top of the aquifer down to a depth equal to 90 % of the adapter thickness. If the piezometers penetrated 20 % of the aquifer thickness, the correction value for a given *r/b* value would be found from the *z* = 80 listing.

Frequently it would be necessary to make a double or triple interpolation to use the data from these tables. Such interpolation probably would be best accomplished from a plot of *f(s)* versus log *r/b* for each of the *d/b*, *zw/b*, and *z/b* values bounding the actual values of these parameters.

Bottom of Screen in Pumped Well is 100. Per Cent of Aquifer Thickness Below Top of Aquifer

Top of Screen in Pumped Well is 90. Per Cent of Aquifer Thickness Below Top of Aquifer

Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.828	−3.457	−2.674	−2.134	−1.732	−1.421	−0.972	−0.673	−0.468	−0.229	−0.113	−0.056	−0.020
10.	−4.785	−3.415	−2.633	−2.095	−1.696	−1.387	−0.944	−0.650	−0.451	−0.219	−0.219	−0.053	−0.019
20.	−4.651	−3.284	−2.506	−1.976	−1.585	−1.284	−0.860	−0.584	−0.400	−0.191	−0.093	−0.046	−0.016
30.	−4.408	−3.048	−2.280	−1.763	−1.388	−1.104	−0.715	−0.471	−0.315	−0.145	−0.069	−0.034	−0.012
40.	−4.020	−2.674	−1.925	−1.434	−1.086	−0.833	−0.503	−0.312	−0.198	−0.085	−0.039	−0.018	−0.006
50.	−3.415	−2.095	−1.387	−0.944	−0.650	−0.451	−0.219	−0.108	−0.053	−0.013	−0.003	−0.001	0.000
60.	−2.444	−1.185	−0.566	−0.225	−0.035	0.067	0.138	0.135	0.111	0.063	0.033	0.017	0.006
70.	−0.736	0.341	0.725	0.829	0.808	0.736	0.556	0.399	0.280	0.137	0.067	0.033	0.012
80.	2.897	3.170	2.791	2.312	1.875	1.511	0.983	0.648	0.432	0.199	0.095	0.046	0.016
90.	13.344	8.218	5.575	3.974	2.926	2.207	1.322	0.831	0.539	0.241	0.113	0.055	0.019
100.	21.264	11.404	7.087	4.778	3.395	2.499	1.454	0.899	0.578	0.256	0.120	0.058	0.020

Top of Screen in Pumped Well is 80. Per Cent of Aquifer Thickness Below Top of Aquifer

Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.785	−3.415	−2.633	−2.095	−1.696	−1.387	−0.944	−0.650	−0.451	−0.219	−0.108	−0.053	−0.019
10.	−4.739	−3.371	−2.590	−2.055	−1.658	−1.352	−0.916	−0.628	−0.434	−0.210	−0.103	−0.051	−0.018
20.	−4.597	−3.232	−2.457	−1.929	−1.542	−1.246	−0.829	−0.561	−0.383	−0.182	−0.089	−0.044	−0.015
30.	−4.336	−2.979	−2.216	−1.705	−1.335	−1.059	−0.681	−0.448	−0.299	−0.138	−0.066	−0.032	−0.011
40.	−3.912	−2.572	−1.834	−1.354	−1.019	−0.778	−0.467	−0.290	−0.184	−0.079	−0.036	−0.017	−0.006
50.	−3.232	−1.929	−1.246	−0.829	−0.561	−0.383	−0.182	−0.089	−0.044	−0.011	−0.003	−0.001	0.000
60.	−2.076	−0.877	−0.331	−0.057	0.079	0.142	0.168	0.145	0.114	0.062	0.032	0.016	0.006
70.	0.227	0.992	1.113	1.044	0.920	0.789	0.561	0.391	0.272	0.131	0.064	0.032	0.011
80.	6.304	4.280	3.150	2.401	1.867	1.471	0.939	0.615	0.410	0.189	0.090	0.044	0.015
90.	12.080	7.287	4.939	3.545	2.635	2.005	1.219	0.773	0.505	0.228	0.107	0.052	0.018
100.	13.344	8.218	5.575	3.973	2.926	2.207	1.322	0.831	0.539	0.241	0.113	0.055	0.019

Top of Screen in Pumped Well is 70. Per Cent of Aquifer Thickness Below Top of Aquifer

Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.710	−3.342	−2.562	−2.029	−1.634	−1.330	−0.897	−0.613	−0.423	−0.204	−0.100	−0.049	−0.017
10.	−4.659	−3.293	−2.515	−1.985	−1.593	−1.293	−0.868	−0.591	−0.406	−0.195	−0.095	−0.047	−0.017
20.	−4.500	−3.138	−2.368	−1.848	−1.468	−1.179	−0.778	−0.523	−0.355	−0.168	−0.082	−0.040	−0.014
30.	−4.203	−2.853	−2.100	−1.601	−1.245	−0.981	−0.626	−0.410	−0.273	−0.126	−0.600	−0.029	−0.010
40.	−3.705	−2.381	−1.666	−1.212	−0.902	−0.683	−0.408	−0.254	−0.162	−0.071	−0.033	−0.016	−0.005
50.	−2.853	−1.601	−0.981	−0.626	−0.410	−0.273	−0.126	−0.060	−0.029	−0.007	−0.002	−0.000	0.000
60.	−1.189	−0.230	0.100	0.218	0.251	0.248	0.206	0.157	0.115	0.059	0.030	0.015	0.005
70.	3.064	2.155	1.638	1.286	1.028	0.830	0.553	0.374	0.255	0.122	0.059	0.029	0.010
80.	7.239	4.463	3.104	2.289	1.745	1.359	0.859	0.561	0.374	0.173	0.083	0.040	0.014
90.	8.651	5.592	3.958	2.925	2.220	1.716	1.067	0.687	0.453	0.206	0.098	0.048	0.017
100.	9.019	5.915	4.223	3.134	2.382	1.840	1.140	0.731	0.481	0.218	0.103	0.050	0.017

Top of Screen in Pumped Well is 60. Per Cent of Aquifer Thickness Below Top of Aquifer

Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.597	−3.232	−2.457	−1.929	−1.542	−1.246	−0.829	−0.561	−0.383	−0.182	−0.089	−0.044	−0.015
10.	−4.538	−3.175	−2.403	−1.880	−1.497	−1.206	−0.799	−0.538	−0.367	−0.174	−0.084	−0.041	−0.015
20.	−4.348	−2.994	−2.233	−1.725	−1.358	−1.082	−0.705	−0.470	−0.318	−0.149	−0.072	−0.035	−0.012
30.	−3.986	−2.650	−1.918	−1.442	−1.110	−0.868	−0.549	−0.358	−0.239	−0.110	−0.053	−0.026	−0.009
40.	−3.336	−2.055	−1.394	−0.993	−0.731	−0.552	−0.331	−0.208	−0.135	−0.060	−0.028	−0.014	−0.005
50.	−2.055	−0.993	−0.552	−0.331	−0.208	−0.135	−0.060	−0.028	−0.014	−0.003	−0.001	−0.000	0.000
60.	1.196	0.854	0.658	0.524	0.424	0.347	0.236	0.163	0.113	0.055	0.027	0.013	0.005
70.	4.424	2.679	1.847	1.358	1.037	0.811	0.518	0.342	0.231	0.108	0.052	0.026	0.009
80.	5.634	3.670	2.622	1.958	1.502	1.174	0.745	0.488	0.326	0.152	0.073	0.035	0.012
90.	6.154	4.140	3.026	2.295	1.777	1.397	0.890	0.582	0.388	0.179	0.086	0.042	0.015
100.	6.304	4.280	3.150	2.401	1.867	1.471	0.939	0.615	0.410	0.189	0.090	0.044	0.015

Top of Screen in Pumped Well is 50. Per Cent of Aquifer Thickness Below Top of Aquifer

Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.434	−3.075	−2.307	−1.791	−1.415	−1.131	−0.739	−0.493	−0.333	−0.156	−0.075	−0.037	−0.013
10.	−4.360	−3.005	−2.243	−1.732	−1.364	−1.087	−0.707	−0.470	−0.317	−0.149	−0.072	−0.035	−0.012
20.	−4.119	−2.777	−2.036	−1.549	−1.205	−0.951	−0.611	−0.403	−0.271	−0.127	−0.061	−0.030	−0.010
30.	−3.626	−2.327	−1.642	−1.214	−0.924	−0.719	−0.453	−0.296	−0.198	−0.092	−0.044	−0.022	−0.008
40.	−2.609	−1.486	−0.976	−0.691	−0.513	−0.392	−0.243	−0.157	−0.105	−0.048	−0.023	−0.011	−0.004
50.	−0.000	−0.000	−0.000	−0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 1 *Continued*

60.	2.609	1.486	0.976	0.691	0.513	0.392	0.243	0.157	0.105	0.048	0.023	0.011	0.004
70.	3.626	2.327	1.642	1.214	0.924	0.719	0.453	0.296	0.198	0.092	0.044	0.022	0.008
80.	4.119	2.777	2.036	1.549	1.205	0.951	0.611	0.403	0.271	0.127	0.061	0.030	0.010
90.	4.360	3.005	2.243	1.732	1.364	1.087	0.707	0.470	0.317	0.149	0.072	0.035	0.012
100.	4.434	3.075	2.307	1.791	1.415	1.131	0.739	0.493	0.333	0.156	0.075	0.037	0.013
Top of Screen in Pumped Well is 40. Per Cent of Aquifer Thickness Below Top of Aquifer													
Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0 −4.203	−2.853	−2.100	−1.601	−1.245	−0.981	−0.626	−0.410	−0.273	−0.126	−0.060	−0.029	−0.010	
10.	−4.102	−2.760	−2.017	−1.530	−1.185	−0.931	−0.593	−0.388	−0.259	−0.120	−0.057	−0.028	−0.010
20.	−3.756	−2.447	−1.748	−1.305	−1.002	−0.783	−0.497	−0.325	−0.218	−0.101	−0.048	−0.024	−0.008
30.	−2.949	−1.786	−1.231	−0.905	−0.691	−0.541	−0.345	−0.228	−0.154	−0.072	−0.035	−0.017	−0.006
40.	−0.798	−0.569	−0.439	−0.349	−0.282	−0.231	−0.157	−0.108	−0.075	−0.037	−0.018	−0.009	−0.003
50.	1.370	0.662	0.368	0.220	0.139	0.090	0.040	0.019	0.009	0.002	0.001	0.000	0.000
60.	2.224	1.370	0.929	0.662	0.488	0.368	0.220	0.139	0.090	0.040	0.019	0.009	0.003
70.	2.657	1.767	1.279	0.961	0.740	0.578	0.366	0.239	0.159	0.074	0.035	0.017	0.006
80.	2.899	1.996	1.489	1.150	0.905	0.722	0.470	0.313	0.212	0.100	0.048	0.024	0.008
90.	3.025	2.117	1.602	1.253	0.998	0.804	0.532	0.359	0.244	0.116	0.056	0.028	0.010
100.	3.064	2.155	1.638	1.286	1.028	0.830	0.553	0.374	0.255	0.122	0.059	0.029	0.010
Top of Screen in Pumped Well is 20. Per Cent of Aquifer Thickness Below Top of Aquifer													
Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−3.336	−2.055	−1.394	−0.993	−0.731	−0.552	−0.331	−0.208	−0.135	−0.060	−0.028	−0.014	−0.005
10.	−3.020	−1.822	−1.235	−0.886	−0.659	−0.501	−0.305	−0.193	−0.126	−0.057	−0.027	−0.013	−0.005
20.	−1.576	−1.070	−0.788	−0.600	−0.467	−0.368	−0.235	−0.154	−0.102	−0.047	−0.023	−0.011	−0.004
30.	−0.057	−0.248	−0.278	−0.261	−0.230	−0.197	−0.140	−0.098	−0.068	−0.033	−0.016	−0.008	−0.003
40.	0.519	0.219	0.083	0.014	−0.020	−0.036	−0.042	−0.036	−0.028	−0.015	−0.008	−0.004	−0.001
50.	0.808	0.482	0.311	0.207	0.140	0.096	0.046	0.022	0.011	0.003	0.001	0.000	0.000
60.	0.978	0.643	0.458	0.338	0.255	0.194	0.117	0.072	0.046	0.020	0.009	0.004	0.001
70.	1.084	0.745	0.554	0.426	0.334	0.265	0.170	0.112	0.075	0.034	0.016	0.008	0.003
80.	1.149	0.808	0.614	0.482	0.385	0.311	0.207	0.140	0.096	0.046	0.022	0.011	0.004
90.	1.185	0.843	0.647	0.514	0.415	0.338	0.229	0.157	0.109	0.053	0.026	0.013	0.005
100.	1.196	0.854	0.658	0.524	0.424	0.347	0.236	0.163	0.113	0.055	0.027	0.013	0.005
Bottom of Screen in Pumped Well is 90. Per Cent of Aquifer Thickness Below Top of Aquifer													
Top of Screen in Pumped Well is 80. Per Cent of Aquifer Thickness Below Top of Aquifer													
Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0 −4.743	−3.373	−2.592	−2.057	−1.660	−1.354	−0.916	−0.628	−0.434	−0.210	−0.103	−0.051	−0.018	
10.	−4.694	−3.326	−2.547	−2.015	−1.621	−1.318	−0.887	−0.606	−0.417	−0.201	−0.098	−0.048	−0.017
20.	−4.547	−3.179	−2.407	−1.883	−1.499	−1.207	−0.799	−0.538	−0.366	−0.174	−0.084	−0.041	−0.015
30.	−4.263	−2.910	−2.151	−1.666	−1.283	−1.013	−0.648	−0.425	−0.283	−0.131	−0.062	−0.030	−0.011
40.	−3.803	−2.470	−1.747	−1.274	−0.952	−0.722	−0.431	−0.267	−0.170	−0.074	−0.034	−0.016	−0.006
50.	−3.048	−1.763	−1.104	−0.715	−0.471	−0.315	−0.145	−0.069	−0.034	−0.008	−0.002	−0.001	0.000
60.	−1.708	−0.569	−0.096	0.111	0.193	0.218	0.198	0.156	0.116	0.061	0.031	0.015	0.006
70.	1.189	1.644	1.500	1.258	1.032	0.843	0.566	0.384	0.263	0.125	0.061	0.030	0.011
80.	9.712	5.389	3.509	2.491	1.859	1.431	0.895	0.582	0.387	0.179	0.086	0.042	0.015
90.	10.816	6.356	4.303	3.117	2.344	1.803	1.115	0.716	0.471	0.214	0.101	0.049	0.017
100.	5.425	5.032	4.064	3.168	2.457	1.915	1.190	0.763	0.500	0.226	0.107	0.052	0.018
Top of Screen in Pumped Well is 70. Per Cent of Aquifer Thickness Below Top of Aquifer													
Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.651	−3.284	−2.506	−1.976	−1.585	−1.284	−1.860	0.584	−0.400	−0.191	−0.093	−0.046	−0.016
10.	−4.597	−3.232	−2.457	−1.929	−1.542	−1.246	−0.829	−0.561	−0.383	−0.182	−0.089	−0.044	−0.015
20.	−4.424	−3.085	−2.299	−1.784	−1.409	−1.127	−0.737	−0.492	−0.333	−0.157	−0.076	−0.037	−0.013
30.	−4.100	−2.755	−2.010	−1.520	1.173	−0.919	−0.582	−0.379	−0.252	−0.116	−0.056	−0.027	−0.009
40.	−3.547	−2.235	−1.536	−1.101	−0.810	−0.069	−0.361	−0.224	−0.144	−0.064	−0.030	−0.014	−0.005
50.	−2.572	−1.354	−0.778	−0.467	−0.290	−0.184	−0.079	−0.036	−0.017	−0.004	−0.001	−0.000	0.000
60.	−0.562	0.248	0.433	0.439	0.395	0.339	0.240	0.168	0.117	0.057	0.028	0.014	0.005
70.	4.965	3.061	2.094	1.515	1.138	0.878	0.551	0.362	0.243	0.114	0.055	0.027	0.009
80.	9.410	5.109	3.260	2.277	1.680	1.283	0.796	0.517	0.344	0.160	0.076	0.037	0.013
90.	6.304	4.280	3.150	2.401	1.867	1.471	0.939	0.615	0.410	0.189	0.090	0.044	0.015
100.	2.897	3.170	2.791	2.312	1.875	1.511	0.983	0.648	0.432	0.199	0.095	0.046	0.016
Top of Screen in Pumped Well is 60. Per Cent of Aquifer Thickness Below Top of Aquifer													
Piez. Depth	Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness												
	5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0 −4.520	−3.157	−2.384	−1.861	−1.478	−1.187	−0.782	−0.524	−0.355	−0.167	−0.081	−0.039	−0.014	
10.	−4.455	−3.095	−2.326	−1.808	−1.431	−1.145	−0.750	−0.501	−0.334	−0.159	−0.077	−0.037	−0.013
20.	−4.247	−2.897	−2.142	−1.641	−1.282	−1.015	−0.654	−0.432	−0.290	−0.136	−0.065	−0.032	−0.011
30.	−3.845	−2.517	−1.797	−1.335	−1.017	−0.789	−0.494	−0.321	−0.213	−0.009	−0.047	−0.023	−0.008
40.	−3.108	−1.848	−1.217	−0.847	−0.613	−0.458	−0.273	−0.173	−0.114	−0.052	−0.025	−0.012	−0.004
50.	−1.601	−0.626	−0.273	−0.126	−0.060	−0.029	−0.007	−0.002	−0.000	0.000	0.000	0.000	0.000
60.	2.410	1.533	1.066	0.774	0.577	0.440	0.269	0.172	0.113	0.052	0.025	0.012	0.004
70.	6.144	3.458	2.220	1.534	1.113	0.836	0.506	0.374	0.214	0.099	0.047	0.023	0.008
80	6.547	3.837	2.566	1.840	1.378	1.062	0.666	0.435	0.291	0.136	0.065	0.032	0.011
90	3.757	2.780	2.176	1.735	1.395	1.127	0.746	0.500	0.338	0.159	0.077	0.037	0.013
100.	1.318	1.905	1.838	1.609	1.358	1.129	0.767	0.520	0.354	0.167	0.081	0.039	0.014

TABLE 1 *Continued*

Top of Screen in Pumped Well is 50. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.336	−2.979	−2.216	−1.705	−1.335	−1.059	−0.681	−0.448	−0.299	−0.138	−0.066	−0.032	−0.011	
10.	−4.254	−2.902	−2.145	−1.642	−1.280	−1.012	−0.648	−0.425	−0.284	−0.131	−0.063	−0.030	−0.011
20.	−3.986	−2.650	−1.918	−1.442	−1.110	−0.868	−0.549	−0.358	−0.239	−0.110	−0.053	−0.026	−0.009
30.	−3.430	−2.146	−1.482	−1.076	−0.809	−0.672	−0.388	−0.253	−0.169	−0.079	−0.038	−0.019	−0.007
40.	−2.256	−1.189	−0.739	−0.506	−0.369	−0.282	−0.177	−0.118	−0.081	−0.039	−0.019	−0.010	−0.003
50.	0.854	0.524	0.347	0.236	0.163	0.113	0.055	0.027	0.013	0.003	0.001	0.000	0.000
60.	3.872	2.154	1.362	0.920	0.650	0.473	0.269	0.163	0.103	0.045	0.021	0.010	0.003
70.	4.716	2.823	1.871	1.310	0.953	0.714	0.428	0.271	0.177	0.081	0.038	0.019	0.007
80.	4.424	2.679	1.847	1.358	1.037	0.811	0.518	0.342	0.231	0.108	0.052	0.026	0.009
90.	2.114	1.701	1.410	1.172	0.973	0.807	0.554	0.380	0.262	0.125	0.061	0.030	0.011
100.	0.227	0.992	1.113	1.044	0.920	0.789	0.561	0.391	0.272	0.131	0.064	0.032	0.011

Top of Screen in Pumped Well is 40. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.078	−2.732	−1.985	−1.494	−1.147	−0.893	−0.557	−0.357	−0.234	−0.105	−0.050	−0.024	−0.008	
10.	−3.966	−2.629	−1.894	−1.417	−1.083	−0.840	−0.523	−0.336	−0.220	−0.100	−0.047	−0.023	0.008
20.	−3.577	−2.279	−1.596	−1.171	−0.885	−0.683	−0.424	−0.274	−0.181	−0.083	−0.040	−0.019	−0.007
30.	−2.658	−1.533	−1.021	−0.734	−0.552	−0.428	−0.272	−0.180	−0.122	−0.058	−0.028	−0.014	−0.005
40.	−0.153	−0.148	−0.141	−0.132	−0.122	−0.111	−0.088	−0.068	−0.051	−0.027	−0.014	−0.007	−0.003
50.	2.327	1.214	0.719	0.453	0.296	0.198	0.092	0.044	0.022	0.005	0.001	0.000	0.000
60.	3.158	1.881	1.228	0.840	0.592	0.428	0.237	0.139	0.086	0.036	0.016	0.008	0.003
70.	3.336	2.052	1.389	0.988	0.726	0.547	0.328	0.207	0.135	0.061	0.029	0.014	0.005
80.	2.899	1.761	1.228	0.917	0.711	0.564	0.368	0.247	0.168	0.080	0.039	0.019	0.007
90.	0.961	0.896	0.807	0.709	0.612	0.523	0.374	0.264	0.185	0.091	0.045	0.022	0.008
100.	−0.575	0.305	0.548	0.588	0.555	0.497	0.373	0.269	0.191	0.095	0.047	0.023	0.008

Top of Screen in Pumped Well is 30. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−3.705	−2.381	−1.666	−1.212	−0.902	−0.683	−0.408	−0.254	−0.162	−0.071	−0.033	−0.016	−0.005	
10.	−3.528	−2.227	−1.540	−1.113	−0.827	−0.627	−0.376	−0.235	−0.151	−0.067	−0.031	−0.015	−0.005
20.	−2.844	−1.684	−1.134	−0.815	−0.608	−0.465	−0.286	−0.183	−0.120	−0.055	−0.026	−0.013	−0.004
30.	−0.798	−0.569	−0.439	−0.349	−0.283	−0.231	−0.157	−0.108	−0.075	−0.037	−0.018	−0.009	−0.003
40.	1.264	0.560	0.271	0.130	0.055	0.015	−0.019	−0.026	−0.024	−0.015	−0.008	−0.004	−0.002
50.	1.996	1.150	0.722	0.470	0.313	0.212	0.100	0.048	0.024	0.006	0.001	0.000	0.000
60.	2.260	1.388	0.927	0.643	0.457	0.331	0.181	0.104	0.063	0.025	0.011	0.005	0.002
70.	2.224	1.370	0.929	0.662	0.488	0.368	0.220	0.139	0.090	0.040	0.019	0.009	0.003
80.	1.767	1.041	0.719	0.539	0.421	0.338	0.225	0.154	0.106	0.051	0.025	0.012	0.004
90.	0.106	0.277	0.328	0.330	0.309	0.279	0.213	0.157	0.113	0.057	0.029	0.014	0.005
100.	−1.189	−0.230	0.100	0.218	0.251	0.248	0.206	0.157	0.115	0.059	0.030	0.015	0.005

Top of Screen in Pumped Well is 20. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−3.123	−1.854	−1.211	−0.830	−0.588	−0.428	−0.239	−0.141	−0.087	−0.036	−0.016	−0.008	−0.003	
10.	−2.768	−1.594	−1.035	−0.714	−0.511	−0.375	−0.213	−0.128	−0.080	−0.034	−0.015	−0.007	−0.002
20.	−1.137	−0.754	−0.542	−0.404	−0.307	−0.237	−0.145	−0.092	−0.060	−0.027	−0.013	−0.006	−0.002
30.	0.565	0.152	0.008	−0.046	−0.065	−0.068	−0.058	−0.044	−0.033	−0.017	−0.008	−0.004	−0.002
40.	1.167	0.603	0.370	0.221	0.133	0.078	0.024	0.003	−0.004	−0.006	−0.004	−0.002	−0.001
50.	1.411	0.851	0.554	0.372	0.253	0.174	0.083	0.041	0.020	0.005	0.001	0.000	0.000
60.	1.467	0.904	0.605	0.419	0.296	0.114	0.114	0.063	0.037	0.014	0.006	0.003	0.000
70.	1.344	0.802	0.530	0.369	0.266	0.197	0.115	0.071	0.045	0.020	0.009	0.004	0.002
80.	0.899	0.471	0.303	0.221	0.173	0.140	0.096	0.068	0.048	0.024	0.012	0.006	0.002
90.	−0.552	−0.211	−0.056	0.020	0.056	0.071	0.073	0.061	0.047	0.026	0.013	0.007	0.002
100.	−1.670	−0.653	−0.260	−0.084	−0.000	0.039	0.062	0.057	0.046	0.026	0.014	0.007	0.003

Top of Screen in Pumped Well is 10. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−2.055	−0.993	−0.552	−0.331	−0.208	−0.135	−0.060	−0.028	−0.014	−0.003	−0.001	−0.000	−0.000	
10.	−1.070	−0.600	−0.368	−0.235	−0.154	−0.102	−0.047	−0.023	−0.011	−0.003	−0.001	−0.000	−0.000
20.	0.219	−0.014	−0.036	−0.042	−0.036	−0.028	−0.015	−0.008	−0.004	−0.001	−0.000	−0.000	−0.000
30.	0.643	0.338	0.194	0.117	0.072	0.046	0.020	0.009	0.004	0.001	0.000	0.000	−0.000
40.	0.808	0.482	0.311	0.207	0.140	0.096	0.046	0.022	0.011	0.003	0.001	0.000	−0.000
50.	0.854	0.524	0.347	0.236	0.163	0.113	0.055	0.027	0.013	0.003	0.001	0.000	0.000
60.	0.808	0.482	0.311	0.207	0.140	0.096	0.046	0.022	0.011	0.003	0.001	0.000	0.000
70.	0.643	0.338	0.194	0.117	0.072	0.046	0.020	0.009	0.004	0.001	0.000	0.000	0.000
80.	0.219	0.014	−0.036	−0.042	−0.036	−0.028	−0.015	−0.008	−0.004	−0.001	−0.000	−0.000	0.000
90.	−1.070	−0.600	−0.368	−0.235	−0.154	−0.102	−0.047	−0.023	−0.011	−0.003	−0.001	−0.000	0.000
100.	−2.054	−0.993	−0.552	−0.331	−0.208	−0.135	−0.060	−0.028	−0.014	−0.003	−0.001	−0.000	0.000

Bottom of Screen in Pumped Well is 80. Per Cent of Aquifer Thickness Below Top of Aquifer

Top of Screen in Pumped Well is 70. Per Cent of Aquifer Thickness Below Top of Aquifer

Distance of Piezometer from Pumped Well, as Per Cent of Aquifer Thickness

Piez. Depth		5.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00	60.00	80.00	100.00	120.00	150.00
0.0	−4.560	−3.196	−2.421	−1.895	−1.509	−1.215	−0.803	−0.539	−0.366	−0.172	−0.083	−0.041	−0.014	
10.	−4.500	−3.137	−2.366	−1.844	−1.463	−1.174	−0.771	−0.516	−0.349	−0.164	−0.079	−0.039	−0.014